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IMPACTS OF WATER LEVEL FLUCTUATIONS ON KOKANEE REPRODUCTION IN FLATHEAD LAKE

Annual Progress Report FY1983

By

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Effects of Operation of Kerr and Hungry Horse Dam on
Reproductive Success of Kokanee in the Flathead System

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EXECUTIVE SUMMARY

This study was initiated in the fall of 1981 to document the extent of kokanee spawning in shoreline areas of Flathead Lake and determine the effect of water level fluctuations and other factors on spawning, incubation, emergence and survival. The contribution from on-shore (to depths 6.1 m below full pool elevation) and off-shore spawners (to depths greater than 6.1 m below full pool elevation) was also determined. Investigation of the influence of groundwater on the reproductive success of on and off-shore spawners occurred during the 1982-83 field season.

Fifty-one shoreline areas including historic spawning areas, stream outlets and groundwater upwellings were surveyed for spawning activity from 22 October through 22 December. The areas were equally distributed between the east and west shores. Adult kokanee were initially observed on 22 October in Yellow Bay and a seep North of Dee Creek. Adult kokanee were observed over a longer period of time in 1982 than in 1981. A greater number of spawners in 1982 appeared to explain the greater length of time adults were observed.

Seventeen areas in eleven bays were utilized by spawning kokanee during 1982. Nine of these bays were located on the east shore and two on the west shore. All of the east shore areas reported as kokanee spawning areas in 1953 were used in 1982. Only 11 percent of the 1953 west shore areas were utilized in 1982. A total of 1,029 redds was counted in the 17 areas. The number of redds at each area ranged from two at Lakeside to 216 at Gravel Bay. Spawning occurred in water depths of 0.26 m at Dr. Richard's Bay to 20 m at Woods Bay. Fifty percent of the redds were located above minimum pool. Seventy-five percent of the redds above minimum pool were built between 2885.0 and 2888.0 ft. Kokanee constructed 75 percent more redds in 1982 than 1981.

Four spawning areas below minimum pool and four areas above minimum pool were selected to collect microhabitat data and determine embryonic survival throughout the incubation period. Fifteen to twenty percent of the redds constructed in each area were marked for further study. Microhabitat data collected from each area included intergravel dissolved oxygen, groundwater stage and velocity, substrate composition, gravel movement and intergravel temperatures. Intergravel dissolved oxygen concentrations were adequate for successful embryo incubation (>7.0 mg/l) in all study areas except for Yellow Bay, the deeper stations in the Gravel Bay spawning area and along the southern transect in the Woods Bay spawning area. Concentrations in these areas or zones within areas varied from 0 to 4.7 mg/l . Seventy-four percent of sampling sites in the Yellow Bay spawning area were less than 4.0 mg/l.

General trends in gravel movement in the shoreline areas during the incubation period supported trends observed during the 1981-82 season. Additional information collected during 1982-83 documented the effect of closed dock structures on gravel deposition and scour. Substrate composition changes occurred in areas above minimum pool with a shift to a greater percentage of fines.

Flathead Lake elevation fluctuations during the spawning and incubation period of 1982-83 were similar to the 1981-82 season. The mean monthly decline in lake stage during December, January and February was 1.7 ft. Minimum pool of 2884.03 ft. was reached in March and was held near that level for over two months. Eighty-four percent of the redds constructed above minimum pool were exposed by lake drawdown during the incubation period. Minimum daily air temperature dropped below -10°C only once during the early incubation period.

Embryo survival and development was monitored in naturally constructed redds and from experimental egg plants. Habitat most conducive to survival was located in gravels above minimum pool prior to lake drawdown. Survival at the four areas sampled ranged from 57 to 84 percent with a mean survival rate of 78 percent. This compared to a mean survival rate of 48 percent from redds constructed below minimum pool.

The effect of winter ambient air temperatures on egg survival in redds exposed by lake drawdown was insignificant during the 1982-83 incubation period. Without the overshadowing effect of freezing temperatures on embryo survival, length of exposure of redds by lake drawdown played a critical role. Redds moistened by only damp gravel and sand were found to have suffered complete mortality after 69(±14) days of exposure. Egg bags planted in Skidoo Bay harvested on a monthly basis further documented and defined this relationship between exposure and survival. Embryonic survival was negatively correlated to length of exposure ($r = -.9104$, $p<0.01$). Based on this correlation, 100 percent mortality would occur after 78 days of exposure without freezing temperatures.

Groundwater stage reacted differently to lake stage fluctuation in each study spawning area exposed by lake drawdown. In two of the five spawning areas, groundwater stage acted independently of lake fluctuation. In the other areas, groundwater stage mirrored lake stage with a lag time before reaching equilibrium. Only the rate of equalizing with lake stage varied between areas. The steepness of the water table determined the length of time and the vertical spawning area wetted by groundwater after lake drawdown had exposed the gravels.

Intergravel dissolved oxygen levels appeared to play the most critical role in survival of redds constructed below minimum pool. Lowest rates of survival were found in areas or zones within areas where intergravel dissolved oxygen was less than 5.0 mg/l. The

Yellow Bay spawning area had the poorest survival with 13 percent surviving to the eyed stage. After two months of incubation, complete mortality occurred in egg bags planted in Yellow Bay where intergravel dissolved oxygen levels were less than 3.0 mg/l.

As gravels became exposed by lake drawdown, ambient air temperatures significantly affected their temperatures. Cooler gravel temperatures reduced temperature unit accumulation in incubating embryos, delaying development. Depending on the location of the redd, development could be reduced by up to one month in exposed gravels.

A partial emergence of sac fry to approximately two inches (5.1 cm) below gravel surface was observed in redds above minimum pool which had remained wetted by groundwater or were within the wave zone. Because of this partial emergence, alevins were vulnerable to desiccation as lake stage continued to decline, suffication due to increased fines or debris, predation and/or removal by wave action. Survival in these redds was reduced from 80 to 90 percent to 10 to 20 percent after partial emergence.

Emergence traps were placed over marked redds in Gravel, Woods, Blue and Yellow bays. Emerging fry were captured in all bays monitored except Yellow Bay. Fry were initially captured on 7 April with a peak in emergence on 19 May. Last emerging fry were captured on 8 June. Fry emergence in 1982 occurred over a similar period but with the peak occurring 20 days earlier. Based on data collected during the emergence period, survival to fry emergence in Gravel Bay was calculated at 29 percent of egg deposition or 67,212 fry.

Lateral intergravel movement occurred through gravels with up to 27.2 percent fines (<6.35 mm) in experimental channels at Somers Hatchery. Eight and thirty-six percent of the fry moved 4.3 m through 30 and 20 percent fines, respectively.

Fry length, weight and condition were determined from fry captured in emergence traps at Woods, Blue and Gravel bays. The only significant relationships were found at Gravel Bay between fry condition and depth of strata and fry condition and emergence density. Condition increased with a decrease in depth, while density decreased.

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Laney Hanzel and Scott Rumsey continued to provide advice and guidance to the study. Thanks to Joe Huston and Stuart Keinow for providing kokanee eggs and hatchery space for experimental studies. Dave Cross of the Confederated Salish and Kootenai Tribes, Jim Clarr of the Bureau of Indian Affairs, Richard Prange of the Bureau of Reclamation, Frank Pickett of Montana Power Company and Pat Graham, Scott Rumsey and Laney Hanzel of the Department of Fish, Wildlife and Parks critically reviewed the manuscript. Cathy Turley Addington, Shirly Peterson and Erika Sackett typed the manuscript.

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INTRODUCTION

Kokanee salmon (Oncorhynchus nerka), the land-locked form of sockeye salmon, were originally introduced to Flathead Lake in 1916. By 1933, kokanee had become established in the lake and provided a popular summer trolling fishery as well as a fall snagging fishery in shoreline areas (Alvord 1975). Presently, Flathead Lake supports the second highest fishing pressure of any lake or reservoir in Montana (Montana Department of Fish and Game 1976). During 1981-82, the lake provided 168,792 man-days of fishing pressure (Graham and Fredenberg 1982). Ninety-two percent of the estimated 536,870 fish caught in Flathead Lake in 1981-82 were kokanee salmon. Kokanee also provided forage for bull trout seasonally and year round for lake trout (Leathe and Graham 1982).

Kokanee rear to maturity in Flathead Lake, then return to various natal grounds to spawn. Spawning occurred in lake outlet streams, springs, larger rivers (McMullin and Graham 1981, Fraley and Graham 1982, and Fraley and McMullin 1983) and lake shoreline areas in suitable but often limited habitat. Shoreline spawning in Flathead Lake was first documented in the mid-1930's. Spawning kokanee were seined from shoreline areas in 1933 and 21,000 cans were processed and packed for distribution to the needy (Alvord 1975). Stefanich (1953 and 1954) later documented extensive but an unquantified amount of spawning along the shoreline as well as runs in Whitefish River and McDonald Creek in the 1950's. A creel census conducted in 1962-63 determined 11 to 13 percent of the kokanee caught annually were taken during the spawning period (Robbins 1966). During a 1981-82 creel census, less than one percent of the fishermen censused on Flathead Lake were snagging kokanee (Graham and Fredenberg 1982).

The operation of Kerr Dam, located below Flathead Lake on the Flathead River, has altered seasonal fluctuations of Flathead Lake. Lake levels presently remain high during kokanee spawning in November and decline during the incubation and emergence periods. Groundwater plays an important role in embryo and fry survival in redds of shoreline areas exposed by lake drawdown. Stefanich (1954) and Domrose (1968) found live eggs and fry only in shoreline spawning areas wetted by groundwater seeps. Impacts of the operation of Kerr Dam on lakeshore spawning have not been quantified. Recent studies have revealed that operation of Hungry Horse Dam severely impacted successful kokanee spawning and incubation in the Flathead River above Flathead Lake (Graham et al. 1980, McMullin and Graham 1981, Fraley and Graham 1982 and Fraley and McMullin 1983). Flows from Hungry Horse Dam to enhance kokanee reproduction in the river system have been voluntarily met by the Bureau of Reclamation since 1981.

In lakeshore spawning areas in other Pacific Northwest systems, spawning habitat for kokanee and sockeye salmon was characterized by seepage or groundwater flow where suitable substrate composition existed (Foerster 1968). Spawning primarily occurred in shallower depths (<6 m) where gravels were cleaned by wave action (Hassemer and Rieman 1979 and 1980, Stober et al. 1979a). Seasonal drawdown of reservoirs can adversely affect survival of incubating kokanee eggs and fry spawned in shallow shoreline areas. Jeppson (1955 and 1960) and Whitt (1957) estimated 10-75 percent kokanee egg loss in shoreline areas of Pend Oreille Lake, Idaho after regulation of the upper three meters occurred in 1952. After 20 years of operation, Bowler (1979) found Pend Oreille shoreline spawning to occur in fewer areas with generally lower numbers of adults. In studies on Priest Lake, Idaho, Bjornn (1957) attributed frozen eggs and stranded fry to winter fluctuations of the upper three meters of the lake. Eggs and fry frozen during winter drawdown accounted for a 90 percent loss to shoreline spawning kokanee in Donner Lake, California (Kimsey 1951). Stober et al. (1979a) determined irrigation drawdown of Banks Lake, Washington reduced shoreline survival during five of the seven years the system was studied.

The goal of this phase of the study was to evaluate and document effects of the operation of Kerr Dam on kokanee shoreline reproduction in Flathead Lake. Specific objectives to meet this goal are:

1) Delineate the extent of successful shoreline spawning in Flathead Lake both on-shore (to an approximate depth of 6.1 m below full pool elevation) and off-shore (approximately 6.1-21.3 m below full pool elevation).

2) Quantify and qualify influence of groundwater on reproductive success of on-shore spawners. The effects of groundwater on spawning and incubation on off-shore spawners will also be studied. Rates of groundwater discharge and groundwater chemistry will be established in spawning and non-spawning areas. Those data will be compared and contrasted in an attempt to delineate parameters affecting spawning site selection and embryo success.

3) Determine the relative contributions of major spawning areas to the total kokanee population.

DESCRIPTION OF STUDY AREA

Flathead Lake is a large oligomesotrophic lake located in northwestern Montana (Stanford et al. 1981). It has the greatest surface area (476.6 km^2) of any natural freshwater lake west of the Mississippi River. The lake has a maximum length of 43.9 km and a maximum breadth of 24.9 km. Its mean depth is 32.5 m with a maximum depth of 113 m located near Yellow Bay (Potter 1978). The 199.1 km shoreline of the lake is characterized by numerous protected bays and inlets with gravel and cobble beaches. Approximately 50 percent of the shoreline substrate is composed of gravel and cobble (Figure 1). Sand and finer silts are generally

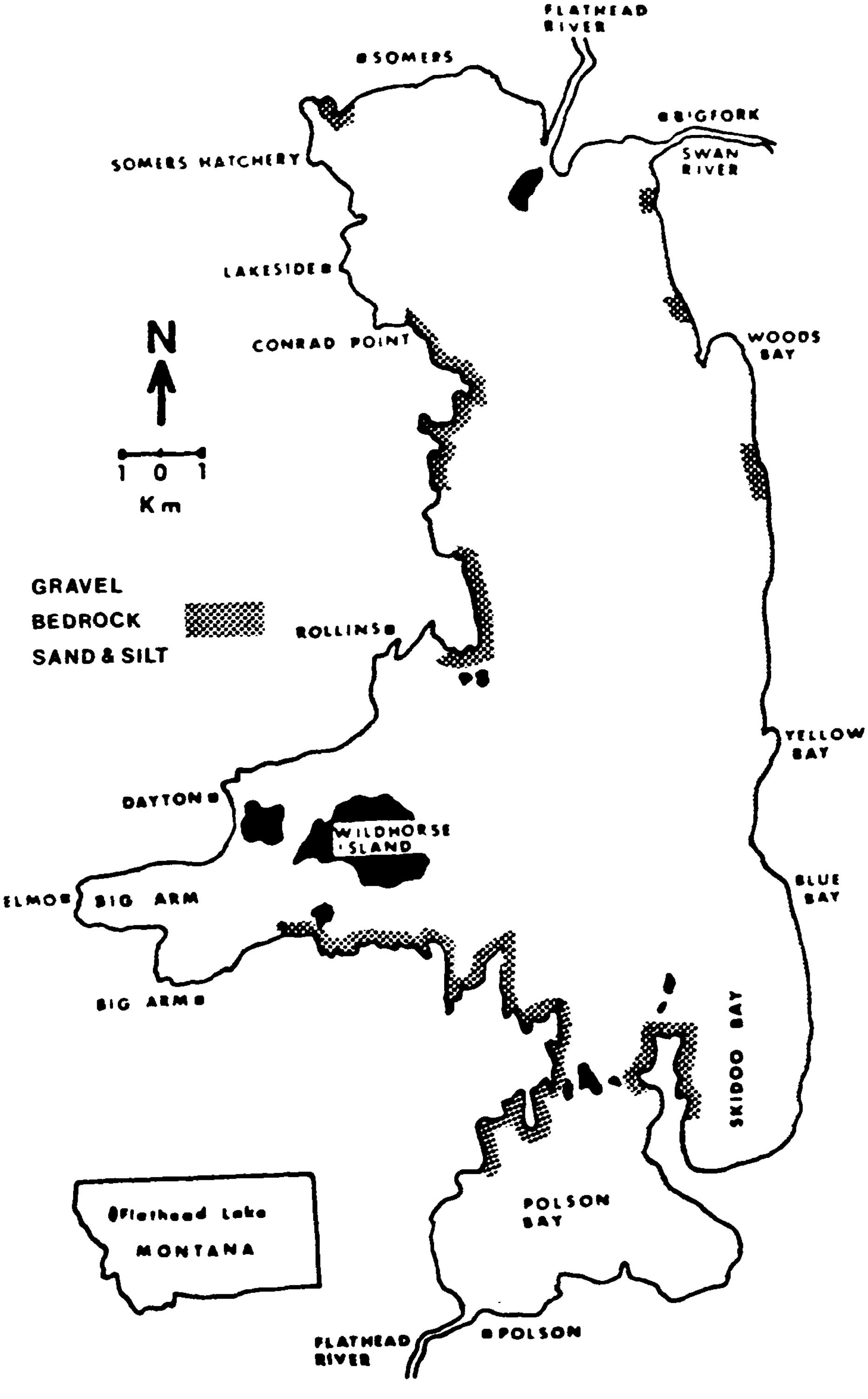

Figure 1. Map of Flathead Lake, including substrate composition of shoreline.

restricted to the north and south end of the lake and compose 17 percent of the shoreline. The remaining 36 percent of the shoreline is characterized by steep cliffs and exposed bedrock.

Permanent and summer homes are found along the entire shoreline of Flathead Lake. Larger population centers are located at Polson, Somers, Lakeside and Bigfork. Moderating air temperatures, created by the buffering capacity of a large lake, have allowed successful cherry production on much of the land adjacent to the east shore. Agricultural production including cattle, sheep, grain and hay are restricted primarily to the southern and northern ends.

Kerr Dam, located 7 km downstream of the natural lake outlet, was closed in April 1938. Kerr has provided the bulk of Montana Power Company's systems load frequency control with a generating capacity of 168,000 kilowatts (Graham et al. 1981). The Kerr facility has controlled water levels of Flathead Lake between elevations 878.7 m (2883 ft) and 881.8 m (2893 ft) since its closing. Prior to impoundment by Kerr Dam, water levels for Flathead Lake remained relatively constant from September to mid-April (Figure 2). Spring runoff increased the elevation to the maximum for the year in May and June. Since impoundment, maximum lake elevation has been reached in May and maintained into September. Recreational and operational constraints on the facility require the minimum pool of 878.7 m be drafted by April 15, an elevation of 881.1 m be reached by Memorial Day and maximum pool level maintained through Labor Day (Montana Power Company, pers. comm.).

Two major tributaries to Flathead Lake, the South Fork of the Flathead River and Swan River, are presently regulated by hydroelectric facilities (Figure 3). The Swan River diversion at Bigfork was built in 1902 with a generating capacity of 4,150 kilowatts (Graham et al. 1981). Hungry Horse Dam, located on the South Fork Flathead River 8.5 km above its confluence with the main river, was closed in September, 1951. Hungry Horse has a capacity to generate 285,000 kilowatts, regulating one-third of the drainage area to Flathead Lake.

Kokanee salmon provided the largest fishery to Flathead Lake and the upper Flathead River (Robbins 1966, Hanzel 1977, Graham and Fredenberg 1982 and Fredenberg and Graham 1982). A creel census conducted in 1981-82 on the lake and upper drainage estimated 204,732 fisherman-days per year (Graham and Fredenberg 1982 and Fredenberg and Graham 1982). Kokanee represented 80 and 92 percent of the catch in the river and lake, respectively. Kokanee were captured by several angler methods including summer boat trolling, fall shoreline snagging and a winter hand-line fishery.

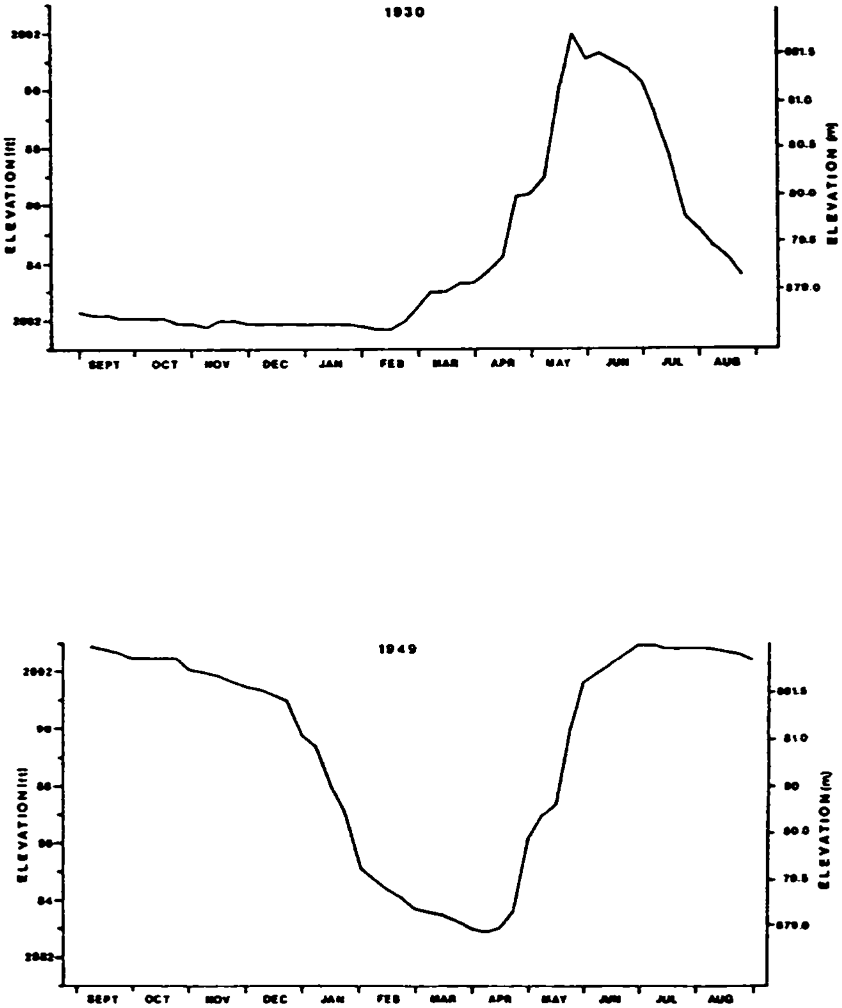

Figure 2. Annual lake levels of Flathead Lake in 1930, prior to construction of Kerr Dam and in 1949, after construction of Kerr Dam.

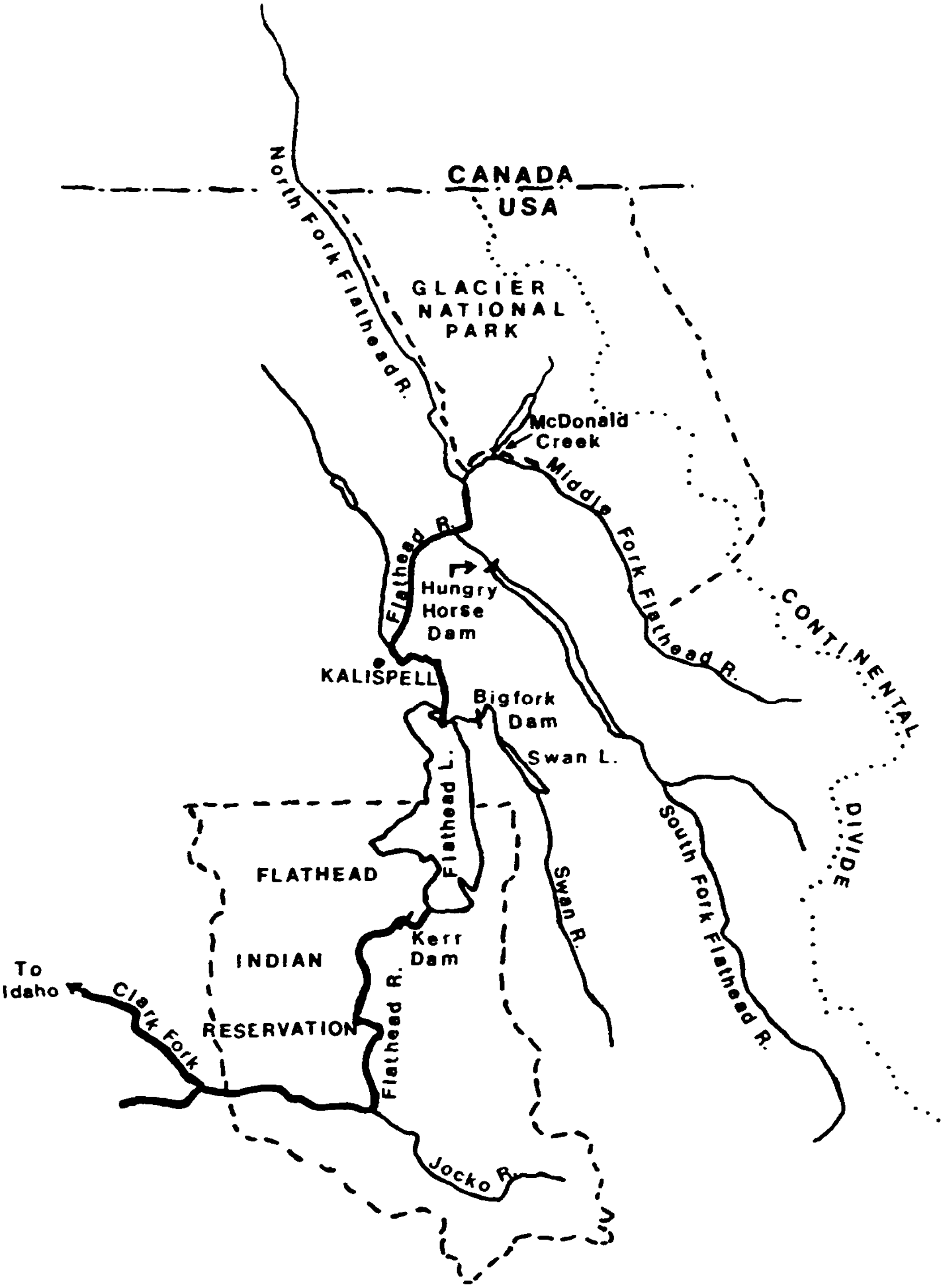

Figure 3. Map of Flathead River drainage.

METHODS

KOKANEE SPAWNER SURVEY

Attention was focused on shoreline areas of Flathead Lake previously identified as kokanee spawning sites, groundwater upwellings or surface water inlets. Fisherman information was also utilized to locate spawning areas. Historic spawning areas documented in the 1950's by Stefanich (1953, 1954) and Hanzel (pers. comm.) were monitored on a semi-weekly basis throughout December. Areas with groundwater potential or surface water inlets, but lacking verified kokanee spawning activity, were monitored less frequently, usually weekly or biweekly.

Shoreline spawning activity was monitored by various methods beginning in mid-October. Initial sitings were observed from the bow of a slow cruising jet boat or from a pram modified with a plexiglass viewing window (Decker-Hess and Graham 1982). After locating redds or mature kokanee in shoreline areas with the pram or jet boat, the area was inventoried by SCUBA divers. Divers thoroughly investigated the spawning site horizontally and vertically. Redds and mature adults were counted and approximate locations were recorded.

Sex ratio, fecundity, age composition and length measurement (to the nearest mm) information was gathered from adult kokanee. Egg counts were made only from females showing no signs of egg exudation (sac enveloping eggs were intact). Otoliths were used to determine adult kokanee age by sex and lake area. Fish were collected for analysis by the creel clerk during October and November, 1982. In spawning areas where an insufficient sample size of adult kokanee were collected by the creel clerk, floating shoreline gill nets were used. Gill nets were set either overnight or during daylight hours depending on the area.

CREEL CENSUS OF FLATHEAD LAKE SNAG FISHERY

A creel census of the Flathead Lake shoreline snag fishery was conducted from 15 October through 15 November 1982. The creel design employed was modified from Graham and Fredenberg (1982).

Weekends and weekdays were treated separately in scheduling counts and interview days. Five weekdays and three weekend days were selected for sampling in a two week period. Starting and ending times for sampling days were chosen with non-replacement by weekday and weekend to insure adequate coverage of daylight hours.

Because potential snagging locations on the east shore were located along 30 miles of shore, only half of the area could be adequately covered in one day (Figure 4). The first count day included Woods and Yellow bays (Section 9-1). The second count day encompassed the area of shoreline from Blue to Skidoo bays (Section 9-2) including Blue Bay, Talking Water Creek, Dee Creek,

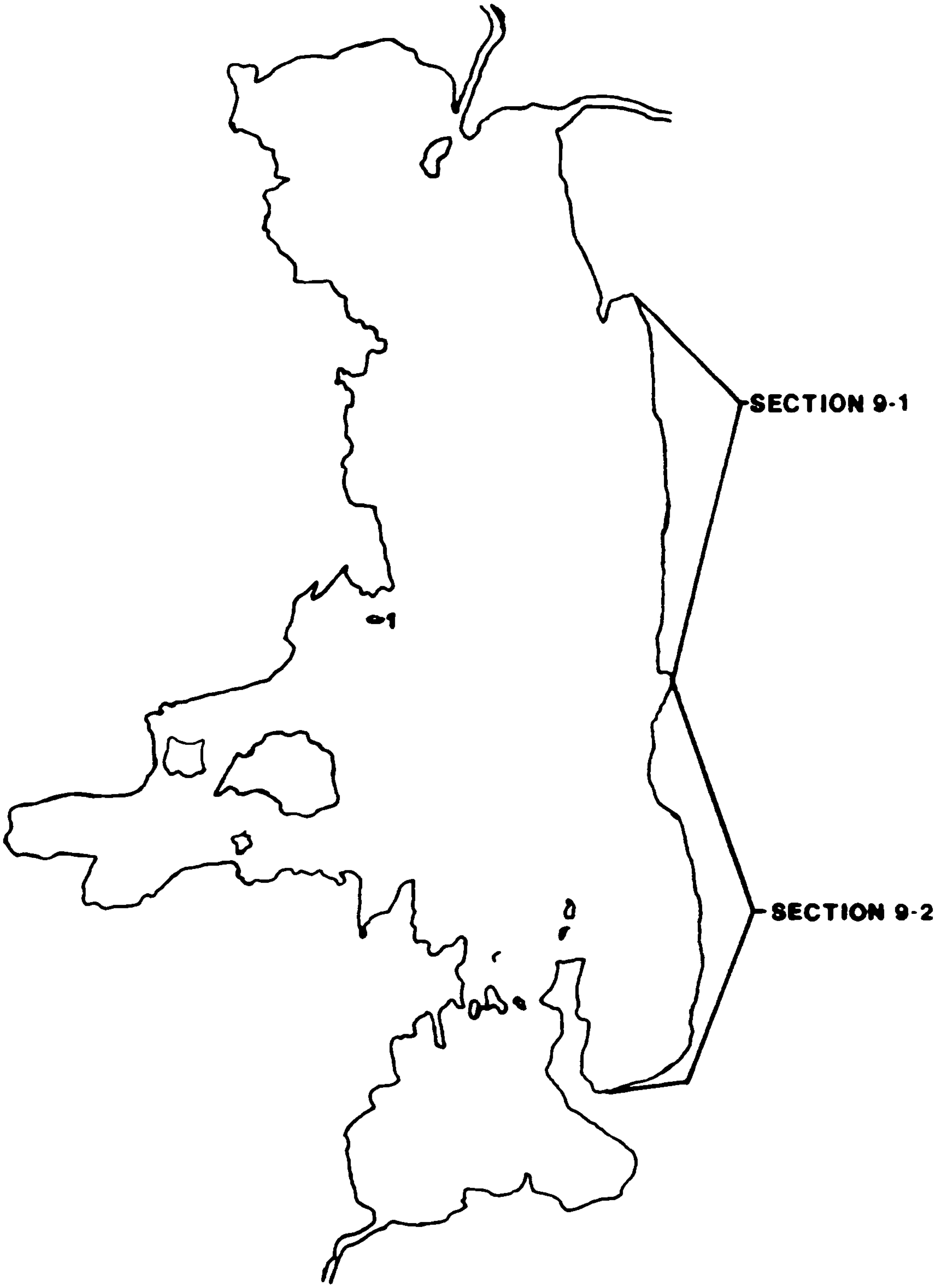

Figure 4. Map of Flathead Lake with creel census locations designated.

Gravel Bay, Dr. Richard's Bay, Pine Glen Resort and Skidoo Bay. Two counts were made daily with no more than six hours and no less than three hours elapsing between counts. The sequence of counts was reversed every third scheduled sampling day beginning with the south end of the lake (Skidoo Bay) and ending with Bigfork Bay-Swan River on the fourth sampling day.

The creel clerk worked 10 hour days during the sampling period. Snag fishermen were interviewed by party size unless the party size happened to be one. Interview questions included origin of fishing party, bait type, hours fished, if the fishing trip was complete or incomplete and the number of fish harvested/-released. Count and interview data were recorded on code forms and entered for computer analysis. The computer program used was developed by the Department of Fish, Wildlife and Parks following the procedures of Nuehold and Lu (1957). Analysis included fisherman pressure and harvest estimate, origin of fisherman and catch rates.

LAKE LEVEL FLUCTUATIONS AND AIR TEMPERATURES

Daily lake elevations during 1982-83 were determined from the U.S.G.S. gauge station at Polson. The climatologic station located at the Yellow Bay Biological Station on Flathead Lake collected the daily minimum and maximum air temperatures used for the study.

SPAWNING SITE INVENTORY AND MICROHABITAT

Spawning areas were mapped upon completion of major spawning activity. Because of the depth of most redds, SCUBA techniques were necessary to accurately chart the sites. To locate and record redds and spawning area boundaries, a metric fiberglass tape was stretched parallel to the shoreline for the length of the spawning area. Exact redd locations were determined by two measurements; distance on the parallel tape and elevation of the redd. Because redds were quickly rendered unidentifiable by wave action depositing sediment and moving gravel, measurements of this accuracy were necessary. Three transects used to collect microhabitat data spanned the width of the spawning area and were spaced laterally to accurately define the entire area. Information collected from the transects included bottom elevations and contours, intergravel dissolved oxygen concentrations and gravel movement recordings. This information was also gathered at fewer points in several study spawning areas where habitat was similar to other sampled areas. Total spawning area and mean redd size were determined from field measurements.

Substrate samples for compositional analysis were collected from the study spawning areas. Two to four samples were collected during each sampling period. To evaluate substrate compositional changes during the incubation period, samples were collected from the same location immediately following spawning and again prior to emergence. Depending on the depth of water, samples were collected with a shovel and grid, the substrate corer or by SCUBA divers. Five to ten kg samples were placed in 19 liter plastic buckets for further analysis (Shirazi and Seim 1979). Samples were dried and sieved through .063 mm, 2 mm, 6.35 mm, 16 mm, 50.6 mm and 76.2 mm mesh. Percent dry weight (accurate to 1 gm) was calculated for each sample.

Deposition or scour of fine materials as lake stage increases may reduce or enhance fry emergence from spawning areas above minimum pool. To monitor this potential effect, a substrate sample was taken from Skidoo Bay spawning area with each 0.5 m increase in lake stage.

Various methods have been used to determine the effect of substrate composition on salmonid embryo survival and emergence. Predicted embryo survival from the substrate composition collected in shoreline spawning areas will be determined using percent fines (<6.35 m) and cumulative distribution of sediment particle size (Tappel and Bjornn, 1983 and Irving, in press).

Intergravel dissolved oxygen samples were collected by a SCUBA diver using a hand operated rotary pump (Decker-Hess and Graham 1982). A second diver on the surface used a floating discharge hose to collect samples in 325 ml B.O.D. bottles. Samples were collected at four meter intervals along transects. To avoid contamination by lake water of the intergravel sample yet collect water from the egg depositional strata, all samples were taken 15.2 cm into the gravel. Samples were analyzed in the field using the modified Winkler method (Environmental Protection Agency 1974). There was no difference in dissolved oxygen concentrations of samples fixed in situ versus those fixed at the surface.

In reservoirs or regulated natural lakes where water levels fluctuate, shoreline materials are continually resuspended and redistributed in the littoral zone by wave, wind or ice action (Hildebrand 1980). Shoreline structures, i.e. docks or boat houses, may also affect gravel movement and/or distribution. To quantify these phenomena in Flathead Lake, gravel movement was monitored monthly along spawning area transects. Elevations were taken at one meter intervals with a transit and stadia rod.

Several techniques were employed to measure groundwater stage and velocity in the study spawning areas. Seepage meters were used in areas when depth of water exceeded two meters (Lee and Cherry 1978) (Figure 5). Instruments were placed along transects or in a horizontal or vertical pattern that described the spawning area. Water was collected from the meters on a monthly basis. Velocity in ml/min and dissolved oxygen concentrations were determined. Seepage meters were also used to describe the groundwater system outside the spawning area boundaries. Four to five seepage meters were placed throughout the bay at a similar elevation and run bimonthly. Sandpoints were used to collect groundwater

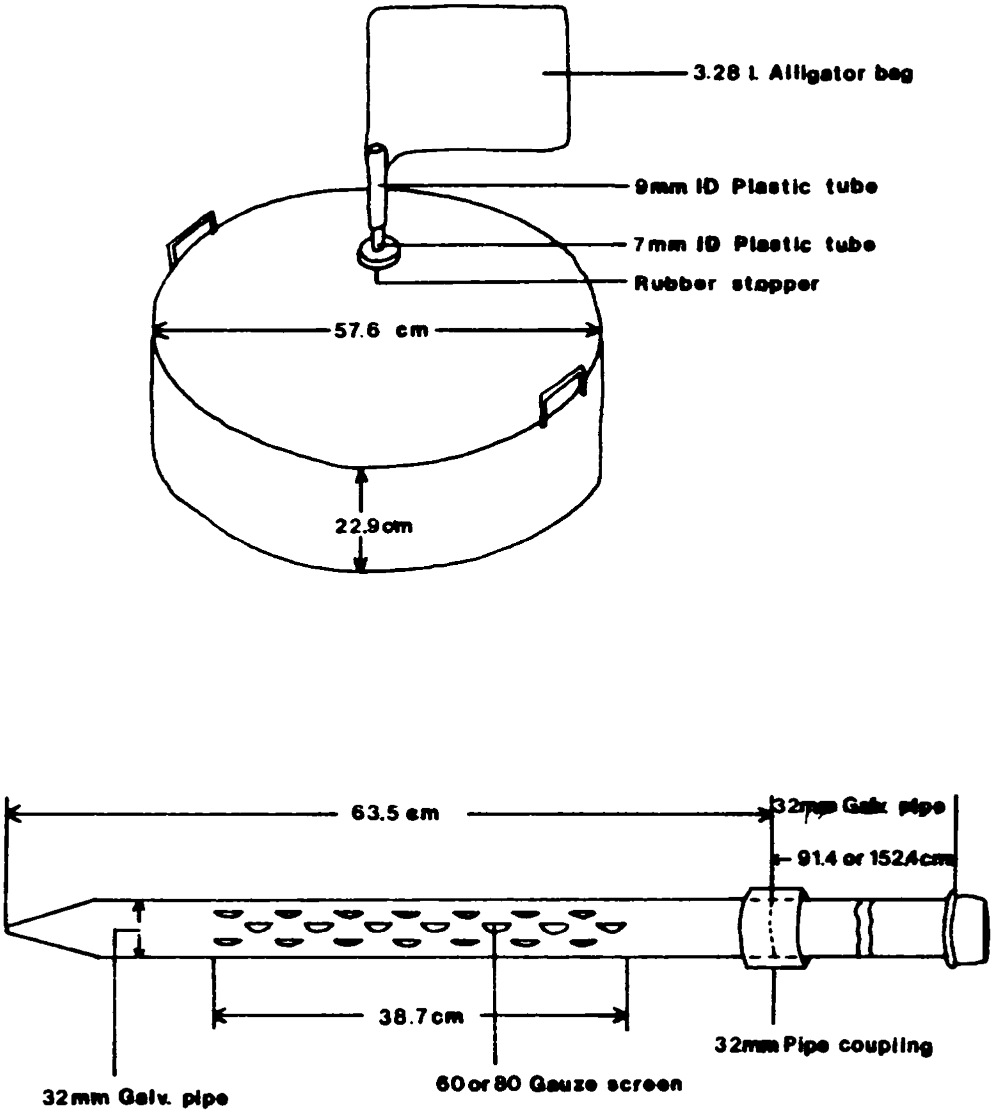

Figure 5. Design and dimensions of seepage meter (Lee and Cherry 1978) and sandpoint used in groundwater measurement.

information in areas exposed by lake drawdown (Terhurne 1958) (Figure 5). Two to four sandpoints were placed in each spawning area. Additional sandpoints were placed as lake levels receded. Information collected from each sandpoint included groundwater stage, velocity and dissolved oxygen. Continuous water level recorders registered groundwater stage in four meter deep wells in three spawning areas. The wells were placed .75-1 m above maximum pool to monitor groundwater stage level throughout the spawning, incubation and emergence period. A complete discussion of methods can be found in Woessner and Brick (1983).

EMBRYO SURVIVAL AND DEVELOPMENT

Kokanee embryo and alevin survival in shoreline areas was assessed by two methods. Natural redds were excavated at the eyed and alevin stages of development. Experimental egg bags were placed in various habitat types to supplement data gathered on natural spawned redds. The bags were harvested on a monthly basis.

In the eight spawning areas selected for further study for 1982-83, 16 percent of the counted redds were marked for excavation during the incubation and emergence periods. As spawning neared completion, a 0.6 m length of 13 mm diameter rebar was driven into the upper center of the study redds. Redds were excavated by various methods depending on the depth of water over the redd. Dry redds and redds affected only by groundwater were excavated using a shovel. Redds covered with less than one meter of water were sampled with a hydraulic sampling device similar to that designed by McNeil (1964) and used by McMullin and Graham (1981), Fraley and Graham (1982) and Fraley and McMullin (1983). In deeper redds, one hydraulic pump modified with a venturi suction device collected eggs/alevins which were manually agitated from the spawning gravels.

Green eggs were planted in two habitat types: 1) groundwater areas above minimum pool, and 2) a groundwater area below minimum pool. Site selection was based on groundwater properties and substrate composition similar to known spawning areas. In each habitat type, four horizontal lines each containing ten egg bags were spaced to thoroughly describe the plant area. Fifty eggs were placed in fiberglass screen bags with gravel and stapled shut.

Substrate composition, bottom elevation and apparent velocity were determined at each egg bag line once during the incubation period. Intergravel dissolved oxygen concentrations were determined immediately after the plant and again near the completion of the experiment.

The top two lines of green egg plants in the habitat type above minimum pool were removed by wave action two months after burial. These lines were replanted in February with eyed eggs and monthly harvest continued.

Thirty-one day recording single and four probe thermographs were installed to record gravel temperatures at four spawning areas. Intergravel temperatures were monitored throughout the spawning and incubation periods and temperature units for various stages of development were calculated. A four probe thermograph was placed in Skidoo Bay, a spawning area above minimum pool, to monitor gravel temperature changes with lake drawdown. Probes were buried 15 cm in the gravel at bottom elevations of 880.3 m (2888 ft), 879.7 m (2886 ft), 879.0 m (2884 ft) and 878.8 m (2883.3 ft). To monitor the effect of lake depth on gravel temperatures, a four probe thermograph was employed at Yellow Bay. Probes were buried at 878.5 m (2882.13 ft), 877.2 m (2877.79 ft), 875.9 m (2873.79 ft) and 874.9 m (2870.38 ft). Single probe thermographs were placed at Dr. Richard's Bay South and Crescent Bay on the west shore at bottom elevation 878.7 m (2882.75 ft).

FRY EMERGENCE AND DISTRIBUTION

In late March, deep water fry emergence traps designed by Stober et al. (1979a) and modified by Hassemer (in press) were placed over marked redds in four east shore spawning areas. Information gathered from the traps included emergence timing, the effect of depth and density on fry quality and quantity and embryo survival to emergence. Traps were checked weekly and captured fry were preserved in ten percent formalin. No more than ten fry were kept from each trap during each sampling period. Fry were measured to 0.5 mm and weighed to the nearest 0.1 gram. Condition factors were determined.

To determine subgravel movement of emerging fry in spawning areas below minimum pool, six groups of 100 eyed eggs were placed under or adjacent to six deep water fry traps. Two groups were placed under traps and one group each was planted to the left, right, behind and in front of four more traps.

Survival to fry emergence was calculated for the Gravel Bay spawning area. Data used for the calculation included number of redds constructed, mean fecundity, mean redd size, area covered by emergence traps and the mean fry captured per trap. The assumption was made that if the entire redd was covered by fry traps, 100 percent of the emerging fry from that redd would be captured. The calculation used to determine percent survival from egg deposition to fry emergence was:

$$\text{percent survival to emergence} = \frac{(\#\ \text{traps needed to cover entire redd} \times \text{mean fry captured per trap}) \times \text{total number of redds}}{\text{Fecundity} \times \text{total number of redds}}$$

Emergence traps designed for use in lotic systems by Phillips and Koski (1969) were modified to trap emerging fry from shallow

(<1 m deep) redds. The traps were constructed of a frame of steel strap with fiberglass screen covering a 0.5 m^2 area.

Night tows to capture emerging fry in shoreline areas were conducted during May and June. Two one-meter nets were towed approximately 7.5 m off the stern of the jet boat on booms extending 1.5 m out from the boat sides. Design of the nets, towing schedule and net placement was determined from findings reported by Johnson (1956). Tows were started at dusk and length of time towed, area covered and fry collected were recorded. Captured fry were preserved and handled in a similar manner to those captured in the fry traps.

Experimental Emergence Studies

Artificial spawning channels at the Somers Fish Hatchery, Flathead Lake, were used in a fry emergence experiment designed to determine if fry could move laterally in groundwater through various substrate concentrations to emerge into a body of water. The control channel, simulating a nongroundwater situation with water flowing over the substrate, contained 10 percent fines less than 6.35 mm. The experimental channels contained 10, 20, 30 and 40 percent fines less than 6.35 mm. Three hundred eyed eggs were planted at the head of each channel in early April. Because of eratic flows throughout the month, near complete mortality occurred by the first of May. The channels were redesigned using 3 mm mesh aluminum screen to obstruct upward movement which allowed higher flows to be maintained. Because sac fry could not be easily handled without harm, the channels were replanted using Vibert boxes for support.

RESULTS AND DISCUSSION

KOKANEE SPAWNER SURVEY

Monitoring of shoreline areas for kokanee spawning activity began 22 October and ended 22 December. During this two month period, 51 bays, stream outlets and groundwater upwellings were surveyed for spawning activity (Appendix A Figure 1, Table 1). The areas were equally distributed between the east and west shores. Four new areas on the east shore, Pine Glen Resort, a seep north of Dee Creek, the east shore of Woods Bay and Flathead Lake Lodge Bay, were included in the east shore monitoring. These areas were added to the schedule based on their groundwater potential or fisherman information. A total of 90 km of shoreline was monitored during the fall of 1982.

Adult kokanee were initially observed on 22 October in Yellow Bay and a seep north of Dee Creek (Appendix A, Table 2). Spawning activity occurred in all areas over a two month period with two noticeable peaks (Figure 6). The majority of the early peak in activity on 27 October resulted from kokanee observations in shoreline areas above minimum pool and at areas south of Gravel Bay. The major contributors to the second activity peak in late November were from spawners below minimum pool and from areas north of Gravel Bay. Kokanee were observed in the deeper areas as late as 22 December.

Adult kokanee were observed over a greater period of time in 1982 than 1981. Spawning kokanee were initially observed nine days earlier in 1982 and extended 14 days later into December. Only one peak of activity containing fewer numbers of spawners occurred in mid-November in 1981. Hassemer and Rieman (1979) observed kokanee over a longer period of time with a later peak when densities were higher in Priest Lake, Idaho. Stober et al. (1979a) found a similar pattern in kokanee spawning in Banks Lake, Washington.

Temporal distribution of redd construction in 1982 was similar to observations of adult kokanee (Figure 7). The earliest peak in redd construction occurred during the first week of November in 1981 compared to the end of October in 1982. The major peak of construction occurred at a similar time period during 1981 and 1982.

Adult kokanee remained in the spawning areas during the daylight hours, but no spawning activity was observed. Other researchers reported behavior ranging from abandonment of shoreline areas during daylight to round-the-clock residence in shoreline spawning areas (Lindsay and Lewis 1957, Whitt 1957 and Lorz and Northcote 1965).

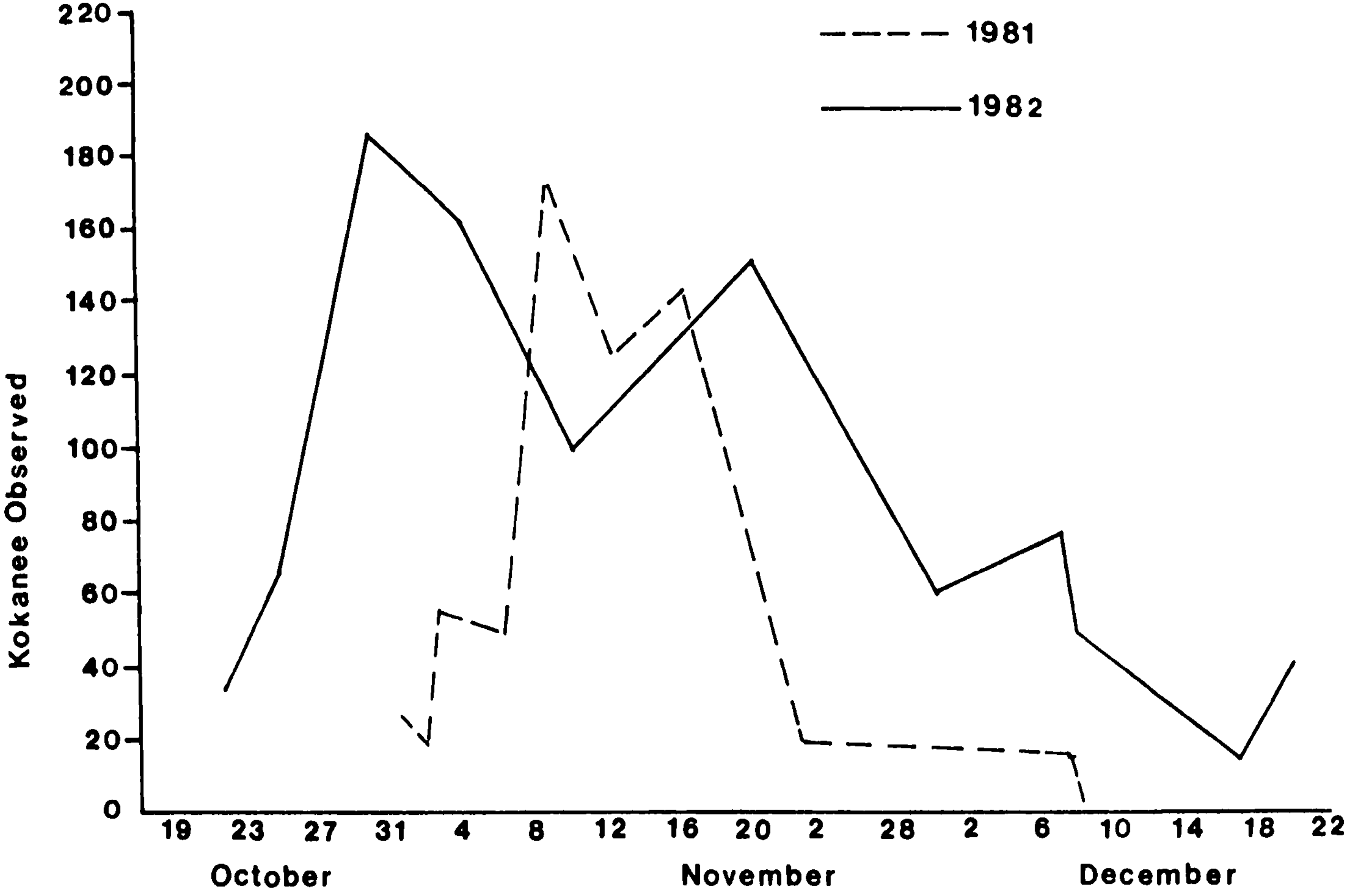

Figure 6. Temporal distribution of kokanee spawners in shoreline areas of Flathead Lake during 1981 and 1982.

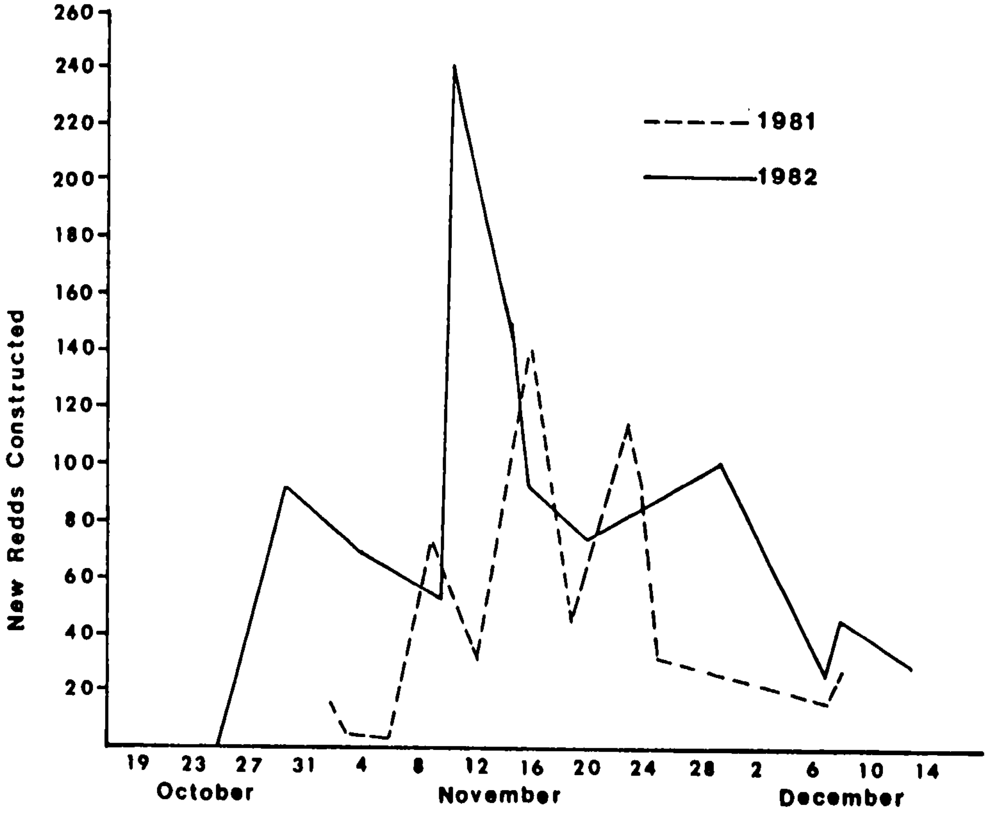

Figure 7. Temporal distribution of new redds constructed by kokanee salmon in shoreline areas of Flathead Lake during 1981 and 1982.

Adult kokanee were first observed in shoreline spawning areas when water temperatures dropped between 9.4-10.6°C (49-51°F). First redds were constructed when temperatures were between 8.6 and 9.7°C (47.5 to 49.5°F) and redd construction peaked at 6.9 to 8.1°C (44 to 45.5°F). Chambers et al. (1954) observed sockeye salmon spawning at temperatures between 10.6 to 12.2°C. From a general review of kokanee, Hunter (1973) reported spawning occurred at 6.6 to 12.2°C and Seeley and McCammon (1966) found 7 to 12°C a preferred temperature for spawning.

Seventeen areas in eleven bays were utilized by spawning kokanee during 1982 (Figure 8). Nine of these areas were located on the east shore and two on the west shore. All of the east shore spawning areas reported by Stefanich (1953) were utilized by kokanee in 1982. Only 11 percent of the 1952 areas on the west shore were utilized in 1982.

Two SCUBA counts of shoreline spawning areas were attempted between 10 November and 13 December (Table 1). Second counts were attempted in Dr. Richard's and Skidoo bays, but wave and wind action rendered redds unidentifiable. In the areas where second counts were completed, additional redd construction occurred between the two dates. Data collected from floating gill net sets in Dr. Richard's and Skidoo bays suggested additional spawning also occurred in these areas after the first count (Table 2). Gill nets set on 22 November captured 97 adult kokanee in these two bays. Thirty and 67 percent of the females captured in Skidoo and Dr. Richard's bays, respectively, were ripe, suggesting spawning had not been completed.

A total of 1,029 redds was counted in the 17 spawning areas. Redd concentrations varied from two at Lakeside to 216 at Gravel Bay (Table 3). Kokanee constructed 75 percent more located redds in 1982 than 1981 (Table 4). An increase in number of redds occurred in all areas except for two areas above minimum pool; Talking Water Creek and Dr. Richard's Bay.

Redd depth at time of construction varied from .26 m at Dr. Richard's Bay to 20 m at Woods Bay. Fifty percent of the redds located were constructed above minimum pool compared to 63 percent in 1981. In other studies on regulated lakes and reservoirs in the Pacific Northwest, shallow depths have been found to be preferred habitat by shoreline spawning kokanee. Stober et al. (1979a and b) found the majority of redds built in Banks Lake, Washington located between 1.5 to 4.6 m. In gravel beach areas in Coeur d'Alene and Priest Lakes, Idaho, Hassemer and Rieman (1979 and 1980) found most redds built at depths between 10.2 cm and 127 cm. Whitt (1957) reported the majority of redds built in a major spawning area in Lake Pend Oreille were at depths of less than two meters. The deepest redd observed was in six meters of water. A greater quantity of clean substrate in the wave zone of natural beach areas was cited as the primary reason for a greater concentration of spawning kokanee in certain areas of Coeur

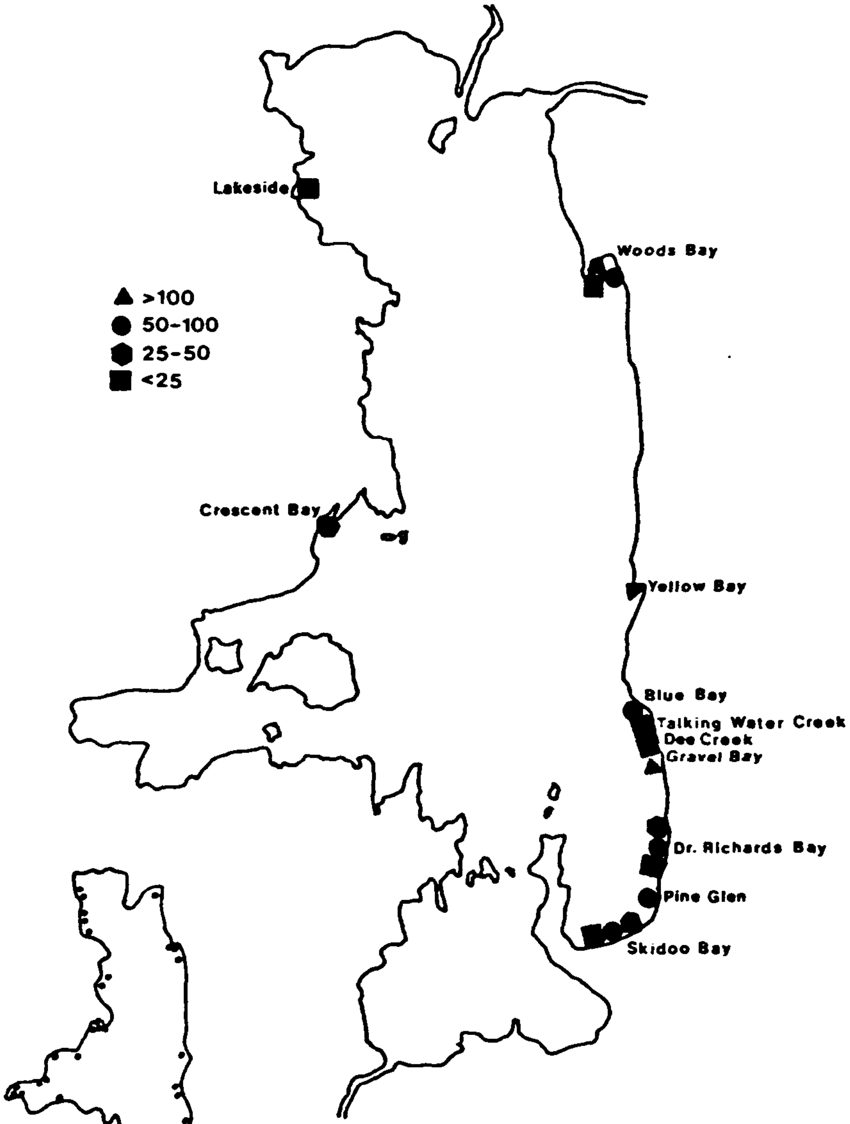

Figure 8. Location of shoreline spawning areas in Flathead Lake, 1982. Shape of symbol denotes number of redds in each area. Smaller map describes locations of shoreline areas of Flathead Lake found by Stefanich in 1952.

Table 1. Comparison of duplicate redd counts using SCUBA techniques in shoreline spawning areas, Flathead Lake, 1982.

	First count (November 10-30)	Second count (November 16-December 13)
Woods Bay	55	68
Yellow Bay	144	168
Blue Bay	34	55
Gravel Bay	212	216
Dr. Richard's Bay	45	---*
Pine Glen Resort	67	85
Skidoo Bay West	43	---*
Skidoo Bay East	68	---

* Wave and wind action had made redds unidentifiable.

Table 2. Location, number of fish caught, sex ratio, number of females ripe and duplicate SCUBA count information for gill net sets conducted during November, 1982.

Location	Date net set	No. fish caught	Sex ratio F:M	Percent females ripe	Dates of SCUBA counts 1st	2nd	Percent change in counts
Gravel Bay	11/19	53	1:3.4	8	11/30	12/8	2+
Yellow Bay	11/19	25	1:2.5	10	11/16	12/8	15+
Dr. Richard's	11/22	41	1:3.4	67	11/11	—*	—
Skidoo Bay	11/22	56	1:2	30	11/10	—*	—

* Because redds became unidentifiable shortly after their construction, a second count could not be completed.

Table 3. Final SCUBA counts of kokanee redds by area and number above and below minimum pool in shoreline areas of Flathead Lake, 1982 (percent in parentheses).

Location	Number of redds	Number above minimum pool	Number below minimum pool
Woods Bay			
East	56	56	0
West Deep	110	0	110
West Shallow	22	22	0
Yellow Bay	197	72	125
Blue Bay	55	0	55
Talking Water Creek	4	4	0
Gravel Bay	216	0	216
Gravel Bay South	22	12	10
Dr. Richard's Bay			
North	45	43	2
South	15	15	0
Boat launch	27	27	0
Skidoo Bay			
East	43	43	0
West	68	68	0
Point	15	15	0
Pine Glen	85	85	0
Crescent Bay	31	31	0
Lakeside	2	2	0
Dee Creek	16	16	0
TOTAL	1,029	511(50%)	518(50%)

Table 4. Comparison of final SCUBA counts of kokanee redds by area in Flathead Lake in 1981 and 1982.

Location	1981	1982	Change
Woods Bay	57	188	+
Yellow Bay	152	197	+
Blue Bay	45	55	+
Talking Water Creek	12	4	+
Gravel Bay	37	238	+
Dr. Richard's Bay	181	87	+
Pine Glen	Not sampled	85	----
Skidoo Bay	103	126	+
Crescent Bay	5	31	+
Dee Creek	0	16	+
Lakeside	2	2	No change
TOTAL	594	1,029	+75%

d'Alene Lake, Idaho and Banks Lake, Washington (Hassemer and Rieman 1980 and Stober et al. 1979a).

Although Woods Bay West Deep was utilized both years by spawning kokanee, redds were located at considerably greater depths during 1982. Thirty-five redds were located in Woods Bay Deep in 1981, down to 11 meters. Over three times as many redds were located during 1982 with redd depth to 20 m. Stober et al. (1979a) attributed increased depth of kokanee spawning in Banks Lake, Washington to increased densities of spawners. Hassemer and Rieman (1980) reported kokanee spawning to 20 m on a road fill slope in Coeur d'Alene Lake, Idaho.

Evaluation of the pram as a trend estimator of kokanee shoreline spawning continued during 1982. Redd counts from the glass bottomed pram were compared to chronologically close SCUBA counts (Table 5). The pram enumerated 62 percent of the total redds located by SCUBA compared to 61 percent in 1981. Pram counts from each area were strongly correlated with SCUBA surveys ($r = .75$, $p<0.01$). Eighty-four percent of the redds in spawning areas above minimum pool were enumerated from the pram. Only 47 percent of the deeper redds (greater than three meters) were enumerated using the pram. Because of the variation in pram counts in shallow areas overestimating number of redds, a much greater correlation was achieved when only the deep area counts were correlated ($r = .9616$, $p<0.01$). The pram may be a more useful predictor in the deeper areas but more reliable for an actual count in the shallower areas. Stober et al. (1979a) concluded the glass bottom pram was useful only as a relative density indicator and then only when densities were low.

Adult kokanee were collected from six areas for size and age composition (Appendix A Table 3). Total length of female spawners for all age classes ranged from 345 to 429 mm with a mean length of 374 mm, slightly longer than in 1981. Seventy-six percent of the 111 females collected were Age IV+. The remainder of the fish were Age III+. Contribution by Age IV+ females by area ranged from 8.3 percent at Dr. Richard's Bay to 50 percent at Pine Glen. Average fecundity was 1,062 eggs compared to 1,056 eggs in 1981. Mean length of 181 adult male kokanee was 394 mm, one mm smaller than the mean for 1981. Forty percent of the fish aged were Age IV+ with the remainder of the fish Age III+. The greater percentage of males being III+ during 1982 may explain the smaller mean size. Sixty-six percent of the males in 1981 were IV+.

Age and size of spawners varied between the six shoreline areas sampled. Age and size of spawners in Dr. Richard's and Gravel bays were similar with 70 to 90 percent of both sexes being Age III+. In Yellow Bay, the majority of males were Age IV+, while the majority of females were Age III+. In all other areas, little variation in spawner age composition occurred between sexes.

Table 5. Comparison of redd counts from the pram with chronologically close SCUBA redd counts for shoreline spawning areas of Flathead Lake, 1982.

Location	Pram count	SCUBA count
Woods Bay		
West shallow	30	22
West deep	20	50
Yellow Bay	70	144
Blue Bay	25	34
Dr. Richard's Bay	30	45
Skidoo Bay		
West	50	43
East	50	68
Pine Glen	50	67
Gravel Bay	40	100
TOTAL	365	573

CREEL CENSUS OF FLATHEAD LAKE SNAG FISHERY

Characteristics of the Fishery Population

Twenty-two fisherman interviews were conducted on the east shore of Flathead Lake from 21 October to 15 November, 1982. Six of these interviews were collected in Section 9-1 and 16 from Section 9-2. Snag fishermen expended 73.5 hours of snagging effort and caught a total of 235 kokanee. The creel also included one cutthroat trout, one bull trout and one lake whitefish taken with lures. Sixty-nine percent of the fishermen creeled were from Lake County. The remainder of the fishermen were from Missoula County (23%), Flathead County (excluding Kalispell) (4%) and four percent from other western Montana counties. Ninety-five percent of the lakeshore snaggers were fishing from shore and caught an estimated 3.2 kokanee per hour. Mean party size was 1.7 anglers.

Estimates of Fisherman Pressure and Harvest

The combined pressure estimate for Sections 9-1 and 9-2 was 636 angler hours (±345; $p \leq 0.95$), or 262 angler man-days. An angler-day averaged 2.42 fishing hours per completed trip. Total estimated harvest for Sections 9-1 and 9-2 was 2,185 kokanee (±1,772; $p \leq 0.95$). When the point harvest estimate was compared to total number of fish counted (calculated by multiplying final SCUBA redd count by three fish (Fraley and McMullin 1983]), 38 percent of the shoreline spawning kokanee were creeled. The small sample size reflected a general lack of effort expended by snaggers for shoreline spawning kokanee. Fifty percent of the total lakeshore interviews were conducted in Skidoo Bay. No snag fishermen were ever observed in Gravel or Dr. Richard's bays. Because of the low numbers of kokanee presently utilizing shoreline areas, the potential existed for fisherman to harvest a significant portion of these isolated populations.

Historic Perspective of Flathead Lake Snag Fishery

A considerable decline in shoreline snagging effort has occurred over the last 20 years. During 1962 and 1963, an average of 12 percent of the annual kokanee harvest, or 31,823 kokanee, occurred during the months of October, November and December (Robbins 1966). Kokanee catch rates increased from .8 fish per hour during the May to September period to 2.5 from October to December. Robbins attributed the catch rate increase to the snagging fishery in shoreline areas from mid-October through mid-December. In 1981, Graham and Fredenberg (1982) estimated kokanee harvest during the October to December period at 21,471 or four percent of the annual harvest. Eighty-two percent or 17,600 kokanee of this harvest occurred in October, prior to the observed dates of kokanee congregating in shoreline areas. Only 14 percent of the harvest from October to December or 2,997 kokanee occurred in November, the month when the majority of spawning occurred. Catch rates in 1981 showed a slight decline from .61 kokanee per hour from May to September to .5 kokanee per hour during the October to December period.

LAKE LEVEL FLUCTUATIONS AND AIR TEMPERATURES

Flathead Lake level fluctuations during the spawning and incubation period of 1982-83 were similar to the 1981-82 season (Figure 9). During the major portion of the spawning period, lake levels declined from 881.2 m (2891.23 ft) to 880.9 m (2890.01 ft) or .37 m. Lake levels declined during December, January and February at a rate of .34 m, .74 m and .56 m, respectively, compared to .5 m, .75 m and .3 m during 1981-82. Although rate of drawdown was nearly identical the two years, lake stage remained .07 m to .3 m higher during the period of 5 November to 15 March in 1982-83. A minimum pool of 879.05 m (2884.03 ft) was reached on 21 March, 1983 compared to a slightly lower level of 879 m (2883.75 ft) on 9 March, 1982. During both years, the lake stage was held for over two months at a level 2.4 m (8 ft) below maximum pool and remained near minimum pool 10 days longer in April, 1983. The average monthly lake stage increase of .8 m during April, May and June, 1983 was identical to 1982.

Minimum daily air temperature at the climatological station at Yellow Bay dipped below -10°C only on 15 December during the spawning-incubation period of 1982-83 (Figure 10). Lake stage was 880.7 m (2889.4 ft) on this date, exposing no constructed redds.

SPAWNING SITE INVENTORY AND MICROHABITAT

Parameters important to spawning site selection and successful embryo survival included intergravel dissolved oxygen, groundwater seepage or surface flow, substrate composition, gravel movement and gravel temperatures. Information to define these parameters was collected at Yellow, Gravel, Woods, Skidoo, and Dr. Richard's bays. Less detailed information was collected at Woods Bay East, Blue Bay, Pine Glen Resort and Crescent Bay.

Spawning Area Characteristics and Redd Distribution

Shoreline redds located in Flathead Lake were constructed in two distinctive shoreline gradient types (Figure 11). Spawning areas with the majority of the redds above minimum pool (>95%) were characterized by a gentle gradient of 7.4 to 11.6 percent. These included Dr. Richard's Bay North and South, Woods Bay East, Pine Glen Resort and Skidoo Bay East and West. Areas where the majority of the redds were constructed below minimum pool were characterized by a steeper gradient of 19 to 57 percent. These areas were Gravel, Blue, Yellow and Woods bays. The steepness of Woods Bay (41 to 57 percent) allowed gravel to be maintained free of sediment deposition to depths of 20 m. Hassemer and Rieman (1980) suggested a steep slope increased the ratio of bottom area to lake surface area which may serve to reduce the level of sedimentation.

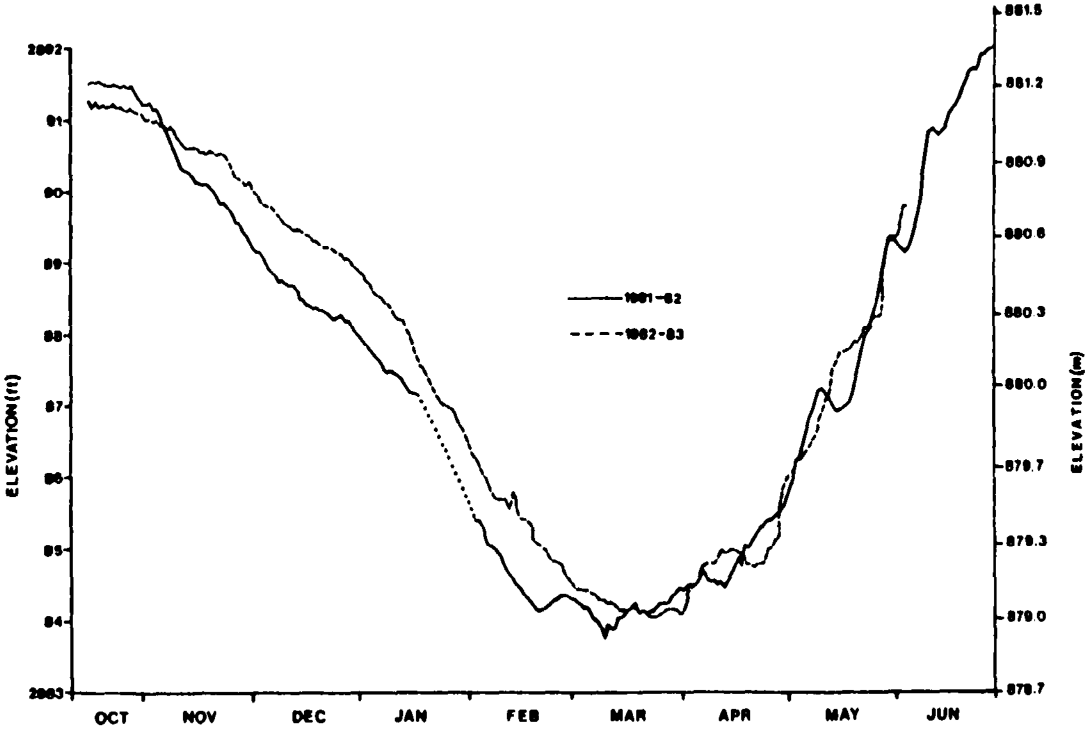

Figure 9. Flathead Lake levels in meters and feet from 15 October to 30 June for 1981-82 and 1982-83. Dotted line represents missing data.

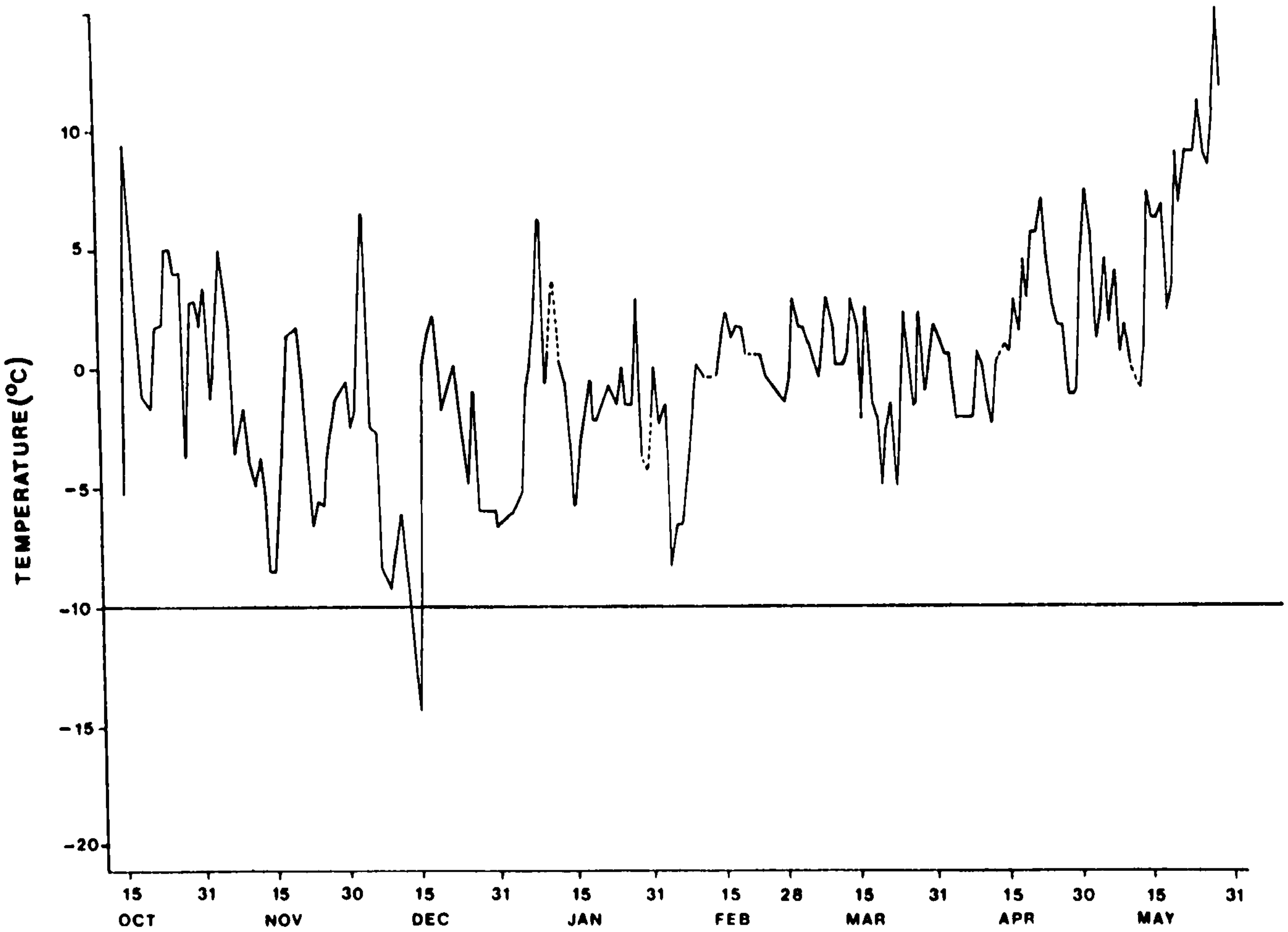

Figure 10. Minimum daily air temperatures at Big Fork climatological station (No. 135) at Yellow Bay on Flathead Lake, Montana. Period of data includes 15 October 1982 through 31 May 1983.

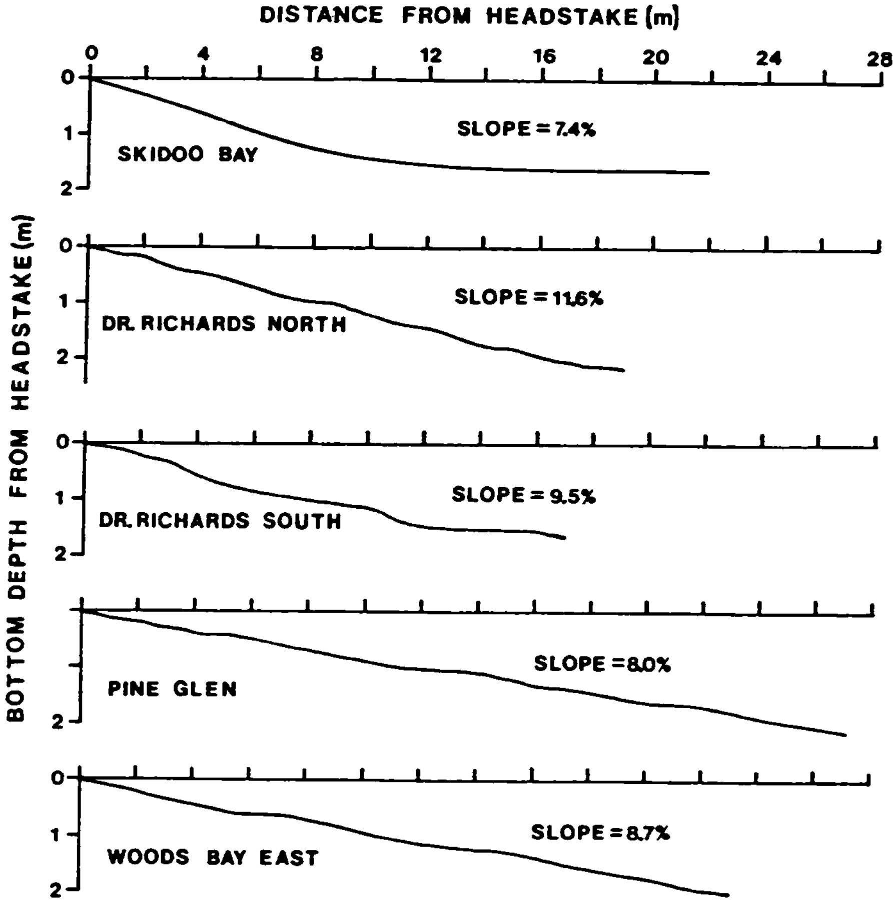

Figure 11. Shoreline slope by bottom depth (in meters) for Skidoo, Dr. Richard's North and South, Pine Glen, Woods, Woods East, Gravel, Yellow and Blue bays spawning areas. Slope is presented in percent.

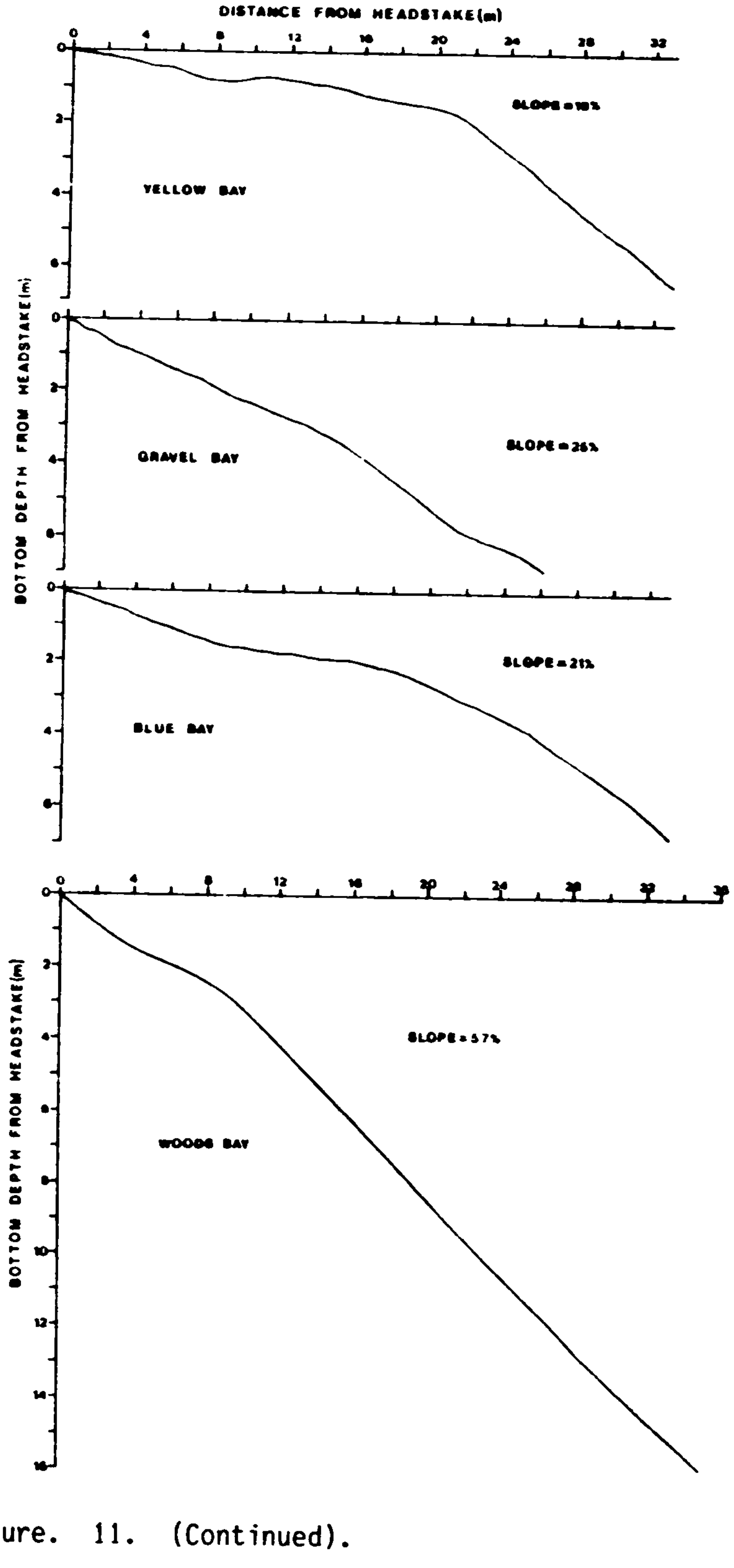

Figure. 11. (Continued).

Spawning Areas Above Minimum Pool

The 45 redds located in the northern area of Dr. Richard's Bay were scattered in a 387 m^2 area (Appendix A Figure 2). Redds were distributed between bottom elevations 878.7 m (2882.98 ft) and 880.8 m (2889.81 ft) (Figure 12). Ninety-six percent of the redds were built above minimum pool. One hundred and six redds were built in a slightly smaller area (315 m^2) in Dr. Richard's Bay North spawning area in 1981.

Two major spawning areas were located in Skidoo Bay during 1982. Forty-three redds were located in a 387 m^2 eastern shoreline area of the bay (Appendix A Figure 3). Eighty-six redds were located in the same area during 1981. Redds were distributed between bottom elevations of 879.2 m (2884.64 ft) and 880.6 m (2889.12 ft) (Figure 12). The second area in Skidoo Bay, located 74 m west of the eastern area, was the site of 68 redds in 1982. Only 17 redds were counted in this area in 1981. Redds were normally distributed in a 12x54 m area between bottom elevations 880.6 m (2889.12 ft) and 879.3 m (2884.8 ft). Eighty-four percent of the located redds were constructed between 879.3 mm (2885.0 ft) and 880.3 m (2888.0 ft). Fifteen redds were also located in Skidoo Bay in an isolated area approximately 400 m west of the western area. All redds constructed in Skidoo Bay were located above minimum pool.

Kokanee utilizing the spawning areas in Dr. Richard's and Skidoo bays appeared to prefer a particular range of depth within the available habitat. Seventy-five percent of the redds located were built in a one meter vertical band between 879.3 (2885.0 ft) and 880.3 m (2888.0 ft) (Figure 13). Based on available microhabitat data, no differences in this zone and the remainder of the available habitat was apparent.

Three additional shoreline areas above minimum pool were utilized by spawning kokanee in 1982. Fifty-six redds were constructed in a 20x43 m area on the east shore of Woods Bay. Redds were distributed in a 0.6 m vertical band between bottom elevations of 879.7 m (2886.23 ft) and 880.3 m (2888.17 ft). A 12x40 m area on the west shore of Woods Bay was the location of 22 redds. Redds were scattered between bottom elevations of 879.4 m (2885.28 ft) and 880.3 m (2888.28 ft). Eighty-five redds were located along the shoreline of the Pine Glen Resort in Skidoo Bay. Seventy of the redds were located in a 10x52 m area ranging in bottom elevations of 878.9 m (2883.5 ft) to 879.9 m (2886.8 ft). The remaining redds were located at shallower depths between 879.9 m (2886.8 ft) and 880.5 m (2888.8 ft). Pine Glen Resort and Woods Bay East were not located as spawning areas in 1981. Twenty-two redds were located and counted at Woods Bay West in 1981.

Intergravel dissolved oxygen was sampled along transects at Skidoo Bay East and Dr. Richard's Bay North and South and randomly

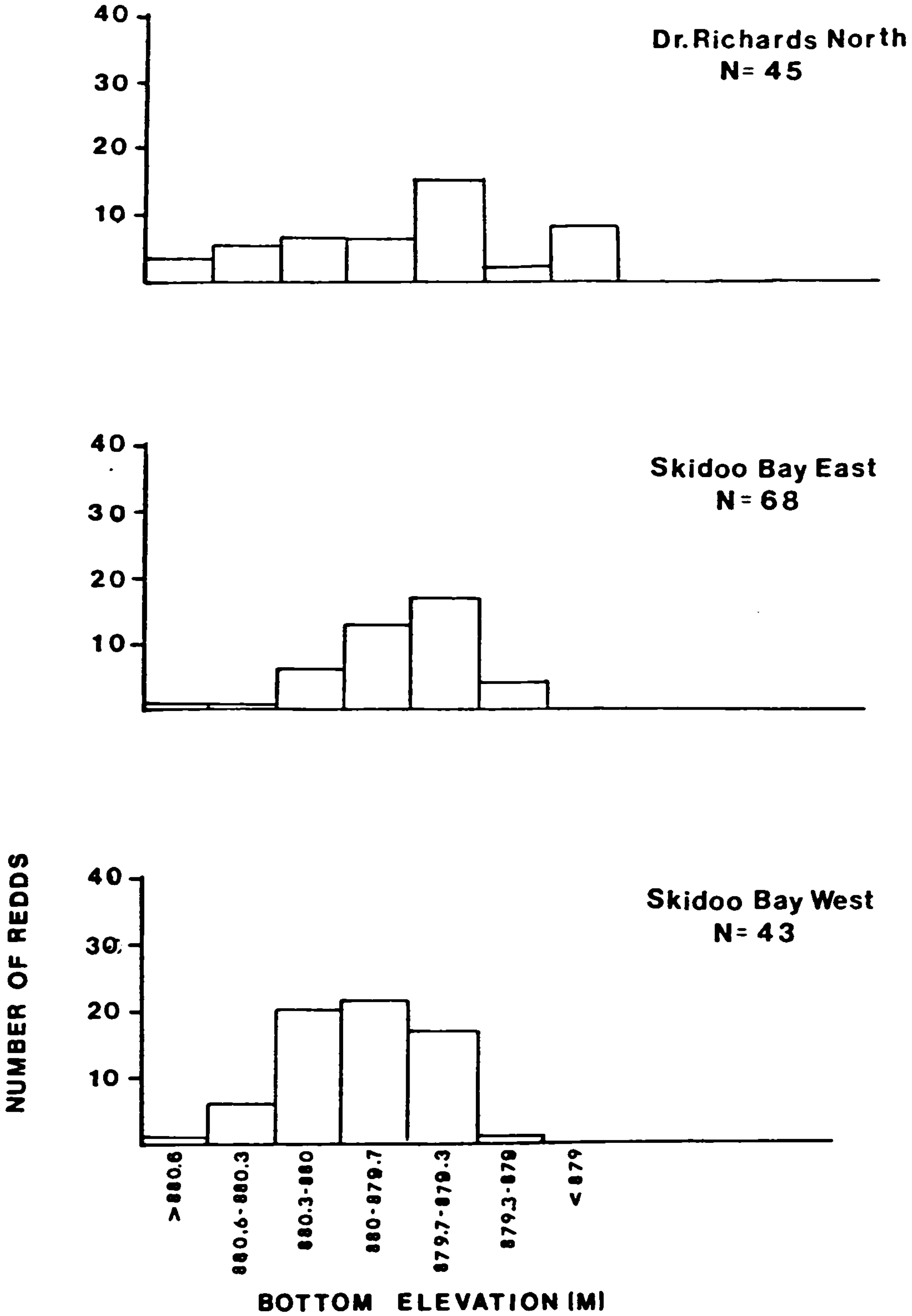

Figure 12. Vertical distribution of redds by bottom elevation in meter intervals for Skidoo Bay East and West and Dr. Richard's Bay North. Total number of redds are presented for each area.

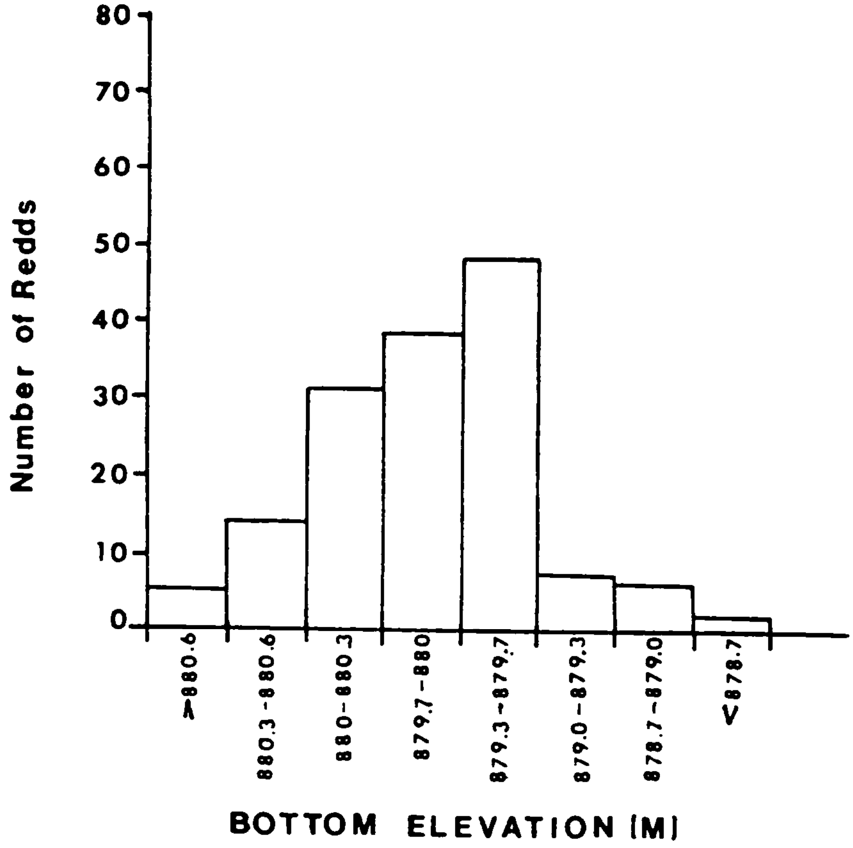

Figure 13. Vertical distribution of redds by bottom elevation in meter intervals from Skidoo Bay East and West and Dr. Richard's Bay North in Flathead Lake, 1982.

at Pine Glen Resort and Skidoo Bay West (Appendix A Table 4). Dissolved oxygen concentrations were above 7.0 mg/l at 49 of the 53 sampling stations during November and March. Oxygen concentrations dropped slightly between the two sampling dates at Skidoo Bay East. No pattern or change was apparent at the other spawning areas sampled.

Spawning Areas Below Minimum Pool

Three major spawning areas were located below minimum pool during the 1982-83 season. The deep area at Woods Bay was located on the west shore of the bay. Sixty-five redds were scattered within a 784 m^2 area (Appendix A, Figure 4). This was the deepest spawning area located and redds ranged from bottom elevations of 863.9 m (2834.47 ft) to 877.1 m (2887.5 ft). Redd distribution revealed little preference for depth within the spawning area (Figure 14). The lower boundary of the spawning area was defined by the gradient lessening and sediment deposition occurring. An additional 38 redds were located in Woods Bay at bottom elevations from 867.0 m (2844.47 ft) to 877.5 m (2879.0 ft) in a band north of the major area. Woods Bay was used by spawning kokanee in 1981 but only to depths of 11 m. Intergravel dissolved oxygen was sampled along three transects in Woods Bay in April (Appendix A Table 4). Bottom elevations of collecting sites varied from 858.9 m (2817.9 ft) to 879.1 m (2884.2 ft). Intergravel dissolved oxygen concentrations varied from 1.7 to 10.9 mg/l. Concentrations were generally above 6.0 mg/l except for sites along the southern transect. Concentrations varied from 1.7 to 4.7 mg/l in the southern area.

The largest concentration of 216 redds was located in an 1159 m^2 area in Gravel Bay (Appendix A Figure 5). Twenty-two additional redds were located in Gravel Bay south of the major area. Redds were constructed between bottom elevations of 872.6 m (2863.0 ft) and 879.6 m (2886.0 ft). Ninety-eight percent of the redds were located below minimum pool. The majority of the redds were spawned at depths from 872 m (2860.9 ft) to 875 m (2870.7 ft) and 876 m (2874.0 ft) to 878 m (2880.6 ft) (Figure 14). The maximum depth of redds was apparently defined by large clumps of macrophytic growth over a more gentle gradient. Several scattered redds were found constructed in this area where plant growth had been fanned away and spawning occurred in the gravel below. Thirty-seven redds were constructed in Gravel Bay in 1981. Intergravel dissolved oxygen samples were taken along three transects in November and March (Appendix A Table 4). Bottom elevations of sampling sites varied from 872.4 m (2862.38 ft) to 879.0 m (2883.86 ft). Dissolved oxygen concentrations in November varied from <1.0 to 11.5 mg/l. Only the bottom station on each transect was below 5.0 mg/l. By March, intergravel dissolved oxygen had increased by 2.0 to 5.0 mg/l at the sampling sites except for the deeper station on each line.

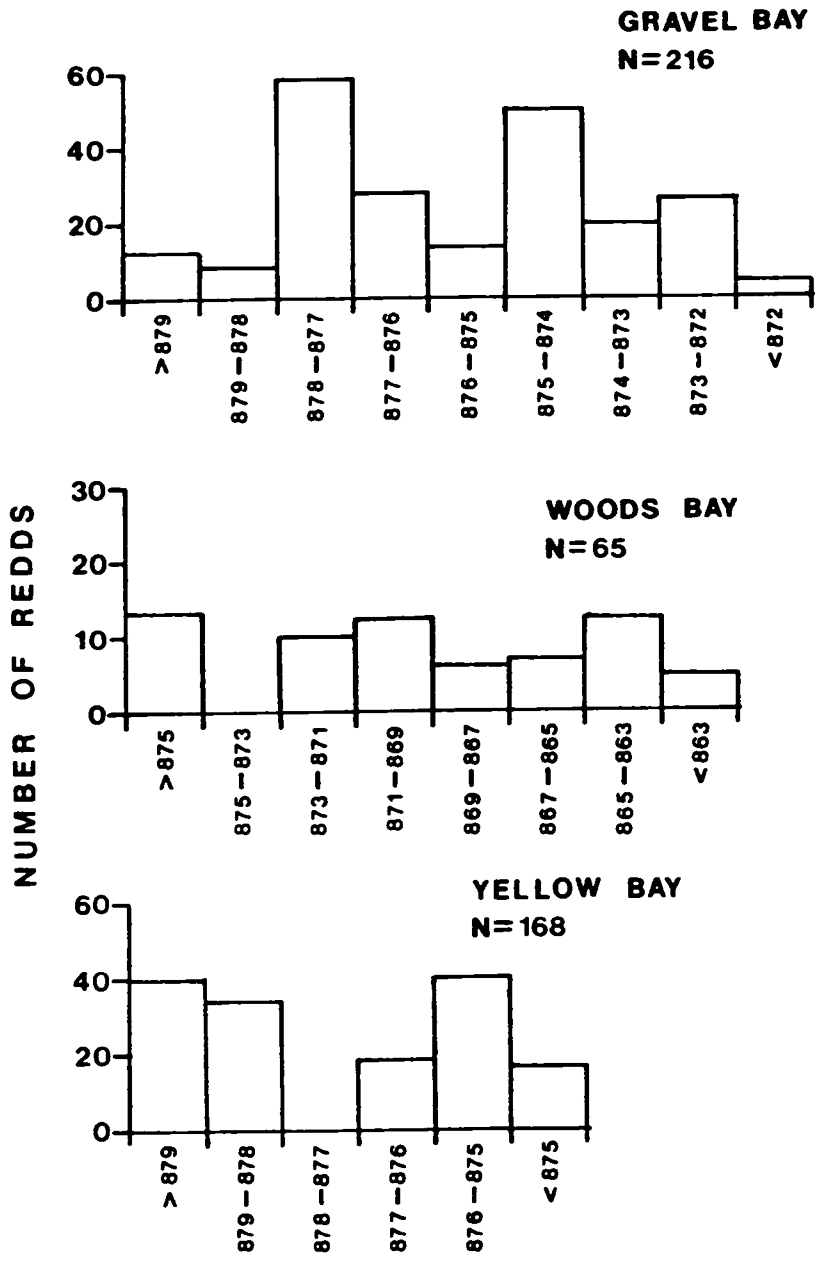

Figure 14. Vertical distribution of redds by bottom elevation in meter intervals for Yellow, Gravel and Woods bays. Total number of redds are presented for each area.

The 168 redds counted in the major spawning area of Yellow Bay were located in an 808 m^2 area (Appendix A Figure 6). Although only 20 additional redds were counted in 1982 compared to 1981, the area utilized was 75 percent larger. Redds were distributed in two vertical bands between bottom elevations 874.9 m (2870.6 ft) and 876.2 m (2874.6 ft) and 878.0 m (2880.6 ft) and 879.5 m (2885.6 ft) (Figure 14). Sixty-two percent of the redds in the major area were located below minimum pool. Twenty-nine additional redds were counted in Yellow Bay outside the major area boundaries. Ninety percent of these redds were located above minimum pool. Intergravel dissolved oxygen concentrations were taken along three transects in Yellow Bay in early December, April and June. Bottom elevations of the 19 sampling sites varied from 873.3 m (2865.06 ft) to 879.7 m (2886.06 ft) (Appendix A Table 4). Intergravel dissolved oxygen concentrations were extremely low in December, varying from 0.3 to 8.8 mg/l. Seventy-four percent of the samples were less than 4.0 mg/l. By the April sampling date, intergravel dissolved oxygen concentrations had increased with few stations below 6.0 mg/l (Figure 15). Concentrations on the east and central transects remained high in June. Concentrations along the west transect were at or below 5.1 mg/l. Little variation in intergravel dissolved oxygen occurred between samples collected in March, 1982 and April, 1983 (Table 6). Intergravel dissolved oxygen concentrations were not sampled in November 1981 to document if a similar increase occurred between November and March.

The 55 redds counted in Blue Bay were constructed within a 384 m^2 area. Redds were distributed along a nine meter length of shoreline between bottom elevations of 873.5 m (2865.67 ft) and 877.3 m (2878.38 ft). Blue Bay received similar use by spawning kokanee in 1981 when 45 redds were counted.

Gravel Movement

General trends in gravel movement in six shoreline spawning areas supported trends observed during the 1981-82 season. These trends were: 1) the zone of greatest scour or deposition was located within the wave zone; 2) lake stage fluctuation allowed the entire width of spawning areas above minimum pool to be subjected to wave action; 3) the least gravel movement occurred during the most stable lake stage conditions, i.e. minimum and maximum pool and, 4) scour and deposition was most intensive when rate of decline or increase in lake elevation was greatest. Additional information collected during 1982-83 documented the effect of dock structures on gravel deposition and scour.

Areas least affected by gravel movement were located below minimum pool. Gravel movement in the Gravel Bay spawning area occurred only within the wave zone (Figure 16). Little change in gravel elevations occurred along the remainder of the transect. Although located on the east shore, Gravel Bay is sheltered to some degree from southwest and northwest winds.

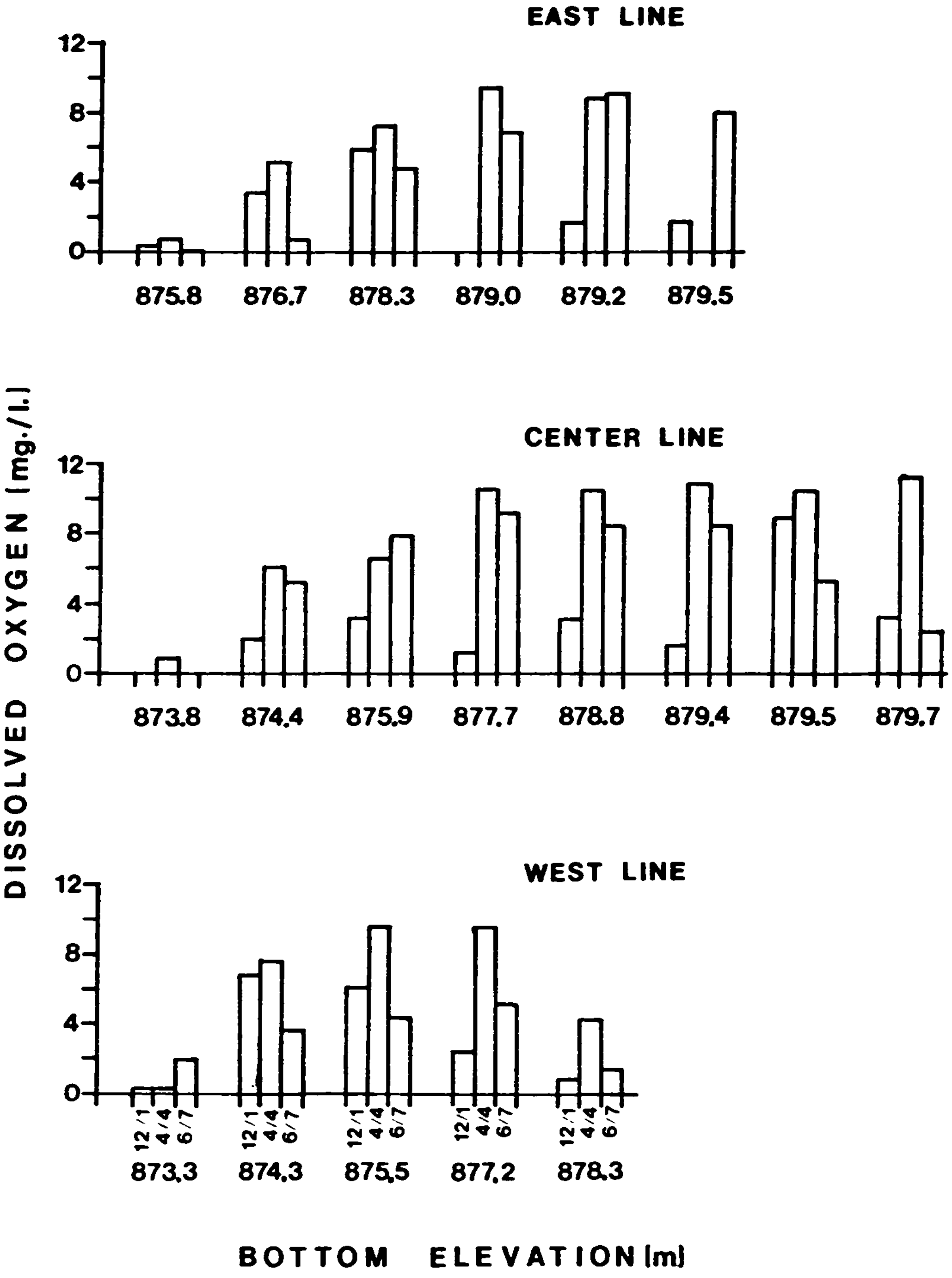

Figure 15. Intergravel dissolved oxygen concentrations by bottom elevation along 3 transects in Yellow Bay spawning area. Samples were collected at each transect on 1 December, 1982 and 4 April and 7 June 1983. Bottom elevations in meters and oxygen in mg/l.

Table 6. Comparison of intergravel dissolved oxygen concentrations (in mg/l) along transects in the Yellow Bay spawning areas on 21 March, 1982 and 4 April, 1983. Sampling sites are located by bottom elevation in meters.

Location	Bottom elevation (m)	1982	1983
East transect	879.0	9.9	9.4
	878.3	9.4	7.1
	876.7	2.4	5.2
	875.8	---	<1.0
Middle transect	878.7	8.4	10.5
	877.9	9.2	10.8
	875.7	9.1	6.5
	873.9	.9	.6
West transect	876.8	8.9	9.3
	875.8	9.2	9.6
	874.9	8.9	7.7
	873.7	6.9	<1.0

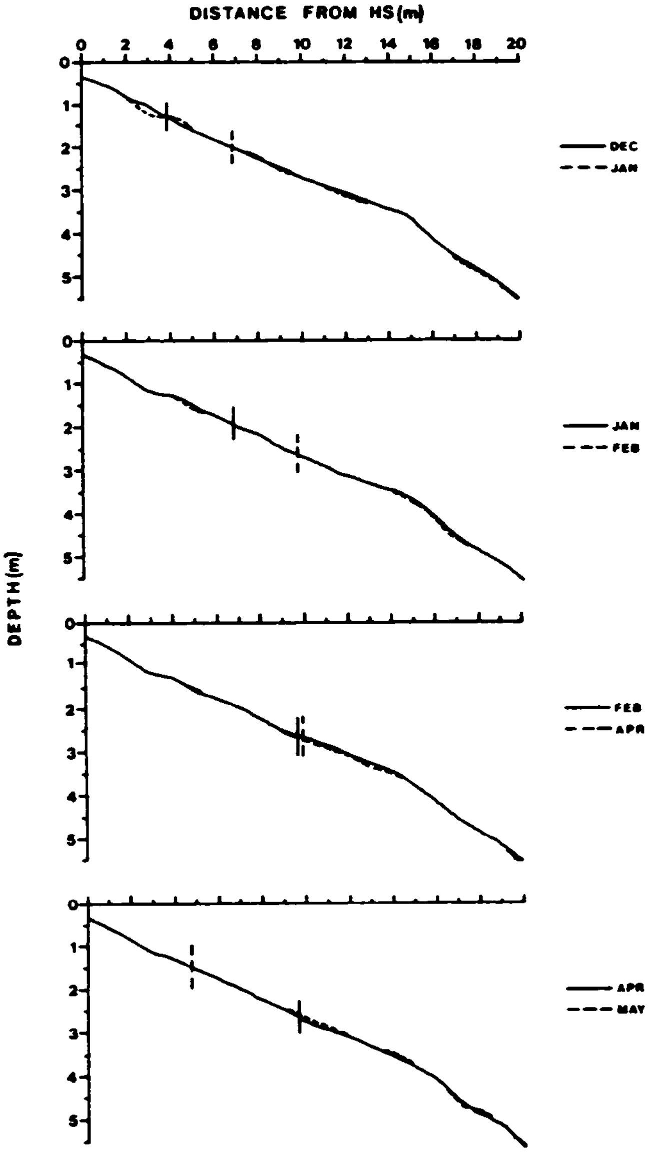

Figure 16. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the Gravel Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence of line denotes lake elevation is above transect headstake.

Wave action eroding the gravel banks of Yellow Bay Creek caused the majority of gravel movement in the Yellow Bay spawning area (Figure 17). As the creek banks began to erode and scour with lake drawdown, wave action moved the gravels to deeper portions of the spawning area. A 0.5-1 m thick layer of gravel measuring 8x16 m was deposited in the spawning area. By May, the gravel had slumped to the bottom of the transect with little change occurring once full pool had been reached in June.

Dr. Richard's Bay, located in a shallow inlet on the east shore, was the spawning area most exposed to the prevailing winds. Gravel movement was minimal along the northern transect during full pool (Figure 18). Gravel movement was greatest during drawdown when up to .5 m of gravel was scoured along the transect. An additional gravel transect was placed in Dr. Richard's Bay which was protected by a closed dock from the prevailing southwesterly winds (Figure 19). Although the entire length of the transect was above minimum pool, the elevational changes did not follow the general trends observed along other transects above minimum pool. Little change occurred in the wave zone during the entire period of measurement.

Although gravel movement in Skidoo Bay followed the general trends for areas above minimum pool, elevational changes were not as severe as Dr. Richard's Bay North (Figure 20). This appeared to be a result of the protected location of the bay from the prevailing westerly winds, the nature of the substrate composition which was finer and more compacted and a lesser shoreline gradient.

Substrate Composition

Spawning Area Characteristics

Kokanee salmon selected substrate in the Yellow Bay spawning area with the majority ranging between 2 to 16 mm. The contribution of fines (less than 6.35 mm) in the Yellow Bay spawning area was 38.4 percent. Substrate with a higher percent of larger material was selected in the Gravel Bay spawning area. Ninety-five percent of the mean substrate composition was greater than 6.35 mm (Figure 21). Substrate selected in the Woods Bay spawning area was generally composed of material larger than 16 mm in diameter.

Larger substrate (>50.8 mm) was the only substrate size not represented in the Skidoo Bay spawning area. The substrate was equally divided within the range of .063 to 16 mm. Concentrations of 33 and 59 percent fines (<6.35 mm) were found at Pine Glen Resort and Skidoo Bay West, respectively (Figure 21). Substrate composition at Crescent Bay on the west shore was characterized by materials ranging from .063 to 16 mm during the incubation period. Thirty-eight percent of the material was less than 6.35 mm. Seventy-six percent of the substrate composition of

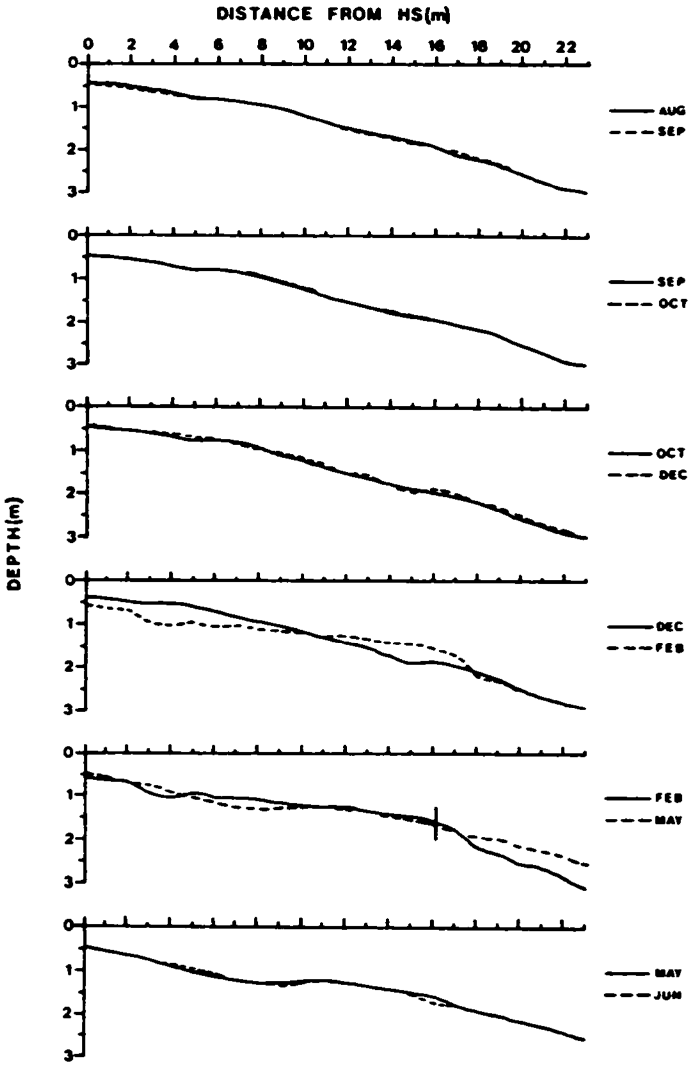

Figure 17. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Yellow Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence of line denotes lake elevation is above transect headstake.

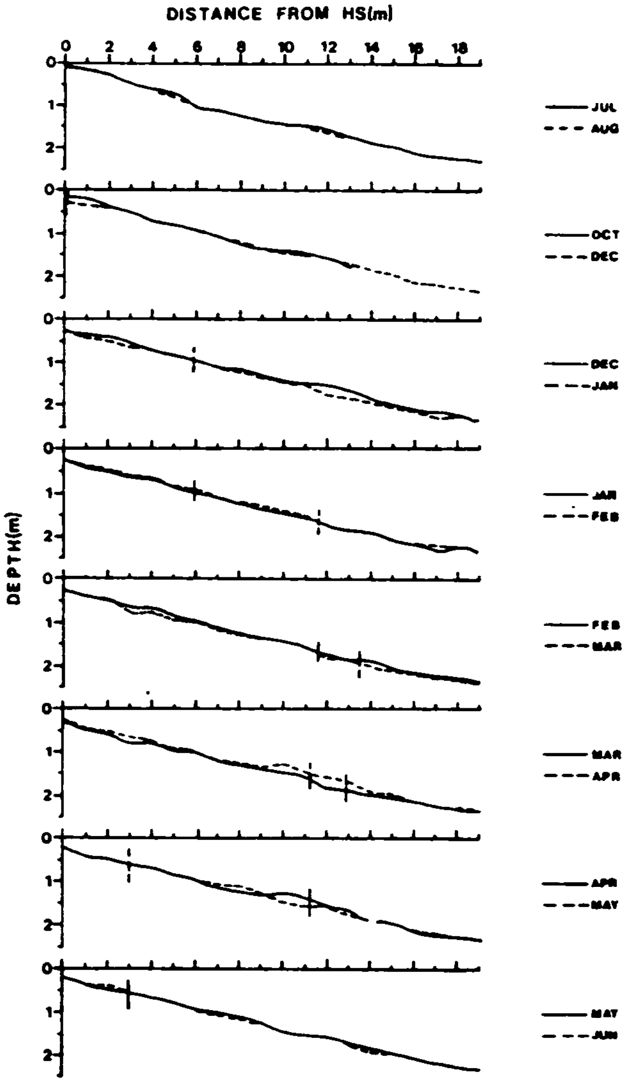

Figure 18. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Dr. Richard's Bay North spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represents location of water's edge at time of measurements. Absence of line denotes lake elevation above transect headstake.

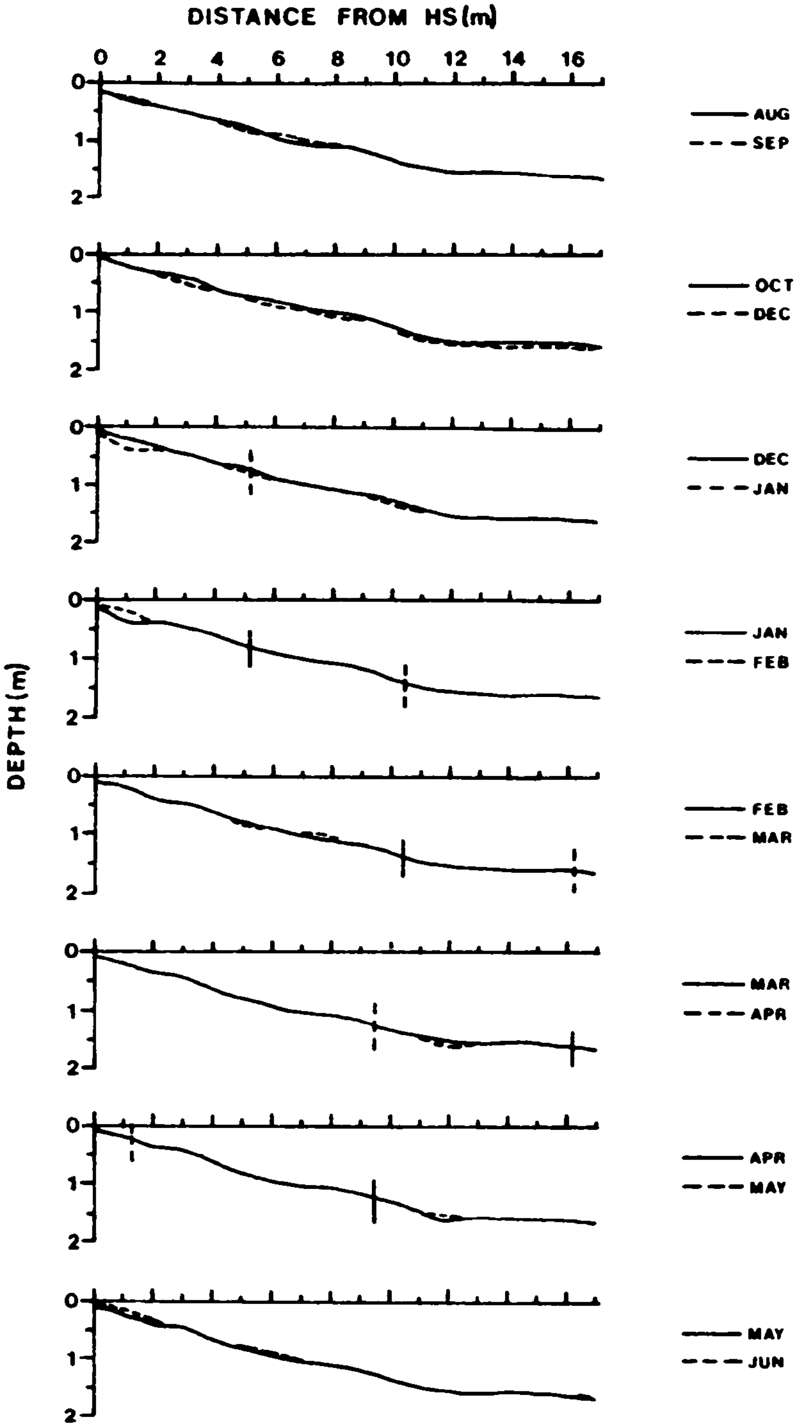

Figure 19. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Dr. Richard's Bay South spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence of line denotes lake elevation is above transect headstake.

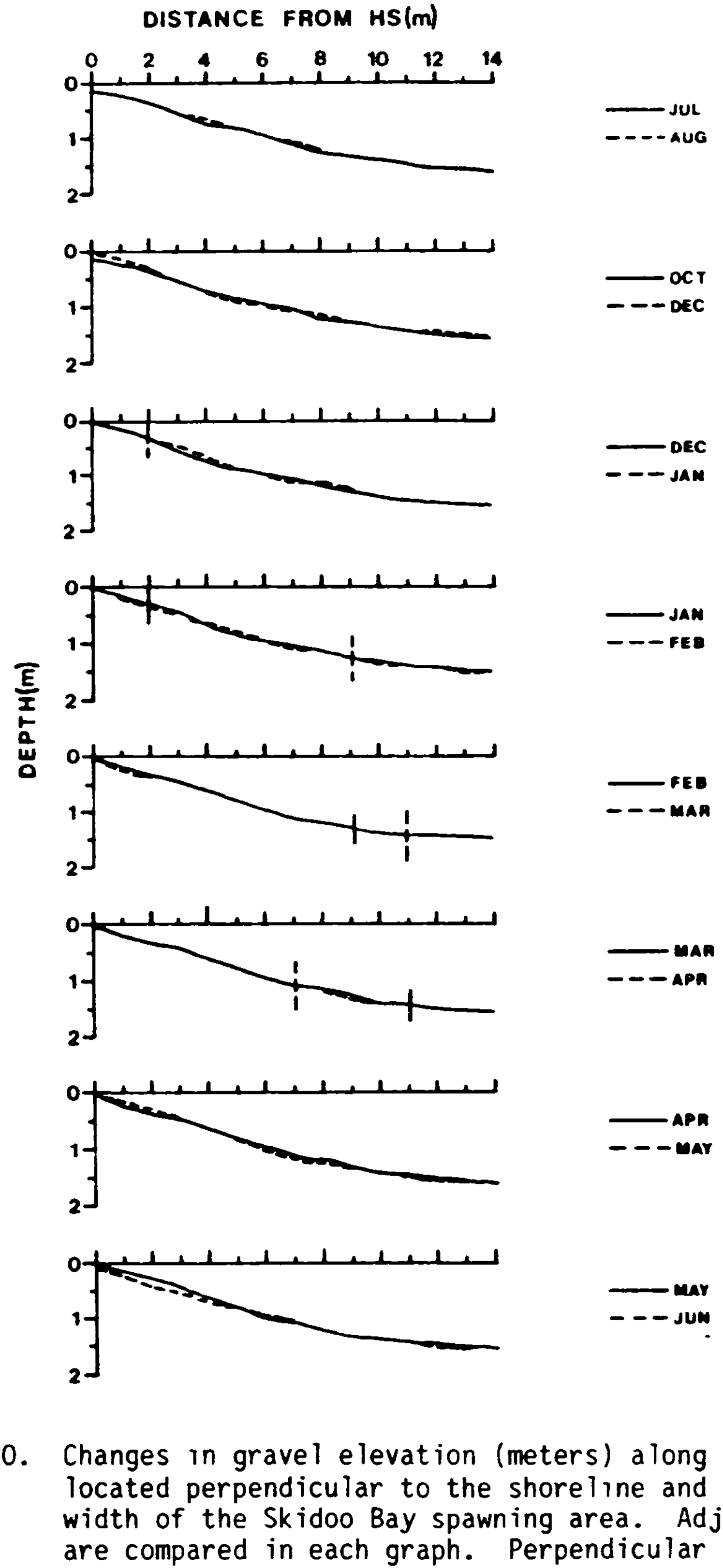

Figure 20. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Skidoo Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence of line denotes lake elevation above transect headstake.

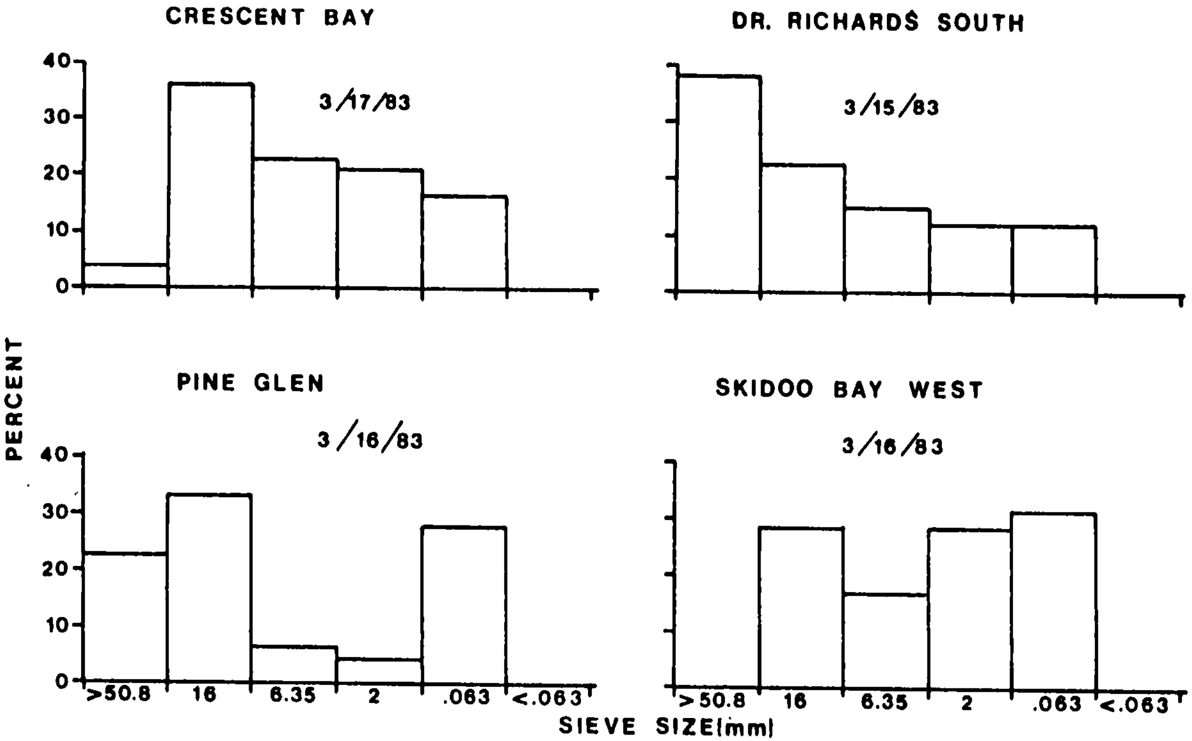

Figure 21. Substrate composition at Crescent, Dr. Richard's South, Pine Glen and Skidoo West bays during March, 1983.

Dr. Richard's Bay North was greater than 16 mm. This larger composition reflected the exposed nature of the bay to the prevailing southwesterly winds which sorted the finer material out of the area. Individual sample composition by percent sieve size are listed in Appendix B, Table 1.

Temporal Distribution

Substrate compositional changes between spawning and incubation were minimal at areas below minimum pool (Figure 22). The only substrate change at Yellow Bay occurred with a doubling in material between .063 to 2 mm. This may have resulted from the substrate from Yellow Bay Creek washing into the spawning area. A shift to a greater percentage of material less than 6.35 mm occurred in Skidoo Bay East from December to March (Figure 23). Percentage of material less than 6.35 mm increased from 36.1 to 60 percent. A similar shift occurred during the 1981-82 field season (Decker-Hess and Graham 1982). Because substrate samples were not taken from similar bottom elevations at Dr. Richard's Bay North in December and March, samples were not comparable.

Intergravel Temperatures

Intergravel temperatures ranged from 2.3° to 12.9°C during the sampling period at Dr. Richard's Bay on the east shore and 3.8° to 12.9°C at Crescent Bay on the west shore. A similar pattern in the intergravel temperatures existed between the two stations until 10 December (Figure 24). After this time and until 15 May, temperatures on the west shore were .5 to 2.5°C warmer than the east shore.

The multiprobe thermograph placed at Yellow Bay spawning area was used to determine a change in intergravel temperatures from depth or groundwater inflows. Intergravel temperature was not correlated to a change in depth in the Yellow Bay spawning area (Appendix A Figures 7 and 8). The shallowest (878.5 m) and deepest (874.9 m) probes exhibited little difference in temperature throughout the recording period. The probe buried at 875.9 m (2873.79 ft), the second deepest probe, was consistently warmer than the other three probes throughout the period of record. The area may have been a zone less influenced by the cooler subsurface flow of Yellow Bay Creek. Air temperatures affected intergravel temperatures only as air temperatures increased. A 5°C increase in air temperature in April was reflected at each probe by a 1 to 3°C increase. Air temperature had a lesser effect on intergravel temperatures with an increase in depth. A change in intergravel temperature occurred after the banks of Yellow Bay Creek slumped, depositing .3 to 1 m of gravel over the upper two probes. Temperature increased and more closely mirrored air temperatures after the deposition.

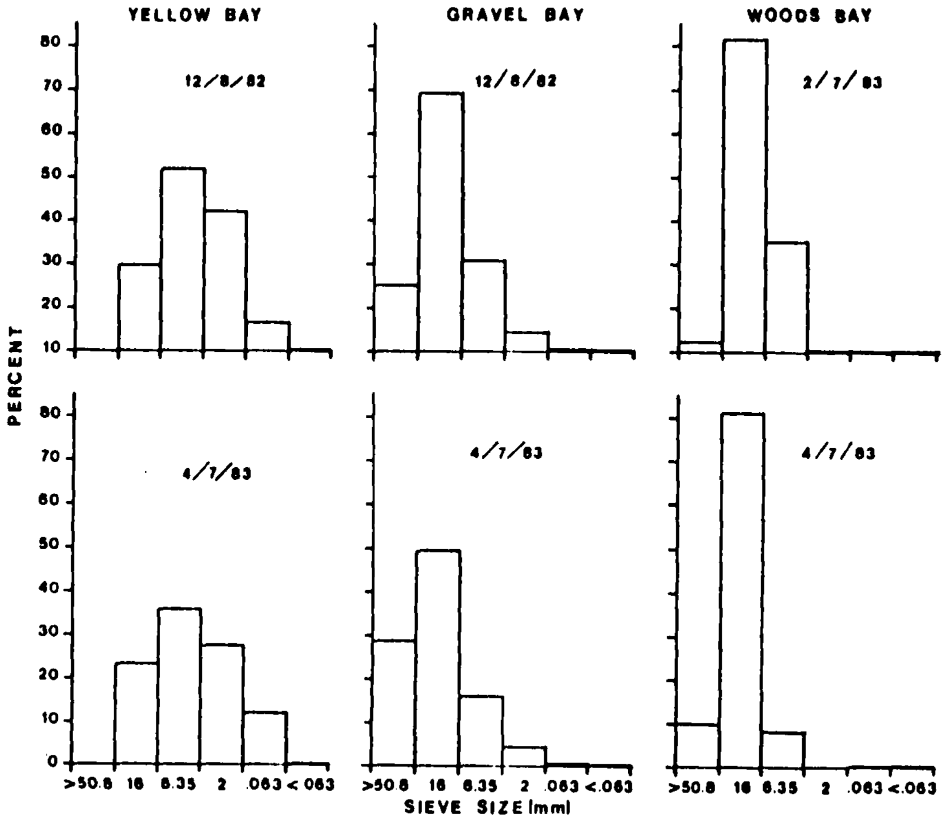

Figure 22. Substrate composition on 8 December, 1982 and 7 April, 1983 at Yellow, Woods and Gravel bays.

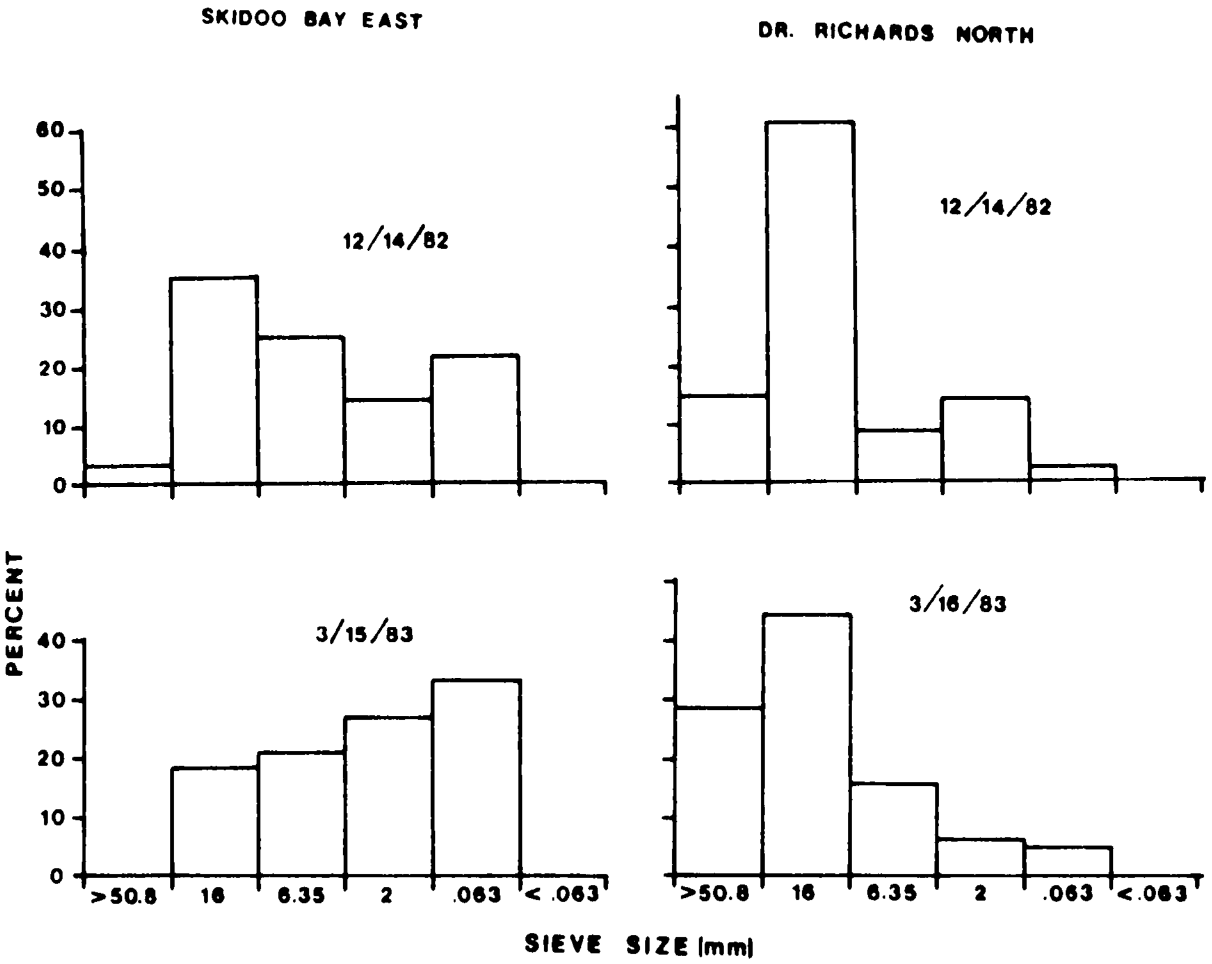

Figure 23. Substrate composition on 14 December 1982 and 15 March 1983 at Skidoo Bay East and Dr. Richard's Bay North.

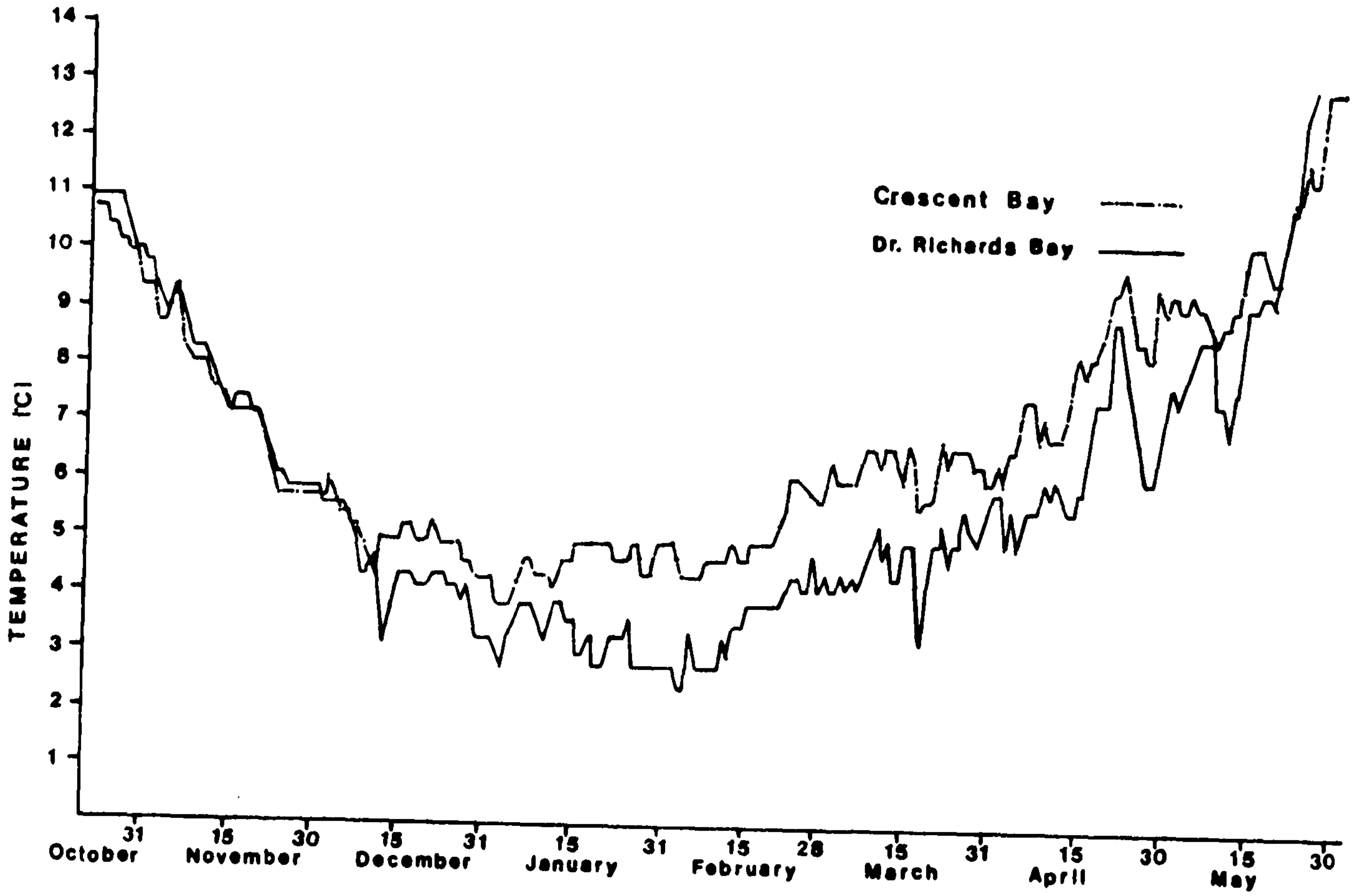

Figure 24. Comparison of intergravel temperatures (°C) at Dr. Richard's Bay South on the east shore and Crescent Bay on the west shore for the period of 15 October 1982 through 31 May 1983.

EMBRYO SURVIVAL AND DEVELOPMENT

The intergravel environment of salmonid spawning areas is seldom conducive to high survival of incubating embryos. Royce (1959), Johnson (1965) and Koski (1966) reported survival to emergence ranging from 10 to 30 percent for various salmonid species in unaltered spawning environs. McNeil (1968) determined that incubation mortality was the most important factor governing year class strength of pink salmon in southeast Alaska streams. Stober et al. (1978) obtained similar results with sockeye salmon in the Cedar River, Washington. With naturally occurring mortality of this magnitude, negative impacts from changes in the physiochemical environment of the spawning site can have significant effects on a salmonid population.

Spawning Areas Above Minimum Pool

Redds were sampled in three study spawning areas in January to determine embryo survival to the eyed stage. Ten percent of the constructed redds were sampled. Eleven redds were sampled at Skidoo Bay East and West, five redds at Pine Glen Resort and five redds at Dr. Richard's Bay North (Appendix C Figures 1, 2 and 3). Four of the sampled redds had been exposed by lake drawdown prior to sampling. Mean survival for the three areas to the eyed stage was 78 percent (Table 7). Survival for Dr. Richard's North, Skidoo Bay East and West and Pine Glen Resort was 57, 75 and 84 percent, respectively. Based on visual observations of the stage of decomposition of the eggs, the majority of the mortality at Skidoo Bay resulted from superimposition during redd construction. Mortality at Pine Glen Resort and Dr. Richard's Bay was more recent. Survival in individual redds is listed in Appendix C Table 1.

The remainder of marked redds above minimum pool were sampled for survival to hatching from the end of February through April. When the majority of eggs examined in an excavated redd were live and eyed, the eggs were reburied and sampled again at a later date. This allowed for a redd with a known survival to be monitored as length of exposure by drawdown increased. Redds above minimum pool at Yellow Bay and Woods Bay East were also included in the sampling.

The effect of ambient air temperatures on egg survival in exposed redds was insignificant during the 1982-83 incubation period. Minimum temperatures fell below the critical level of -10°C only once. The effect of freezing ambient air temperatures on salmonid embryos in dewatered gravel after short periods of time (6 to 48 hours) has been well documented in the literature (McNeil 1967, McMullin and Graham 1981 and Fraley and Graham 1982).

Without the overshadowing effect of freezing temperatures on embryo survival, length of exposure of redds by lake drawdown played a critical role. As length of exposure increased, survival

Table 7. Mean percent survival to the eyed stage for sampled redds at Dr. Richard's Bay North, Skidoo Bay East and West and Pine Glen Resort. Sampling occurred from 10 to 21 January, 1983.

Location	Number redds sampled	Number days redds exposed prior to sampling	Percent survival	Total egg count	Stage of development
Dr. Richard's	5	0	57	178	95% eyed
Pine Glen	5	2	84	828	82% eyed
Skidoo Bay	11	3	75	910	99% eyed
Total or Mean	21	2	78	1,905	91% eyed

of redds above minimum pool at Dr. Richard's, Skidoo, Woods East and Yellow bays and Pine Glen Resort declined (Table 8). Redds moistened only by damp gravel and sand were found to have suffered complete mortality after 45 to 95 days. In redds sampled twice during the incubation period, slightly desiccated eyed eggs were found after 10 to 51 days of exposure. Eggs had suffered complete mortality and total decomposition after being exposed an additional 25 to 58 days.

The effect of exposure by drawdown on embryo survival was further documented and defined by an experimental egg plant in Skidoo Bay. Because the egg bags were harvested on a monthly basis, the relationship between survival and length of exposure could be more accurately defined. Embryonic survival was negatively correlated to length of exposure ($r= -.9104$, $p \leq 0.01$) (Figure 25). Based on this correlation, 100 percent mortality from exposure without freezing temperatures would occur after 78 days. Ten days of exposure would reduce embryo survival by 18 percent. Complete mortality in natural redds sampled during the 1982-83 field season occurred after 69 ($\pm$14) days of exposure.

Based on horizontal redd distribution during 1982 at Skidoo Bay East and West and Dr. Richard's Bay North, complete mortality from exposure by lake drawdown would have occurred to all redds constructed above 879.7 m (2886.0 ft). This would result in mean mortality for the three areas from drawdown alone of 67 percent.

The disappearance of eggs by decomposition rather than movement or emergence was verified by a short experiment. One hundred eyed eggs from the Somers Hatchery were placed in a 19 L bucket with moist gravel of 40 percent fines (<6.35 mm). The bucket was left for 64 days under natural conditions to simulate the shoreline environment. No eggs or parts of eggs were found in the gravels upon completion of the experiment. The only evidence of eggs having been present was a faint "fishy" odor in the gravels.

Embryo tolerance to dewatering has been documented by various authors in systems subjected to hydroelectric drawdown in the Pacific Northwest. In experimental channels, Reiser and White (1981a) reported steelhead and spring chinook eggs were able to survive in a dewatered environment through the eyed stage if moisture remained near saturation and gravel temperatures were acceptable. Alevins were able to tolerate less than 10 hours of dewatering. Hawke (1978) found high survival of pre-eyed and eyed eggs that were stranded up to three weeks in damp gravel. His results were similar to those of Reiser and White concerning alevins intolerance to dewatering. Becker et al. (1982) reported chinook salmon alevins less tolerant to dewatering than embryos with 11 percent survival after only eight hours of dewatering. All eggs in dewatered gravels of Banks Lake, Washington were reported by Stober et al. (1979a) to be dead.

Table 8. Relationship between percent embryo survival and length of exposure by lake drawdown from redds sampled at Dr. Richard's North and South, Skidoo, Woods East and Yellow bays and Pine Glen Resort.

Area	Redd number	Wetted condition	Number days exposed prior to sampling	Percent survival	Stage of development
Dr. Richard's Bay	11	WBG[1]	10	85	100% eyed
Skidoo Bay West	11	WBG	21	31	16% hatch
Yellow Bay	16	WBG	22	95	100% eyed
Skidoo Bay West	8	WBG	29	77	1% hatch
Dr. Richard's	7	WBS[2]	34	31	100% eyed
Woods Bay East	5	Moist	37	85	100% eyed
Skidoo Bay West	9	Moist	45	0	89% hatch
Yellow Bay	16	WBG	46	95	100% eyed
Pine Glen	12	Moist	51	85	100% eyed
Dr. Richards' Bay	6	WBG	57	12	100% eyed
Woods Bay East	5	dry/moist	62	0	Complete decomposition
Dr. Richard's Bay	11	dry/moist	68	0	Complete decomposition
Skidoo Bay East	10	dry	70	0	?
	2	dry	70	0	Complete decomposition
Pine Glen	12	Moist	76	0	Complete decomposition
Yellow Bay	16	dry/moist	95	0	Complete decomposition

1/ Wetted by groundwater at time of sampling.
2/ Wetted by stream at time of sampling.

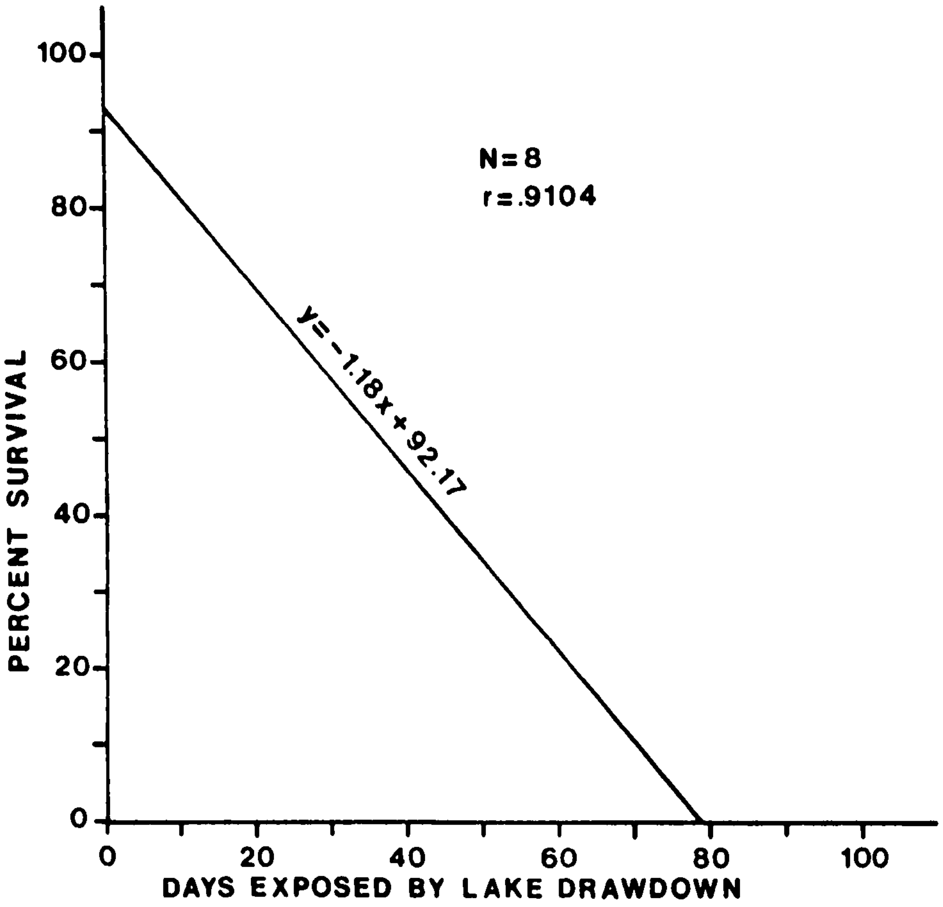

Figure 25. The relationship between percent survival and number of days exposed by lake drawdown from experimental egg plants at Skidoo Bay, 1982-83.

Because only 30 redds were located throughout Crescent Bay on the west shore, experimental egg bag lines were used to document embryo survival. Completed mortality occurred in the original egg bag lines at 879.6 m (2886.0 ft) to 880.3 m (2888.0 ft) after wave action removed the bags. Because the fiberglass bags created more resistance to wave action compared to individual eggs and could be more easily jarred, it is not known if significant mortality from jarring would occur in natural redds. The lines were replanted with eyed eggs in early February. Survival in gravels from 879.6 m (2886.0 ft) to 880.3 m (2888.0 ft) was 72 to 97 percent (Table 9). A subsurface spring wetted the exposed bags during drawdown. Survival below 879.0 m (2884.0 ft) was zero after one month of incubation. Mean intergravel dissolved oxygen levels above 879.6 m and below 879.0 m was 9.0 mg/l and 0.6 mg/l, respectively (Appendix A, Table 4). Monthly apparent velocity measurements were consistently lower below 879.0 m (2884.0 ft) than at shallower stations. Based on this preliminary analysis of west shore habitat, survival was restricted at Crescent Bay to the narrow zone of gravels from 879.6 m (2886.0 ft) to 880.3 m (2888.0 ft).

Groundwater Stage and Embryo Survival

Groundwater flow, or subsurface stream flow from Station Creek in Dr. Richard's Bay North acted independently of lake stage fluctuation (Figure 26). During the period of record, the water table remained .36 to .42 m below the ground surface. The fluctuation of the water table varied only by .06 m. During the same period, lake stage declined by .86 m and increased .55 m. Because the water table remained within the egg depositional zone (15 cm below ground surface) throughout the incubation period, lake stage fluctuation may not play a critical role in embryo survival at Dr. Richard's Bay North (Figure 27).

The water table at Dr. Richard's Bay South spawning area mirrored lake stage fluctuation throughout the period of record (Figure 28). Water table adjustment to lake stage was rapid with levels never more than .15 m above lake stage. Vertical shoreline area wetted by groundwater to the egg depositional zone increased during lowest lake stage an additional 5.5 m (Figure 29). Because of the shallow gradient of the increased wetted area, this would only increase wetted redds from 879.08 m (2884.11 ft) to 879.17 m (2884.40 ft). During the early incubation period, wetted area was increased by an additional 1 to 2 m. Because the water table closely mirrored lake stage throughout the incubation period, groundwater levels played a minimal role in increasing survival of incubating embryos exposed by lake drawdown in the Dr. Richard's Bay South spawning area.

Although the water table at the Pine Glen Resort spawning area mirrored lake stage fluctuation, adjustment was more gradual and the gradient steeper than Dr. Richard's Bay South. Steepness of the gradient increased over time. The difference between water table level to lake level increased from .06 m in January to .33 m

Table 9. Percent survival, stage of development and microhabitat data for four egg bag lines at Crescent Bay, 1982-83.

Location	Sample Date	Elevation (m)	Percent survival	Stage of development	DO mg/l	Apparent velocity ml/min	Percent substrate <6.35 mm	Temperature unit (°C)
Line 1	12/15	880.3	97	100% green				152
	1/25		0		9.9	9.8	14	NS *
Line 1 (eyed plant)	2/9			100% eyed				453.5
	3/2		97	100% eyed				565.5
	4/21		72	90% yolk sac absorption				908
Line 2	12/15	879.6	90	100% green				152
	1/25		0		8.2	10.0	6	
Line 2 (eyed plant)	2/9			100% eyed				453.5
	3/2		95	1% hatch				565.5
	4/21		86	90% yolk sac absorption				908
Line 3	12/15	879.0	0	100% green				NS
	1/25		0		1.2	1.5	30	NS
	3/2		0					NS
Line 4	12/15	878.4	1	100% green				152
	1/25		0		0.0	---	34	NS
	3/2		0					NS

*NS = No Sample.

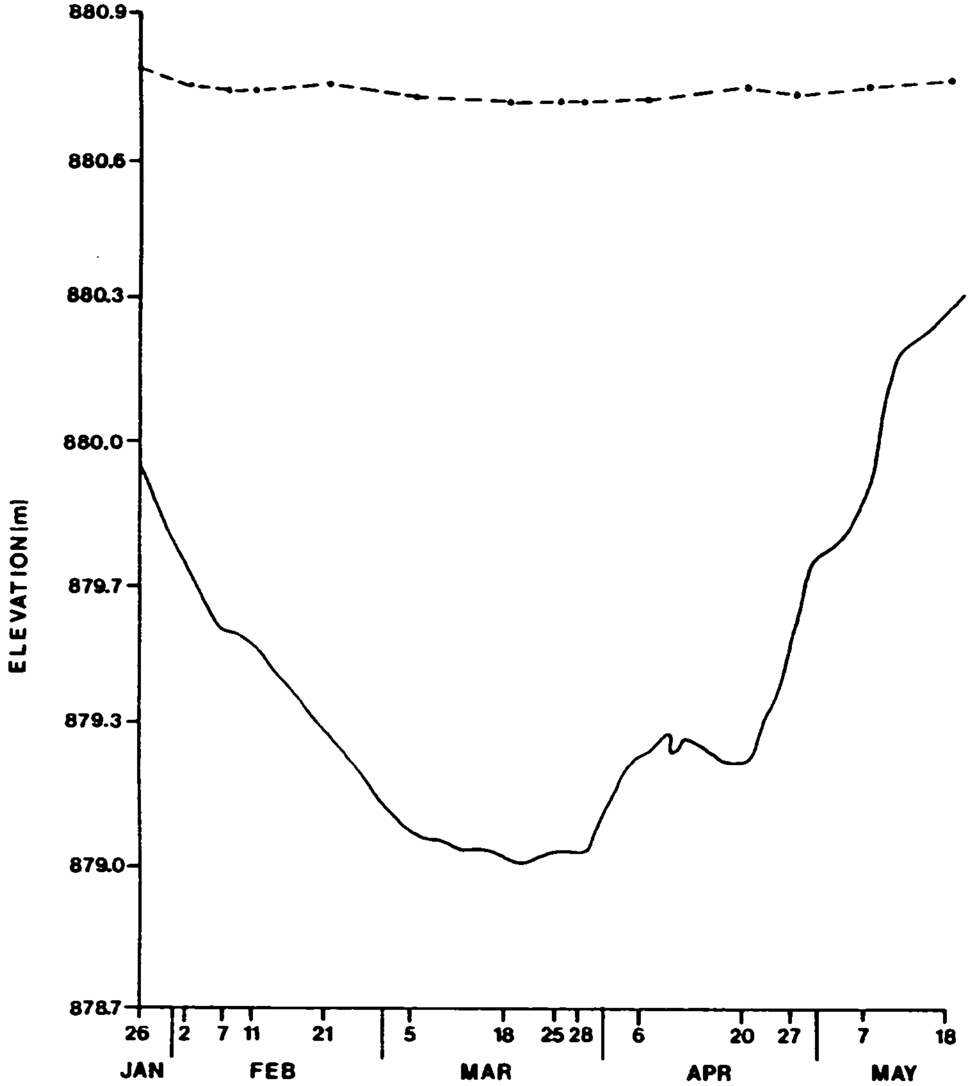

Figure 26. Comparison of lake level fluctuations (solid line) to water table fluctuations (dotted line) at sandpoint BH-1 at Dr. Richard's Bay North from 26 January to 18 May, 1983.

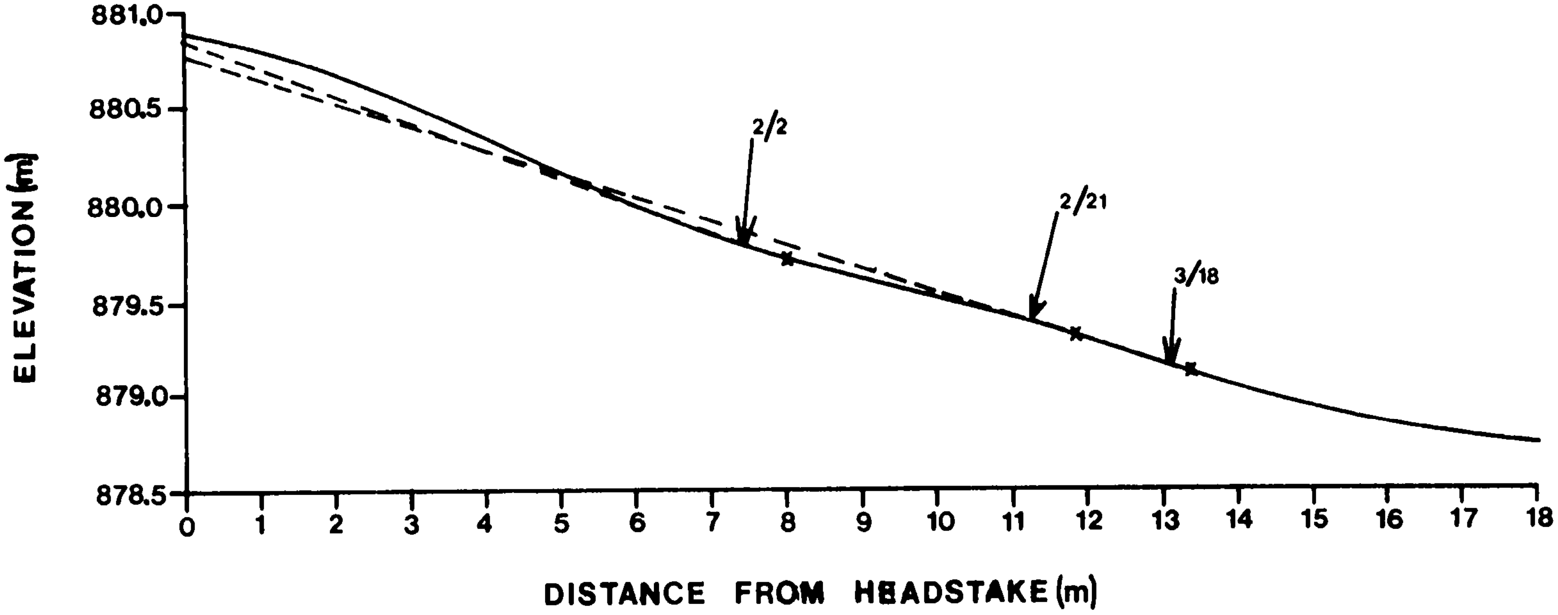

Figure 27. Water table profile at Dr. Richard's Bay North, sandpoint BH-1. Dashed line represents table and solid line represents land surface (transect perpendicular to shoreline).

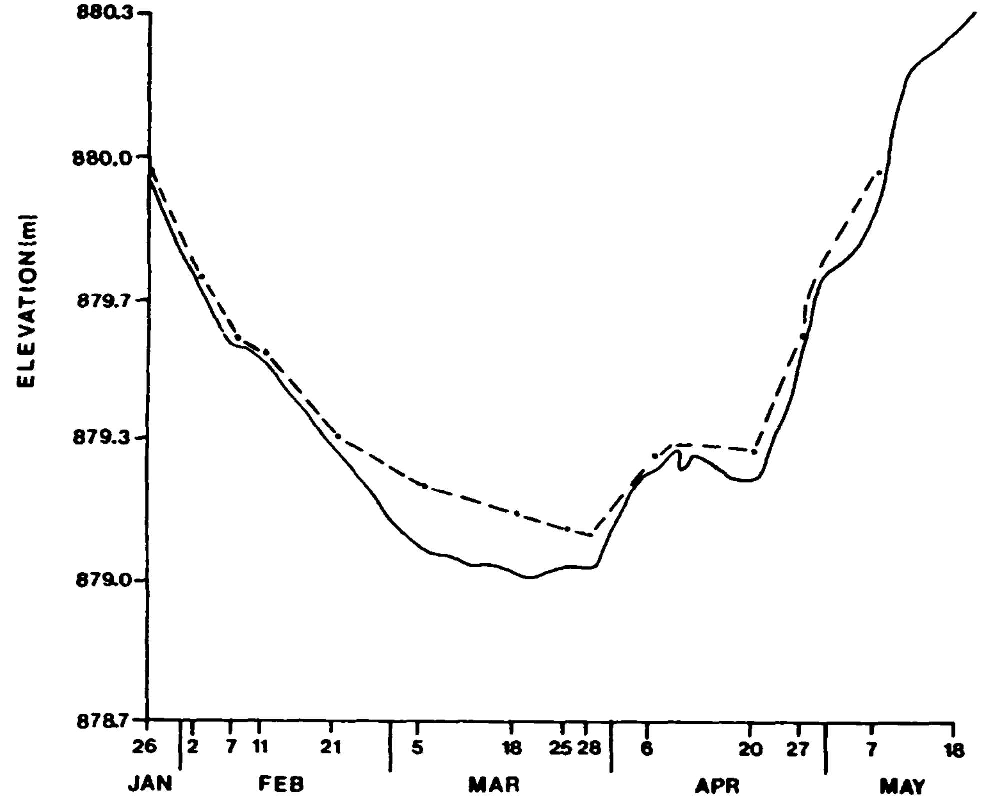

Figure 28. Comparison of lake level fluctuations (solid line) to water table fluctuations (dotted line) at sandpoint DR-1 at Dr. Richard's Bay South from 26 January to 18 May, 1983.

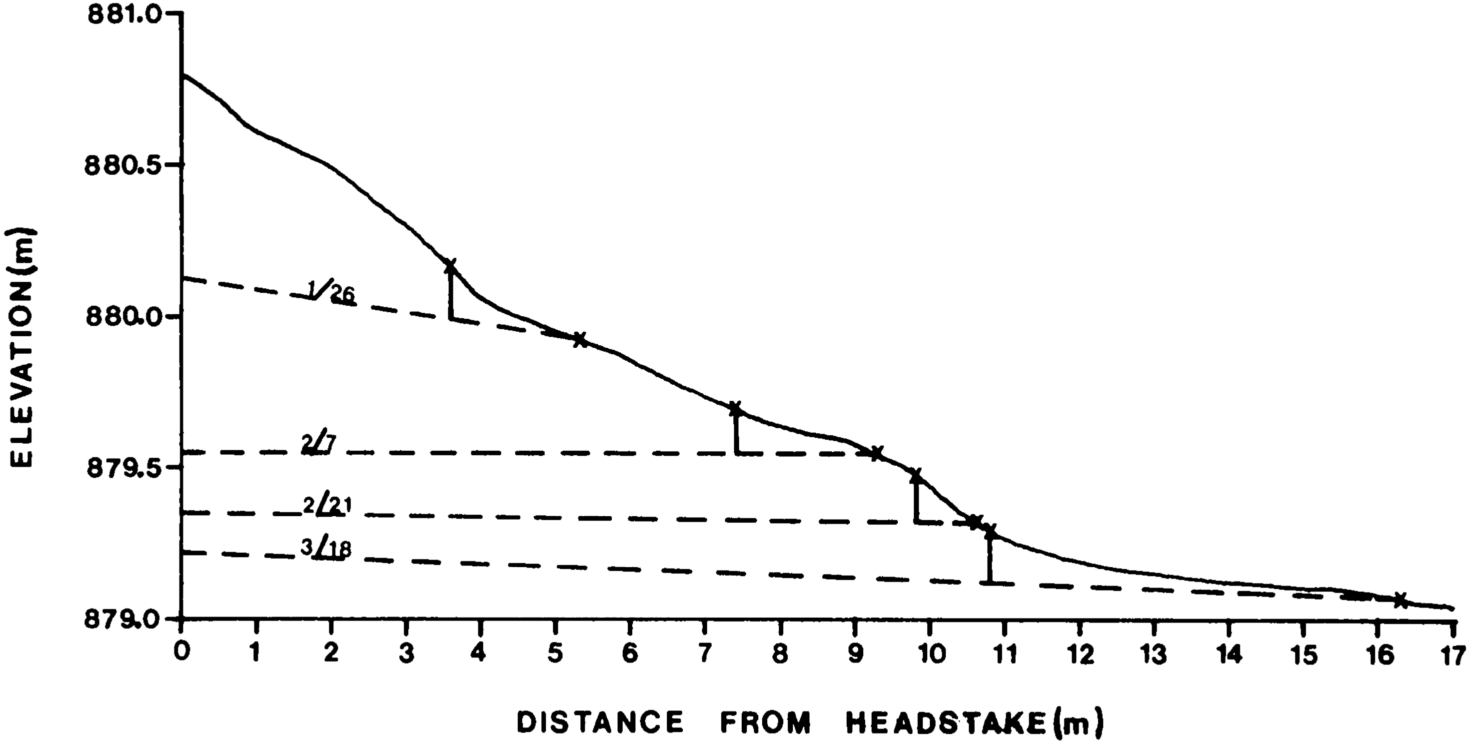

Figure 29. Water table profile at Dr. Richard's Bay South, sandpoint DR-1. Dashed line represents water table and solid line represents land surface (from transect perpendicular to the shoreline). Vertical line connecting water table to land surface represents maximum vertical location of water table at 15 cm (egg depositional zone) below land surface.

in mid-March (Figure 30). Additional wetted horizontal shoreline to the egg depositional zone was increased only .5 to 1.0 m by water table levels (Figure 31). Groundwater levels played a minimal role in increasing embryo survival in exposed gravels of Pine Glen Resort spawning areas.

The water table level at Skidoo Bay spawning area fluctuated with lake levels but was not mirrored closely (Figure 32). Steepness of the gradient between water table and lake level increased during the period of record, ranging from .08 m in January to .52 m by mid-March. An additional 1.5 to 4.5 m of vertical shoreline to the egg depositional zone was wetted by groundwater (Figure 33). During the period of minimum pool (month of March), groundwater level increased the zone of wetted redds from 879.1 m (2884.11 ft) to 879.6 m (2885.83 ft). This would wet an additional 11 redds or 26 percent of the spawning area in Skidoo Bay East.

Spawning Areas Below Minimum Pool

Redds were sampled in three study spawning areas in January to determine embryonic survival to the eyed stage. Six percent of the total constructed redds were sampled during this period. Twelve redds were sampled at Gravel Bay, seven at Woods Bay and nine at Yellow Bay (Appendix C Figures 4, 5 and 6). A total of 5,518 eggs were collected from the sampled redds. Mean survival for the three areas to eyed stage was 48 percent. Area survivals were 83, 13, and 39 percent for Gravel Bay, Yellow Bay and Woods Bay, respectively (Table 10).

Table 10. Mean percent survival to the eyed stage for sampled redds at Gravel, Woods and Yellow bays. Sampling occurred from 17 January to 7 February, 1983.

Location	Number redds sampled	Percent survival	Total count	Stage of development
Gravel Bay	12	83	2,443	86% eyed
Yellow Bay	9	13	2,159	74% eyed
Woods Bay	7	39	916	94% eyed
Total or Mean	28	48	5,518	86% eyed

Survival in individual redds at Gravel Bay ranged from 20 to 97 percent and was not related to depth (Appendix C Table 1). The microhabitat of Gravel Bay was characterized by well oxygenated gravels except along its lower boundary, stable gravel with a low

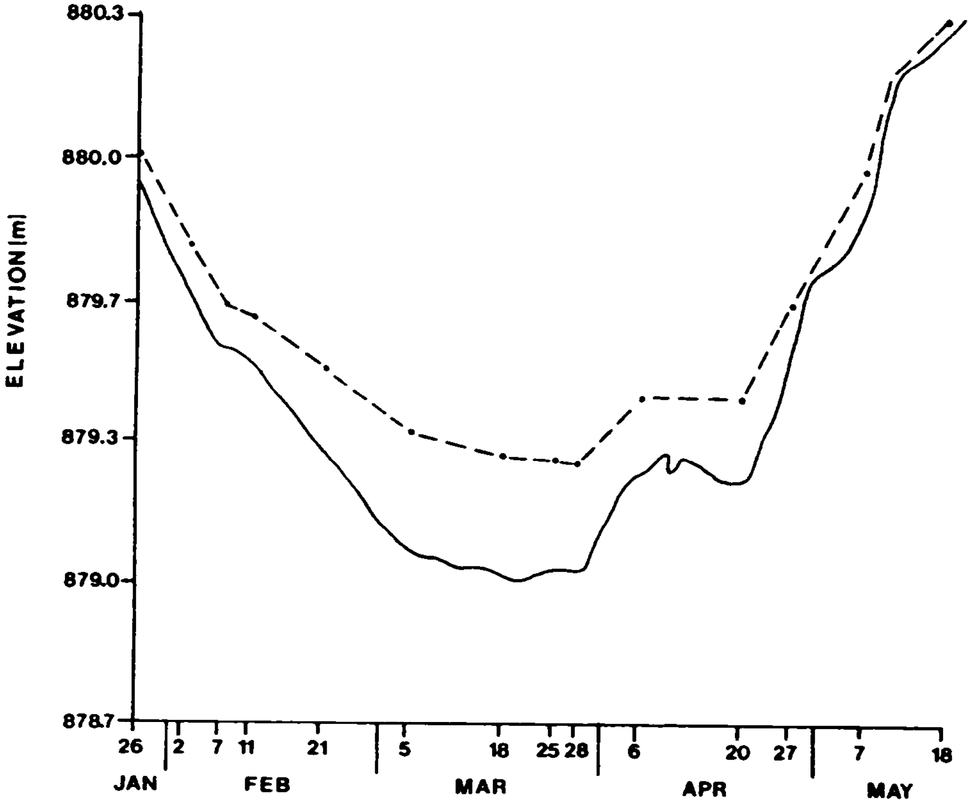

Figure 30. Comparison of lake level fluctuations (solid line) to water table fluctuations (dotted line) at sandpoint PG-1 at Pine Glen Resort from 26 January to 18 May, 1983.

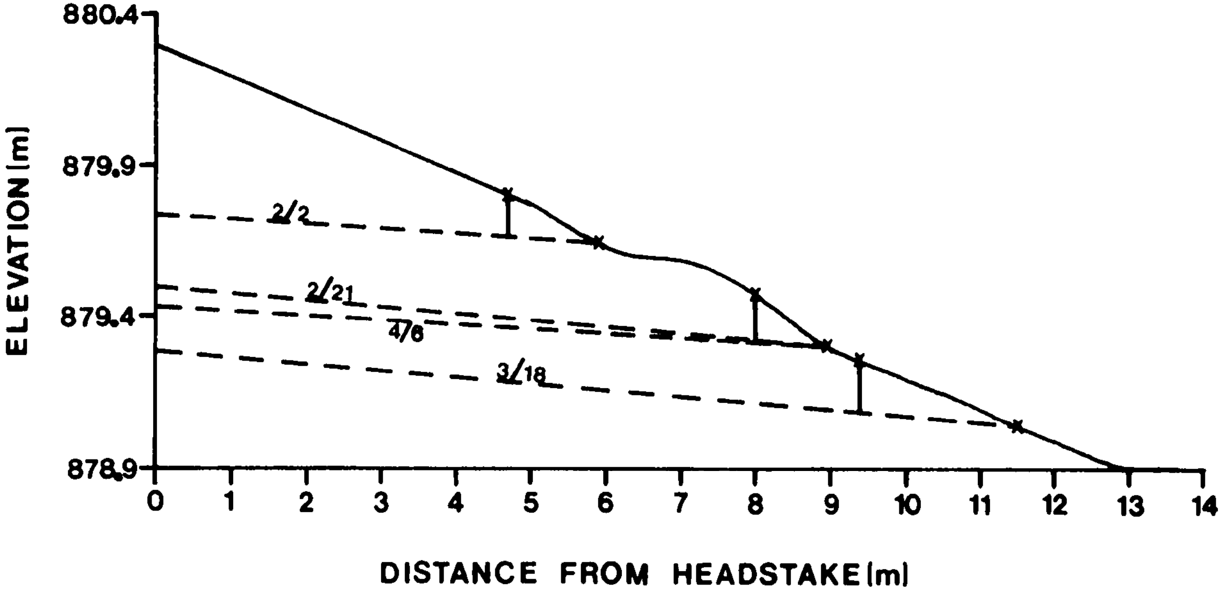

Figure 31. Water table profile at Pine Glen Resort, sandpoint PG-1. Dashed line represents water table and solid line represents land surface (from transect perpendicular to the shoreline). Vertical line connecting water table to land surface represents maximum vertical location of water table at 15 cm (egg depositional zone) below land surface.

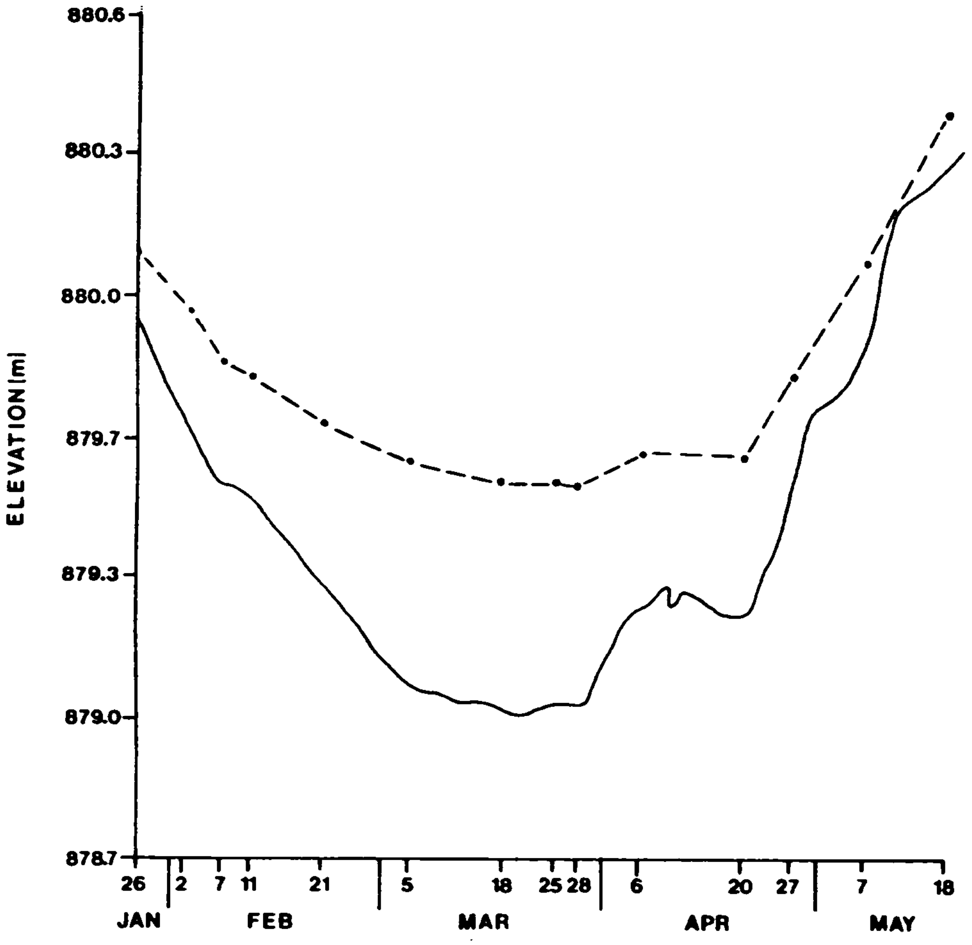

Figure 32. Comparison of lake level fluctations (solid line) to water table fluctuations (dotted line) at sandpoint SKB-2B at Skidoo Bay East from 26 January to 18 May, 1983.

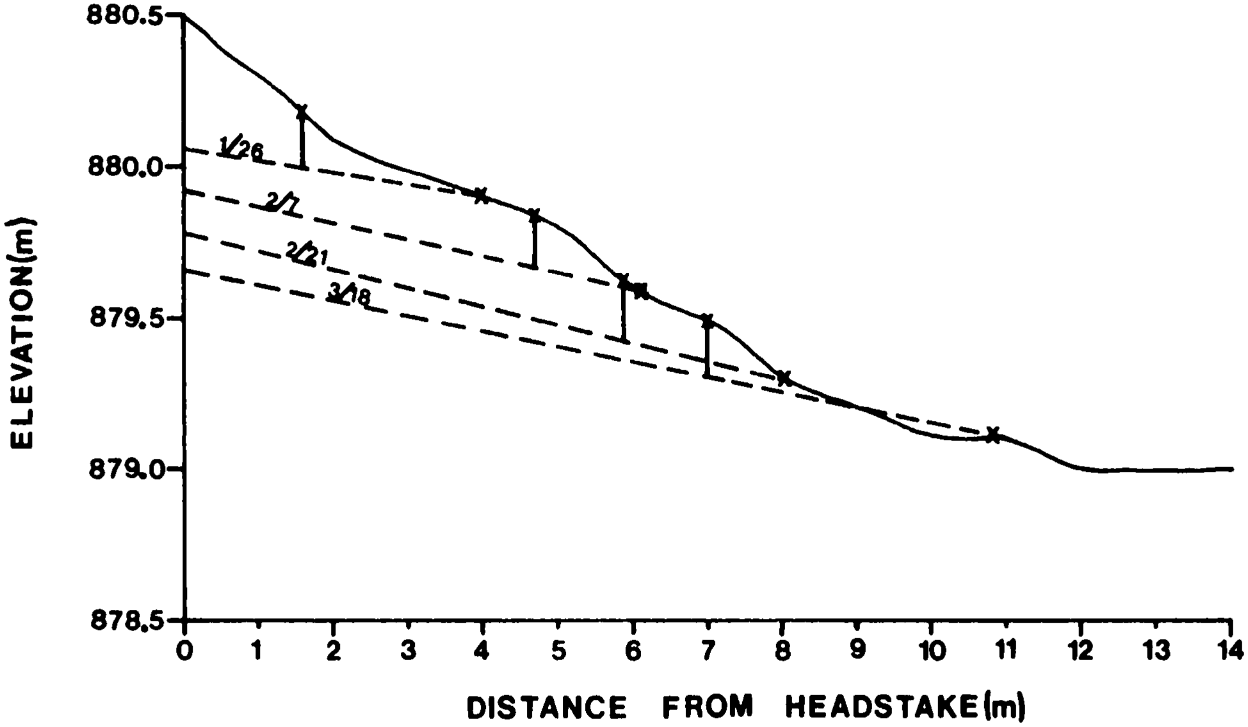

Figure 33. Water table profile at Skidoo Bay East, sandpoint SKB-2B. Dashed line represents water table and solid line represents land surface (from transect perpendicular to the shoreline). Vertical line connecting water table to land surface represents maximum vertical location of water table at 15 cm (egg depositional zone) below land surface.

percentage of fines and groundwater seepage rates similar to or greater than the other deep spawning areas.

Survival in individual redds at Yellow Bay varied from 0 to 85 percent (Appendix C Table 1). Complete mortality occurred in 56 percent of the redds sampled. Intergravel dissolved oxygen levels throughout the Yellow Bay area during the early stages of incubation ranged from 0 to 7.5 mg/l. Seventy-nine percent of the 19 oxygen samples collected were less than 4.0 mg/l with 50 percent of the samples less than 2.0 mg/l. Redds were sampled at Yellow Bay in March to determine survival to hatching. Mean survival of 659 eggs from six redds was one percent. Eggs planted adjacent to the Yellow Bay spawning area also experienced poor survival. After one month of incubation, survival in the four lines ranged from 3 to 58.5 percent (Table 11). Survival declined to zero at all lines after two months of incubation. Dissolved oxygen levels at the four lines of 1.0 to 3.3 mg/l at the time of planting appeared to play the critical role in embryo survival. Apparent velocity measurements and percent fines (<6.35 mm), ranging from 11.2 to 29.2, were similar to those found in other shoreline areas.

Mean survival to the eyed stage for the seven redds sampled at Woods Bay was 39 percent. Survival at individual redds varied from 0 to 82 percent (Appendix C Table 1). Low intergravel dissolved oxygen levels in the Woods Bay area appeared to play a role in survival. Redds with survival of 10, 11 and 0 percent were located where dissolved oxygen concentrations ranged from 2.8-3.4 mg/l. Redds with survival of 39 to 82 percent were located in intergravel dissolved oxygen zones of 6.3-8.3 mg/l.

Numerous investigators have researched the effects of dissolved oxygen concentrations on embryo survival and development. Table 12 presents critical values of dissolved oxygen determined for various salmonid species under natural and laboratory conditions. Critical values varied considerably depending on the stage of development at which the embryo was exposed to oxygen stress. Becker et al. (1982) reported demand for dissolved oxygen appeared to be greatest (5.8-10 mg/l) immediately before hatching. Although critical values were considerably lower at earlier stages of development, studies conducted by Alderdice et al. (1958), Shumway et al. (1964) and Silver et al. (1963) concluded embryos developing under dissolved oxygen stress can survive hatching although they may be smaller and weaker with less chance for survival under natural conditions. Mason and Chapman (1965) and Mason (1969) found first emerging coho fry and larger fry size were directly related to intergravel dissolved oxygen concentrations. These larger fry became the ecological dominants in populations of coho fry in lab aquaria.

Table 11. Percent survival, stage of development, bottom elevation, microhabitat data for four egg bag lines adjacent to Yellow Bay spawning area, 1982-83.

Location	Date sampled	Elevation (m)	Percent survival	Stage of development	Dissolved oxygen (mg/l)	Apparent velocity ml/min	Percent fines (<6.35mm)	Temperature units (°C)
Line 1	12/14	878.4	14	100% green	1.0(12/1)	20.7	29.16	163
	1/18		0					297
Line 2	12/14	877.3	6	100% green	3.2(12/1)	9.6	19.6	146
	1/18		0					268
Line 3	12/14	876.05	58.5	100% green	3.3(12/1)	11.8	23.2	176
	1/18		0					338
Line 4	12/14	874.4	3	100% green	1.0(12/1)	9.3	11.2	157
	1/18		0					297

Table 12. Critical values of dissolved oxygen concentrations determined for various salmonid species at different stages of development.

Source	Species	Stage of development	Days	Centigrade temperature units	Critical value of dissolved oxygen[1]
Wickett (1954)	Chum salmon	Pre-eyed	0	---	0.72
		Pre-eyed	5	---	1.67[2]
		Pre-eyed	12	---	1.14
		Faintly-eyed	85	---	3.70
Alderdice et al. (1958)	Chum salmon	---	---	2.2	.72
		---	---	2.6	1.67
		---	---	26.7	1.14
		---	---	67.3	3.96
		---	---	90.1	3.70
		---	---	149	5.66
		---	---	196	6.60
		---	---	251.3	7.19
Lindroth (1942)	Atlantic salmon	Domed	---	---	.76
		Nearly hatching	---	---	5.80
		Hatching	---	---	10.00
Hayes et al. (1951)	Atlantic salmon	Eyed	25	---	3.1
		Hatching	50	---	7.1
Silver et al. (1963)	Steelhead	Hatching	---	---	1.6
	Chinook	Hatching	---	---	1.6[2]
Phillips & Campbell (1961)	Steelhead	Hatching	---	---	7.2
	Coho salmon	Hatching	---	---	8.0
Shumway et al. (1964)	Coho salmon	Hatched	---	---	2.5
McNeil (1964)	Pink salmon	Hatched	---	---	7.5
Gangmark & Bakkala (1958)	King salmon	Hatched	---	---	5.0

1/ Critical value just meets the demands of the embryo.

2/ Lethal value is the highest concentration all embryos killed.

Intergravel Temperatures and Embryo Development

As gravels became exposed by lake drawdown, temperature unit accumulation began to vary with ambient air temperature. Intergravel temperatures in the area of Skidoo Bay exposed by lake drawdown were significantly affected by ambient air temperatures (Appendix A, Figure 9 and 10). The upper probe (Probe 1) at Skidoo Bay, located at elevation 880.3 m (2888.0 ft) was exposed by drawdown from 13 January to 20 May. Probe 2, located at elevation 879.7 m (2886.0 ft) was exposed from 4 February to 28 April. Probe 3 was buried at bottom elevation 879.0 m (2884.0 ft). Probe 3 was not completely exposed by lake drawdown during the period of record. It was covered by only 3 to 5 cm of water from 17 March to 23 March. Probe 4, buried at elevation 878.8 m (2883.3 ft), was never exposed to ambient air temperatures. Recorded temperatures at Probe 4 were used as a standard to quantify the effect of ambient air temperatures on exposed gravel temperatures.

Intergravel temperatures at Probe 1 (880.3 m) were consistently higher than the control prior to exposure (Figure 34). Upon exposure to ambient air temperatures, gravel temperature decreased 5.5°C. Throughout the period of exposure, gravel temperatures reflected ambient air temperatures (Appendix A Figure 9 and 10). Probe 2 (879.7 m) followed a similar pattern upon exposure to ambient air temperatures (Figure 35). Upon rewetting, gravel temperatures resumed the temperature observed prior to exposure. Temperatures at Probe 3 were consistently higher than the control probe except for the week period when 3-5 cm of water covered the probe (Figure 36). During this time, temperatures dropped 4°C, reflecting ambient air temperatures.

Prior to exposure by lake drawdown, sufficient temperature units needed to reach the eyed stage were accumulated by embryo in gravels at or above 880.3 m (2888.0 ft). After exposure of gravels by drawdown to air temperatures, temperature unit accumulation began to decline (Figure 37). Hatching and yolk sac absorption would be delayed by embryos in gravels from 879.7 m (2886.0 ft) to 880.3 m (2888.0 ft) by 9 to 29 days compared to development below 879.7 m. Considerable variation in temperature units needed for development existed in egg bags planted in Skidoo Bay (Appendix C Table 2). Egg bags unexposed by lake drawdown developed on a normal schedule when compared to other bodies of water (Table 13). In exposed gravels, no hatching had occurred after 600 temperature units. Complete mortality occurred in the exposed bags prior to the next sampling. Becker et al. (1982) reported a retardation in development of chinook salmon embryo with increased exposure to ambient air temperatures by dewatering. Long periods of low temperatures were found to be tolerable if initial incubation temperature was above 5-6°C for one month. Yolk sac absorption was directly related to temperature in studies on chinook salmon (Heming 1982).

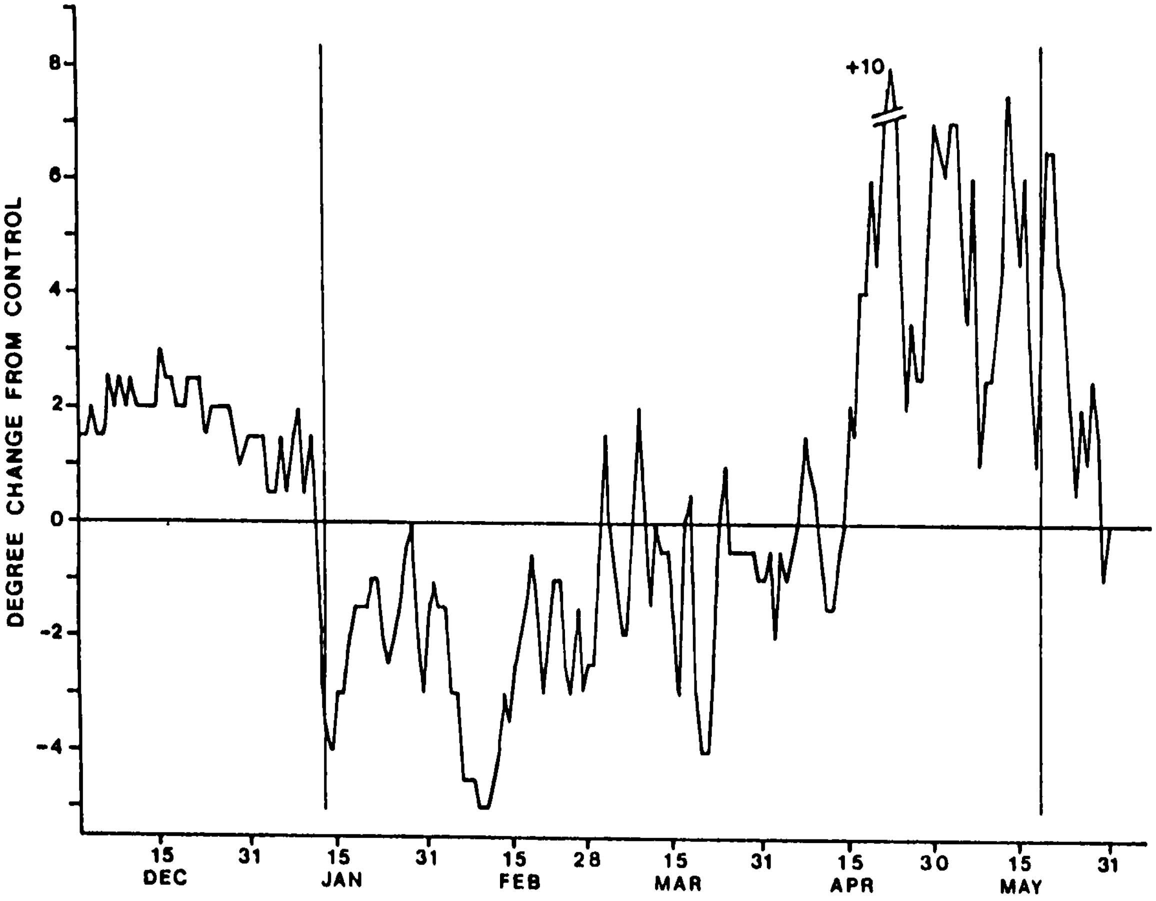

Figure 34. Intergravel temperature relationship between Probe 1, buried at bottom elevation of 880.3 m (2888 ft) to Control Probe 4 at 878.8 m (2883.3 ft). Area between vertical line delineates length of exposure at Probe 1 to lake drawdown.

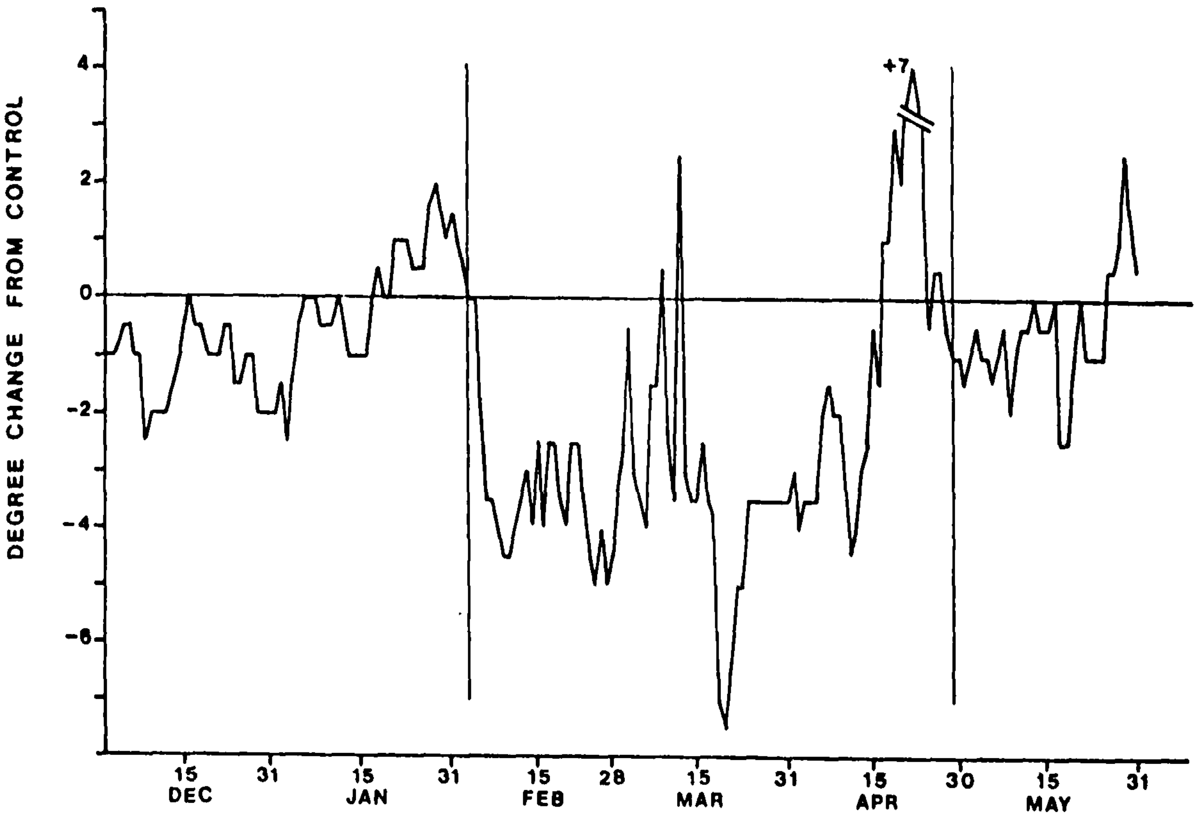

Figure 35. Intergravel temperature relationship at Skidoo Bay between Probe 2, buried at bottom elevation of 879.7 (2886 ft) to Control Probe 4 at 878.8 m (2883.3 ft). Area between vertical lines delineates length of exposure at Probe 2 to lake drawdown.

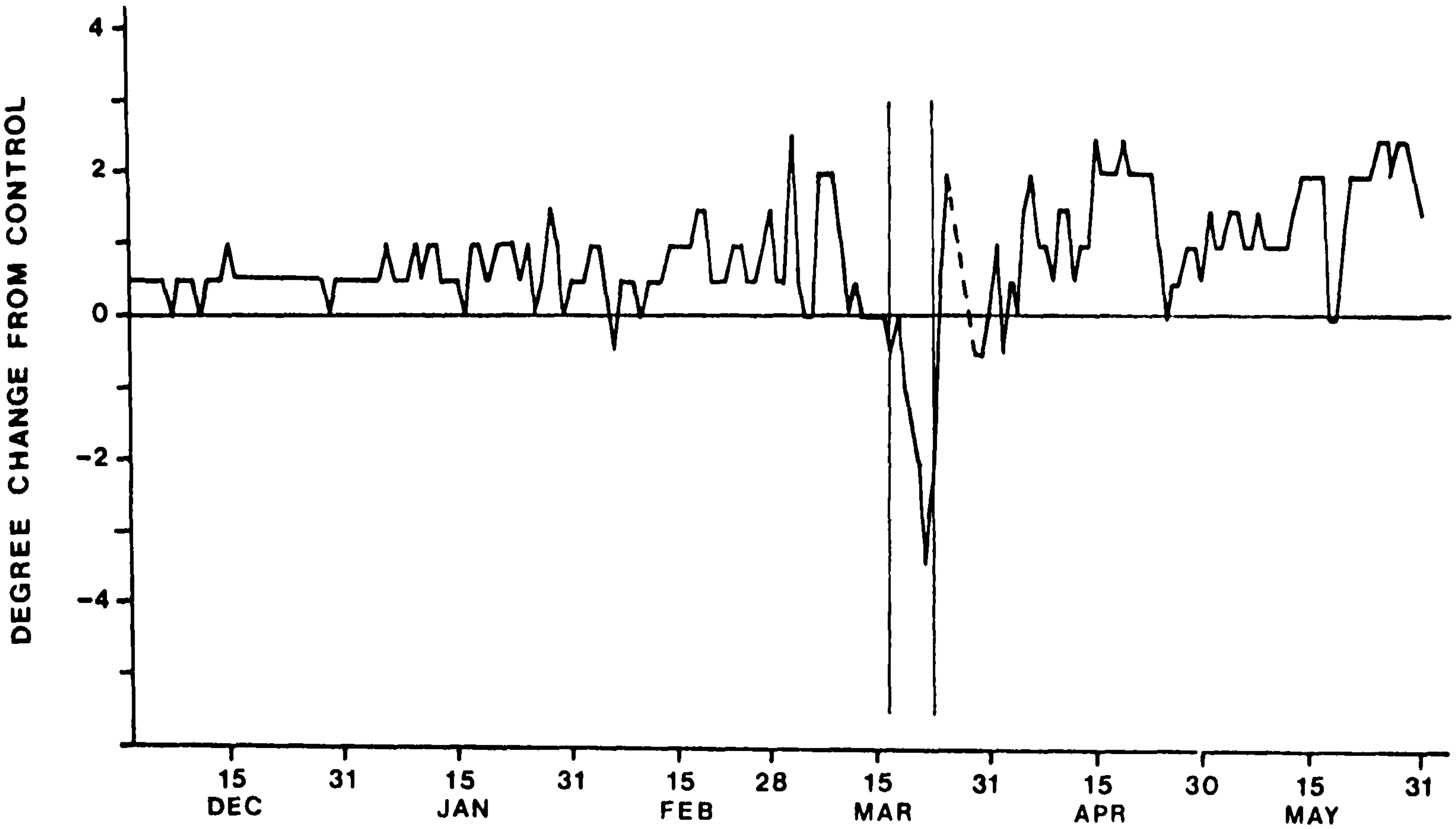

Figure 36. Intergravel temperature relationship at Skidoo Bay between Probe 3, located at bottom elevation of 879.0 m (2884 ft) to control Probe 4 at 878.8 m (2883.3 ft). Area between vertical lines delineates length of exposure at Probe 3 to lake drawdown.

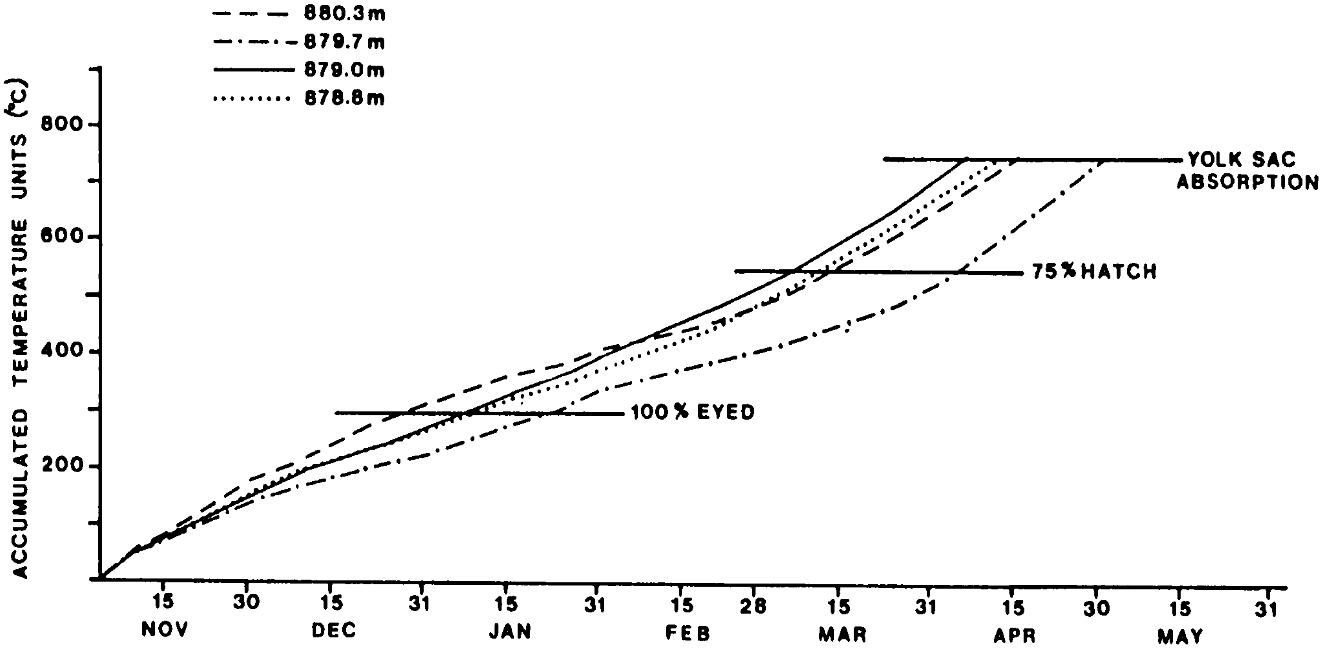

Figure 37. Accumulated temperature units from four gravel zones at Skidoo Bay spawning area from 1 November, 1982 to 30 April, 1983. Various stages of development denoted by horizontal lines.

Table 13. Comparison of centigrade temperature units to various stages of development for kokanee/ sockeye salmon. One °C temperature unit equals 1°C over freezing for a 24-hour period.

	100% eyed		35-75% hatch		Yolk sac absorption	
Location	Centigrade temperature units (CTU)	Number of days	CTU	Days	CTU	Days
Flathead Lake (Decker-Hess & Graham 1982)						
Dr. Richard's Bay	331.4	82	526	143	710.6	177
Yellow Bay	470.3	112	619.2	143	---	---
Flathead Lake (Hatchery)	300	41	580	110	760	138
Flathead River (Fraley and Graham 1982)						
Non-spring	280	66	480	138	700	195
Spring	300	45	540	104	850	154
Redfish Creek (Fleck, pers. comm.)	312.8	--	487.8	---	630.6	---
Iliamna Lake (Olsen 1968)	406	--	467-685	---	933	---
Columbia River (Meekin 1967)	505	--	716	---	1000	---
Skidoo Bay (exposed by lake drawdown)	597.5	120	---	---	---	---
Skidoo Bay (unexposed by lake drawdown)	233	60	491	120	765	160

FRY EMERGENCE AND DISTRIBUTION

Fry Emergence

Spawning Areas Above Minimum Pool

Fry development and emergence in spawning areas above minimum pool were monitored in Pine Glen Resort and Skidoo Bay. Bottom elevation of the six monitored redds ranged from 879.0 m (2884.0 ft) to 879.6 m (2885.8 ft) (Appendix C Table 1). At the time of sampling, redds remained wetted by the lake, groundwater or were within the wave zone. Following hatching, fry apparently partially emerged to within 5 to 10 cm of the gravel surface. Alevins were found completing their development at the cobble/sand interface in water 1 to 5 cm deep. Because of this partial emergence, alevins were vulnerable to desiccation as lake stage continued to decline, suffication by increased fines or debris brought in by wave action, predation and removal by wave action. After one month of partial emergence, survival in individual redds declined from between 80 and 90 percent to between 10 and 20 percent. Redds were located in substrate ranging in composition from 33 to 60 percent fines (<6.35 mm). Phillips et al. (1975), Shelton (1955) and Koski (1966) reported stress by entrapment from high percent fines caused premature emergence.

Three shallow water fry traps were placed over redds at Pine Glen Resort on 29 March at bottom elevations from 878.9 m (2883.53 ft) to 879.0 (2883.85 ft). Water depth over the redds was 0.3 m and lake stage was increasing. These redds were never exposed by lake drawdown. Due to poor design, traps could not be opened without complete removal. Sediment deposited on the wire trap prevented observations into the trap for fry presence or absence. No fry were found when traps were removed on 6 May.

Spawning Areas Below Minimum Pool

Temporal Distribution

Emergence traps were placed over marked redds in Gravel, Yellow, Woods and Blue bays during the week of 22 March. Additional traps were placed randomly in Gravel Bay on 7 April. The traps were checked weekly and remained in place through 15 June. Emerging kokanee fry were captured in all bays monitored except Yellow Bay (Appendix D Table 1). In the 14 traps located in Gravel Bay, a total of 523 emerging fry were captured. Fry were captured in 72 percent of these traps. The first emerging fry were captured on 14 April and fry continued to emerge until 8 June (Figure 38). A peak in emergence occurred on 19 May, 35 days after emergence began. A total of 175 emerging kokanee fry were captured in the five traps located in Blue Bay. Fry were captured in 60 percent of these traps. Emergence began on 11 May and was completed by 1 June (Figure 38). Peak emergence occurred on 25 May, 14 days after initial fry were captured. Fry were captured

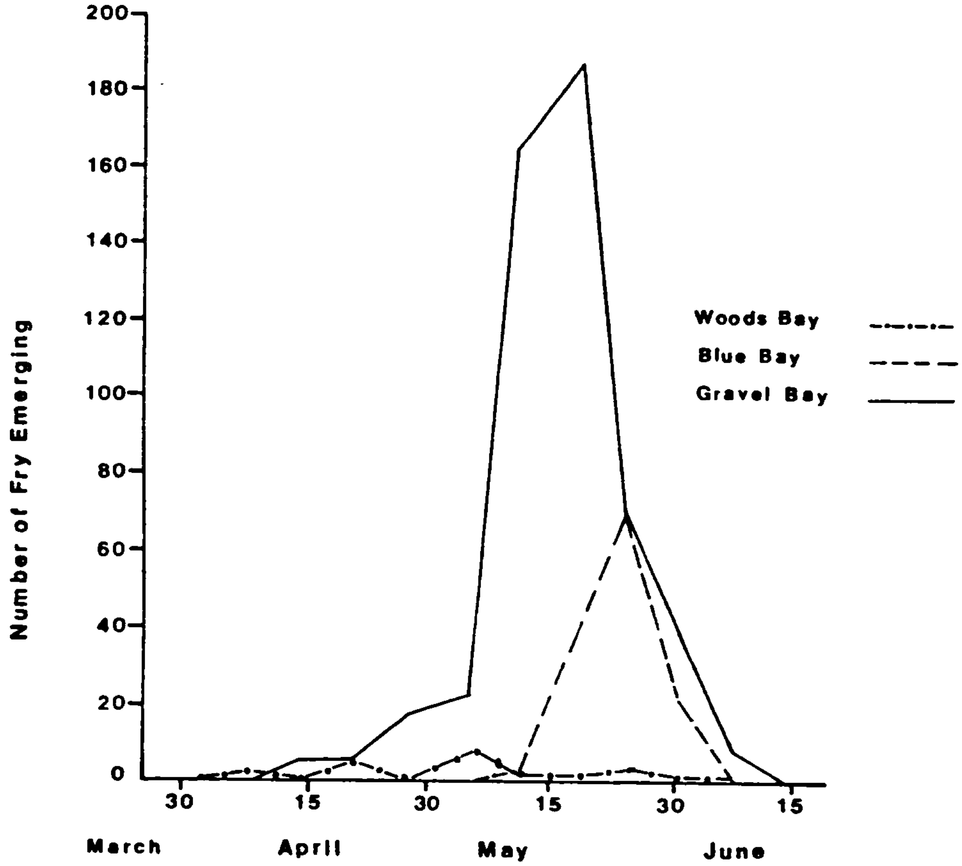

Figure 38. Temporal distribution of kokanee fry catch from emergence traps in Gravel, Blue and Woods bays from 30 March to 15 June, 1983.

in eight of the ten traps located in Woods Bay. Fry emergence began on 7 April and was completed by 1 June. Highest numbers of kokanee fry were captured on 4 May, 28 days after emergence began. A total of 20 fry were captured from the Woods Bay spawning area. The yolk sac was not completely absorbed on 80 percent of the emerging fry caught in Woods Bay. Reasons for this emergence prior to yolk sac absorption were not determined. Tagart (1976) reported 5.3 percent of the fry emerging from Clearwater River, Washington emerged as sac fry. The seven emergence traps placed in Yellow Bay were monitored from 4 April through 15 June. No emerging fry were captured from the area. Based on the one percent survival observed in six redds during March, it appears survival in marked redds dropped to zero by April.

Fry emergence from deep spawning areas occurred over a similar period of time during 1982 and 1983 (Figure 39). Emergence began on 9 April and was completed on 8 June in 1982. Emergence began four days earlier and was completed at the same date in 1983. Peak emergence was 20 days earlier in 1982 however, occurring on 29 April compared to the 19 May in 1983. Spawning, however, occurred over a similar period of time during the two years. Thermograph data to determine temperature units was unavailable for the major emergence areas for the two years sampled.

Vertical Distribution

Fry emergence traps were placed in the four spawning areas below minimum pool at elevations varying from 861.4 m (2826.13 ft) to 878.2 m (2881.13 ft). Number of fry captured per trap ranged from one at 861.4 m (2826.11 ft) at Woods By to 101 fry at 876.3 m (2875.05 ft) at Gravel Bay (Appendix D Table 1). The zone of highest catch per trap ranged between 875 m (2870.7 ft) and 877 m (2877.3 ft). The zone of greatest redd concentration was from 874 m (2867.45 ft) to 880 m (2877.14 ft), but was not correlated to the zone of highest survival in embryo studies (Appendix C, Table 1) or higher dissolved oxygen concentrations.

Survival to Fry Emergence

Survival to fry emergence was calculated for the Gravel Bay spawning area. The calculation assumed if the entire redd was covered by fry traps, all emerging fry would be captured. Based on information gathered from the fry trap experiment in Gravel Bay, it did not appear lateral movement through the gravels was significant. Fry were only captured in significant numbers from traps where eyed eggs had been planted directly beneath them (Appendix D Table 2). One fry was captured in a trap with a plant directly behind it and one from a trap with a plant to the left.

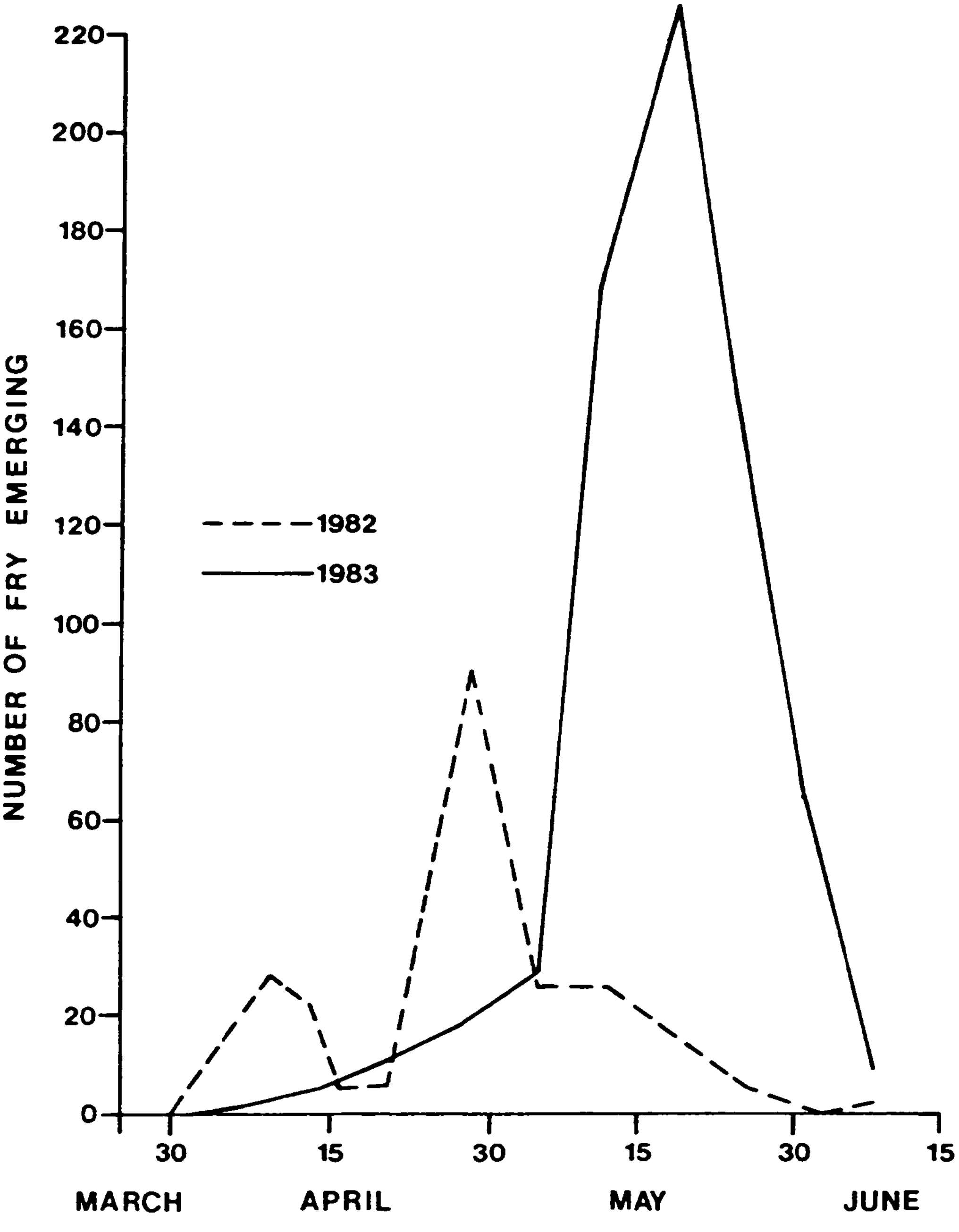

Figure 39. Comparison of temporal distribution in fry emergence from spawning areas below minimum pool for 1982 and 1983.

Information used in the calculation included:

Number of redds = 216
Mean size of redd = 2.08 m^2
Area covered by emergence trap = .25 m^2
Mean fry captured per trap = 37.4
Mean fecundity = 1062 eggs/female
Number of traps needed to cover entire redd area = 8.32

Based on this information, survival to fry emergence in gravel bay was calculated at 29 percent of egg deposition or 67,212 fry.

Survival to fry emergence for various salmonid species has been documented in many artificial and natural systems throughout North America (Table 14). Success of natural spawning areas has been highly variable, ranging from a low of 1.05 percent found for sockeye by Foerster (1938) to 77.3 percent for coho (Tagart 1976). In the upper Flathead River system, Fraley and McMullin (1983) reported survival to fry emergence in five natural spawning areas from 5 to 69 percent.

Fry Distribution

Kokanee fry distribution following emergence was monitored at Gravel and Woods bays. Towing of one meter nets was performed weekly from 19 April through 8 June in Gravel Bay and on 12 and 18 May in Woods Bay.

A total of 25 fry were captured by towing from the Gravel Bay spawning area (Table 15). Fry were captured during three consecutive weeks beginning 27 April through 11 May. Greatest number of fry captured preceded the peak in fry emergence (Figure 40). Three fry were captured by towing in the Woods Bay spawning area on 12 and 18 May (Table 15). A peak in fry emergence occurred a week earlier on 6 May. Johnson (1956) reported emerging fry moved to a pelagic, plankton feeding existence soon after entering the lake. Newly emerged kokanee fry in Cultus Lake schooled almost immediately upon emergence and moved offshore to water depths up to 7 mm (Brannon 1972).

Substrate Composition and Fry Emergence

The adverse effects of fine substrate on salmonid embryo survival and fry emergence have been well documented in the literature. Fine sediments filling interstitial spaces reduce gravel permeability, apparent velocity and dissolved oxygen, create stress causing premature fry emergence, trap larvae trying to emerge and reduce fry length (Peters 1962, Phillips et al. 1975, Koski 1966 and 1972, and Hall and Lantz 1969). Bjornn (1969) found substrate composition of 20 percent fine material reduced dissolved oxygen levels to lethal limits.

Table 14. Survival to fry emergence for various species of salmonids from natural and artificial systems in North America. Stage of development is also included.

Author	Year	Species	Natural or artificial redds	Survival percent	Stage of development
Foerster	1938	Sockeye	Natural	1.05-3.23	Fingerling
J. Fish. Board Can.	1956	Sockeye	Natural	1.8-25.0	Fry
Wales & Coots	1955	Chinook	Natural	7-32	Fry
Pritchard	1947	Coho	Natural	11.8-30.4	Fry
Shapovalov & Taft	1954	Coho	Aritificial	16.2	Fry
Cederholm & Tagart	Unpub.	Coho	Artificial	2.6-63.8	Fry
Tagart	1976	Coho	Natural (mean)	.9-77.3 29.8	Fry
Koski	1966	Coho	Natural (mean)	0-78 27.1	Fry Fry
Ringler	1970	Coho	Natural	17-44	Fry
Hausle	1973	Brook trout	Artificial	62	Fry
Myren	1956	Pink salmon	Natural	.2-20	Fry
Briggs	1953	Silver salmon	Natural	74.3	Fry
		King salmon	Natural	86	Fry
		Steelhead	Natural	64	Fry
Linsay & Lewis	1975	Kokanee	Natural (mean)	43	Fry
Fraley	1983	Kokanee	Natural (mean)	25	Fry
Stober et. al.	1979a	Kokanee	Natural (altered)	.55-18	Fry

Table 15. Catches of kokanee fry by night tows at Gravel and Woods bays from 19 April to 8 June, 1983. Number of tows and weather and lunar conditions are also presented.

	4/19	4/27	5/5	5/11	5/19	5/25	6/1	6/8
Gravel Bay								
# tows	4	6	7	7	8	8	6	4
# fry captured	0	4 kok	16 kok	5 kok	0	0	0	0
Weather/lunar conditions	Calm/			calm/ no moon	calm/ half moon	half moon	1 ft waves full moon	1 ft waves no moon
Woods Bay								
# tows				5	6			
# fry captured				2	1			
Weather/lunar conditions				calm/ no moon	calm/ half moon			

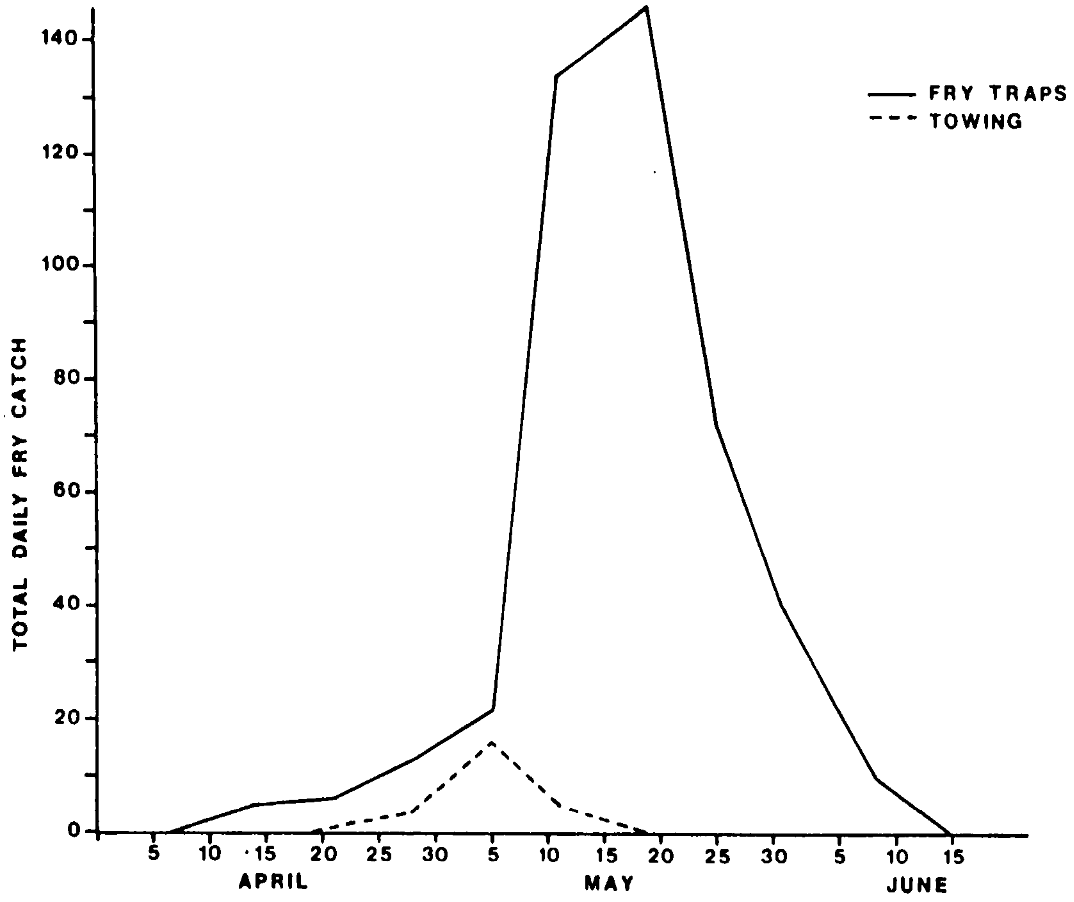

Figure 40. Comparison of temporal distribution of number of fry captured in emergence traps and by towing in Gravel Bay during 1983.

The drawdown of regulated lakes and reservoirs allows fine substrate to accumulate in shoreline areas. Flushing of these sediments by wave action is lost until the lake stage returns to higher levels. If drawdown occurs during the incubation period, embryos and alevins in the shoreline spawning areas can be subjected to accumulations of fine sediments. This phenomenon was observed at Skidoo Bay. At spawning, fines averaged 31.6 percent of the substrate. By the end of the incubation period fines had increased to over 60 percent in the drawdown zone. As lake stage increased beginning in April, fines were flushed out of the spawning area by wave action and reduced to 11 percent by 28 June (Appendix B, Table 1).

The standard method of describing substrate composition of salmonid spawning gravels is to report percent fine material. Problems with this method have related to determining standard sieve size and the effects of various sizes of substrate on embryo survival. Recently, other descriptive methods have been designed to more accurately assess total substrate composition of salmonid spawning habitat. Cumulative particle size distribution curves have been determined for kokanee salmon survival to emergence by Irving (in press).

Irving's method and a method using percent material less than 6.35 mm (Reiser and Bjornn 1979) were used to predict survival to fry emergence for eight shoreline spawning areas of Flathead Lake (Figure 41 and 42). Survival was based on substrate composition only. Estimates do not reflect other microhabitat parameters affecting shoreline survival (i.e. gravel movement, exposure by lake drawdown, dissolved oxygen). Results were similar for the two methods for all areas except Yellow and Crescent bays (Table 16). The majority of the material <6.35 mm in the composition of the two areas was >2 mm. Because the cumulative particle size method related the percent of material <2 mm to the percent <6.35 mm, low percentages of the 2 mm sieve size would increase predicted survival.

Experimental Emergence Studies

Lateral movement by emerging fry through gravel wetted only by subsurface flow has been suggested in the literature but not well documented. Studies done by Bams (1969) concluded fry emergence was geotactically induced and an orientation to a secondary mechanism (water movement) would result only from blockage of the primary mechanism by darkness, light, or physical barrier. Reiser and White (1981b) reported absence of surface water triggered lateral movement of chinook and steelhead fry through gravel when fine sediments did not limit movement.

Experiments at the Somers Hatchery to determine lateral intergravel movement by emerging fry found highest survival of 64 percent occurred in the control channel. This was the only channel where water flowed over the gravel surface. Channel 2,

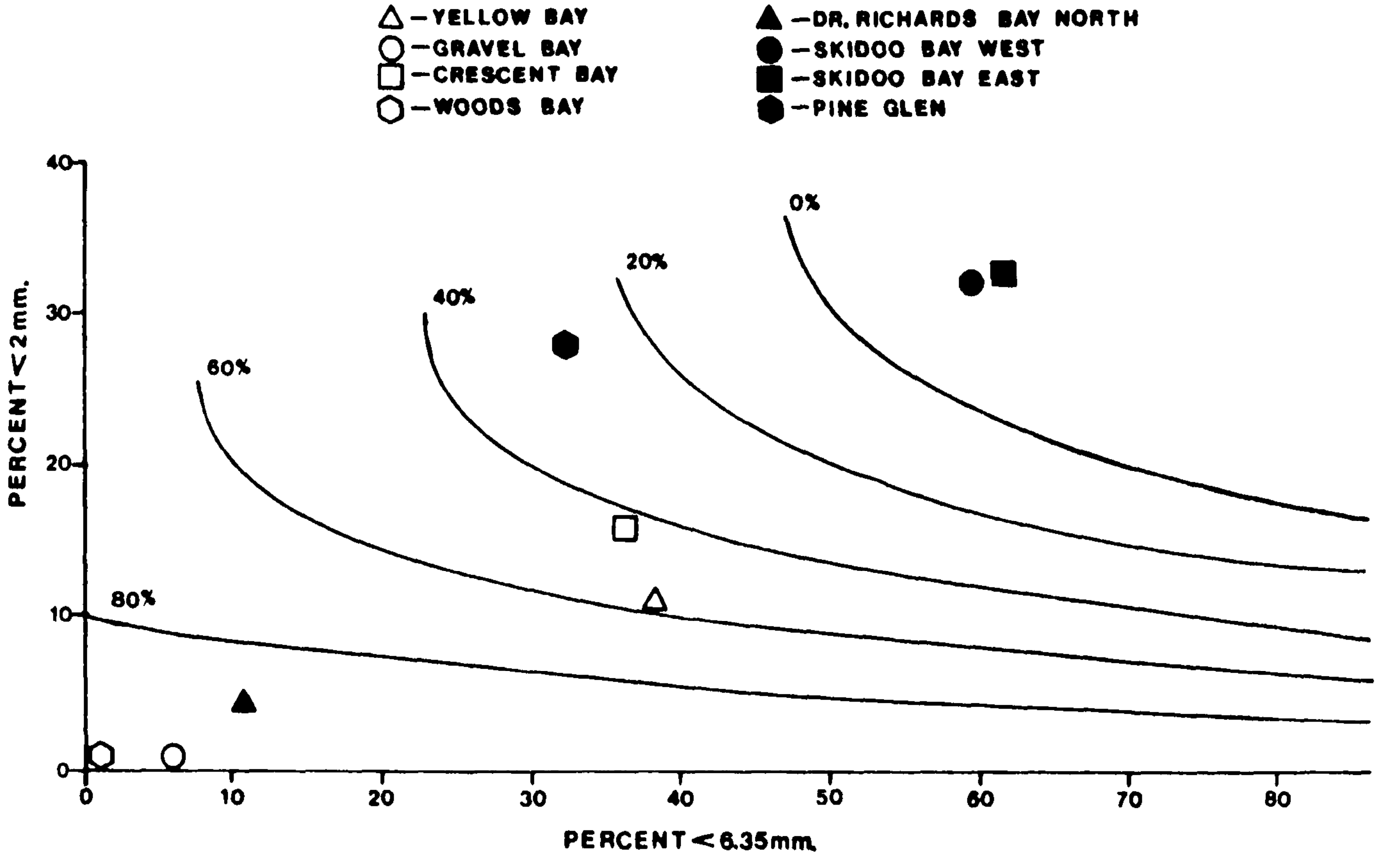

Figure 41. Predicted kokanee survival to emergence from eight shoreline areas of Flathead Lake using cumulative particle size distribution curves (Irving, in press). The analysis was based on substrate composition samples collected during the late incubation-early emergence period, 1983.

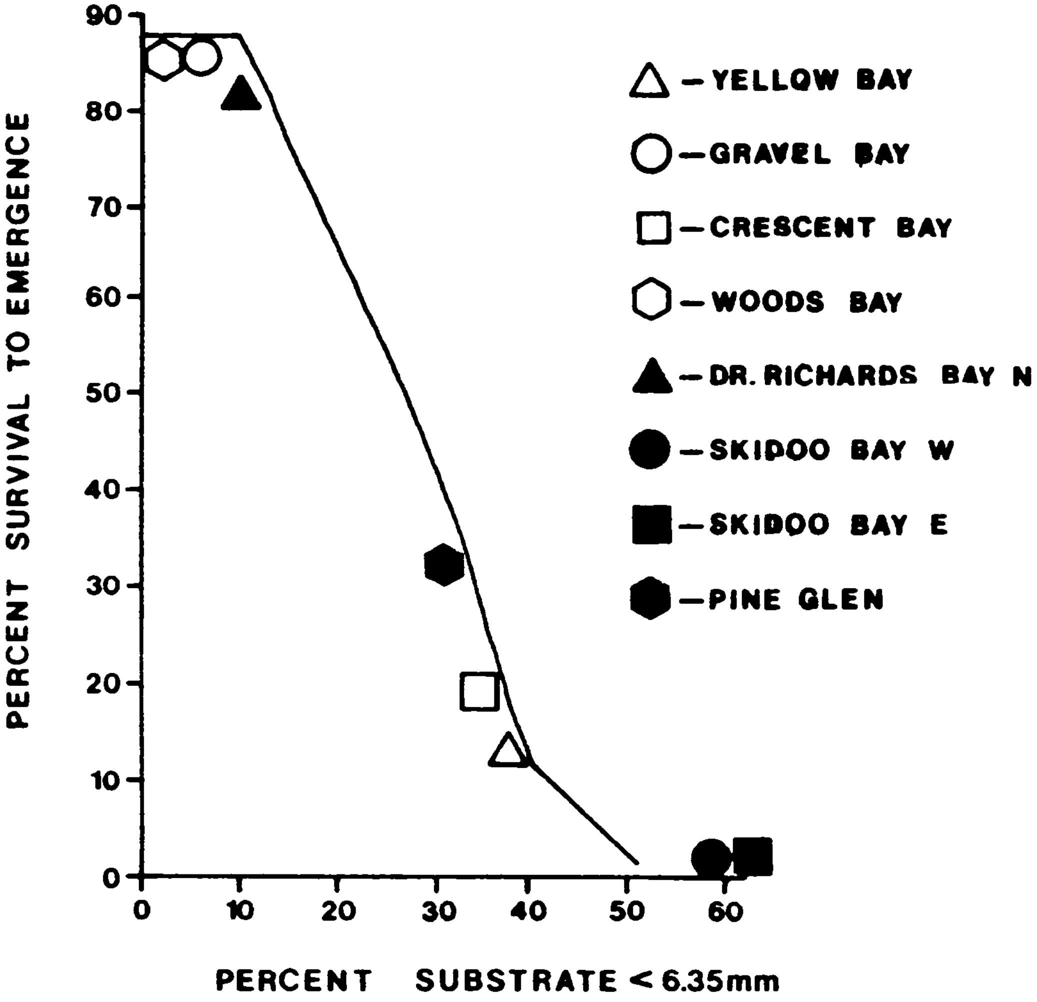

Figure 42. Predicted survival to emergence in eight shoreline areas of Flathead Lake based on salmon studies using percent fine material less than 6.35 mm (Reiser and Bjornn 1979). The analysis was based on samples collected during the late incubation-early emergence period, 1983.

Table 16. Predicted mean percent survival by substrate composition for eight shoreline spawning areas using percent fines <6.35 mm and cumulative particle size distribution. Irving (in press) and Reiser and Bjornn (1979).

Location	Percent composition <6.35 mm	Cumulative particle size distribution
Yellow Bay	12	58
Gravel Bay	90	98
Crescent Bay	20	44
Woods Bay	90	98
Dr. Richard's Bay North	82	90
Skidoo Bay West	0	0
Skidoo Bay East	0	0
Pine Glen	32	28

with only subsurface flow and 10 percent fines, was eliminated from the experiment due to a continual interruption in water supply. Channel 5 (42.1 percent fines) was also eliminated from the experiment because of design failure allowing fry to emerge and travel above the substrate. Percent emergence declined with an increase in percent fines in Channel 3 (19.3 percent fines) and Channel 4 (27.2 percent fines). Thirty-six percent of the fry emerged and moved laterally 4.3 m through 19.3 percent fines and 8 percent moved laterally 4.3 m through 27.2 percent fines. A flow of .003 cfs was maintained from the water source at the three channels.

Fry emergence occurred over a 10 day period from 22 May through 1 June in the control channel (Figure 43). Peak emergence occurred 10 days after emergence began. Emergence occurred over a longer period of time from 13 May to 6 June in Channel 3 (19.3 percent fines). All fry prior to 22 May emerged with a partial yolk sac from this channel. Emergence from channel 4 (27.2 percent fines) occurred over a week period from 12 to 20 May. All the fry from Channel 4 emerged with a partial yolk sac.

Fry Quality

Higher condition of emerging fry has been related to an initial advantage in foraging ability and acquisition of feeding territory and less susceptibility to damage by predation, competition and starvation (Koski 1975, Stober et al. 1979b, Stober and Hamalainen 1979 and 1980, Becker et al. 1981 and Heming 1982). Stober et al. (1979b) reported fry quality to primarily be determined by egg size and parental characteristics with environmental conditions having a secondary influence. Fry quality has been negatively correlated to substrate composition, intergravel dissolved oxygen and temperature (Koski 1975). Fry condition has been related to temporal distribution, depth of strata and density (Stober et al. 1979b).

A total of 172 fry captured from emergence traps were used from Gravel Bay for fry quality measurements (Appendix D Table 3). Length frequency was normally distributed within a range of 22.0 to 26.5 mm with a mean length of 24.2 mm (Figure 44). Forty-eight emerging fry from Blue Bay ranged from 23 to 26 mm with an average of 24.7 mm (Appendix D Table 3, Figure 44). Mean length of 20 fry from Woods Bay was smaller than the other two areas (23.4 mm) although the difference was not significant. Fry were randomly scattered over a range in length from 18.5 to 26.0 mm (Figure 44). Eighty percent of the fry from Woods Bay emerged as sac fry, explaining the smaller size and larger length frequency. Stober and Hamalainen (1979) reported 94 percent of the sockeye fry captured in Cedar River, Washington measured 25 to 29 mm with a mean length of 25.9 mm.

Mean condition (K) of emerging fry for Gravel, Blue and Woods bays was .676 (±.05), .69 (±.03) and .85 (±.16), respectively

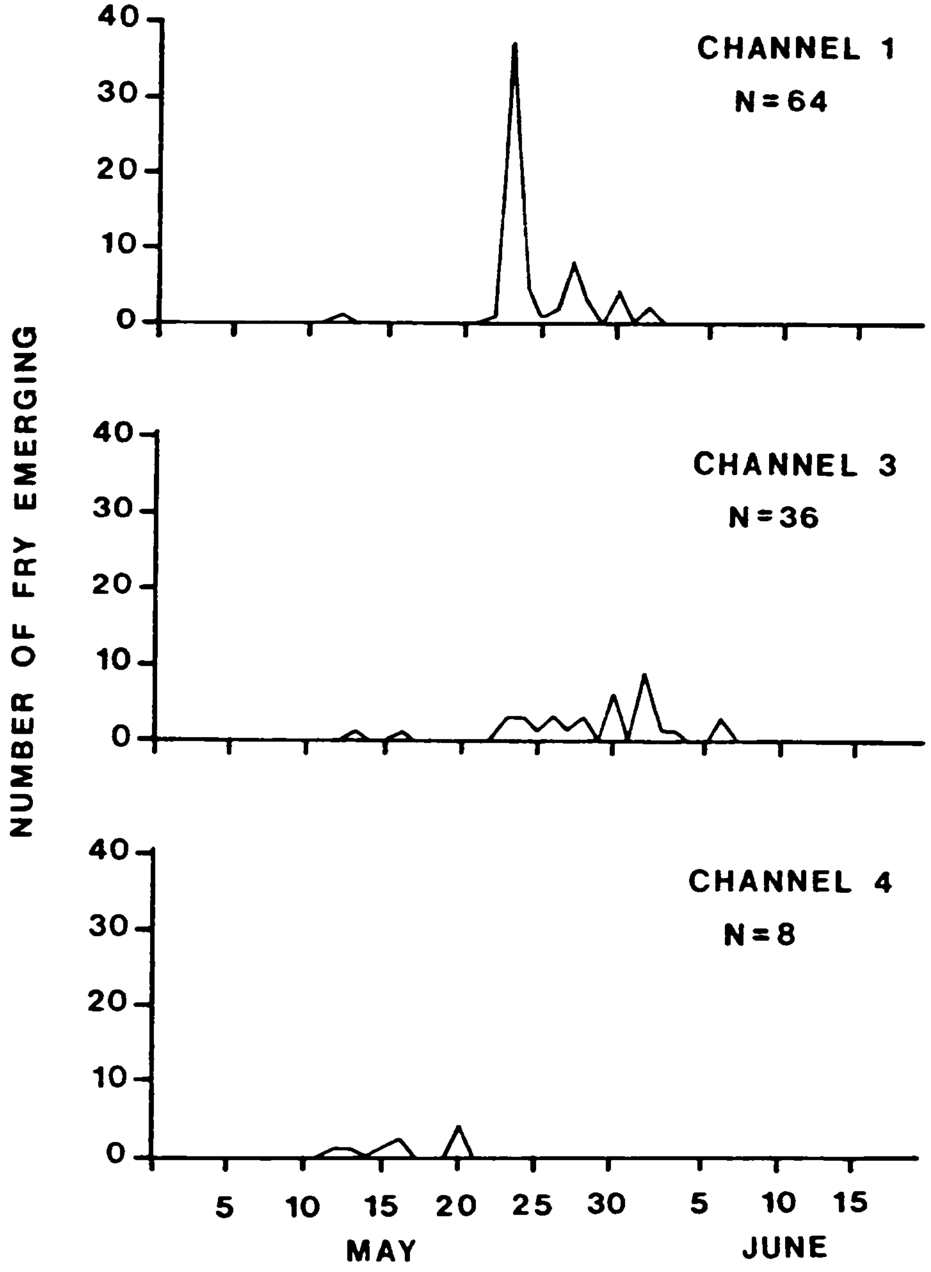

Figure 43. Temporal distribution of fry emergence by lateral movement in experimental channels at Somers Hatchery, Flathead Lake, 1983. Total number of fry emerging is also given.

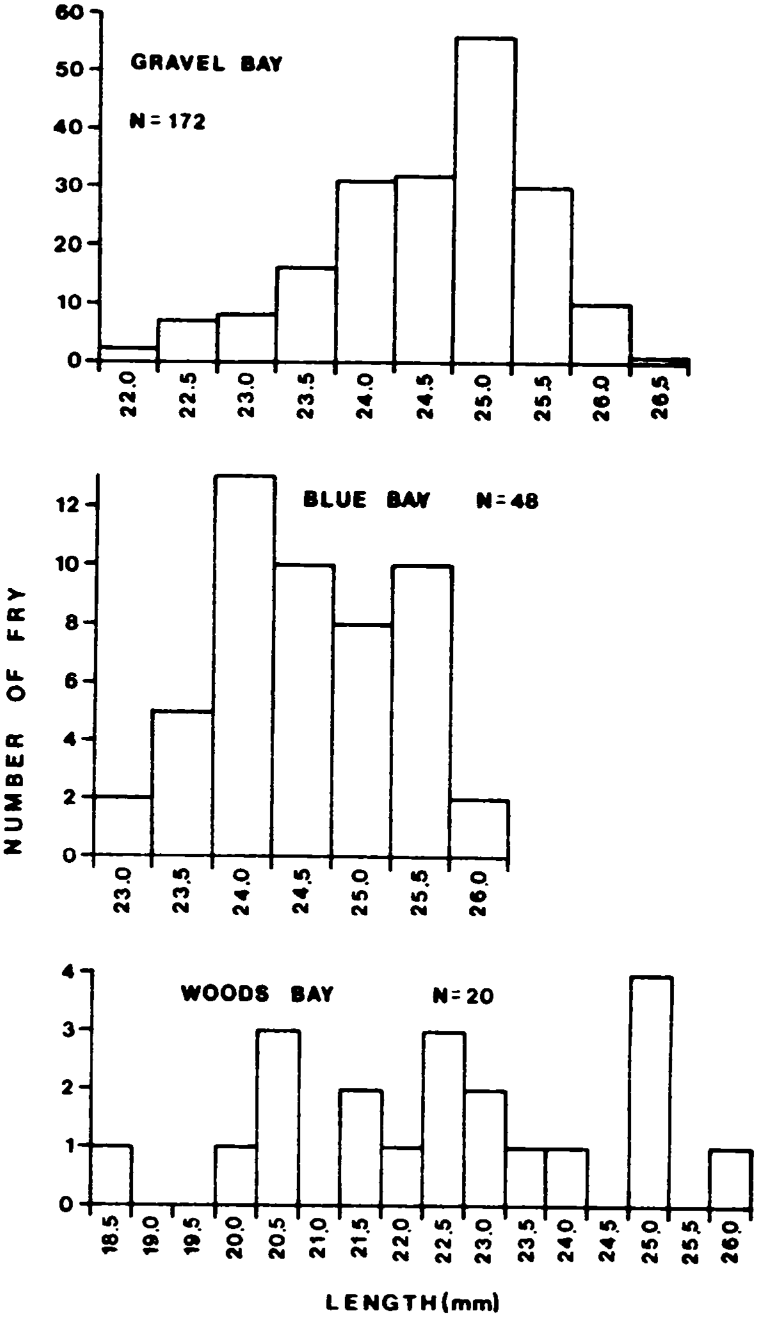

Figure 44. Length frequency distribution of emerging kokanee fry from traps in Gravel, Woods and Blue bays, 1983.

(Appendix D, Table 4). Differences between the three areas were not significant. Condition at Woods Bay was highest as a result of the large yolk sac retained by 80 percent of the emerging fry. High condition resulting from emergence prior to complete development has not been related to high survival (Stober and Hamalainen 1979). Stober and Hamalainen (1980) found mean condition of .78 with a range of .64 to .88 in sockeye fry emerging from Cedar River, Washington.

There were no general trends in fry condition and emergence density or temporal distribution between Gravel, Blue or Woods bays. Fry condition at Gravel Bay fluctuated at low densities during early emergence (Figure 45). A decline in condition occurred following the peak in emergence. Density was significantly related to fry condition at Gravel Bay ($r= .7293$, $p\leq .05$). Condition of fry at Woods Bay decreased as emergence progressed. This was probably a result of earlier emerging fry retained a partial yolk sac. Condition was positively related to density following peak emergence. Fry condition was inversely related to density during and following peak emergence at Blue Bay (Figure 45). No relationship existed between condition and temporal distribution.

A significant inverse relationship existed between depth of strata and fry condition at Gravel Bay spawning area ($r= -.75$, $p\leq .01$). Condition increased with a decrease in depth while density decreased (Figure 46). There was no relationship between depth of strata and fry condition at Blue or Woods bays. Stober et al. (1979b) reported lowest condition of emerging kokanee fry from Banks Lake, Washington from shallowest (4.6 m) and deepest (13.7 m) strata although the relationship was not significant.

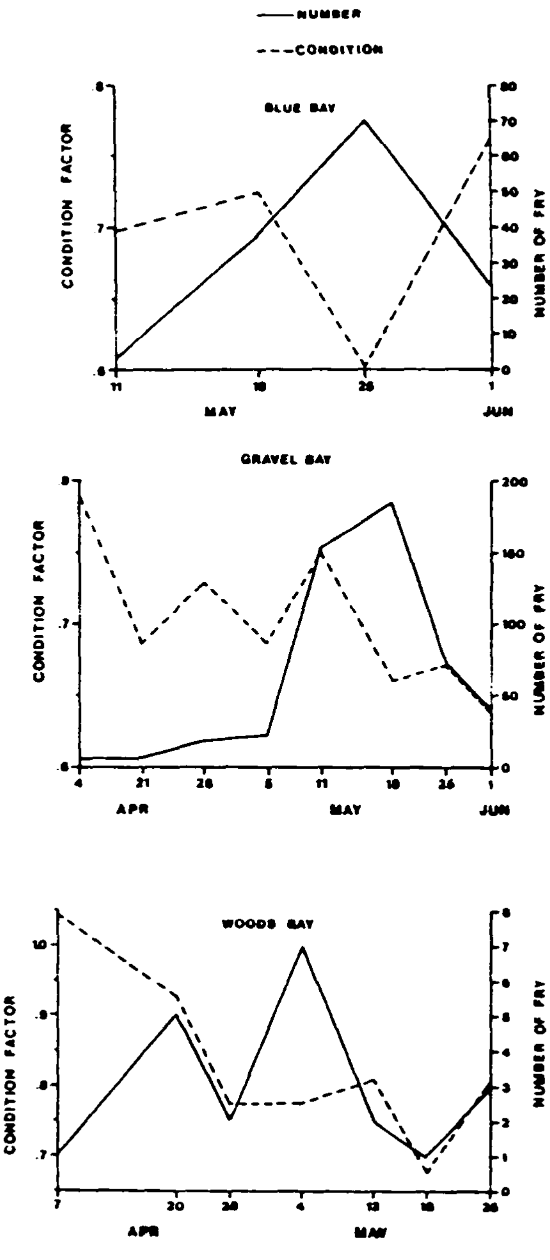

Figure 45. Temporal distribution of emerging fry by condition and number from Gravel, Woods and Blue bays from 4 April to 1 June, 1983.

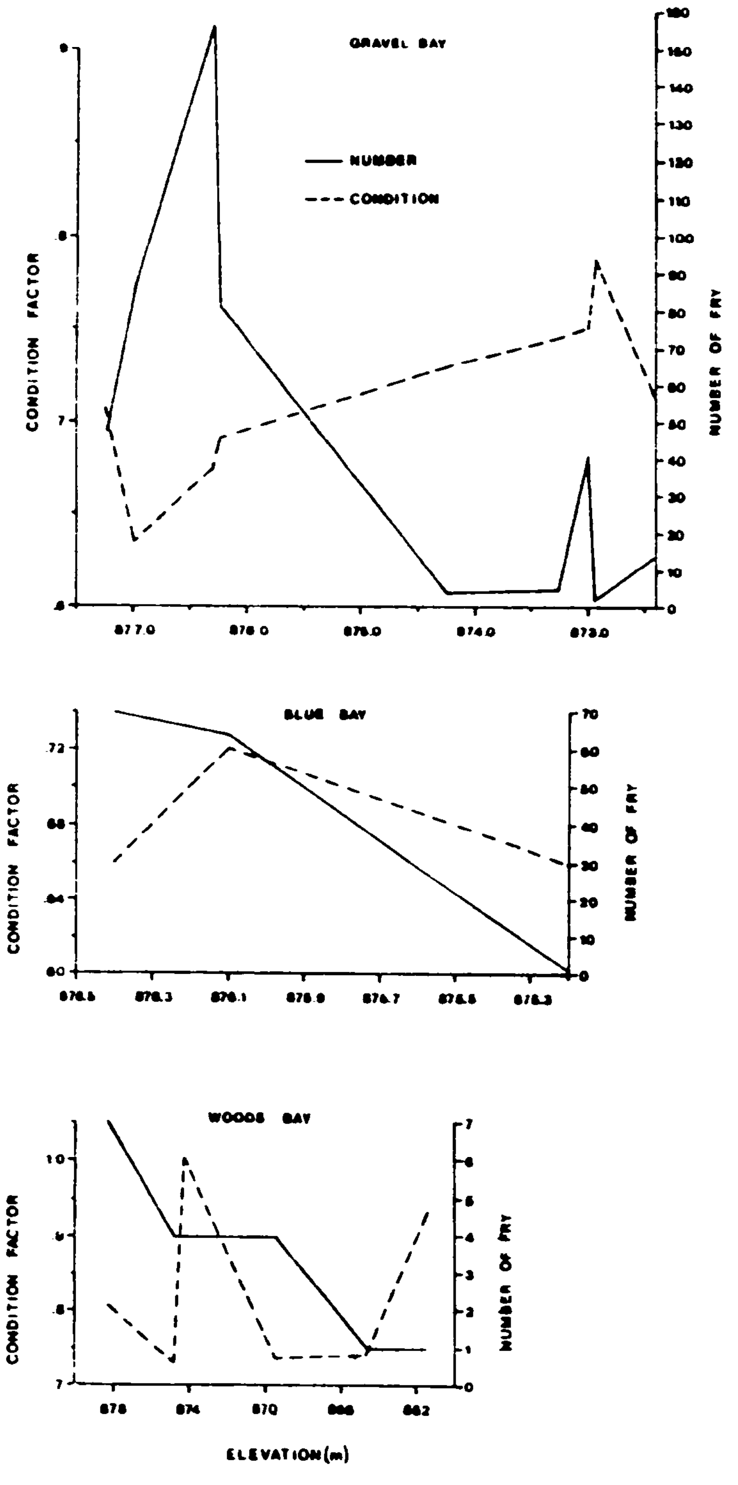

Figure 46. Number and condition factor of emerging fry by depth strata for Gravel, Blue and Woods bays during April to May, 1983.

CONCLUSIONS

The operation of Kerr Dam during 1982-83 was found to have significant impacts on shoreline embryo survival above minimum pool regardless of ambient air temperatures. The present dam operation of drawing down the reservoir at an average monthly rate of .55 m through February and holding the pool near minimum until spring refill is not conducive to successful shoreline embryo survival.

Major impacts from the 1982-83 operation of Kerr Dam on kokanee embryo survival included loss of optimum incubating gravels, mortality resulting from dessication, and a delay in embryo development. Prior to lake drawdown, habitat most suitable for successful embryo incubation and survival in shoreline areas occurred in gravels above minimum pool (2884 to 2889 feet bottom elevation). Mean survival to eyed stage was 78 percent above minimum pool compared to 48 percent from areas below minimum pool. Intergravel dissolved oxygen levels appeared to play a critical role in embryo mortality in two of the three areas below minimum pool.

The effect of ambient air temperatures on embryo survival in redds exposed by lake drawdown was insignificant during the 1982-83 incubation period. Minimum temperatures fell below the critical level of $-10^{o}C$ only once. Length of exposure of redds by lake drawdown played a critical role in survival in 1982-83. Natural redds moistened by damp gravel and sand suffered complete mortality after 69(±14) days of exposure. Results from an experimental egg plant negatively correlated survival to length of exposure by lake drawdown ($r = -.9104$, $p<0.01$). Horizontal distribution of redds at three shoreline areas in 1982 revealed exposure of this length would have occurred to all redds constructed above 879.7 m (2886.0 ft). This would have resulted in mean mortality for the three areas from drawdown alone of 67 percent.

Groundwater stage reacted independently of lake stage at two of the five spawning areas above minimum pool. In the other three areas, groundwater stage mirrored lake stage with lag time before reaching equilibrium. The steepness of the water table determined the length of time and the vertical spawning area wetted by groundwater after lake drawdown had exposed the gravels.

Temperature unit accumulation by developing embryos in exposed gravels declined with ambient air temperatures. Hatching and yolk sac absorption were delayed in gravels from 2886.0 feet to 2888.0 feet by 9 to 29 days compared to development below 2888.0 feet. Slowing embryo development as a result of reduced gravel temperatures may increase the opportunity for successful fry emergence from the upper gravels into the lake during spring refill.

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APPENDIX A

Kokanee spawning survey and microhabitat

Table 1. Dates when 51 shoreline areas of Flathead Lake were surveyed for kokanee spawning activity during the fall of 1982. Spawning activity was located using a glass bottomed pram, jet boat or with SCUBA techniques.

	Dates of observation		
Location	October	November	December
West Shore Flathead Lake			
Somers Bay		2, 12, 17, 24	10, 19
Hatchery Bay		2, 12, 17, 24	10, 19
Marco Bay		2, 12, 17, 24	10, 19
Mountainview Terrace Bay		2, 12, 17, 24	10, 19
Bay south of Point Caroline		2, 12, 17, 24	10, 19
Lakeside		2, 12, 17, 24	10, 19
Stoner Creek		2, 12, 17, 24	10, 19
Peaceful Bay		2, 12, 17, 24	10, 19
Hockaday Bay		2, 12, 17, 24	10, 19
Hughes Bay		2, 12, 17, 24	10, 19
Deep Bay		2, 12, 17, 24	10, 19
W. Shore State Park	26	2, 12, 17, 24	10, 19
Goose Bay	26	2, 12, 17, 24	10, 19
Table Bay	26	2, 12, 17, 24	10, 19
Zelezny Bay	26	2, 12, 17, 24	10, 19
Hyde Bay	26	2, 12, 17, 24	10, 19
Bennetts Bay	26	2, 12, 17, 24	10, 19
Dewey Bay	26	2, 12, 17, 24	10, 19
Canal Bay	26	2, 12, 17, 24	10, 19
Crescent Bay	26	2, 12, 17, 24	10, 19
One Mile South Crescent Bay			
Dayton Creek		17	3, 10, 19
Elmo Bay		17	3, 10, 19
Big Arm Bay		17	3, 10, 19
White Swan Bay		17	3, 10, 19
Indian Bay		17	3, 10, 19
Wildhorse Island		17	3, 10, 19
East Shore Flathead Lake			
Bigfork Bay	24	5, 30	
Bay with Flathead Guest Ranch	24	5, 30	
Woods Bay	24	5, 12, 20, 30	7
Hunger Creek	24	5, 30	13
Mauzey Creek	24	5, 30	
Crane Creek	24	5, 30	
Howsley Creek	24	5, 30	

Table 1. (Continued).

Location	Dates of observation		
	October	November	December
Glen Creek	24	5, 30	
Bohannon Creek	24	5, 30	
Gunderson Creek	24	5, 30	
Lolo Creek	24	5, 30	
Yellow Bay	24, 25	4, 11, 16	8, 20
Sunset Bay	25	4	8, 20
Blue Bay	25, 30	4, 11, 15, 22	8, 20
Teepee Creek	25, 30	4, 11, 22	8, 20
Talking Water Cr.	25, 30	4, 11, 22	8, 20
Boulder Creek	22, 25, 30	4, 11, 22	8, 20
Seep North Dee Cr.	22, 25, 30	4, 11, 22	8, 20
Dee Creek	22, 25, 30	4, 11, 22	8, 20
Gravel Bay	25, 30	4, 11, 15, 22, 30	8, 20
South to Dr. Richard's Bay	25, 30	4, 11, 15, 22	9, 14
Dr. Richard's Bay	25, 30	4, 11, 22	9, 14
Pine Glen Resort	25, 30	4, 10, 16, 22	9, 14
Skidoo Bay	25, 30	4, 10, 22	9, 14

Table 2. Daily pram counts and total SCUBA counts of kokanee spawners and new redds built in shoreline areas of Flathead Lake during October, November and December, 1982. Left hand number represents fish seen, right number represents new redds counted.

	10/22	10/25	10/30	11/4	11/10	11/11	11/15	11/16	11/20	11/30	12/7	12/8	12/13	12/17	12/20
Woods Bay															
Point						0f/15r			0f/7r						
East									0f/56r						
West						25f/30r			150f/20r		75f/25r		0f/28r		
Yellow Bay															
Major	30f/0r		25f/	40f/6r		30f/70r		0f/74r				20f/24r			12f/
Boat ramp				0f/2r											
Flume		20f/		4f/		0f/6r									16f/
Blue Bay		0	0			45f/25r	0f/9r					30f/21r			12f/
South Blue			0			0f/4r									
Gravel			6f/4r	8f/7r		4f/37r	50f/88r			60f/99r				15f/	
Dr. Richard's		35f/1r	20f/4r	55f/		0f/47r	0f/52r								
Pine Glen			45f/21r	55f/14r	0f/17r			0f/18r							
Skidoo Bay															
West		0	55f/21r	0f/29r	0f/0r										
East		0	40f/40r	0f/10r	100f/18r										
Point		0			0f/15r										
Crescent				12f/0r		0f/16r		2f/13r				20f/2r			
Buswell's	5f/	10f/	0	0											
Total Fish	35	65	191	162	100	104	50	0	150	60	75	50	0	15	40
Total Redds	--	1	90	68	50	244	149	92	73	99	25	45	28	0	

Table 3. Total length and age composition with totals and means of adult kokanee salmon collected by gill nets in seven shoreline areas of Flathead Lake in November, 1982.

	Length (mm)						Age Composition									
	Male			Female			Male				Female				Percent Combined	
							III+		IV+		III+		IV+			
	N	Range	x̄	N	Range	x	N	%	N	%	N	%	N	%	III+	IV+
Big Fork	26	365-424	394	24	353-391	373	12	60	8	40	18	94.7	1	5.3	77	23
Yellow Bay	32	368-422	388	22	348-401	371	14	43.8	18	56.3	15	75.0	5	25.0	56	44
Gravel Bay	42	371-414	388	12	353-389	374	24	77.4	7	22.6	7	70.0	3	30.0	76	24
Dr. Richard's	29	363-439	401	12	348-393	378	20	74.1	7	25.9	11	91.7	1	8.3	80	20
Blue Bay					Small sample - 3 fish total											
Skidoo Bay	34	348-419	395	33	345-429	384	15	51.7	14	48.3	18	66.7	9	33.3	59	41
Pine Glen Resort	16	381-419	399	7	373-399	381	8	50.0	8	50.0	3	50.0	3	50.0	50	50
Lake Overall	181	348-439	394	111	345-429	374	93	60.0	62	40.0	72	76.6	22	23.4	66	34

Table 4. Intergravel dissolved oxygen concentrations (in mg/l) by bottom elevation and transect location from Yellow Bay, Skidoo Bay, Dr. Richard's Bay, Woods Bay, Gravel Bay, Pine Glen Resort and Crescent Bay.

Location	Distance from headstake	Bottom elevation (m)	Dissolved oxygen (mg/l)	
			4/4	5/18
Woods Bay				
South Transect	0	870.2	1.7	
	4	868.5	4.7	
	8	866.2	2.8	
	12	864.4	3.0	
	16	862.6	3.4	
	20	860.7	6.4	
	27	858.9	6.6	
Center Transect	0	879.1	10.9	9.4
	4	877.6	6.8	5.0
	8	876.0	6.3	4.2
	12	874.9	5.8	9.0
	16	872.9	7.0	10.1
	20	870.7	6.8	9.6
	24	868.7	5.6	6.2
	28	866.7	6.3	6.9
	32	864.7	7.8	7.0
North Transect	0	878.8	11.7	
	4	877.0	8.3	
	8	875.0	9.0	
	12	872.9	7.3	
	16	870.8	3.4	
	17.1	870.2	7.2	

			Dissolved oxygen (mg/l)		
			11/30	3/14	6/7
Gravel Bay					
West Transect	0	878.6	8.95	11.4	NS
	4	877.1	7.95	11.0	NS
	8	876.3	5.6	8.5	NS
	12	875.4	3.1	0	NS
Center Transect	0	879.0	5.8	10.8	NS
	4	878.2	11.5	10.9	NS
	8	876.8	No water	10.4	NS
	12	875.7	7.4	8.3	NS
	16	874.8	7.1	9.1	NS
	19	874.3	<1.0	8.9	NS

Table 4. (Continued).

Location	Distance from headstake	Bottom elevation (m)	Dissolved oxygen (mg/l)		
			11/30	3/14	6/7
East Transect	0	878.9	5.5	11.3	1.5
	4	877.8	9.8	11.4	10.1
	8	876.3	8.7	9.3	9.2
	12	875.1	9.0	10.8	4.8
	16	873.9	7.6	NW	7.0
	20	873.0	7.0	8.7	7.2
	24	872.4	5.0	0.2	0

Location	Distance from headstake	Bottom elevation (m)	Dissolved oxygen (mg/l)		
			12/1	4/4	6/7
Yellow Bay					
East Transect	0	879.5	1.8	NW	8.2
	4	879.2	1.6	8.7	9.0
	8	879.0	<1.0	9.4	6.7
	12	878.3	5.7	7.1	4.7
	16	876.7	3.6	5.2	0.6
	19	875.8	0.3	<1.0	---
Center Transect	0	879.7	3.35	10.9	2.5
	4	879.5	8.8	10.5	5.6
	8	879.4	1.6	10.8	8.3
	12	878.8	2.8	10.5	8.5
	16	877.7	1.2	10.8	9.0
	20	875.9	3.05	6.5	7.8
	24	874.4	1.8	6.1	5.3
	26	873.8	No water	0.6	No water
West Transect	0	878.3	.7	4.2	1.5
	4	877.2	1.9	9.3	5.1
	8	875.5	7.6	9.6	4.4
	12	874.3	6.6	7.7	3.8
	15	873.3	No water	No water	1.9

Location	Distance from headstake	Bottom elevation (m)	Dissolved oxygen (mg/l)	
			12/9	3/15
Skidoo Bay East				
West Transect	0	881.2	No water	No water
	4	880.6	12.8	No water
	8	880.0	11.2	7.1
	12	879.4	8.9	7.4
	16	879.2	9.1	6.1

Table 4. (Continued).

Location	Distance from headstake	Bottom elevation (m)	Dissolved oxygen (mg/l)	
			12/9	3/15
Midwest Transect	0	881.3	NW	NW
	4	880.8	11.0	NW
	8	880.1	9.6	7.9
	12	879.5	9.7	8.6
	16	879.1	NW	8.4
Mideast Transect	0	881.3	NW	NW
	4	886.8	9.2	NW
	8	880.2	9.4	7.0
	12	879.5	9.5	7.4
	16	879.2	8.5	9.1
East Transect	0	881.4	NW	NW
	4	880.8	9.5	NW
	8	880.2	10.1	8.9
	12	879.5	9.2	8.9
	16	879.2	5.5	8.6
Skidoo Bay West				
	Random	880.3	9.2	10.2
	Random	879.8	5.2	10.0
	Random	879.5	7.7	9.5
	Random	879.4	9.8	6.9
	Random	879.2	8.0	5.3
	Random	880.0	8.4	10.3
	Random	880.0	9.8	8.4
			Dissolved oxygen (mg/l)	
			12/9	3/16
Pine Glen Resort				
	Random	880.3	7.5	NW
	Random	879.9	8.4	NW
	Random	879.7	9.5	9.5
	Random	879.4	10.2	9.0
	Random	879.1	9.3	9.5
	Random	879.0	9.5	9.5
	Random	879.3	8.7	8.5
	Random	879.4	9.5	9.5
	Random	879.6	8.8	9.2

Table 4. (Continued).

Location	Distance from headstake	Bottom elevation (m)	Dissolved oxygen (mg/l) 3/15
Dr. Richard's Bay			
South Transect	0	880.6	NW
	4	876.7	NW
	8	879.7	8.7
	12	879.2	11.2
	16	879.1	10.0
North Transect	0	880.6	10.0
	4	880.3	9.1
	8	879.7	12.3
	12	879.2	11.7
	16	878.8	8.5
	20	878.6	11.2

			Dissolved oxygen (mg/l)		
			1/28	3/17	6/6
Crescent Bay					
Forman's	0	881.8	NS	NW	2.6
	4	881.1	NS	9.7	0.7
	8	880.7	NS	10.5	8.1
	12	880.1	9.9	10.6	4.8
	16	879.6	8.2	10.7	7.7
	20	879.0	1.2	5.5	9.7
	24	878.7	0.2	.5	NW
Harvey's	0	880.6	9.9	NS	
	4	880.1	10.3	NS	
	8	879.6	10.2	NS	
	12	879.3	9.2	NS	
	16	878.6	7.3	NS	
	19	878.5	0	NS	

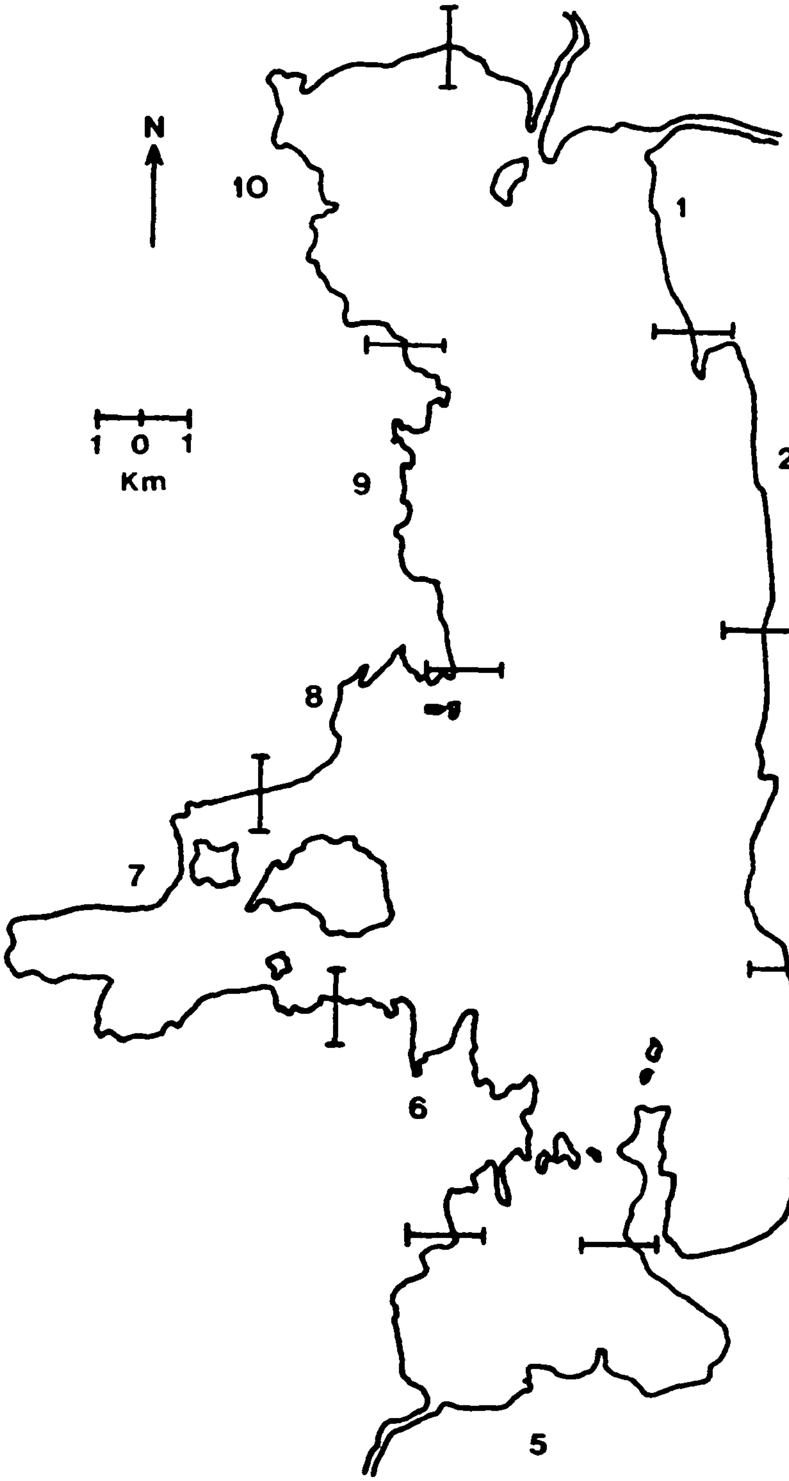
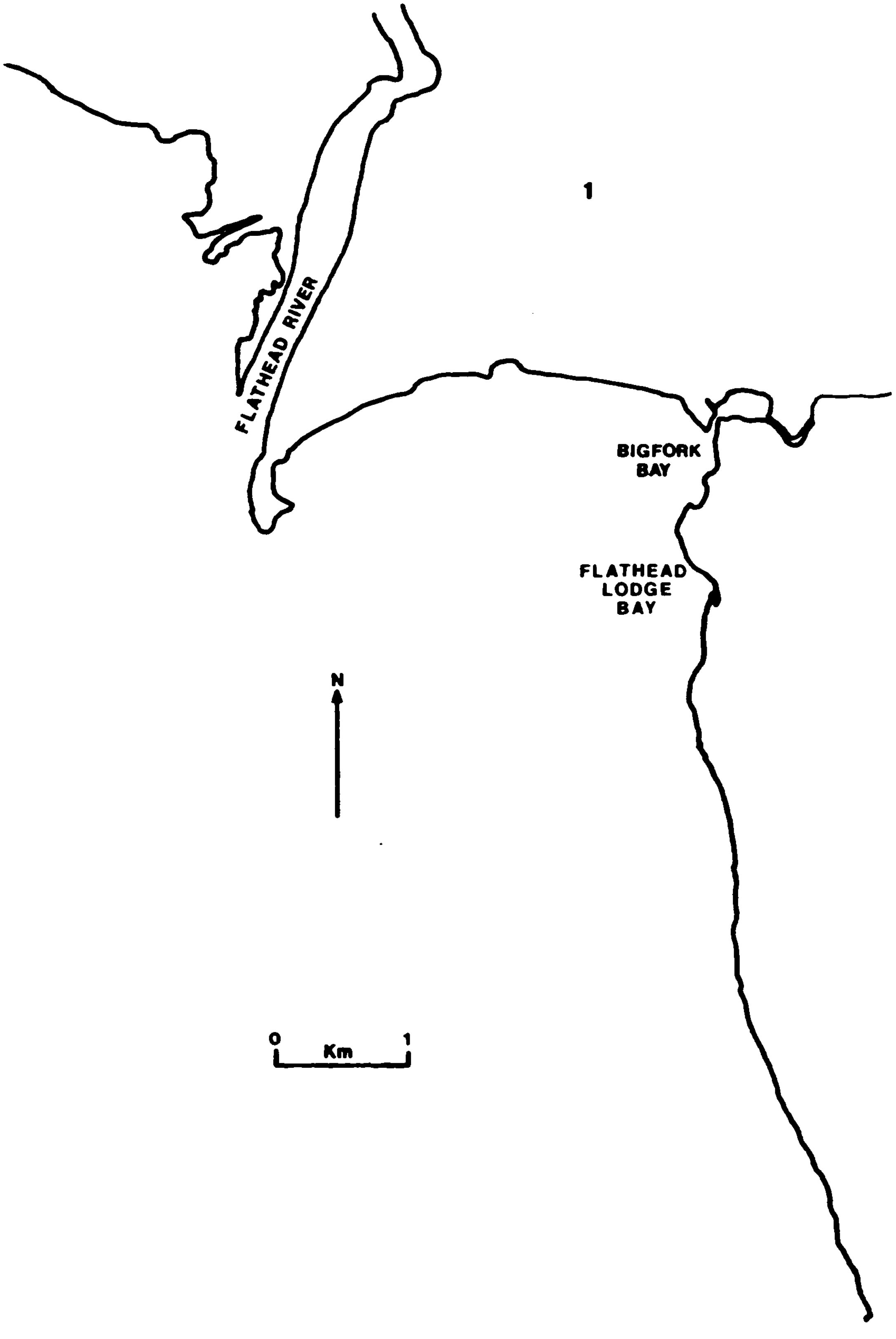
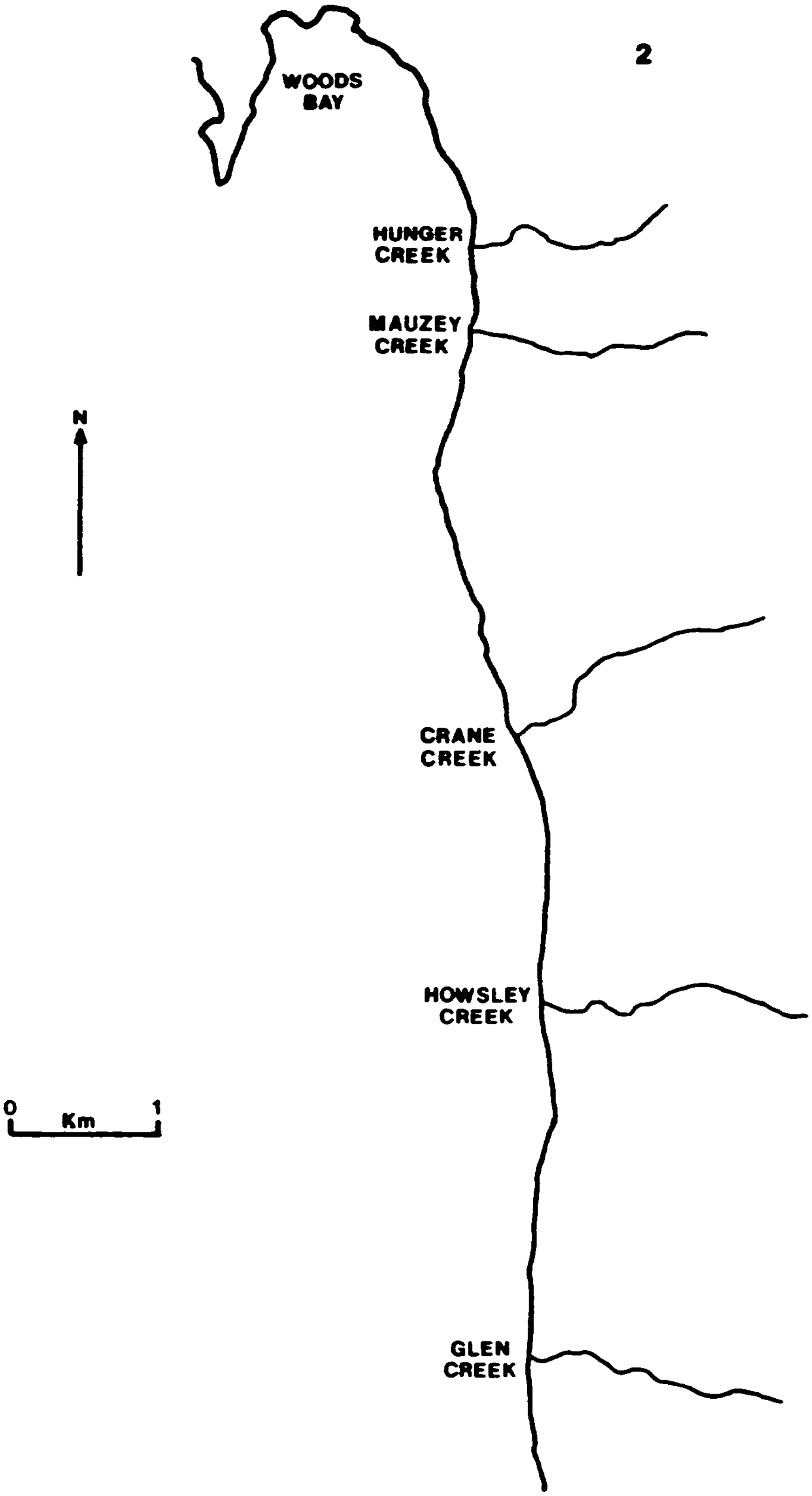
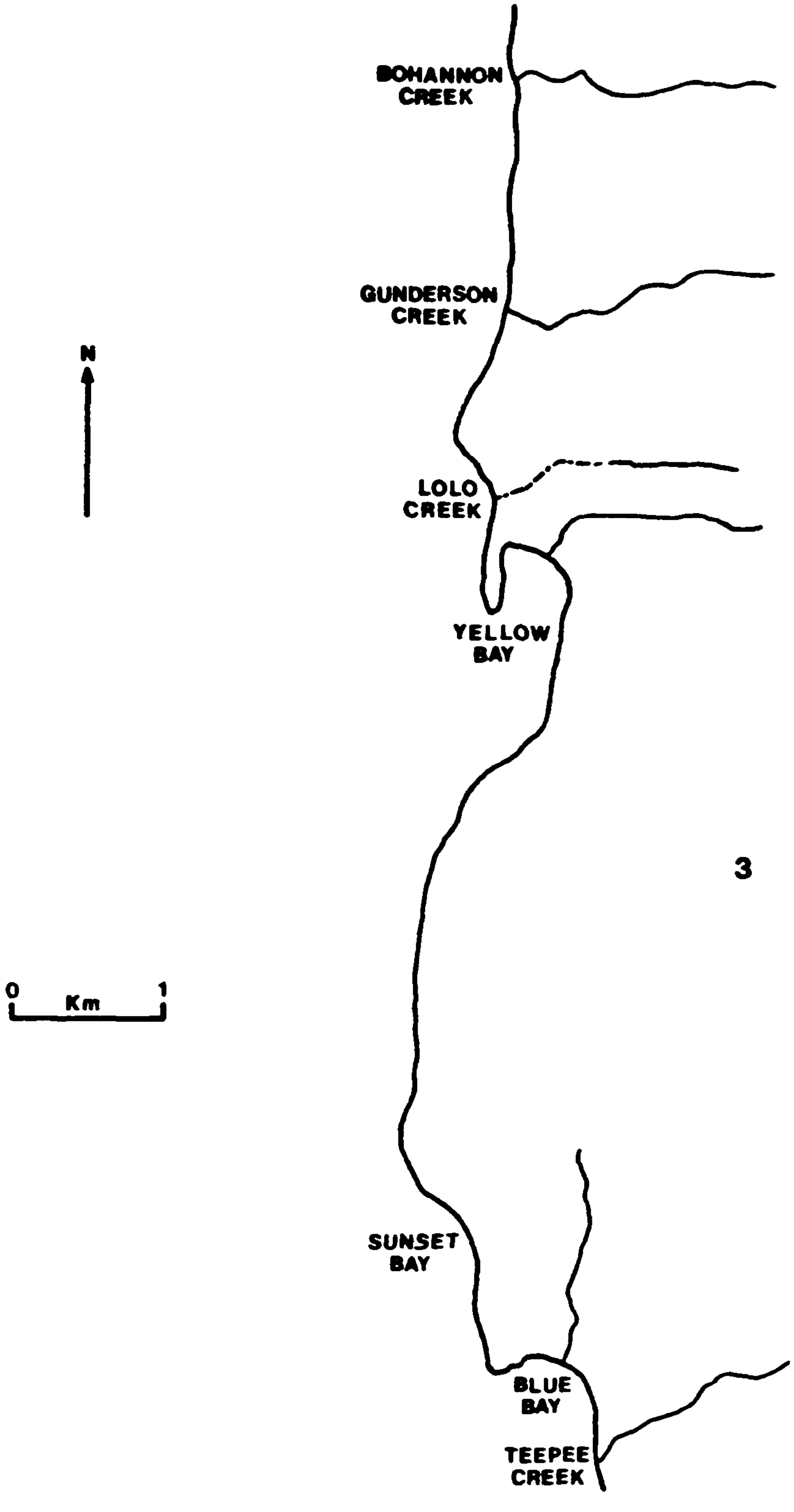
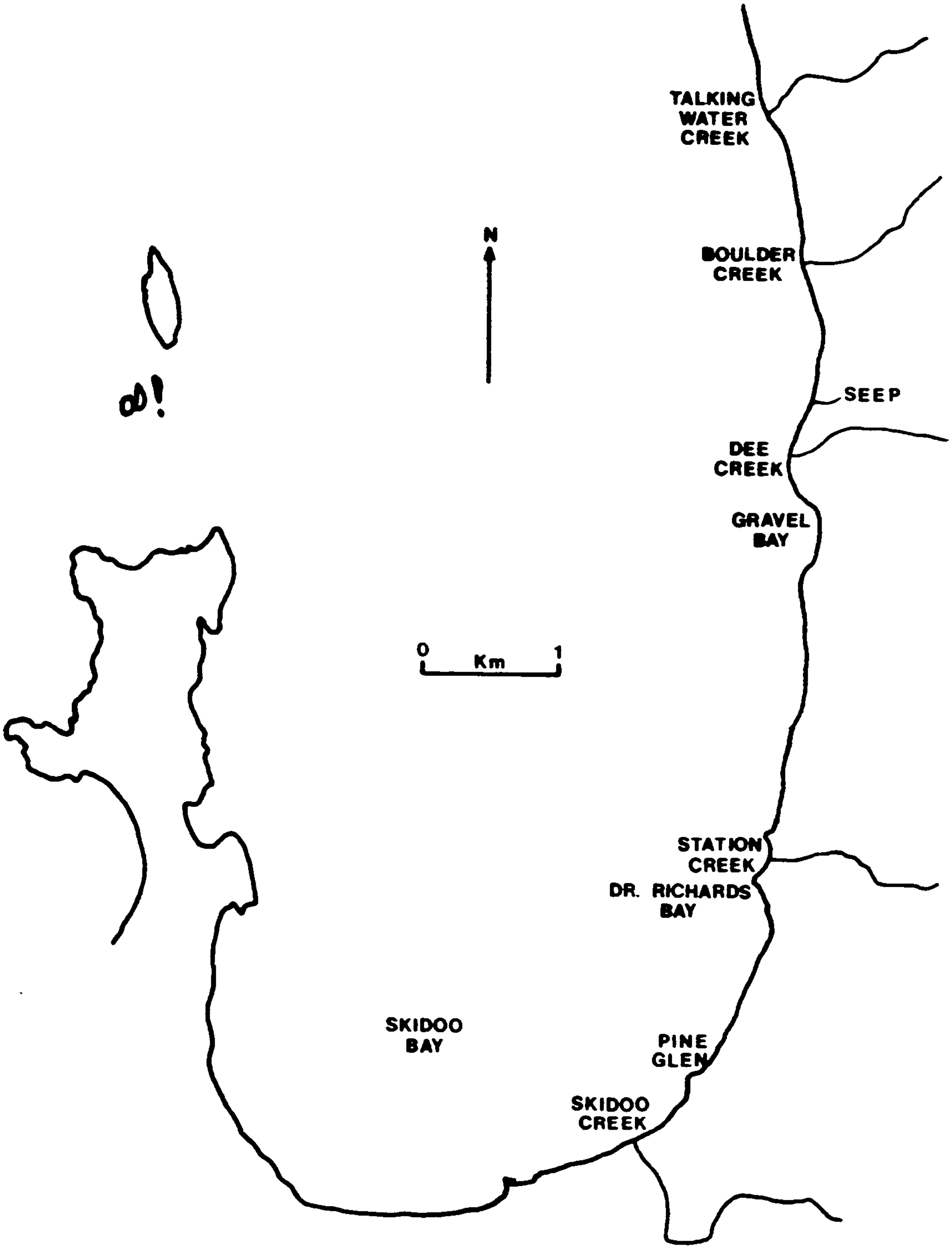


Figure 1. (Includes pages 112-121). Maps of Flathead Lake shoreline designating the S1 areas surveyed for kokanee spawning activity during the fall of 1982. Pages 112-121 breaks down shoreline into ten sections with locations of each area surveyed.

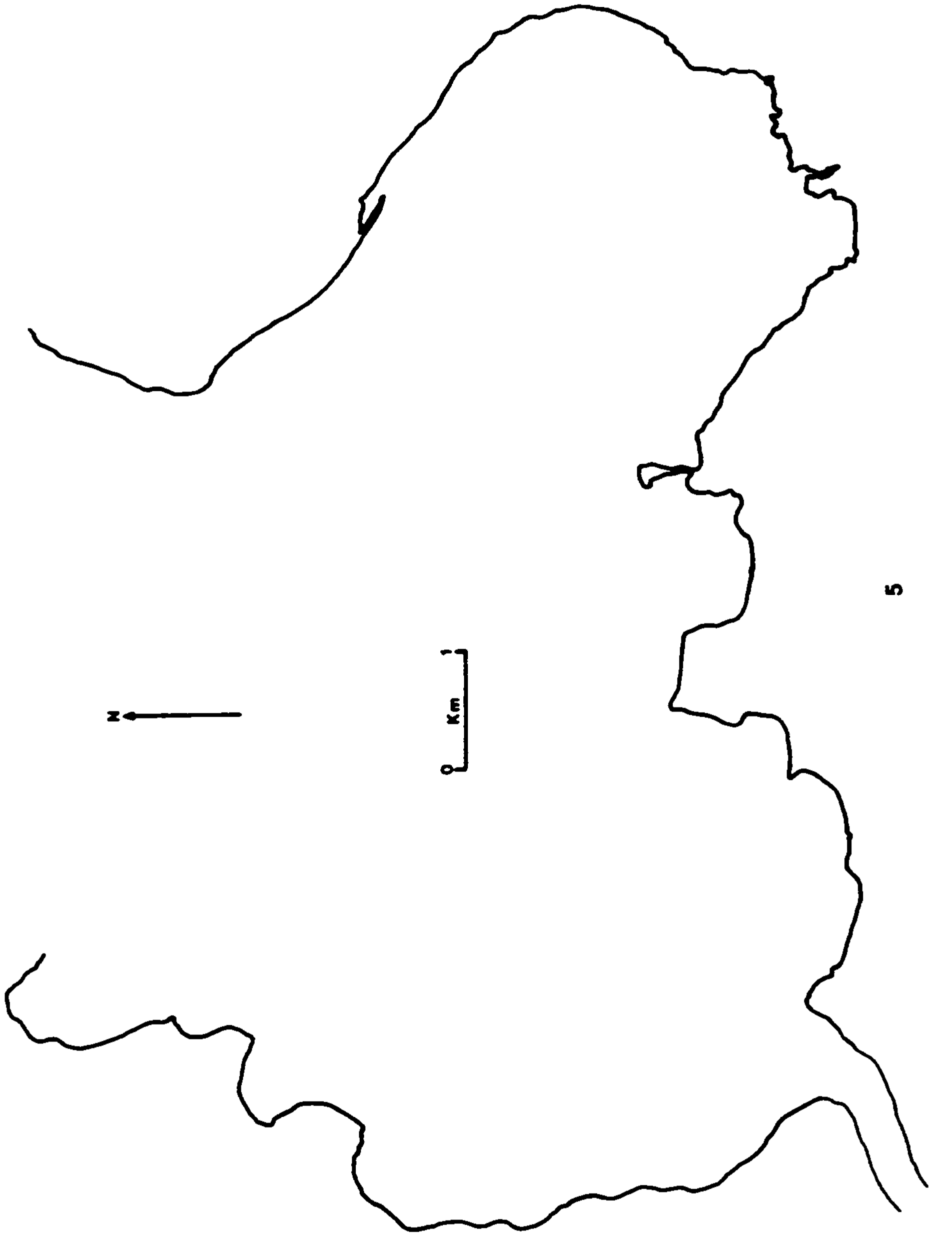

1
FLATHEAD RIVER
BIGFORK BAY
FLATHEAD LODGE BAY
N
0
Km
1

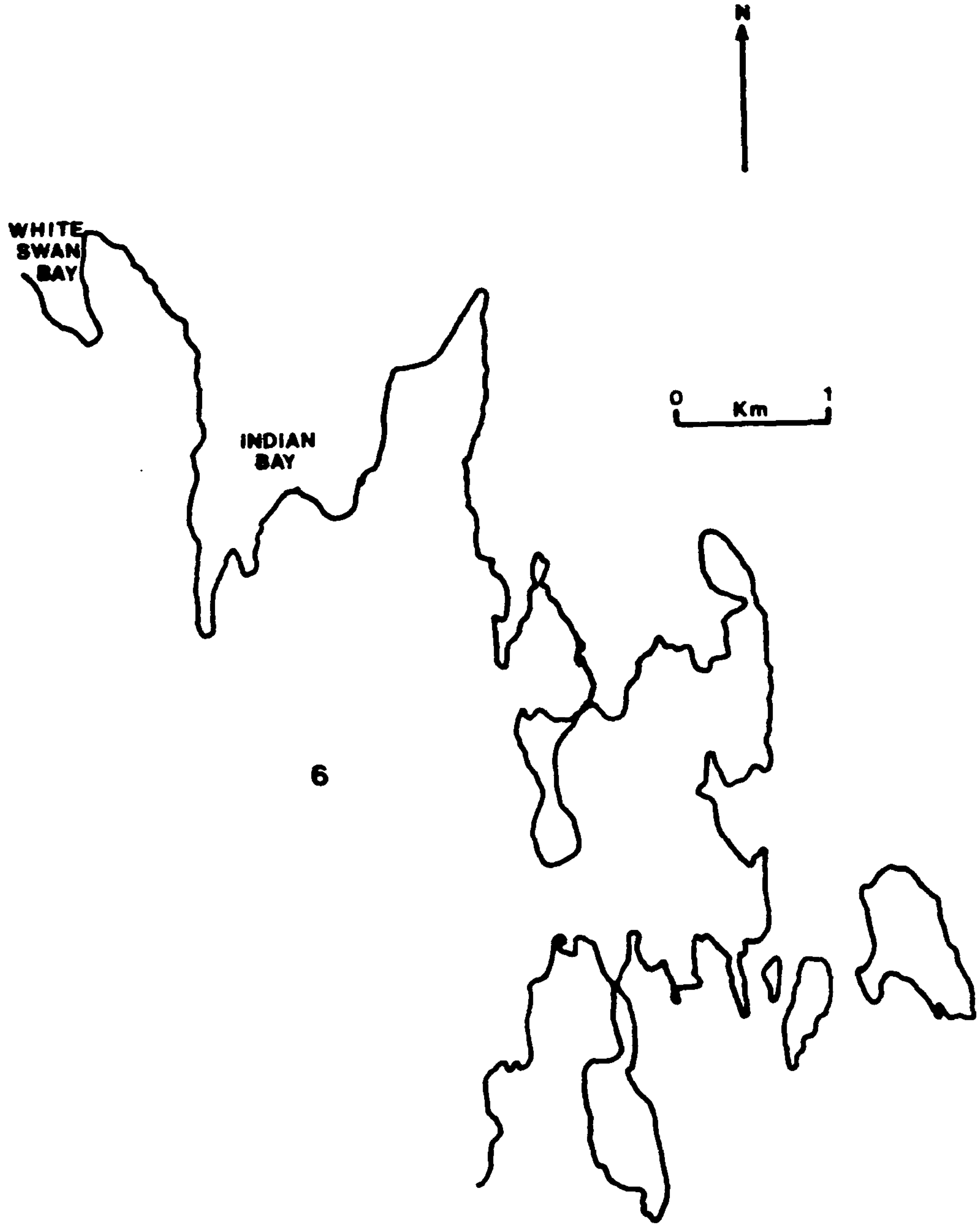

2
WOODS BAY
HUNGER CREEK
MAUZEY CREEK
N
CRANE CREEK
HOWSLEY CREEK
0 Km 1
GLEN CREEK

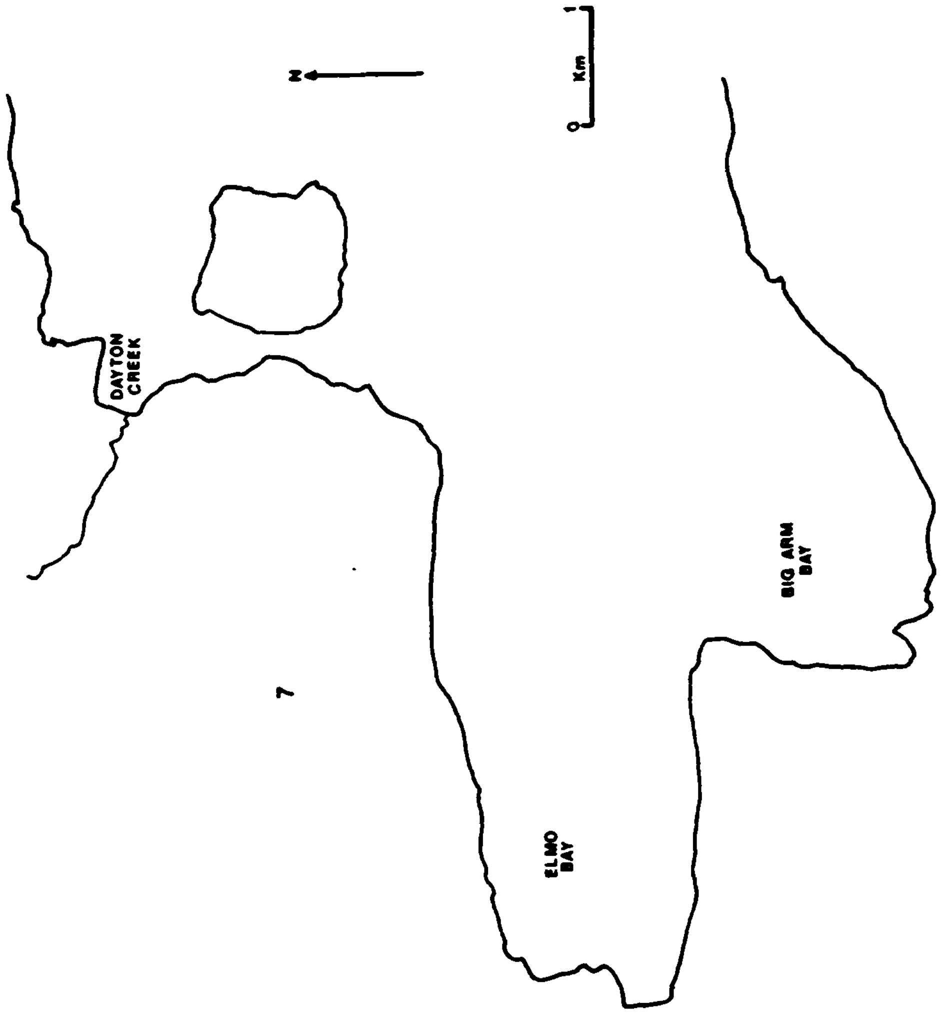

BOHANNON CREEK
GUNDERSON CREEK
N
LOLO CREEK
YELLOW BAY
3
0 Km 1
SUNSET BAY
BLUE BAY
TEEPEE CREEK

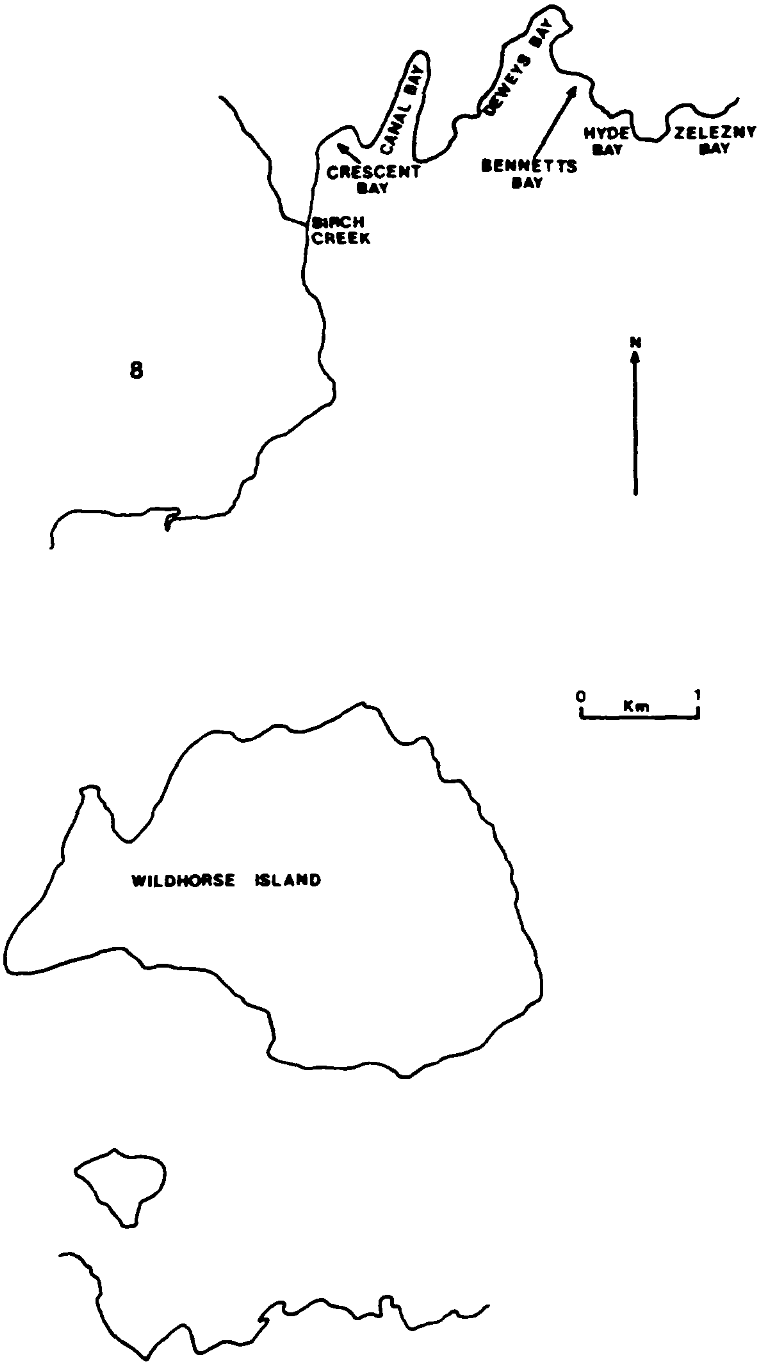

TALKING WATER CREEK
N
BOULDER CREEK
SEEP
DEE CREEK
GRAVEL BAY
0 Km 1
STATION CREEK
DR. RICHARDS BAY
SKIDOO BAY
PINE GLEN
SKIDOO CREEK

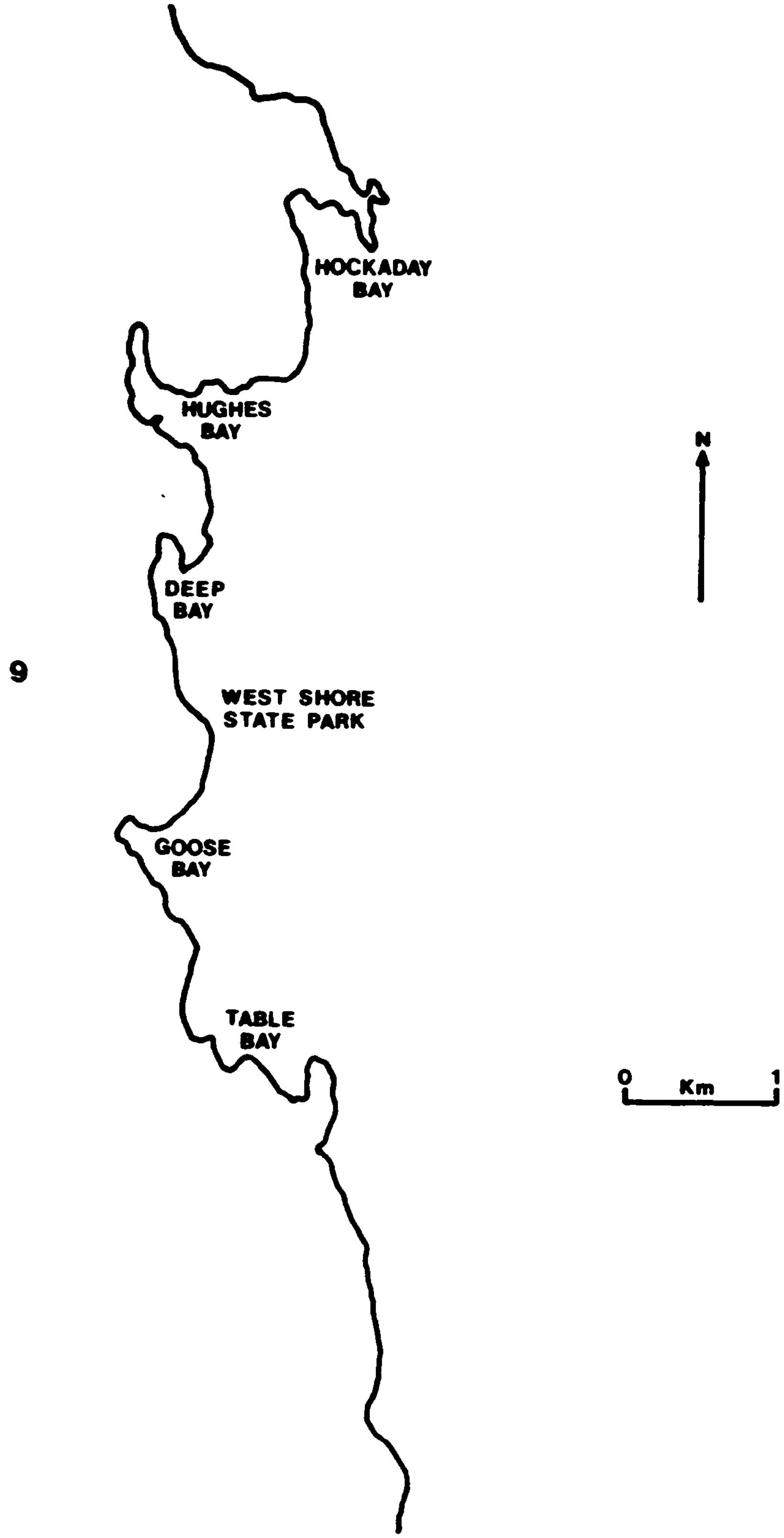
4


N
0
Km
1
5

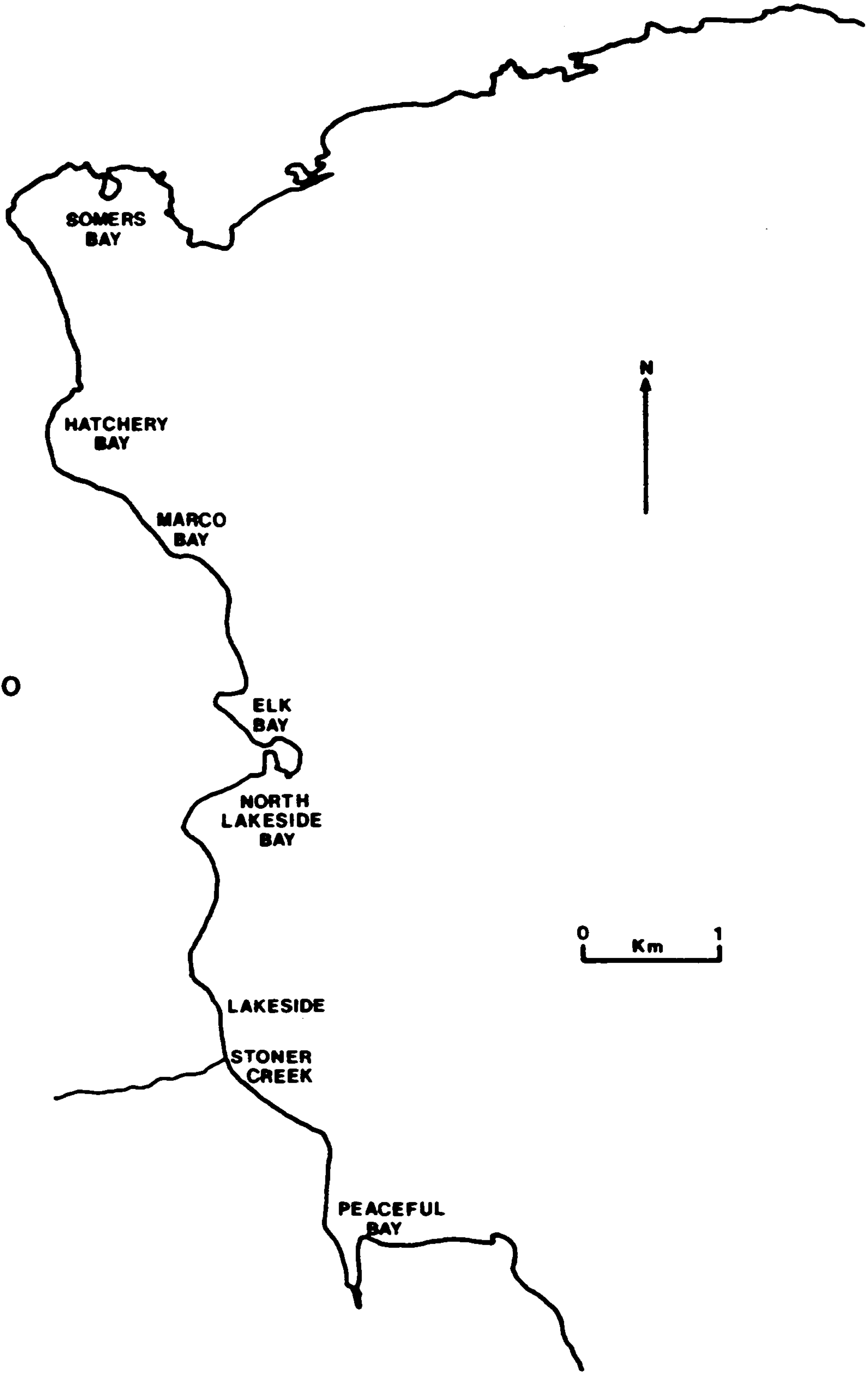

N
WHITE SWAN BAY
INDIAN BAY
0 Km 1
6


N
0 Km 1
DAYTON CREEK
7
ELMO BAY
BIG ARM BAY


CANAL BAY
DEWEYS BAY
CRESCENT BAY
BENNETTS BAY
HYDE BAY
ZELEZNY BAY
BIRCH CREEK
8
N
0 Km 1
WILDHORSE ISLAND


HOCKADAY BAY
HUGHES BAY
DEEP BAY
9
WEST SHORE STATE PARK
GOOSE BAY
TABLE BAY
N
0
Km
1

10


SOMERS BAY
HATCHERY BAY
MARCO BAY
ELK BAY
NORTH LAKESIDE BAY
LAKESIDE
STONER CREEK
PEACEFUL BAY
N
0 Km 1

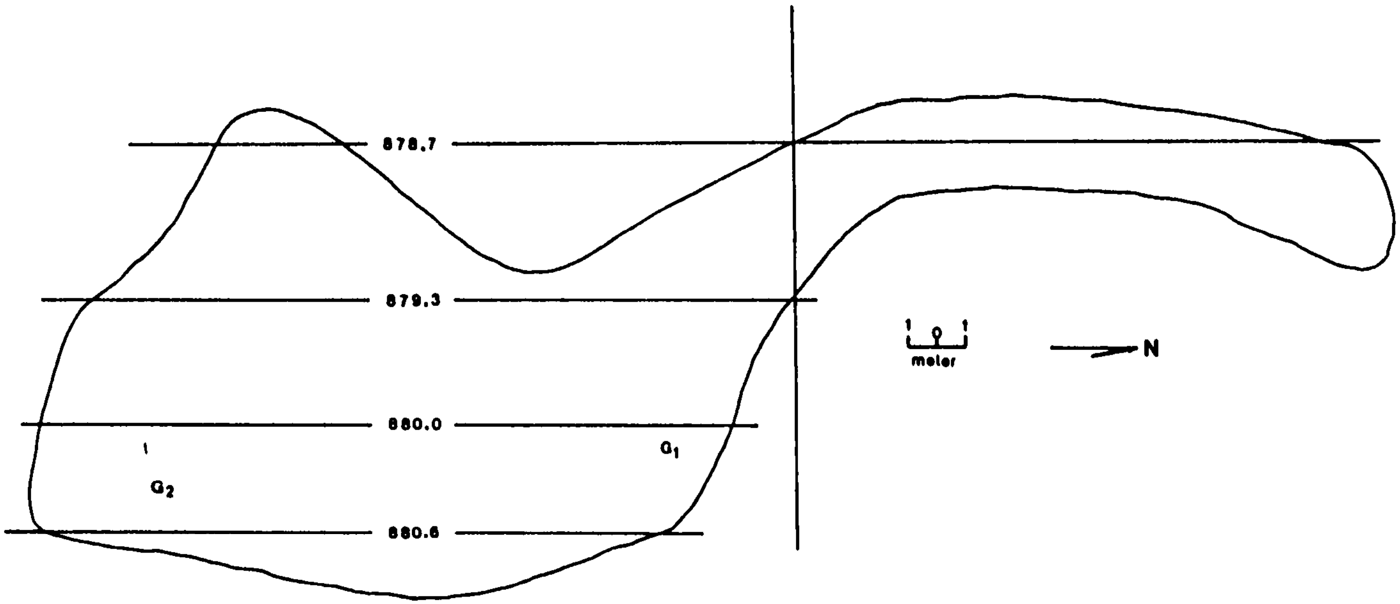


Figure 2. Area and depth contour lines (in meters) for Dr. Richard's Bay North spawning area. The perpendicular line represents location of dissolved oxygen and gravel transect. G_1 and G_2 represent the gravel composition sample site.

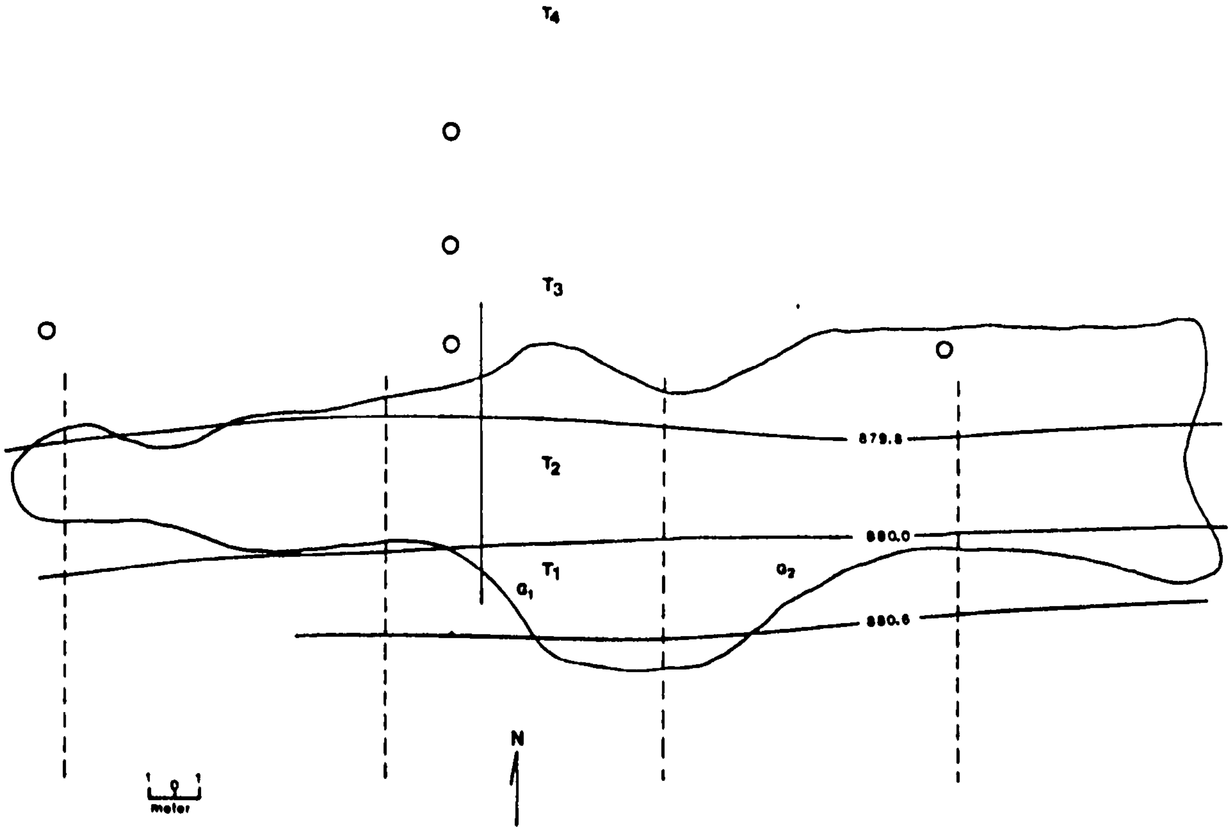


Figure 3. Location and depth contours (in meters) for Skidoo Bay East. Dashed lines represent dissolved oxygen transects and solid line is location of gravel transect. Circles represent seepage meter locations, G_1 and G_2 are locations of substrate samples and T_1 through T_4 are the locations of thermograph probes.

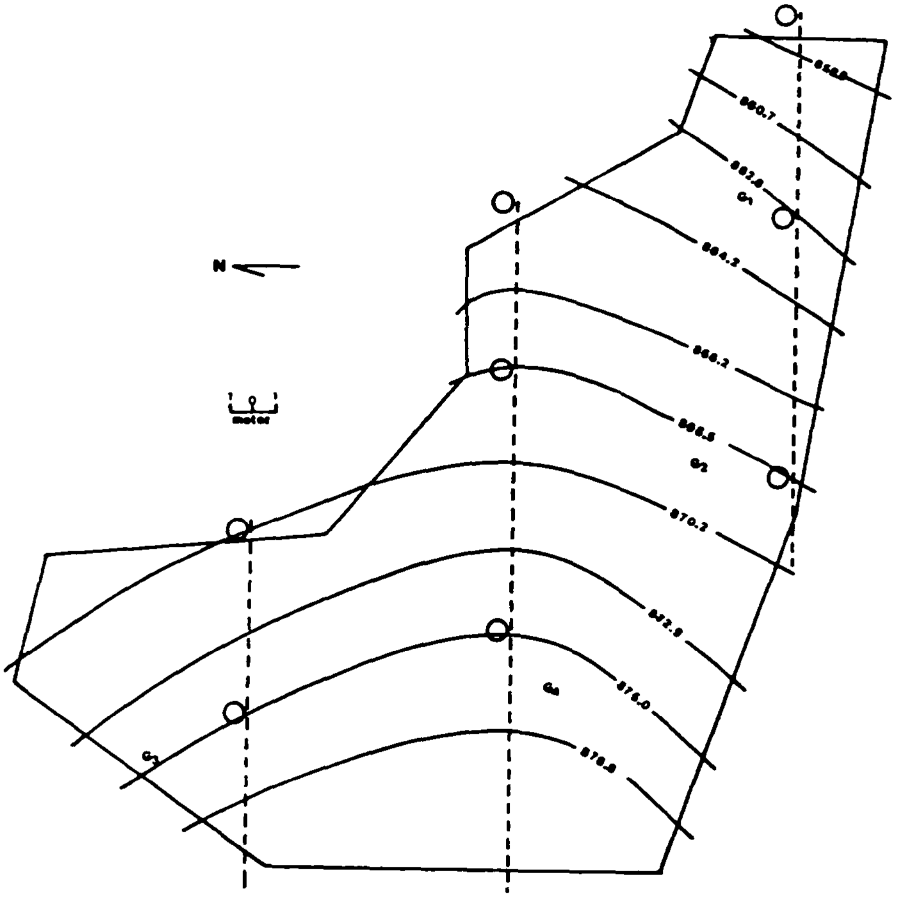


Figure 4. Location and depth contour lines (in meters) for the major spawning area in Woods Bay. Perpendicular lines to shore represent location of dissolved oxygen transects, circles represent seepage meter locations, and G_1-G_4 indicate where substrate composition samples were collected.

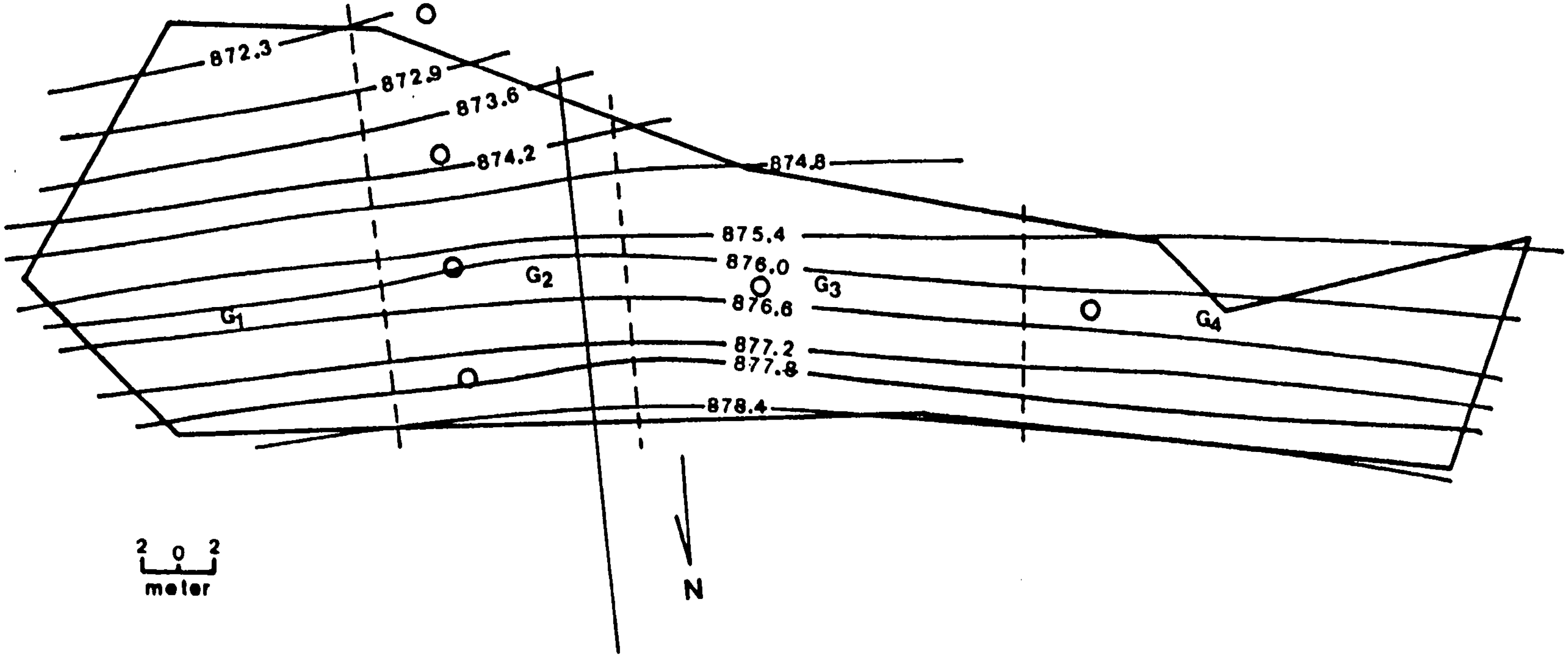


Figure 5. Area and depth contour lines (in meters) for Gravel Bay spawning area. Perpendicular dashed lines represent locations of dissolved oxygen transect and solid line is gravel transect location. Circles represent locations of seepage meters and G_1 through G_4 represent substrate composition samples sites.

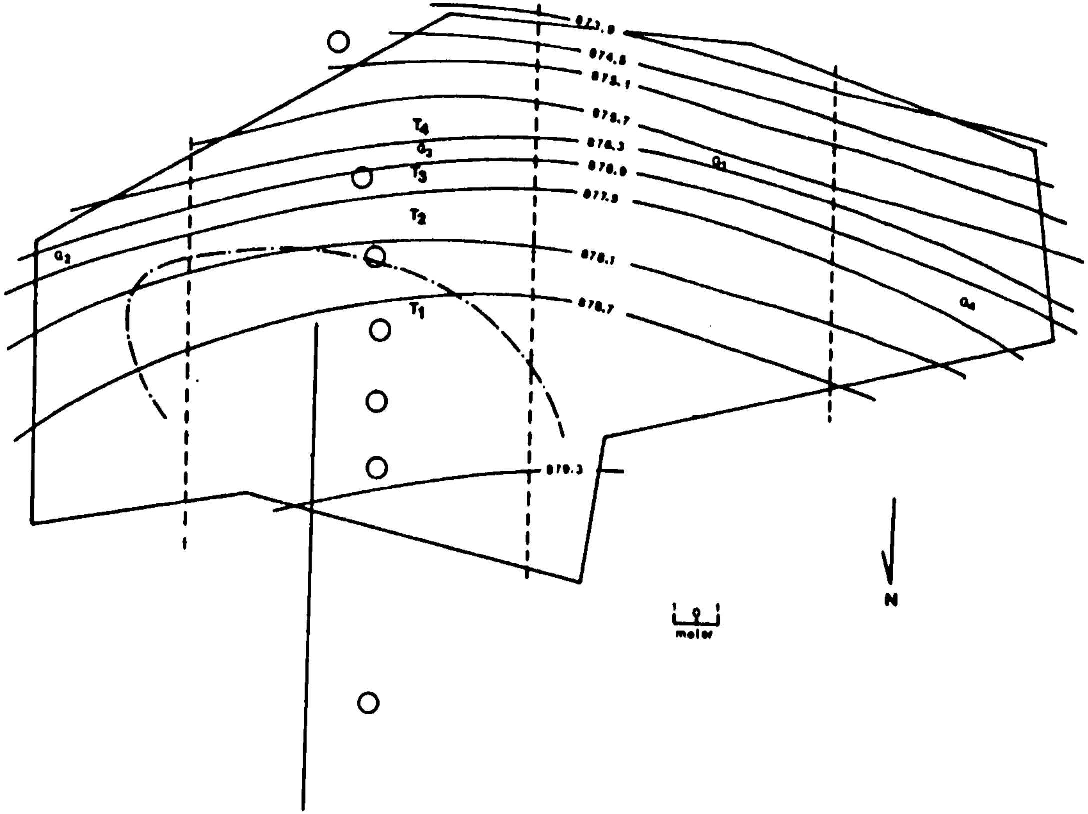


Figure 6. Location and depth contour lines (in meters) for the major spawning area in Yellow Bay. Perpendicular lines to shore represent location of dissolved oxygen transects (dashed line) and gravel transects (solid line). Circles represent seepage meter locations, G_1-G_4 represent location of substrate composition samples, and T_1-T_4 represent location of thermograph probes.

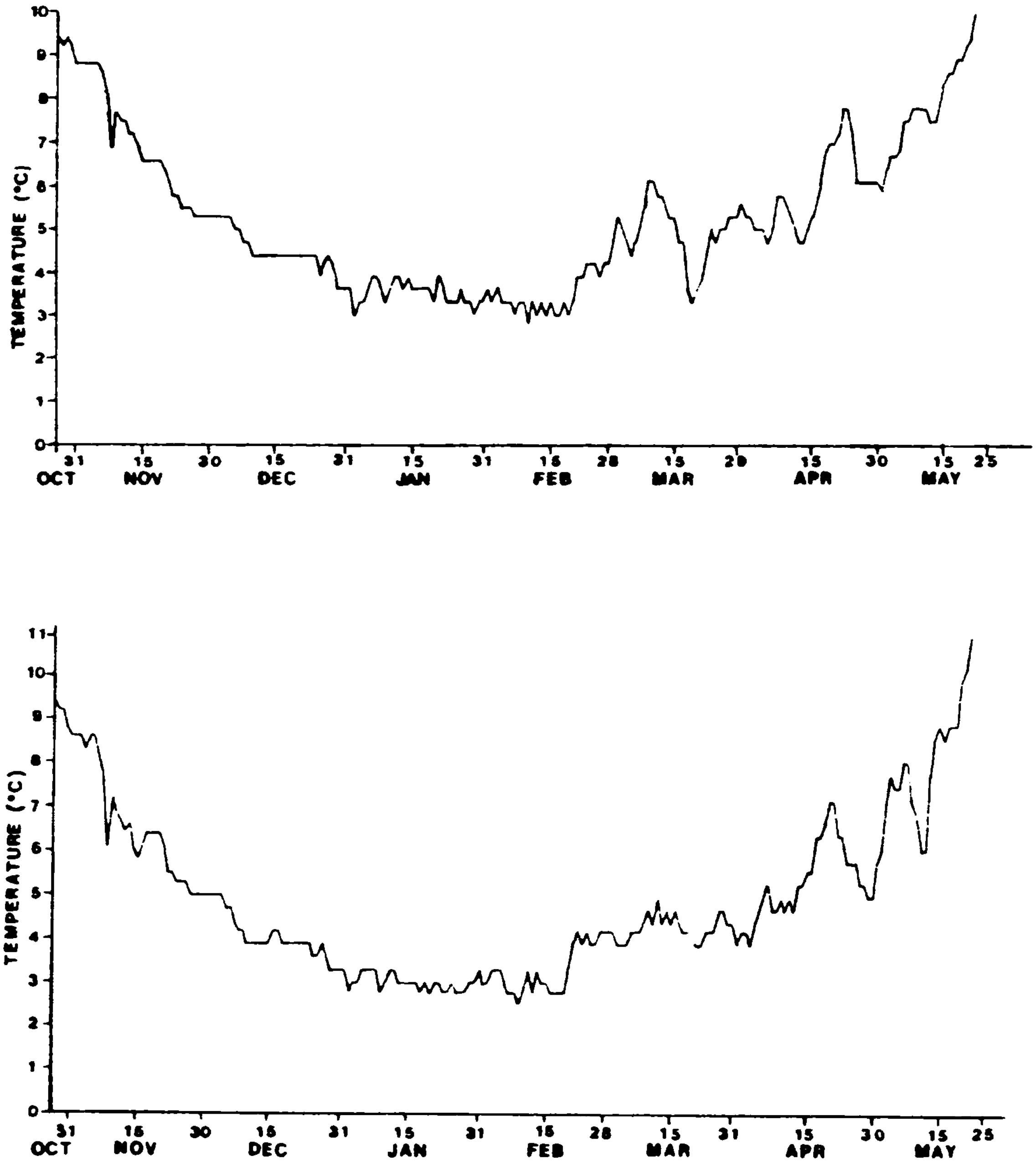


Figure 7. Recorded intergravel temperatures at bottom elevations of 878.5 m (2882.13 ft) (upper figure) and 877.2 m (2887.79 ft) (lower figure) from 27 October to 22 May, 1983 at Yellow Bay spawning area.

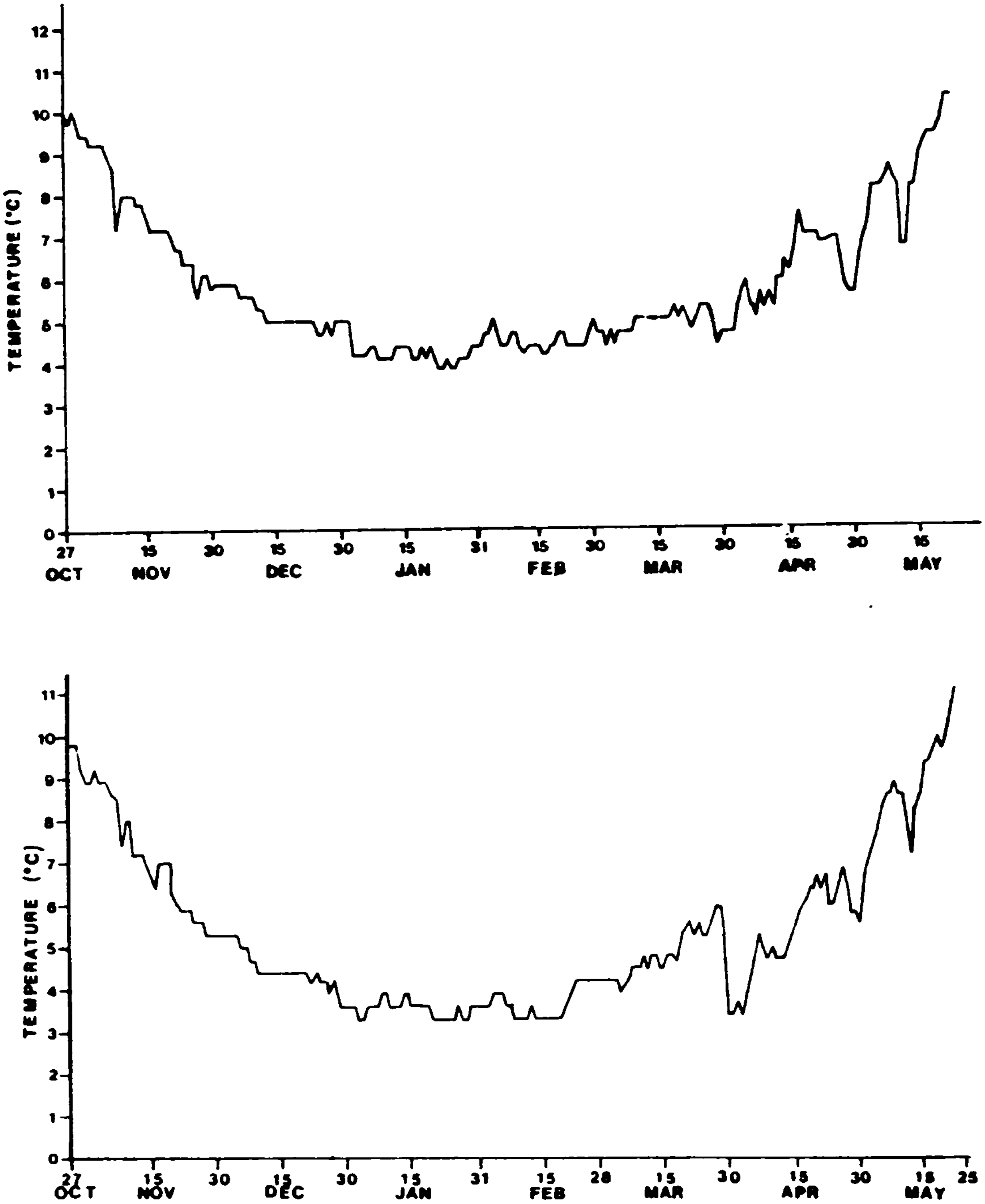


Figure 8. Recorded intergravel temperatures at bottom elevations of 875.9 m (2873.79 ft) (upper figure) and 874.9 m (2870.38 ft) (lower figure) from 27 October to 22 May, 1983 at Yellow Bay spawning area.

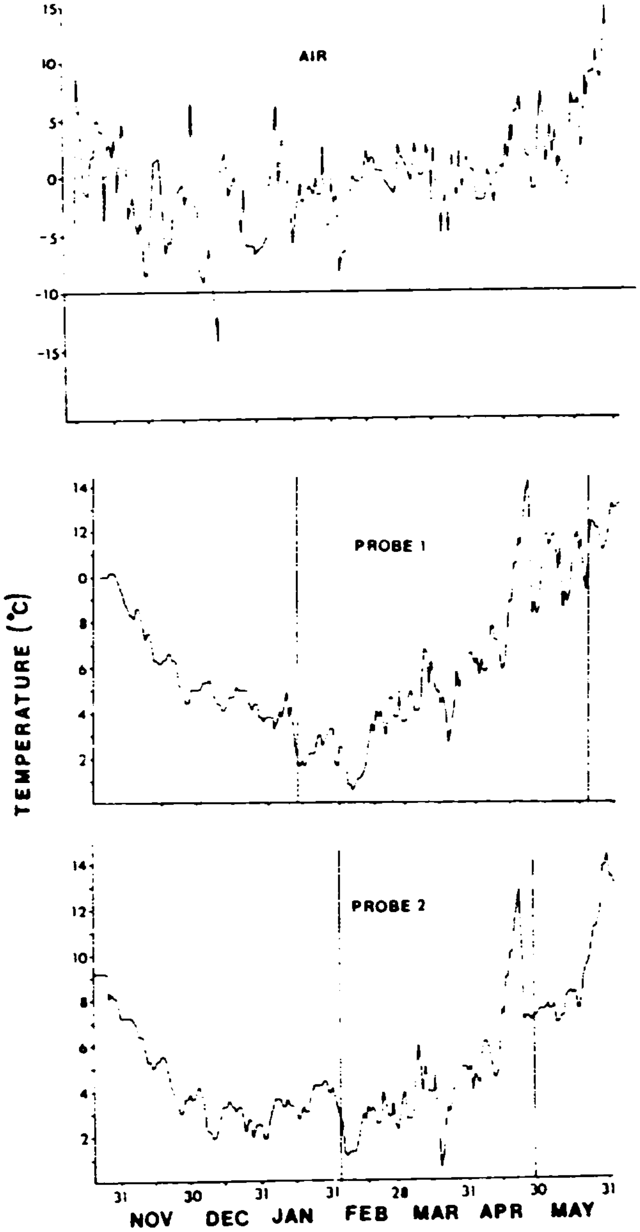


Figure 9. Comparison of intergravel temperatures at Probe 1 (bottom elevation 880.3 m, 2888.0 ft) and Probe 2 (bottom elevation 879.7 m, 2886.0 ft) at the Skidoo Bay spawning area with minimum air temperatures from Yellow Bay Climatological Station for 15 October to 31 May, 1983. Area between vertical lines represent the period of probe exposure by lake drawdown.

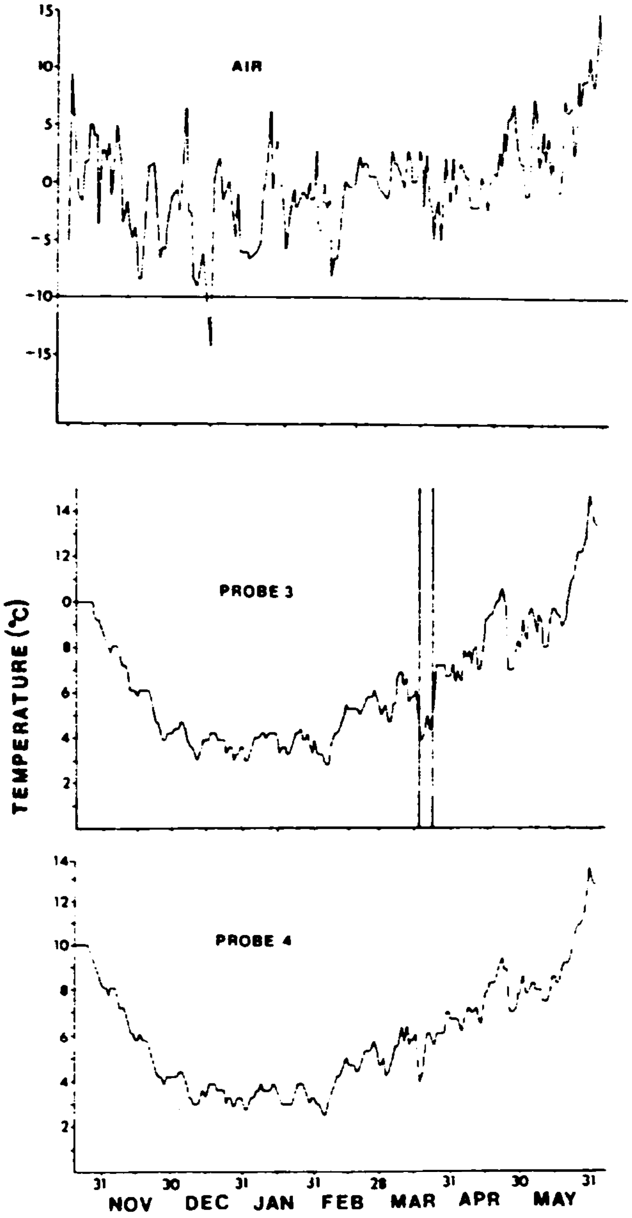


Figure 10. Comparison of intergravel temperatures at Probe 3 (bottom elevation 879.0 m, 2884.0 ft) and Probe 4 (bottom elevation 878.8 m, 2883.3 ft) at the Skidoo Bay spawning area with minimum air temperatures from Yellow Bay Climatological Station for 15 October to 31 May, 1983. Area between the vertical lines represent the period of probe exposure by lake drawdown.

APPENDIX B

Substrate composition samples for shoreline spawning areas of Flathead Lake.

Table 1. Percent composition of substrate samples, date sampled and bottom elevation (in meters) for shoreline spawning areas of Flathead Lake. Location of gravel sample identified on Appendix A, Figure

Location	Date	Elevation (m)	Percent Composition Sieve sizes (mm) >50.8	16	6.35	2	.063	<.063
Yellow Bay (G1)	12/8/82	876.5	0	22.0	46.2	25.2	6.4	.1
Yellow Bay (G2)	12/8/82	876.5	0	31.9	47.4	17.7	2.7	.3
Yellow Bay (G3)	12/8/82	876.8	0	8.9	33.3	46.0	11.7	.1
Yellow Bay (G4)	12/8/82	876.5	0	15.1	41.6	38.3	4.5	.5
Yellow Bay (G1)	4/7/83	876.5	0	15.5	38.8	34.9	10.7	.2
Yellow Bay (G2)	4/7/83	876.5	0	40.0	33.6	10.1	15.5	.8
Yellow Bay (G3)	4/7/83	876.8	0	7.9	40.2	40.3	11.4	.1
Yellow Bay (G4)	4/7/83	876.5	0	30.0	32.8	25.6	11.2	.5
Woods Bay (G1)	2/7/83	862.8	3.0	88.8	8.1	0	0	0
Woods Bay (G2)	2/7/83	868.9	1.2	87.8	10.7	.1	.2	.1
Woods Bay (G3)	2/7/83	875.0	4.3	71.4	24.1	0	.1	0
Woods Bay (G4)	2/7/83	875.6	1.6	39.0	58.5	.9	0	0
Woods Bay (G1)	4/7/83	862.8	3.3	82.2	14.4	0	0	0
Woods Bay (G2)	4/7/83	868.9	27.2	72.4	.3	0	0	0
Woods Bay (G3)	4/7/83	875.0	10.5	88.9	.4	0	.1	0
Woods Bay (G4)	4/7/83	875.6	0	80.8	19.1	0	.1	0
Skidoo Bay East (G1)	12/14/82	880.3	7.5	35.3	25.3	15.0	16.7	.2
Skidoo Bay East (G2)	12/14/82	880.3	0	34.3	24.9	14.0	26.6	.2
Skidoo Bay East (G1)	3/15/83	880.3	0	23.1	26.4	26.6	23.8	.2
Skidoo Bay East (G2)	3/15/83	880.3	0	13.7	15.9	27.8	42.5	.1
Skidoo Bay West	3/16/83	878.4	0	13.3	14.9	31.6	40.2	.1
Skidoo Bay West	3/16/83	878.4	0	33.7	18.8	25.1	22.3	.1
Dr. Richard's Bay North (G1)	12/14/82	880.2	24.7	35.4	9.3	25.2	5.1	.2
Dr. Richard's Bay North (G2)	12/14/82	880.3	3.8	86.6	6.0	2.8	.7	.1
Dr. Richard's Bay North	3/16/83	879.1	17.1	44.9	18.6	10.4	8.9	.2
Dr. Richard's Bay North	3/16/83	879.1	39.0	44.7	13.6	1.9	.7	.1
Dr. Richard's Bay South	3/15/83	879.5	36.8	22.2	16.0	11.8	12.1	1.1
Dr. Richard's Bay South	3/15/83	879.2	37.8	20.6	12.2	12.4	16.3	.7

Table 1. (Continued).

Location	Date	Elevation (m)	Percent Composition Sieve sizes (mm) >50.8	16	6.35	2	.063	<.063
Blue Bay	12/8/82	876.2	6.5	38.8	36.6	16.5	1.5	.1
Blue Bay	12/8/82	879.2	0	66.1	24.8	8.2	.8	.1
Blue Bay	4/7/83	876.2	7.1	45.6	32.8	11.4	2.9	.2
Blue Bay	4/7/83	879.2	0	2.9	10.3	47.2	38.7	.9
Gravel Bay (G1)	12/8/82	876.2	26.7	67.1	6.1	.1	.1	0
Gravel Bay (G2)	12/8/82	876.2	20.0	38.7	39.9	1.3	0	0
Gravel Bay (G3)	12/8/82	876.2	0	71.6	15.0	12.7	.7	0
Gravel Bay (G4)	12/8/82	876.2	13.6	60.3	21.8	3.9	.3	.1
Gravel Bay (G1)	4/7/83	876.2	45.0	36.3	16.4	2.1	.1	0
Gravel Bay (G2)	4/7/83	876.2	37.7	49.4	8.1	3.6	1.1	.1
Gravel Bay (G3)	4/7/83	876.2	27.0	41.2	19.0	11.3	1.3	.1
Gravel Bay (G4)	4/7/83	876.2	5.0	70.7	21.3	1.6	1.2	.2
Pine Glen	3/16/83	879.0	2.2	41.0	8.5	6.8	40.8	.8
Pine Glen	3/16/83	879.4	54.0	23.2	5.4	2.7	14.2	.4
Crescent Bay	3/17/83	879.5	5.1	41.1	10.7	20.7	22.3	.1
	3/17/83	879.8	2.6	31.0	34.4	20.9	10.9	.1
Skidoo Bay Monitoring	4/18/83	879.3	16.1	49.5	16.5	4.0	13.6	.3
Skidoo Bay Monitoring	5/2/83	879.3	23.6	57.6	8.2	2.9	7.7	.1
Skidoo Bay Monitoring	5/13/83	879.3	30.1	49.2	7.8	4.0	8.9	.1
Skidoo Bay Monitoring	6/2/83	879.3	18.9	57.5	8.1	4.2	11.3	.1
Skidoo Bay Monitoring	6/28/83	879.3	37.3	43.7	7.1	4.2	7.6	.1

APPENDIX C

Egg Development and Survival

Table 1. Redd location by bottom elevation (m) and number (correspond with those indicated on Figures 1-6), date redd exposed by drawdown and rewetted, date sampled, percent survival, total number of eggs and alevins collected, stage of development and number of days exposed prior to sampling.

Location	Redd number	Elevation (m)	Date exposed	Date rewetted	No. days exposed prior to sampling	Date sampled	Percent survival		Stage of development	Total number	
							Eggs	Alevins		Eggs	Alevins
Skidoo Bay	1W	880.6	12/26	5/27	16	1/10			No eggs found		
	1E	880.5	1/1	5/25	10	1/11	100		100% eyed	68	0
	3W	880.5	1/1	5/25	12	1/12			No eggs found		
	9E	880.3	1/12	5/22	0	1/12			No eggs found		
	4E	879.7	2/4	4/29	0	1/12	84		100% eyed	299	
	2W	879.7	2/4	4/29	0	1/10	17		100% eyed	81	
	5W	879.5	2/12	4/26	0	1/13	100		100% eyed	121	
	8E	879.4	2/17	4/25	0	1/14	99		100% eyed	215	
	3E	879.3	2/24	4/22	0	1/14	47		90% eyed	73	
	6W	879.3	2/26	4/16	0	1/13	100		100% eyed	41	
	4W	879.1	2/27	3/30	0	1/13	100		100% eyed	12	
Mean or Total							75%			910	
	9W	880.1	1/14	5/10	45	2/28	0	0	89% hatch	3	24
	8W	879.8	1/30	5/5	29	2/28	78	50	1% hatch	147	2
	11W	879.6	2/7	4/27	21	2/28	29	44	16% hatch	370	48
Mean or Total							43	30		517	74
	10E	880.1	1/18	5/11	70	3/29	0		---	120	
	2E	880.1	1/18	5/11	70	3/29	0		---	300-600	
	13W	879.6	2/6	4/27	51	3/29		80-100	90% hatch		200-300
					70	4/18		0-10	100% hatch		200-300
	14W	879.0			51	3/29		80-100	100% hatch		200-300
					70	4/18		0-10	100% hatch		200-300
	7E	879.5	2/17	4/25	40	3/29	0	70	100% hatch	36	219
	6E	879.7	2/4	4/29	84	5/6	0	63	100% hatch	16	27
	5E	879.6	2/7	4/27	79	5/6	0		---	10	
	7W	879.2	2/27	4/17	50	5/17			No eggs found		

Table 1. (Continued).

Location	Redd number	Elevation (m)	Date exposed	Date rewetted	No. days exposed prior to sampling	Date sampled	Percent survival		Stage of development	Total number	
							Eggs	Alevins		Eggs	Alevins
Dr. Richard's Bay	8	880.7	12/17	5/26	0*	1/21	88		98% eyed	111	
	1	880.5	1/1	5/25	0*	1/21			No eggs found		
	5	879.7	2/3	5/1	0	1/21			No eggs found		
	4	879.1	3/5	3/21	0	1/21			No eggs found		
	3	878.7	Never dry		0	1/21	4		100% uneyed	67	
	11	880.1	1/16	5/12	10	1/26	80-90		100% eyed	200-300	
	11	880.1	1/16	5/12	68	3/25	0		---	10- 20	
	6	879.9	1/27	5/7	57	3/25	12		100% eyed	538	
	6	879.9	1/27	5/7	81	4/18	90		2% hatch	60	
	6	879.9	1/27	5/7	rewetted	5/2	0		---	14	
	7	879.4	2/19	4/24	34*	3/25	31		100% eyed	138	
	9	880.6	12/28	5/25	0*	5/2		76	100% hatch	17	
	10	879.4	2/18	4/25	rewetted	5/17			No eggs found		
Pine Glen Resort	13	880.5	1/1	5/24	11	1/12	84		100% eyed	307	
	11	879.8	1/29	5/6	0	1/12	54		76% eyed	151	
	4	879.3	2/19	4/25	0	1/14	97		27% eyed	149	
	6	879.3	2/26	4/4	0	1/14	96		100% eyed	81	
	9	878.9	---	---	0	1/14	96		99% eyed	140	
Mean or Total							$\bar{x}$ = 84		$\bar{x}$ = 82%	828	
	12	880.4	1/8	5/24	51	2/28	80-90		100% eyed	500-600	
	12	880.4	1/8	5/24	76	3/25	0		---	0	
	2	879.3	2/22	4/22	8	2/28	90	90	30% hatch	100-200	30-70
	2	879.3	2/22	4/22	33	3/25		10	100% hatch		100-300
	3	879.3	2/21	4/23	32	3/25		100	100% hatch		100-200
	8	879.0	Never dry		0	3/25	65	100	3% uneyed 38% hatch	221	88
	1	879.1	3/19	3/24					Never sampled; rebar removed		
	10	879.0	Never dry						Placed fry trap		
	7	878.9	Never dry						Placed fry trap		
	5	879.9	Never dry						Placed fry trap		

Table 1. (Continued).

Location	Redd number	Elevation (m)	Date exposed	Date rewetted	No. days exposed prior to sampling	Date sampled	Percent survival Eggs	Percent survival Alevins	Stage of development	Total number Eggs	Total number Alevins
Woods Bay Shallow East	1	880.3	1/12	5/21	Rebar pulled by bulldozer						
	2	880.3	1/12	5/21	Rebar pulled by bulldozer						
	3	880.0	1/21	5/10	38	2/28			No eggs found		
	4	879.8	1/28	5/6	66	4/4			No eggs found		
	5	879.8	1/21	5/4	37	2/28	90-100		100% eyed	200-300	
					62	3/25	0			0	
	6	879.8	1/30	5/4	63	4/4			No eggs found		
West	1	880.3	1/10	5/23	84	4/4			No eggs found		
	2	880.0	1/20	5/10	74	4/4			No eggs found		
	3	879.7	2/3	4/29	60	4/4			No eggs found		
	4	879.6	2/7	4/26	63	4/11			No eggs found		
	12	879.6				1/20			No eggs found		
	11	878.8				1/20	70		100% eyed	150	
	10	877.7				1/20	92		97% eyed	78	
	7	877.3				1/20	80		94% eyed	261	
	8	877.1				1/20	97		87% eyed	531	
	9	876.6				1/20	97		64% eyed	167	
	6	876.1				1/20	95		96% eyed	613	
	5	875.0				1/19	20		75% eyed	161	
	3	874.1				1/19			No eggs found		
	4	874.0				1/19	89		59% eyed	189	
	2	872.6				1/19			No eggs found		
	1	872.3				1/19	61		69% eyed	293	
Total or Mean							83		86% eyed	2443	
	13	877.4				3/14	98		100% eyed	168	
	14	876.8				3/22		90	100% hatch	10	
	15	873.6				3/22	19	42	69% hatch	47	
	16	874.7				3/22	90	3	96% eyed	29	

Table 1. (Continued).

Location	Redd number	Elevation (m)	Date exposed	Date rewetted	No. days exposed prior to sampling	Date sampled	Percent survival Eggs	Percent survival Alevins	Stage of development	Total number Eggs	Total number Alevins
Yellow Bay	16	880.3	1/13	5/23	22	2/4	90-100		100% eyed	100-200	
					46	2/28	90-100		100% eyed	100-200	
					95	4/18	0		---	0	
	1	878.9	Never dry			1/17	0		---	558	
	2	878.6	Never dry			1/17	24		37% eyed	482	
	3	878.0	Never dry			1/17	0		---	157	
	4	877.1	Never dry			1/17	85		100% eyed	179	
	5	876.6	Never dry			1/17	0		---	137	
	6	876.4	Never dry			1/18	19		100% eyed	52	
	8	875.9	Never dry			1/18	0		---	22	
	7	874.8	Never dry			1/18	0		---	334	
	9	874.4	Never dry			1/18	.4		100% eyed	238	
Total or Mean							$\bar{x}$ = 13		74% eyed	2159	
	13	878.9				3/21	0		---	70	
	10	878.4				3/21			No eggs found		
	12	876.9				3/21			No eggs found		
	11	875.8				3/21	0		---	8	
	15	874.8				3/21	2		100% eyed	282	
	14	874.2				3/21	0		---	299	
Total or Mean							$\bar{x}$ = 1		100% eyed	659	
Woods Bay Deep	3	877.2		2/4	39				44% eyed	105	
	7	875.6		2/7	82				100% eyed	171	
	6	872.5		2/7	10				100% eyed	99	
	2	870.5		2/4	62				100% eyed	76	
	1	866.5		2/4	0				100% eyed	163	
	5	864.4		2/4	53				100% eyed	209	
	4	862.6		2/4	11				100% eyed	93	
Total or Mean					39%					916	

Table 2. Date sampled, bottom elevation, percent survival, stage of development and microhabitat data for egg bag lines at Skidoo Bay, 1982-83.

Location	Date sampled	Bottom elevation (m)	Total number eggs	Percent survival	Stage of development	Dissolved oxygen (mg/l)	Apparent velocity (ml/mm)	Temperature units (°C)	No. days exposed prior to sampling
Line 1	12/14	880.3	50	70	100% green	10.7	8.4	151	0
	1/14		51	21.5	20% eyed			278	1
New line 1	2/9							453.5	
	3/15		50	68	100% eyed			597.5	34
	4/25		15	0	---			825	75
Line 2	12/14	879.7	50	0	---	9.6	7.1	106	0
	1/14		50	0	---			198.5	0
New Line 2	2/9							453.5	
	3/15		50	87	100% eyed			565	34
	4/25		5	0	---			---	75
	5/27		8	0	---			---	79
Line 3	12/14	879.24	50	90	100% green	9.7	9.4	125	0
	1/14		50	93	20% eyed			242	0
	3/15		49	41.5	20% hatch			524	17
	4/25		42	15.5	75% yolk sac absorption	7.9		814.5	58
Line 4	12/14	879.05	50	98	100% green	9.4	11.3	125.5	0
	1/14		46	94	100% eyed			233	0
	3/15		50	24	83% hatch			491	0
	4/25		42	38	75% absorb	10.9		765	0

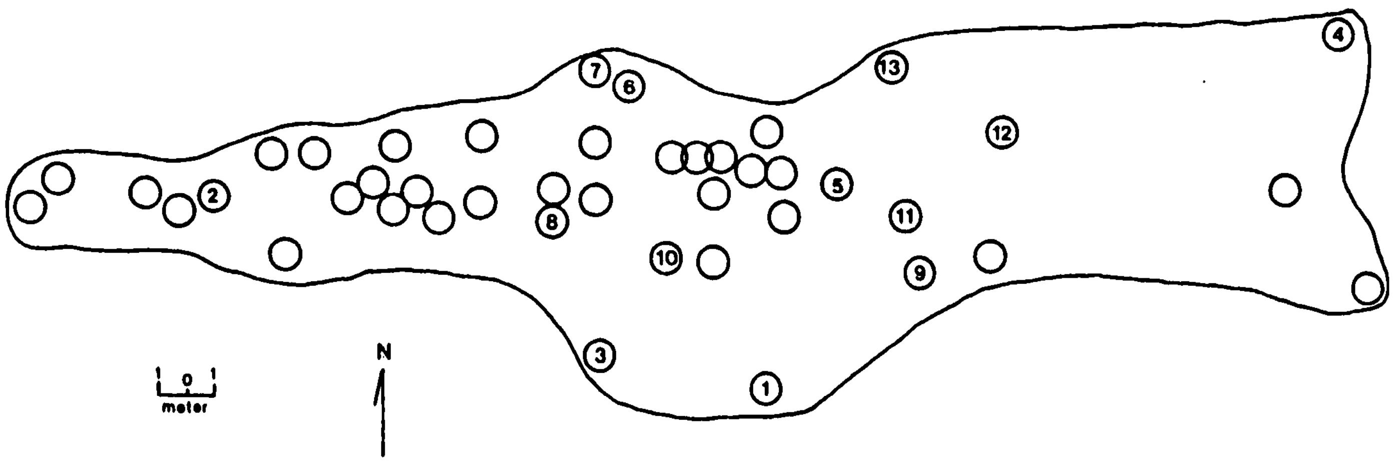


Figure 1. Location of redds in Skidoo Bay East spawning area. Numbered redds indicate those excavated for embryo survival studies.

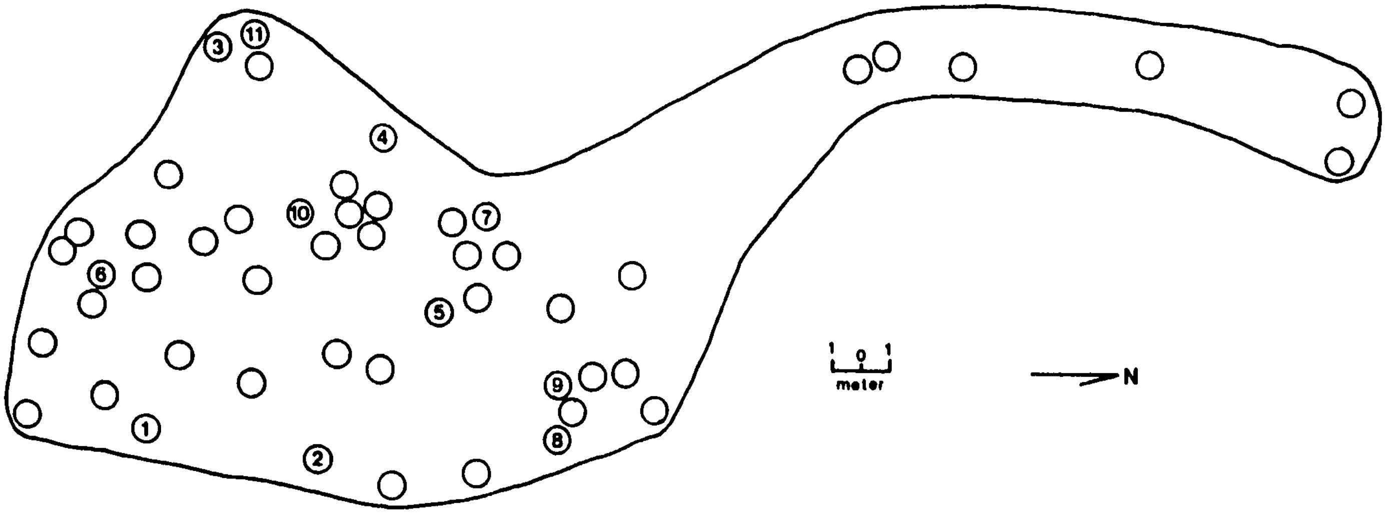


Figure 2. Location of redds in Dr. Richard's Bay North spawning area. Numbered redds indicate those excavated for embryo survival studies.

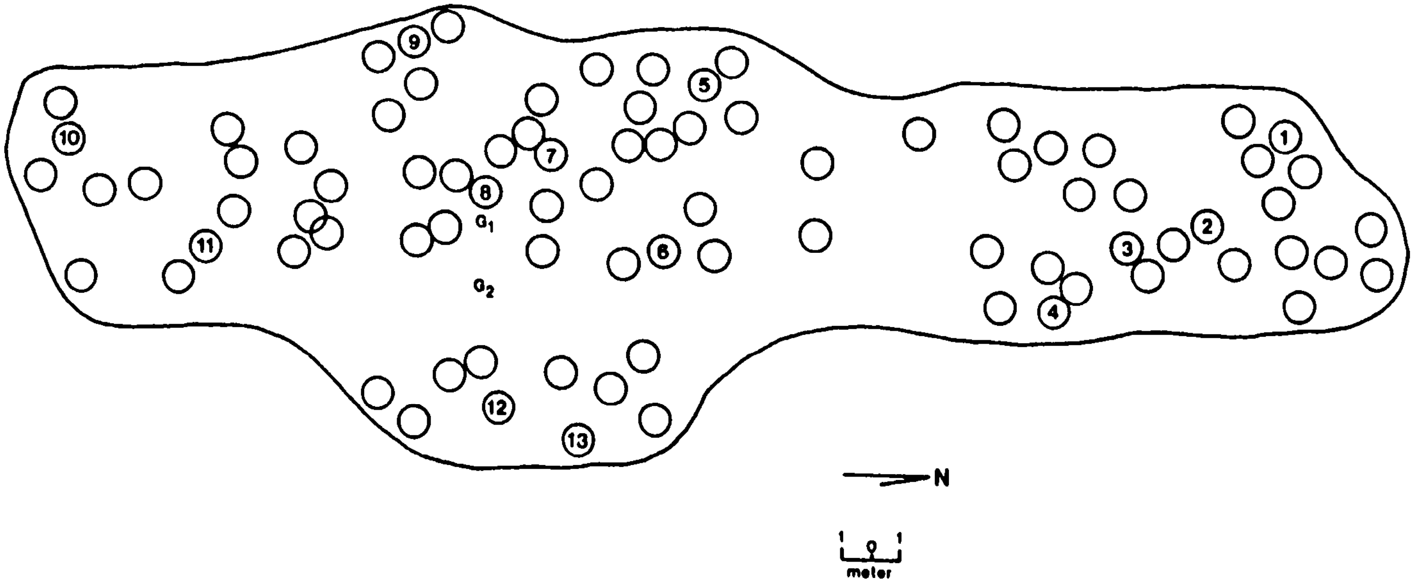


Figure 3. Location of redds in Pine Glen Resort spawning area. Numbered redds indicate those excavated for embryo survival studies. G_1 and G_2 indicate location of substrate composition samples sites.

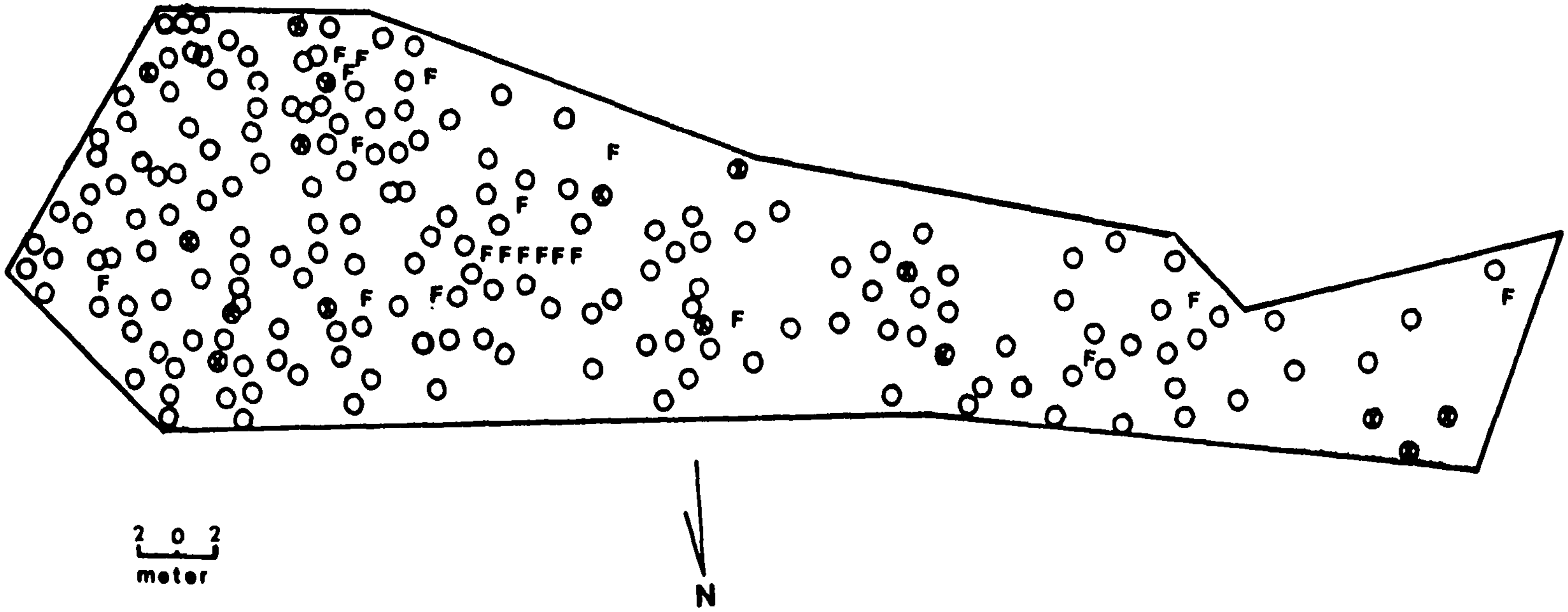


Figure 4. Location of redds in Gravel Bay spawning area. Circled x's indicate redds excavated for embryo survival studies. F's represent location of fry emergence traps.

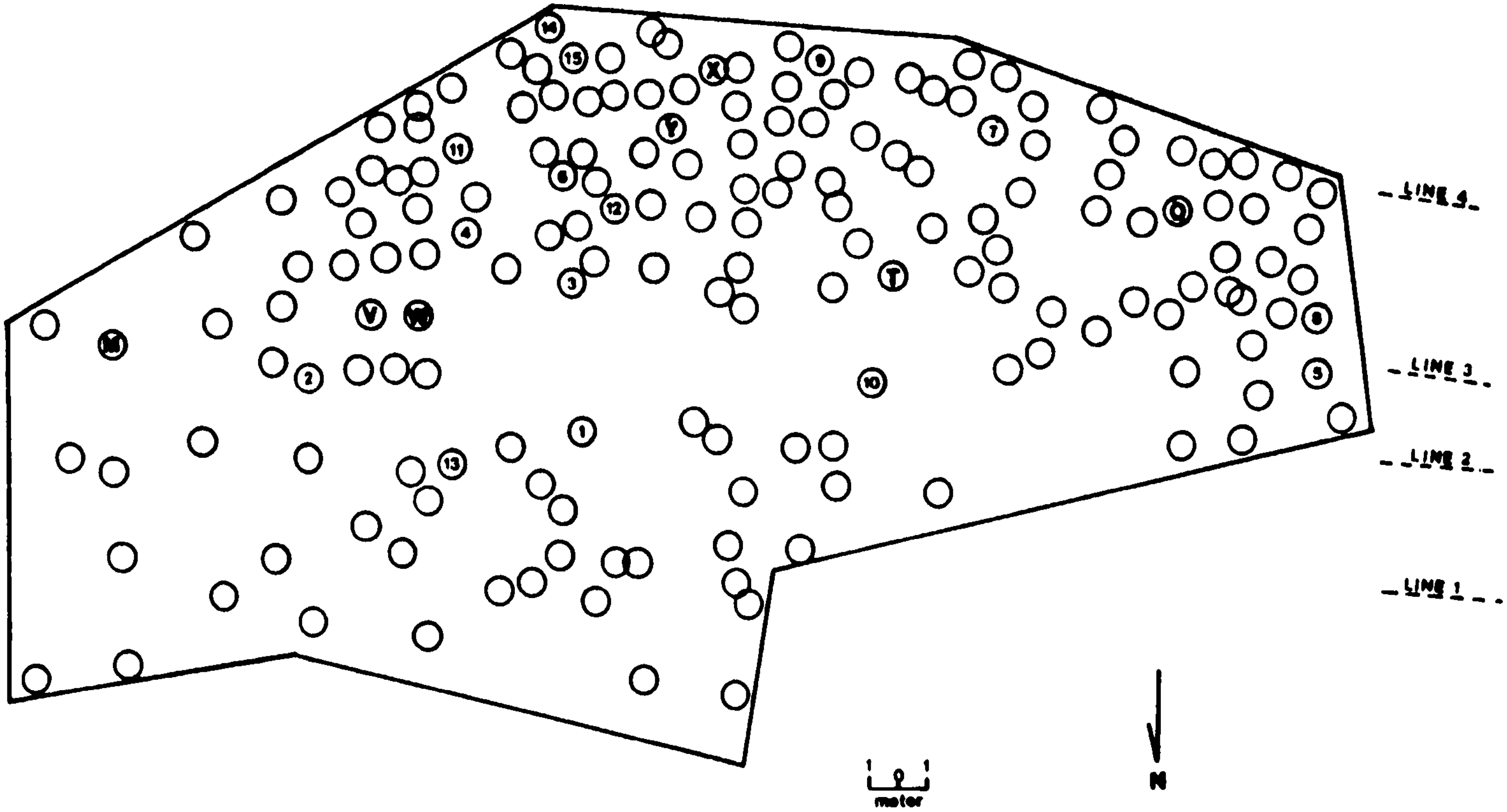


Figure 5. Location of redds in Yellow Bay spawning area. Numbered redds indicate those excavated for embryo survival studies. Letter redds indicate those covered by fry emergence traps.

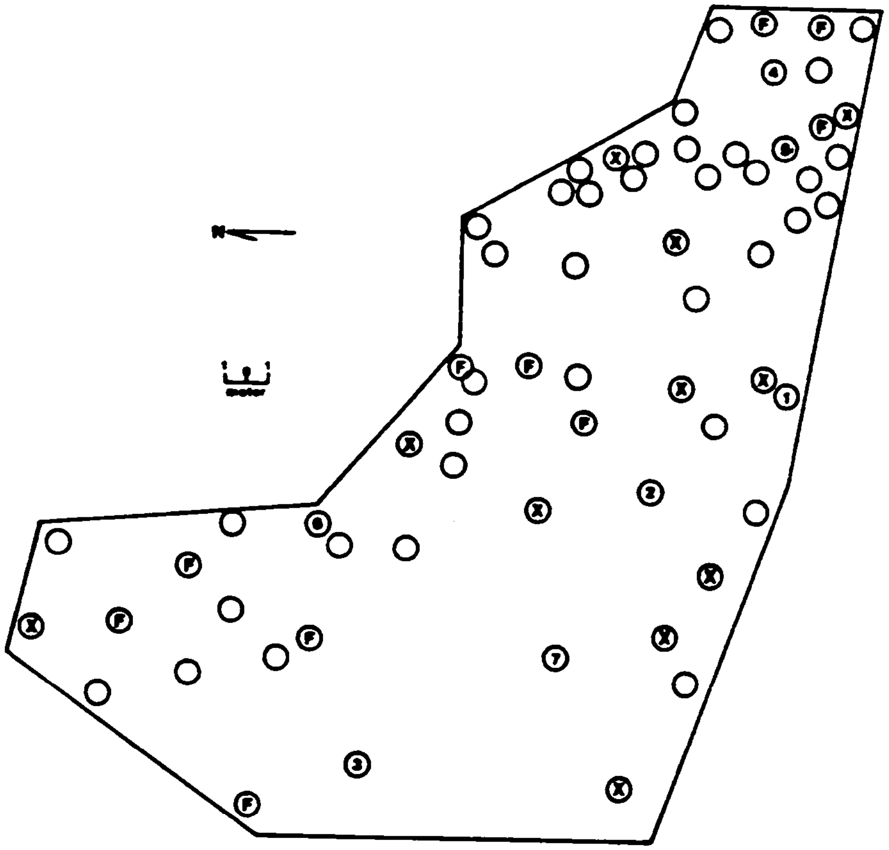


Figure 6. Location of redds in Woods Bay spawning area. Numbered redds indicate those excavated for embryo survival studies. Redds with F indicated those covered by fry emergence traps.

APPENDIX D

Fry Emergence and Distribution

Table 1. Location of bottom elevation (in meters), date placed and weekly catch from fry emergence traps in Gravel, Blue, Woods and Yellow bays, from 31 March to 8 June, 1983.

Trap number	Date placed	Bottom elevation (m)	Dates checked											
			3/31	4/7	4/14	4/21	4/28	5/5	5/11	5/19	5/25	6/1	6/8	Total
Gravel Bay														
015	3/22	877.2	0	0	0	0	0	0	2	24	22	0	0	48
33	3/24	876.9	0	0	0	0	1	0	35	85	15	4	0	140
49	3/22	876.9	0	0	0	0	0	0	0	20	13	0	0	33
23	3/24	876.3	0	0	0	0	1	15	101	36	3	0	0	156
11	4/7	876.2		0	5	6	16	9	2	1	0	32	10	81
14	3/22	874.8	0	0	0	0	0	0	0	0	0	0	0	0
47	3/22	874.2	0	0	0	0	0	0	0	0	3	1	0	4
05	4/7	873.8		0	0	0	0	0	0	0	0	0	0	0
F2	4/7	873.2		0	0	0	0	0	3	0	2	0	0	5
027	3/24	873.0	0	0	0	0	0	0	12	19	7	3	0	41
ZZ	4/7	872.9		0	0	0	0	0	2	0	0	0	0	2
DD	3/24	872.4	0	0	0	0	0	0	0	0	0	0	0	0
CC	3/24	872.4	0	0	0	0	0	0	7	1	6	0	0	14
029	3/24	872.4	0	0	0	0	0	0	0	0	0	0	0	0
Total			0	0	5	6	18	24	164	186	71	40	10	524
Blue Bay														
032	3/25	876.6	0	0	0	0	0	0	0	0	0	0	0	0
PP	3/25	876.4	0	0	0	0	0	0	2	35	30	3	0	70
RR	3/25	876.1	0	0	0	0	0	0	0	3	40	21	0	64
016	3/25	875.2	0	0	0	0	0	0	1	0	0	0	0	1
SS	3/25	875.2	0	0	0	0	0	0	0	0	0	0	0	0
		874.6												
Total			0	0	0	0	0	0	3	38	70	24	0	135

Table 1. (Continued).

Trap number	Date placed	Bottom elevation (m)	Dates checked 3/31	4/7	4/14	4/21	4/28	5/5	5/11	5/19	5/25	6/1	6/8	Total
Woods Bay														
AA	3/24	878.2	0	0	0	5SF[2]	0	1SF	1SF	0	0	0	0	7
017	3/24	874.8	0	0	0	0	1SF	3SF	0	0	0	0	0	4
7	3/24	874.2	0	1SF	0	0	1SF	3SF	0	0	0	0	0	5
041	3/24	873.9	0	0	0	0	0	0	0	0	0	0	0	0
051	3/24	869.3	0	0	0	0	0	0	0	1	2	1	0	4
033	3/24	869.0	0	0	0	0	0	0	0	0	0	0	0	0
06	3/24	869.0	0	0	0	0	0	0	0	0	0	0	0	1
048	3/24	864.5	0	0	0	0	0	0	1SF	0	0	0	0	1
03	3/24	862.3	0	0	0	0	0	0	1SF	0	0	0	0	1
013	3/24	861.4	0	0	0	0	0	0	1SF	0	0	0	0	1
Total			0	1	0	5	2	7	4	1	3	1	0	24
WW	3/29	877.2	No kokanee fry or any other species captured in traps during period of placement.											
MM	3/29	877.1												
VV	3/29	876.8												
TT	3/29	875.5												
YY	3/29	875.1												
OO	3/29	874.3												
XX	3/29	874.2												

1/ Traps over same redd.
2/ Premature kokanee fry with yolk sac.

Table 2. Weekly catch from experimental emergence traps placed in Gravel Bay at bottom elevation 876.6 m and planted 24 March, 1983 with 100 eyed kokanee eggs. Circle (trap) and dot (plant) represent location of planted eggs to trap.

Trap number	Location trap to eggs[1]	3/31	4/7	4/14	4/21	4/28	5/5	5/11	5/19	5/25	6/1	6/8	Total
HH	⊙	0	0	0	0	0	0	2	31	15	1	0	49
KK	•O	0	0	0	0	0	0	0	0	1	0	0	1
BB	Ȯ	0	0	0	0	0	0	0	0	0	0	0	0
EE	O•	0	0	0	0	0	0	0	0	0	0	0	0
FF	Ọ	0	0	0	0	1	0	0	0	0	0	0	1
GG	⊙	0	0	0	3	1	0	0	6	18	1	0	29

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[1] Dot indicates egg plant, circle indicates fry trap.

Table 3. Length (mm), weight (gm) and condition ($K = \frac{W^{105}}{L^3}$) for emerging kokanee fry collected from Gravel, Blue and Woods bays by date and trap from 31 March to 8 June, 1983. Means are presented for each sampling day per trap.

Trap	April 28			May 11			May 19			May 25			June 1		
number	L	W	K	L	W	K	L	W	K	L	W	K	L	W	K
Gravel Bay															
015				23.5[1]	.103	.794	25.0	.113	.723	24.0	.106	.767			
				25.0	.107	.685	25.0	.115	.736	24.5	.102	.694			
							25.5	.115	.694	24.5	.105	.714			
							24.0	.106	.767	24.5	.111	.755			
							25.5	.103	.621	24.5	.095	.646			
							26.0	.108	.614	24.5	.100	.680			
							25.0	.100	.640	25.0	.111	.710			
							25.0	.111	.710	25.5	.101	.609			
							24.5	.099	.673	24.5	.106	.721			
							24.5	.093	.632	24.5	.111	.755			
MEAN				24.3	.105	.740	25.0	.106	.681	24.6	.105	.705			
033	23.0	.105	.863	25.0	.114	.730	25.0	.105	.672	24.0	.089	.644	24.5	.076	.517
				25.0	.108	.691	25.0	.108	.691	24.0	.090	.651	25.0	.078	.499
				24.5	.112	.762	24.0	.106	.767	24.5	.091	.619	25.3	.088	.543
				25.2	.117	.731	24.5	.108	.734	24.5	.083	.564	24.5	.073	.496
				24.5	.120	.816	25.0	.103	.659	25.0	.089	.570			
				24.0	.086	.622	25.0	.103	.659	24.0	.064	.463			
				24.5	.116	.789	24.5	.100	.680	24.7	.085	.564			
				24.2	.106	.748	25.0	.104	.666	24.0	.084	.608			
				24.0	.105	.760	25.0	.095	.608	22.5[2]	.039	.342			
				24.8	.110	.721	25.0	.100	.640	24.0	.083	.600			
MEAN	23.0	.105	.863	24.6	.109	.737	24.8	.103	.678	24.3	.081	.587	24.8	.079	.514

Table 3. (Continued).

Trap number	April 28			May 5			May 11			May 19			May 25		
	L	W	K	L	W	K	L	W	K	L	W	K	L	W	K
023	24.5	.094	.639	24.5	.103	.700	25.5	.114	.688	25.0	.102	.653	25.0	.102	.653
				25.0	.104	.666	25.5	.114	.688	25.5	.109	.657	25.5	.105	.633
				25.0	.108	.691	25.5[1]	.112	.675	25.5	.105	.657	25.5	.085	.513
				25.0	.107	.685	25.5	.112	.675	26.0	.104	.592			
				25.0	.109	.698	25.5	.111	.669	26.0	.105	.597			
				25.0	.098	.627	26.0	.096	.546	26.0	.103	.586			
							26.0	.116	.660	25.5	.106	.639			
							26.0	.110	.626	26.0	.107	.609			
							25.5	.109	.657	25.5	.097	.585			
							25.5	.102	.615	25.0	.093	.595			
							25.0	.110	.704						
MEAN	24.5	.094	.639	24.9	.105	.678	25.6	.110	.655	25.6	.103	.617	25.3	.097	.600
049										25.0	.079	.506	23.5	.083	.640
										23.5	.079	.609	23.5[1]	.086	.663
										24.5	.078	.530	23.7	.072	.541
										23.5	.080	.616	23.0	.075	.663
										24.0	.082	.593	24.5	.080	.544
										24.0	.065	.470	22.5	.076	.667
										24.2	.071	.501	24.0	.079	.571
										23.5	.085	.655	23.0	.079	.649
										23.5	.075	.578	23.0	.077	.633
										23.5	.078	.601	23.0	.076	.625
MEAN										23.9	.077	.566	23.4	.078	.620

Table 3. (Continued).

Trap number	April 14			April 21			April 28		
	L	W	K	L	W	K	L	W	K
011	24.0	.110	.796	24.5	.112	.762	25.0	.101	.646
	24.0	.107	.774	25.0	.109	.698	25.0	.114	.730
	24.0	.110	.796	25.5	.106	.639	25.0	.110	.704
	24.0	.102	.738	24.5	.102	.694	25.0	.108	.691
	23.5	.110	.848	25.5	.104	.627	25.0	.102	.653
				25.0	.109	.698			
MEAN	23.9	.108	.790	25.0	.107	.686	25.0	.107	.685

Trap number	May 5			May 11			May 19			June 1		
	L	W	K	L	W	K	L	W	K	L	W	K
011	25.0	.104	.666	25.0	.106	.678	25.0	.105	.672	25.5	.094	.567
	24.5	.100	.680	24.5	.112	.762				25.0	.103	.659
	24.5	.104	.707							25.0	.101	.646
	25.0	.113	.723							25.2	.096	.600
	24.5	.100	.680							25.0	.100	.640
										25.0	.092	.589
										25.0	.098	.627
										25.0	.097	.621
										25.0	.095	.608
										25.0	.092	.589
										25.0	.097	.621
MEAN	24.7	.104	.691	24.8	.109	.720	25.0	.105	.672	25.1	.097	.615

Table 3. (Continued).

Trap number	April 28			May 11			May 19			May 25			June 1		
	L	W	K	L	W	K	L	W	K	L	W	K	L	W	K
HH				25.0	.117	.749	23.0	.088	.723	21.5	.073	.735	25.0	.095	.608
				21.5[1]	.082	.825	22.0	.076	.714	24.5	.099	.673			
							22.5	.079	.694	23.2	.093	.745			
							22.5	.088	.773	24.0	.097	.702			
							23.0	.085	.699	25.5	.099	.597			
							23.5	.089	.686	25.0	.099	.634			
							23.0	.084	.690	25.0	.095	.608			
							22.0	.081	.761	21.5	.097	.976			
							23.0	.088	.723	23.0	.096	.789			
							23.0	.085	.699	22.0	.070	.657			
MEAN				23.3	.100	.787	22.8	.084	.716	23.5	.092	.712	25.0	.095	.608
KK										22.0	.044	.413			
FF	25.0	.121	.774												

	April 21			April 28			May 19			May 25			June 1		
	L	W	K	L	W	K	L	W	K	L	W	K	L	W	K
GG	25.5	.118	.712	24.5	.099	.673	23.0	.077	.633	24.0	.108	.781	23.5	.085	.655
	25.5	.104	.627				22.5	.075	.659	23.5	.085	.655	22.0	.068	.639
	25.0	.105	.672				23.0	.075	.616	24.0	.086	.622	22.5	.064	.562
							23.0	.091	.748	23.0	.073	.600			
							22.5	.078	.685	23.8	.093	.690			
							24.0	.059	.427	24.0	.102	.738			
										23.0	.074	.608			
										25.0	.114	.730			
										24.0	.096	.694			
										22.5	.062	.544			
MEAN	25.3	.109	.670	24.5	.099	.673	23.0	.076	.628	23.7	.089	.666	22.7	.072	.619

Table 3. (Continued).

Trap number	May 11			May 19			May 25			June 1		
	L	W	K	L	W	K	L	W	K	L	W	K
47							25.0	.103	.659	24.0	.103	.745
							24.5[1]	.108	.734			
							24.0[1]	.103	.745			
MEAN							24.5	.105	.713	24.0	.103	.745
F2	25.5	.121	.730									
	25.5	.118	.712									
	23.5	.125	.963				25.0	.108	.691			
							25.0	.107	.685			
MEAN	24.8	.121	.802				25.0	.108	.688			
027	23.5	.109	.840	23.0	.102	.838	23.0	.098	.805	24.5	.092	.626
	22.5	.103	.904	23.8	.093	.690	23.5	.097	.747	22.0	.090	.845
	24.0	.096	.694	23.0[1]	.095	.781	23.5	.089	.686	23.5	.088	.678
	23.5	.099	.762	24.0	.101	.731	23.8	.090	.668			
	24.0	.106	.767	24.5	.100	.680	23.5	.100	.771			
	24.0	.106	.767	22.5	.092	.808	24.0	.098	.709			
	26.0	.124	.706				22.5[1]	.095	.834			
	24.0	.104	.752									
	22.5	.095	.834									
	22.5	.100	.878									
MEAN	23.7	.104	.790	23.5	.097	.755	23.4	.095	.746	23.3	.090	.716
ZZ	25.0	.116	.742									
	24.0[1]	.115	.832									
MEAN	24.5	.116	.787									

Table 3. (Continued).

Trap number	May 11			May 19			May 25			June 1		
	L	W	K	L	W	K	L	W	K	L	W	K
CC	25.5	.119	.718				25.5	.105	.633			
	25.5	.125	.754				25.0	.102	.653			
	26.5	.130	.699				26.0	.106	.603			
	25.5	.125	.754				25.0	.100	.640			
	25.2	.122	.762				25.5	.099	.597			
	25.5	.125	.754				22.0	.108	.101			
	25.5[1]	.130	.784				25.5	.099	.597			
MEAN	25.6	.125	.746				24.9	.103	.676			
<u>Blue Bay</u>												
PP	25.5	.121	.730	25.5	.129	.778	25.5	.071	.428			
	25.5	.121	.730	24.0	.105	.760	25.5	.076	.458			
				24.0	.100	.723	23.5	.074	.570			
				24.0	.112	.810	25.0	.072	.461			
				24.5	.097	.660	23.5	.074	.570			
				24.0	.120	.868	24.5	.078	.530			
				26.0	.126	.717	25.0	.078	.461			
				25.0	.121	.774	24.5	.072	.490			
				25.0	.098	.627	25.0	.099	.634			
				25.5	.099	.597	24.0	.071	.514			
MEAN	24.5	.121	.730	24.8	.111	.731	24.6	.077	.512			
RR				24.5	.104	.707	24.0	.105	.760			
				24.0	.102	.738	25.0	.102	.653			
				24.5	.105	.714	23.5	.101	.778			
							25.5	.107	.645			
							24.5	.109	.741			
							25.0	.094	.602			

Table 3. (Continued).

Trap number	May 11			May 19			May 25			June 1		
	L	W	K	L	W	K	L	W	K	L	W	K
RR (cont.)							24.0	.098	.709	24.0	.109	.788
							23.5	.097	.747	25.0	.119	.762
							24.5	.099	.673	24.5	.103	.700
							25.0	.075	.480	24.0	.102	.738
							24.5	.103	.700	23.5	.107	.824
							25.5	.094	.567	23.0	.102	.838
							24.5	.101	.687	25.5	.107	.645
							24.0	.097	.702	23.0	.103	.847
										24.0	.107	.774
										24.0	.102	.738
MEAN				24.3	.104	.720	24.5	.099	.675	24.1	.106	.765
016	26.0	.116	.660									

	April 20			April 26			May 4			May 12		
	L	W	K	L	W	K	L	W	K	L	W	K
Woods Bay												
AA	20.5[1]	.081	.940				22.5[1]	.084	.737	23.5[1]	.098	.755
	20.5[1]	.069	.801									
	20.5[1]	.086	.998									
	20.0[1]	.081	1.01									
	22.0[1]	.096	.902									
MEAN	20.7	.083	.930				22.5	.084	.737	23.5	.098	.755
017				25.0	.110	.704	21.5[1]	.078	.785			
							24.0[1]	.100	.723			
							21.5[1]	.076	.765			
MEAN				25.0	.110	.704	22.3	.085	.758			

Table 3. (Continued).

Trap number	April 7			April 26			May 4		
	L	W	K	L	W	K	L	W	K
7	18.5[1]	.091	1.44	22.5[1]	.097	.852	23.0[1]	.102	.838
							22.5[1]	.094	.825
MEAN	18.5	.091	1.44	22.5	.097	.852	22.8	.098	.832
	May 12			May 18			May 25		
	L	W	K	L	W	K	L	W	K
051				25.0[1]	.106	.678	26.0	.140	.797
							25.0	.127	.813
MEAN				25.0	.106	.678	25.5	.134	.805
048	25.0	.115	.736						
013	23.0[1]	.114	.937						

[1] Sac fry
[2] Dried out

Table 4. Mean length (mm), weight (gm), condition ($K = \frac{W10^5}{L^3}$) and number by trap and area for emerging kokanee fry from Gravel, Woods and Blue bays from 31 March to 8 June, 1983. Traps are located by bottom elevation in meters.

Trap number	Bottom elevation (m)	Mean length	Mean weight	Mean condition	Number of fry examined
Gravel Bay					
015	78.05	24.6	.105	.709	23
33	77.13	24.3	.095	.676	35
49	77.05	23.7	.078	.593	20
023	75.13	25.2	.102	.638	30
11	74.79	24.8	.105	.694	11
47	68.05	24.3	.104	.729	4
F2	64.79	24.9	.115	.745	5
027	64.13	23.5	.097	.752	26
ZZ	63.79	24.5	.116	.787	2
CC	62.13	25.3	.114	.711	14
Mean/Total		24.2(±.56)	.097(±.01)	.676(±.05)	172
Woods Bay					
AA	81.13	22.2	.088	.807	7
017	70.13	23.7	.098	.731	4
7	68.13	21.3	.095	1.041	5
051	52.13	25.3	.120	.742	2
048	36.13	25.0	.115	.736	1
013	26.13	23.0	.114	.937	1
Mean/Total		22.6(±1.97)	.098(±.01)	. 85(±.16)	20
Blue Bay					
PP	75.18	25.0	.103	.658	22
RR	74.18	24.3	.103	.720	25
016	71.53	26.0	.116	.660	1
Mean/Total		24.7(±.7)	.103(±.006)	. 69(±.03)	48

APPENDIX E

Kokanee Food Habits

INTRODUCTION

In the fall of 1981 the Montana Department of Fish, Wildlife and Parks (MDFWP) initiated a study to document the extent of kokanee spawning in shoreline areas of Flathead Lake and to determine the effects of water level fluctuations and other factors on spawning, incubation, emergence and survival (Decker-Hess and Graham 1982). In order to completely understand the population dynamics of the kokanee in Flathead Lake and to be able to fully interpret the results of the spawning study, it is necessary to consider other factors that may affect the kokanee populations.

In 1982, the MDFWP completed a fish food habits study on Flathead Lake as part of a comprehensive baseline study of the Flathead River basin (Leathe and Graham 1982). Results of this study indicated that kokanee salmon in Flathead Lake fed almost exclusively on crustacean zooplankton. A change in the species composition and/or abundance of crustacean zooplankton in the lake could have significant impacts on the Flathead Lake kokanee population.

Zooplankton occupy a relatively low position in the trophic web of Flathead Lake and would therefore be among the first organisms affected by changes in lake water quality. The upper Flathead River basin faces possible large-scale exploitation of such resources as coal, gas, oil, timber and water which could have serious adverse effects on the water quality of Flathead Lake. In 1980 and 1981, a few specimens of opossum shrimp (Mysis relicta) were collected from Flathead Lake. If Mysis become established in Flathead Lake in the future, they could also affect the zooplankton population.

In the face of these potential impacts, a sampling program has been developed to monitor the Flathead Lake crustacean zooplankton population on an annual basis. This report presents the data that were collected during the first year of this program.

STUDY AREA

Flathead Lake is one of the largest natural freshwater lakes west of the Mississippi and is located in northwest Montana. A complete description of the morphometry and drainage system of Flathead Lake is reviewed by Leathe and Graham (1982).

METHODS

PHYSICAL LIMNOLOGY

Temperatures were measured to the nearest 0.5°C at one meter intervals to a depth of 30 m using an Applied Research FT3 hydrographic thermometer. Water transparency was established to the nearest 0.5 m using a 20 cm diameter secchi disc.

ZOOPLANKTON

Zooplankton were collected using a 0.5 m diameter Wisconsin type closing net with a one meter long filtering cone constructed of 80 micron Nitex netting. The net was equipped with a General Oceanics Model 2030 flowmeter equipped with a low speed rotor. The net was modified to prevent back-spinning of the meter during descent. A two kilogram weight was attached at the bottom of the net to insure swift vertical descent. Plankton hauls were made from a 4.9 m boat equipped with a boom and snatch block. The net was retrieved by hand at a rate of 0.8 to 0.9 meters per second. Boat position was maintained by rowing to insure vertical tows. Duplicate zooplankton tows were made on a biweekly basis at the single sampling site. Sampling was conducted from early April through the end of October. The upper 15 m of the water column were sampled by lowering the net to a depth of 15 m then pulling it vertically to the surface. An attempt was made to measure the filtering efficiency of the plankton net using flow meter readings and times. The flow meter began giving erratic readings during the sampling season which could not be corrected. A net filtering efficiency of 58 percent, established by Leathe and Graham (1982) for this same net system, was used in all calculations.

Duplicate zooplankton samples were combined in the field and preserved in a mixture of four percent formalin with 40 g/liter sucrose (Haney and Hall 1973). Samples were diluted in the laboratory and counts were made on each of three one-milliliter subsamples in a Sedgwick-Rafter cell. The enumeration of three to five subsamples typically results in a + 10 to 15% estimate of true sample density (Kutkuhn 1958). Subsamples were withdrawn using a Hensen-Stempel pipette. Plankton counts were made using a binocular compound microscope at 40X total magnification. The microscope was equipped with a graduated mechanical stage. Separate counts were made to estimate the densities of <u>Leptodora</u> and adult <u>Epischura</u>, since these organisms were relatively large and seldom appeared in subsamples during zooplankton counts. In an attempt to get information on the trends of these species in the population, a 20 ml subsample was withdrawn from the initial dilution and examined under low power using a dissecting microscope. These organisms were counted and their densities were expressed as number per cubic meter of water.

SAMPLING SITE

Because of the homogeneous nature of the zooplankton population of Flathead Lake determined by Leathe and Graham (1982), a single sample site was determined sufficient to adequately monitor the zooplankton population. Area 2-4, located near Bigfork, Montana, was selected on the basis of good available baseline data for the site and easy accessibility for sampling (Figure 1).

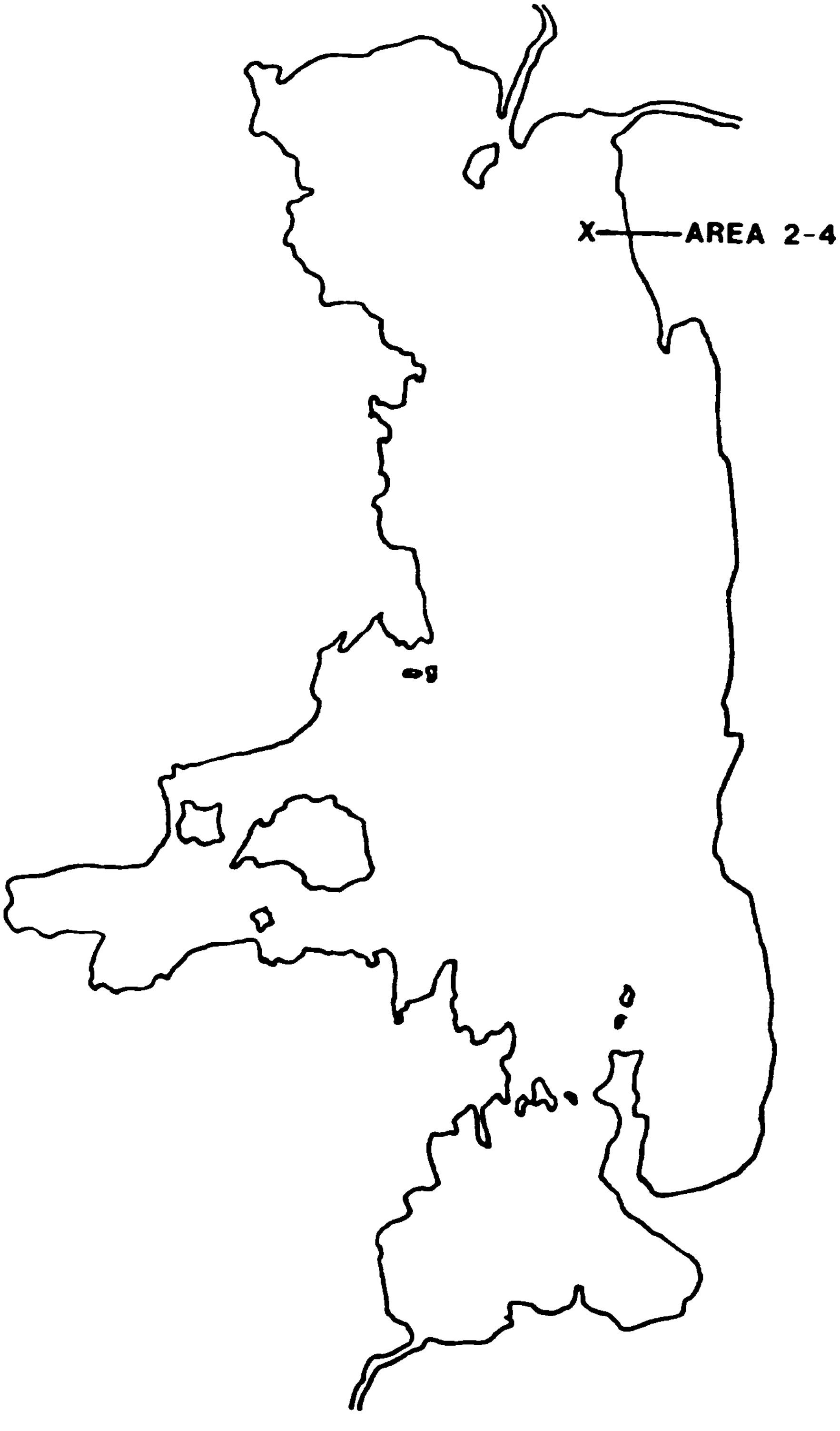


Figure 1. Map of Flathead Lake, Montana identifying location of zooplankton sampling station near Bigfork Bay.

DATA ANALYSIS

Seasonal zooplankton densities presented by Leathe and Graham (1982) were for the upper 30 meters of surface water. It was necessary to recalculate these data for the upper 15 meters of water in order to compare it to the 1982 data. All densities presented in this report are for the upper 15 meters of surface water.

RESULTS

PHYSICAL LIMNOLOGY

Seasonal or yearly changes in water temperatures in Flathead Lake can influence the species composition and abundance of crustacean zooplankton within the lake.

The pattern of mean water temperatures of the upper 15 meters of Flathead Lake were very similar for the springs of 1981 and 1982 (Figure 2). However, mean water temperatures ranged from 1.5 to 4°C colder in 1982 then in 1981 for the period of early April through the end of June. Mean 1982 water temperatures were warmer than mean 1981 temperatures for approximately two weeks in late July and early August. The 1982 mean temperatures were more than 6°C colder than the 1981 mean temperatures by the end of August. The maximum average water temperature in 1982 was 17.9°C compared to maximums of 19.4°C for 1981 and 18.6°C for 1980.

The pattern of thermal stratification of Flathead Lake was less pronounced at the sampling location during 1982 than in any other year. The upper 30 meters of water was isothermal during the first two sampling periods (April 9 and 23). Thermocline (depth where water temperatures 1°C or more per meter of depth) first appeared in early July, one month later than in 1981. This thermocline had completely destratified by the end of July. A thermocline was again present during one sampling period in mid-August, and a very weak thermocline was seen on 24 September. By 8 October, the first 30 meters of water were again isothermal at 12°C. Leathe and Graham (1982) found the thermocline lasted from early June through late October in 1981 and from the first sampling period in early July through late October in 1980.

Secchi disc readings ranged from 3.5 to 10.5 meters with an average reading of 6.8 meters during the 1982 sampling period.

ZOOPLANKTON

The average total density of crustacean zooplankton collected from Flathead Lake was comparable for 1980, 1981 and 1982. Samples collected in 1982 averaged 20.8 organisms per liter with a peak density of 49/l occurring in early June. The average density in 1981 was 19.9/l with a peak density of 43.5/l in early June. The average density in 1980 was 17.7/l with a peak density of 28.4

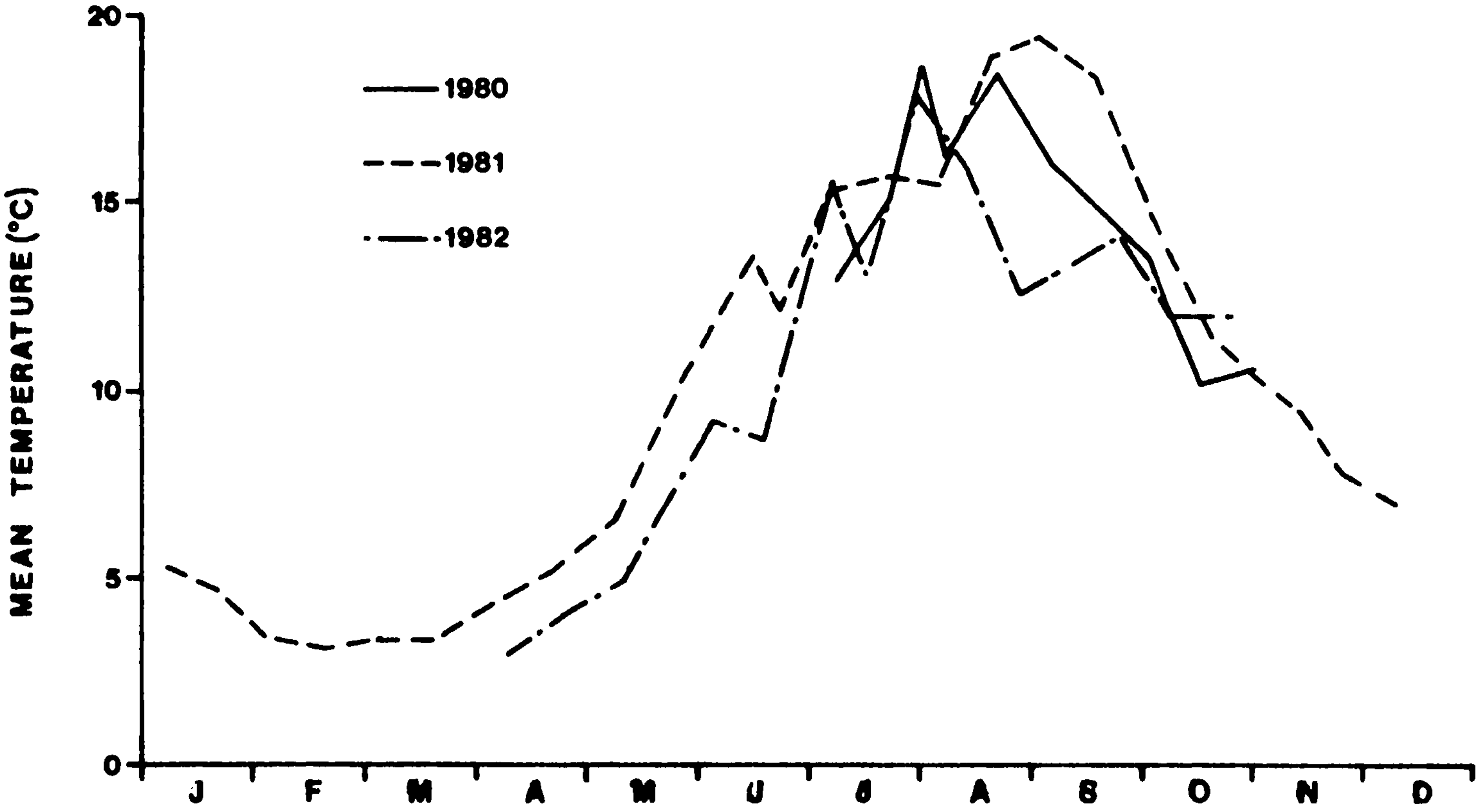


Figure 2. Mean water temperature (°C) in the surface waters (0-15 m) at Station 2:4 of Flathead Lake during 1980, 1981 and 1982.

in early August.

The crustacean zooplankton community was composed of four cladoceran and three copepod species during the 1982 sampling period. A similar composition was found in 1980 and 1981 (Leathe and Graham 1982). The cladoceran species collected included; *Leptodora kindtii*, a large organism which is predatory on other zooplankton, and *Daphnia thorata*, *Daphnia longiremis* and *Bosmina longirostris*, which are all filter feeding herbivores. The largest copepod found was *Epischura nevadensis*, also a predator on smaller zooplankton. *Diaptomus ashlandi*, a filter feeding herbivore and *Cyclops bicuspidatus thomasi*, an omnivore, were the other copepod species found.

The 1982 crustacean zooplankton population in Flathead Lake was dominated by copepods. *Diaptomus* and *Cyclops* comprised an average of 92 percent of the zooplankton (excluding copepod nauplii). The cladocerans *Daphnia thorata*, *Daphnia longiremis* and *Bosmina* only comprised an average of six percent of the total zooplankton population. This compares to a 1981 average composition of 79 percent copepods and 21 percent cladocerans and a 1980 average composition of 77 percent copepods and 23 percent cladocerans (Figure 3). *Leptodora* and *Epischura* accounted for an average of less than one percent of the total zooplankton density in all three years.

Diaptomus was the most numerous zooplankton species present in Flathead Lake in 1980, 1981 and 1982 (excluding copepod nauplii). In 1982, *Diaptomus* composed a much larger percent of the total zooplankton sample than in the two preceding years. In 1982, an average of 82 percent of the zooplankton density was comprised of *Diaptomus* compared to an average of 64 percent in 1981 and 58 percent in 1980. The seasonal density patterns for *Diaptomus* were very similar in 1981 and 1982 (Figure 4). Peak densities occurred in early June during both years, but peak densities were approximately eight organisms per liter higher in 1982. The average concentration of *Diaptomus* during the 1982 sampling period was 16.9/l compared to an average concentration of only 12.6/l in 1981. It was difficult to make comparisons with 1980 data since sampling did not start until mid-June and peak density periods were missed for most species.

Cyclops, the other major copepod species in Flathead Lake, showed similar seasonal density trends in 1981 and 1982 (Figure 4). Densities peaked once in the spring with a second lower peak in the middle of the summer. The spring peak occurred almost a month later in 1982 than in 1981. By the time the second density peak occurred in early August, water temperatures were similar and both densities peaked at approximately the same time. The maximum *Cyclops* densities were slightly larger in 1982, but the average percent composition of *Cyclops* in the zooplankton population was larger in 1981. *Cyclops* comprised an average of 16 percent of the

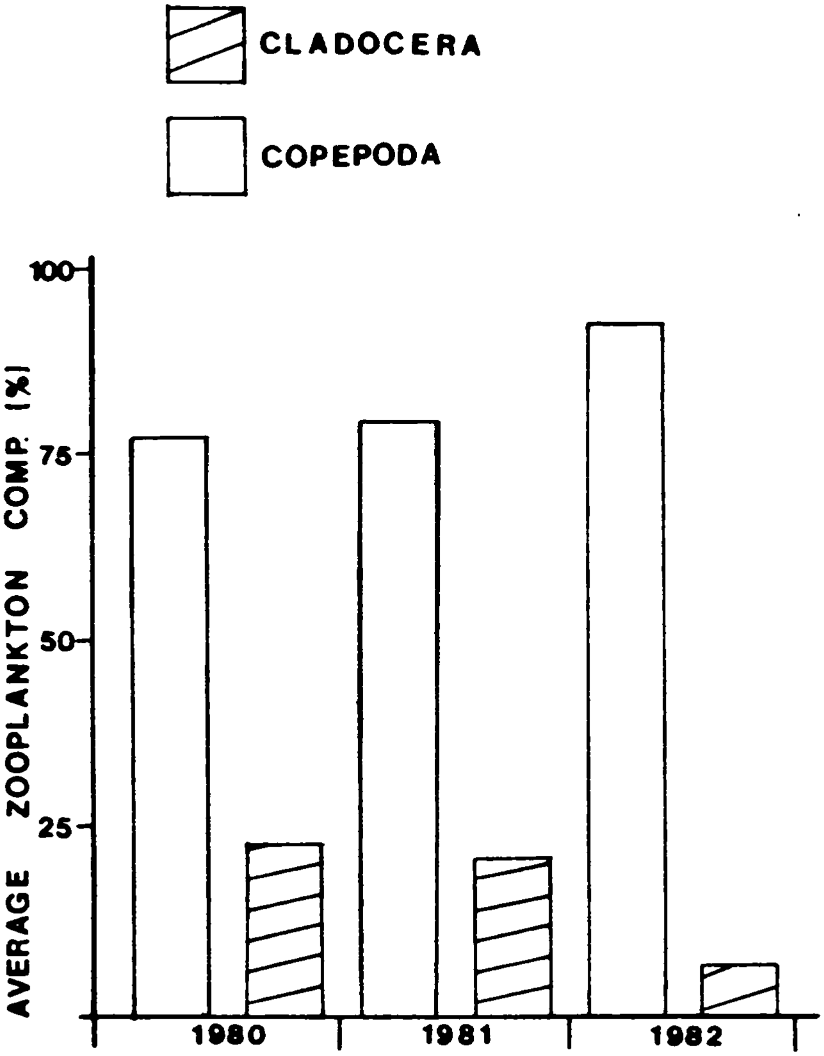
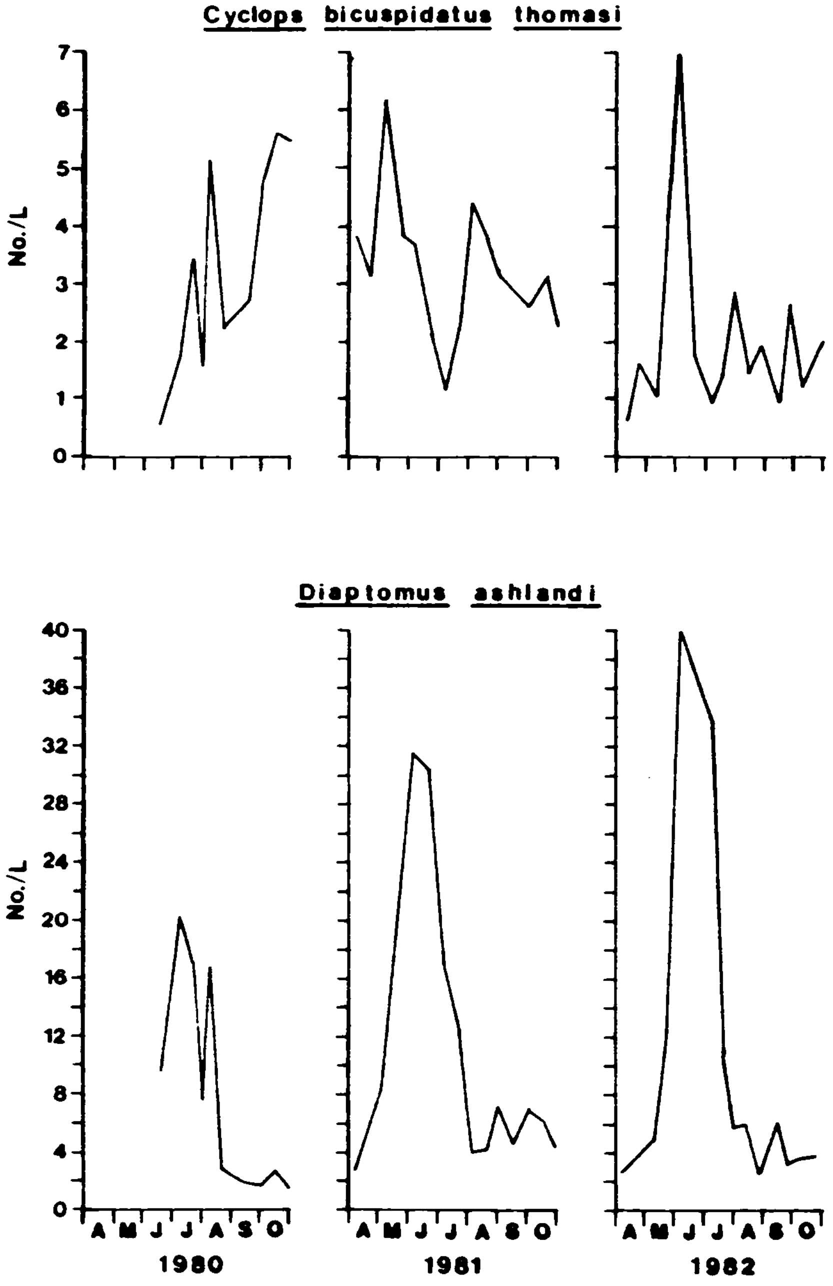


Figure 3. Comparison of zooplankton composition by percent of Cladocera and Copepod in the surface waters (1-15 m) from Flathead Lake, Montana at Station 2:4 for 1980, 1981 and 1982.



Cyclops bicuspidatus thomasi

Diaptomus ashlandi

Figure 4. Seasonal density trends (no./l) of the copepods Cyclops bicuspidatus and Diaptomus ashlandi in the surface waters of Flathead Lake during 1980, 1981 and 1982.

zooplankton population density in 1981 compared to only 12 percent in 1982.

Daphnia thorata was the most common cladoceran species found in Flathead Lake. Trends in density of *Daphnia thorata* followed similar patterns in 1981 and 1982, but the first *Daphnia thorata* did not appear in the plankton samples until mid-May in 1982 compared to early April in 1982 (Figure 5). Peaks in density also occurred later in 1982. The density of *Daphnia thorata* was less in 1982 compared to the preceding two years. The maximum density reached in 1982 was 2.9/1 compared to maximum densities of 3.6/1 and 4.5/1 for 1980 and 1981, respectively. Percent composition of *Daphnia thorata* in zooplankton population was also less in 1982, dropping from 12 percent in 1980 and 1981 to only 4 percent in 1982.

Densities of *Daphnia longiremis* were noticeably different in 1980 and 1981, but maximum densities for both years were greater than 1.0/1 (Figure 5). *Daphnia longiremis* made no significant contribution to the zooplankton population in 1982 with a maximum species density of less than 0.1/1. *Daphnia longiremis* did not appear in the 1982 plankton samples until mid-June. They were present in the plankton samples by early April in 1981.

Bosmina densities peaked almost a month later in 1982 than in 1982 (Figure 5). The maximum 1982 *Bosmina* density was 13.1/1 compared to a maximum 1981 density of 4.7/1. The average contribution of *Bosmina* to the total zooplankton population was only 1.3 percent in 1982 compared to average contributions of 7.6 percent in 1981 and 4.2 percent in 1980.

Seasonal density trends of adult *Epischura* were similar for 1981 and 1982 (Figure 6). Densities peaked at approximately the same time both years, although the peak spring density was much lower in 1982.

Leptodora began to appear in plankton samples almost a month earlier in 1982 then they did in 1981 (Figure 6). The peak density of *Leptodora* also occurred approximately one month earlier in 1982 than in 1980 or 1981. The 1982 density peaked slightly higher than the 1981 level, but still less than half the level reached in 1980.

DISCUSSION

A decrease in the prevalence of the three major species of cladocerans in the zooplankton samples from Flathead Lake occurred in 1982. *Daphnia longiremis* was almost nonexistent during the sampling period. The peak densities of both *Daphnia thorata* and *Bosmina* were smaller than the preceding two years, and their contribution to the total zooplankton population remained low throughout the study period. Because *Daphnia thorata* was the major food item in the summer diet of kokanee in Flathead Lake

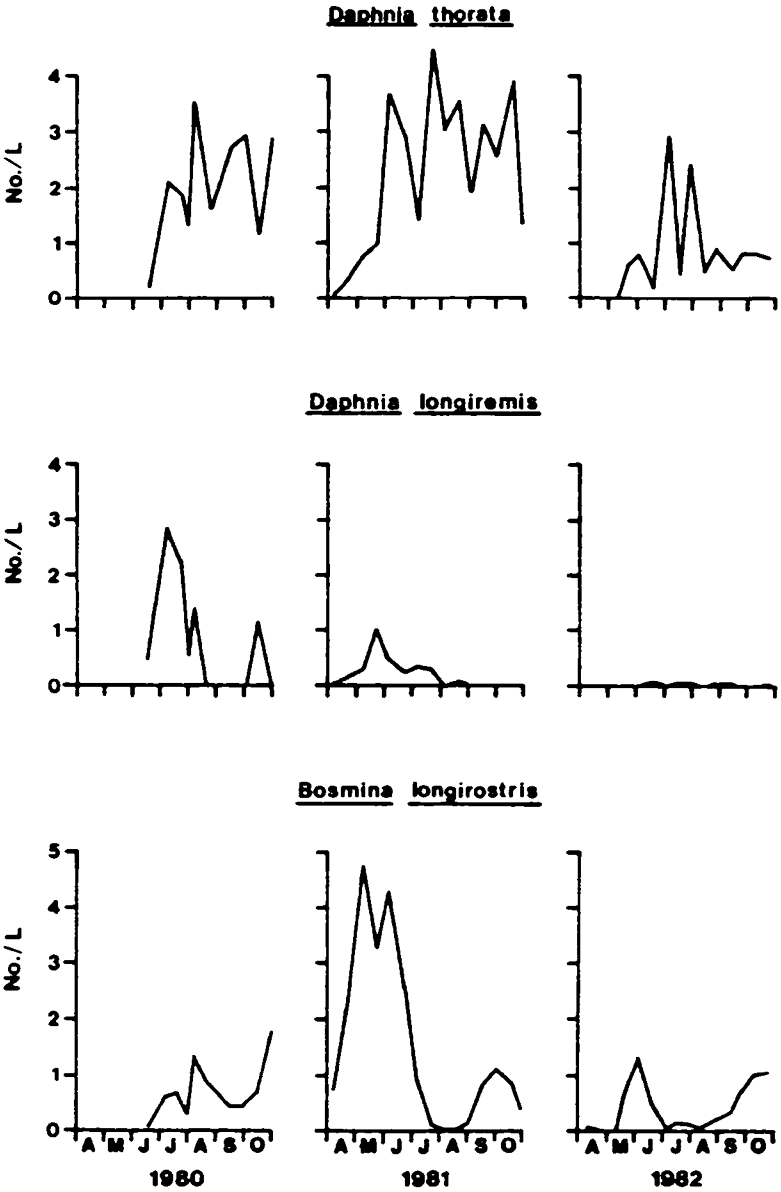


Figure 5. Seasonal density trends (no./l) of the three principal cladoceran species, *Daphnia thorata*, *D. longiremis* and *Bosmina longirostris* in the surface waters (0-30 m) at Station 2:4 of Flathead Lake during 1980, 1981 and 1982.

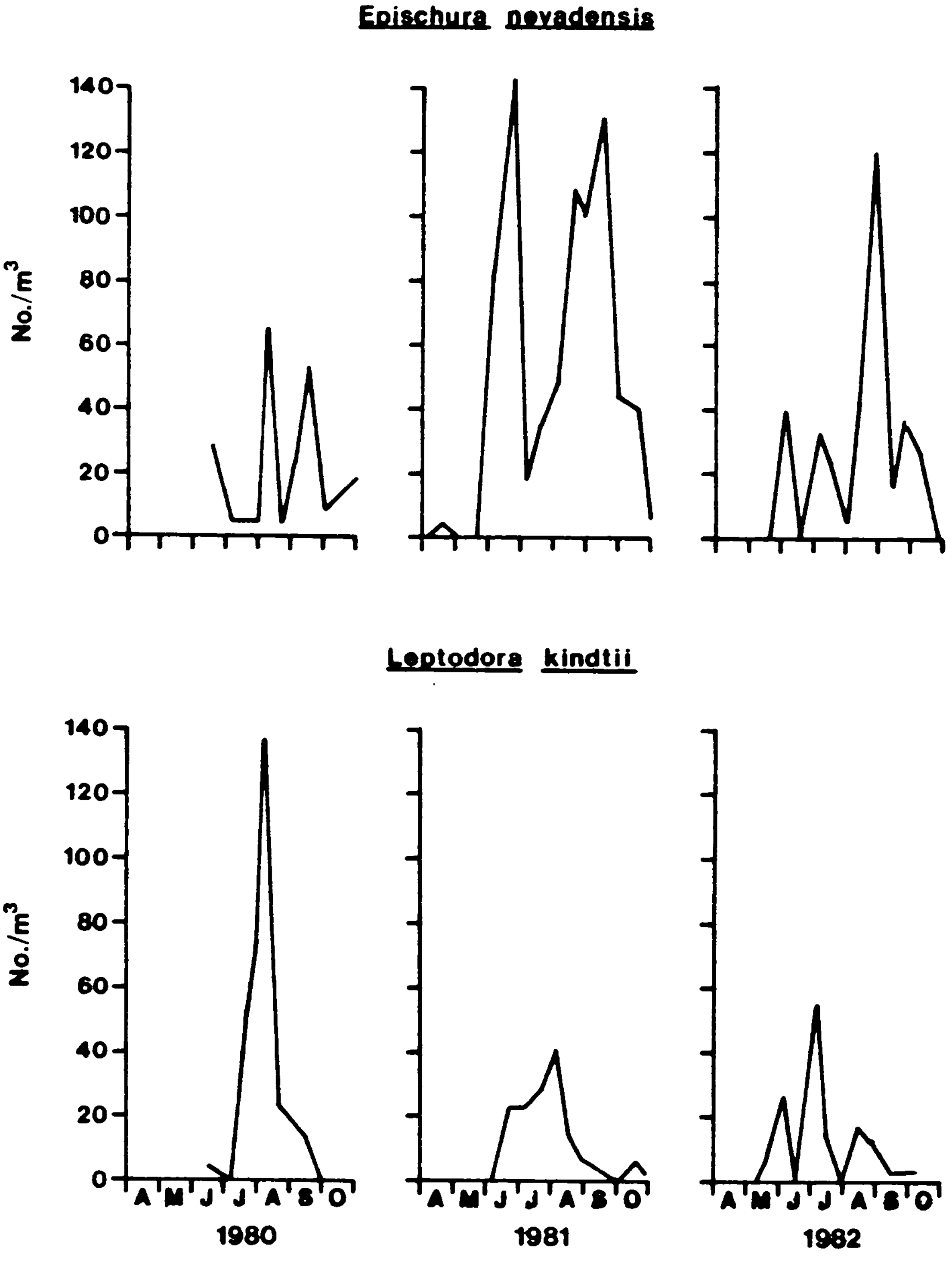


Figure 6. Seasonal density trends (no./m³) of Leptodora kindtii and Epischura nevadensis in the surface waters (0-15 m) at Station 2:4 of Flathead Lake during 1980, 1981 and 1982.

(Leathe and Graham 1982), it is not known what impact these smaller densities of Daphnia had on kokanee, if any.

In the copepod populations, Diaptomus attained a much larger density in 1982 than in 1980 or 1981, and remained a more significant part of the total zooplankton population throughout the sampling period. Cyclops densities remained quite similar to the preceding two years, although average densities during 1982 were slightly lower.

Few conclusions could be drawn from zooplankton data collected in Flathead Lake during the last three years. Previously collected information concerning the Flathead Lake zooplankton population has been very limited. Trends seen in 1982 may have been natural occurring population fluctuations or may be the first indications of a shift in the population structure of the Flathead Lake zooplankton community.

The lower water temperatures in 1982 may have affected the cladoceran population. Daphnia thorata and Daphnia longiremis did not appear in the 1982 plankton samples until at least a month later than they did in 1981. Bosmina densities did not begin increasing until a month later than was observed in 1981. The introduction of Mysis into some lakes in the Pacific Northwest appears to have caused delays in the spring appearance of cladocerans and resulted in decreased cladoceran densities throughout the summer (Goldman et al. 1979; Cooper and Goldman 1980; Murtaugh 1981; Rieman and Falter 1981; Threlkeld 1981). A similar pattern was observed in the 1982 Flathead Lake zooplankton population. However, based on the extremely small number of Mysis collected from Flathead Lake during 1981 and 1982, it was very unlikely that the Mysis population in Flathead Lake had reached a level high enough to affect the zooplankton population.

The data presented in this report demonstrates the magnitude of natural population fluctuations and the need for continued monitoring of the Flathead Lake zooplankton population. Zooplankton play an important role in the population dynamics of Flathead Lake kokanee and it is essential to recognize and identify differences between natural fluctuations and permanent shifts in zooplankton populations.

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