Impacts of Water Level Fluctuations on Kokanee Reproduction in Flathead Lake

Prepared by

Janet Decker-Hess, Project Biologist
and
Patrick J. Graham, Project Leader

Sponsored by

Bonneville Power Administration
Portland, Oregon

December, 1982

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 importance of spawning on-shore (to depths 6.1 m below full pool elevation) and off-shore (to depths greater than 6.1 m below full pool elevation) was also determined.

Forty-eight shoreline areas including historic kokanee spawning sites, surface stream outlets and groundwater upwellings were monitored for spawning activity from 28 October through 22 December. These areas were primarily located on the east and west shores of the lake. The first spawning activity was observed on 1 November in Yellow Bay and the last activity recorded on 8 December in Skidoo Bay.

Spawning activity was observed in ten shoreline areas in 1981 with nine of these areas being located on the east shore. A surface stream or groundwater seep occurred in each area. A total of 592 redds were observed in the 10 areas. The number of redds ranged from 5 at Crescent Bay to 152 at Yellow Bay. Spawning occurred in water depths from 0.35 m (880.6 m msl) to 7.35 m (873.6 m msl). Sixty-three percent of the redds located were constructed above the minimum pool elevation of 878.7 m (2883 feet). Only five percent of the redds were located in off-shore areas or at depths greater than 6.1 m below full pool elevation.

Two areas in Yellow and Skidoo bays and two areas in Dr. Richard's Bay were selected to collect microhabitat data and monitor embryonic success throughout the incubation period. Three of these areas were characterized by a shallow shoreline gradient with the majority of redds counted above minimum pool level. The Yellow Bay area was characterized by steeper shoreline gradient with the majority of the redds located below minimum pool.

Microhabitat data collected from the spawning areas included intergravel dissolved oxygen concentrations, gravel movement, substrate composition and intergravel temperatures. Intergravel dissolved oxygen concentrations during the incubation period tended to decrease with an increase in lake depth. Concentrations in the spawning gravels of 0 mg/l were reported from Yellow Bay near the deeper boundaries of the spawning area. General trends in vertical gravel movement were: 1) the greatest movement occurred within the wave zone, 2) lake stage fluctuation allowed the entire width of shallow gradient spawning areas to be subjected to wave action; and 3) the magnitude of gravel deposition or scour was related to the rate and stability of lake stage. Compositional changes in substrate also occurred during the incubation period. Deposition of fine material occurred in areas protected from the prevailing winds and a loss of those materials was observed in areas exposed to the wind.

The mean monthly decline in lake stage during December, January and February was 0.5 m. Minimum pool elevation of 879 m (2883.75 ft.) was reached in March and held for only a few days. However, lake levels remained at or below 879.3 m (2885 ft.) for a two and one-half month period during incubation exposing 80-90 percent of the redds constructed above minimum pool.

Embryo development and survival was monitored in naturally constructed redds and experimental egg plants located in various habitat types. Mean survival to hatching in the redds sampled above minimum pool was nine percent. Mortality resulted from dessication, freezing and gravel movement. Moisture to incubating embryos exposed by drawdown was provided by groundwater seeps in the Skidoo Bay spawning area. The apparent velocity of the groundwater was inadequate, however, to prevent freezing in the gravels during a week-long period when air temperatures ranged from -11 to -22°C. Survival in wetted redds constructed at or near minimum pool ranged from 10 to 50 percent. Survival in sampled redds located below minimum pool was 16 percent. Survival decreased with an increase in depth where dissolved oxygen concentrations were less than 3 mg/l.

The experimental egg plants in Yellow and Dr. Richard's bays supported the results found in natural redds sampled below minimum pool. Survival decreased with depth and total mortality occurred where intergravel dissolved oxygen concentrations were 2 mg/l or less. Survival in natural and artificial redds were limited to gravels at or near minimum pool to a depth of 877.2 m (2878.0 ft.).

Fry emergence was monitored at the four study spawning areas and two additional deep areas, Blue and Gravel bays. Many of the redds in the shallow spawning areas remained exposed at the time of predicted emergence. Shallow water fry traps, electrofishing or net towing did not capture fry from Skidoo or Dr. Richard's bays, although excavation of redds indicated fry had emerged. Two hundred twenty-seven fry were captured from six of the eight deep water emergence traps in Blue Bay. Emergence began 9 April and continued through 8 June. No kokanee fry were captured in 20 emergence traps in Yellow and Gravel bays. Prematurely emerging sac fry were captured in Skidoo Bay in March.

Sixty-seven thousand fry were released in three shoreline areas in May to assess the methodology of standpipe planting for imprinting purposes, kokanee survival from emergent fry to adult and the potential of these areas to successfully incubate kokanee embryos.

ACKNOWLEDGEMENTS

Rick Adams and Ken Frazer provided invaluable assistance during the course of this study. Their reliability and competency in the field as well as in the office provided continuity to the first year of study. Their efforts are greatly appreciated. Jon Cavigli was also a member of the field crew during 1981.

Delano Hanzel and Scott Rumsey have been working on the wiley kokanee of Flathead Lake for 15 years. Their experience and expertise provided background information and guidance throughout the study. Experiments with kokanee eggs and fry would not have been possible without the assistance of Stewart Kienow and the Flathead Lake Hatchery. Thanks to fellow biologists, Brad Shepard, for his assistance with substrate analysis, and John Fraley and Steve Leathe for their thought provoking discussions and ideas. Bob McFarland and Delano Hanzel assisted with computer anaylsis and operation and Mary Chubb and Cathy Turley typed the manuscript.

This study was funded by the Bonneville Power Administration.

TABLE OF CONTENTS

TABLE OF CONTENTS CONT.

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES CONT.

LIST OF FIGURES CONT.

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 and Fraley and Graham 1982) 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 during 1962-64 (Robbins 1966) estimated 12-14 percent of the total fishing effort on Flathead Lake for kokanee occurred during the spawning season. In a recent creel census, conducted during 1981-82, less than one percent of the fishermen creeled 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 period. Groundwater, or subsurface flow, 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 in shoreline spawning areas of Flathead Lake only in areas wetted by groundwater seeps. Impacts of the operation of Kerr Dam on lakeshore spawning have not been quantified. Studies in recent years have revealed that operation of Hungry Horse Dam, located above Flathead Lake, severely impacted successful kokanee spawning and incubation in the main river (Graham et al. 1980, McMullin and Graham 1981 and Fraley and Graham 1982).

In lakeshore areas, 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 Reiman 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% kokanee egg loss in shoreline areas of Pend Oreille Lake, Idaho after regulation of the upper 3 m 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% 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. Kokanee spawning occurred from 1.5 to 4.6 m below full pool along beach areas.

The goal of this phase of the study is to evaluate and document effects from the operation of Kerr Dam on kokanee shoreline reproduction. 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 the influence of groundwater on reproductive success of on-shore spawners in Flathead Lake subject to dewatering by lake drawdown.

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 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 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 of 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. Operation of the facility also has influenced Flathead Lake elevations throughout the year.

Kokanee salmon have provided the largest fishery to Flathead Lake and the upper Flathead River (Robbins 1966, Hanzel 1977, Graham and Fredenberg

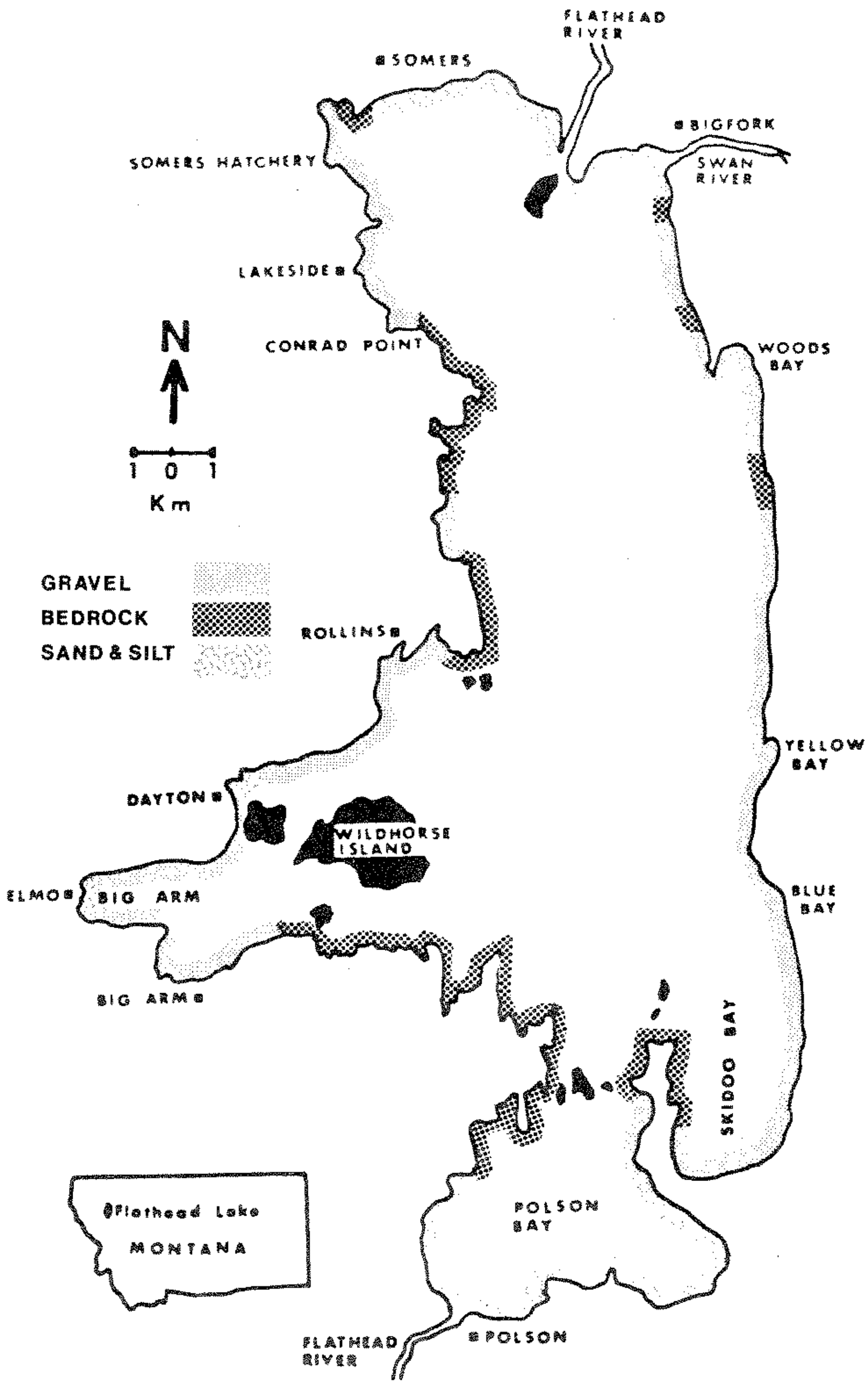


Figure 1. Map of Flathead Lake, including substrate composition of shoreline.

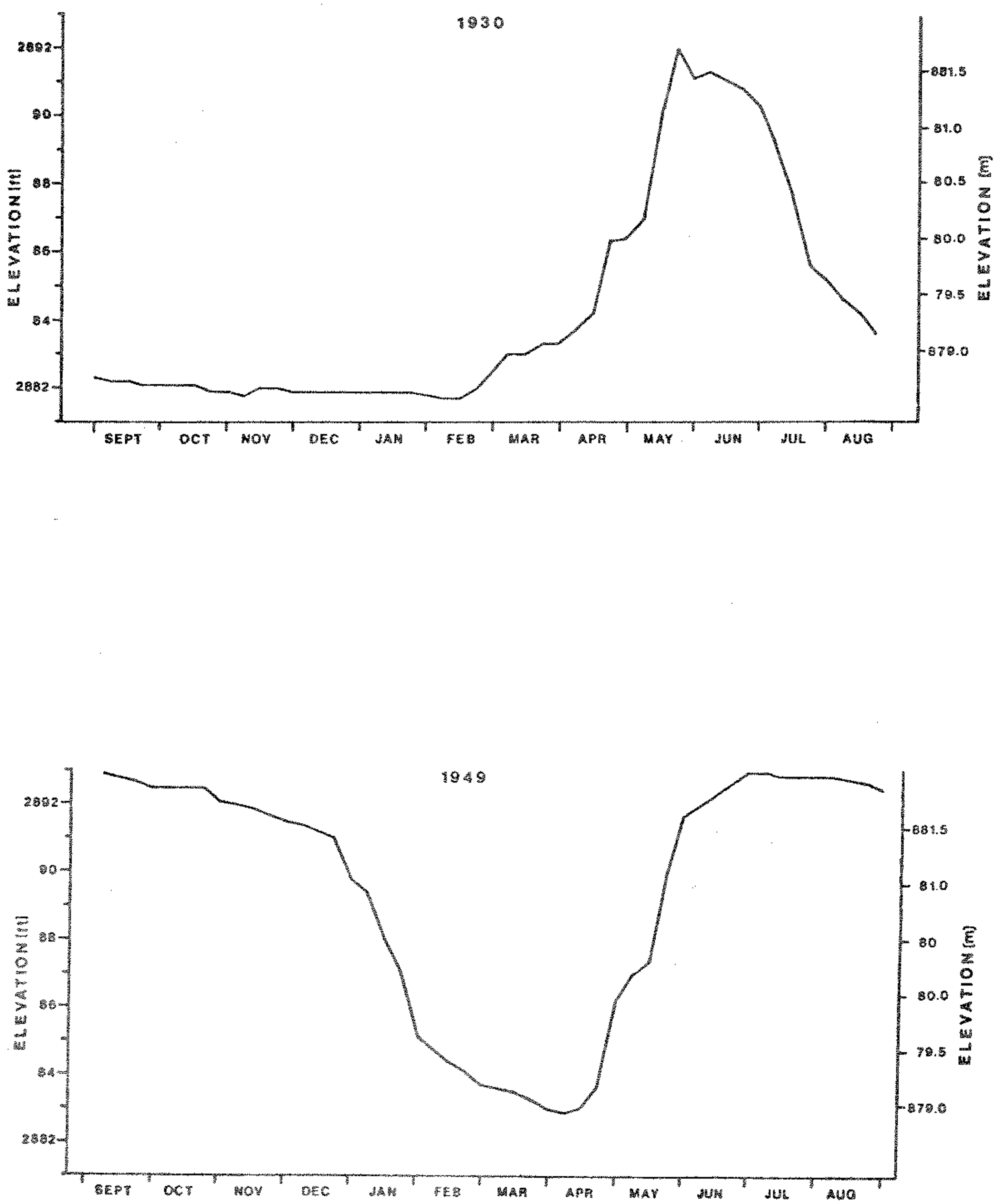


Figure 2. Annual lake levels of Flathead Lake in 1930, prior to construction of Kerr Dam and in 1949, after construction of Kerr Dam.

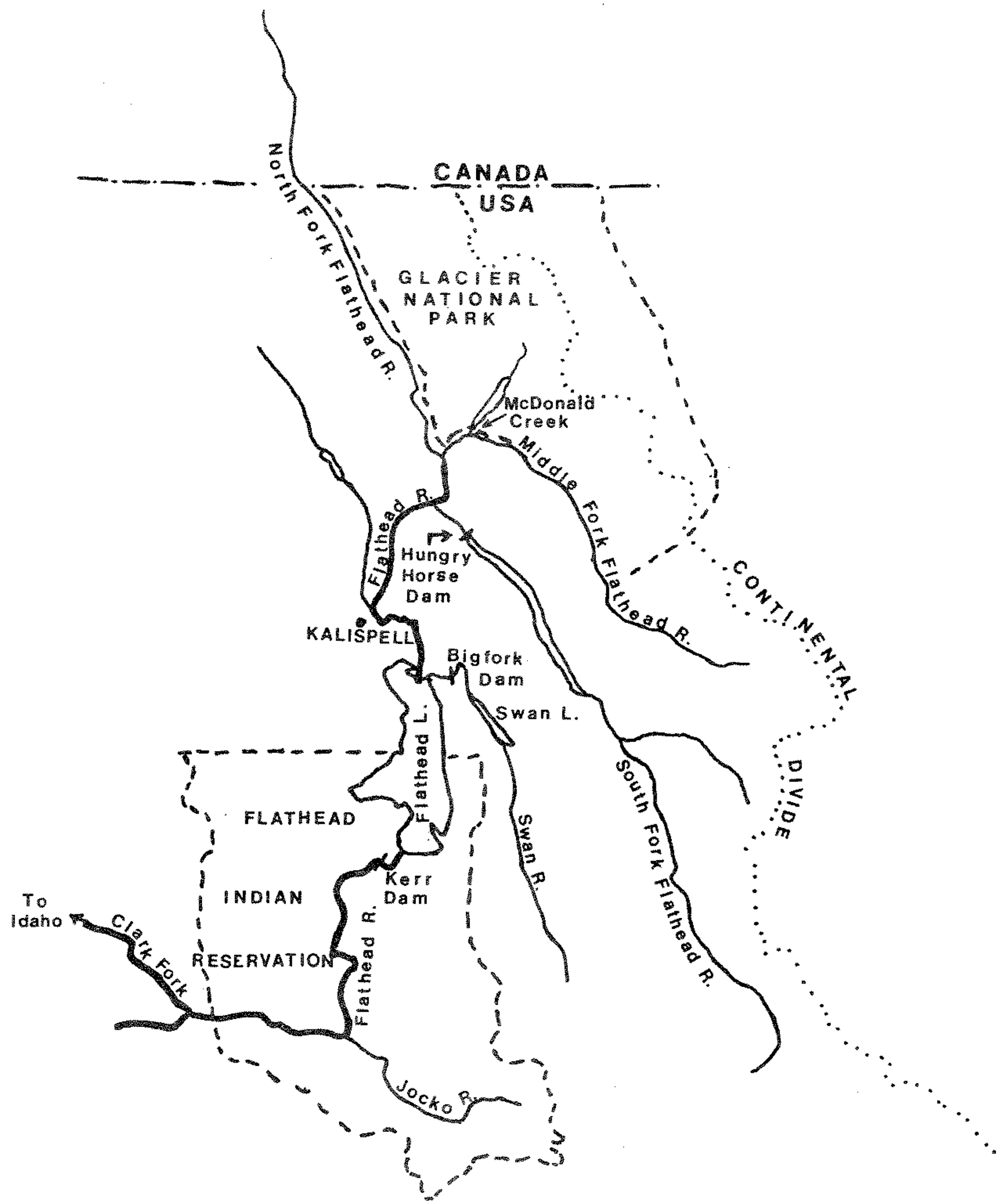


Figure 3. Map of Flathead River drainage.

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% 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.

METHODS

KOKANEE SPAWNER SURVEY

Beginning in mid-October, attention was focused on shoreline areas of Flathead Lake previously identified as kokanee spawning sites, groundwater upwellings, or surface water inlets. 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. Initial sitings were observed from the bow of a slow cruising jet boat or from a pram modified with a plexiglass viewing window (Figure 4). The pram was constructed from 1"x2" and 1"x4" lumber and covered with 3/8"(9.5mm) exterior plywood. The bottom and side seams were sealed with fiberglass. The pram measured 2.5 m x 1.2 m with 43.2 cm high sides. The viewing window measured 37.5x60.3 cm and was made of 6.35 mm plexiglass. A plywood deck extended back 116.8 cm from the bow to cover the viewing window. A tarp extending from the deck over the observer was used to block out light to the window. The pram was powered by a 2.7 kg thrust electric motor mounted on the stern and operated by a two person crew. One person observed spawning activity through the viewing window, while the other individual steered the boat and recorded redd or fish location.

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. Potential spawning was defined vertically by the extent which the gravel substrate was free from sediment deposition. Redds and mature adults were counted and approximate locations were recorded.

Floating shoreline gill nets were set at historic kokanee spawning sites during November, 1981. Information gathered from the fish collected included sex ratio, fecundity, age composition and length measurements to the nearest mm. Egg counts were made only from females showing no signs of egg exudation (i.e. sac enveloping the eggs was intact). The otoliths were used to determine adult kokanee age and analyzed by sex and lake area.

LAKE FLUCTUATIONS AND AIR TEMPERATURES

Daily lake elevations during 1981-82 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 this study.

SPAWNING SITE INVENTORY AND MICROHABITAT

Spawning areas were mapped upon completion of major spawning activity.

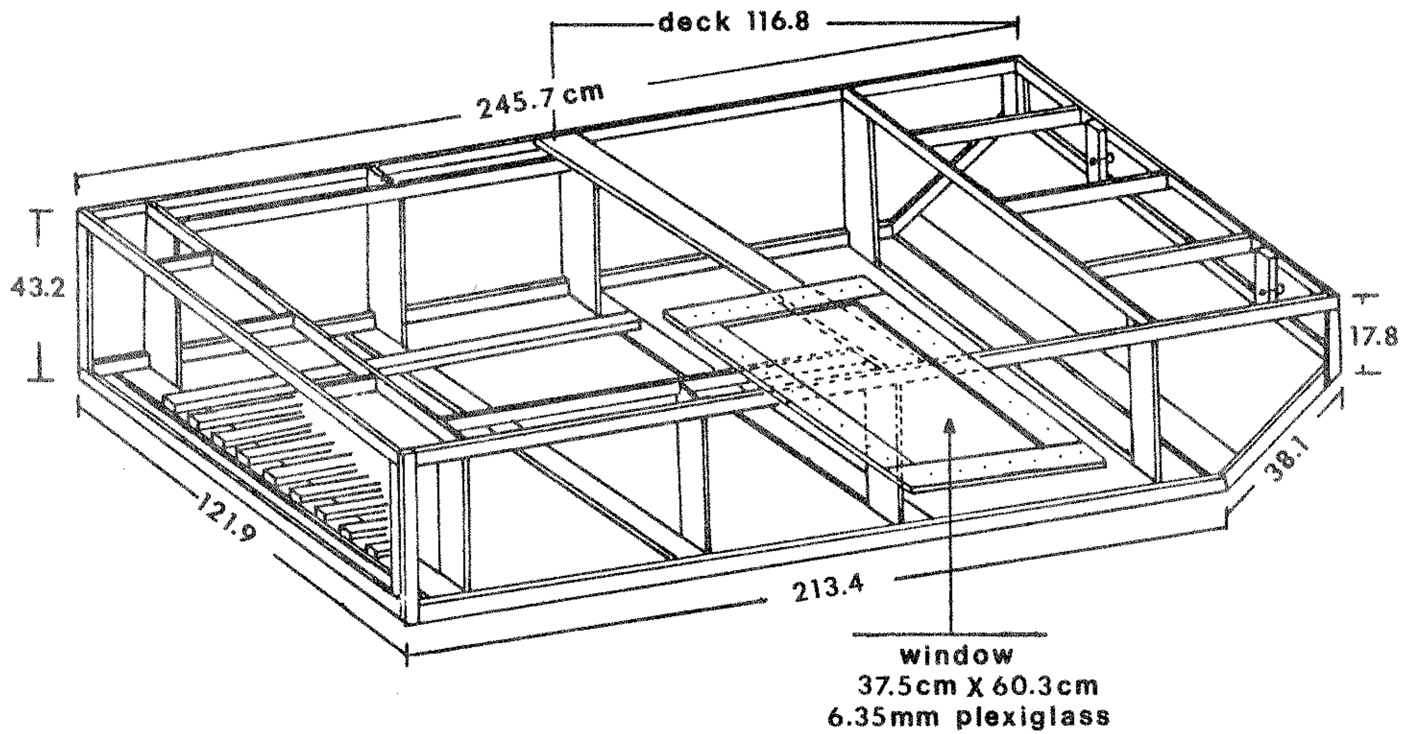


Figure 4. Construction design and measurements for pram with plexiglass window for viewing kokanee spawning activity. All measurements are in centimeters.

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 distance out from the parallel tape. Because redds were quickly rendered unidentifiable from wave action depositing sediment and moving gravel, measurements of this accuracy were necessary.

Three transects spanned the width of the spawning area and were spaced laterally to accurately define microhabitat of the entire area. Information collected from the transects included bottom elevations and contours, redd location by elevation, substrate composition and intergravel dissolved oxygen concentrations. Total spawning area and mean redd size were also determined from field measurements.

Nine substrate samples were collected from the spawning areas selected for further study. Fewer samples were randomly collected from spawning areas which were not monitored during the incubation period. A shovel and a 19 liter plastic bucket with lid was used by a team of SCUBA divers to collect substrate samples. Shirazi and Seim (1979) recommended a 5-10 kg substrate sample be collected to accurately define the composition. 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) and percent volume (accurate to 100 ml) were calculated for each sample. Analysis of substrate composition group means within, without and between spawning areas was performed using the "TGROUPED" test from the Montana State Statistical Library (Lund 1979).

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, fredle index (Lotspiech and Everest 1980), geometric mean (Platts et al. 1979), and cumulative distribution of sediment particle size (Tappel 1981 and Irving in press).

Intergravel dissolved oxygen samples were collected by a SCUBA diver using a Black and Decker Model J50-1500 hand operated rotary pump. A 45.7 cm long probe of 3.2 mm galvanized pipe was connected to the pump by 7.9 mm ID plastic tubing (Figure 5). The discharge hose consisted of 7.9 mm ID plastic tubing connected to 6.3 ID surgical tubing. The depth of sample from water surface determined length of the discharge hose. To prevent contamination of the intergravel sample by lake water, the probe was passed through a 12.7 cm^2 foam rubber backed steel plate before it was driven into the substrate. A second diver on the surface used a floating discharge hose to collect samples in 325 ml. B.O.D. bottles. Analysis of samples were determined in the field by the modified Winkler method (Environmental Protection Agency 1974).

Meekin (1967), Chambers et al. (1955) and Sheridan (1962) found dis-

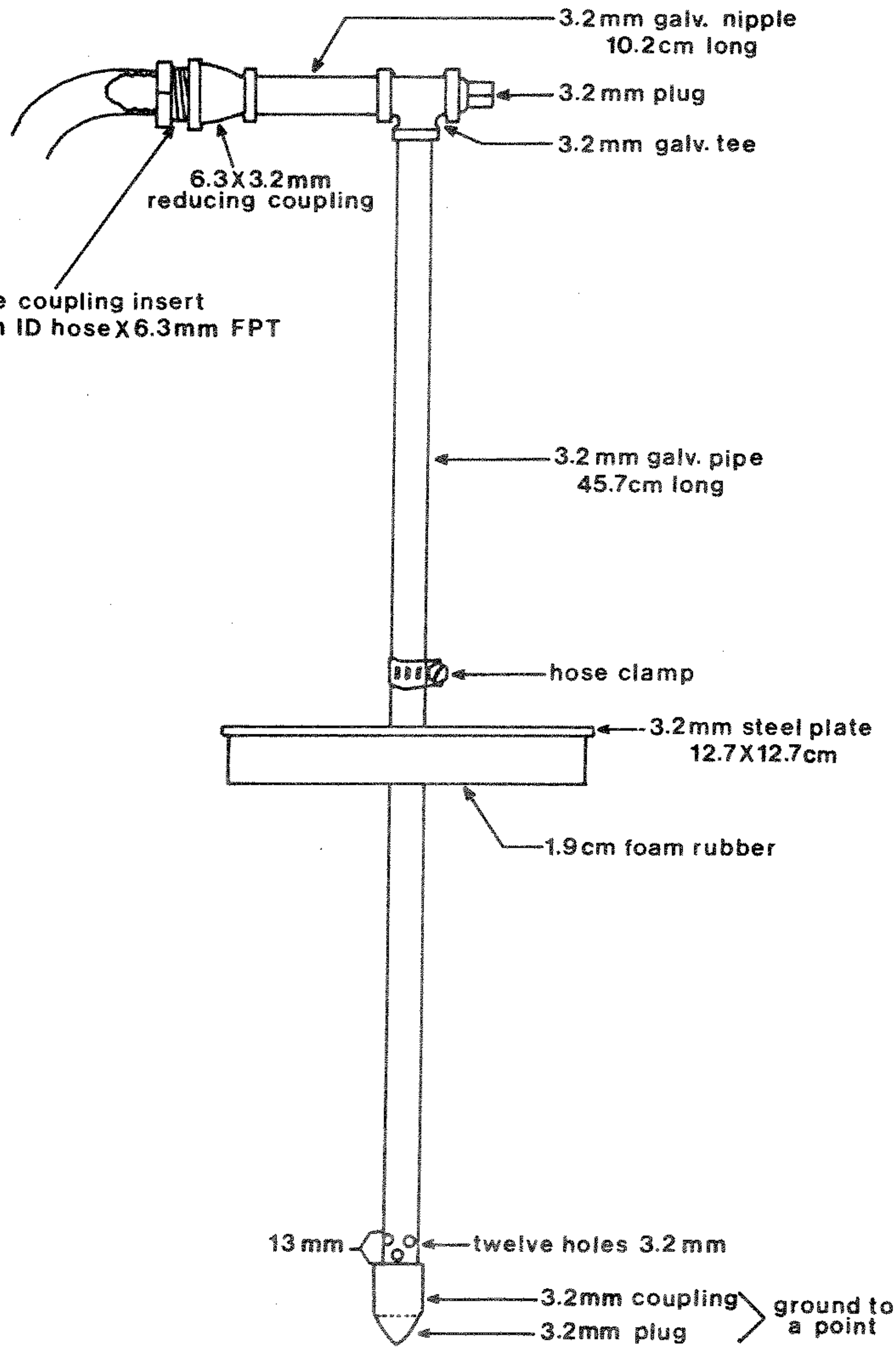


Figure 5. Dimensions of probe used for collecting intergravel water samples in kokanee shoreline spawning areas.

solved oxygen of intergravel water decreased with depth in the substrate. A considerable decrease in intergravel dissolved oxygen occurred between 10.2 and 20.3 cm within the substrate during this study season. The decrease was believed to be a result of the pump drawing in lake water when the sample was collected close to the substrate surface. 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.

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). To quantify this phenomena in Flathead Lake, a single transect was established spanning the width of each spawning area perpendicular to the shoreline at study spawning areas. Elevation of the gravel along the transect was taken monthly at one meter intervals to monitor gravel movement.

EMBRYO SURVIVAL AND DEVELOPMENT

Kokanee embryo and alevin mortality in shoreline areas was assessed by two methods. Natural redds were excavated on a monthly basis throughout the incubation period. 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 four spawning areas selected as study sites for 1981, 15-20% of the counted redds were marked for excavation during the incubation period. This resulted in marking 10 to 20 redds in each area. Immediately after spawning ceased, a 0.6 m length of 13 mm diameter rebar was driven into the center of the study redds. Redds were excavated monthly 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) and Fraley and Graham (1982). A dual pump hydraulic sampler with a venturi suction device was operated by two SCUBA divers to excavate eggs from deeper redds as described by Stober et al. (1979a) (Figure 6).

Green eggs were planted in three habitat types: 1) stream outlet areas above minimum pool level, 2) stream outlet areas below minimum pool level, and 3) non-stream outlet areas below minimum pool level. Fifty eggs were placed in 7.6x10.2 cm fiberglass screen bags with gravel and stapled shut. In each habitat type, four horizontal lines each containing five egg bags were spaced to thoroughly describe the plant area. Substrate composition, bottom elevation and intergravel dissolved oxygen concentration were determined at each egg bag line once during the incubation period.

Thirty-one day recording thermographs were installed to record gravel temperatures adjacent to two egg plant areas. Intergravel temperatures

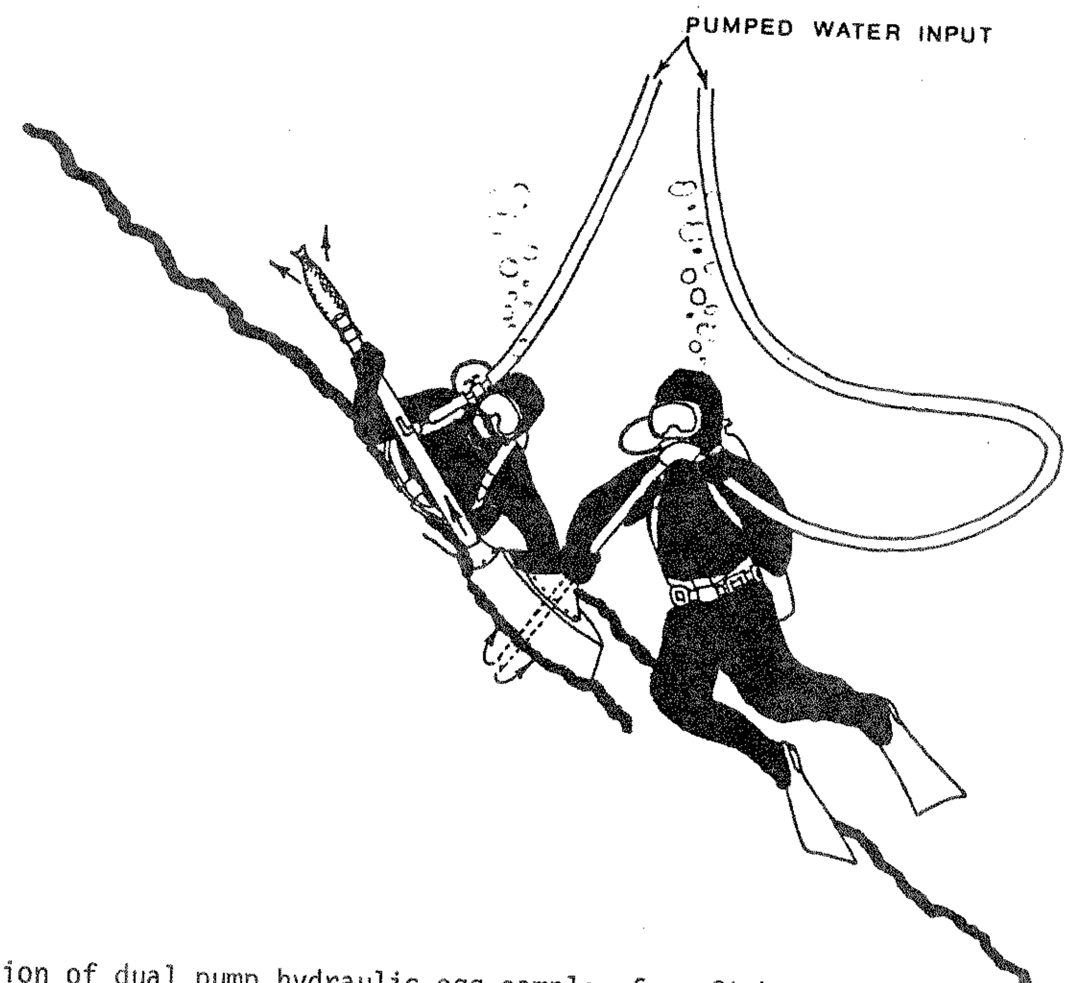


Figure 6. Operation of dual pump hydraulic egg sampler from Stober et al. 1979a.

were monitored throughout the incubation period and temperature units for various stages of development were calculated.

FRY EMERGENCE AND DISTRIBUTION

In late March, fry emergence traps were placed in five east shore spawning areas. Information desired from the traps included fry quality and quantity at various depths, the effect of fry density on fry quality, and whether lateral movement occurred in areas exposed by lake drawdown. Captured fry were counted and measured to the nearest mm. The traps were tended on a weekly basis from the end of March through the first week in June.

Deep water emergence traps designed by Stober et al. (1979a) and modified by Hassemer (in press) were placed in Yellow, Blue and Gravel bays (Figure 7). The number of traps placed in each area varied depending on the number or redds counted during the spawning season.

Emergence traps designed for use in lotic systems by Phillips and Koski (1969) were modified to trap emerging fry from shallow (<1m deep) redds. The traps were constructed of a frame of steel strap with fiberglass screen covering a 0.5 m^2 area.

Nightly tows to capture emerging fry in shoreline areas were conducted during May and June. Two one-meter nets were towed approximately 7.5m 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.

Experimental Fry Plants

In April, 1982, 67,000 kokanee fry reared at Somers Hatchery, Montana, were used for experimental fry plants along Flathead Lake shoreline. Gravel areas with known streams or groundwater seeps were surveyed intensively for potential release sites. Measurements for intergravel dissolved oxygen, substrate composition, apparent velocity and percent spawning gravel exposed by drawdown were taken along transects in potential areas.

To permanently mark the experimental fry for future identification, they were fed oxytetracycline for no less than ten days prior to release. Ten PVC standpipes modified from designs by Phillips and Campbell (1961) and McCuddin (1977) were used for fry release at the planting locations (Figure 8). The "T" chamber and the lower 10cm of pipe were buried in the seep or stream gravel. Groups of 1,000 fry were funneled into the standpipe for simulation of natural emergence from the gravel. It was hoped that sufficient resident time in the gravels would result in imprinting the fry to return to that site to spawn as an adult. Upon completion of the plant, the standpipes remained in the gravels for no less than 24 hours.

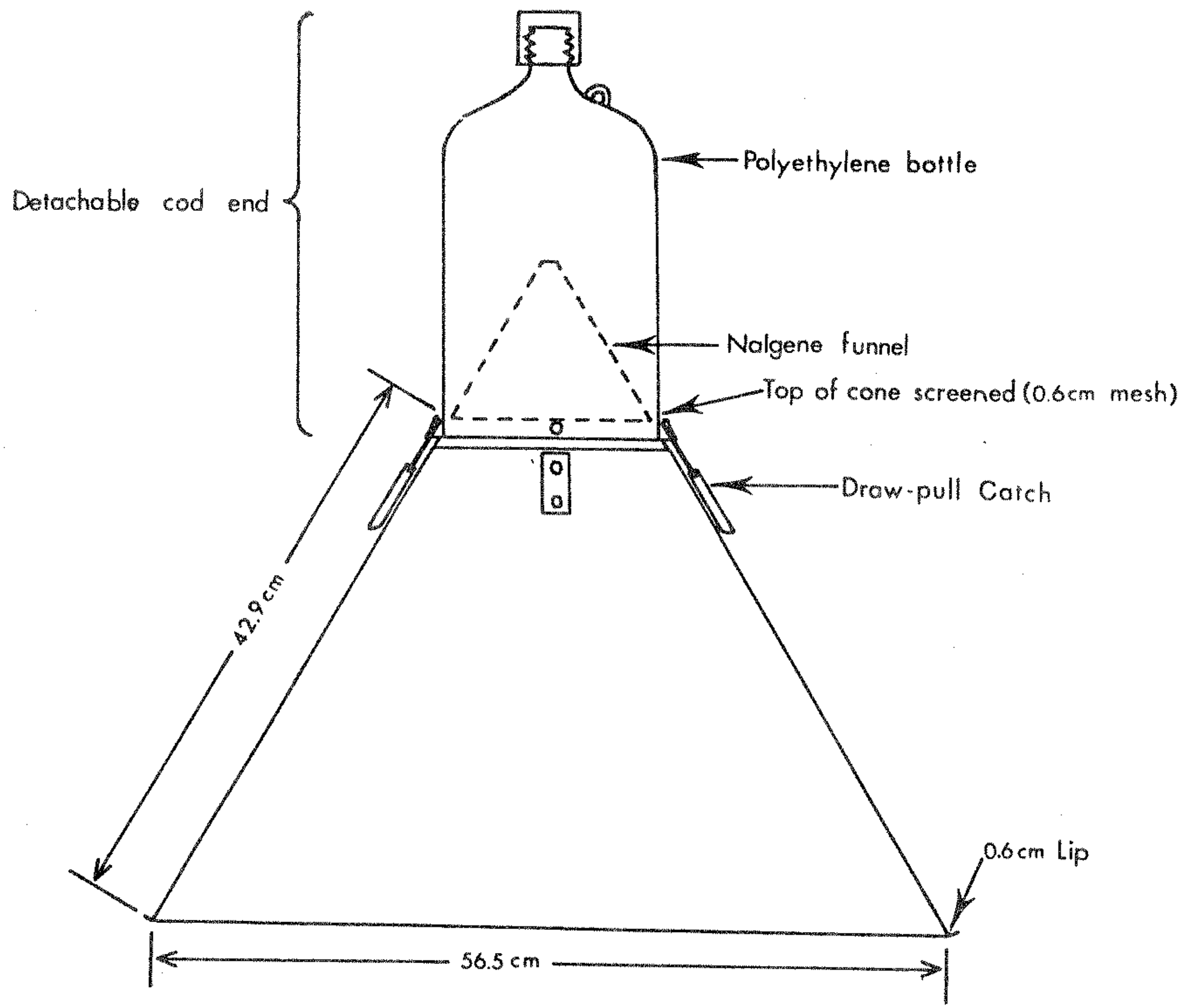


Figure 7. Design of deep water emergence fry trap from Stober et al. 1979a.

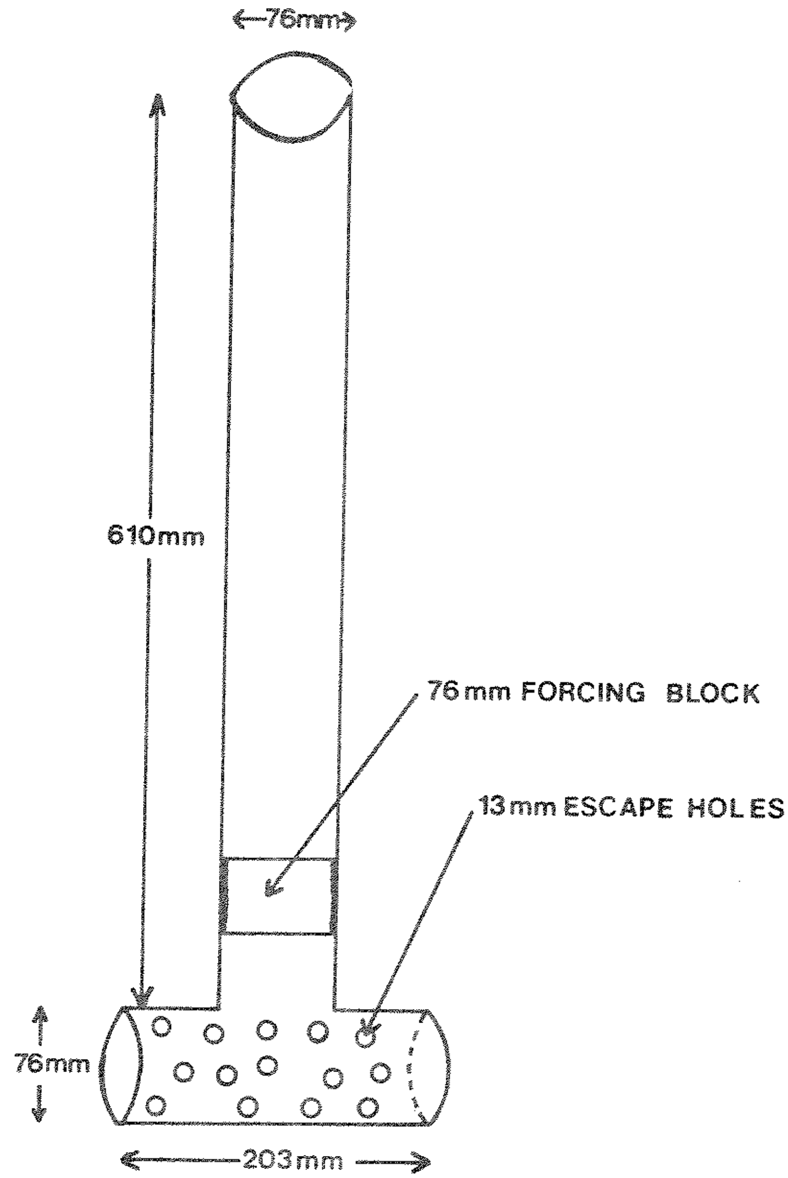


Figure 8. Dimensions and design of PVC standpipe used for releasing hatchery-reared kokanee salmon fry in shoreline areas of Flathead Lake.

Five to ten percent of the fry planted at each site were dyed with Bismark Brown-Y to monitor short term distribution and movement (Bouchard and Mattson 1961). A concentration of dye of 1:30,000 for 0.75 hours, was determined by Fraley and Graham (1982) to be adequate for recognition of the dye up to 20 days. Acclimation to the spring or stream water temperature occurred while the fry were being dyed.

RESULTS AND DISCUSSION

KOKANEE SPAWNER SURVEY

Monitoring of shoreline areas for kokanee spawning activity began 28 October and ended 22 December. During this two month period 48 areas, 27 on the west shore and 21 on the east shore, were checked for spawning activity (Appendix A Table 1, Figure 1). Approximately 85 km of shoreline was investigated for spawning activity during the fall of 1981.

Initial spawning activity was observed in shoreline areas of Yellow Bay on 1 November (Appendix A Table 2). Small schools of 4-60 adult salmon were located in east shore bays during the first week in November with peak numbers occurring between 9 November and 16 November (Figure 9). Spawning activity dropped off significantly following the peak period. The last new redds were located on 8 December in Skidoo Bay.

Adult kokanee remained in the spawning areas during the daylight hours, but no spawning activity was observed. Lindsay and Lewis (1975) reported spawning kokanee in Odell Lake, Oregon leave shoreline areas at sunrise and return after dark to spawn. Few dead or dying adults were found in the spawning areas of Flathead Lake following redd construction and spawning. Post-spawning behavior was not assessed. Most dead spawners in Banks Lake were located either downslope (>5m) or away from the spawning area (Stober et al. 1979a).

Ten spawning areas in eight bays were located along the shoreline of Flathead Lake during the 1981 season including nine areas on the east shore and one area on the west shore (Figure 10). This represented only 26% of the 31 spawning areas located by Stefanich (1953) during the fall of 1952.

Spawning kokanee and redds were enumerated from a glass bottom pram throughout the spawning season (Appendix A Table 2). Cumulative pram counts of redds and adult kokanee observed in shoreline areas were compared. The correlation ($r = .973$)($p < .01$) between these two counts suggested that regardless of sex ratio, either count method estimated spawning activity. Counts of fish and redds in future years will verify or discredit the use of these methods as trend estimators.

SCUBA counts of redds in shoreline areas began on the 20 November. Because of wave action rendering redds unidentifiable shortly after construction, only one redd count using SCUBA occurred at each area. A total count of 592 redds was made in the ten areas (Table 1). Concentrations of redds ranged from 5 in Crescent Bay to 152 in Yellow Bay. Three bays, Yellow, Dr. Richard's and Skidoo, accounted for 74% of the total number of redds observed. Spawning occurred in water depths ranging from 0.35 m to 7.35 m, which translated to lake bottom elevations ranging between 880.6 m (2889.14 ft.) to 873.6 m (2866.21 ft.). Sixty three percent of the redds constructed were located above the minimum pool level.

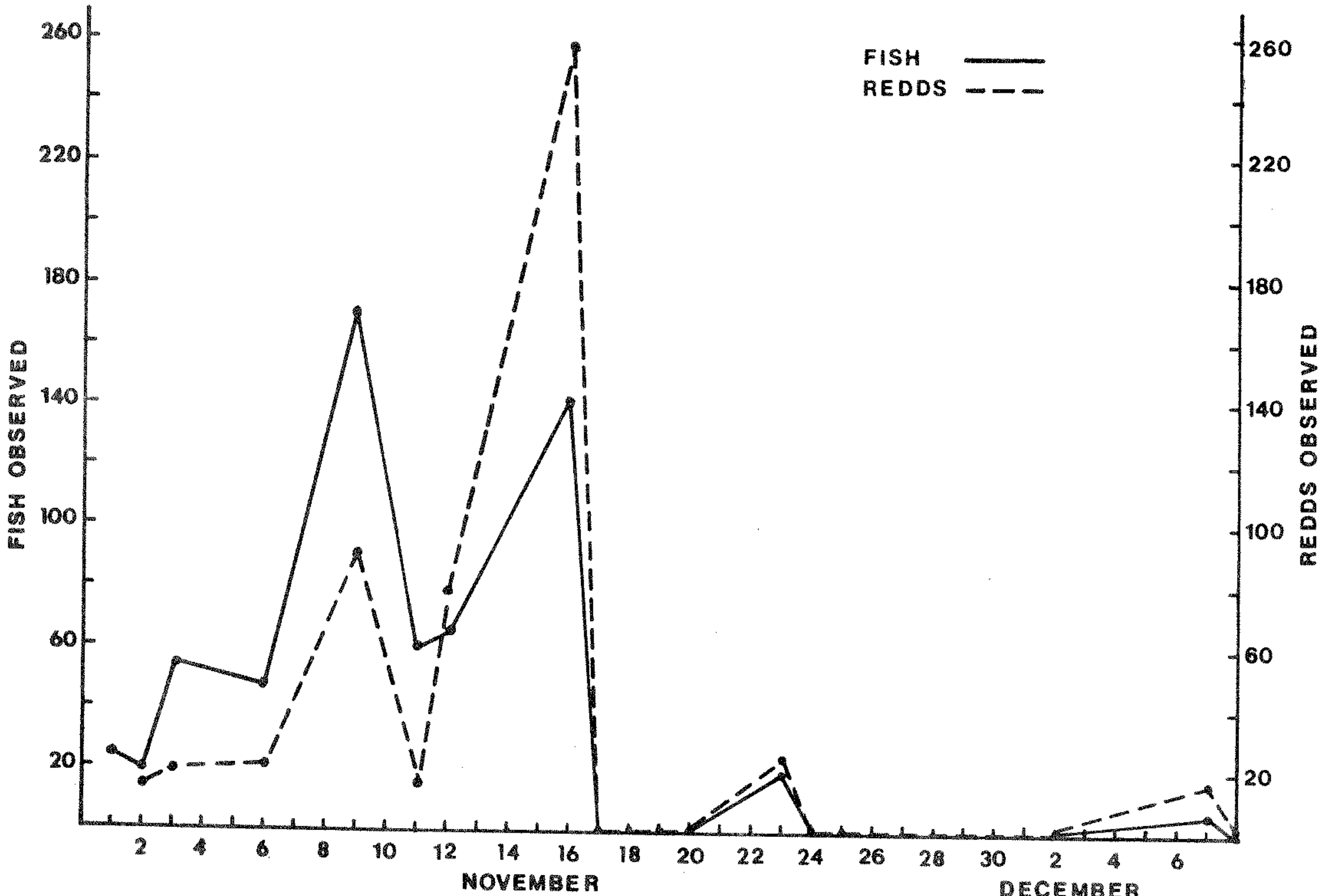


Figure 9. Temporal distribution of kokanee spawners and new redds observed from a glass-bottomed pram in shoreline areas of Flathead Lake, November and December 1981.

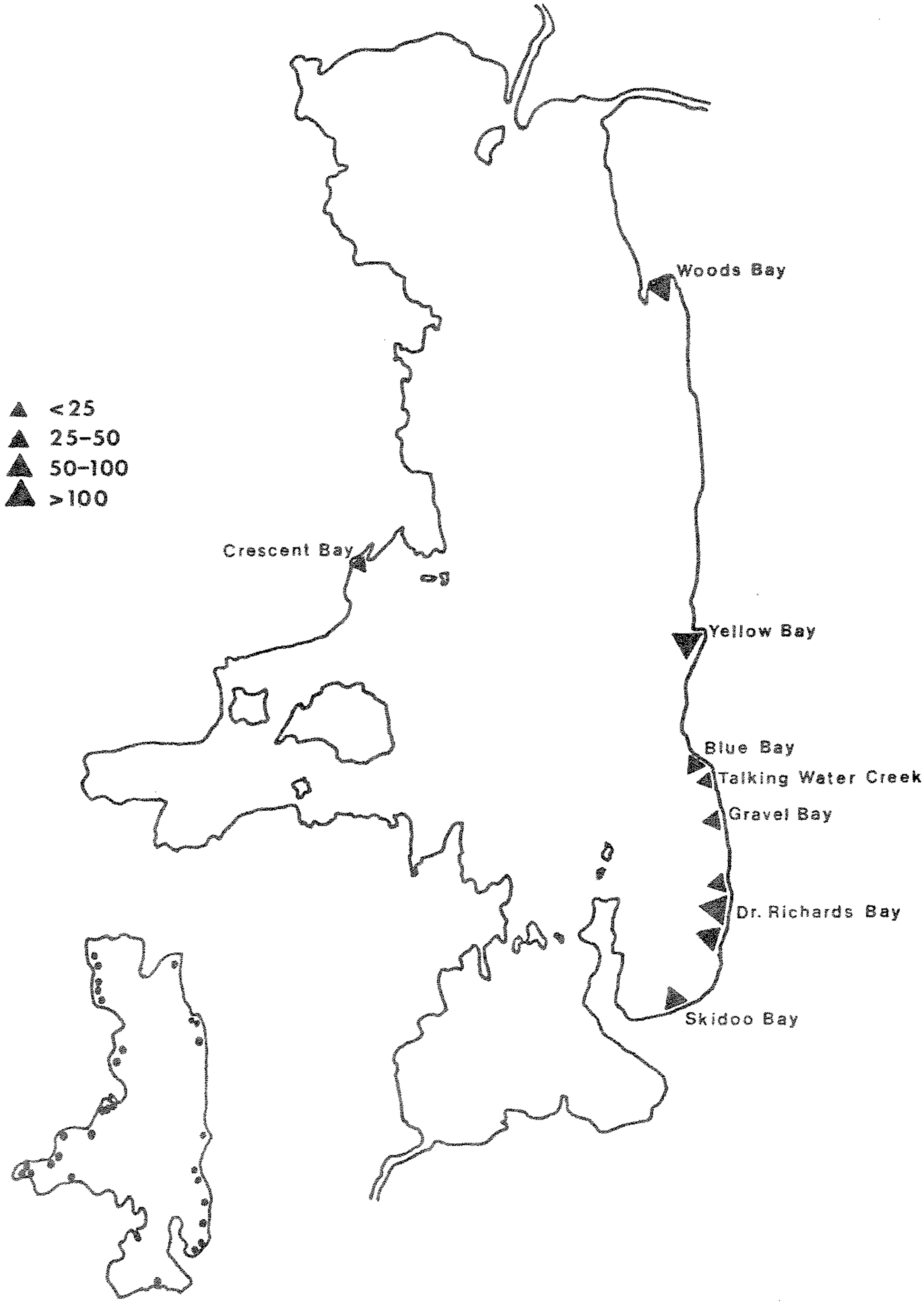


Figure 10. Location of shoreline spawning areas in Flathead Lake, 1981. Size of triangle denotes number of redds in each area. Smaller map describes locations of spawning kokanee in shoreline areas of Flathead Lake found by Stefanich in 1952.

Table 1. Final SCUBA counts of kokanee redds by area and above and below minimum pool along the shoreline of Flathead Lake, 1981 (percent in parentheses).

Location	Number of redds	Number of redds above 878.7m(2883 ft.)	Number of redds below 878.7m(2883 ft.)
Woods Bay	57	22	35
Yellow Bay	152	28	124
Blue Bay	45	0	45
Talking Water Creek	12	12	0
Gravel Bay	37	19	18
Dr. Richard's Bay			
North	106	106	0
South	63	63	0
Boat Launch	12	12	0
Skidoo Bay	103	103	0
Crescent Bay	5	5	0
	592	370 (63%)	222 (37%)

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 Lake, Idaho, Hassemer and Rieman (1979 and 1980) found most redds built at depths between 10.2 cm and 127 cm. The only occurrence of kokanee spawning on deeper substrate has been reported by Hassemer (in press, 1982) on a road fill slope in Coeur d'Alene Lake, Idaho. He found broadcast spawning occurring down to depths of 20 m. Maximum depth utilized by kokanee spawning in Flathead Lake appeared to be limited to depths where gravel was clean. In all areas where spawning activity was observed, kokanee spawned to the boundary of clean gravel. Clean gravel was gravel and cobble which had not been covered by sediment or silt to the extent that shape and size was no longer visibly distinguishable. Data collected by Hassemer and Rieman (1979) on Priest Lake, Idaho found vertical redd distribution to be normally distributed. Because of this distribution, they concluded kokanee exhibited a preference for water depth within the expanse of available habitat. In natural beach areas, Hassemer and Rieman (1980) and Stober et al. (1979a) determined the greater quantity of clean substrate produced in the wave zone was the primary reason for a greater concentration of spawning kokanee in certain areas.

Total redd counts using the pram were compared to redd counts conducted by SCUBA divers to assess the reliability of the pram counts as an estimator of trends in abundance of shoreline spawning kokanee. Although observations from the pram enumerated only 61 percent of the redds, this method appeared to have predictive value for determining trends in abundance of redds during the 1981 spawning season (Figure 11). Cumulative pram counts from each area correlated with SCUBA surveys showed a significant ($p<0.01$) relationship between the two methods ($r=.912$).

The value of gill net catches to predict abundance of shoreline spawning kokanee was determined by relating net catches to SCUBA redd counts for each spawning area (Table 2). The relationship was not significant or highly correlated ($r=.545$). Although the gill net catches did not appear to be a reliable indicator of spawning activity, the information collected was used to assess fecundity, spawner length and age composition of spawners.

Based on the correlation of pram counts and gill net catches to final SCUBA counts, pram counts provided a better relative index for predicting actual numbers of redds observed during 1981. Stober et al. (1979a) compared pram and SCUBA counts of kokanee spawners in Banks Lake and found SCUBA to be a more reliable method. After three years of study, they concluded the glass bottom pram was useful only as a relative density indicator and only then when densities were moderate to low.

Six shoreline spawning areas on the east and west shores of Flathead Lake were gill netted during the week of 16 November 1981. Ninety-four percent of the 197 spawners caught were from the southern half of the east shore. Total length of female kokanee for all age classes ranged from 320 to 399 mm with a mean length of 370 mm (Appendix A, Table 3).

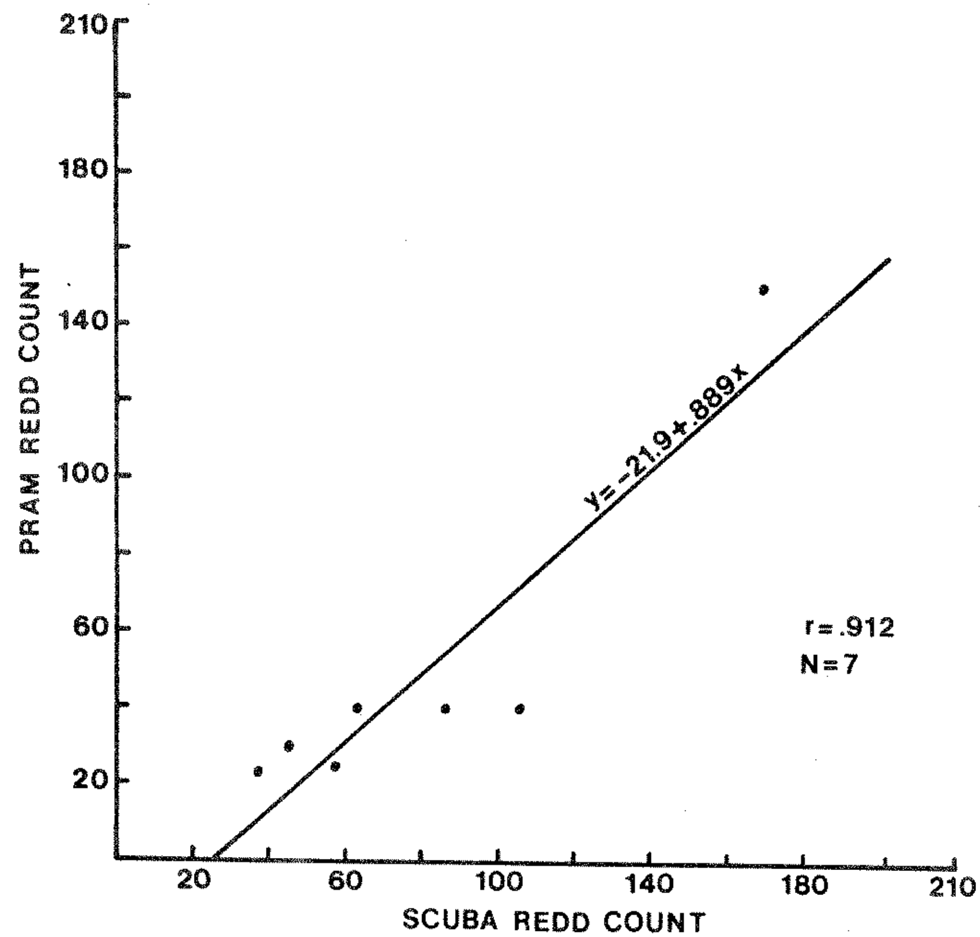


Figure 11. The relationship between total redd counts from the pram and final redd counts with SCUBA from spawning areas in Flathead Lake, November 1981.

Table 2. Comparison of female gill net catch, total pram counts and final SCUBA redd counts for all spawning areas in Flathead Lake, 1981.

Location	Female gill net catch	Pram redd counts	Final SCUBA redd counts
East Shore Areas			
Yellow Bay	28	150	152
Dr. Richard's Bay (S)	NS*	40	106
Dr. Richard's Bay (N)	13	40	63
Skidoo Bay	54	40	86
Woods Bay	0	25	57
Blue Bay	NS	30	45
Gravel Bay	NS	23	37
West Shore Areas			
Crescent Bay	0	NS	5
West Shore State Park	0	0	0
TOTAL	95	348	551

* Not Sampled.

From a sample of 76 females, age IV+ fish dominated the spawning population with a mean percent composition of 62.5%. The remaining 33 fish captured were III+. Average fecundity of nine spawners from Skidoo and Dr. Richard's bays was 1056 eggs (Appendix A Table 4). This compared to 924 eggs per female kokanee in the Flathead River system (Fraley and Graham 1982). Mean length of adult male kokanee from a sample of 95 fish was 393 mm. Sixty-six percent of the 66 male kokanee aged in the four shoreline areas were age IV+.

Kokanee shoreline spawners have been collected by gill nets and seining since 1970 (Montana Department of Fish, Wildlife and Parks, Kalispell). Since 1976 there has been an increase in total length of both sexes of kokanee caught in shoreline areas (Figure 12). This is a 3.4% increase in total length since 1980 and a 17.1% increase since 1976. Trends in percent of age IV+ spawners in four east shore spawning areas has occurred over the last 12 years with a general increase in age IV+ spawners since 1978.

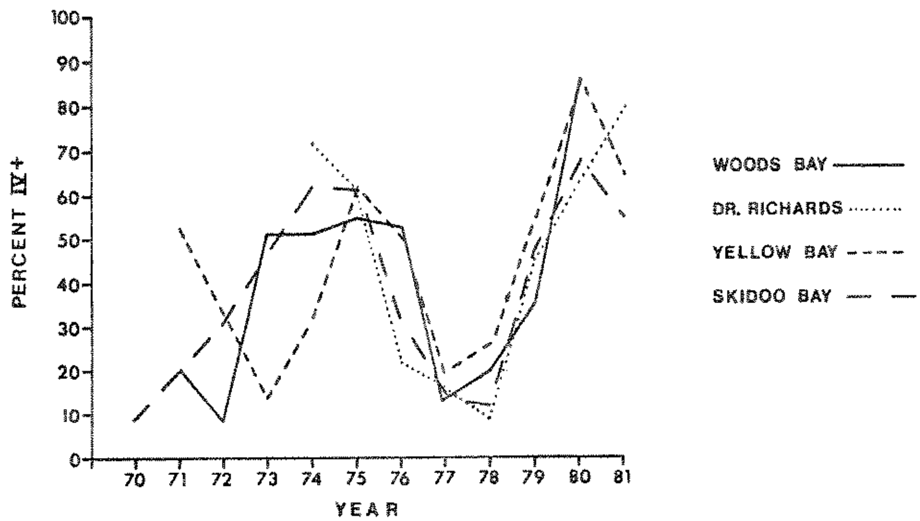
LAKE LEVEL FLUCTUATIONS AND AIR TEMPERATURES

During the major shoreline spawning period from 1 November through 16 November 1981, Flathead Lake elevations declined from 881.2 m (2891.24 ft.) to 880.91 m (2890.14 ft.)(Figure 13). The monthly decline in lake levels in December, January and February were 0.5 m, 0.75 m and 0.3 m, respectively. Although the minimum pool elevation of 879 m (2883.75 ft.) was reached on 9 March, 1982 and held only a few days, lake levels remained 2.4 m (8 ft.) below maximum pool for over two months. Highest lake stage of 881.7 m (2892.59 ft.) was recorded on 29 June. The average monthly lake stage increase during April, May and June was .8 m (2.65 ft.).

Minimum daily air temperatures at the climatoligic station located on Flathead Lake at Yellow Bay, were at or below 0°C for 108 days during the incubation period and below -10°C for 18 days (Figure 14). Temperatures decreased throughout the winter season and culminated in a week long period in February when minimum temperatures ranged between -11.7°C to -21.1°C. All redds constructed above lake bottom elevation of 879.3 m (2884.85 ft.) were exposed to these temperatures.

SPAWNING SITE INVENTORY AND MICROHABITAT

Parameters important to spawning site selection and successful embryo survival included occurrence of groundwater seepage or surface flow, intergravel dissolved oxygen, substrate composition, shoreline gradient and gravel movement. Information to define these parameters was collected from the four study spawning areas, Yellow and Skidoo bays and the two areas at Dr. Richard's Bay. Information was collected to a lesser degree at Crescent, Blue and Gravel bays.



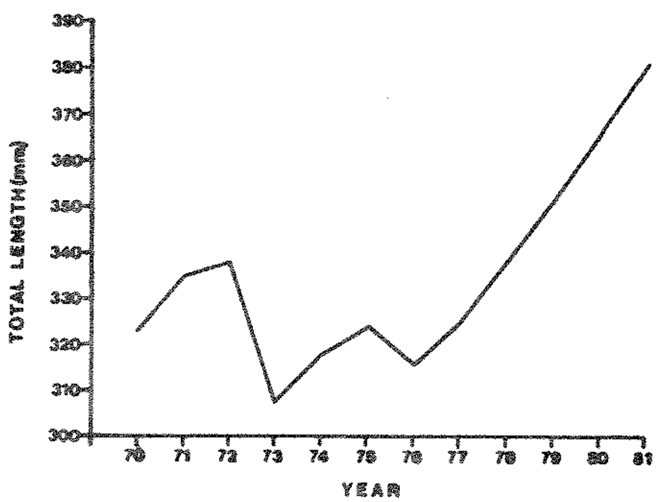


Figure 12. Percent composition of Age IV+ male and female kokanee spawners in four shoreline areas of Flathead Lake from 1970-1982. Total length (mm) of male and female kokanee spawners gill netted or seined from the east and west shores of Flathead Lake from 1970 to 1982.

Figure 13. Flathead Lake levels in meters and feet from 1 November 1981 to 30 June 1982. Dashed line represents missing data.

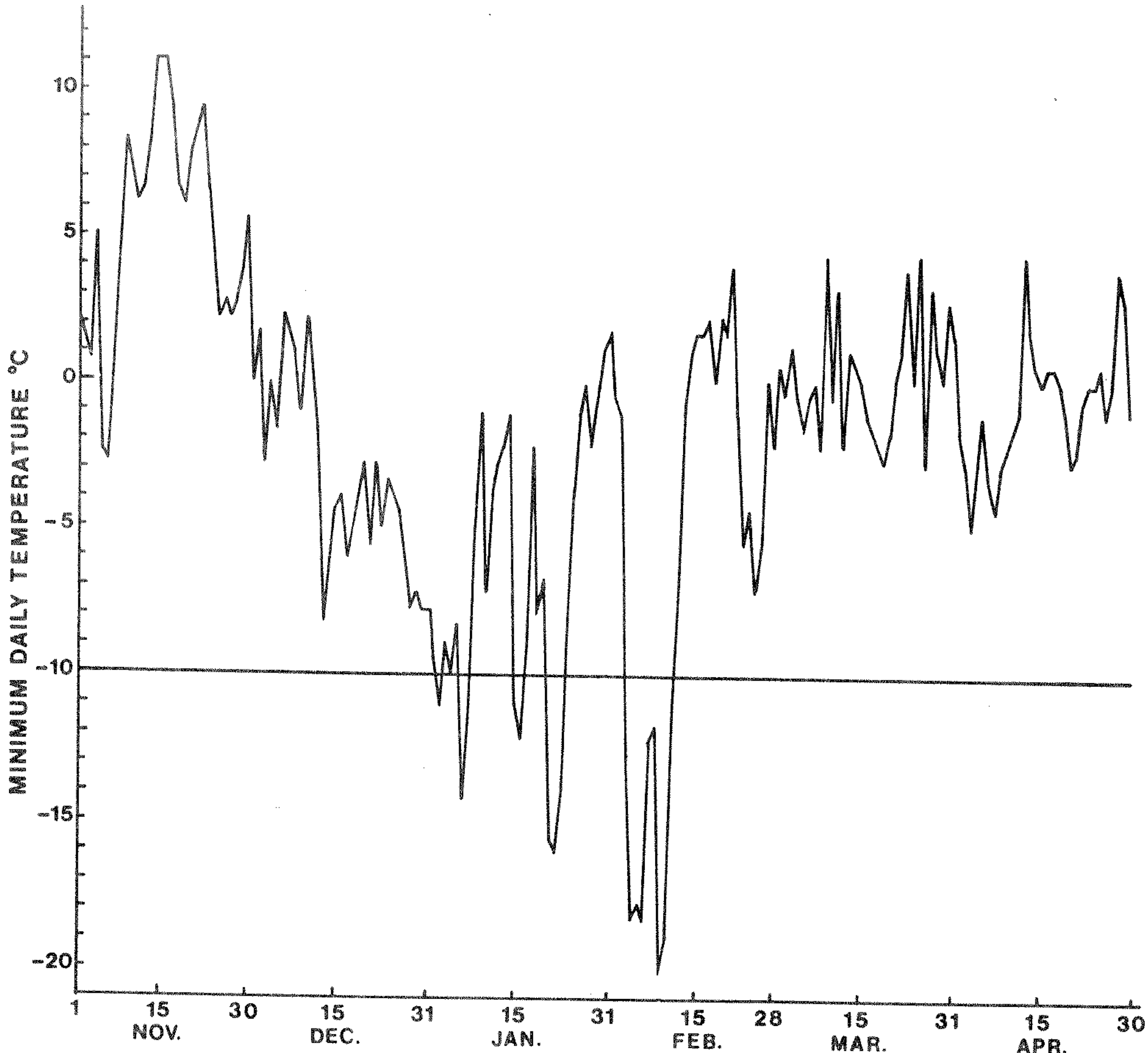


Figure 14. Minimum daily air temperatures at Bigfork climatological station (13S) at Yellow Bay on Flathead Lake, Montana. Period of temperature information includes 1 November 1981 through 30 April 1982.

Shoreline Gradient and Redd Distribution

Redd located in Flathead Lake were constructed in two distinctive shoreline gradient types (Figure 15). Spawning areas at Skidoo, Dr. Richard's and Crescent bays were characterized by a gentle gradient with an 8 to 10.4% slope. The majority of the redds located in these areas were above minimum pool elevation. The deeper areas, Yellow, Blue and Gravel bays were steeper with a mean gradient of 27.4%. The majority of redds spawned in these areas were located below minimum pool elevation.

The largest spawning area (468.3m^2) with the highest concentration of redds (124) was located in Yellow Bay (Appendix A, Figure 2). Approximately 30 more redds were randomly located within the bay, but not within the boundaries of the major spawning area. The redds were constructed in a normal distribution pattern between bottom elevations of 878.7 m (2882.72 ft.) and 873.6 m (2866.21 ft.) (Figure 16). Eighty percent of the redds were located between 875 m - 878 m.

One hundred and six redds were constructed in a 315 m^2 northern shoreline area of Dr. Richard's Bay (Appendix A, Figure 3). Redds were distributed between bottom elevations 878.9 m (2883.5 ft.) and 880.6 m (2889.13 ft.). All redds were located above minimum pool elevation. The 63 redds built in a southern area of Dr. Richard's Bay were concentrated in a 381.3 m^2 area (Appendix A, Figure 4). Redds were distributed between bottom elevations of 879.1 (2884.31 ft.) and 880.5 m (2888.81 ft.). All redds were located above minimum pool elevation.

The 86 redds counted within the major area at Skidoo Bay were located in a 328 m^2 area (Appendix A, Figure 5). Seventeen additional redds were located in the bay, but not within the boundaries of the major spawning area. Vertical distribution of the redds ranged between bottom elevations of 879.1 m (2884.14 ft.) and 880.4 m (2888.3 ft.). Eighty percent of the redds were constructed between bottom elevations of 879 m to 880 m (Figure 16). All redds were located above minimum pool elevation.

Seepage Flow and Dissolved Oxygen

Intergravel water flow through the spawning gravels supplied oxygen to embryos and removed metabolic wastes produced by the eggs. Foerster (1968) found subsurface flow or groundwater seepage to be characteristic of sockeye salmon shoreline spawning areas. Olsen (1968) found sockeye spawning in fine gravels and sand where groundwater seeps were present, and in larger substrate where no upwellings were present. He suggested that in larger substrate normal lake currents were enough to provide good water exchange.

All shoreline spawning areas in Flathead Lake were located at the outflow of a surface stream or an upwelling of groundwater. Yellow Bay Creek seeped into the Yellow Bay spawning area through a gravel windrow deposited during maximum pool. As the lake level began to decline in September, the creek's water seeped through the gravel dyke, emerging

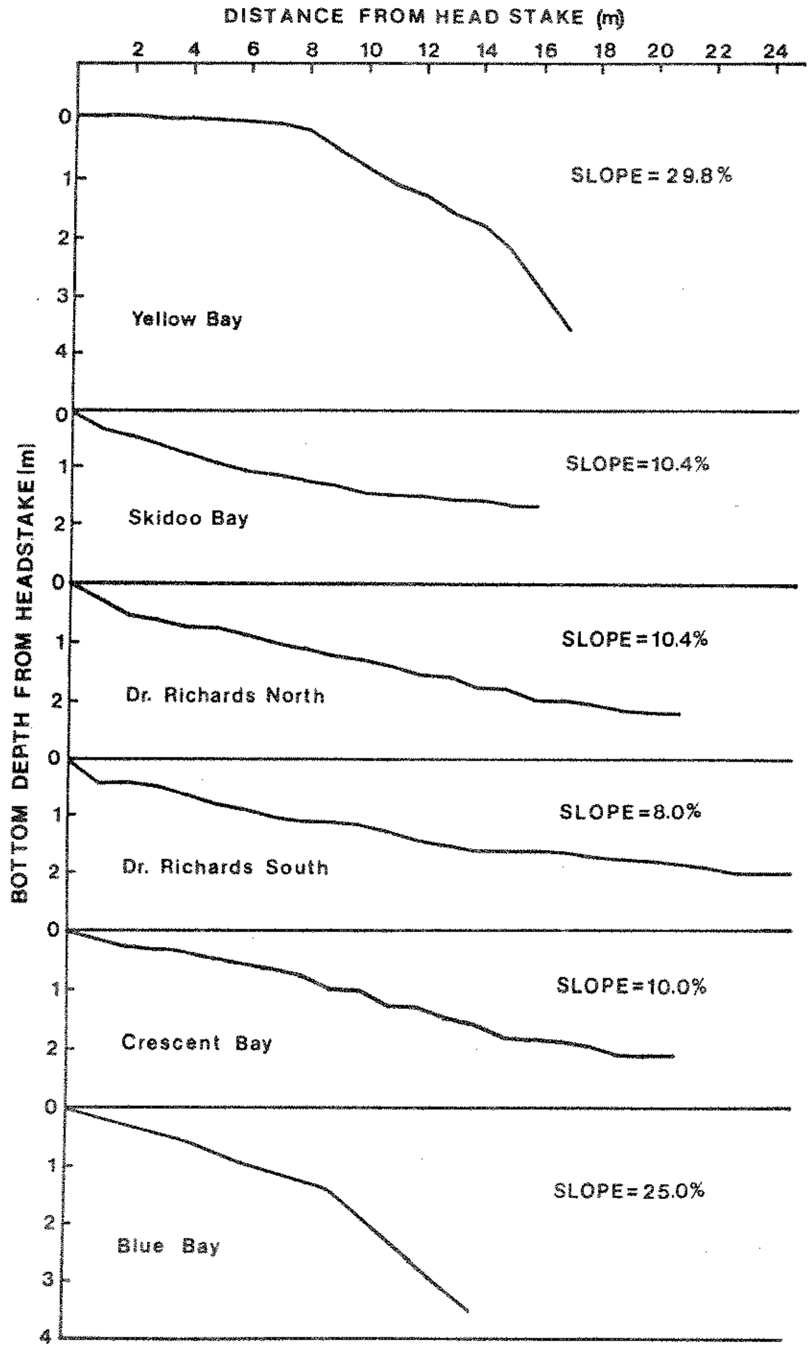


Figure 15. Shoreline slope by bottom depth (in meters) for Yellow, Skidoo, Dr. Richard's North and South, Crescent and Blue bays spawning areas.

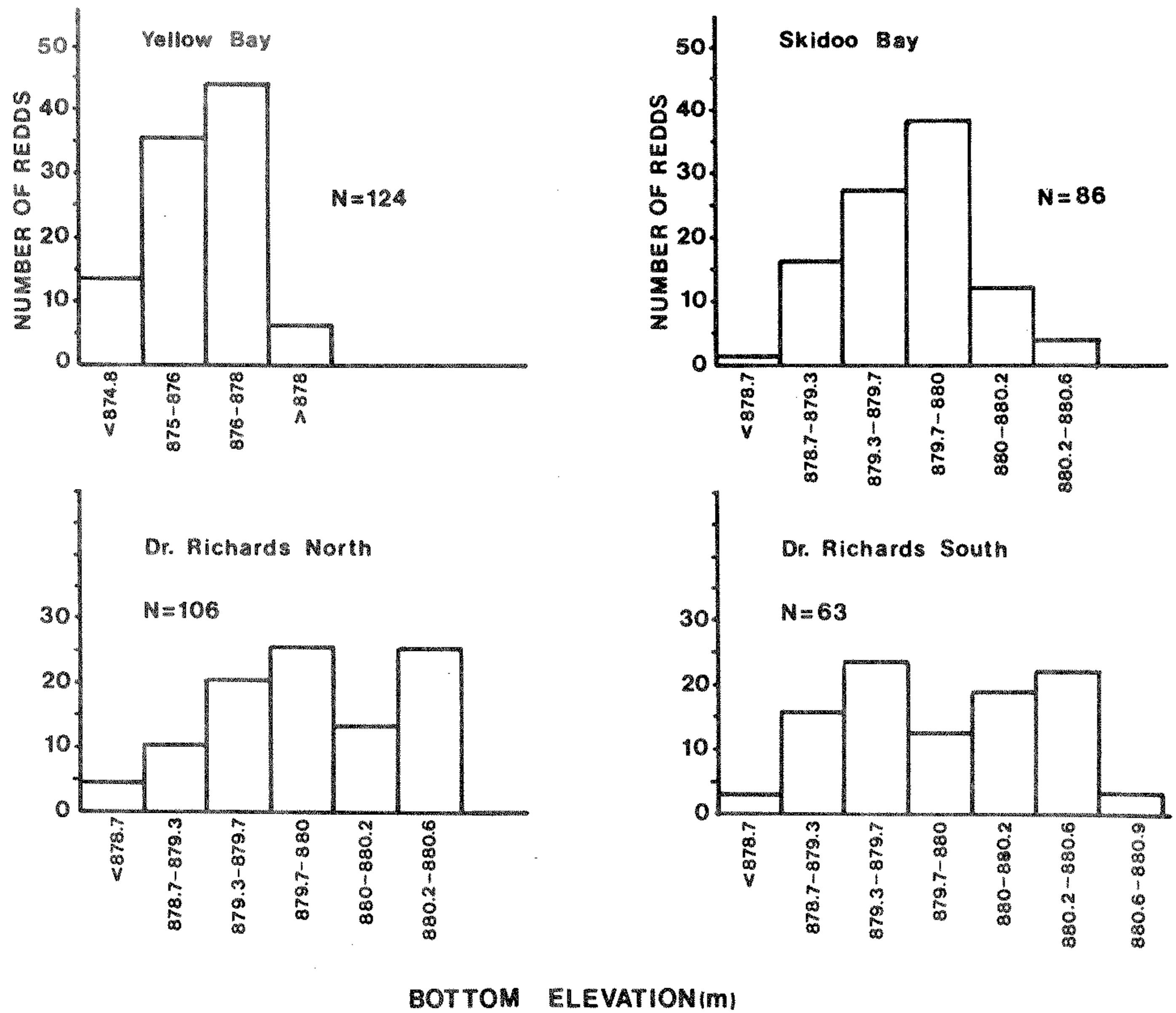


Figure 16: Vertical distribution of redds by bottom elevation in meter intervals for the spawning areas of Yellow and Skidoo bays and the two areas of Dr. Richard's Bay.

horizontally in a fan shaped pattern. The largest concentration of redds were located in front of this fan.

Intergravel dissolved oxygen concentrations varied between 0.9 to 9.9 mg/l along the transects in the Yellow Bay spawning area (Appendix A, Table 5). Concentrations tended to decrease with an increase in water depth. Along the eastern and center transects, concentrations decreased significantly at the deeper spawning boundary. These low concentrations of dissolved oxygen were not reflected in lower number of redds constructed in these areas.

Station Creek discharged near the middle of the northern spawning area in Dr. Richard's Bay. The southern spawning area was characterized by an unquantified source of groundwater inflow. Intergravel dissolved oxygen concentrations were never less than 8.2 mg/l in either area (Appendix A, Table 5).

The Skidoo Bay spawning area contained numerous groundwater seeps. Preliminary apparent velocity measurements were higher within the spawning area than those collected outside the spawning area boundary. Dissolved oxygen concentrations of the spawning area groundwater were never below 7.0 mg/l (Appendix A, Table 5).

Gravel Movement

General trends in gravel movement in four shoreline spawning areas were: 1) the zone of greatest scour or deposition was located within the wave zone; 2) lake stage fluctuation allowed the entire width of the spawning area to become 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 intense when rate of decline in lake elevation was greatest.

The least amount of gravel elevation change occurred along the transects in Skidoo Bay on the east shore and Crescent Bay on the west shore (Figures 17 and 18). This appeared to be a result of the protected location of both bays to the prevailing westerly winds and the nature of the substrate composition which was finer and more compacted than other areas. Lake stage fluctuation and the collapse of the gravel windrow in February created the most dramatic elevation change along the Yellow Bay transect (Figure 19). As a result of the windrow collapsing and washing into the lake, up to 0.7 m of gravel was deposited along the lower portion of the transect. Yellow Bay's gravel was loosely compacted and was exposed to southwesterly winds and storms. Dr. Richard's Bay, located in a small inlet on the east shore, was the most exposed spawning area to the prevailing winds. Considerable gravel movement occurred there during the incubation period, particularly in February (Figure 20).

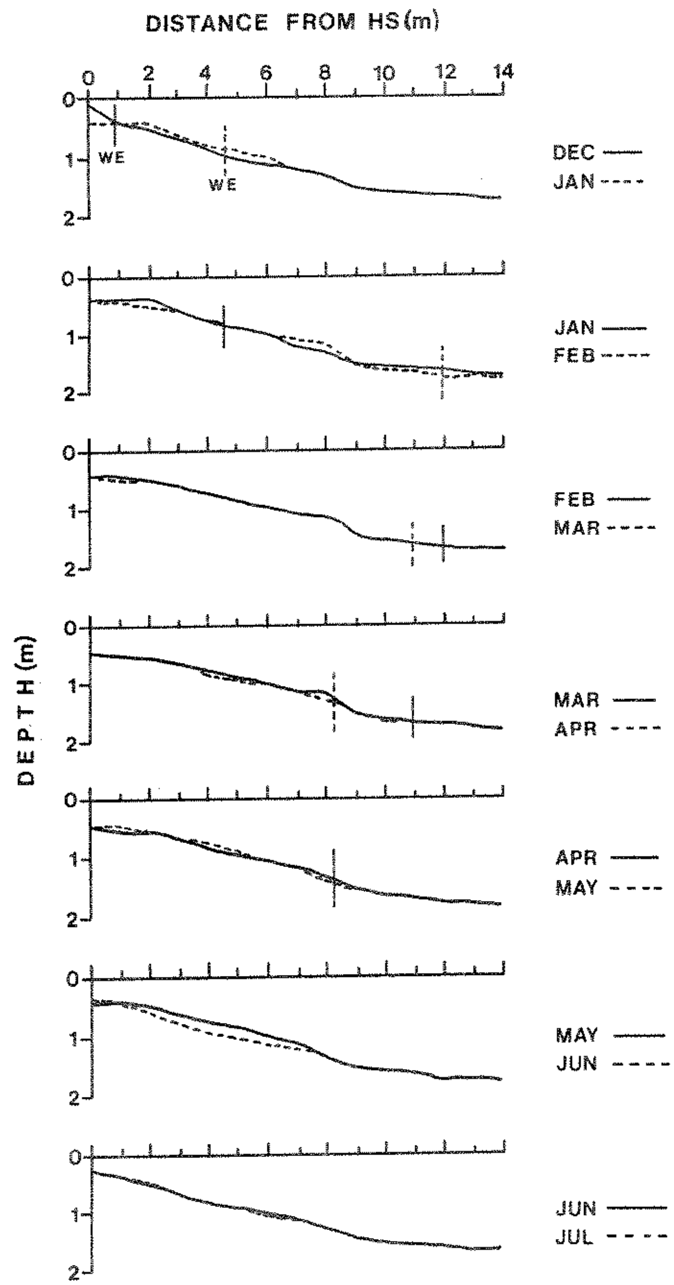


Figure 17. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Skidoo Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence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

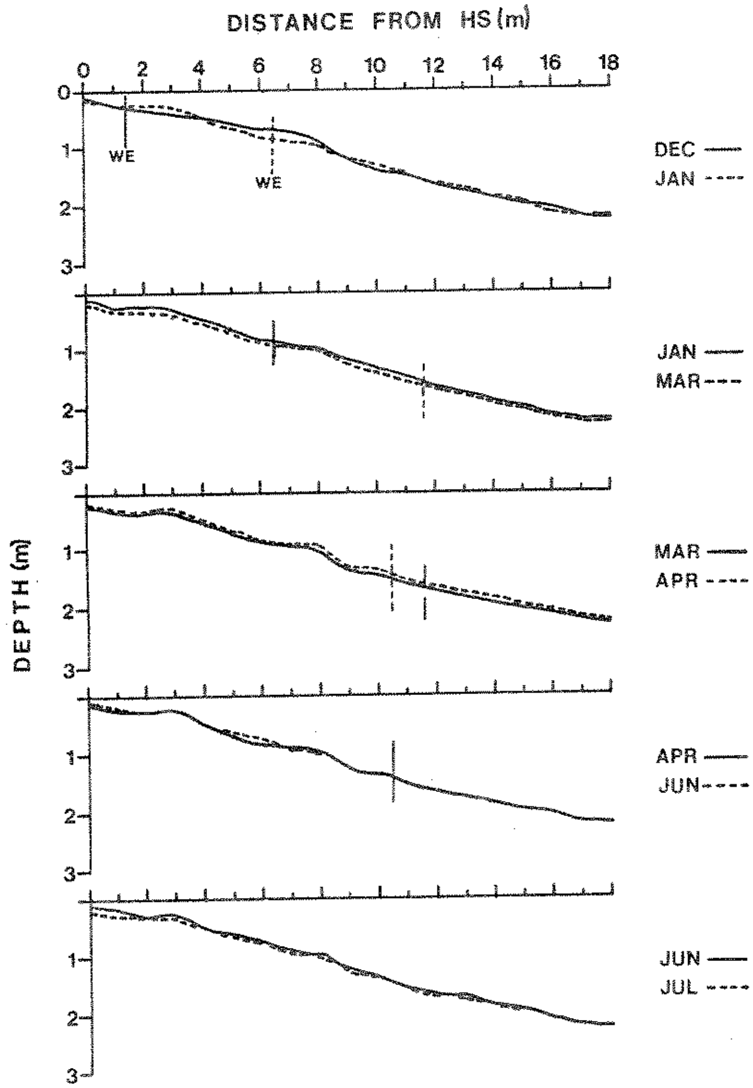


Figure 18. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Crescent Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence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

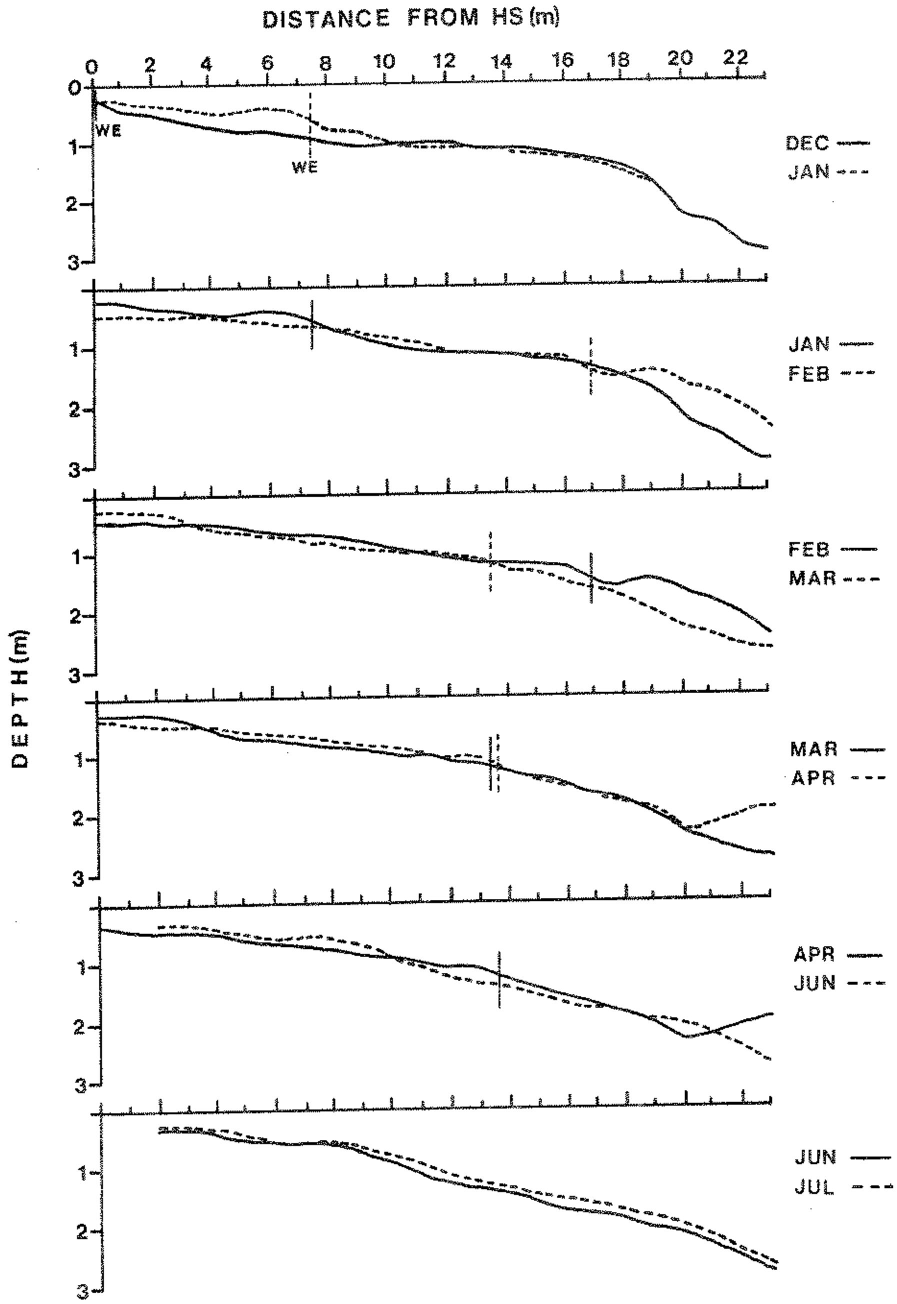


Figure 19. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Yellow Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements. Absence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

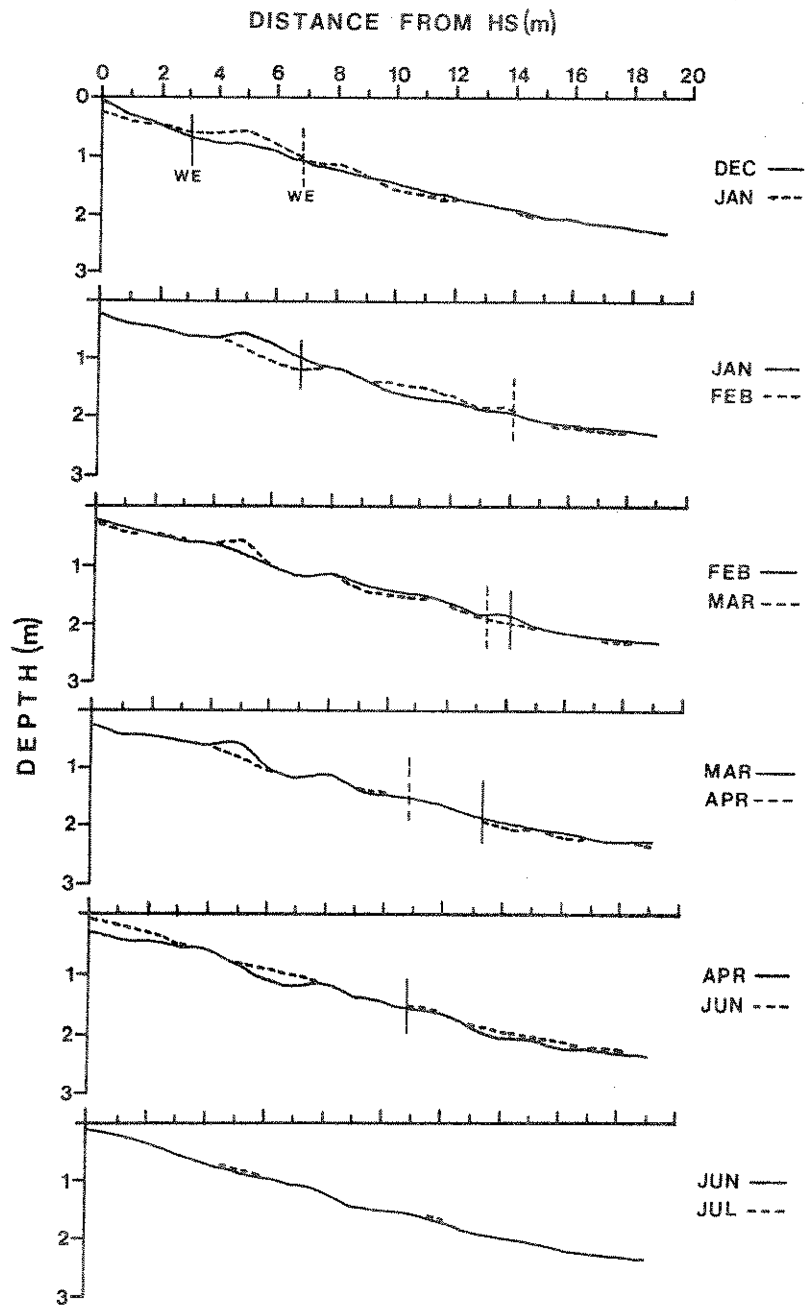


Figure 20. Changes in gravel elevation (meters) along a transect located perpendicular to the shoreline and spanning the width of the Dr. Richard's Bay spawning area. Adjacent months are compared in each graph. Perpendicular lines on transect represent location of water's edge at time of measurements.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

Substrate Composition

Spawning Area Characteristics

Eighty-three percent of the substrate composition from samples collected in the Skidoo Bay spawning area ranged between 6.35 mm and 76.2 mm in diameter. Kokanee selected normally distributed substrate in the Yellow Bay spawning area. Ninety-five percent of the substrate composition ranged between 2 mm and 16 mm in size. Eighty-six percent of the substrate in the Dr. Richard's spawning area was composed of material varying in size from 6.35 to 76.2 mm. Reiser and Bjornn (1979) reported sockeye salmon selecting substrate within the 13-102 mm range. Andrew and Geen (1960) found sockeye spawning in substrate generally less than <50.8 mm, but noted gravel size selection was partially a function of body size.

Vertical and Horizontal Distribution

Although observable trends in substrate composition existed horizontally and vertically in each spawning area, no definite pattern occurred between areas. Highest percent fines (<6.4 mm) in Skidoo Bay occurred on the westerly transect, decreased easterly and increased with depth (Appendix B, Figure 1). The pattern in Yellow Bay was reversed with percent fines increasing easterly and with a decrease in depth (Appendix B Figure 2). Due to the loss of four of the nine samples in Dr. Richard's Bay, an analysis of the vertical and horizontal composition was not possible (Appendix B, Figure 3). The overall trend from Dr. Richard's Bay was a high percentage of larger substrate (>16 mm) with a lesser amount of gravel and sand. The distributional pattern in Yellow Bay with the highest percentage of coarse material (>50.8 mm) located at the deepest stratum was similar to the major spawning area in Banks Lake, Washington (Stober et al. 1979a).

Temporal Distribution

A measureable change in substrate composition occurred between the spawning and incubation period in all shallow gradient spawning areas (Figure 21 and 22). An increase in larger substrate (>50.8 mm) occurred at Dr. Richard's Bay. This probably resulted from wind and wave action in this exposed bay removing the fines and gravels from the shoreline substrate. A considerable decrease occurred in large size gravels (>6.4 mm) with a shift to greater percent composition of fines (<6.4 mm) in the Skidoo Bay spawning area. Percent fines increased from 12-20% during spawning to 26.2 to 67.5% during incubation. This may have resulted from wind and wave action suspending fine sediment from Skidoo Bay and redepositing it in the spawning area.

Area Substrate Composition Comparisons

Significant differences in mean substrate composition existed between the three major spawning areas. All gravel sizes in Yellow Bay and Skidoo Bay areas were significantly different ($p<.05$) with the exception of the 16-50.8 mm size range. Dr. Richard's Bay had significantly greater percent composition of the largest and smallest substrate sizes ($p<.05$)

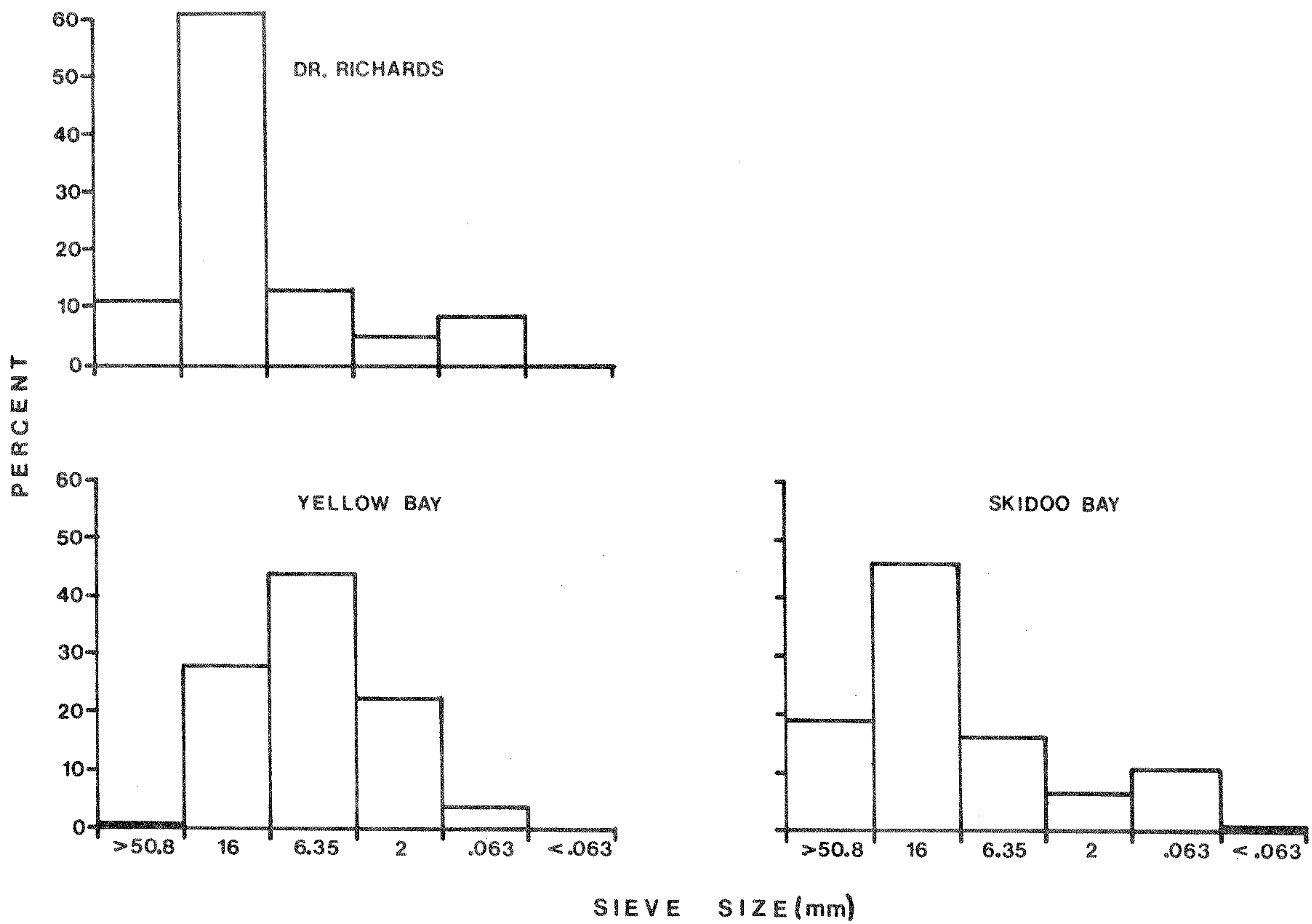


Figure 21. Mean percent substrate composition of Dr. Richard's, Skidoo and Yellow bays' spawning areas randomly collected in November, 1981.

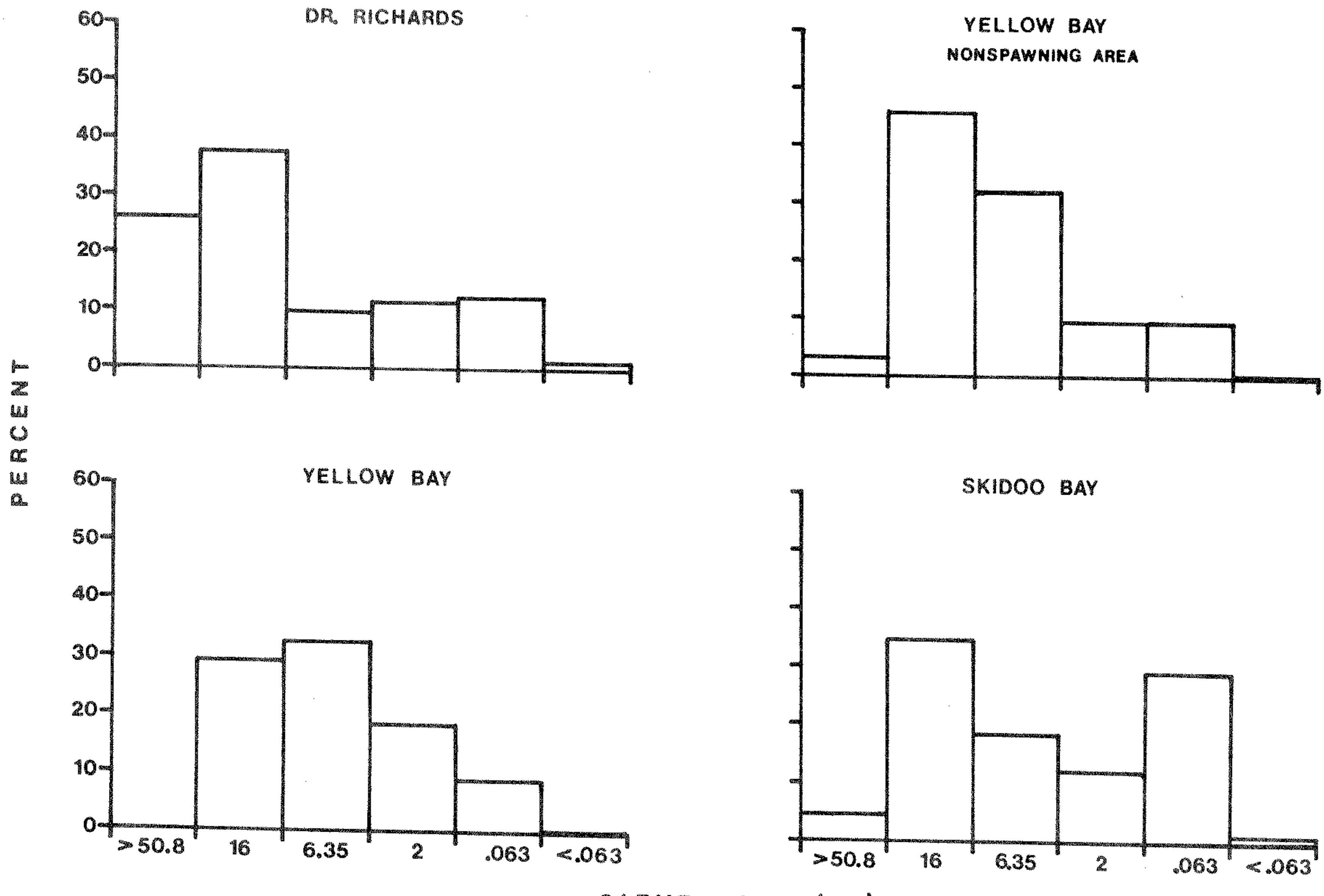


Figure 22. Mean percent substrate composition of Dr. Richard's, Skidoo and Yellow bays' spawning areas collected along transects and from nonspawning areas of Yellow Bay in March, 1982.

compared to Yellow Bay which had a larger proportion in the 2 and 6.35 mm sizes ($p<.05$). The substrate of Dr. Richard's and Skidoo bays spawning areas were more similar with significant differences only in three of the six gravel sizes seived ($p<.05$). There was also no significant differences in mean substrate composition within the Yellow Bay spawning area to that collected outside the spawning area. Based on the substrate composition analysis of the three areas, there did not appear to be a strong selection by shoreline spawning kokanee for a particular percent composition within the gravel seive range of .063 to 76.2 mm.

EMBRYO SURVIVAL AND DEVELOPMENT

The intergravel environment of salmonid spawning areas is seldom conducive to high survival of incubating embryos. Royce (1959), Koski (1966) and Johnson (1965) 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.

Natural Redd Sampling

Only a portion of live embryos were collected from a redd during the initial sampling period. Redds were then resampled throughout the incubation period to monitor cumulative mortality.

Spawning Areas Above Minimum Pool Elevation

Thirteen percent of the redds located above minimum pool elevation were excavated in Skidoo Bay and the two areas in Dr. Richard's Bay during the incubation period (Appendix C, Figures1, 2 and 3). Mean survival to hatching for the 33 redds sampled was 9%. Mean percent survival for Dr. Richard's Bay North, Dr. Richard's Bay South and Skidoo Bay was 0, 12% and 19%, respectively. Survival for individual redds at each area were listed in Appendix C, Table 1.

Lake water maintaining embryo wetness and providing insulation from subzero air temperatures appeared to play a significant role in embryo survival in exposed shoreline spawning areas of Flathead Lake. Of the seven redds where partial embryo survival occurred in Dr. Richard's Bay South and Skidoo Bay, five of these redds were located at or near minimum pool (Table 3).

Table 3. Elevation in meters, percent survival at time of last sampling and stage development in 17 redds excavated in Dr. Richard's Bay South and Skidoo Bay, 1982. Minimum pool of 879.0 m was reached on 9 March , 1982.

Location	Redd elevation (m)	Percent survival	Stage of development
Dr. Richard's Bay	880.2	0	
Dr. Richard's Bay	880.0	0	
Skidoo Bay	880.0	0	
Skidoo Bay	879.9	100	eyed/ sac fry
Skidoo Bay	879.7	0	
Skidoo Bay	879.7	0	
Skidoo Bay	879.7	0	
Dr. Richard's Bay	879.6	7.7	
Dr. Richard's Bay	879.5	0	
Dr. Richard's Bay	879.4	0	
Dr. Richard's Bay	879.4	0	
Dr. Richard's Bay	879.3	0	
Skidoo Bay	879.3	10	sac fry
Dr. Richard's Bay	879.2	43.5	30% sac fry
Dr. Richard's Bay	879.1	50	eyed
Skidoo Bay	879.1	23.2	sac fry/yolk sac absorption
Dr. Richard's Bay	879.05	13.8	eyed

Although groundwater was available to redds exposed by lake drawdown in Skidoo Bay, complete mortality occurred in 57% of the redds excavated (Appendix C, Table 1). After a seven day period of ambient minimum air temperatures which ranged between -11.7°C and -21.1°C, frozen eyed eggs were collected from these redds. A redd containing live eyed-eggs and alevins was located near the redds where freezing had caused total mortality. Percent composition of fine sediments and groundwater volume and velocities may play an important role in survival of exposed redds. Reiser and White (1981a) reported best survival of chinook embryo in dewatered incubation channels which contained a small amount (10 percent) of fine material (<.84 mm). Up to 65 percent mortality resulting from freezing was reported by McNeil (1967) in an Alaskan stream after maximum daytime temperatures remained below 0°C for at least two consecutive days. Kimsey (1951) reported all eggs, except those in seepage areas, experienced at least occassional freezing during drawdown in a shoreline area of Donner Lake, California. In green egg experiments with kokanee embryos, Fraley and Graham (1982) reported better survival in dewatered channels containing moderate amounts (21 to 40 percent) of fine material (<6.35 mm) when air temperatures were well below 0°C. Total mortality occurred in all channels after 8 hours of exposure to air temperatures of -13 to -23°C. Significant mortality occurred in all sediment mixtures at air temperatures below -10°C. Similar results were obtained by McMullin and Graham (1981).

There was no survival in 6 of the 13 redds sampled in Dr. Richard's Bay South. All six redds were exposed by drawdown for at least two months of the incubation period. The shallow depth of eggs deposited in this area (5-10 cm) did not insulate them from dessication and freezing. After lake drawdown, groundwater depth in the area was 15-30 cm below egg deposition and did not maintain egg wetness. In experimental channels, Reiser and White (1981a) reported steelhead and spring chinook alevins tolerated less than 10 hours of dewatering. Incubating eggs, however, were able to tolerate long periods of dewatering if the gravels remained damp. Hawke (1978) found high survival of pre-eyed and eyed eggs that were stranded up to three weeks in gravel that was damp. His results were similar to those of Reiser and White concerning alevins intolerance to dewatering. All eggs were reported by Stober et al. (1979a) to be dead in dewatered gravels of Banks Lake, Washington.

Only four eggs were found in 13 redds randomly sampled in the Dr. Richard's Bay North spawning area. The area was scoured by severe wave action which occurred prior to initial redd sampling in January. Depth of scour, as measured by rebar buried in individual redds, was 5 to 15 cm. McNeil (1967) reported high mortality from gravel movement by no live or dead eggs being collected from 68 points sampled in the Harris River in Alaska. He also noticed a significant reduction in volume of fines and silts in the substrate composition. Gangmark and Bakkala (1960) estimated 96 percent mortality to emergence in king salmon as a result of streambed movement during incubation.

Spawning Areas Below Minimum Pool Elevation

Redds marked in Yellow Bay were located below minimum pool (Appendix C, Figure 4). Twelve of the 14 redds marked were sampled during the incubation period (Appendix C, Table 1). Only five of the redds sampled contained eggs with a mean percent survival of 15.9 percent. Lowest survival in individual redds corresponded closely to areas with low levels of intergravel dissolved oxygen (Table 4). The lower oxygen concentrations were found near the deepest boundaries of the spawning area. In the Blue Bay spawning area and in egg bag lines in Yellow Bay, low dissolved oxygen concentrations were also found correlated with increased depth. Sampling of shallower redds in Yellow Bay terminated in February after massive gravel deposition occurred in the area. This resulted from the natural gravel windrow holding Yellow Bay Creek, eroding and finally breaking. Approximately 40 percent of the total redds in the Yellow Bay area were within the deposition area. Of the eggs sampled at the end of January in the depositional area, only 6 percent were faintly eyed. The extent of mortality from agitation or jarring depends on the stage of embryonic development (Foerster 1968). Twenty to fifty percent mortality can occur between the time when cell division commences until eye pigmentation begins if movement occurs.

Numerous investigators have researched the effects of dissolved oxygen concentrations on embryo survival and development. Table 5 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. Immediately before hatching has been determined to be the stage of development when demand for dissolved oxygen concentrations were greatest (5.8-10 mg/l). 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 hatch 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.

Experimental Egg Plants

Egg bags were planted to monitor embryo survival above or near minimum pool elevation in habitat influenced by a stream or subsurface flow, at bottom elevations of 878.3 m, 878.9 m and 879.5 m in Yellow Bay and the outlet of Dee Creek. Survival in all bags after one month of incubation and prior to drawdown exposure, was 100 percent. Due to extensive wave action and gravel movement in early February, all bags at or near minimum pool elevation in Yellow Bay and Dee Creek were lost following the initial harvest.

Table 4. Percent survival of five redds sampled in the Yellow Bay spawning area in January, 1982. Intergravel dissolved oxygen concentrations in mg/l are included.

Redd bottom elevation (m)	Percent survival	Intergravel Oxygen oxygen concentration (mg/l)
873.9	0	2.8
874.3	10	0.9
874.4	0	6.9
875.4	0	0.9
877.5	69.6	9.1

Table 5. 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[1/] dissolved oxygen
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.

Three deeper areas were planted with egg bags to compare survival below minimum pool in habitats influenced and uninfluenced by surface or subsurface flow. After measuring various physical parameters at each egg bag line, it was determined that considerable substrate composition variation and an incomplete understanding of subsurface flow dynamics existed. Substrate composition for the three areas were displayed in Appendix B, Figures 4-6). Although similarities in certain intergravel parameters and their effect on embryo survival occurred between the three study sites, the original purpose for the selection of these areas was no longer pertinent. Egg bags were planted at lake bottom elevations of 876.9, 877.2, 877.7 and 878.0 m in two areas in Yellow Bay and one area in Dr. Richard's Bay. Physical descriptions of the sites and their monthly embryo survival are listed in Appendix C, Table 2.

Complete mortality occurred in the deepest lines in all three areas where intergravel dissolved oxygen concentrations varied between 0 to 2.8 mg/l. After being in this anaerobic environment for a month, eggs were black and marbled with hydrogen sulfide gas being released when eggs were broken open. In the two areas in Yellow Bay, survival dropped off considerably in the upper lines after the first month and development of surviving embryos was retarded. This may have resulted from low intergravel dissolved oxygen concentrations, cooler water temperatures, or inadequate groundwater velocities. Highest embryo survival occurred in the upper two lines at Dr. Richard's Bay. Survival decreased with advanced development, but 44 percent of the eggs planted survived to alevin stage. High survival was attributed to 75-100% substrate composition being >16 mm. This allowed for normal lake currents to provide good water exchange to the eggs.

Embryo Development

Embryo development was monitored from egg bag plants in Dr. Richard's Bay, Yellow Bay and the outlet of Dee Creek. Considerable variation in temperature units needed for development existed between areas as well as between egg bag lines within the same area (Appendix C, Table 3). Development from Dr. Richard's Bay and at the outlet of Dee Creek fell within the range of accumulated temperature units reported by other studies on kokanee salmon (Table 6). Eggs in the Yellow Bay area needed 150-300 additional temperature units than the other areas to reach the eyed stage. Oxygen concentrations of the intergravel environment of eggs with delayed development in Yellow Bay were only 5.5 mg/l.

Deformities, premature hatching, retardation in development and weaker and smaller fry have been related to oxygen stress by Alderdice et al. (1958), Shumway et al. (1961), and Silver et al. (1963). In laboratory studies by Mason (1969), developmental delay was overcome by an additional 66 temperature units at 5 mg/l and 168 temperature units at 3 mg/l for coho fry to complete development. Temperature may also retard embryonic development or cause mortality. Alderdice and Velsen (1978) and Stober et al. (1978) reported more temperature units were recorded

Table 6. 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.

Location	100% eyed		35-75% hatch		Yolk sac absorption	
	Centigrade temperature units (CTU)	Number of days	CTU	Days	CTU	Days
Dr. Richard's Bay	331.4	82	526	143	710.6	177*
Dee Creek	234.2	77	---	---	---	---
Yellow Bay	470.3	112	619.2	143	---	---
Yellow Bay	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	---

* Only partial yolk sac on 50% of alevins.

for chinook and kokanee salmon at elevated or depressed incubation temperatures.

Substrate Composition and Embryo Survival

The adverse effects of fine substrate on salmonid embryo and fry survival 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.

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 shoreline spawning areas can be subjected to accumulations of fine sediments.

Percent of fine sediments have been the standard method of describing substrate composition of salmonid spawning gravels. Problems with this method have related to determining standard seive 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. These include geometric mean (Platts et al. 1979), fredle index (Lotspeich and Everest 1980) and cumulative particle size distribution (Tappel 1981 and Irving in press). These methods have been designed to be used in a predictive manner in determining embryo and fry survival from substrate composition.

Percent survival to emergence was predicted using survival curves created from previous studies on salmon and steelhead. These curves were used in predicting substrate composition and survival for three east shore spawning areas and one west shore spawning area of Flathead Lake (Figure 23-26, Table 7).

Table 7. Predicted mean percent survival by substrate composition for four shoreline areas by geometric mean, fredle index, percent fines <6.4 mm and cumulative particle size distribution.

Location	Geometric mean	Fredle index	Percent Composition <6.4mm	Cumulative Particle Size Distribution
Skidoo Bay	46.8	53	28	34
Yellow Bay	45	78	47.6	60
Crescent Bay	47.9	79	51	42.9
Dr. Richard's Bay	95	90	59.7	57

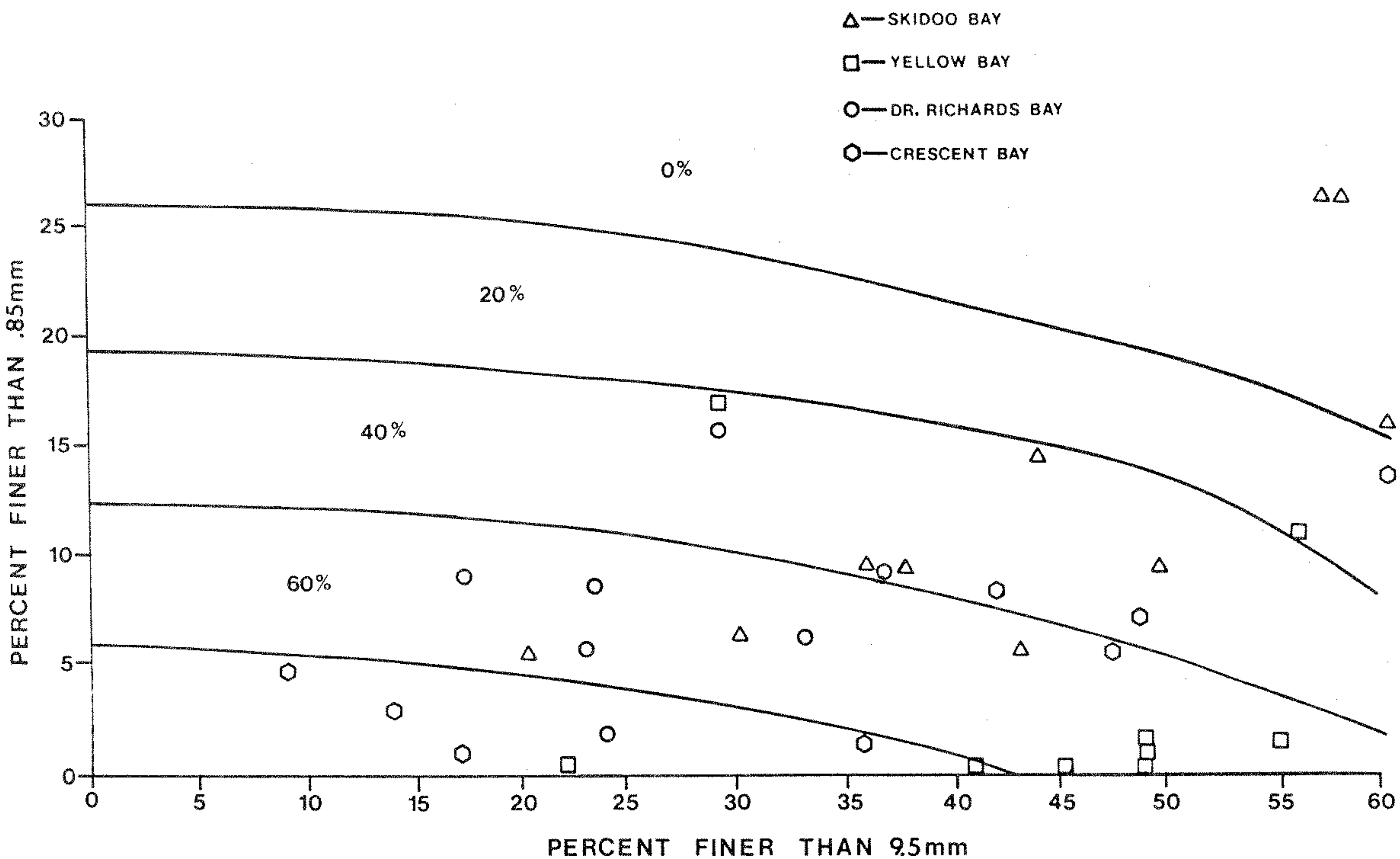


Figure 23. Predicted kokanee egg survival based on survival curves determined from kokanee salmon studies (Irving in press). Nine substrate samples were collected from four spawning areas of Flathead Lake along transect lines.

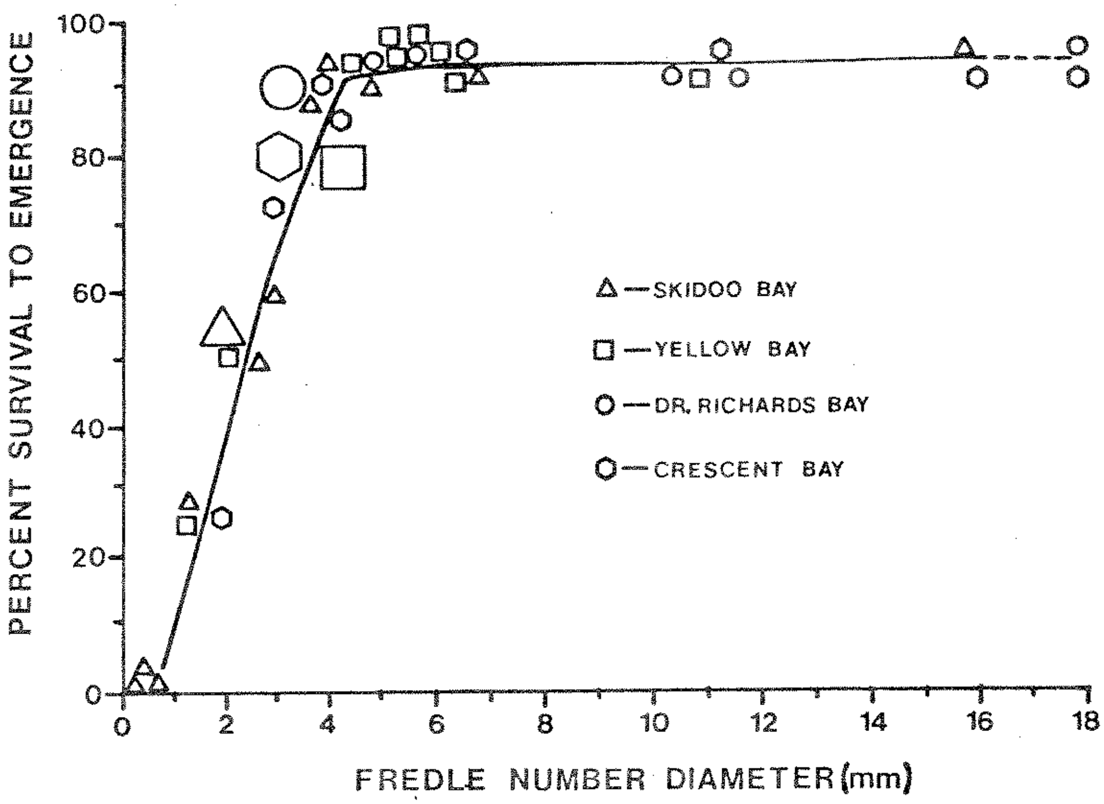


Figure 24. Predicted kokanee embryo survival to emergence in four spawning areas of Flathead Lake based on salmon and steelhead studies (Tappel 1981). Analysis was based on fredle indices calculated from nine samples collected from the spawning area. Larger symbols denote the mean survival for each area.

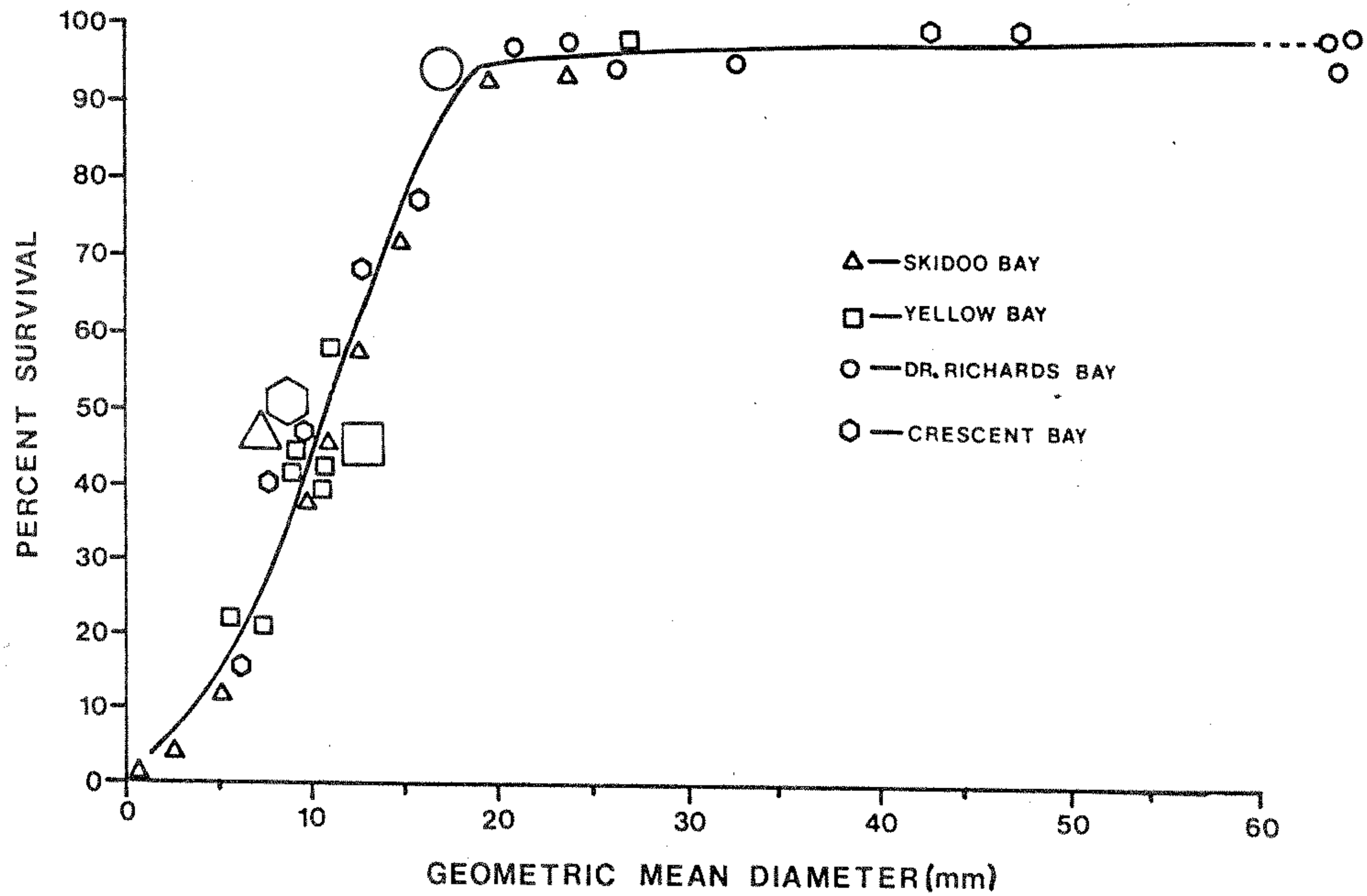


Figure 25. Predicted survival of kokanee embryos in four shoreline spawning areas of Flathead Lake based on salmon and steelhead studies (Platts et al. 1979). The analysis was based on geometric means calculated from nine samples from each spawning area. The larger symbols denote the mean percent survival for each area.

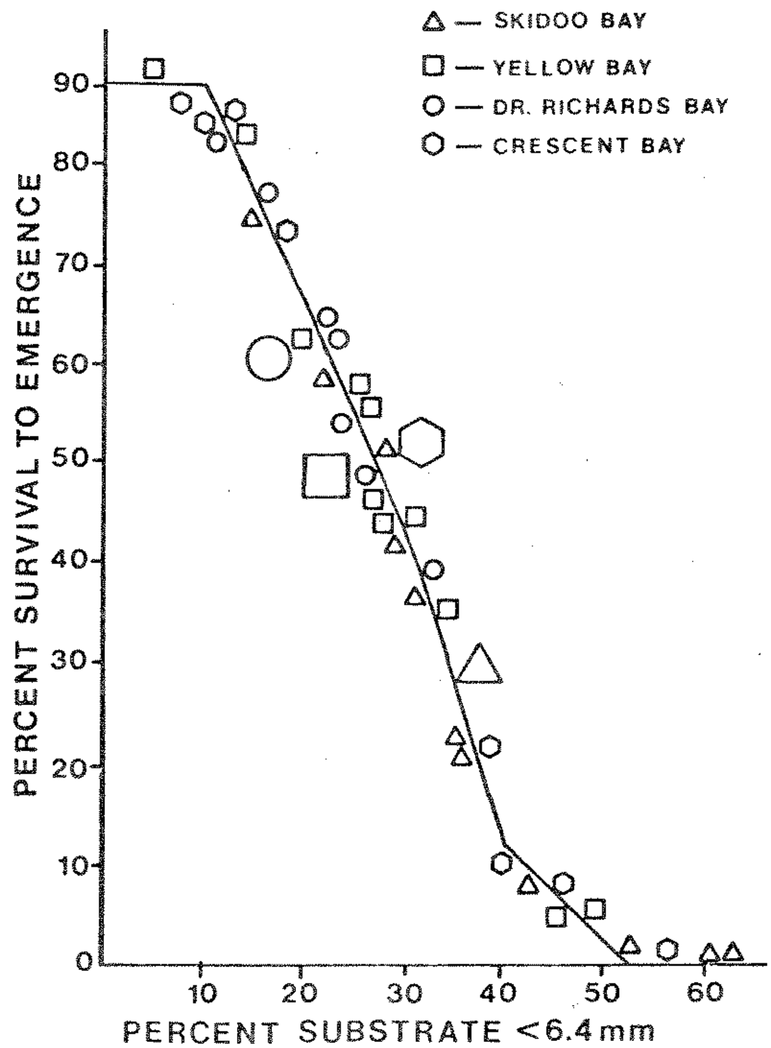


Figure 26. Predicted survival to emergence of kokanee embryos in four shoreline areas of Flathead Lake based on salmon studies using percent fine material less than 6.4 mm (Reiser and Bjornn 1979). The analysis was based on percent fines <6.4 mm from nine samples from each spawning area. The larger symbol denotes the mean percent survival for each area.

Predicted survival by three of the methods was similar for the four areas. Based on these predictive methods and excluding direct embryonic mortality by freezing and dessication created by lake drawdown, substrate composition may account for 10 to 72 percent of fry mortality in Skidoo, Crescent and Dr. Richard's bays. As reported earlier, measureable changes in substrate composition in Skidoo Bay occurred between spawning and fry emergence. The change was most apparent in material less than 6.4 mm in diameter. Because of the more extreme impacts observed from exposure by lake drawdown on embryo survival, it is difficult at this time to assess the role of substrate composition on survival.

FRY EMERGENCE AND DISTRIBUTION

Fry Emergence

Spawning Areas Above Minimum Pool Elevation

Approximately 200-300 sac fry emerged from the gravels of Skidoo Bay during 10 and 11 March and were found in groups of 20-30 along the water's edge of the spawning area. These prematurely emerging sac fry had an average length of 20.7 mm, 25% smaller than buttoned-up fry emerging in Blue Bay. A predictive program was used for determining accumulated temperature units for the fry by measurements of total length, eye diameter, and head width (Rumsey and Hanzel, MDFWP, Kalispell)(Appendix D, Table 1). The fry had accumulated an average of 546 centigrade temperature units, which verified these fry had recently hatched (Table 6). It is unknown where these fry emerged from in the spawning area or if they moved laterally to emerge. Phillips et al. (1975), Shelton (1955) and Koski (1966) reported stress by entrapment from high percent fines caused premature emergence.

No eggs or fry were found in several redds excavated in Skidoo and Dr. Richard's bays on 22 April. These redds had previously contained live eggs and alevins when sampled in March. Emerging fry were not captured in Skidoo or Dr. Richard's bays using shallow water fry traps, net towing or electrofishing. Since the lake did not completely wet the spawning area until 28 May, any successful fry emergence that may have occurred involved lateral movement to some degree. 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. Although groundwater flow existed in the exposed portion of the Skidoo Bay spawning area, fine sediment levels (<6.4 mm) up to 65% of the composition may have restricted lateral movement by fry.

Spawning Areas Below Minimum Pool Elevation

Emergence traps were placed in the Blue and Yellow bays spawning areas on 30 March and in Gravel Bay on 16 April. The traps were checked weekly and remained in place until 20 June, 1982. Replacement of traps and collecting bottles occurred frequently in Yellow Bay due to wave action moving and destroying traps. Emerging kokanee fry were captured only in traps located in the Blue Bay spawning area (Appendix D, Table 2 . Two hundred twenty-seven fry were captured in six of the eight traps in the spawning area. The first emerging fry were captured on 9 April and fry continued to emerge until 8 June (Figure 27). A peak in emergence occurred on 29 April, three weeks after the first fry had been captured. Koski (1966) reported peak emergence for coho salmon occurring 8 to 10 days after first emergence. Stober et al. (1979b) reported similar results for kokanee fry emerging from shoreline areas in Banks Lake. Koski (1966) and Dill (1969) reported a general trend toward a longer period of emergence with a higher percentage of fines in the substrate composition. Percent substrate <6.4 mm in the Blue Bay spawning area varied from 16.4 to 55.1 percent (Appendix B, Figure 7). Prolonged emergence could have resulted from a high percentage of fines at certain redds in the spawning areas.

As a result of the large concentration of redds located in the Yellow Bay spawning area, twelve traps were randomly placed in the area at elevations ranging from 874.2 m (2867.93 ft.) to 878.6 m (2882.53 ft.). No kokanee fry were captured throughout the two-month period the traps were in the area. Redside shiner (*Richardsonius balteatus*) and slimy sculpin (*Cottus cognatus*) were the only species caught in the traps. The low intergravel dissolved oxygen levels and considerable gravel movement during the incubation period may have resulted in extremely high embryonic mortalities.

Fry Distribution and Shoreline Plants

Kokanee fry distribution in Yellow and Blue bays were monitored biweekly with tows beginning at dusk. Towing was performed from 13 April to 9 June,1982. The fry catch during the two-month period consisted of three fry from the Blue Bay spawning area (Table 8). Whitefish fry were captured from all bays where towing was performed.

Sixty-seven thousand kokanee fry were planted in May and June in three shoreline areas (Table 9). Fry were released in two shoreline areas on the east shore, Blue Bay and Skidoo Creek outlet, and Crescent Bay on the west shore. All three areas were selected on the basis of substrate composition, spawning habitat below minimum pool and groundwater or surface flow availability (Appendix D, Table 3). All areas had historically been used by shoreline spawning kokanee in the 1950's, but showed little or no use during 1981. Plants were made to assess the methodology of standpipe planting for imprinting purposes, kokanee survival from emergent fry to adult and the potential of these three areas to successful incubate kokanee embryos. Approximately 2 to 10 percent mortality occurred during planting as a result of crushing by lake substrate within the standpipes. To monitor planted fry distribution and survival, the biweekly fry tows

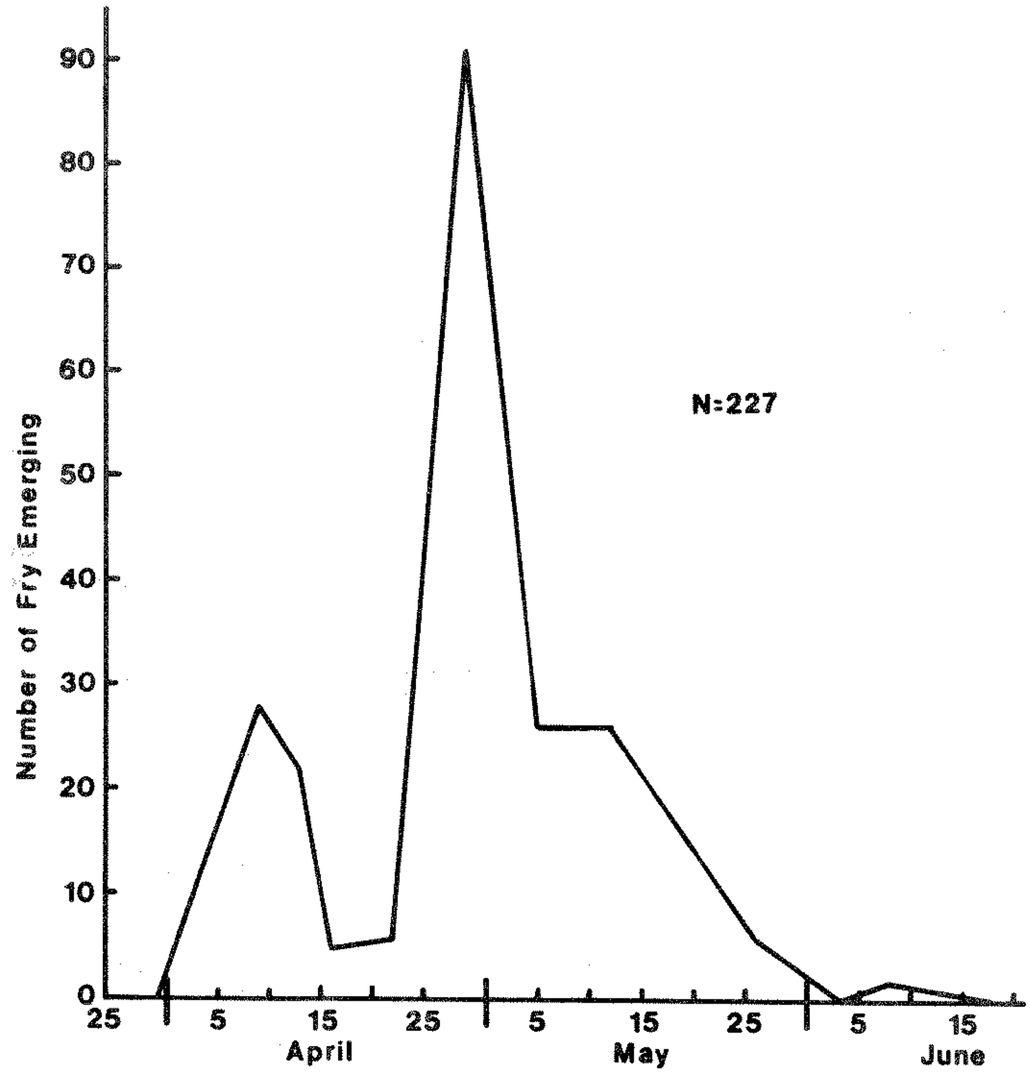


Figure 27. Mean weekly kokanee fry catch from eight emergence traps in Blue Bay, Flathead Lake from 30 March to 15 June 1982.

Table 8. Location, date and catch of biweekly tows in shoreline areas of Flathead Lake during April through June, 1982. Kokanee = KOK; Whitefish = WF.

Date	Blue Bay	Yellow Bay	Other Bays
4/13	Unsuccessful - buried net		
4/14	4 tows - 12 WF		
4/27	4 tows - 11 WF	4 tows - 2 WF	
5/5	4 tows - 9 WF, 2 KOK	2 tows - 1 shiner, 2 WF	Shocked Skidoo Bay - 30 min. caught 1 perch (4")
5/12	3 day tows - 4 WF 4 night tows - 5 WF, 1 KOK	6 day tows - 8 WF 2 night tows - 3 WF	
5/19	4 tows - 1 WF	3 Tows - 1 WF	
5/26	3 tows - 2 KOK		Skidoo Creek - 3 tows - 3 dead and 3 live KOK
6/1			Hatchery Bay - 4 tows - 29 WF
6/3	3 tows - 2 WF		Skidoo Creek - 3 tows - 34 WF
6/8	4 tows - 2 WF, 1 KOK 1 lake trout fry		Skidoo Creek - 5 tows - 32 WF
6/9			Crescent Bay - 4 tows - 5 WF
6/9			Hatchery Bay - 4 tows - 3 WF

Table 9. Fry plant locations, dates and numbers released for three shoreline areas of Flathead Lake, May-June, 1982.

Location	Date	Number of fry released
Blue Bay	5/24	20,000
Outlet of Skidoo Creek	5/25	20,000
Crescent Bay	5/27	10,000
	6/10	17,000

were expanded to include these areas. Three additional fry were captured in Blue Bay following the plant and six fry (three live and three dead) were captured at the Skidoo Creek outlet. None of the fry captured were stained with Bismark Brown-Y.

CONCLUSIONS

Data collected during the 1981-82 spawning period demonstrated that the operation of Kerr Dam affected kokanee reproduction in shoreline areas of Flathead Lake and may restrict successful incubation to a narrow band between minimum pool level and 1.5 m below minimum pool level.

The drawdown of Flathead Lake during the 1981-82 water year was relatively rapid, declining on the average of 0.5 m per month in December, January and February. Egg mortality was documented in redds and experimental egg plants above minimum pool, below minimum pool and during lake-stage drawdown. Eighty to ninety percent of the redds constructed above minimum pool were exposed by the first week of February. Lake elevations remained at this level or lower for two and one half months of the incubation period. Incubation mortality in redds sampled above minimum pool resulted from dessication and freezing.

Egg mortality also occurred during drawdown when gravel was scoured, dislodging eggs. Gravel movement in shoreline spawning areas was largest within the wave zone area; showed the least change during stable pool conditions and was most intense when rate of lake stage decline was greatest. Intergravel dissolved oxygen concentrations in spawning areas below minimum pool decreased with an increase in depth. Intergravel dissolved oxygen concentrations in the areas sampled were unacceptable for kokanee embryo survival at depths greater than 4.6 m (15 ft.) below full pool.

Efforts during the 1982-83 field season will center on 1) quantifying role of groundwater on incubation success, 2) modeling historical drawdown patterns and weather conditions during the kokanee spawning season and 3) continued collection of baseline inventory data presented in this report.

LITERATURE CITED

Alderdice, D. F. and F.P.J. Velsen. 1978. Relation between temperature and incubation time for eggs of chinook salmon (*Oncorhynchus tshawytscha*). J. Fish.Res. Bd. Can. 35:69-75.

Alderdice, D.F., W.P. Wickett and J.R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Bd. Can. 15(2):220-249.

Alvord, W. 1975. History of the Montana Fish and Game Dept. Mont. Fish and Game, Helena, MT.

Andrew, F.J. and G.H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Frazer Lake system. Int. Pac. Salmon Fish. Comm. Bull XI 259p.

Bams, R.A. 1969. Adaptations of sockeye salmon associated with incubation in stream gravels. pp. 71-87. in: T.G. Northcote, Ed. Symposium on salmon and trout in streams. Univ. British Columbia, Vancouver, B.C.

Bjornn, T.C. 1957. A survey of the fishery resources of Priest and Upper Priest lakes and their tributaries. Idaho Dept. of Fish and Game Completion Report F-24-R. 176p.

Bjornn, T.C. 1969. Embryo survival and emergence studies. Idaho Dept. of Fish and Game Job Completion Report F-49-R-6, Job 6. p.33-41.

Bouchard, L.G. and C.R. Mattson. 1961. Immersion staining as a method of marking small salmon. Prog. Fish.-Cult. Vol. 23(1):34-40.

Bowler, B. 1979. Kokanee spawning trends in Pend Oreille Lake. Idaho Dept. of Fish and Game Job Performance Report, F-73-R-1, Job II. p. 57-77.

Chambers, J.S., G. H. Allen and R.T. Pressy. 1955. Research relating to a study of spawning grounds in natural areas. An. Rept., Wash. Dept. Fish. to U.S. Army Corps of Eng. Contract #DA35-026-Eng-20572. 175p.

Dill, L.M. 1969. The sub-gravel behavior of Pacific salmon larvae. pp. 89-99. in: T.G. Northcote, Ed. Symposium on salmon and trout in streams. Univ. British Columbia, Vancouver, B.C.

Domrose, R. 1968. Kokanee redd exposure and hatching success in relation to receding Flathead Lake levels. Mont. Dept. Fish, Wildl. and Parks, Kalispell, MT. 2p.

Environmental Protection Agency. 1974. Methods for chemical analysis of water and wastes. EPA-625-/6-74-003a. E.P.A. Environmental Monitoring and Support Laboratory. 298p.

Fraley, J.J. and P.J. Graham. 1982. Impacts of Hungry Horse Dam on the fishery in the Flathead River - Final Report, USDI Bureau of Reclamation, Mont. Dept. Fish, Wildl. and Parks, Kalispell, MT. 91 pp.

Fredenberg, W. and P.J. Graham. 1982. Flathead River fisherman census, U.S. Environmental Protection Agency, Mont. Dept. Fish, Wildl. and Parks, Kalispell, MT.

Foerster, R.E. 1968. The sockeye salmon *Oncorhyncus nerka*. Fisheries Research Board of Canada Bull. 162. 422p.

Gangmark, H.A. and R. G. Bakkala. 1958. Plastic standpipe for sampling streambed environment of salmon spawn. U.S. Fish and Wildl. Service Spec. Scientific Report: Fisheries No. 261. 20p.

Gangmark, H.A. and R.G. Bakkala. 1960. A comparative study of unstable and stable (artificial channel) spawning streams for incubating king salmon at Mill Creek. Calif. Fish and Game 46:151-164.

Graham, P. J., D. Read, S. Leathe, J. MIller and K. Pratt. 1980. Flathead River Basin Fishery Study. Mont. Dept. of Fish, Wildl. and Parks. Kalispell, MT. 117pp.

Graham, P., R. Penkal, S. McMullin and P. Schladweiler. 1981. Montana recommendations for a fish and wildlife program. Submitted to Pacific Northwest Electric Power and Conservation Planning Council. 123pp.

Graham, P.J. and W. Fredenberg. 1982. Flathead Lake fisherman census, U.S. Environmental Protection Agency, Mont. Dept. Fish, Wildl. and Parks. Kalispell, MT.

Hall, J.D. and R. L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cuttroat trout in coastal streams. pp. 335-375. in: T.G. Northcote, Ed. Symposium on salmon and trout in streams. Univ. British Columbia, Vancouver, B.C.

Hanzel, D.A. 1977. Angler pressure and game fish harvest estimates for 1975 in the Flathead River system above Flathead Lake. Mont. Dept. Fish and Game, Kalispell, MT.

Hassemer, P.F. and B.E. Rieman. 1979. Kokanee life history studies in Priest Lake - spawning evaluation. Idaho Dept. of Fish and Game, Job Performance Report F-73-R-1, Job III. p.89-105.

Hassemer, P.F. and B.E. Rieman. 1980. Coeur d'Alene Lake spawning evaluations. Idaho Dept. of Fish and Game, Job Performance Report F-73-R-2, Job III. p. 89-95.

Hawke, S.P. 1978. Stranded redds of quinnat salmon in the Mathias River, South Island, New Zealand. N.Z. Journal of Marine and Freshwater Research. 12(2):167-71.

Hayes, F.R., I.R. Wilmot and D.A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. J. Exp. Zool. 116(3):377-395.

Hildebrand, S.G. ed. 1980. Analysis of environmental issues related to small-scale hydroelectric development. III:Water level fluctuation. Environ. Sci. Div. Publ. #1591. Oak Ridge Nat'l Lab., Oak Ridge, Tenn. 37830

Jeppson, A. 1955. Evaluation of spawning areas in Lake Pend Oreille and tributaries upstream from Albeni Falls Dam in Idaho, April, 1954-May 31, 1955, including suppl(e)emental information on the life history of kokanee. Idaho Dept. of Fish and Game Job Completion Report F-3-R-4 and F-3-R-5, Work Plan 2. 36 pp.

Jeppson, P. 1960. Evaluation of kokanee and trout spawning areas in Pend Oreille Lake and tributary streams. Idaho Dept. Fish and Game Job Progress Report F-3-R-10. p. 43-66.

Johnson, W.E. 1956. On the distribution of young sockeye salmon (*Oncorhynchus nerka*) in Babine and Nilkitkwa Lakes, B.C. J. Fish. Res. Bd. Can. 13(5):695-708.

Johnson, W.E. 1965. On mechanisms of self-regulation of population abundance in *Oncorhynchus nerka*. Mitt. Internat. Verein. Limnol. Vol. 13: p.66-87.

Kimsey, J.B. 1951. Notes on kokanee spawning in Donner Lake, California, 1949. Calif. Fish and Game 37(3):273-79.

Koski, K.V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in 3 Oregon coastal streams. M.S. Thesis Oregon St. Univ. Corvallis, OR. 84pp.

Koski, K.V. 1972. Effects of sediment on fish resources. Presented at Washington State Dept. of Natural Resources Management Seminar, Lake Limarick. April 19-20, 1972.

Leathe, S.A. and P.J. Graham. 1982. Flathead Lake fish food habits study - Final report. Mont. Dept. Fish, Wildl. and Parks. Kalispell, MT. 137pp.

Lindroth, A. 1942. Sauerstoffverbrauch der Fische. I. Verschiendene Entwicklungsund Altersstadien vom Lachs und Hecht. Z.vertl. Physiol. 29:583-594.

Lindsay, R.B. and S.L. Lewis. 1975. Population dynamics of kokanee salmon in Odell Lake Dec. 1, 1974 - June 30, 1975. Oregon Dept. of Fish and Wildl. Job Prog. Rept. F-71-R-11, Jobs 10 and 11. 12p.

Lotspeich, F.B. and F.H. Everest. 1980. Reporting and interpreting textural composition of spawning gravels. Unp. USFS Forestry Science Lab Corvallis, WA.

Lund, Richard E. 1979. A user's guide to MSUSTAT--an interactive statistical analysis package, 1979. Montana State University, Bozeman, MT. 74 pp.

Mason, J.C. and D.W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. J. Fish. Res. Bd. Can. 22:173-190.

Mason, J.C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. J. Fish. Res. Bd. Can. 26:63-91.

McCuddin, M.E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. MS Thesis, Univ. of Idaho, Nov. 1977.

McMullin, S.L. and Graham, P.J. 1981. The impact of Hungry Horse Dam on the kokanee fishery of the Flathead River. Mont. Dept. Fish, Wildl. and Parks. Kalispell, MT. 98 p.

McNeil, W.J. 1964. A method of measuring mortality of pink salmon eggs and larvae. U.S. Fish. Wildl. Serv. Fish Bull., 66(3):575-588.

McNeil, W.J. 1967. Effect of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildl. Serv. Fish. Bull., Vol. 65(2):495-523.

McNeil, W.J. 1968. Survival of pink and chum salmon eggs and alevins, pp. 101-117 in: T.G. Northcote, Ed. Symposium on salmon and trout in streams. Univ. British Columbia, Vancouver, B.C. Canada.

Meekin, T.K. 1967. Observation of exposed fall chinook redds below Chief Joseph Dam during periods of low flow. Oct. 1966 - Jan. 1967. State of Washington, Dept. of Fisheries, Research Division.

Montana Dept. of Fish and Game. 1976. Estimated man-days of fishing pressure by region for the summer and winter season, May 1975-April 1976. Mont. Dept. Fish and Game, Helena, MT.

Olsen, James C. 1968. Physical environment and egg development in a mainland beach area and an island beach area of Iliamna Lake. In: Burgner, Rovert C., Ed. further studies of Alaska sockeye salmon. pp. 171.

Peters, J.C. 1962. The effects of stream sedimentation on trout embryo survival. Third seminar on biological problems in water pollution. p.275-279.

Phillips, R.W. and H.J. Campbell. 1961. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. 14th Ann. Rep. Pac. Mar. Fish Comm. Portland, OR. p. 60-73.

Phillips, R.W. and Koski, K.V. 1969. A fry trap method for estimating salmonid survival from egg deposition to fry emergence. J. Fish. Res. Bd. of Canada. Vol. 26(1):133-141.

Phillips, R.W., R. L. Lantz, E.W. Claire and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. AM. Fish. Soc. 104(3):461-466.

Platts, W.S., M.A. Shirazi and D.H. Lewis. 1979. Sediment particle size used by salmon for spawning with methods for evaluation. E.P.A. Report EPA-600/3-79-043. 33p.

Potter, D.S. 1978. The zooplankton of Flathead Lake: an historical review with suggestions for continuing lake resource management. Ph.D. dissertation, Univ. of Montana. Missoula, Montana.

Reiser, D.W. and T.C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada. USDA Forest Service General Technical Report PNW-96. 54p.

Reiser, D.W. and R.G. White. 1981a. Incubation of steelhead trout and spring chinook salmon eggs in a moist environment. Prog. Fish-Cult. 43(3): 131-134.

Reiser, D.W. and R.G. White 1981b. Influence of streamflow reductions on salmonid embryo development and fry quality. Idaho cooperative Fishery Research Unit, Research Technical Completion Report, A-058-IDA. 154p.

Robbins, O. 1966. Flathead Lake (Montana) fishery investigations, 1961-64. Bureau of Sports Fisheries and Wildlife, Techinical Paper. 45p.

Royce, W.F. 1959. On the possibilities of improving salmon spawning areas. Trans. N. Am. Wildlife Conf. 24:356-366.

Shelton, J.M. 1955. The hatching of chinook salmon eggs under similated stream conditions. Progressive Fish-Cult. 17(1):20-25.

Sheridan, W.L. 1962. Waterflow through salmon spawning riffle in Southeastern Alaska. U.S. Fish and Wildl. Serv. Spec.Sci. Rep. - Fish No. 407. 22p.

Shirazi, M.A. and W.K. Seim. 1979. A stream systems evaluation- an emphasis on spawning habits of salmonids. USEPA/EPA-600/3-79-109. Corvallis Envir. Research Lab. Corvallis, WA.

Shumway, D.L., C.E. Warren and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Am. Fish. Soc. 93(4):342-356.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Am. Fish. Soc. 92(4):327-343.

Stanford, J. A., T. J. Stuart, J. D. Coulter and F.R. Hauer. 1981. Limnology of the Flathead River - Lake ecosystem, Montana. Annual Report, Flathead Research Group, Univ. of Montana Biological Station. Bigfork, MT. 331p.

Stefanich, F.A. 1953. Natural reproduction of kokanee in Flathead Lake and tributaries. Mont. Dept. of Fish and Game Job Completion Report No. F-7-R-2, Job III-A.p.69-74.

Stefanich, F.A. 1954. Natural reproduction of kokanee in Flathead Lake and tributaries. Mont. Dept. Fish and Game Job Completion Report No. F-7-R-3 Job III-A. 10 p.

Stober, Q.J., R. E. Narita and A.H. Hamalainen. 1978. Instream flow and the reproductive efficiency of sockeye salmon. Job Completion Report, OWRT Proj. No. B-065-WASH., Univ. Washington, Coll. Fish, Fish. Res. Inst. FRI-UW-7808. 124p.

Stober, Q.J., R.W. Tyler, C.E. Petrosky, K.R. Johnson, C.F. Cowman, Jr., J. Wilcock, and R.E. Nakatani. 1979a. Development and evaluation of a net barrier to reduce entrainment loss of kokanee from Banks Lake. Final Report, April 1977-March 1979, to U.S. Bur. Reclam., Contract No. 7-07-10-50023, Univ. Washington. Coll. Fish., Fish Res. Inst. FRI-UW-7907. 246 p.

Stober, Q.J., R.W. Tyler, C.F. Cowman, Jr., J. Wilcock, and S. Quinnell. 1979b. Irrigation drawdown and kokanee salmon egg to fry survival in Banks Lake. Final Report. April 1979-Sept. 1979, to U.S. Bur. Reclam., Contract No. 7-07-10-S0023, Univ. Washington, Coll. Fish., Fish. Res. Inst. FRI-UW-7913. 73p.

Tappel, P.D. 1981. A new method of relating spawning gravel size composition to salmonid embryo survival. M.S. univ. of Id. Forest Wildlife Range Experiment station. College of Forestry, Wildlife and Range Sciences. 51p.

Whitt, C.R. 1957. Age and growth characteristics of Lake Pend Oreille kokanee, 1956. Idaho Dept. of Fish and Game Annual Summary Report F-3-R-6 and F-3-R-7, Work Plan 2. 20p.

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

APPENDIX A

Kokanee spawning survey and microhabitat

Table 1. Dates when 48 shoreline areas of Flathead Lake were surveyed for kokanee spawning activity during the fall of 1981. Spawning activity was located using a glass bottomed pram, jet boat or with SCUBA techniques.

Location	Dates of Observation									
West Shore Flathead Lake										
1. Somers Bay	10/28		11/10							
2. Hatchery Bay	10/28		11/10							
3. Marco Bay	10/28		11/10							
4. Mountainview Terrace Bay	10/28		11/10							
5. Bay south of Pt. Caroline			11/10							
6. Lakeside		11/4	11/10							
7. Stoner Creek		11/4	11/10							
8. Peaceful Bay		11/4	11/10							
9. Hockaday Bay		11/4		11/11						
10. Hughes Bay		11/4		11/11						
11. Deep Bay		11/4		11/11						
12. W. Shore State Park		11/4		11/11	11/17	11/20	11/24		12/4	12/22
13. Goose Bay		11/4		11/11	11/17	11/20			12/4	12/22
14. Table Bay		11/4		11/11	11/17	11/20			12/4	12/22
15. Zelezny Bay		11/4		11/11	11/17	11/20			12/4	12/22
16. Hyde Bay		11/4		11/11	11/17	11/20			12/4	12/22
17. Bennetts Bay		11/4		11/11	11/17	11/20			12/4	12/22
18. Dewey Bay		11/4		11/11	11/17	11/20			12/4	12/22
19. Canal Bay		11/4		11/11	11/17	11/20			12/4	12/22
20. Crescent Bay		11/4		11/11	11/17	11/20	11/24		12/4	12/22
21. One mile south Crescent Bay		11/4		11/11	11/17	11/20			12/4	12/22
22. Dayton Creek					11/17			12/2	12/4	12/22
23. Elmo Bay								12/2	12/4	12/22
24. Big Arm Bay								12/2	12/4	12/22
25. White Swan Bay								12/2		
26. Indian Bay								12/2		
27 Wildhorse Island					11/17			12/2		

Table 1. Cont.

	Location	Dates of Observation												
	East Shore Flathead Lake													
1.	Bigfork Bay	10/28					11/12							
2.	Woods Bay						11/12	11/16		11/25			12/8	
3.	Hunger Creek						11/12						12/8	
4.	Mauzey Creek						11/12						12/8	
5.	Crane Creek						11/12						12/8	
6.	Howsley Creek						11/12						12/8	
7.	Glen Creek						11/12						12/8	
8.	Bohannon Creek						11/12						12/8	
9.	Gunderson Creek				11/6	11/9	11/12						12/8	
10.	Lolo Creek				11/6	11/9	11/12						12/8	
11.	Yellow Bay	10/29	11/1	11/3	11/6	11/9	11/12	11/16	11/18	11/23,24,	12/3,	12/7,	12/8,	12/9,12/11
12.	Sunset Bay	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
13.	Blue Bay	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	12/14
14.	Teepee Creek	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
15.	Talking Water Creek	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
16.	Boulder Creek	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
17.	Dee Creek	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
18.	Gravel Bay	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
19.	So. to Dr. Richard's Bay	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
20.	Dr. Richard's Bay	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/23		12/7	12/8	
21.	Skidoo Bay	10/29		11/3	11/6	11/9	11/12	11/16	11/18	11/19		12/7	12/8	

Table 2. Daily pram counts and total SCUBA counts of kokanee spawners and redds built in shoreline areas of Flathead Lake during November, 1981. Left hand number represents fish seen, right number represents redds counted. Italicized numbers represent final redd counts made by SCUBA techniques.

Date	Yellow Bay	Blue Bay	Dr. Richard's Bay North	Dr. Richard's Bay South	Dr. Richard's Bay boat launch	Skidoo Bay	Woods Bay	Gravel Bay	Talking Water Creek	Crescent Bay	Totals
November											
1	25/0										25/0
2	20/15										20/15
3	25/20	0	0	0				0	30/20		55/40
4										0	0
6	44/--		0	0	0		0	4/2			48/2
9	88/55	50/30	0	0	0	0		4/2	30/5		172/92
11			60/15							0	60/15
12	30/--	35/--						0/19			65/19
16	20/60	15/30	0/25	0/40	0/12	30/40	52/25	-/13	25/*12*		142/*272*
17										0	
18	0/										
19						*86*					
20										*30/5*	/5
23	15/		*106*	*63*	*12*			5/25			20/25
24	*152*										
25							*57*			*5*	
December											
2										0	0
7	0	0	0	0	0	*8*/17					*8*/17
8	0	2/*45*					0	*37*			*82*

Table 3. Total length and age composition with totals and means of adult kokanee salmon collected by gill nets in six shoreline areas of Flathead Lake in November, 1981.

	Length (mm)						Age composition															
	Male			Female			Male				Female						Combined					
							III+		IV+		III+		IV+		V+		III+		IV +		V+	
	N	Range	x̄	N	Range	x̄	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Yellow Bay	40	373-421	396	28	325-399	373	8	30	19	70	11	40.7	16	59.3	--	--	19	35	35	65	--	--
Dr. Richards	14	373-404	391	13	345-399	368	3	23.1	10	76.9	1	8.3	10	83.3	1	8.3	4	16	20	80	1	4
Skidoo Bay	36	348-422	389	54	320-394	368	13	50	13	50	21	55	17	45	--	--	34	53	30	47		
Woods Bay	8	377-418	395	0																		
Crescent Bay	3																					
West Shore	1																					
Total or Mean	102		393	95		370	24	34.4	42	65.6	33	34.7	43	62.5	1	2.8	57	34.7	85	64	1	1.3

Table 4. Fecundity counts for female kokanee from Dr. Richard's and Skidoo bays in Flathead Lake, November, 1981.

Total length (mm)	Fecundity #eggs
364	1178
390	1121
365	914
355	1032
384	1076
400	1203
376	966
379	1072
370	940
	$\bar{x}$ = 1055.78

Table 5. Intergravel dissolved oxygen concentrations (in mg/l) by bottom elevation and transect location from Yellow Bay, Skidoo Bay and Dr. Richard's Bay's spawning areas. All samples were collected in March 1982.

Location	Bottom Elevation (m)	Dissolved oxygen concentrations (mg/l)
YELLOW BAY		
East transect		
1	878.94	9.9
2	878.30	9.4
3	877.57	6.8
4	876.86	2.4
Center transect		
1	878.65	8.4
2	877.95	9.2
3	875.73	9.1
4	873.93	.9
West transect		
1	876.78	8.9
2	857.77	9.2
3	874.95	8.9
4	873.74	6.9
DR. RICHARD'S BAY		
East transect		
1	880.31	NWA*
2	879.75	NWA
3	879.31	11.6
4	879.10	11.4
5	878.86	8.7
Center transect		
1	880.50	NWA
2	879.97	NWA
3	879.59	NWA
4	879.48	8.2
5	879.19	9.4
West transect		
1	880.80	Dry
2	880.44	Dry
3	880.21	Dry
4	880.00	Dry
5	879.74	Dry

Table 5 cont.

Location	Bottom Elevation (m)	Dissolved oxygen concentrations (mg/l)
SKIDOO BAY		
West transect		
1	880.42	NWA*
2	880.10	NWA
3	879.72	7.0
4	879.26	8.45
Center transect		
1	880.37	NWA
2	879.85	NWA
3	879.71	8.7
4	879.23	8.65
East transect		
1	880.50	NWA
2	880.18	NWA
3	879.76	7.9
4	879.35	8.1

*NWA = No water available for wetting kokanee embryo; water located below depth of kokanee eggs.

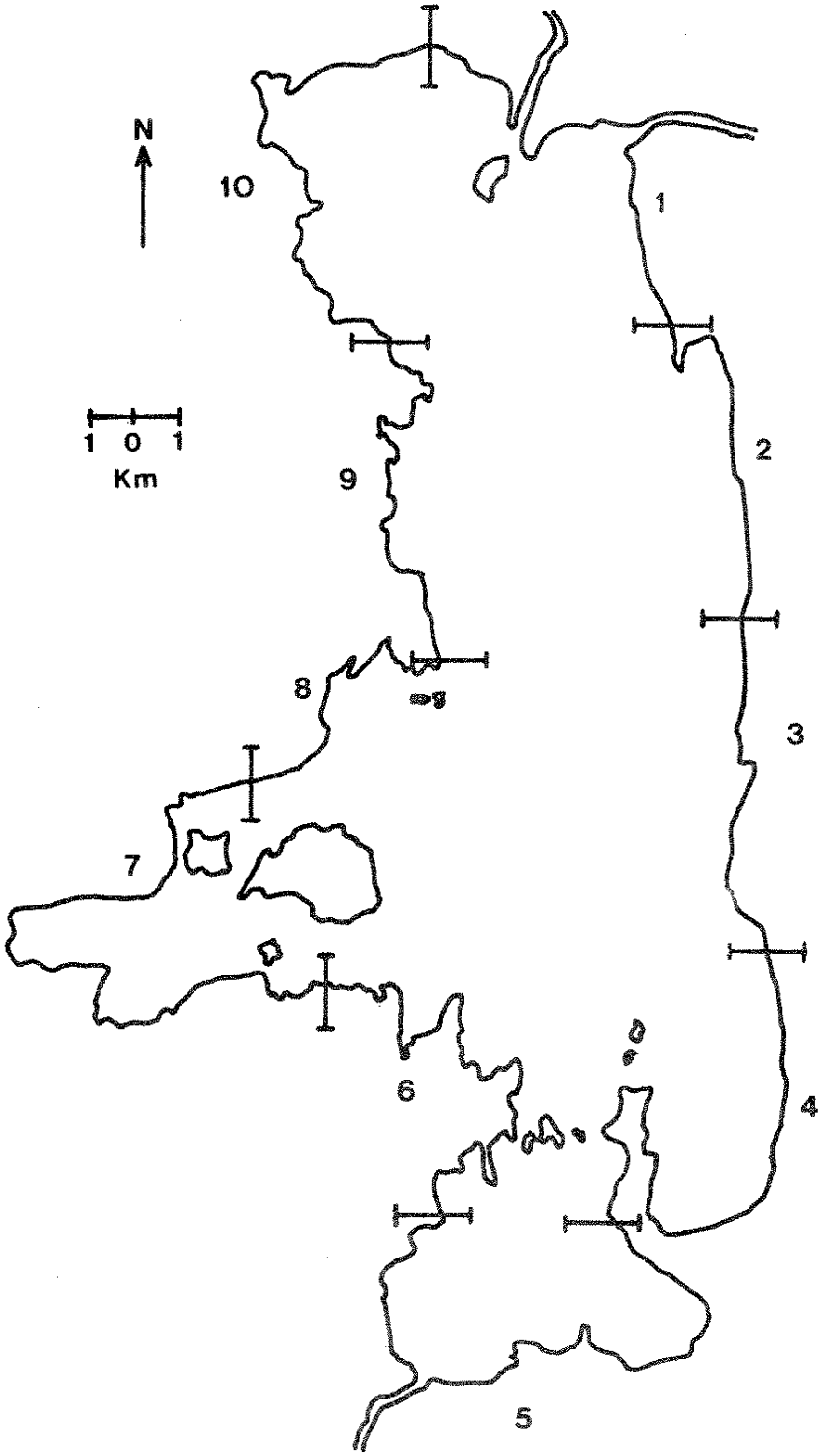
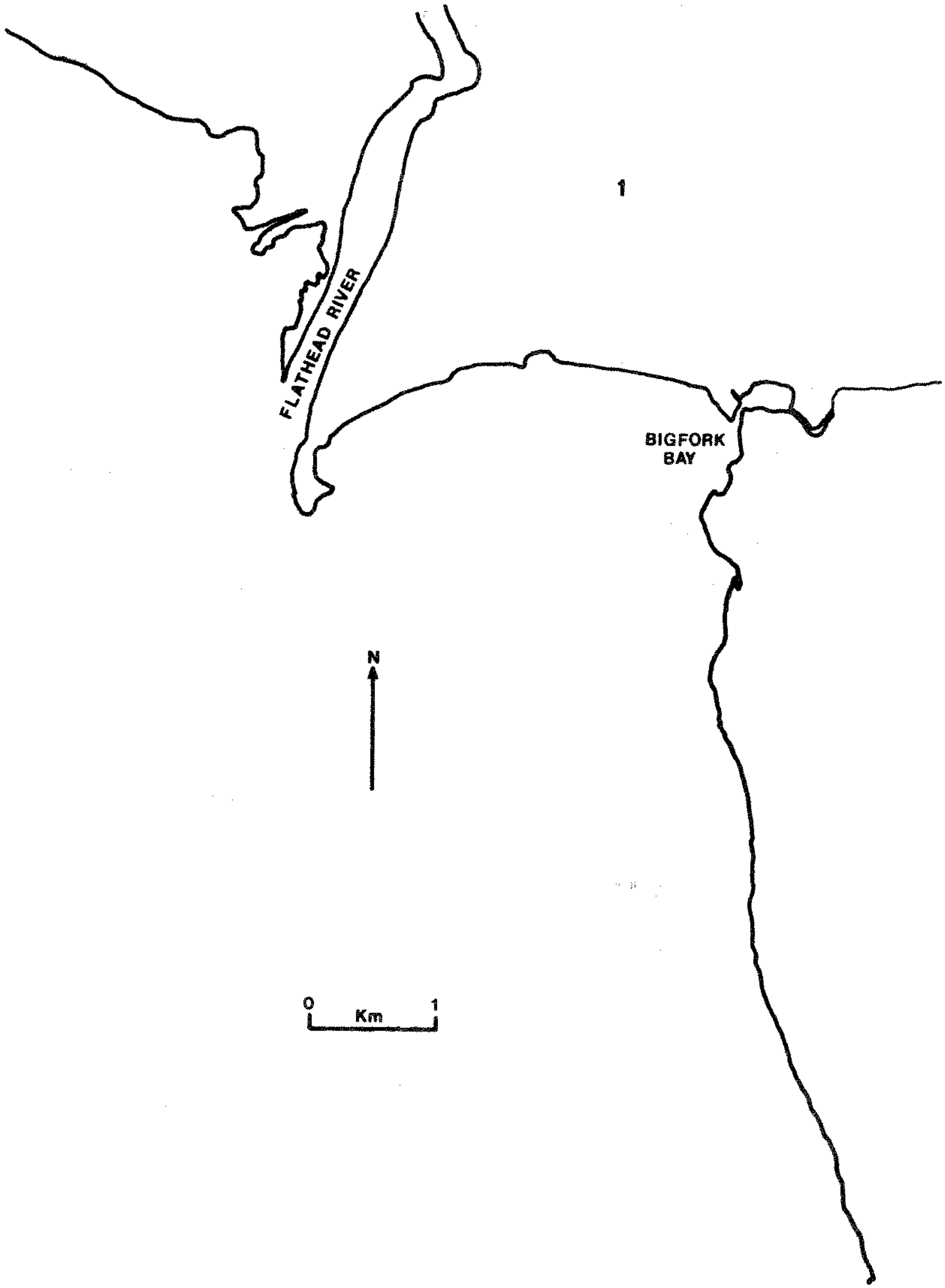
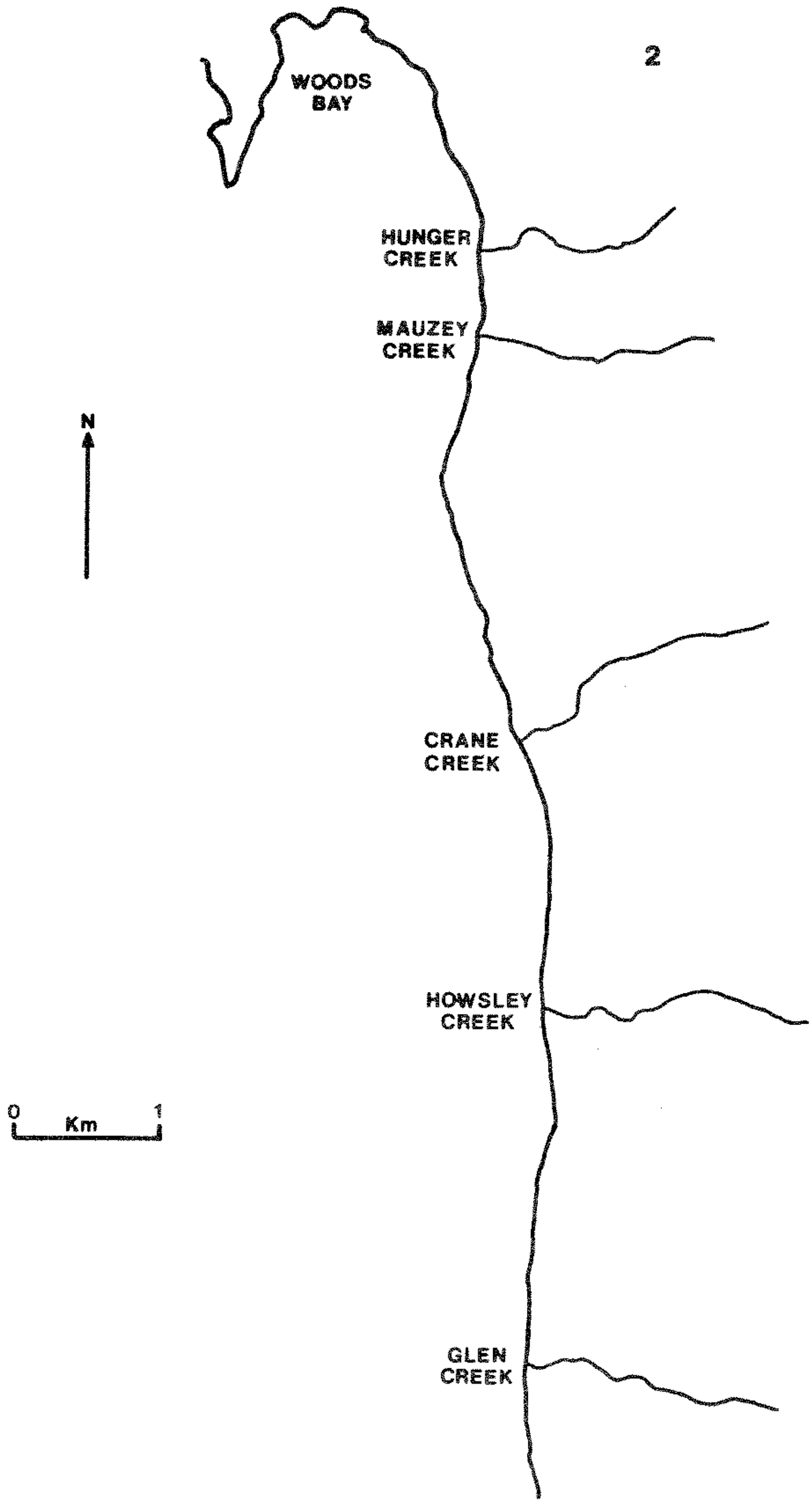
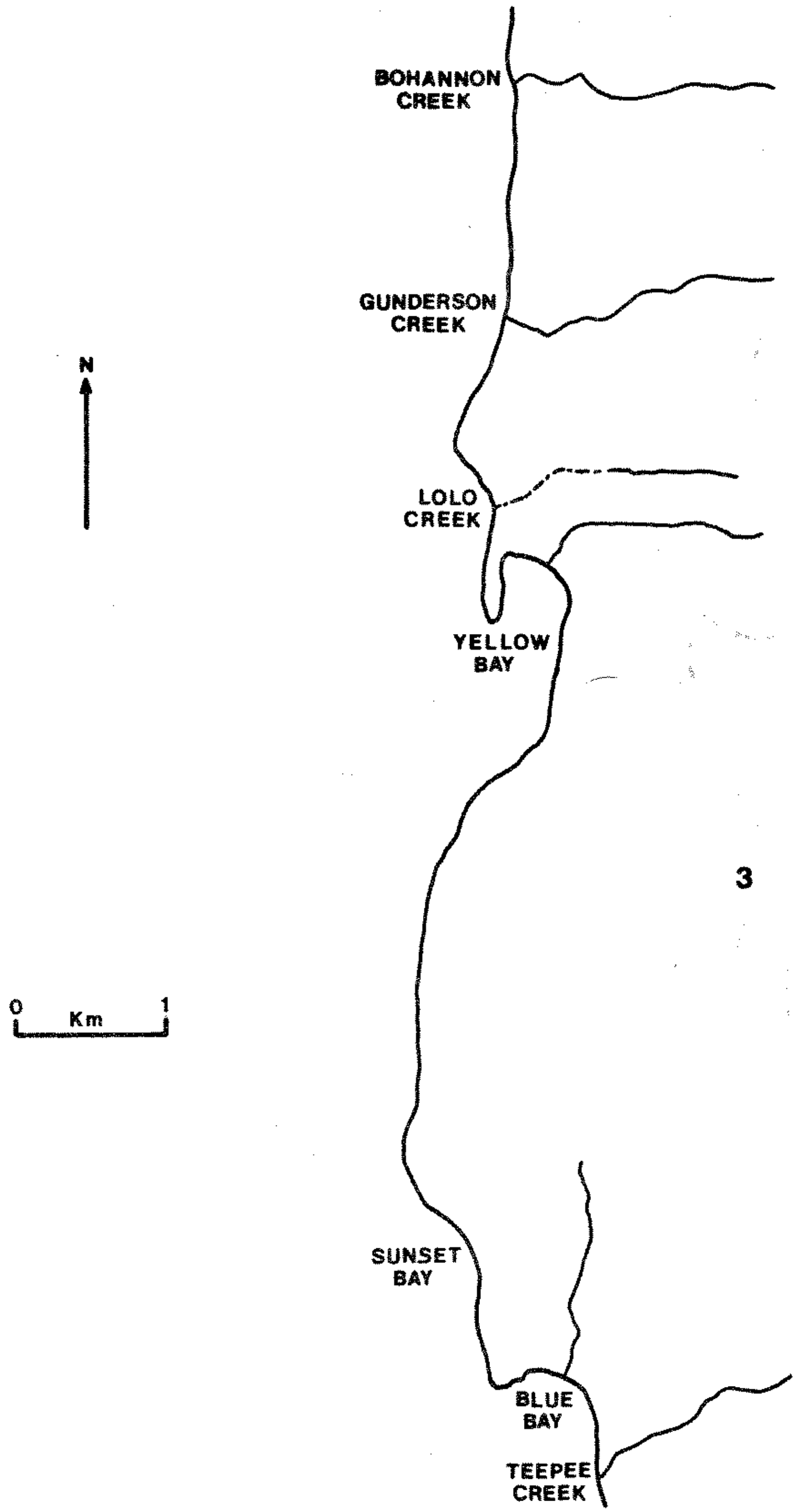


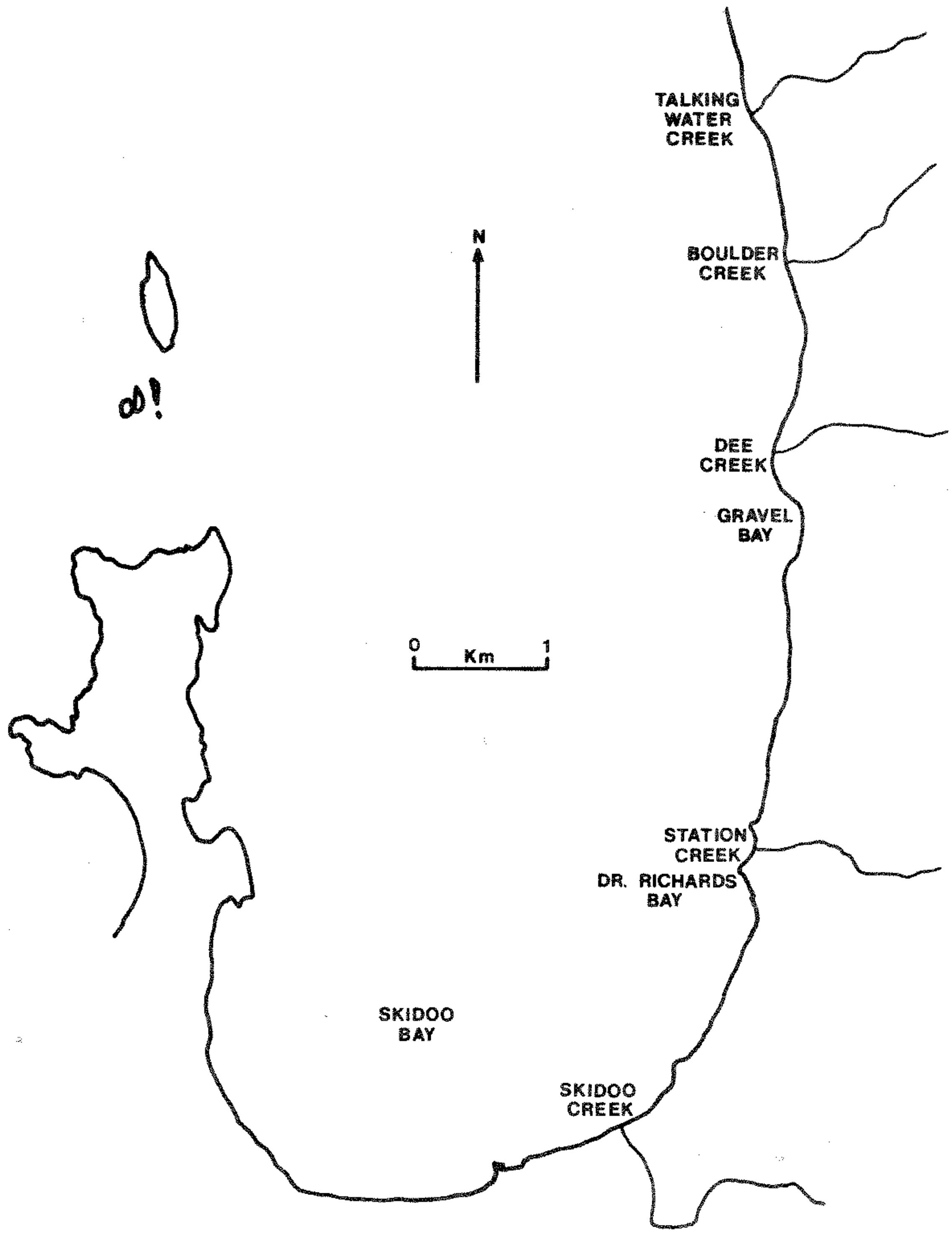
Figure 1. (Includes pages 8-18). Maps of Flathead Lake shoreline designating the 48 areas surveyed for kokanee spawning activity during the fall of 1981. Pages 9-18 breaks down shoreline into ten sections with locations of each area surveyed.



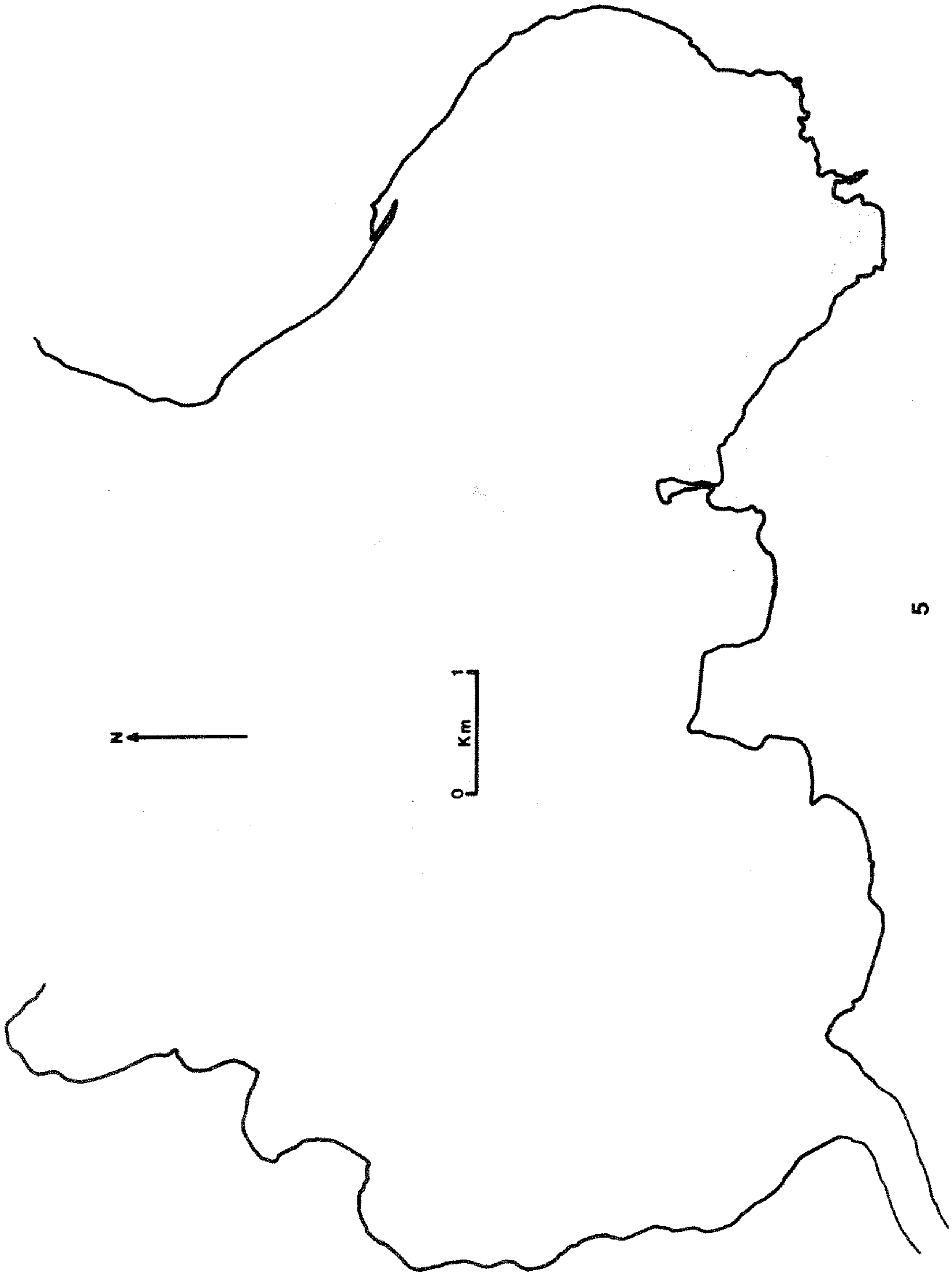
1
FLATHEAD RIVER
BIGFORK
BAY
N
0
Km
1

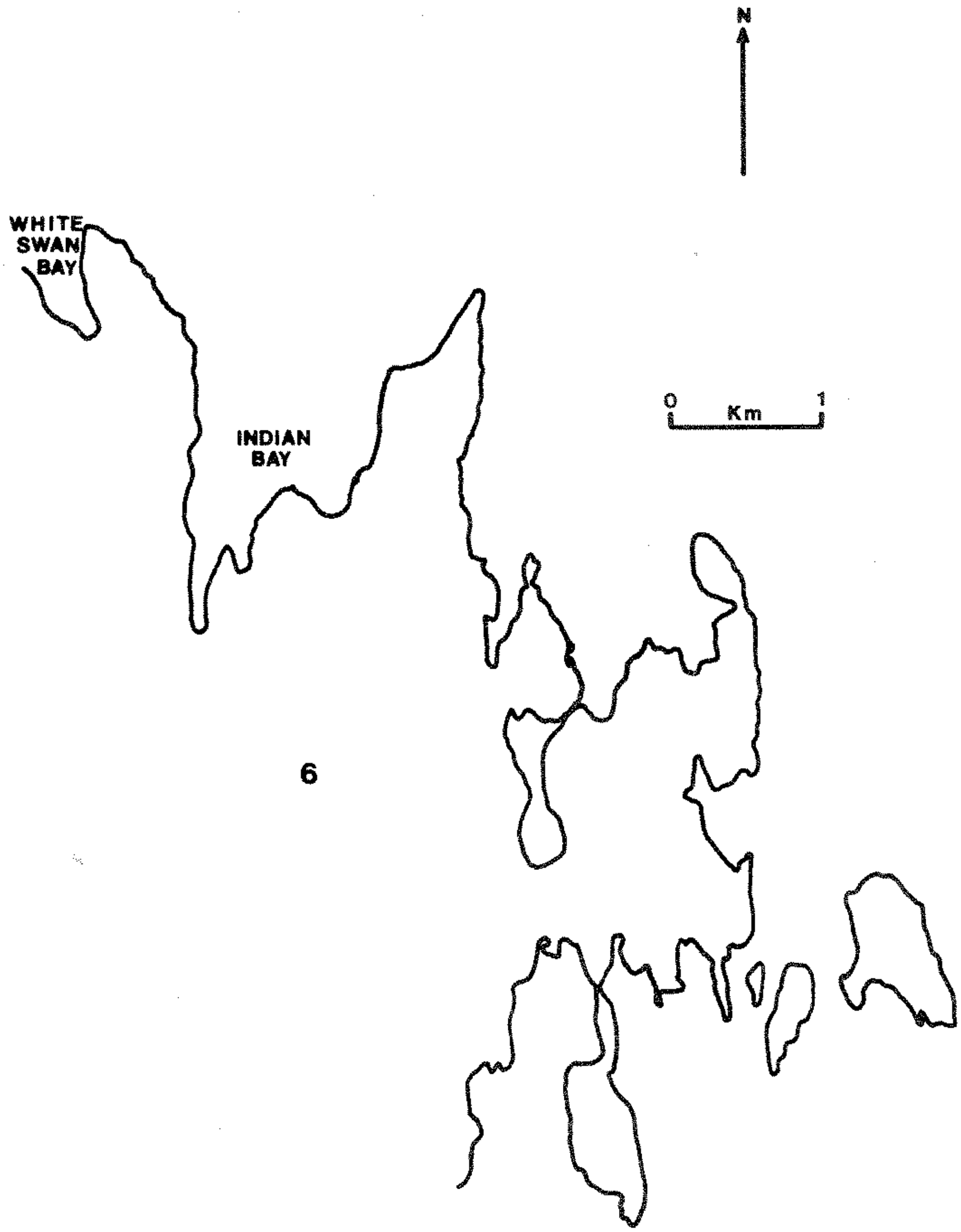

2
WOODS BAY
HUNGER CREEK
MAUZEY CREEK
N
CRANE CREEK
HOWSLEY CREEK
0 Km 1
GLEN CREEK


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

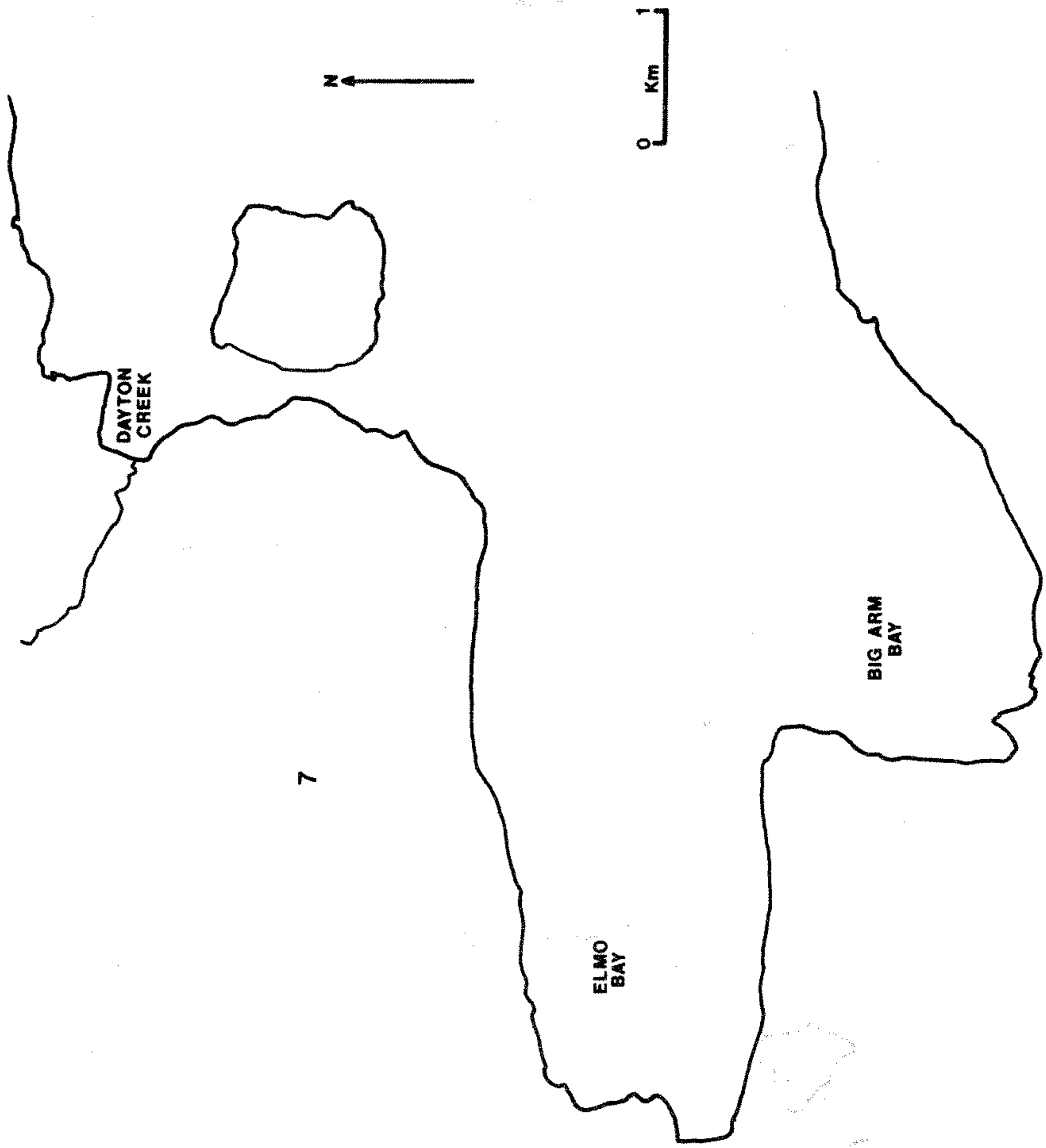

N
0 Km 1
TALKING WATER CREEK
BOULDER CREEK
DEE CREEK
GRAVEL BAY
STATION CREEK
DR. RICHARDS BAY
SKIDOO BAY
SKIDOO CREEK

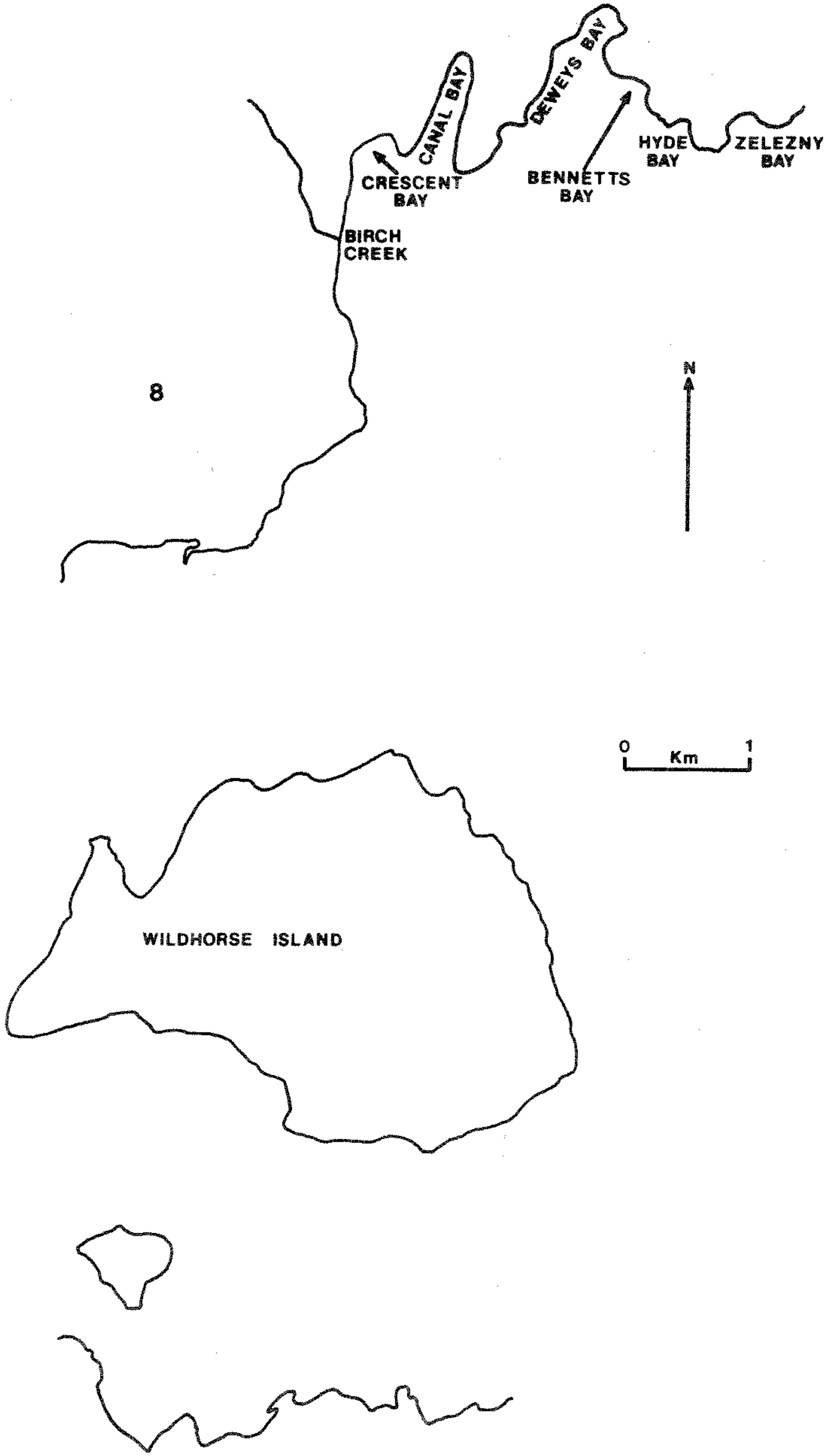
4

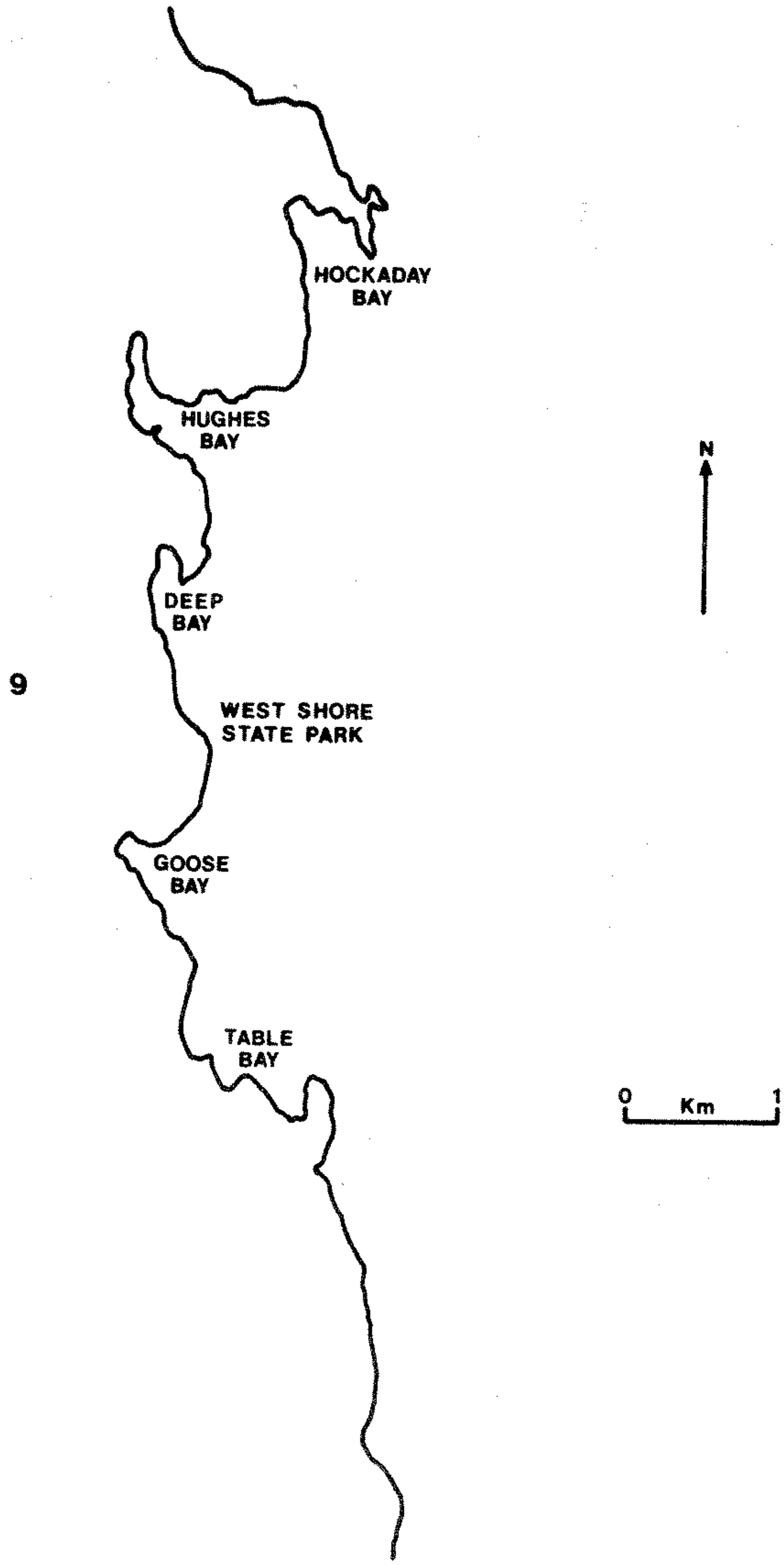

N
0
Km
1
5

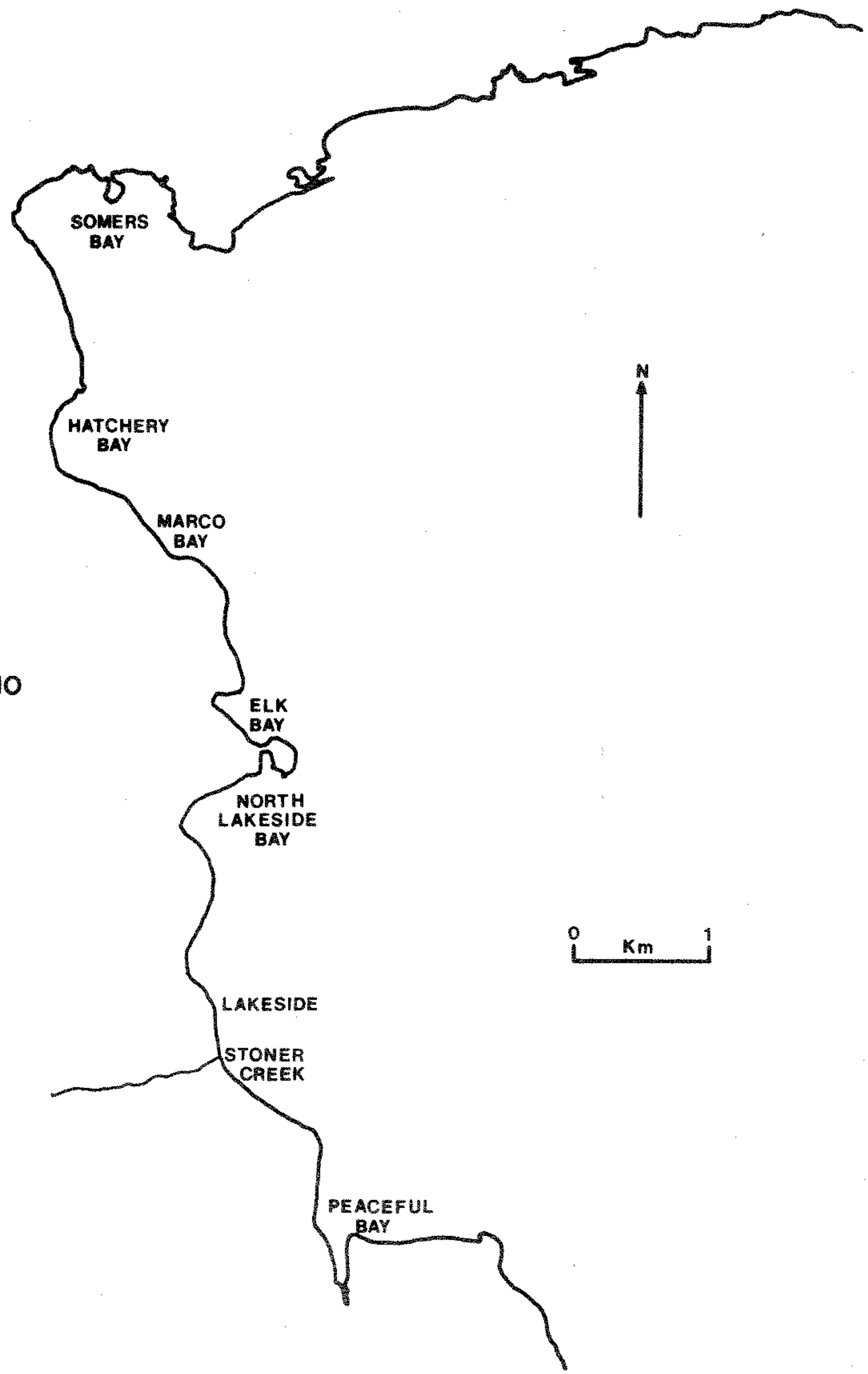


N
WHITE SWAN BAY
INDIAN BAY
0 Km 1
6


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


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

10

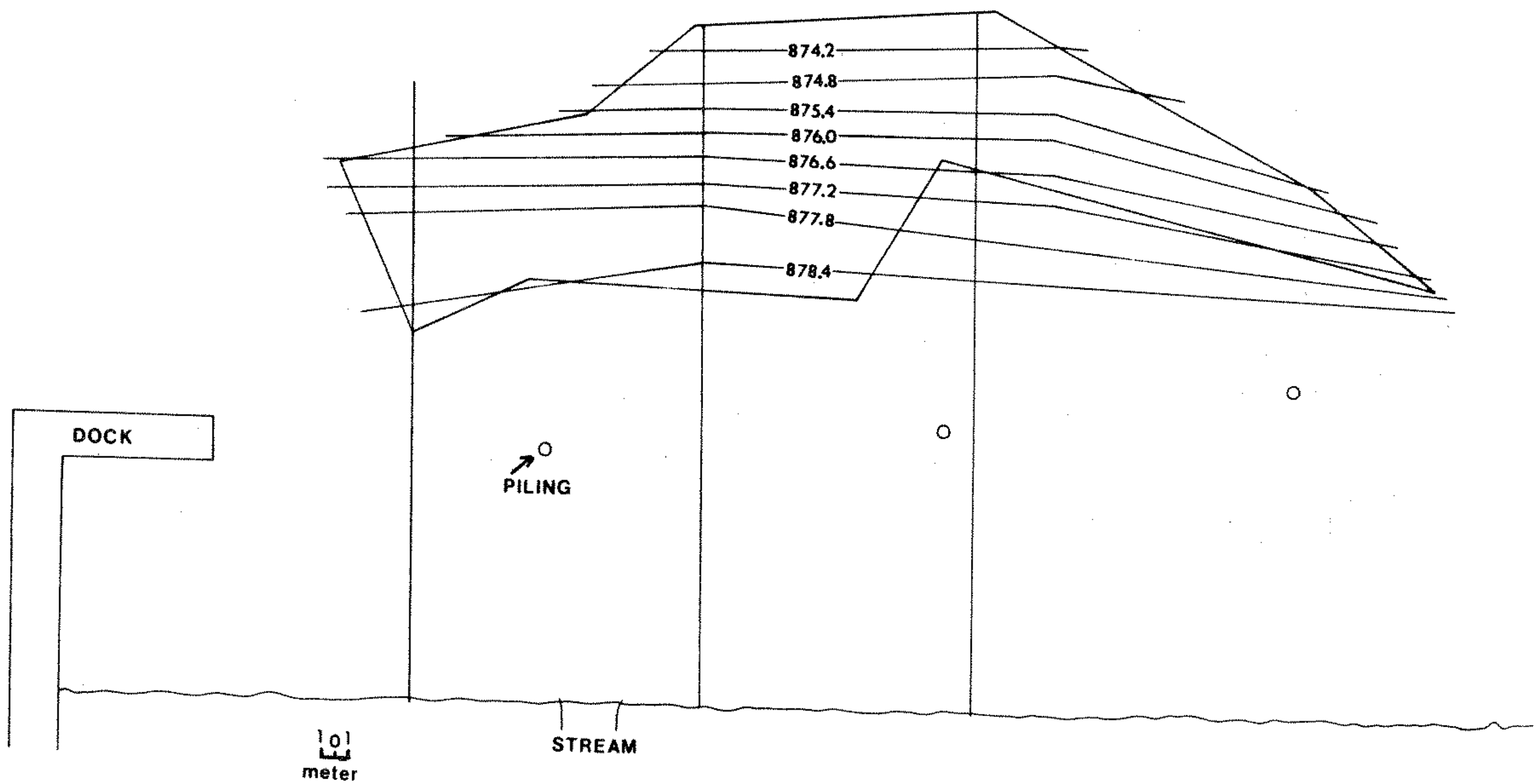


Figure 2. Location and depth contour lines (in meters) for the major spawning area in Yellow Bay. Perpendicular lines to shore represent location of transects where microhabitat data were collected.

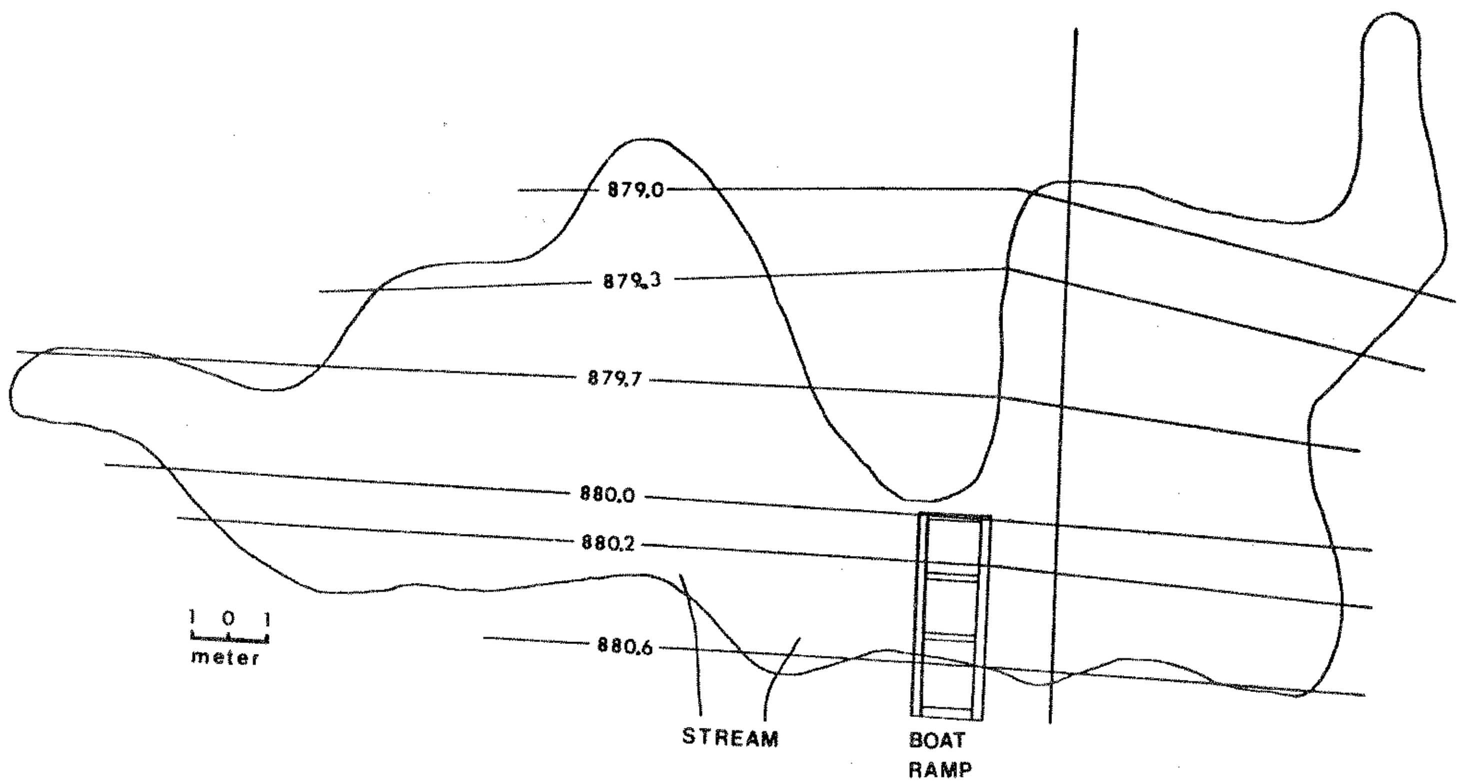


Figure 3. Location and depth contours (in meters) for the Dr. Richard's Bay North spawning area. Perpendicular line represents location of gravel movement transect.

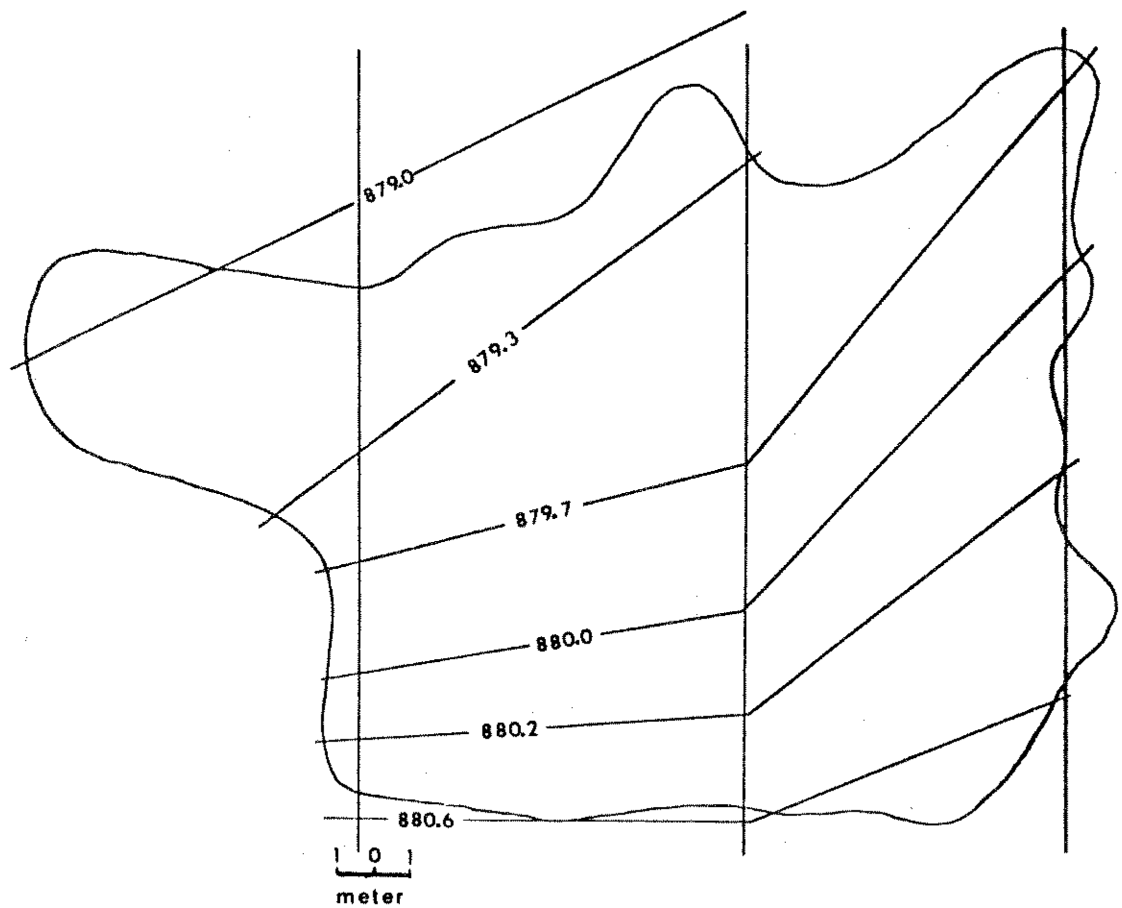


Figure 4. Area and depth contour lines (in meters) for Dr. Richard's Bay South spawning area. Perpendicular lines represent location of transects where microhabitat data were collected.

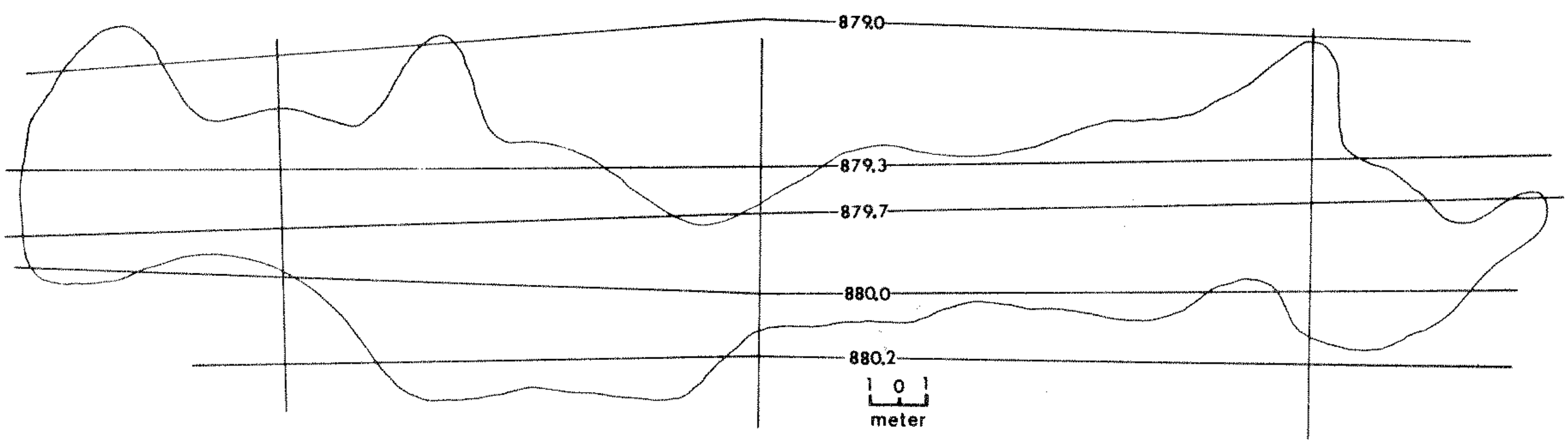


Figure 5. Area and depth countour lines (in meters) for Skidoo Bay spawning area. Perpendicular lines represent location of transects where microhabitat were collected.

APPENDIX B

Substrate composition samples for the spawning areas in shoreline areas of Flathead Lake.

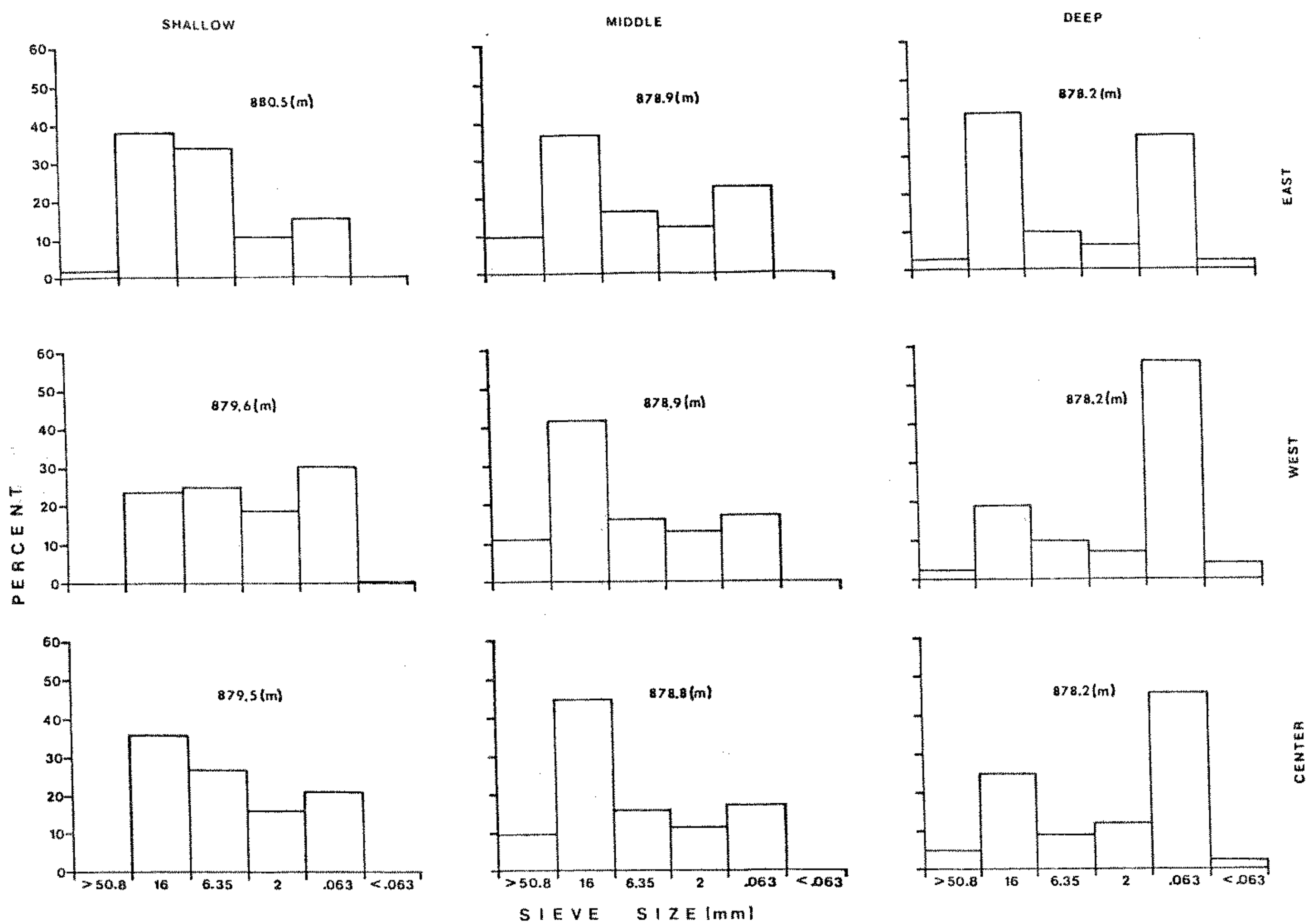


Figure 1. Percent substrate composition for nine samples collected along transects in the Skidoo Bay spawning area. Bottom elevation in meters where sample was collected is provided.

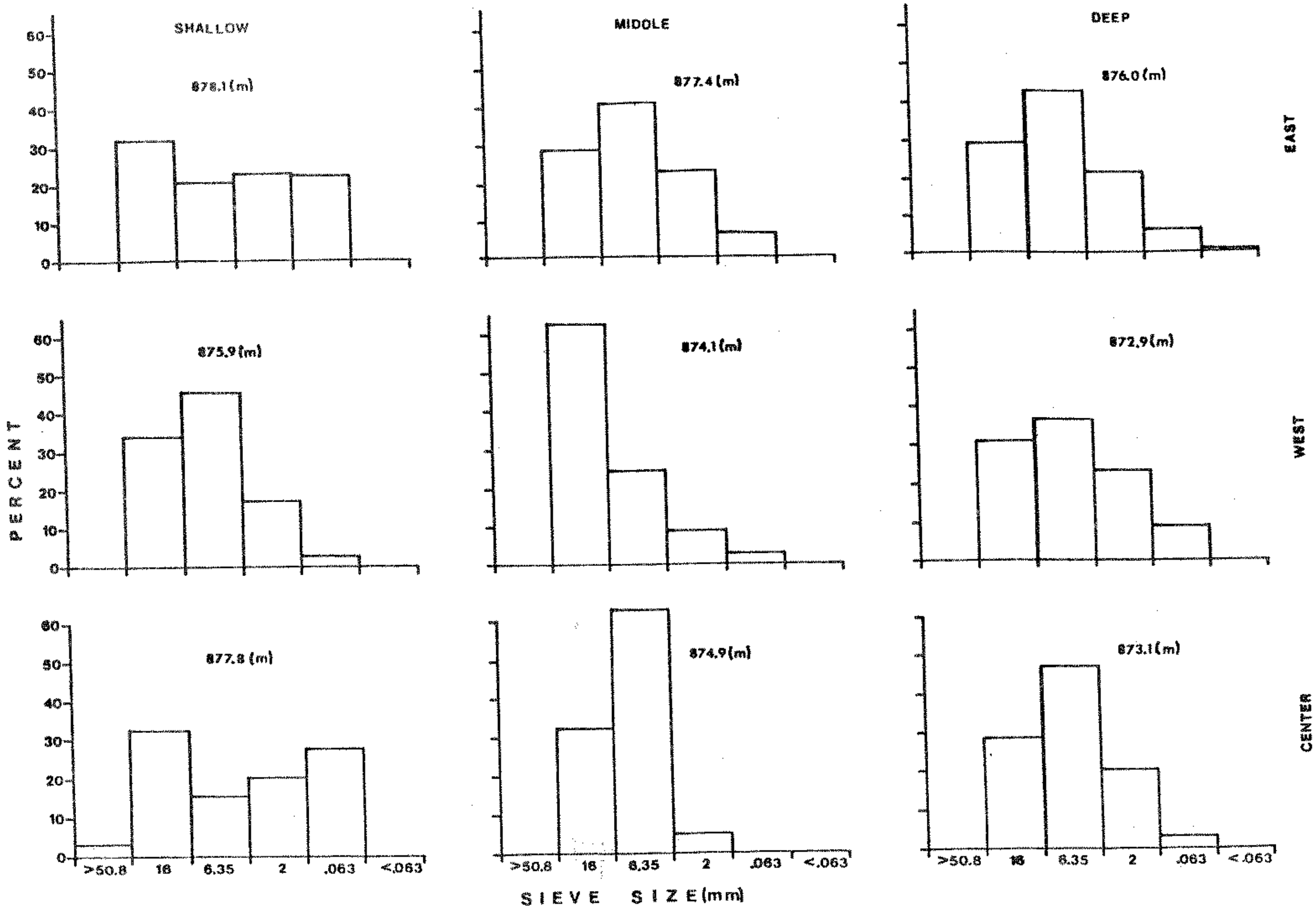


Figure 2. Percent substrate composition for nine samples collected along transects in the Yellow Bay spawning area. Bottom elevation in meters wheresample was collected is provided.

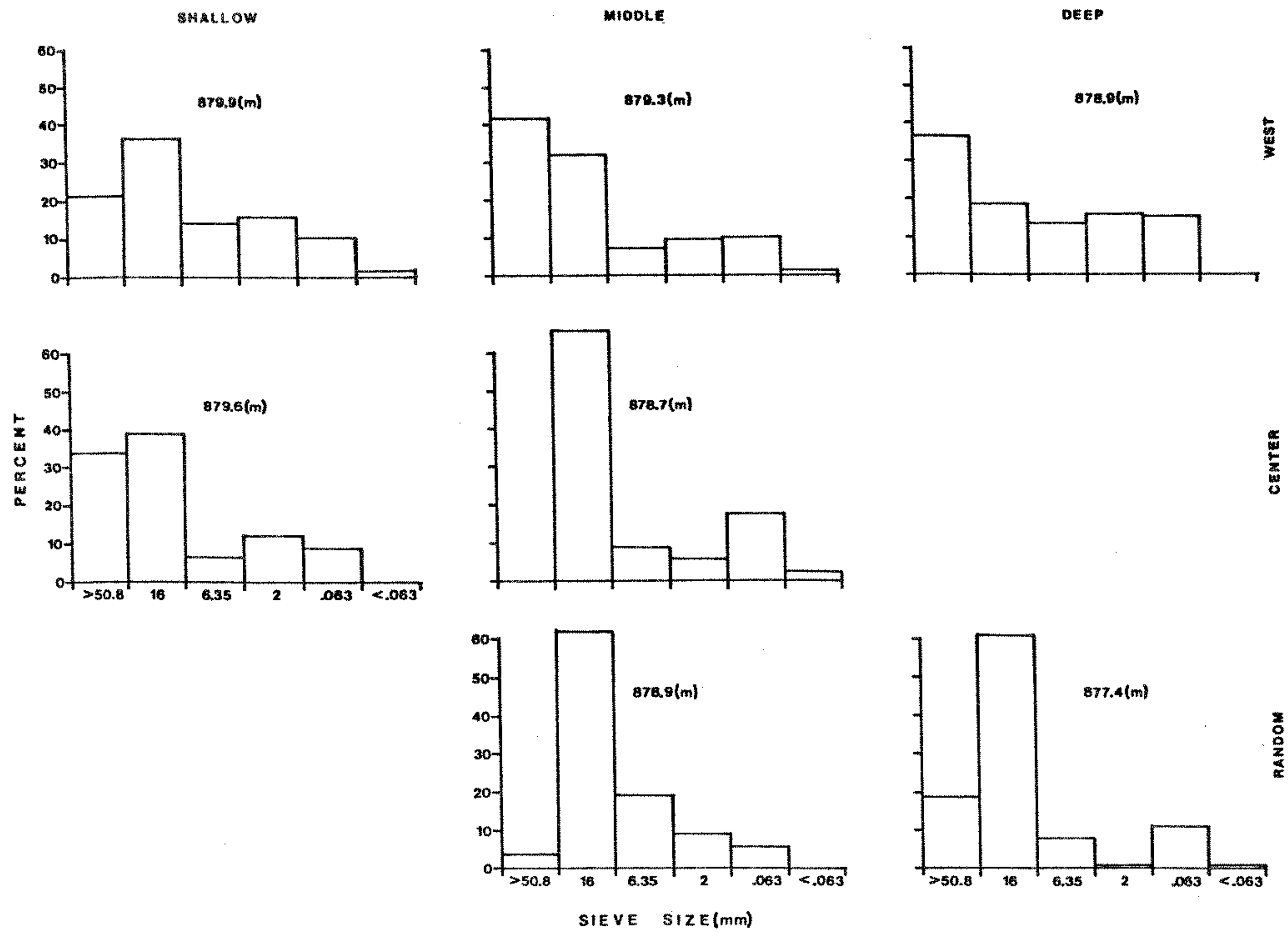


Figure 3. Percent substrate composition for nine samples collected along transects in the Dr. Richard's Bay spawning areas. The west and center samples were collected from the southern spawning area and the random samples were collected from the northern area. Bottom elevation in meters where sample was collected is provided.

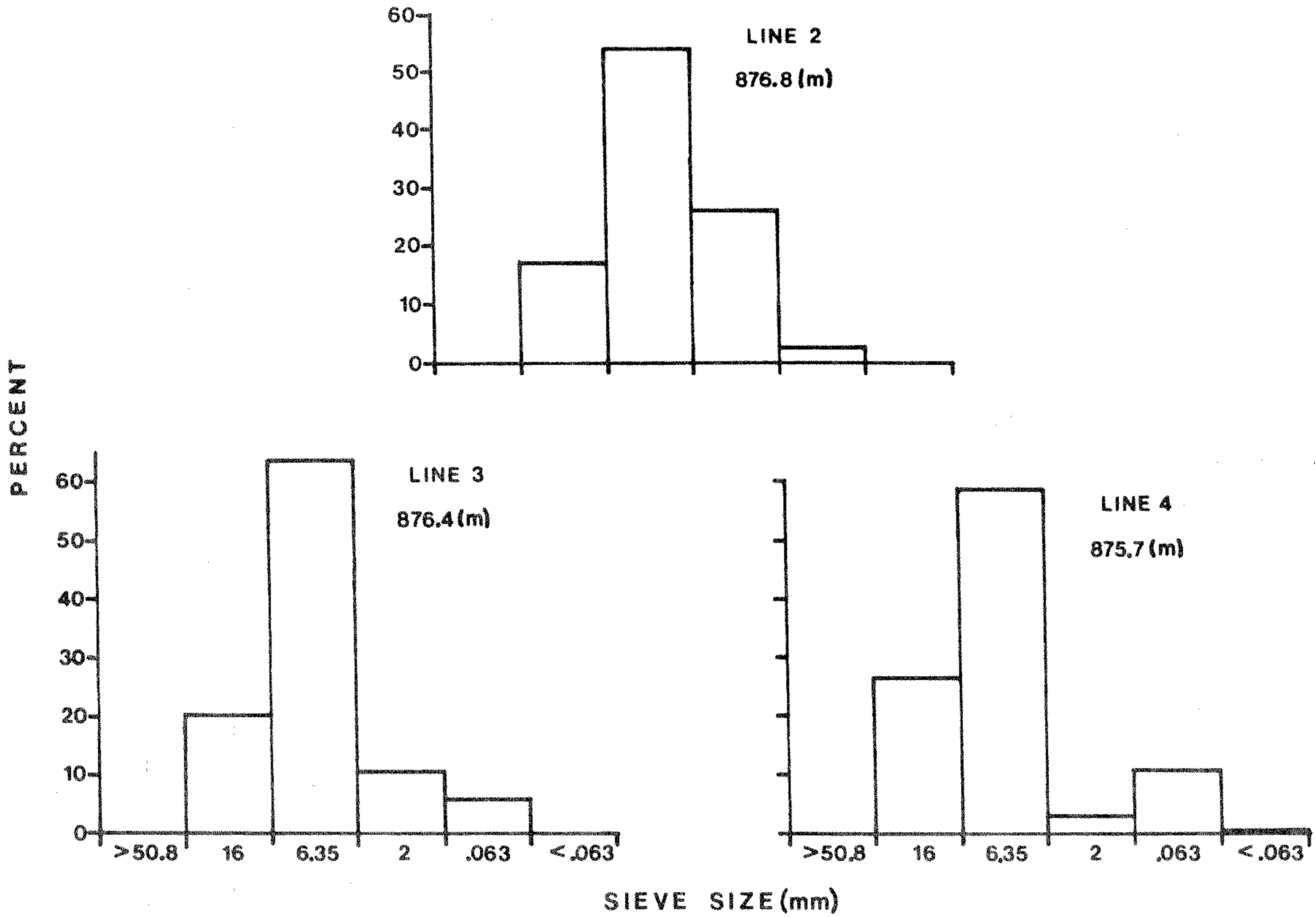


Figure 4. Percent substrate composition of the three egg bag lines located near the Yellow Bay Biological Station. Bottom elevation of the locations of the samples are provided in meters.

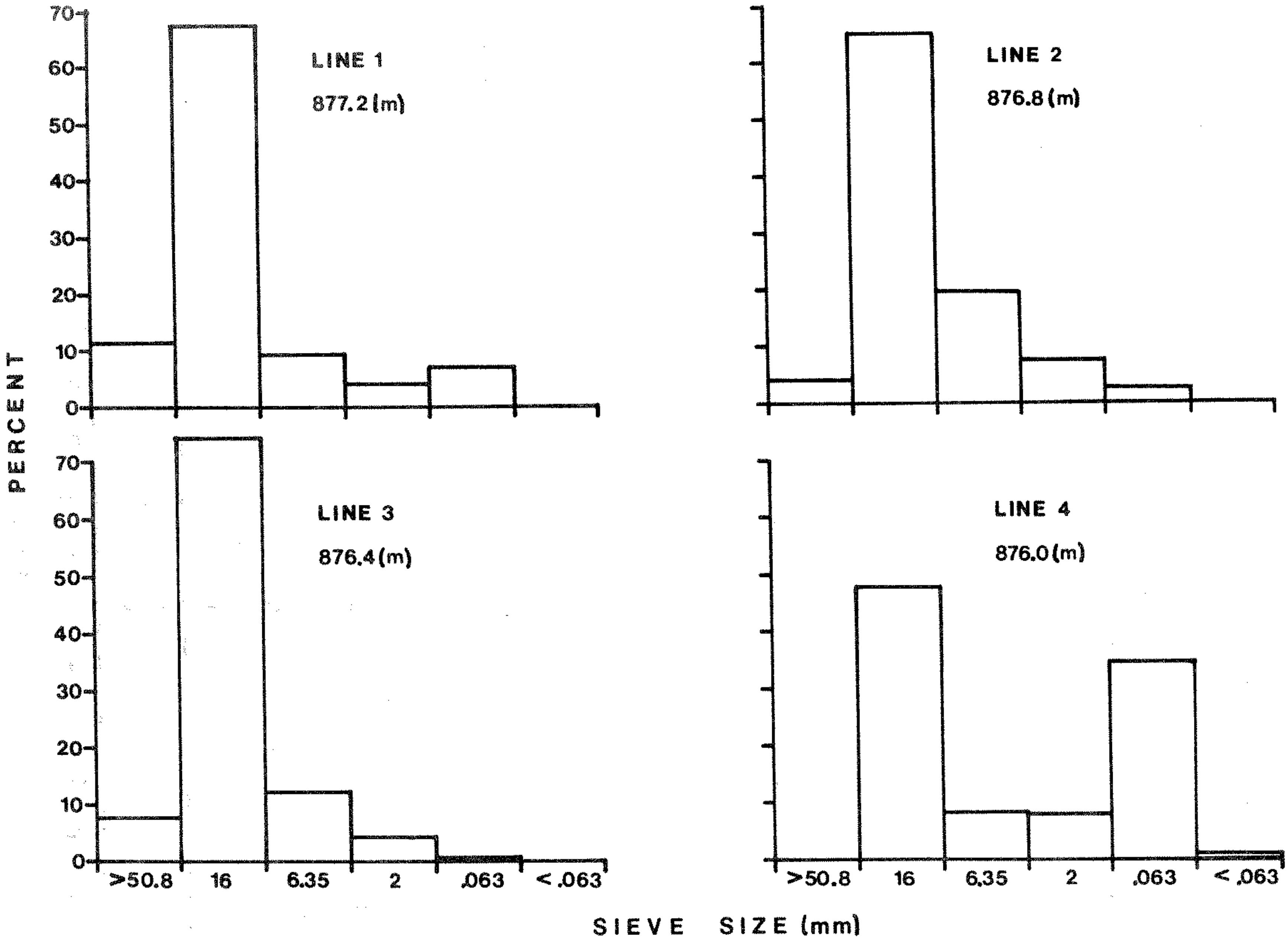


Figure 5. Percent substrate composition for four egg bag lines between the Yellow Bay State Park and Biological Station. Bottom elevations for the location of sample are provided in meters.

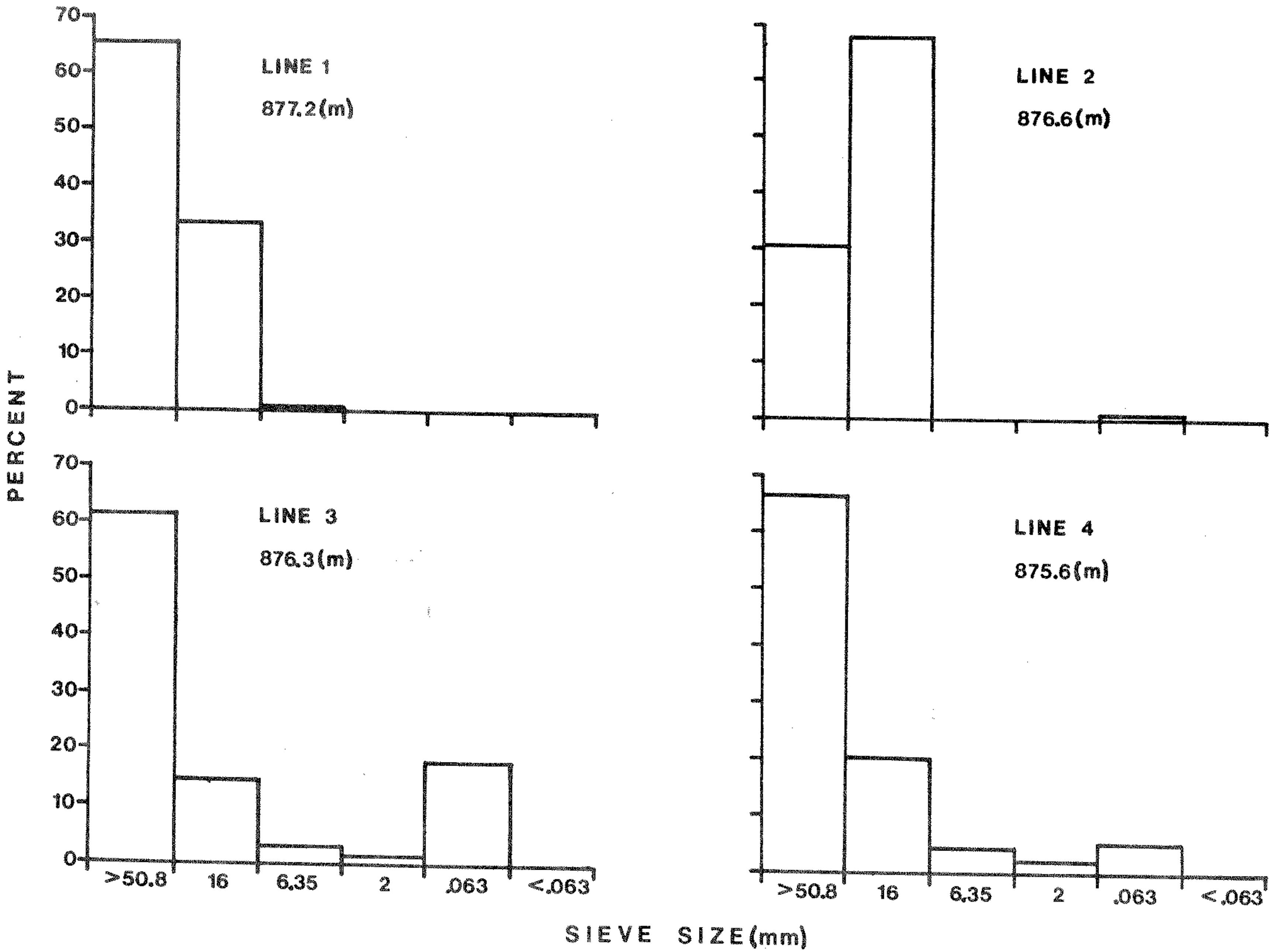


Figure 6. Percent substrate samples from four egg bag lines in Dr. Richard's Bay. Bottom elevation of sample location is provided in meters.

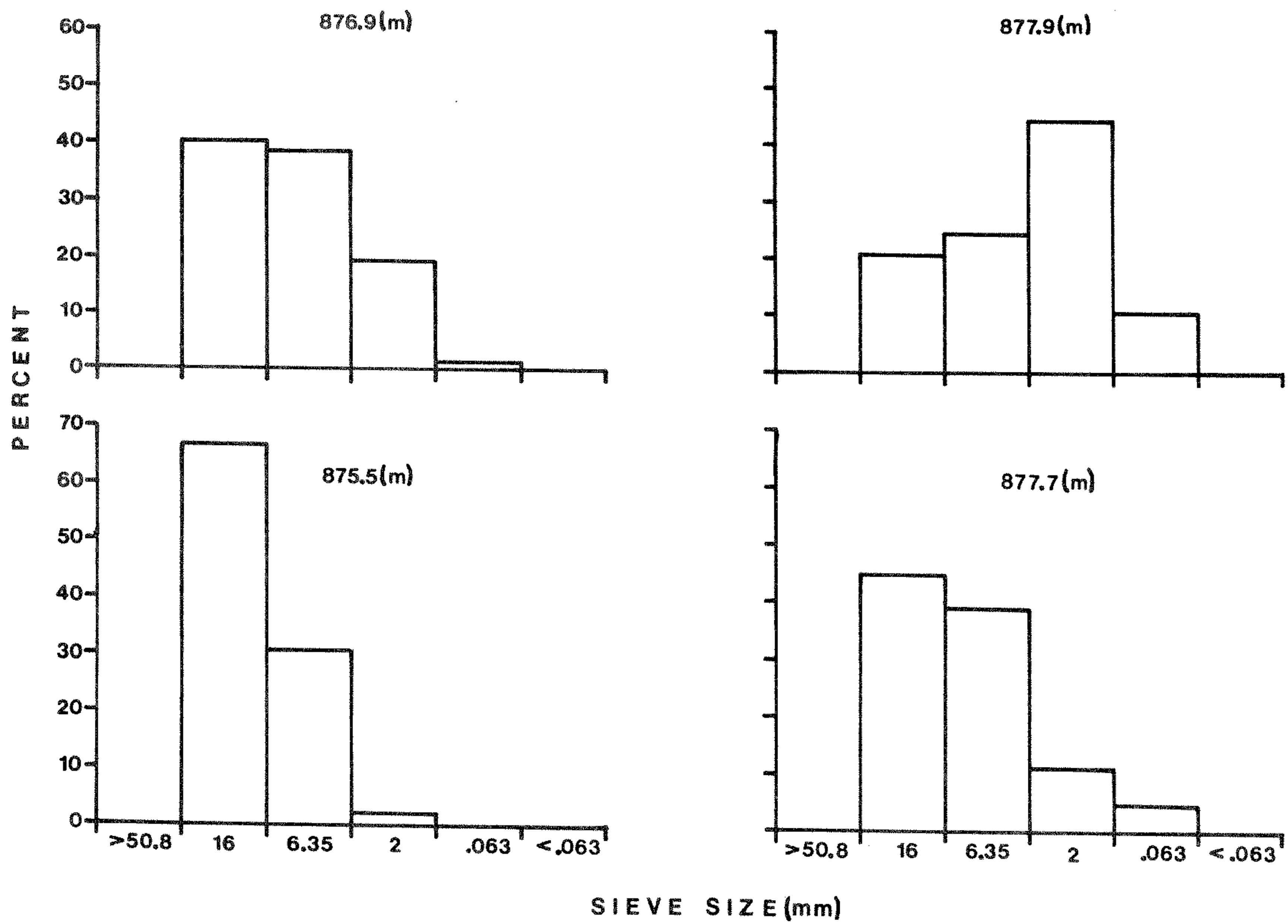


Figure 7. Percent substrate composition for four randomly collected samples from the Blue Bay spawning area. Bottom elevation (m) for sample location is provided.

APPENDIX C

Egg Development and Survival Studies

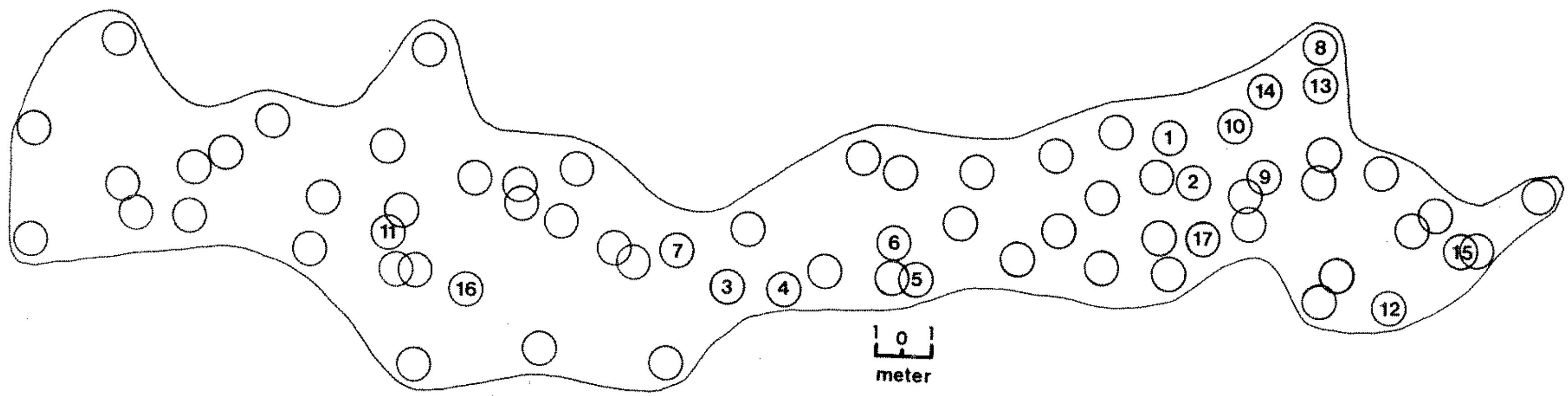


Figure 1. Location of redds in Skidoo Bay spawning area. Numbered redds indicate those excavated for embryo survival studies.

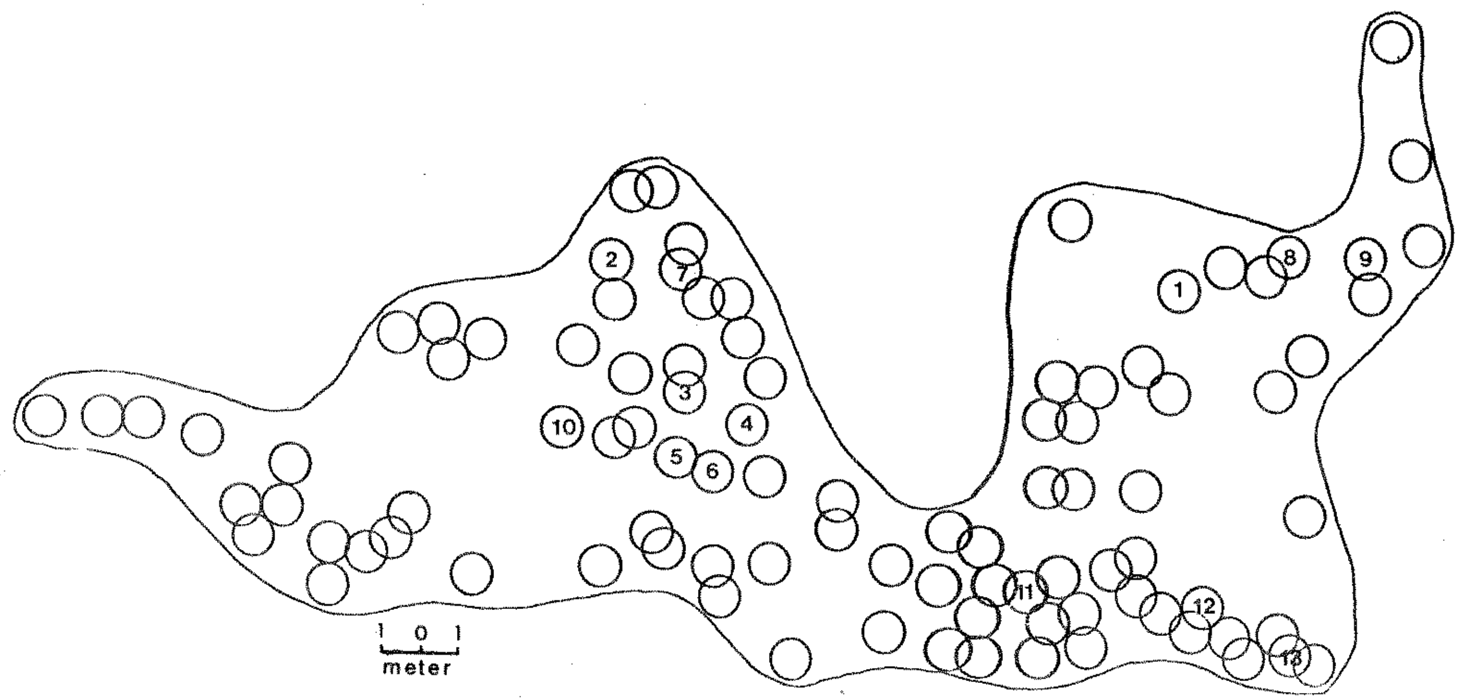


Figure 2. Location of redds in Dr. Richard's Bay North spawning area. Numbered redds indicate those excavated for embryo survival studies.

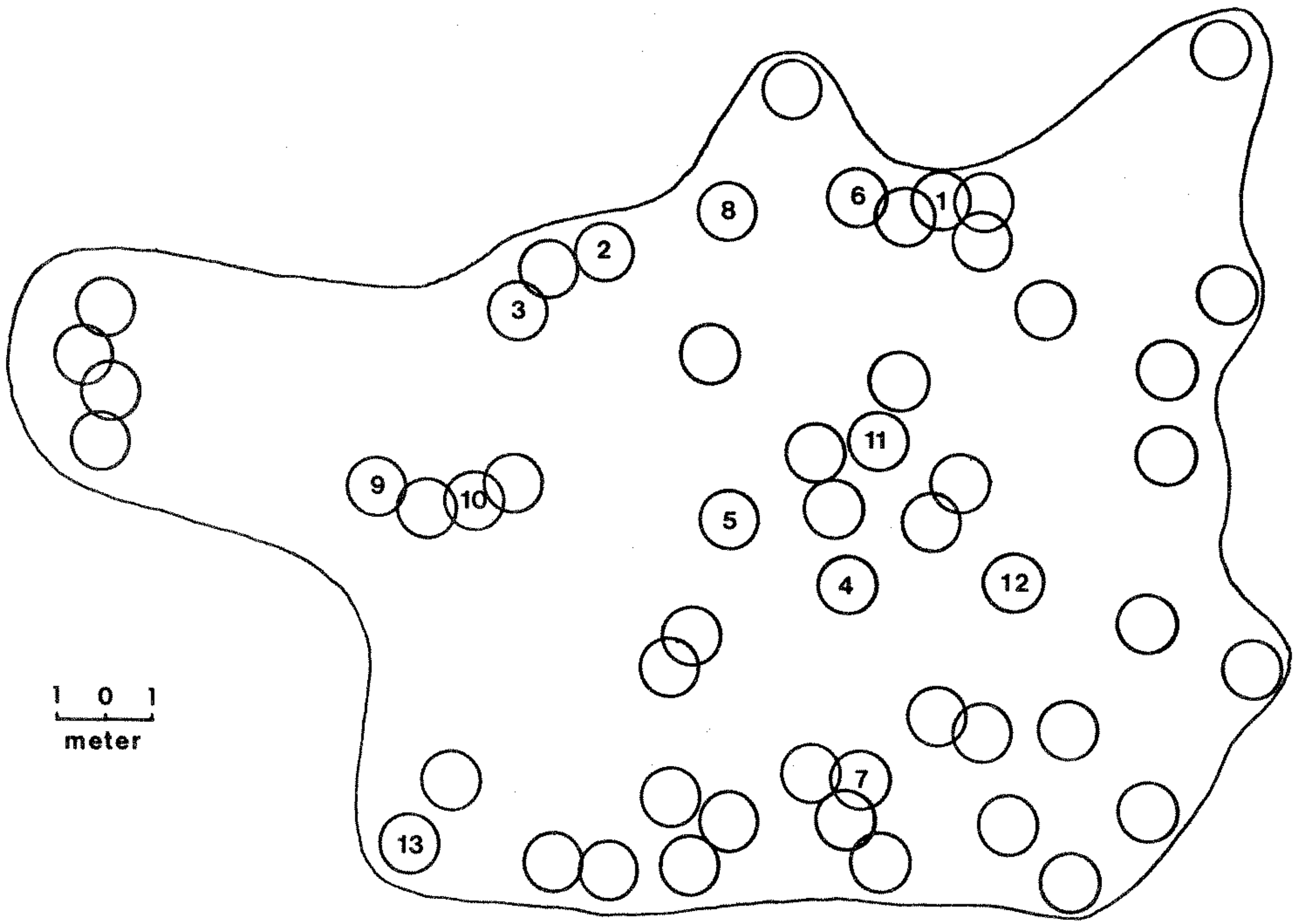


Figure 3. Location of redds in Dr. Richard's Bay South spawning area. Numbered redds indicate those excavated for embryo survival studies.

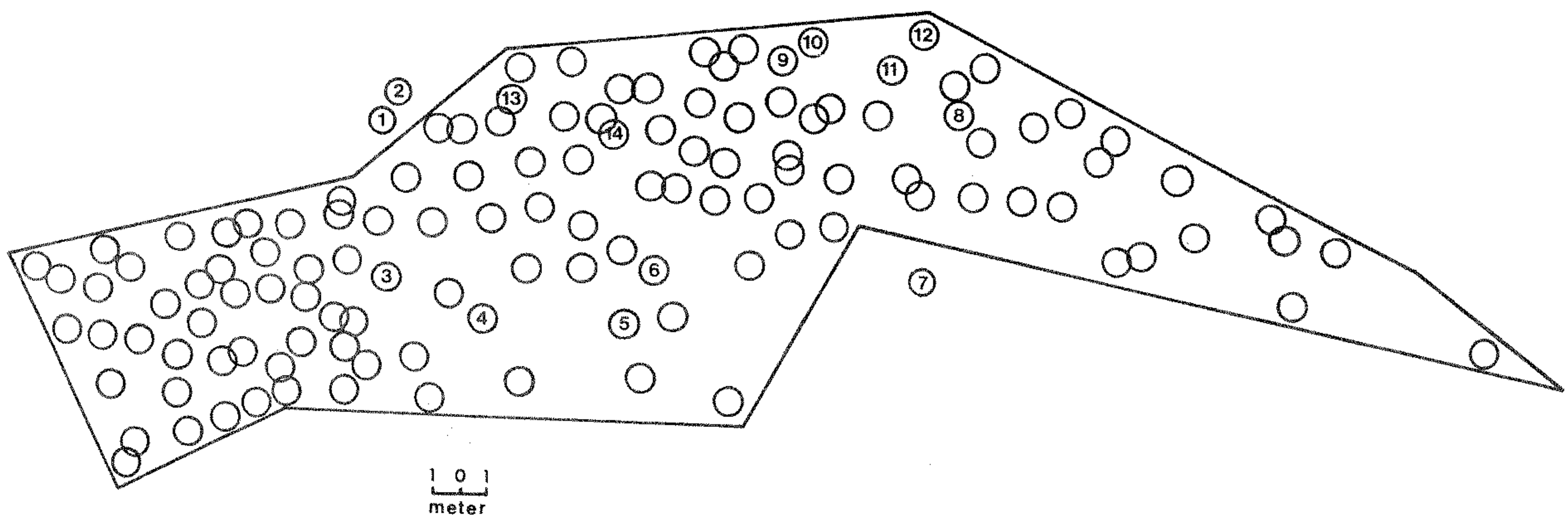


Figure 4. Approximate location of redds in Yellow Bay Spawning area. Numbered redds indicate those excavated for embryo survival studies.

Table 1. Redd location by bottom elevation (m) and number (correspond with those indicated on Figures 1-4), date redd exposed by drawdown, date sampled and percent survival and total number of eggs and alevins collected.

Location	Redd#	Elev. (m)	Date Exposed	Percent survival on Dates Sampled 2/2	2/8	2/16	3/2	3/10	4/7	Total number Eggs	Alevins
Skidoo Bay	12	880.0	1/15						0	NC [1]	NC
	16	880.0	1/15						NEF [2]		
	5	879.9	1/20				100		100	NC	NC
	6	879.8	1/23				NEF				
	4	879.8	1/23	NEF							
	11	879.8	1/23						NEF		
	15	879.8	1/23						NEF		
	3	879.7	1/25		0		0			118	
	17	879.7	1/25						NEF		
	7	879.7	1/28				0			771	38
	18	879.7	1/28					0		NC	
	2	879.3	2/10		NEF						
	1	879.3	2/10	81	29	31	10	NF [3]	NF	62	40
	9	879.2	2/12						NEF		
	10	879,2	2/14						NEF		
	13	879.1	3/2						NEF		
	14	879.1	3/2						NEF		
	8	879.1	3/5				23		NF	6	50
	TOTAL EMBRYOS COLLECTED									957	128

Location	Redd#	Elev. (m)	Date Exposed	Percent survival on dates sampled 1/29	2/1	2/16	3/2	Total number Eggs
Yellow Bay	4	877.9	ND [4]	0		B [5]		2
	5	877.9	ND	NEF		B		
	3	877.5	ND	77.3	63.9	B		207
	6	877.4	ND	NEF		B		
	7	877.4	ND				NEF	
	1	875.4	ND	0	0			10
	13	875.0	ND				NEF	
	8	874.4	ND				0	29
	2	874.3	ND		10			60
	14	874.2	ND				NEF	
	11	874.0	ND				NEF	
	9	874.0	ND				NEF	
	12	874.0	ND				NEF	
	10	873.9	ND				0	3
	TOTAL EMBRYOS COLLECTED							331

Table 1. Cont.

Location	Redd#	Elev. (m)	Date Exposed	Percent survival on dates sampled 2/1	2/2	2/16	3/5	Total number Eggs	Alevins
Dr. Richard's North	13	880.5	12/8				NEF		
	11	880.4	12/13				0	2	
	12	880.4	12/13				NEF		
	5	879.8	1/24				50	2	
	6	879.8	1/24				NEF		
	4	879.7	1/26				NEF		
	3	879.6	1/30	NEF					
	10	879.6	1/30				NS[6]		
	7	879.3	2/10				NS		
	2	879.2	2/13	NEF					
	1	879.1	2/17	NEF					
	8	879.05	3/4				NS		
	9	879.0	3/8				NEF		
	TOTAL EMBRYOS COLLECTED							4	

Location	Redd#	Elev. (m)	Date Exposed	Percent survival on dates sampled 2/1	2/2	2/16	3/5	4/7	Eggs	Alevins
Dr. Richard's South	13	880.4	12/17					NEF		
	7	880.2	1/4						157	
	12	880.0	1/16					0	NC	
	4	879.6	1/28			7.7			1092	
	5	879.5	2/2				0		74	
	9	879.5	2/2					NEF		
	10	879.4	2/6					0	NC	
	11	879.4	2/6					0	NC	
	8	879.3	2/10					0	NC	
	3	879.2	2/11			84.9	43.5	NF	264	26
	2	879.2	2/14			NEF				
	1	879.1	3/4	100	80.3	50			90	
	6	879.05	ND				13.8	0	65	
	TOTAL EMBRYOS COLLECTED								1742	26

1/ NC - No count
2/ NEF - No eggs found
3/ NF - Nothing found
4/ ND - Never dry
5/ B - Buried
6/ NS - Not sampled

Table 2. Date sampled, elevation of lines in meters, percent survival, stage of development and microhabitat parameters for egg bag lines in Dr. Richard's and Yellow bays.

Location	Date Sampled	Elev. (m)	% Survival	% Green	% Eyed	% Hatch	Dissolved oxygen (mg/l)	% fines <6.4mm
Yellow Bay								
Flume Area								
Line 1	1/18	878.2	96	100	0	0	6.25	--
	2/22		84	5	95	0		
	3/22		27	0	100	0		
Line 2	1/18	877.7	100	100	0	0	6.5	28.3
	2/22		0	-	-	-		
	2/22		0	-	-	-		
	3/22		0	-	-	-		
	3/22		0	-	-	-		
Line 3	1/18	877.3	20	100	0	0	5.5	16.1
	2/22		0	-	-	-		
	2/22		0	-	-	-		
	3/22		0	-	-	-		
	3/22		0	-	-	-		
Line 4	1/18	876.6	0	-	-	-	0	14.5
	2/22		0	-	-	-		
	2/22		0	-	-	-		
	3/22		0	-	-	-		
Pump House Area								
Line 1	1/18	878.0	73	100	0	0	9.1	11.2
	2/22		2	100	0	0		
	3/22		10	40	60	0		

Table 2. (Cont.)

Location	Date Sampled	Elev. (m)	% Survival	% Green	% Eyed	% Hatch	Dissolved oxygen (mg/l)	% fines <6.4 mm
	4/21		4	0	50	50		
	5/26		0	-	-	-		
Line 2	1/18	877.7	73	100	0	0	6.8	10.9
	2/22		23	100	0	0		
	3/22		76	0	100	0		
	4/22		10	0	40	60		
	4/22		13	0	100	0		
Line 3	1/18	877.2	66	100	0	0	8.1	5.1
	2/22		79	13	87	0		
	3/1		18	33	67	0		
	3/22		31	33	67	0		
	4/22		12.5	0	100	0		
Line 4	1/18	876.9	0	-	-	-	2.8	43.9
	2/22		0	-	-	-		
	3/22		0	-	-	-		
	4/21		0	-	-	-		
	5/26		0	-	-	-		
Dr. Richard's Bay								
Line 1	1/18	878.1	82	100	0	0	12.4	.2
	2/22		92	0	100	0		
	3/23		80	0	100	0		
	4/22		65	0	74	26		
	5/25		2	0	0	100		
Line 2	1/18	877.5	92	100	0	0	5.6	1.2
	2/22		62	0	100	0		

Table 2. (Cont.)

Location	Date Sampled	Elev. (m)	% Survival	% Green	% Eyed	% Hatch	Dissolved oxygen (mg/l)	% fines <6.4mm
	3/23		31	0	100	0		
	4/22		54	0	88	12		
	5/25		44	0	0	100		
Line 3	1/18	877.2	0	-	-	-	0	20.3
	2/22		0	-	-	-		
	3/23		0	-	-	-		
	4/22		0	-	-	-		
	5/25		0	-	-	-		
Line 4	1/18	876.5	6	100	0	0	0	8.4
	2/22		0	-	-	-		
	3/23		0	-	-	-		
	4/22		0	-	-	-		
	5/25		0	-	-	-		

Table 3. Accumulated centigrade temperature units and stage of development for planted eggs in Dr. Richard's and Yellow bays, 1981-82.

Location	Date Sampled	Stage of Development	Centigrade Temperature Units
Dr. Richard's Bay			
Egg Bag Line 1	1/18	0% Eyed	236
	2/22	100% Eyed	331.4
	3/23	100% Eyed	417.5
	4/22	65% Eyed	526
		35% Fry	
	5/25	100% Fry	710.6
Egg Bag Line 2	1/18	0% Eyed	236
	2/22	100% Eyed	331.4
	3/23	100% Eyed	417.5
	4/22	84% Eyed	526
		16% Fry	
	5/25	100% Fry	710.6
Yellow Bay			
Pump House Line 1	1/18	0% Eyed	216
	2/22	0% Eyed	340.3
	3/22	60% Eyed	470.3
	4/21	50% Eyed	613.6
		50% Fry	
Pump House Line 2	1/18	0% Eyed	216
	2/22	0% Eyed	340.3
	3/22	100% Eyed	470.3
	4/22	25% Eyed	
		75% Fry	619.2
Pump House Line 3	1/18	0% Eyed	216
	2/22	87% Eyed	340.3
	3/23	66% Eyed	475.3
	4/1	66% Eyed	511.2
	4/22	100% Eyed	619.2

APPENDIX D

Fry Emergence and Distribution

Table 1. Measurements (in mm) of total length, eye diameter, and head width of seven prematurely emergent sac fry found in Skidoo Bay spawning area on 11 March 1982. Calculated centigrade temperature units were predicted using a multiple regression model from unpublished data of Hanzel and Rumsey (MDFWP, Kalispell, MT)

Fry	Total Length	Eye Diameter	Head Width		Centigrade Temperature Units
1	22.1	1.55	2.9		586.
2	22.0	1.65	2.85		629.5
3	22.4	1.6	2.85		609
4	18.8	1.35	2.55		431
5	17.5	1.55	2.75		527
6	20.7	1.45	2.55		498
7	21.5	1.5	2.65		537
				$\bar{x}$ =	545.6

Table 2. Location and daily and total catch from emergence traps placed in Blue, Yellow and Gravel bays during April, May and June 1982. Slash indicates trap not in place. (/).

Trap Location & Elevation (m)	Date Traps Placed	Dates Checked											Total
		4/9	4/13	4/16	4/22	4/29	5/5	5/12	5/19	5/26	6/3	6/8	
Blue Bay													
875.3	3/30	0	0	0	0	0	0	0	0	1	0	0	1
875.6	3/30	0	0	0	0	0	0	0	0	0	0	0	0
875.7	3/30	28	22	4	6	91	24	23	4	0	0	1	203
875.8	3/30	0	0	0	0	0	0	0	0	1	0	0	1
876.0	4/13	/	/	0	0	0	0	1	0	0	0	0	1
876.1	3/30	0	0	0	0	0	0	0	12	1	0	0	13
876.1	4/13	/	/	0	0	0	0	0	0	0	0	0	0
876.4	4/13	/	/	1	0	0	2	2	0	3	0	0	8
Total		28	22	5	6	91	26	26	16	6	0	1	227
Yellow Bay													
874.2	3/30	No kokanee fry captured in any traps; sculpins and redside shiners were the only fish captured in traps. Stomachs were checked for kokanee fry remains.											
875.1													
875.3													
876.0													
876.2													
876.2													
876.2													
876.7													
877.0													
877.0													
878.1													
878.2													
878.6													
Total													

Table 2. Continued

Trap Location & Elevation (m)	Date Traps Placed	Dates Checked											
		4/9	4/13	4/16	4/22	4/29	5/5	5/12	5/19	5/26	6/3	6/8	Total
Gravel Bay													
876.1 876.2 876.4 876.4 877.0	4/16	No kokanee fry were captured in traps; sculpins and redside shiners were the only fish captured in traps. Stomachs were checked for kokanee fry remains.											

Table 3. Substrate composition analysis and intergravel dissolved oxygen concentrations by elevation for selected fry plant sites in shoreline areas of Flathead Lake.

Location	Elevation (m)	Dissolved oxygen (mg/l)	Percent Composition Sieve Sizes (mm) 50.8	16	6.35	2	.063	<.063
Blue Bay	879.2	NS*	0	20.7	24.2	44.1	10.9	.1
	876.5	10.9	0	40.3	38.8	19.4	1.5	< .01
	875.8	0.7	NS	NS	NS	NS	NS	NS
	874.6	0.7	NS	NS	NS	NS	NS	NS
Blue Bay	879.2	11.6	NS	NS	NS	NS	NS	NS
	878.6	9.4	0	44.6	39.0	11.2	4.9	.3
	878.2	NS	NS	NS	NS	NS	NS	NS
	877.7	6.4	NS	NS	NS	NS	NS	NS
	876.4	8.6	0	66.6	30.8	2.4	.1	.1
Crescent Bay	880.8	11.4	NS	NS	NS	NS	NS	NS
	880.4	10.6	NS	NS	NS	NS	NS	NS
	880.4	9.3	0	43.0	11.0	34.6	11.2	.2
	880.3	7.2	NS	NS	NS	NS	NS	NS
	880.2	7.3	NS	NS	NS	NS	NS	NS
	880.0	8.4	NS	NS	NS	NS	NS	NS
	879.9	9.1	NS	40.1	18.5	25.0	16.3	.1
	879.7	NS	8.7	64.8	15.3	7.7	3.4	.1
	879.2	NS	NS	30.3	12.7	32.3	25.1	.1
	878.8	NS	24.4	56.1	8.1	4.4	6.7	.3
Skidoo Creek	880.6	9.6	NS	NS	NS	NS	NS	NS
	880.5	7.3	NS	NS	NS	NS	NS	NS
	880.3	8.6	NS	NS	NS	NS	NS	NS
	880.0	6.5	NS	NS	NS	NS	NS	NS
	879.7	7.2	NS	NS	NS	NS	NS	NS
	879.7	5.7	NS	NS	NS	NS	NS	NS
	879.5	2.8	NS	NS	NS	NS	NS	NS

NS* = Not Sampled