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DEVELOPMENT AND EVALUATION OF A NET BARRIER TO REDUCE ENTRAINMENT LOSS OF KOKANEE FROM BANKS LAKE

by

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1.0 ABSTRACT

A net barrier was established in the southeast sector of Banks Lake to reduce the entrainment of mature kokanee into the main irrigation canal. Net maintenance equipment was designed and constructed and included an engine, hydraulic pump, power block and roller and a high-pressure water pump. This equipment was mounted on a small boat-barge which traversed the length of the net during cleaning to remove aquatic weeds and algae with high-pressure water jets.

The escapement of fishes past the barrier net was measured directly by sampling the irrigation canal entrainment. Estimated entrainment of all species combined was lowest in 1977 at 39,392 compared with 149,664 in 1975 and 53,880 in 1976. An estimated deposition of 1,033,812 eggs in 1977 from a total kokanee spawning population of 1,880 compared favorably with an estimated 84,135 eggs from 153 spawners in 1976. This indicates the net was successful in retaining spawners and increasing the potential recovery of the weak 1977 year class. The mature kokanee population of 8,911 in 1977 based on entrainment catches and spawner counts was the lowest of the 3 yr observed. This compares with the combined estimate for 1976 of 32,272. Operation of the barrier net during 1977 is considered to have retained about 21 percent of the population, while in 1976 without a barrier net only about 0.5 percent of the kokanee population remained in the lake. These estimates of retention are not strictly comparable because the total population in 1977 was only about one-third as large as that in 1976.

The number of fish gilled in the barrier net was not significant. Baseline monitoring with gillnets in the main lake basin showed an increase in the abundance of age II kokanee indicating that fishing should improve in 1978.

Two artificial spawning beds were placed in the lake during fall 1977 to test the feasibility of creating kokanee spawning habitat below the level of maximum lake drawdown. Each bed was composed of 38.2 m^3 of washed graded gravel, distributed in a layer averaging 25 cm deep and located about 8 m subsurface. These beds were planted with 100,320 eyed kokanee eggs to test survival and fry production. Fry sampling on the artificial beds as well as the natural spawning areas could determine

the potential of the artificial spawning areas.

The use of a barrier net to reduce the loss of kokanee brood stock from the lake and the establishment of spawning and incubation habitat below the level of maximum lake drawdown could ensure a viable kokanee fishery sustained by a wild kokanee population. Management of the fishery in this manner would maintain the high quality of the existing fishery at the lowest cost and may isolate the wild kokanee population from the annual impacts imposed by irrigation and pumped storage power generation. Several recommendations are made to improve the operation and efficiency of the barrier net including additional evaluation which would aid the management of both the water supply and fisheries in the lake.

2.0 ACKNOWLEDGMENTS

This study was sponsored by the U.S. Bureau of Reclamation; Pacific Northwest Regional Office, Boise, Idaho; and Columbia Basin Irrigation Project, Ephrata, Washington.

The cooperation received from the Washington State Department of Game is greatly appreciated. The Northwest Steelhead and Salmon Council of Trout Unlimited, Wenatchee, Washington, was responsible for providing the materials and manpower to place two artificial spawning beds in Banks Lake.

Part-time field and laboratory assistance provided by students included the following: Mr. Steve Davis and Ms. Susan Paskell.

3.0 INTRODUCTION

The primary purpose of Banks Lake is to function as the equalizing reservoir for the Columbia Basin Irrigation Project. The operational changes imposed on the lake by irrigation result in dramatic effects on the water quality which are exemplified in the aquatic ecosystem and the important sport fish populations. Some of the changes imposed on the lake are beneficial, such as nutrient addition and mixing which stimulate production. Other changes such as frequent, major water level fluctuations as well as entrainment and flushing can impose strict limitations on the ability of the system to produce and sustain aquatic life and fish. Although the full range of interaction has not been determined, the extreme drawdown imposed on the lake due to third powerhouse construction at Grand Coulee Dam in 1973 and 1974 created some undesired reductions of the sport fish populations. The present development of pumped storage power generation on the lake will impose changes which will occur during the winter while expansion of the Columbia Basin Irrigation Project will increase the existing impacts on the aquatic ecology of the lake. The operational use of the lake for water supply and production of electric energy will occur throughout the year once full development is reached.

In spite of the operational effects imposed on Banks Lake throughout its history, a popular sport fishery developed due to the production of relatively large populations of kokanee and other species. The fishery developed along with a maximum annual drawdown of about 4.6 m suggesting that some operational fluctuation of the lake level can be tolerated. However, based on the information obtained in the study of the system from 1973-1977, the magnitude, timing and rate of water level change could be managed in the future to achieve a larger and more consistent standing crop of sport fishes. The occasional severe reduction of a key sport fish year class due to construction or unusual reservoir operation may also be minimized.

The entrainment of kokanee through the irrigation canal is an annual loss which has been imposed on every year class to date. There is little doubt, however, that the entrainment loss constitutes a substantial reduction of the population of mature age III and IV kokanee. Entrainment of adult kokanee through the irrigation canal has been found to seriously deplete the spawning population remaining in the lake where natural reproduction must take place to sustain the species. This loss of large mature kokanee is especially acute on a year class which has previously been reduced in numbers by lake drawdown. This loss of brood stock in 1976 resulted in insufficient egg deposition needed to produce an adequate number of fry the following year. The entrainment loss of adult kokanee also removed large numbers of fish from the concentrated sport troll fishery active on Banks Lake. Therefore, management of the lake level to sustain the natural reproductive potential of kokanee along with retention of the adult kokanee by selective screening of the irrigation outlet would help to insure continuation of a viable sport fishery on Banks Lake.

The objectives of this study were to develop and evaluate a practical and economical means of reducing the loss of sport fish from Banks Lake via entrainment into the irrigation canal. A fish barrier net was designed, constructed and operated to isolate the southeast corner of Banks Lake including the irrigation canal outlet works. This approach was selected to avoid more costly design, construction and maintenance which would be required if a traveling screen or louver structure were developed, an approach which may in fact be less practical.

The net barrier was specifically designed to lead adult 3- and 4-year-old kokanee away from the outlet structure. These age classes are the principal ones entrained and those most desired by the sports angler. Three-year-old kokanee constitute the principal spawning year class and retention of an adequate spawning population in the lake for reproduction is vital to maintenance of the population. Evaluation of the effectiveness of the net barrier required determination of fish entrainment rates into the irrigation canal and the number of kokanee spawners retained in the lake. Gillnet and acoustic sampling was used to determine fish densities, and a limited creel census provided additional relevant information.

Because of the probability that future drawdowns will consistently exceed 4.6 m, an additional study investigated the feasibility of establishing artificial gravel beds in deep waters below the minimum drawdown level to determine if kokanee will utilize the deeper habitat.

4.0 DESCRIPTION OF THE STUDY AREA

Banks Lake was established in 1951 by flooding 10,926.5 ha (27,200 ac) along a 46.5-km (28.9-mi) section of the upper Grand Coulee between two earth-filled dams (Wolcott 1964) (Fig. 1). The North Dam constitutes the northern boundary of the lake. Dry Falls Dam (also known as South Dam) bounds the southern end of the lake. The pumping plant located at the left forebay of Grand Coulee Dam pumps water from Franklin D. Roosevelt Reservoir up 111.2 m (365 ft) into a 2.5-km (1.6-mi) long feeder canal which supplies water to Banks Lake adjacent to the North Dam. The pumping plant contains six pumps, each rated at 45.3 m^3/sec (1,600 cfs) and two pump generators, each rated at 49.6 m^3/sec (1,750 cfs) in the pumping mode. Water for irrigation is withdrawn from Banks Lake through the irrigation canal headworks at Dry Falls Dam to supply the agricultural requirements on about 202,000 ha (500,000 ac) of farmland in the Columbia Basin. The present maximum rate of irrigation withdrawal is 223.6 m^3/sec (7,900 cfs).

The location of the sampling stations established in 1973 to monitor the aquatic ecology and fisheries of the lake are shown in Fig. 1. Sampling was continued at stations 4, 5 and 6 during the present study in an effort to sustain the baseline to aid in the evaluation of the net barrier.

Variations in the operational rates of water supply and withdrawal to Banks Lake result in water level fluctuations of the lake. Rates of irrigation water input and withdrawal and changes in water level elevation from January 1973 to December 1977 are presented in Fig. 2. Maximum surface elevation is 478.5 m (1,570 ft) and at maximum drawdown the surface elevation is 469.4 m (1,540 ft). The annual drawdown does not normally exceed 4.6 m (15 ft) but during the past few years drawdown reached 7.6 m (24.9 ft) and 7.2 m (23.6 ft) during the spring of 1973 and summer of 1974 (Fig. 2). Major decline in the water level has not occurred since 1974.

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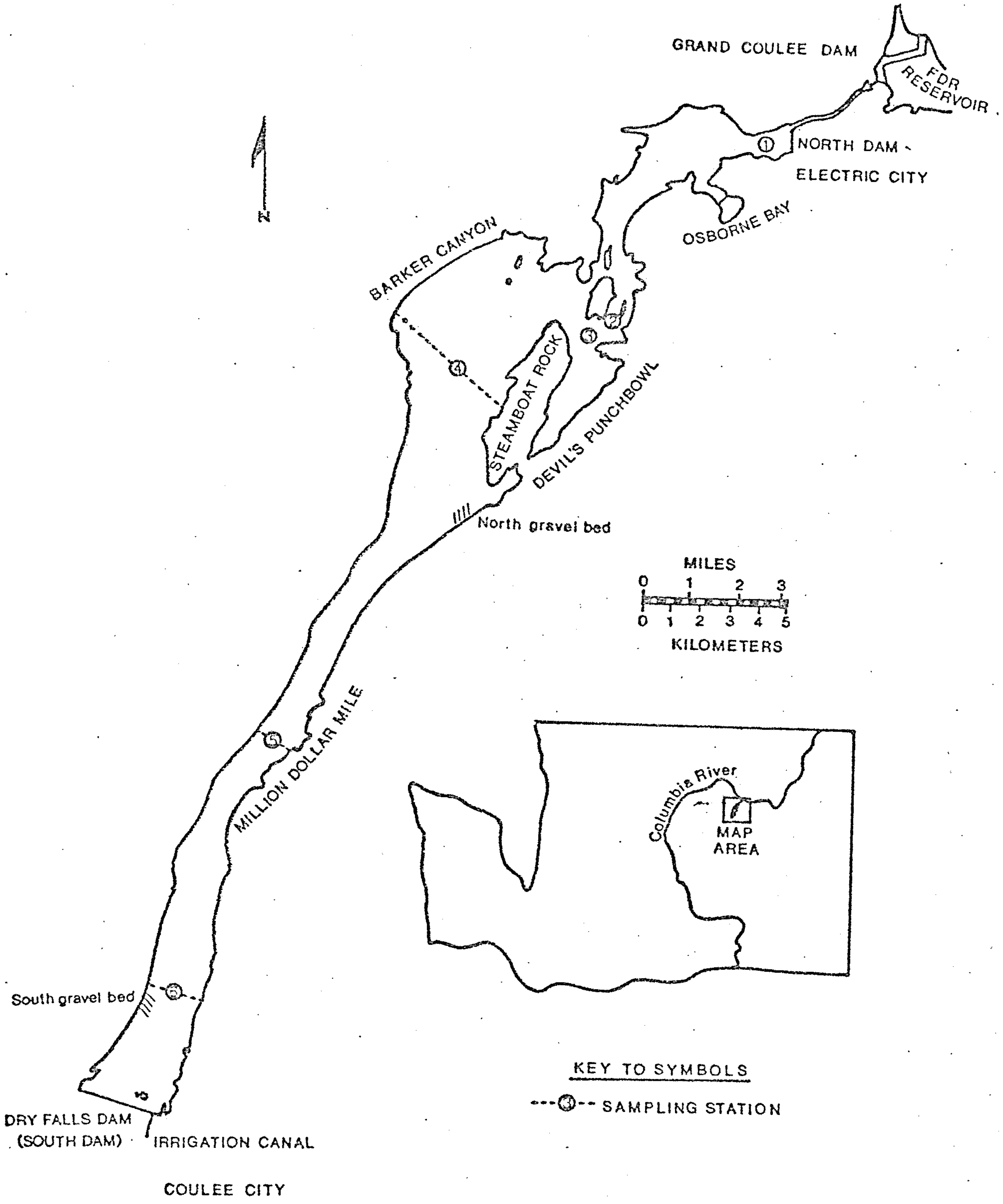

Fig. 1. Geographical location and features of Banks Lake and locations of sampling sites.

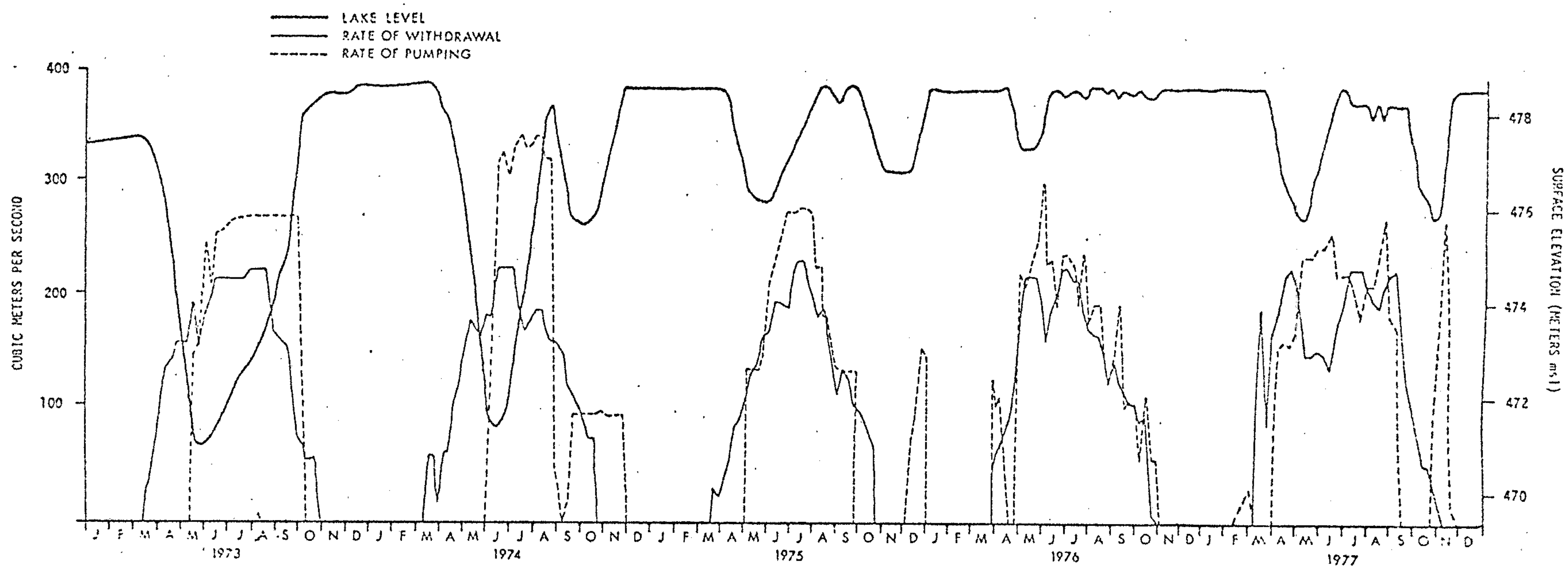

Fig. 2. Banks Lake surface elevations relative to rates of irrigation water input and withdrawal, 1973 to 1977 (USBR).

The south end of Banks Lake near the irrigation outlet is generally less than 12 m deep at full pool. A dredged channel 17 m deep connects the deeper pool to the irrigation canal headworks and allows for irrigation withdrawal at maximum drawdown. The presence of the dredged channel and two islands (Fig. 3) were important morphologic features considered in the design and site selection of the net barrier. The irrigation canal (main canal) headworks are located in the east end of the South Dam, a short distance from Coulee City. The canal was cut through basalt rock and extends south for 3.4 km (2.1 mi) where it leads into Bacon Siphon.

The headworks of the irrigation canal is constructed of concrete. A concrete apron extends 32.9 m downstream into the canal where it abruptly ends. Six outlet tunnels, each 3.7 m wide x 6.4 m high (12 x 21 ft), empty into the canal. Flow of water through each tunnel is regulated by radial gates. At maximum lake elevation, 478.5 m, water was discharged under 9.1 m of pressure head directly through the tunnels and into the irrigation canal.

Sampling stations 7, 8, 9, 10 and 11 were located in the lake near (Fig. 3) the irrigation outlet to aid in additional sampling of the fish populations in and around the barrier net.

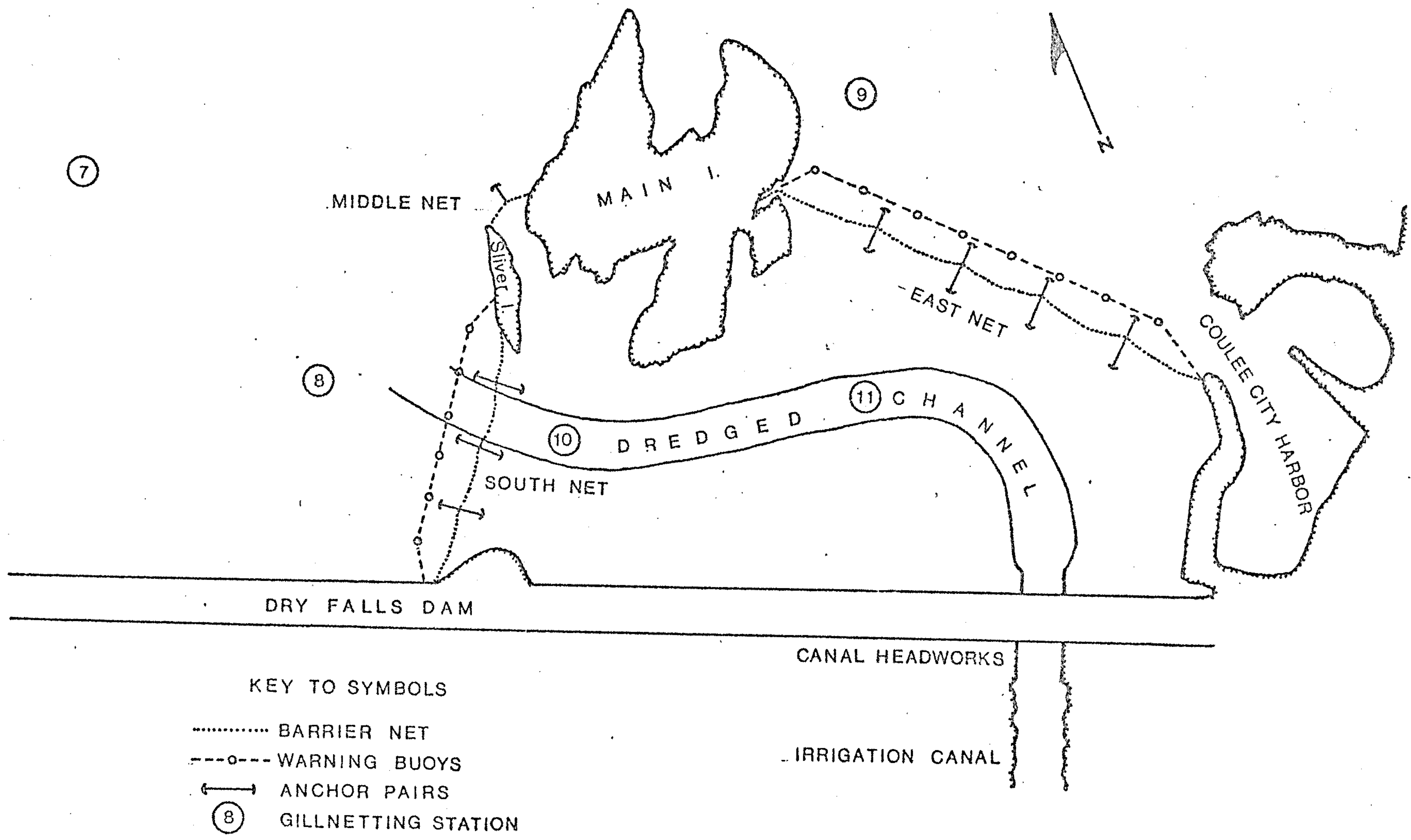

Fig. 3. Southeast corner of Banks Lake showing locations of barrier nets, anchors and gillnet sampling sites.

5.0 MATERIALS AND METHODS

5.1 Barrier Net Development and Operation

5.1.1 Site Selection

Selection of the barrier net sites was a compromise between factors which favored maximizing the distance from the outlet and others which favored minimizing the distance. Those which favored maximum distance were current velocity, anchoring security, and regularity of bottom contour. Those favoring minimum distance were cost of the net, interference with boat traffic and shoreline anglers on Dry Falls Dam.

Preliminary soundings of the general net sites were made using a recording fathometer during October 1976, to determine the suitability of the bottom contour. The east net site was determined to be very suitable because of its moderate depth (9.7 m maximum) and uniform gradient without ledges or abrupt depth changes. The south net site was less suitable because of its greater depth (17 m maximum), presence of a dredged channel, and because of 3-m ledges existing near both ends. The small channel between the two islands was less than 3 m deep and uniform as long as the net was set with a slight westerly bow in order to follow a shoal between the islands.

The cross-sectional bottom contour between specific attachment points for all three nets was sounded through the ice during February 1977 in order to obtain an accurate series of length and depth measurements. Detailed contour maps were drawn of the three net sites for use in construction of nets to fit the cross-sectional openings.

Shoreline attachment points for the ends of the nets were installed by the Bureau of Reclamation at specified locations. The attachment points on Dry Falls Dam, and the two islands consisted of holes drilled into bedrock at 478.5 m elevation into which 20-mm eye bolts were set with epoxy plastic. The attachment point on the jetty at Coulee City Harbor consisted of a deadman embedded in the east slope of the jetty with a cable running through the jetty and emerging on the west slope.

Large, highly visible steel buoys were placed by the Bureau of Reclamation immediately outside the barrier net site at about 60-m intervals across the east and south channels as a warning to boaters (Fig. 3). A 1,290-m cork line strung with 15-cm diameter by 20-cm polystyrene floats was stretched between the steel buoys from shore to shore as a positive deterrent to boaters.

5.1.2 Design and Construction

A net was designed to fit the bottom contour of each opening with 10 percent added to insure surface-to-bottom fit. An additional 5 percent was added uniformly to the length of the east and south nets to insure shore-to-shore fit. The net material used in construction was 83-mm (3 1/4-inch stretched measure) 16-thread knotless dacron. This mesh size was selected because of its low resistance to current and low fouling rate compared with smaller mesh sizes.

Body depth and girth measurements of kokanee determined that the largest of age II kokanee and age III and IV kokanee could not physically pass through 83-mm mesh. However, if kokanee entered the mesh, they could be caught and held (gilled) anterior to the dorsal fin. A low incidence of gilling was anticipated because of the tendency of salmonids to lead along a visible net without attempting to pass through the mesh.

The visibility of the net was enhanced by treating the net with a clear preservative to maintain the white color of the material. After installation of the net visibility was maintained by washing accumulations of periphyton from the mesh at regular intervals.

The net was hung with 13-mm diameter double-braid nylon cork and lead lines. Weight was added by attaching 5-mm chain along the entire length of the lead line. Polystyrene corks measuring 76 mm diameter x 102 mm long were spaced on 30.5-cm centers along the length of the cork line, except along a 46-m section of the south net which spanned the dredged channel. Corks in this section were spaced on 15.2-cm centers to provide extra flotation where the current was expected to be strongest.

The net was held in position by the shoreline attachments and by anchors attached at intervals to the lead line (Fig. 3). These anchors were 27-kg kedges placed in pairs, with one anchor of the pair upstream, and the other anchor downstream from the barrier net and joined by 27-mm polypropylene lines. The joining lines varied in length from 30 m to 60 m, depending on the water depth at the point of installation. A ring attached midway in the joining lines served as a means of connecting and disconnecting the anchor pairs to the lead line (Fig. 4). This feature and the wide spacing between paired anchors was necessary to permit the net to be lifted out of the water for cleaning. The anchor lines were positioned at 83-m intervals along the south net (three pairs) and at 166-m intervals along the east net (four pairs). The anchors were each stabilized against dragging by adding 6 m of 13-mm anchor chain between the anchors and the joining lines. The initial placement of the anchors and subsequent adjustment of their positions was facilitated by surface-buoyed lines attached to one fluke of each anchor.

5.1.3 Cleaning Gear and Procedure

The net cleaning process was mechanized as much as possible to minimize the labor requirements (Fig. 5). An 8-m flat bottom fiberglass work boat was provided by the Bureau of Reclamation for use as a platform on which the gear was mounted and operated. A mast with a boom was mounted on the port side 3 m from the bow. An auxillary 2.8- x 4-m barge constructed of wood and styrofoam was attached to the stern of the work boat for net-cleaning. The cleaning gear consisted of a 25-hp gas engine coupled directly to a hydraulic pump which circulated oil to three hydraulic motors. One motor powered a v-notch roller (power block) which was suspended from the boom and could be lowered and raised by operating a hand winch on the mast. The power block was used to pull the work boat and barge either forward or backward along the net. A second hydraulic motor powered a wide flat, stern roller mounted on the auxillary barge which pulled the net down the length of the work boat and barge to the stern where it was released to fall back into position. To increase the net-pulling capability of this roller, four wooden strips were attached across the width of the roller and the entire roller surface was covered with deep-pile carpeting. A third motor powered a piston water pump which delivered water under 6.328×10^5 kg/m^2 (900 psi) pressure to two hand-operated spray nozzels which were used to remove aquatic weeds and algae from the net.

Additional rollers for guiding the net were positioned at the bow and stern of the work boat and two intermediate guide rollers were positioned atop the net just fore and aft of the power block. With the

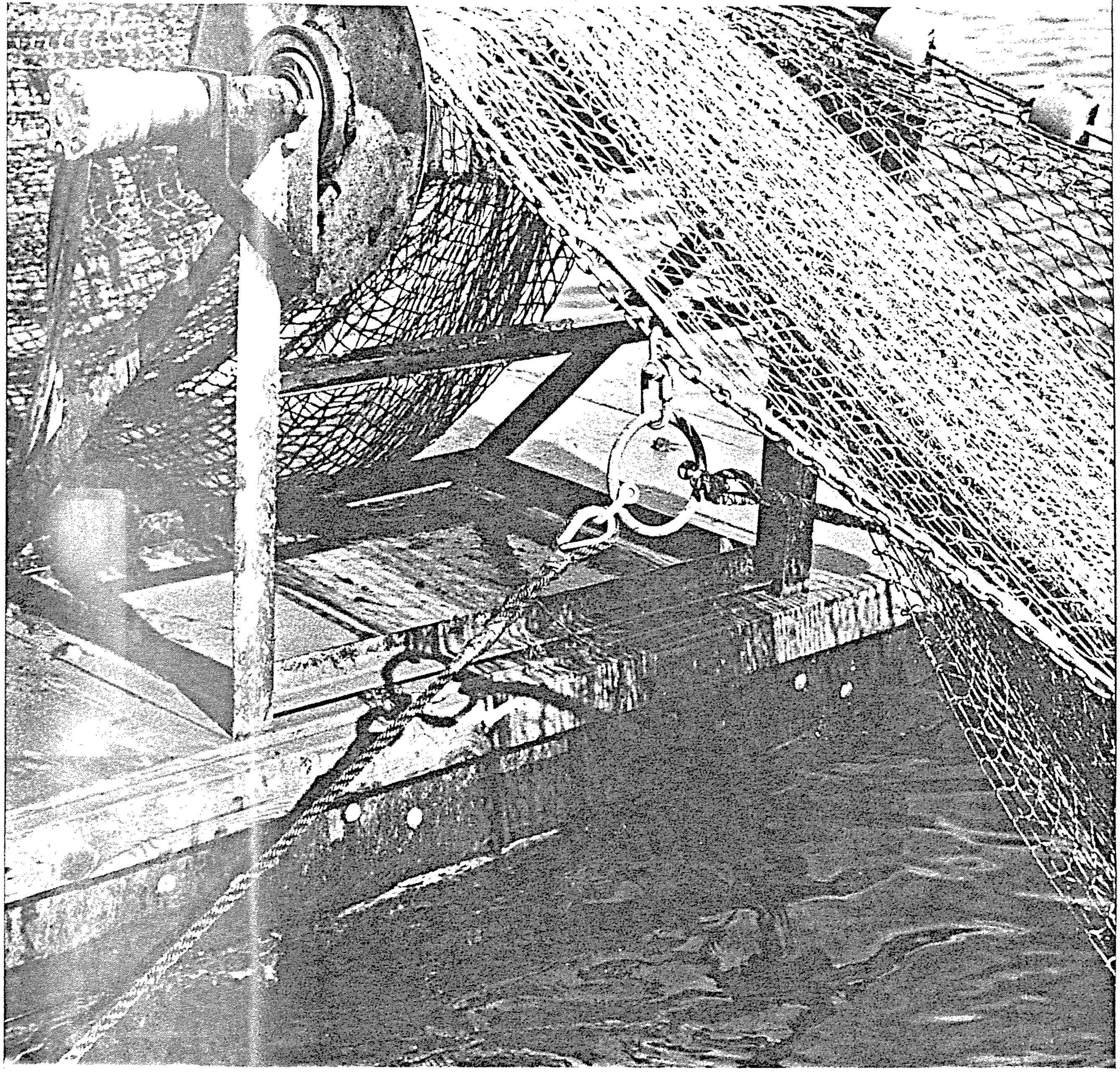

Fig. 4. Stern of the net cleaning barge showing the hydraulically powered roller, the cleaned net and the connecting ring which coupled a pair of anchors to the chain lead line.

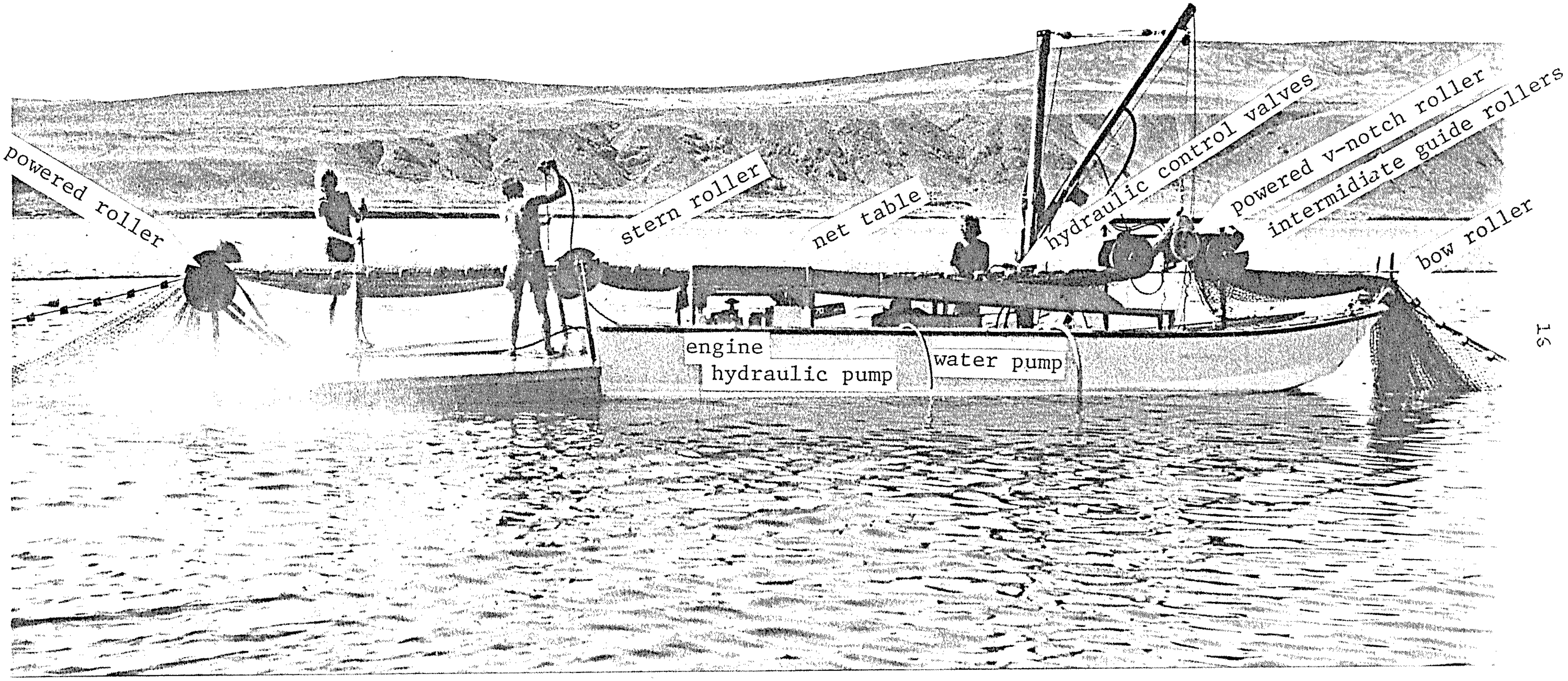

Fig. 5. Apparatus used to lift and clean the barrier net.

power block raised in operating position, these rollers served to lower the center of gravity and increased the degree of contact of the net on the power block and thereby prevented slippage.

The 8-m fiberglass work boat proved to be unsatisfactory due to its confining width and inadequate freeboard of the deck which prevented safe drainage of water and debris through the scuppers. It was necessary to build a false deck the length of the work boat to the height of the gunnels in order to manage the net during the cleaning operation. Operation from a barge would improve the efficiency and safety of this procedure.

The net-cleaning barge was towed by an outboard-powered boat into position within 15 m of one end of the net to be cleaned. The net was lifted manually to the surface and inserted into the rollers. Insertion of the net into the power block was facilitated by lowering the block to the level of the intermediate rollers. The block was then raised about 60 cm to operating height. With the hydraulic system operational, the barge was then moved backward as close to the shoreline as possible by reversing the rotation of the power block and power roller. Cleaning was begun and the power block control was adjusted to move the barge forward along the net at the rate of approximately 2 m/min. The power roller was adjusted to rotate at a slightly faster rate to maintain tension on the netting between the power block and the power roller. One person operated the hydraulic controls while another handled the net to ensure clear passage of the net across the boat and barge. Two additional people operated the sprayers to clean the net.

The cleaning proceeded until the bow reached an attachment point of an anchor pair. The operation was halted while a dropline was attached to the connecting ring. The ring was then unshackled from the lead line and released. The cleaning was continued for one barge length, after which the connecting ring was pulled up by means of the dropline and reshackled to the lead line at the stern. An average of about 15 min was required to pass an anchor point. At anchor points situated in relatively high current velocity, such as midway along the east net, difficulty was experienced in rejoining the net to the connecting ring of the anchor line because the current tended to sweep the net downstream while disconnected. The task of pulling the net back into position in line with the connecting ring was facilitated by towing the lead line of the net upstream with the outboard-powered boat.

5.2 Barrier Net Evaluation

5.2.1 Irrigation Canal Sampling

Determination of the entrainment of fish through the irrigation canal utilized procedures similar to those reported in Stober et al. (1977). Methods and gear used were similar during this study, except for the addition of two gear types and the fact that sampling in 1977 did not include the entire irrigation season.

The primary gear utilized in all years has consisted of a 4.3- x 3.7-m rigid frame with a 3.7- x 3.7-m net constructed of 25-mm stretched no. 252 four-stitch knotless nylon attached to it (Fig. 6). The net and frame were raised and lowered in the trash rack slots at the canal headworks by means of a lift line through two double blocks which were suspended from a 13-mm diameter overhead cable (Fig. 6). Lifting power was provided by attaching the lift line to a motor vehicle. These nets were fished in gates 1 (outside gate) and 4 (inside gate).

In 1977, a method was devised to fish a 1.8- x 2.4-m net (similar construction as above) by suspending it from the frame on cables 9.1 m long. This gear replaced the downstream gear used in 1975 and 1976 which was required at low volume (< 100 m^3/sec) high velocity discharge, characteristic of the early and late irrigation season. The primary advantage of the new gear was that it more effectively fished the turbulent flow and decreased the chance of fish avoidance.

A 1.2- x 1.2-m net was used in 1977 to assess the entrainment of juvenile fishes. This net was fished on 4.6-m warps from the 4.3- x 3.7-m frame in the trash racks of gate 6 (outside gate). The net was constructed of 6-mm stretch mesh of thread size no. 147.

Since the objective of entrainment sampling in 1977 was to evaluate the net barrier, rather than to estimate total irrigation season entrainment, the sampling was not initiated until June 7, well after the beginning of the irrigation season. Sample effort varied from 2 to 4 days per week, with the catch removed every 12 hr. During weeks in which the

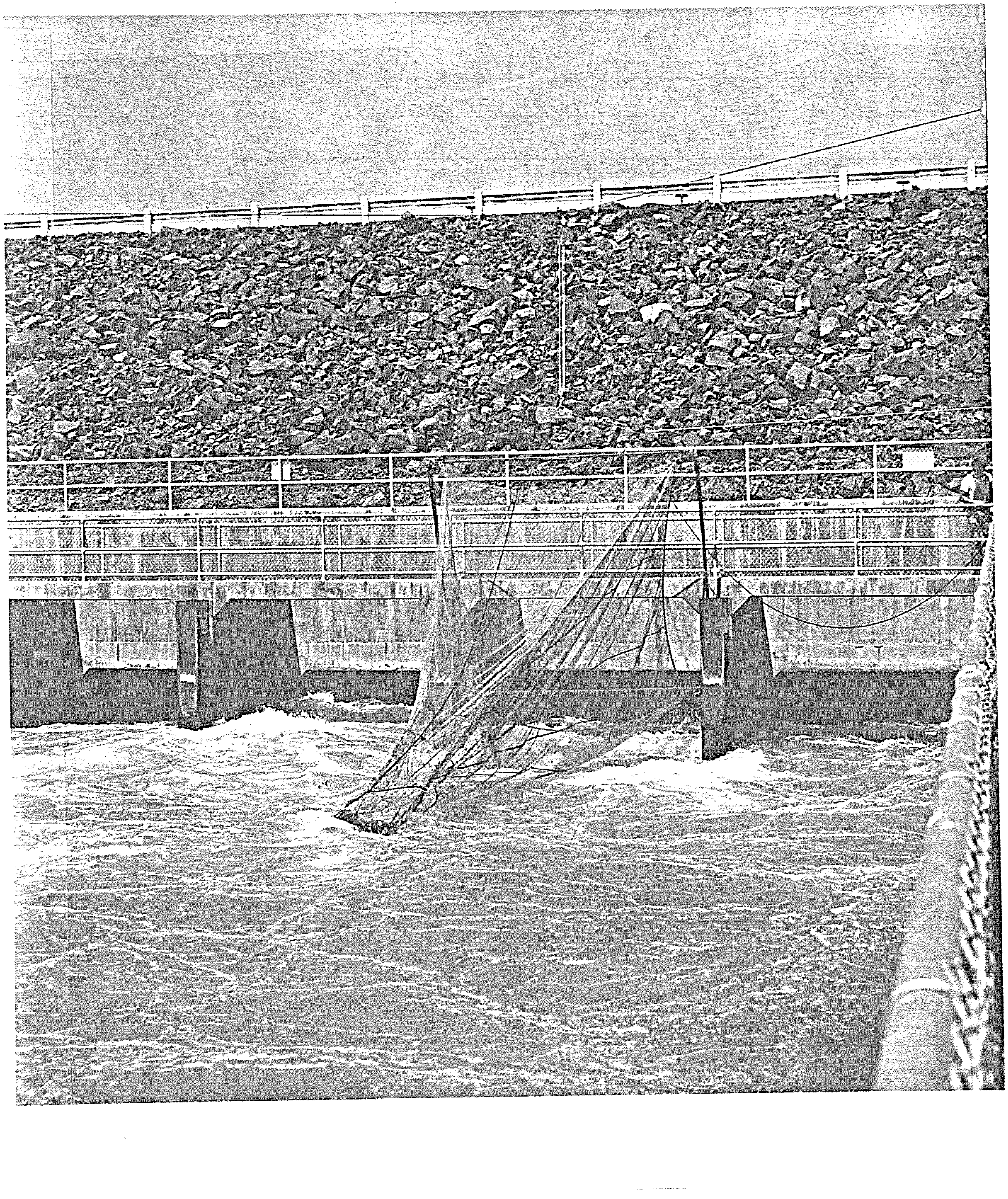

Fig. 6. Irrigation canal sampling net lifted for removal of catch.

barrier net was cleaned, the canal nets were fished continuously throughout the week, in order to determine the effect of barrier net cleaning on the entrainment rate.

Data was recorded and entrainment rates were calculated in the manner described in Stober et al. (1977). Entrainment rate estimates for kokanee, as in past years, took into consideration the tendency for larger catches in the two outside gates. No other species showed this differential.

5.2.2 Gillnet Sampling

Gillnet sampling in 1977 was continued at stations 4, 5, and 6 (Fig. 1) for the purpose of comparing fish population trends in recent years. Variable-mesh nets 30.5 m long by 1.8 m deep, constructed of monofilament nylon in nine variable mesh panels ranging from 2.5 to 12.7 cm and graduated in increments of 1.3 cm, were set horizontally at the surface and bottom in the manner described in Stober et al. (1977). The gillnets were fished monthly for two consecutive 24-hr periods during barrier net operation.

The fish densities immediately inside and outside (stations 8, 9, 10, and 11, Fig. 2) the barrier net were determined during biweekly gillnet sampling as a secondary means of evaluating the efficiency of the barrier net. An additional gillnet site was established at station 7 (Fig. 3) and fished on the same schedule to provide information on fish density between the South Dam and station 6.

5.2.3 Acoustic Sampling

The acoustic techniques and data acquisition system used were those developed by the Marine Acoustic Group at the University of Washington. These methods and equipment have been used extensively to gather acoustic data on fish stocks and have been described in detail by Thorne et al. (1972) and Nunnalee (1973).

During each survey, acoustic data were collected continuously along line transects in the survey area. The transects were located to enable comparisons of fish densities inside the barrier net (transects 1-3), outside the south barrier net (transects 4-7), and outside the east net (transects 8-10), with a deep-water area 3 km northwest of the barrier net (transect 11) (Fig. 7).

The acoustic data were analyzed by the technique of echo counting. Utilizing this method the magnetic tape upon which the data for the survey were recorded was played back through a tape recorder and the analog acoustic data record displayed on an oscilloscope. Fish target echoes were counted as they appeared on the oscilloscope. The peak amplitude and horizontal and vertical location of each target was also determined as the target was counted. Sample volume and target densities were estimated using methods described by Forbes and Nakken (1972).

5.2.4 Spawning Surveys

A rapid means of surveying the 96.5-km (60-mi) length of potential spawning shoreline was developed in 1976 to identify the spawning locations and to estimate numbers of spawning kokanee (Stober et al. 1977). A plywood pram measuring 2.4 x 1.1 m was fitted with a 60- x 60-cm window of 6.35-mm plexiglass. A viewing cone constructed of 6.35-mm plywood was placed over the glass bottom to improve viewing efficiency by minimizing overhead light and glare. Viewing was done through a hole at the top of the cone which was cut to fit a diver's face mask.

A 12-volt electric motor with 5.9-kg thrust propelled the pram from the stern. Steering was designed to permit the viewer to maneuver the pram while viewing. During the weekly surveys, the shoreline was paralleled at a rate of about 0.6 m/sec. Numbers of live and dead kokanee, as well as the suitability of the substrate for spawning, were observed and noted.

Surveys of intensively spawned areas were conducted biweekly by SCUBA divers. Data recorded included counts of live and dead kokanee, location, depth, and area of spawning.

5.2.5 Creel Census

Angler effort estimates were obtained for the south end of Banks Lake, from North Million Dollar Mile access area to the South Dam. The number of boats were counted by project personnel on daily drives along the lake before and after work. Counts began on August 9, and terminated

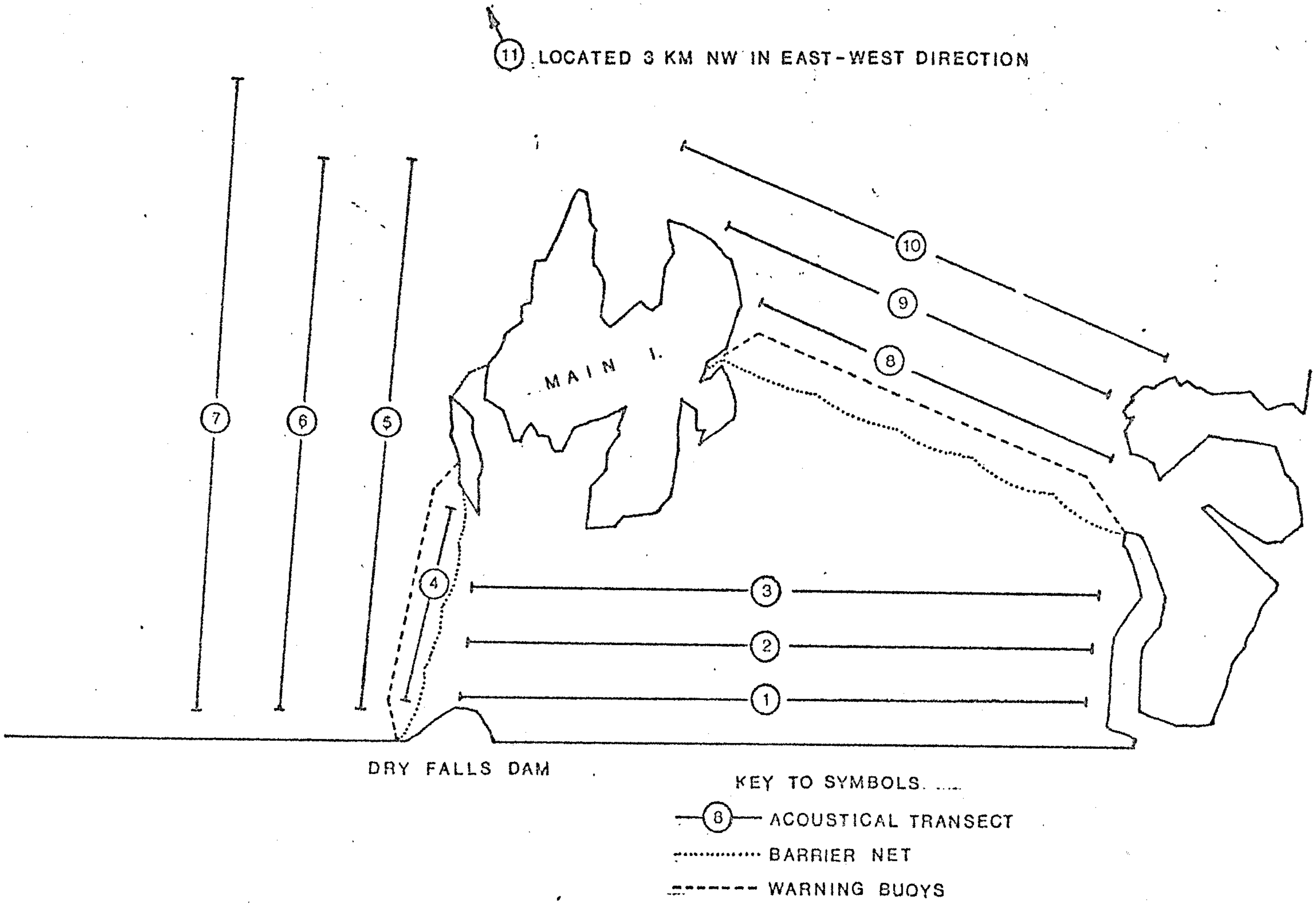

Fig. 7. Locations of acoustical transects near the barrier net in the southeast corner of Banks Lake.

on October 21, 1977, and usually occurred at 7:30 a.m. and between 5:00 and 8:00 p.m. In addition, boat counts were conducted concurrently with gillnet sampling at stations 4-6 and water quality sampling at stations 1-6. These counts were made during midday from 10:00 a.m. to 3:00 p.m.

Estimates of catch per angler-hr were derived from voluntary angler returns of creel census questionnaires between August 27 and November 2, 1977. Creel census boxes containing questionnaires were placed at prominent locations in the harbor area of Coulee City Park and at North Million Dollar Mile access area for distribution and deposit of the completed forms. The following information was requested:

1. Date.
2. Number of people in party.
3. Hours fished.
4. Total fish caught, number of silvers (kokanee), blackmouth (chinook).
5. Comments.

The following equations were used to calculate fishing effort and catch statistics:

$$E_e = Bwd \times Et/Ewd \times A \times T$$

where:

E_e = estimated fishing effort in angler-hr,

Bwd = number of boats fishing during weekday surveys in 1977,

Et/Ewd = ratio of total effort to weekday effort (based on 1975 census),

A = average number of anglers per boat (2.7) (based on 1977 data),

T = average angler fishing time in hr (6.3) (based on 1977 data),

$$CPUE = C_r E_r^{-1}$$

where:

CPUE = catch-per-unit-of-effort (hr),

C_r = catch reported by anglers in creel census questionnaires,

E_r = effort in angler-hr reported in creel census questionnaires.

These statistics were calculated on a monthly time basis. Effort statistics for 1975 were adjusted to include only the south end of Banks Lake, from North Million Dollar Mile access southward, to facilitate comparison between the years.

5.3 Artificial Spawning Beds

The Northwest Steelhead and Salmon Council of Trout Unlimited, Wenatchee Chapter, at the encouragement of the Washington Department of Game (WDG), set the idea of artificial spawning bed development in motion by providing the materials and manpower for the introduction of the gravel into the lake. The Fisheries Research Institute (FRI) research team located suitable areas for bed placement, guided the gravel barge into dumping position, and initiated a limited follow-up evaluation.

5.3.1 Site Selection

Site selection was based on several factors: bottom type, bottom grade, and accessibility. A reasonably solid substrate was necessary for gravel support while the grade had to be of a degree that would not cause the gravel to slide thus dispersing it too thinly. The site also had to be reasonably accessible to minimize barging. After several SCUBA surveys, two sites were selected. The south site was located in the southwest end of the lake approximately 3.2 km from the South Dam and 19 m offshore (Fig. 1). The north site was located along State Highway 155, 30 m offshore from a turnout 3.2 km south of the Steamboat Rock State Park access road. A gravel incubation box was also located on the north site.

The desired water depth of the beds was between 6.1 m (20 ft) and 9.1 m (30 ft). Approximately 38.3 m^3 (50 yd^3) of gravel was dumped at each site. The north bed ranged in water depth from 7.6 m (25 ft) to 9.1 m (30 ft) and measured 7.6 m (25 ft) wide and 15.2 m (50 ft) long.

The south bed ranged in water depth between 6.1 m (20 ft) and 9.1 m (30 ft) and measured 4.6 m (15 ft) wide and 19.8 m (65 ft) long.

5.3.2 Gravel

The gravel consisted of two types: glacial granite for the north bed and gravel box, and crushed basalt for the south bed. Selection of gravel size was based upon the past experience of project personnel in observing kokanee spawning in Banks Lake. The gravel size selected was large enough to allow adequate interstitial water movement to ensure maintenance of dissolved oxygen (DO) levels necessary for egg survival and small enough for excavation of redds by kokanee. The percent size composition for each site was determined by washing gravel samples of known volume through Tyler sieves and determining the percent composition represented by each size in the sample volume. One sample from each site was analyzed.

5.3.3 Gravel Placement

The gravel barge consisted of 45, 50-gal drums supporting a platform and gravel hopper. The gravel capacity of the hopper was approximately 3.1 m^3 (4 yd^3). The craft was propelled and steered by two outboard-powered boats.

As gravel was loaded by power shovel it was washed with water pumped from the lake to remove excess sand and silt. Once the barge was positioned over the dump site by divers, a lever-operated chute was opened and the dumping was begun. A single pass over the area at low speed laid down a gravel strip several inches deep and several feet wide. After several parallel passes, the area was crossed randomly to ensure a thorough covering of the site. A 30.5-cm (12-inch) gravel layer was desired, however, a variable depth averaging about 20.3 cm (8 inches) was achieved.

The gravel-filled egg-incubation box installed at the north site consisted of a 2.1-m (7-ft) x 0.9-m (3-ft) x 35.5-cm (14-inch) pine box with slots in the sides and bottom to permit water exchange. The box was placed near the north gravel bed and filled with gravel by divers.

Gravel placement occurred on the following days: the north bed, October 10; the south bed, October 11 and 12; the gravel box, December 27.

5.3.4 Measurement of Dissolved Oxygen

Dissolved oxygen samples were collected from the north site, south site, and primary natural spawning area on the following dates: November 17, November 29 and November 30. Collection was carried out by two divers using a hand-operated rotary pump with an attached probe which was shoved approximately 10.2 cm (4 inches) into the gravel. Contamination of the water sample by water above the gravel was minimized by placing a sheet of plastic over the sample area and shoving the probe through it. On November 17 five intergravel water samples and five ambient water samples from above the substrate were taken at each of the beds. Analysis of the samples was accomplished by use of DO meter with a chemical analysis via Winkler titration to insure reliability.

5.3.5 Siltation Rate

Silt settling out of the water column was collected in wide-mouth jars measuring 80 mm in diameter. Packs containing three jars each were placed and leveled at the north site, south site, and primary natural spawning area according to the following depth and time periods: 7.9 m (26 ft) from November 4 to November 24, 6.7 m (22 ft) from November 3 to November 30, and 4.0 m (13 ft) from November 3 to November 30, respectively. Shallow placement was necessitated at the primary spawning area by the steep slope and unstable gravel. The silt volume was measured after settling in a graduated cylinder. Measurements were converted to siltation rates (cm/day) for between-site comparisons.

5.3.6 Kokanee Egg Plants

Eggs were planted in the two artificial beds and the gravel box during the last week of December. A total of 100,320 eyed eggs was planted with approximately 5,400, 32,000, and 62,400 each in the gravel incubation box, south site, and the north site, respectively.

Eyed kokanee eggs were obtained from WDG at the Lake Whatcom Hatchery on December 27 and transported to Banks Lake on the same date. During transportation, and until shortly before the eggs were planted, they were contained in a standard egg-transport box provided by WDG. Inside the box, the eggs were contained in three trays, wrapped in wet burlap and packed in ice. Considerable care was taken to maintain the temperature of the eggs at 1°-2° C.

The eggs planted each day were transferred to DO bottles containing approximately 2,000 eggs each. Initially, two divers dug planting trenches in the gravel beds. The trenches were usually dug downslope by one diver followed by a second who widened and deepened the trenches to approximately 10 cm (4 inches). Once all the trenches were dug, one diver poured eggs from the bottles into the trenches while the other followed, filling the trenches. The trenches were slightly mounded, so the actual planting depth was about 12.5 cm (5 inches). The eggs at the north site were planted deeper than at the south because the gravel layer was thicker.

The eggs were planted in the gravel incubation box in two densities; at one end 1,800 eggs were planted in four 3-ft rows (2,143 eggs per m^2), and at the other end 3,600 eggs were planted in three 3-ft rows (4,286 per m^2). A 1-ft center space was left to separate the two densities.

During the kokanee spawning season, counts of live and dead kokanee were made by SCUBA divers on both artificial beds and the primary natural spawning areas.

6.0 RESULTS AND DISCUSSION

6.1 Barrier Net Development and Operation

6.1.1 Installation and Maintenance

The three segments of the barrier net were initially installed on June 23 and 24, 1977. An inspection by SCUBA determined that the east net completely screened the east access to the irrigation canal; however, the south net required lengthening in order to screen the south opening. A 25-m section of net was added near the middle of the south net 2 weeks later. Reinspection of the south net revealed gaps remained near the north and south ends and at both sides of the dredged channel where rapid changes in the bottom contour of the lake existed. These gaps occurred because of excessive tension on the lead line which prevented conformance of the lead line to abrupt changes in the slope of the bottom.

The length and depth of the gaps was observed to vary depending on the amount of tension on the net. Tension increased due to fouling by algae and wind-generated currents, which caused the net to bag between anchor points and the lead line to lift at the gaps. Occasional strong north winds created a visible east flowing surface current along Dry Falls Dam which caused the lead line to lift. During calm weather, the surface current was not easily discernible. Fouling by periphyton prior to the biweekly net cleaning was suspected of contributing to tension on both south and east nets. During a 3-week period in August, streamers of periphyton hanging from the meshes grew from 10 to 20 cm long between cleaning periods (Fig. 8).

The net cleaning operation contributed to the loss of fish in two ways. During the first month of operation, for convenience, the nets were washed only in one direction. After repeated washings of the south net in a northerly direction, it was discovered that slack lead line had accumulated at the north end and the lead line at the south end was under considerable tension. This tension caused large gaps to form across two ledges and undoubtedly was the avenue of escape for most fishes entrained in the canal during this period. After this was recognized, the net was shifted back into position and washed subsequently in alternating north and south directions.

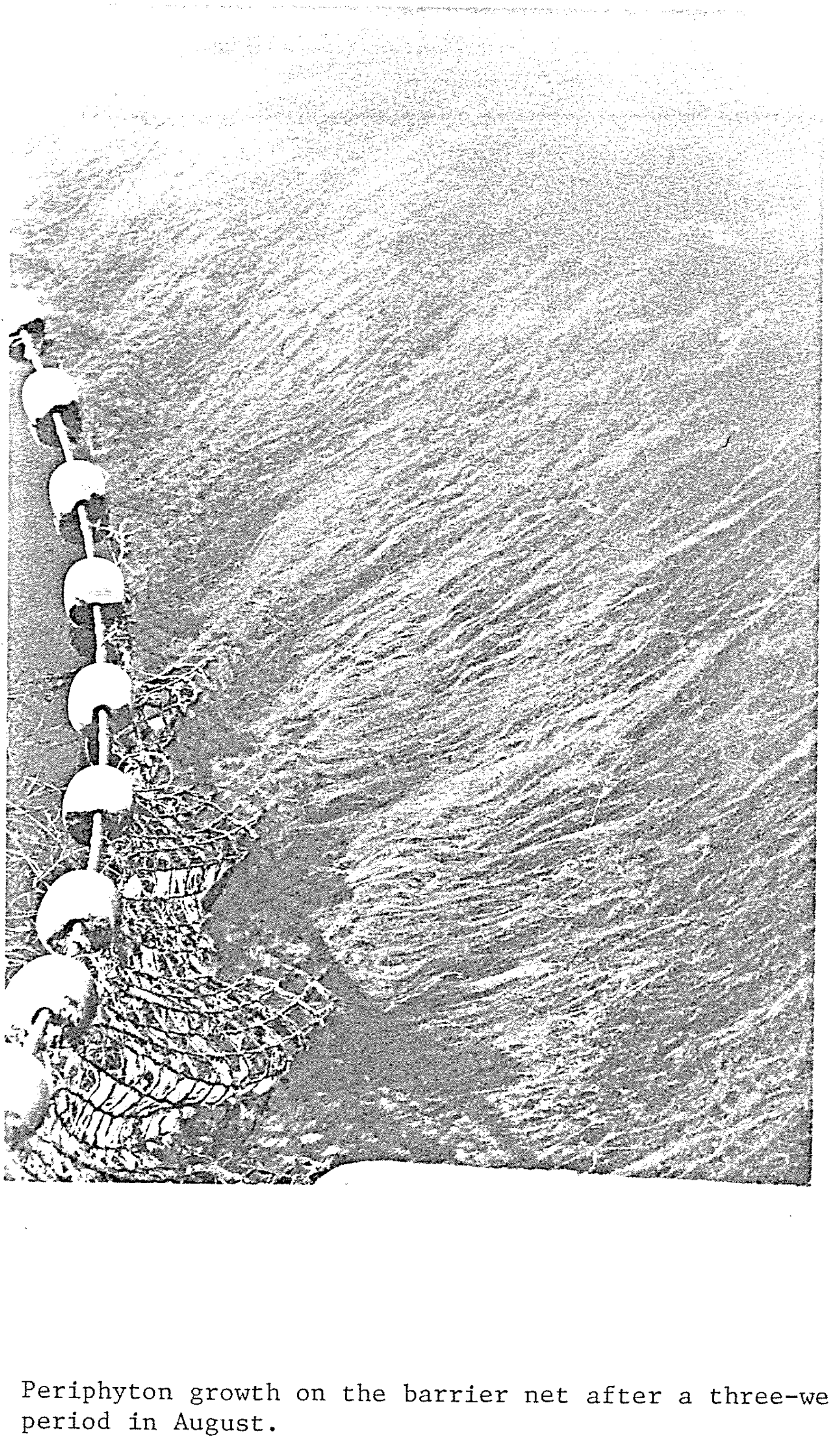

Fig. 8. Periphyton growth on the barrier net after a three-week period in August.

Fish undoubtedly escaped under the lead line while it was raised during the washing operation. However, because this escapement was not detectable in the canal net catches, it was considered of minor importance relative to the steady escapement through gaps around the south net. A considerable escapement of kokanee occurred on September 6 and 7, when failure of the hydraulic equipment halted the washing operation midway along the south net. The center of the net remained lifted for a period of about 16 hr, while repairs were being made. On the following morning when washing was resumed, numerous kokanee were observed jumping inside the barrier net. An increase in canal catches during and shortly after this period indicated that a substantial escapement of kokanee had occurred during the breakdown.

A few remaining gaps in the south net were closed eventually by suspending curtains of weighted netting from the lead line. Because the current was negligible along the bottom, these curtains were hung vertically without tension and conformed well to irregularities in the bottom.

A substantial number of kokanee escaped during October due to a large tear in the south end of the south barrier net caused when a warning buoy broke loose from its moorings and drifted into the net near its attachment at Dry Falls Dam. This tear probably occurred 2 weeks before it was detected because the net was left in place without cleaning during the final 7 weeks of the irrigation season in an effort to minimize the loss of kokanee.

6.1.2 Force Due to Irrigation Flow

The theoretical force acting on the barrier net due to irrigation flow was calculated for the conditions which prevailed in 1977 and for conditions which may be encountered in any future operation of the barrier net. The calculations were based on net porosity, wetted cross-sectional area of the net, and peak flow for a range of lake level conditions to -6.1 m, according to the formula:

$$\text{force on net } (F) = \frac{\frac{Q}{A}^{2}}{2g} \; W \, a \, P \, n$$

where:

Q = irrigation flow,

A = cross-sectional area at the net site,

g = gravitational acceleration,

W = weight of water,

a = wetted cross-sectional area of the net,

P = porosity of the net,

n = viscosity coefficient of water at temperature.

These calculations indicated relatively minor forces owing to two factors; high net porosity (91 percent) and large cross-sectional area of the net site (8,141 m^2 at full lake level, 2,275 m^2 at 6.1 m drawdown). The force increased with increasing drawdown. Under the present irrigation regime in which maximum flows reach 223.7 m^3/sec, a drawdown of 6.1 m will produce a force of 442 kg. Under the future regime in which maximum flows may reach 566 m^3/sec, a drawdown of 6.1 m will produce a force of 2,767 kg. With the present net-suspension system, this force was divided between four shoreline attachment points and seven intermediate anchor points. The distribution of this force was unequal because of unequal currents through the two major openings. The largest force observed in 1977 acted on the intermediate anchor points, particularly those of the east net where the current was greatest. Nearly all of this force was transmitted to the lead-line chain and thus to the upstream anchors. Although the force acting on individual upstream anchors was not measured, it could be estimated roughly from actual experience in manually reconnecting the anchor pairs during the net-cleaning operation.

In practice, fouling by periphyton greatly increased the frictional drag of the net. The additional drag created by periphyton growth probably far exceeded the force of water current on the net material. The greatest tension was encountered during rapid fouling of the net following a windstorm which caused large quantities of rooted aquatic plants to accumulate on the east net. This tension was estimated at about 181.4 kg (400 lb).

The construction and anchoring of the barrier net was adequate to withstand forces considerably greater than were encountered during the 1977 operation. The net cork and lead lines were of 13-mm (1/2-inch) diameter double-braid nylon, which has a breaking strength of 3,402 kg (7,500 lb). The dacron netting used in the net has a breaking strength of 34 kg (75 lb) per strand.

In any future operation of the barrier net in which tension in the lead or cork lines may approach the breaking strength or results in handling problems during net cleaning, the tension may be relieved by adding additional anchors and by lengthening the net to create more sag.

6.2 Barrier Net Evaluation

6.2.1 Irrigation Canal Entrainment

The number of each species of fish entrained into the irrigation canal during 1977 was estimated following the same procedures used in preceding years. Seasonal variations and age compositions of each species were compared with similar data collected during comparable time periods in 1975 and 1976. The entrainment estimates for 1975 and 1976 reported in Stober et al. 1977, were derived from sampling which was conducted during nearly the entire irrigation season, whereas the 1977 estimates were based on a shorter sampling period beginning on June 9 and ending on October 25. Estimates of the escapement of fishes past the barrier net were based on canal catches following the complete installation of the barrier net on July 9. Comparisons between years were made by considering similar time periods from July 9 to the end of the irrigation season (Table 3).

During 1977 the irrigation canal received a variable flow of water from Banks Lake which reached a maximum rate of 223.7 m^3/sec (7,900 cfs) during July and August (Fig. 9). The barrier net was operational after June 9 and subject to maximum discharge rates.

6.2.1.1 Kokanee. The estimated entrainment of kokanee during operation of the barrier net was 7,031 (Table 1). During similar time periods in 1975 and 1976, 100,908 and 32,119 kokanee, respectively, were entrained. Total entrainment of kokanee during the 1975 and 1976 irrigation seasons was 128,397 and 50,007, respectively. The relative abundance of kokanee in the irrigation canal in 1977 was 17.8 percent as compared to 67.4 percent in 1975 and 59.6 percent in 1976. Kokanee entrainment in 1977 reached a maximum in early September which was later in the

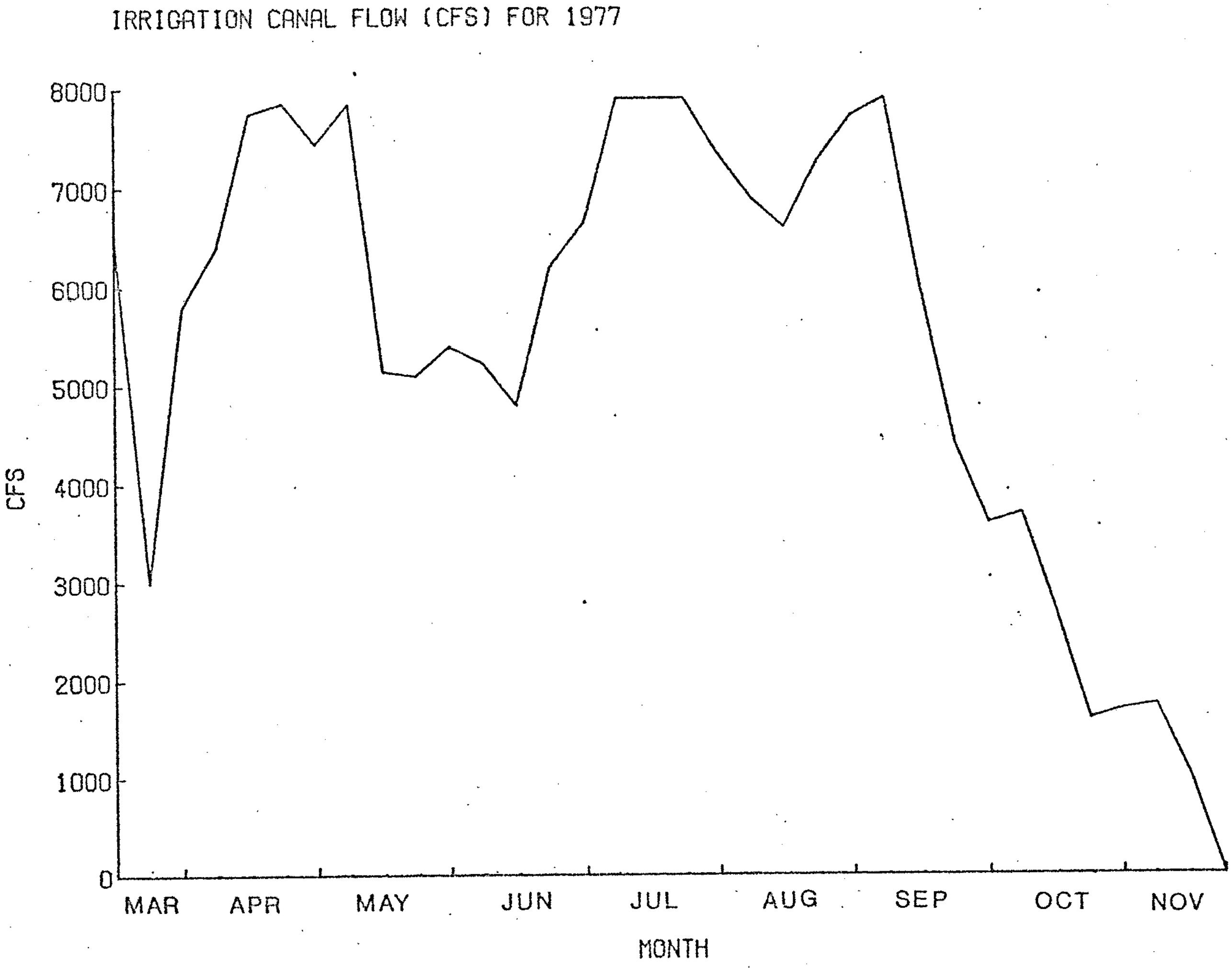

Fig. 9. Average weekly rate of discharge (cfs) through the irrigation canal during 1977 (USBR data).

Table 1. Estimated entrainment, 95% confidence intervals and percent composition by species in the irrigation canal for the period July 9, through October 25, 1975, 1976 and 1977.

	Estimated Total No. Entrained 1975	Interval Estimate α = .05	Estimated Total No. Entrained 1976	Interval Estimate α = .05	Estimated Total No. Entrained 1977	Interval Estimate α = .05	Percent of Total 1975	Percent of Total 1976	Percent of Total 1977
Kokanee	100,908	±6,013	32,119	±5,450	7,031	± 2,513	67.4	59.6	17.8
Yellow perch	16,408	±4,409	3,516	±3,223	22,022	±29,290	11.0	6.5	55.9
Lake whitefish	11,825	±3,533	4,998	±2,870	96	± 159	7.9	9.3	0.2
Carp	6,055	±5,506	1,763	± 668	3,228	± 1,964	4.0	3.3	8.2
Chinook salmon	5,005	±2,440	279	± 274	292	± 434	3.3	0.5	0.7
Longnose sucker	2,247	±1,174	4,987	±3,672	1,978	± 1,243	1.5	9.3	5.0
Mountain whitefish	2,009	±1,049	1,058	± 523	841	± 928	1.3	2.0	2.1
Prickly sculpin	1,789	±1,109	3,578	±2,501	2,062	± 1,901	1.2	6.6	5.2
Rainbow trout	1,659	± 549	385	± 202	94	± 251	1.1	0.7	0.2
Peamouth	903	± 747	928	± 585	1,591	± 1,524	0.6	1.7	4.0
Pumpkinseed sunfish	553	± 445	105	± 171	9	± 42	0.4	0.2	T
Black Crappie	129	± 263	36	± 118	-	-	0.1	0.1	-
Walleye	80	± 172	30	± 68	84	± 184	T	0.1	0.2
Largemouth bass	56	± 96	20	± 65	-	-	T	T	-
Brown bullhead	38	± 61	30	± 90	52	± 130	T	0.1	0.1
Burbot	-	-	-	-	-	-	-	-	-
Largescale sucker	-	-	13	± 44	-	-	-	T	-
Dolly Varden char	-	-	-	-	-	-	-	-	-
White sturgeon	-	-	-	-	12	± 58	-	-	T
Total	149,664		53,880		39,392				

irrigation season than observed previously (Fig. 10). Kokanee entrainment for the 4-week period preceding the installation of the barrier net in 1977 was low (1,115) and did not provide a useful preoperational comparison for evaluation of the barrier.

The weekly entrainment rates are compared between years in Fig. 10. Kokanee entrainment may be partially related to irrigation water withdrawal rate, but the relationship was largely masked by the changing stage of sexual maturity. Mature kokanee were probably entrained in the irrigation canal while actively seeking a current. The entrainment of maturing age III and IV kokanee has been closely related to their abundance in Banks Lake during the 3 yr of sampling. A successive decline in abundance during the last 3 yr has been observed.

A small mesh 1.2- x 1.2-m net was fished in an outside gate of the irrigation canal throughout the 1977 irrigation season to estimate entrainment of juvenile fishes which may have passed through the larger mesh of the standard net. No age 0 or I kokanee were caught in this net during the 1977 season, which led to the conclusion that little or no entrainment of these year classes occurred during the period sampled in 1977.

A comparison of kokanee length-frequency distributions (Fig. 11) over the last 3 yr showed a predominance of ages III and IV during most of the irrigation season. In June and July 1977, age II kokanee were entrained at a fairly high rate relative to older age groups. This may indicate that a relatively strong 1975 year class (age II) exists in the lake compared to the weak 1974 year class (age III).

The entrainment estimate for 1977 indicated that 7,031 kokanee escaped the barrier net into the irrigation canal and that the peak entrainment occurred in early September. This escapement was by far the smallest observed in 3 yr of sampling and the peak occurred later than during the previous 2 yr indicating that the net may have been responsible for delay in the escapement of kokanee. Some escapement in 1977 was expected due to the difficulties in getting the south net to conform to sharp changes in bottom contour. The breakdown in early September of the net-cleaning gear on the south net was known to have allowed an increase in escapement to occur. The entrainment alone cannot be

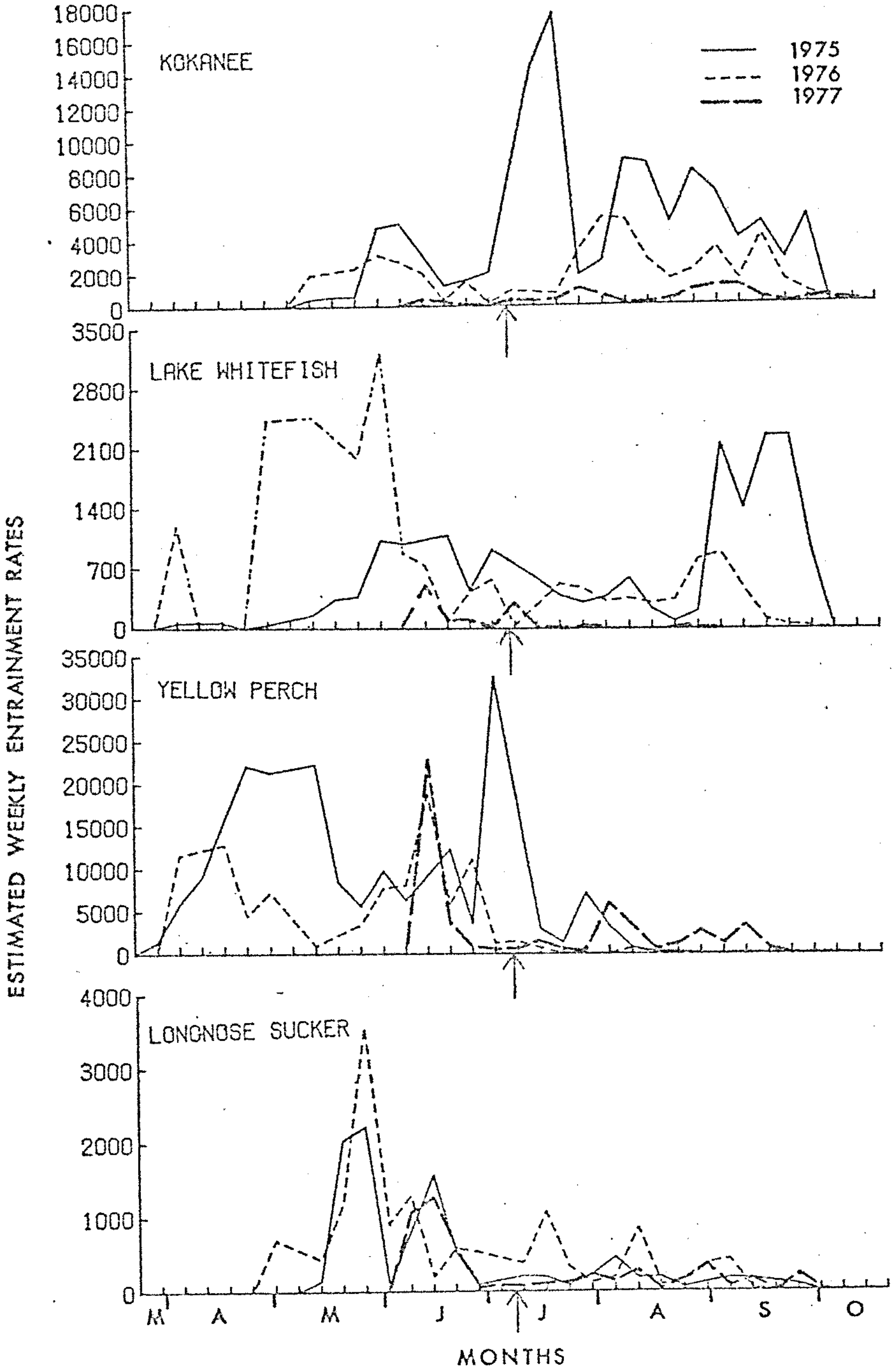

Fig. 10. Total estimated weekly entrainment rates for kokanee, lake whitefish, yellow perch and longnose sucker through the irrigation canal in 1975, 1976 and 1977. Arrow marks start time of barrier operation in 1977.

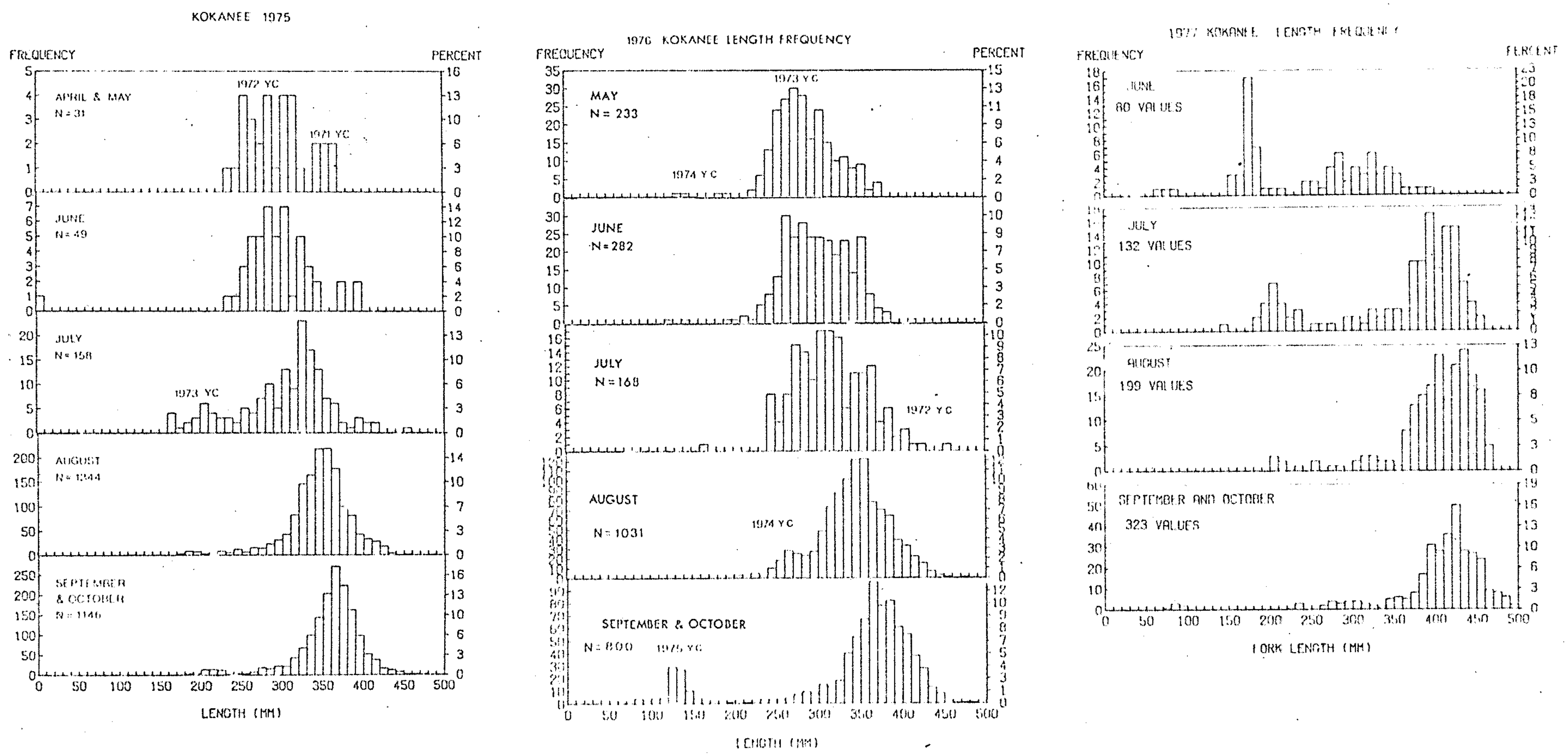

Fig. 11. Monthly length frequency and year class of kokanee caught in irrigation canal entrainment samples in 1975, 1976 and 1977.

considered a complete measure of the efficiency of the barrier net. The spawning population remaining in the lake represented the portion of the population which was deterred by the net.

6.2.1.2 Lake Whitefish. An estimated 96 lake whitefish were entrained after July 9, 1977, as compared to 11,825 during a comparable period in 1975, and 4,998 in 1976. The full-season entrainment of lake whitefish was 19,326 in 1975, and 23,731 in 1976. The relative abundance of lake whitefish in the irrigation canal in 1977 was 0.2 percent as compared to 7.9 percent in 1975, and 9.3 percent in 1976 (Table 1).

Peak weekly entrainment of lake whitefish in 1977 occurred during the 4 weeks preceding installation of the barrier net. During this time, an estimated 1,016 were entrained (Fig. 10). The highest weekly entrainment was 503. After installation of the barrier net, the entrainment of lake whitefish was sharply diminished. The highest weekly entrainment rate was 29. The peak weekly entrainment rate during 1975 occurred during October at 2,270 per week, while in 1976 peaks occurred during June (3,236) and September (898).

Differences in age composition existed during the years sampled, as shown in length-frequency plots (Fig. 12). In 1975 the composition was principally age I (275 mm) and age III and older (455 mm) (Table 2). In 1976, the composition shifted to age II and age III and older, with a small number of age I which appeared during April and May. In 1977, the lake whitefish caught during the entire sampling period were all age II and older. The barrier net clearly reduced the number of lake whitefish entrained.

6.2.1.3 Yellow Perch. An estimated 22,022 yellow perch were entrained during the period in which the barrier net was functional in 1977 (Table 1). During similar July through October periods in 1975 and 1976, 16,408 and 3,516, respectively, were entrained. Total seasonal entrainment for 1975 and 1976 was much higher at 241,528 and 115,146, respectively. As in previous years, the early-season entrainment of yellow perch was high in 1977 (Fig. 10). Entrainment during the 4-week period prior to barrier net installation was 28,675. This was greater than for the remaining 3.5 months of the season. Small yellow perch were not screened effectively by the barrier net, therefore their relative

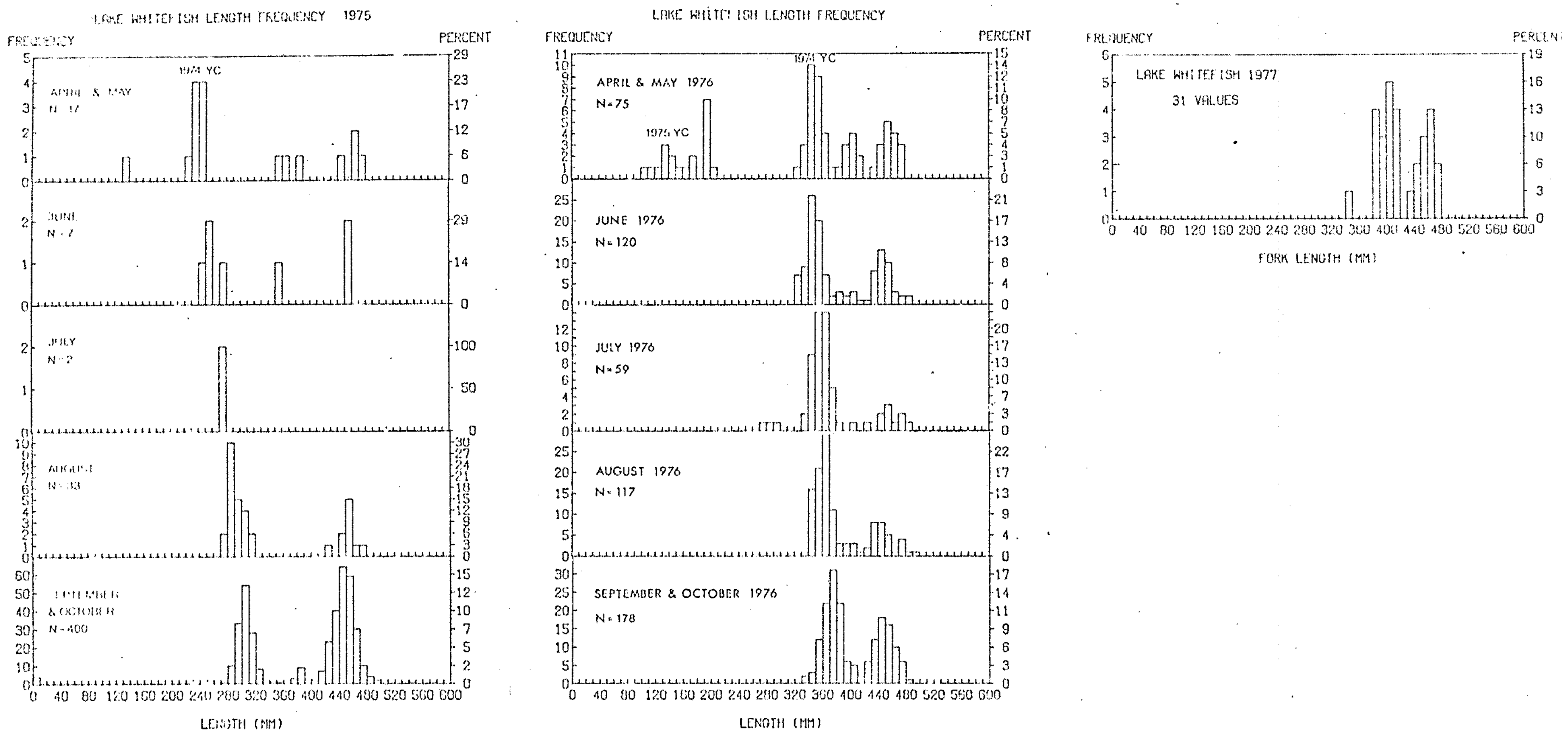

Fig. 12. Monthly length frequency and year class lake whitefish caught in irrigation canal entrainment samples in 1975, 1976 and 1977.

Table 2. Mode length (mm) of lake whitefish entrained in the irrigation canal in 1975, 1976 and 1977.

	1975		1976			1977*	
April, May	240	465	185	345	455		
June	255	455		345	455		
July	275			360	455		
August	285	455		365	440		
September, October	305	445		375	445		
June-October						405	465

*1977 length frequencies were not analyzed by month since only 31 fish were caught throughout the season.

importance in the total catch of all species entrained was inflated. Yellow perch comprised 55.9 percent of the total number entrained in 1977, compared to 11.0 percent in 1975 and 6.5 percent in 1976 (Table 1).

Peak weekly entrainment occurred in the first half of the irrigation season during all 3 yr (Fig. 10). The yellow perch entrainment rate was related to the irrigation water withdrawal rate, year class abundance and reproductive behavior. Perch concentrated onshore for spawning from late March through May and remained onshore from May through early July. After July, the older perch (age II+) began to move offshore while juvenile perch (age 0 and I) remained onshore and subsequently comprised the bulk of perch entrained.

A small mesh, 1.44-m^2 opening, net was fished in an outside gate throughout the 1977 sampling season to estimate the entrainment of juveniles. Use of these data yielded a much higher estimate of 64,676 yellow perch. The 95 percent confidence interval was very wide, 24,960 to 104,392, due to the small sampling area of the net in relation to the total discharge area (160.53 m^2) of the canal. Juvenile yellow perch comprised most of the catch from this net.

A comparison of perch length frequencies (Fig. 13) between years sampled showed a dominance by the 1973 and 1974 year classes of perch throughout the 1975 entrainment season which continued until August 1976, after which the 1975 and 1976 year classes dominated (ages I and 0, respectively). During 1977, the 1974 and 1975 year classes appeared only during June. Following June, the 1976 year class (age I) comprised approximately 99 percent of the catch and was entrained in high numbers, relative to other years, through September. Only one perch from the 1977 year class (age 0) was caught during the past season. From this it appears the 1977 year class of perch may be very weak, however, yellow perch are probably entrained from a somewhat limited area of the lake and canal catches may only reflect local conditions near the canal headworks. Perhaps the abundance of age I perch in the barrier net vicinity depressed the number of age 0, due to predation or avoidance of the area by the young. As expected, the barrier net, because of the mesh size, had little effect on yellow perch. Their abundance in the total entrainment catch increased.

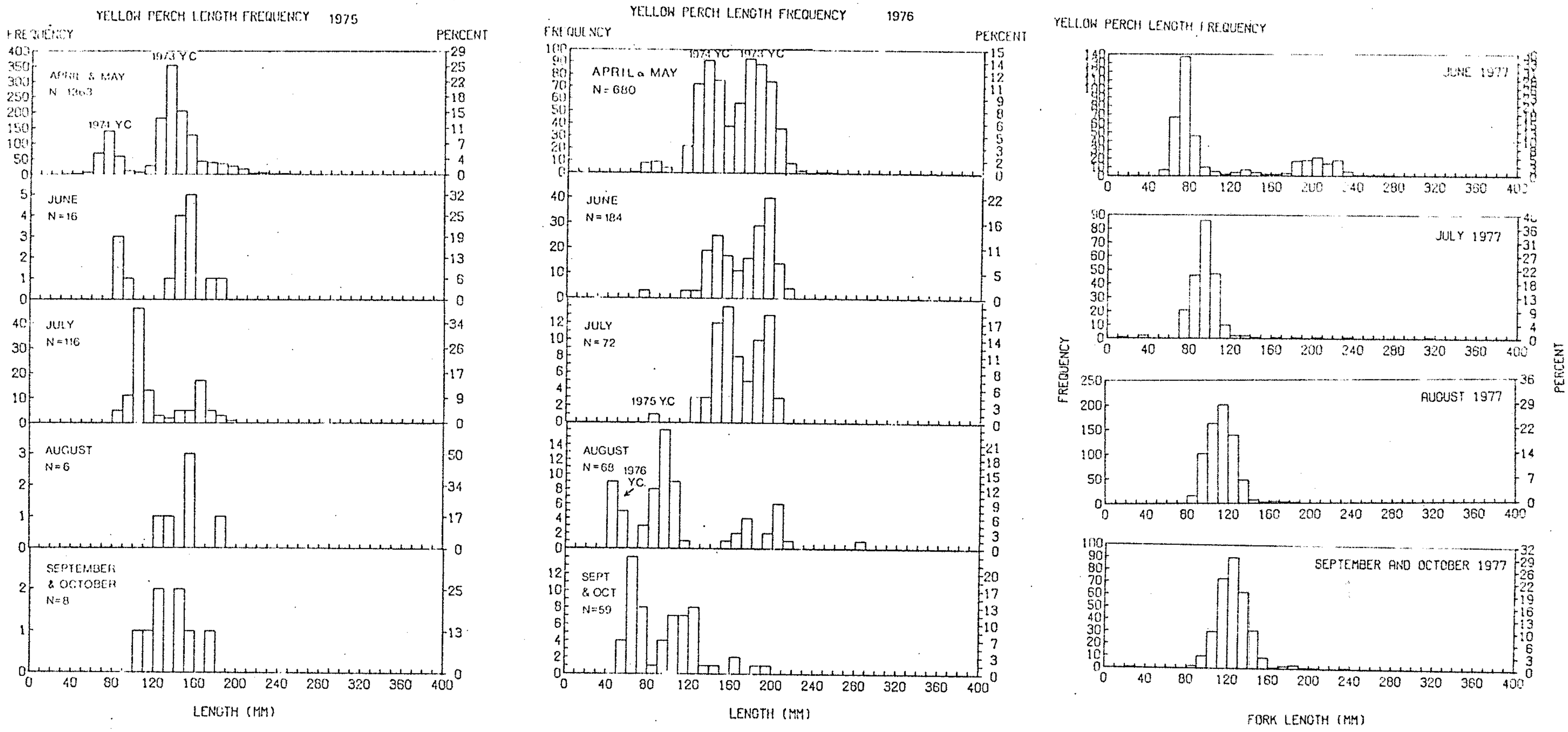

Fig. 13. Monthly length frequency and year class of yellow perch caught in irrigation canal entrainment samples in 1975, 1976 and 1977.

6.2.1.4 Longnose Sucker. An estimated 1,978 longnose suckers were entrained while the barrier net was in place (Table 1). During similar periods in 1975 and 1976, 2,247 and 4,987, respectively, were entrained. Longnose suckers comprised 5.0 percent of the 1977 entrainment, 9.3 percent in 1976, and 1.5 percent in 1975. Total entrainment for the years 1975 and 1976 was 9,895 and 14,399, respectively. During the 4 weeks prior to installation of the barrier net in 1977, an estimated 3,037 longnose suckers were entrained. Peak weekly entrainment of longnose suckers in 1975 and 1976 occurred in June, with 2,219 and 3,567, respectively (Fig. 10). Since sampling in 1977 did not start until late June, the highest peak was probably missed.

6.2.1.5 Carp. An estimated 3,228 carp were entrained during the period July through October 1977 as compared to 1,763 in 1976 and 6,055 in 1975 (Table 1). During the first 4 weeks of 1977, an estimated 626 carp were entrained. Estimated entrainment rates of carp were greater in 1977 than in 1976, but less than in 1975. Maximum entrainment occurred during late August 1977 (Fig. 14).

Length-frequency analysis for all years showed carp had a roughly trimodal distribution (Fig. 15). Age 0's comprised 28 percent, 39 percent and 58 percent of the 1975, 1976 and 1977 catches, respectively. Age I made up 14 percent, 11 percent and 5 percent of the 1975, 1976 and 1977 catches, respectively.

Adult carp were seen many times ramming or jumping over the barrier net in both directions. However, this was not viewed as an attempt to leave through the canal as the number of adults entrained was low. The entrainment of carp apparently was unaffected by the presence of the barrier net.

6.2.1.6 Rocky Mountain Whitefish. The barrier net had a minimal effect upon Rocky Mountain whitefish with only an estimated 841 entrained during July through October 1977 (Table 1). During the same months in 1975 and 1976, an estimated 2,009 and 1,058 were entrained, respectively. Total entrainment for 1975 and 1976 was 2,044 and 1,211, respectively. Prior to installation of the barrier net, an additional 171 were entrained. Their appearance in the catch was sporadic over the 3 yr and peak entrainment never exceeded 500 per week (Fig. 14). They first appeared

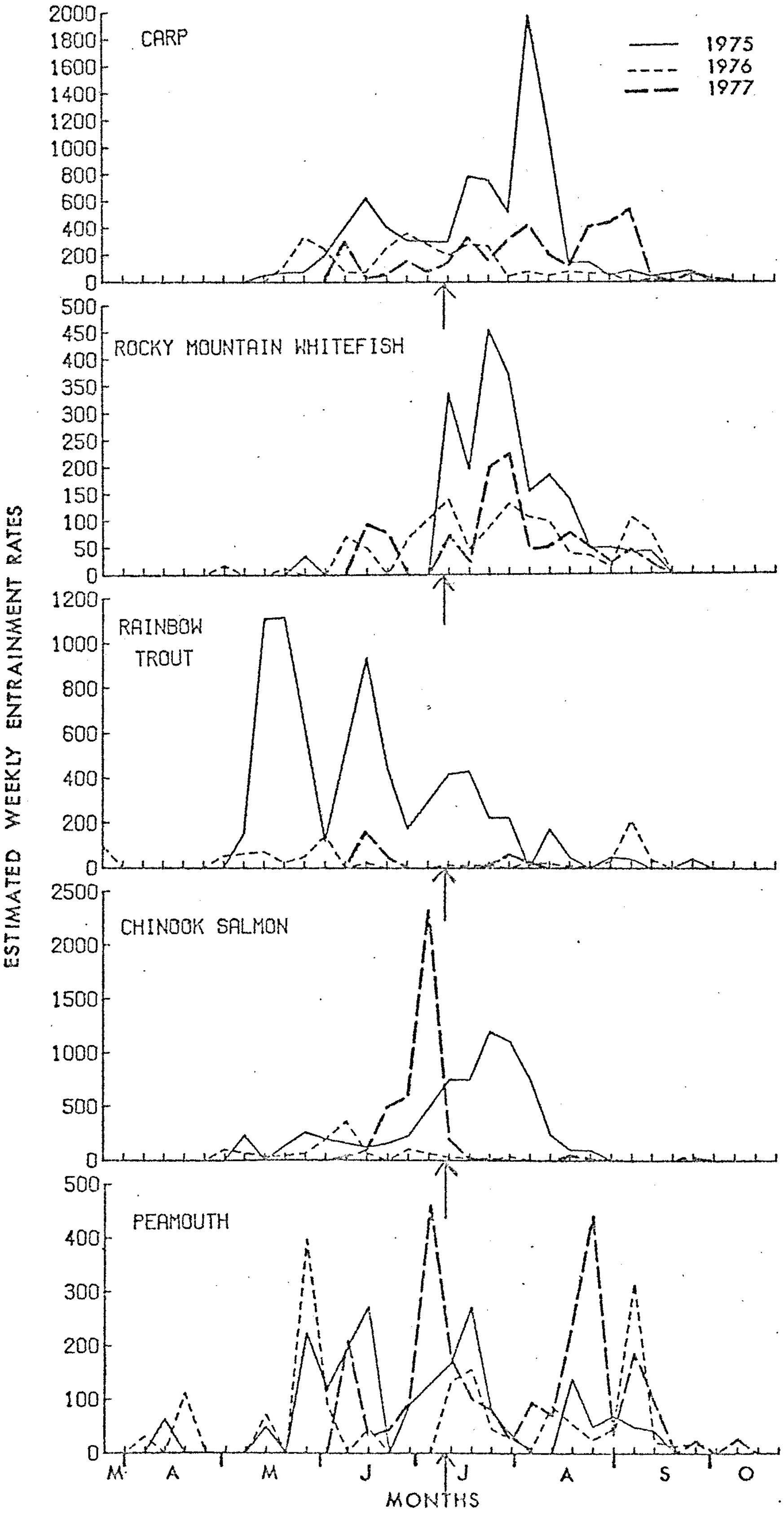

Fig. 14. Total estimated weekly entrainment rates for carp, Rocky Mountain whitefish, rainbow trout, chinook salmon and peamouth through the irrigation canal in 1975, 1976 and 1977. Arrow marks start time of barrier operation in 1977.

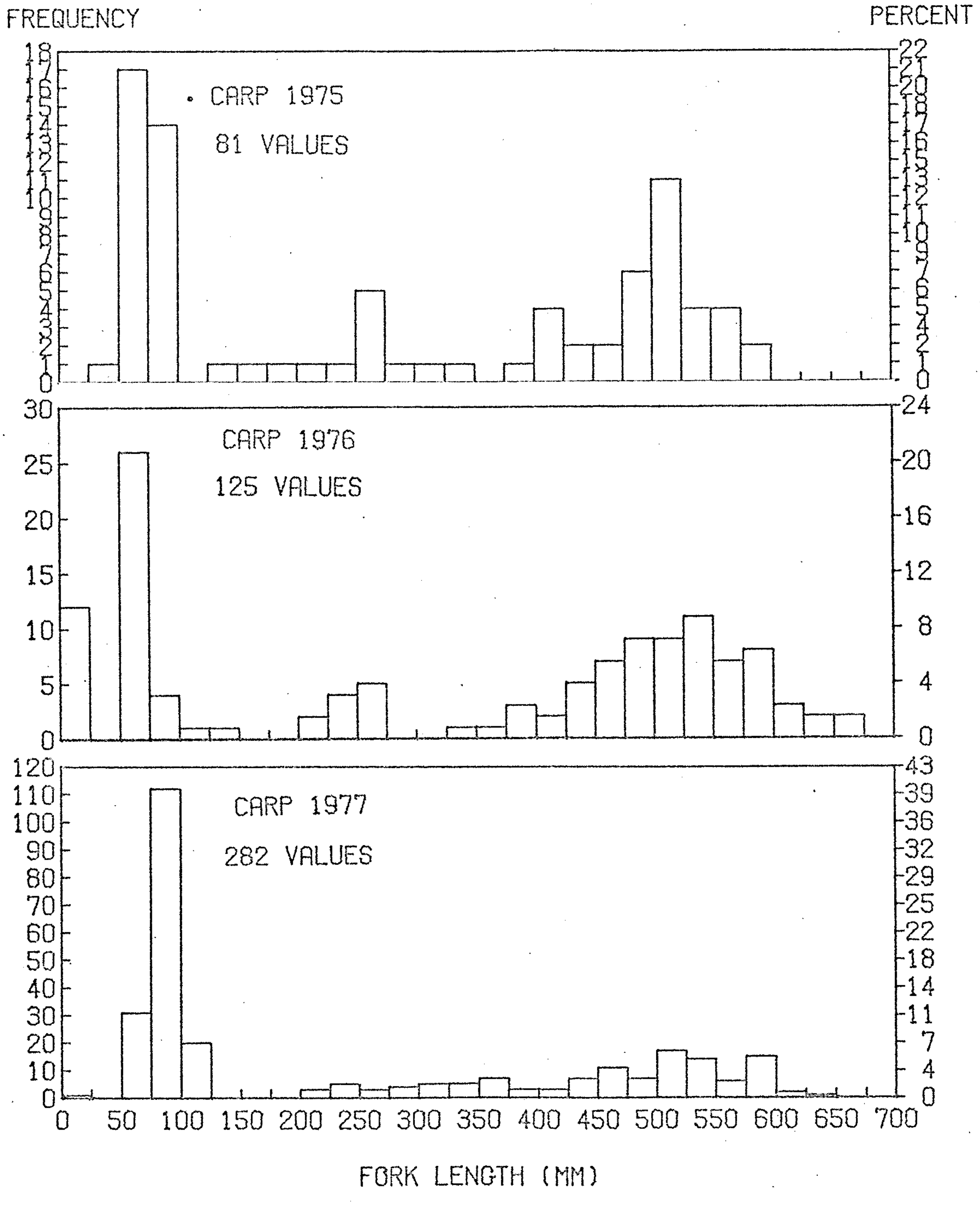

Fig. 15. Composite length frequency analysis of carp caught in irrigation canal entrainment samples in 1975, 1976 and 1977.

in the catch in June and disappeared by late September. During the 3 yr, they comprised 2.1 percent, 2.0 percent and 1.3 percent of the estimated total entrainment for 1977, 1976 and 1975, respectively (Table 1).

Length frequencies of Rocky Mountain whitefish ranged from 90 mm to 420 mm (Fig. 16). During 1977 and 1975, modes occurred at approximately 230 mm and 315 mm. During 1976, the modes were slightly larger at approximately 305 mm and 345 mm.

6.2.1.7 Rainbow Trout. An estimated 94 rainbow trout were entrained while the barrier net was in place in 1977 as compared to 385 and 1,659 during comparable periods in 1976 and 1975, respective (Table 1). Total entrainment for 1975 and 1976 was 7,183 and 916, respectively (Fig. 14). Rainbow trout comprised 0.2 percent, 0.7 percent and 1.1 percent of the 1977, 1976 and 1975 estimates, respectively. Peak weekly rates of rainbow entrainment were 1,200 in 1975 and 200 in 1976. In 1977, rainbow trout were rarely seen in the catch. During the 4 weeks of canal sampling prior to the installation of the barrier net, an estimated 211 rainbow trout were entrained (Fig. 14). Although this was more than double the number entrained during the rest of the season, the reduction was not attributed to the barrier net, but rather to low population abundance as only a few were captured in gillnets during 1977.

Length frequencies showed that there were basically two size groups entrained each year, with modes of approximately 250 mm and 410 mm for 1975 and 1976, and for 1977 approximately 260 mm and 490 mm (Fig. 17).

6.2.1.8 Chinook Salmon. An estimated 292 chinook salmon were entrained while the barrier net was in place during 1977, as compared to 279 and 5,005 during similar time periods in 1976 and 1975, respectively (Table 1). Total estimated entrainment for 1975 and 1976 was 6,976 and 1,212, respectively (Fig. 14). Chinook comprised 0.7 percent, 0.5 percent and 3.3 percent of the estimated entrainment for 1977, 1976 and 1975, respectively.

Chinook was abundant in the canal catches from June until late July in 1976 and 1977, reaching a peak weekly entrainment of 2,400 in early July 1977 (Fig. 14). In 1976 and 1975, weekly peak entrainments were 600 and 1,200. In 1977, during the 4 weeks prior to barrier net installation, 3,542 chinook were entrained.

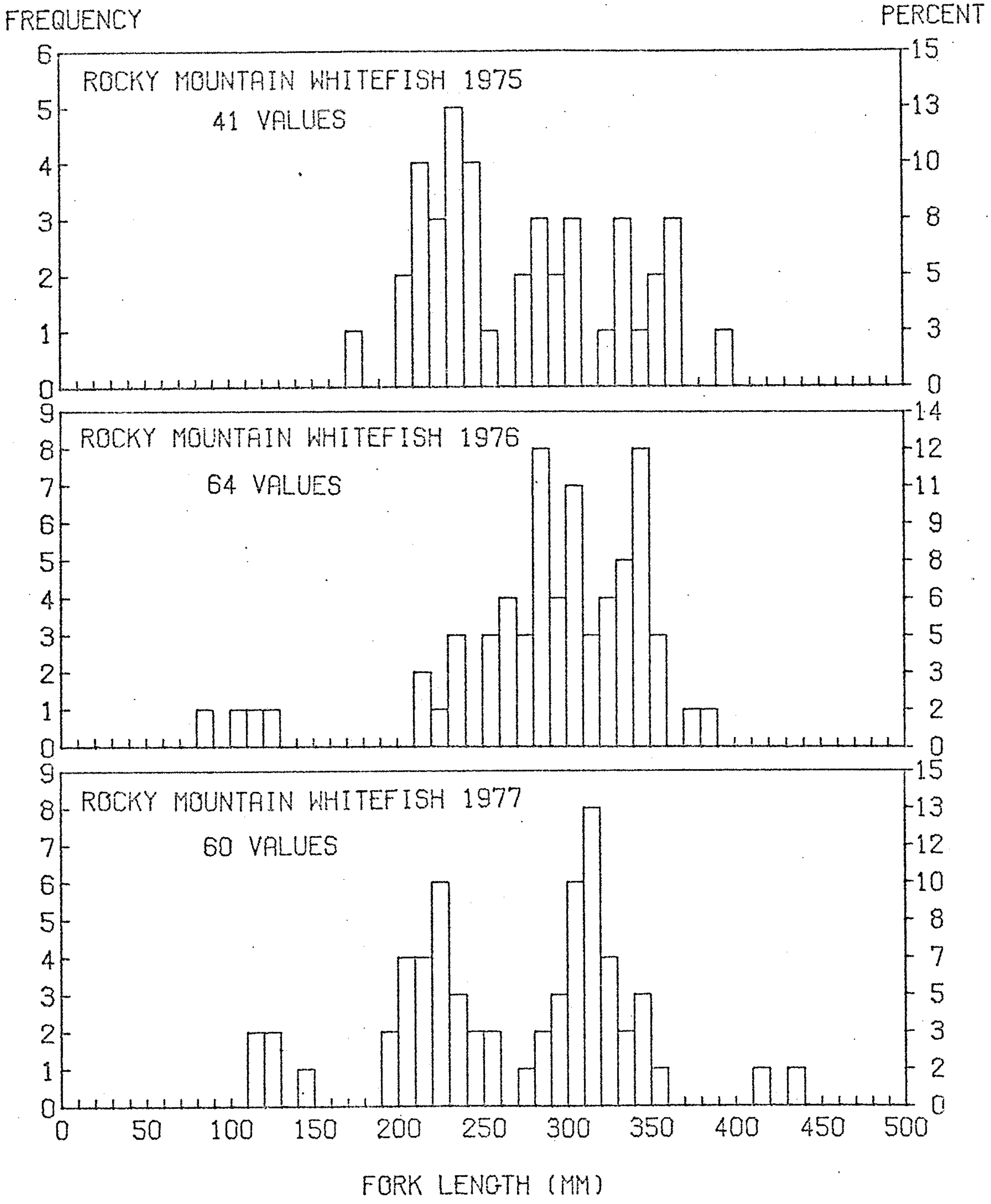

Fig. 16. Length frequency of Rocky Mountain whitefish caught in irrigation canal entrainment samples in 1975, 1976 and 1977,

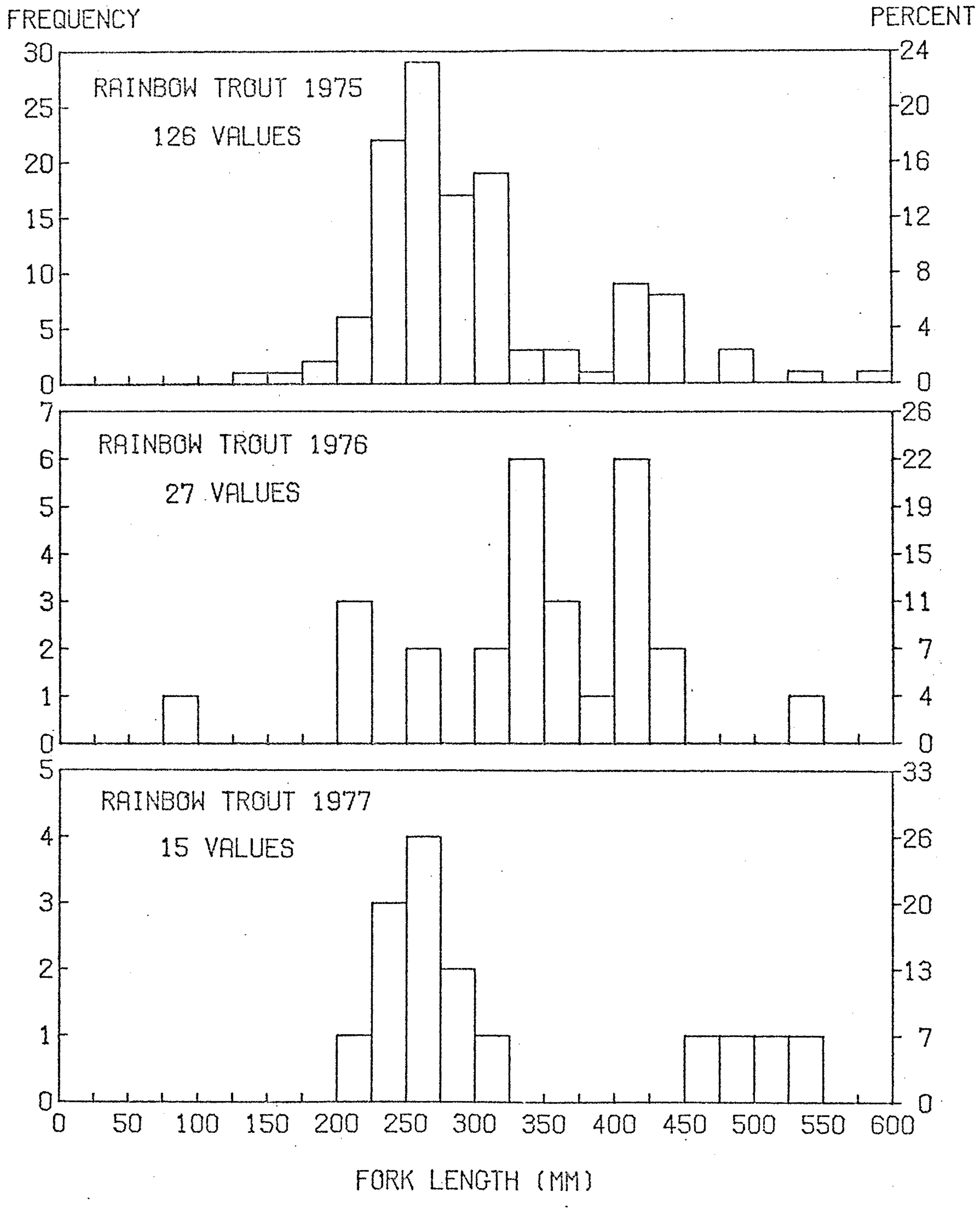

Fig. 17. Length frequency of rainbow trout caught in irrigation canal entrainment samples in 1975, 1976 and 1977,

Comparison of length-frequency data between years showed that these chinook were probably planted in July and October 1976 (Fig. 18). The larger fish entrained during 1977 were probably remnants of either the 1975 or 1974 plant.

6.2.1.9 Peamouth. An estimated 1,591 peamouth were entrained while the barrier net was in place during 1977 as compared to 903 and 928 during similar time periods in 1975 and 1976 (Table 1). Total entrainment for 1975 and 1976 was 2,048 and 1,692, respectively. During 1977 an estimated 842 peamouth were entrained prior to the installation of the barrier net. Peamouth comprised 4 percent of the total entrainment of all species. During 1975 and 1976, they comprised 0.6 and 1.7 percent, respectively. Seasonal entrainment rates were sporadic during all 3 yr (Fig. 14) and did not appear to be affected by the barrier net.

6.2.1.10 Other Species. Additional species were entrained only sporadically in small numbers (Table 1). An estimated 2,062 prickly sculpin were entrained while the barrier net was in place during 1977 as compared to 1,789 and 3,578 during similar time periods in 1975 and 1976. Total entrainment for 1975 and 1976 was 4,174 and 5,657, respectively. Prickly sculpin comprised 5.2 percent, 6.6 percent and 1.2 percent of the entrainment for 1977, 1976, and 1975, respectively. Total entrainment for the 4 weeks preceding installation of the barrier net was estimated at 14,916.

Other species entrained included an estimated nine pumpkinseed sunfish in 1977, as compared to 105 in 1976, and 553 in 1975. Sunfish were normally entrained in the spring during spawning and therefore were not affected due to late installation of the barrier net and irrigation canal sampling.

The estimated entrainment rates of walleye, brown bullhead and white sturgeon, which appeared in the irrigation canal sampling nets were low (Table 1). A total catch of 11 walleye in 1975, six in 1976 and nine in 1977 was recorded. Three brown bullhead each year were caught in 1975, 1976 and nine were caught in 1977. A single specimen of white sturgeon, *Acipenser transmontanus*, heretofore unknown in Banks Lake was caught in an irrigation canal net in 1977. The fish measured 570 mm and weighed 750 g. With the addition of the white sturgeon to

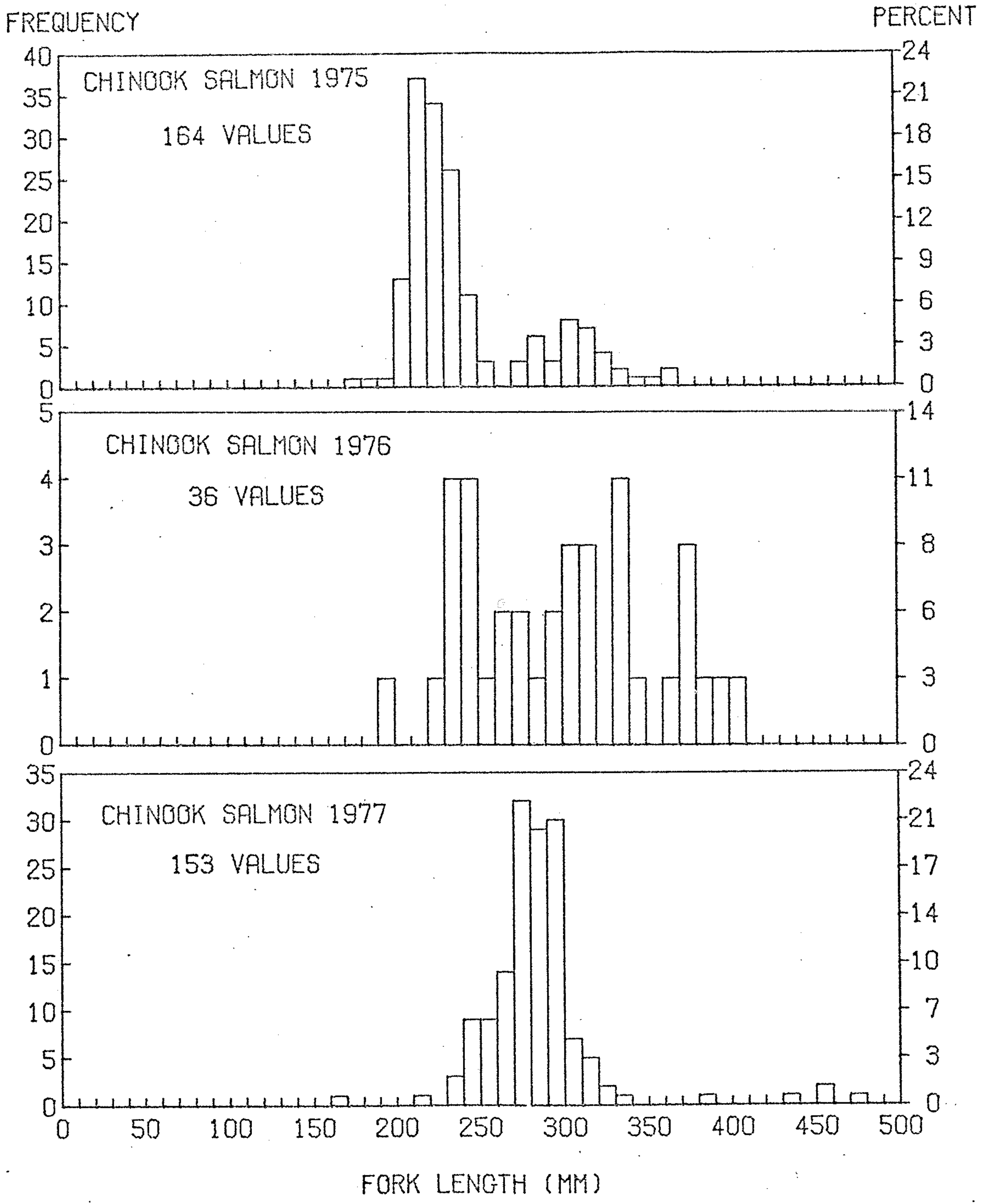

Fig. 18. Length frequency of chinook salmon caught in irrigation canal entrainment samples in 1975, 1976 and 1977.

the species list, 20 of the 23 species known to occur in Banks Lake have now been entrained in the irrigation canal. Only northern squawfish (*Ptychocheilus oregonensis*), brown trout (*Salmo trutta*), and bridgelip sucker (*Catostomus columbianis*) have not occurred in the irrigation canal catch. None of these species are abundant in Banks Lake and their distribution is limited to the north end of the lake.

6.2.2 Kokanee Spawning

Systematic observations of kokanee spawning by means of SCUBA were begun in 1975. An estimated 5,000 to 10,000 kokanee spawned on steep talus shorelines primarily along areas in the southwest and east (Million Dollar Mile) portions of Banks Lake in 1975. Smaller concentrations of spawning kokanee were observed at Coulee City Harbor, the west shore (Million Dollar Mile), Northrup Creek and in the vicinity of the feeder canal. Spawning occurred during October and November at depths from 1 m to 8 m and kokanee appeared to utilize all available gravel of suitable size. The 1976 and 1977 spawning populations were relatively small but were similar with respect to timing and location. Because the population pressure was reduced in 1976 and 1977, spawning occurred only on select gravel deposits in which particle size ranged from 2 mm to 150 mm in diameter.

The surveys conducted in 1976 and 1977 were more comprehensive in area covered and frequency of observation than the 1975 survey and relied primarily on the use of a glass-bottomed pram for underwater viewing, augmented with SCUBA observations. The present survey was designed primarily for comparison with that made in 1976 to help assess the effectiveness of the barrier net on kokanee reproduction. The 1977 survey included all locations which were known to have suitable spawning substrate and duplicated the sites surveyed in 1976, except that a few with limited potential were dropped.

6.2.2.1 Distribution. Kokanee spawning in 1977 was concentrated in one major area designated the primary spawning area (Fig. 19) along the southwest shore of the lake, and three areas with smaller numbers of spawners (Million Dollar Mile, Coulee City Harbor, and South Dam). Very limited spawning was observed outside these areas. The locations of

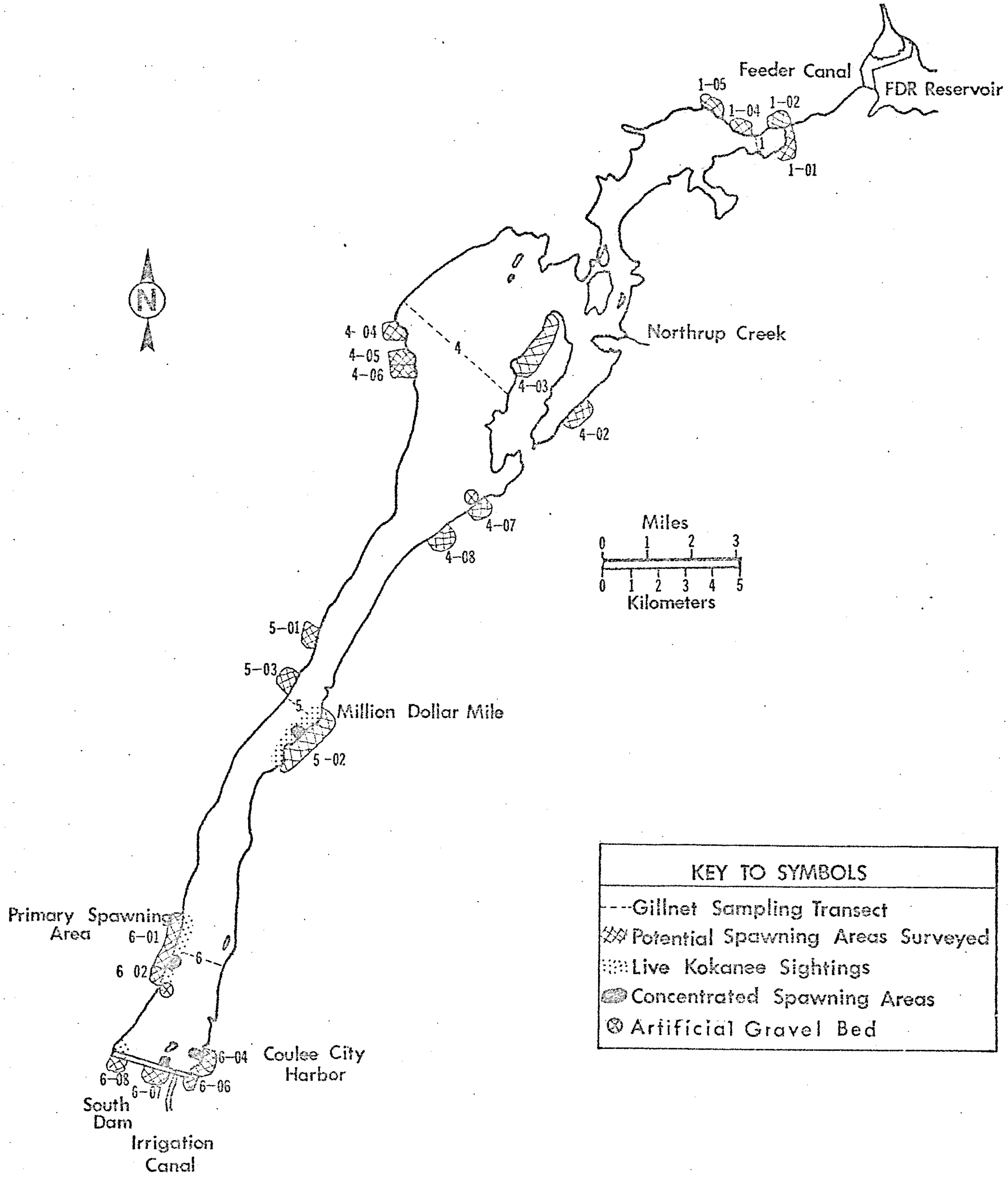

Fig. 19. Map of Banks Lake indicating the areas where suitable shoreline spawning substrate occurred and where live kokanee spawners were observed. The primary kokanee spawning area is located in the southwest quarter of the lake.

spawning in 1977 were similar to those in 1976, with minor exceptions. Sample areas of gravel composed of fill material along Highway 155 which were used by a few spawners in 1976 were not used in 1977. Ninety kokanee were observed along the South Dam, adjacent to the barrier net in 1977, but none were observed there in 1976. In general, spawning in 1975 was more widespread than in 1976 and 1977, however, areas of concentration were the same.

6.2.2.2 Spawning Season. Kokanee spawning in 1977 began in mid-October and continued through the end of November, while water temperature at a depth of 3 m was dropping from 12.3° to 3.8° C. Peak spawning occurred from early to mid-November over a temperature range of 10° to 7.5° C. Timing and temperature range over which spawning occurred were similar to 1976, however, the temperature dropped more rapidly during the 1977 spawning season (Fig. 20).

Water visibility during most of the spawning season was reduced from 1976 (Fig. 20), due to windy conditions and fall drawdown of the reservoir. At the initiation of spawning on October 20, water level was 2.7 m (9.0 ft) below full pool and gradually filled at the rate of 0.14 m/day until November 15, when full pool was reached. The 2.7-m drawdown made some minor potential spawning sites unavailable in 1977, especially areas of roadbed fill.

6.2.2.3 Spawning Population by Site

6.2.2.3.1 Primary site. Most kokanee spawning in 1977 occurred in a section of shoreline near the southwest corner of the lake in the vicinity of transect 6 (primary spawning area). Intensive use of this site by spawners also occurred in 1975 and 1976. A greater quantity of fine, clean substrate existed on the talus slopes in the primary spawning area than elsewhere and was considered to be the reason for the high concentration of spawners.

The 2,400-m long area was surveyed weekly by means of a glass-bottomed pram. Counts of live kokanee in the primary spawning area were two to three times higher in 1977 than in 1976, in spite of reduced visibility (Fig. 21). Counts of dead kokanee were lower in 1977, which was attributed to the poorer visibility. SCUBA observations indicated

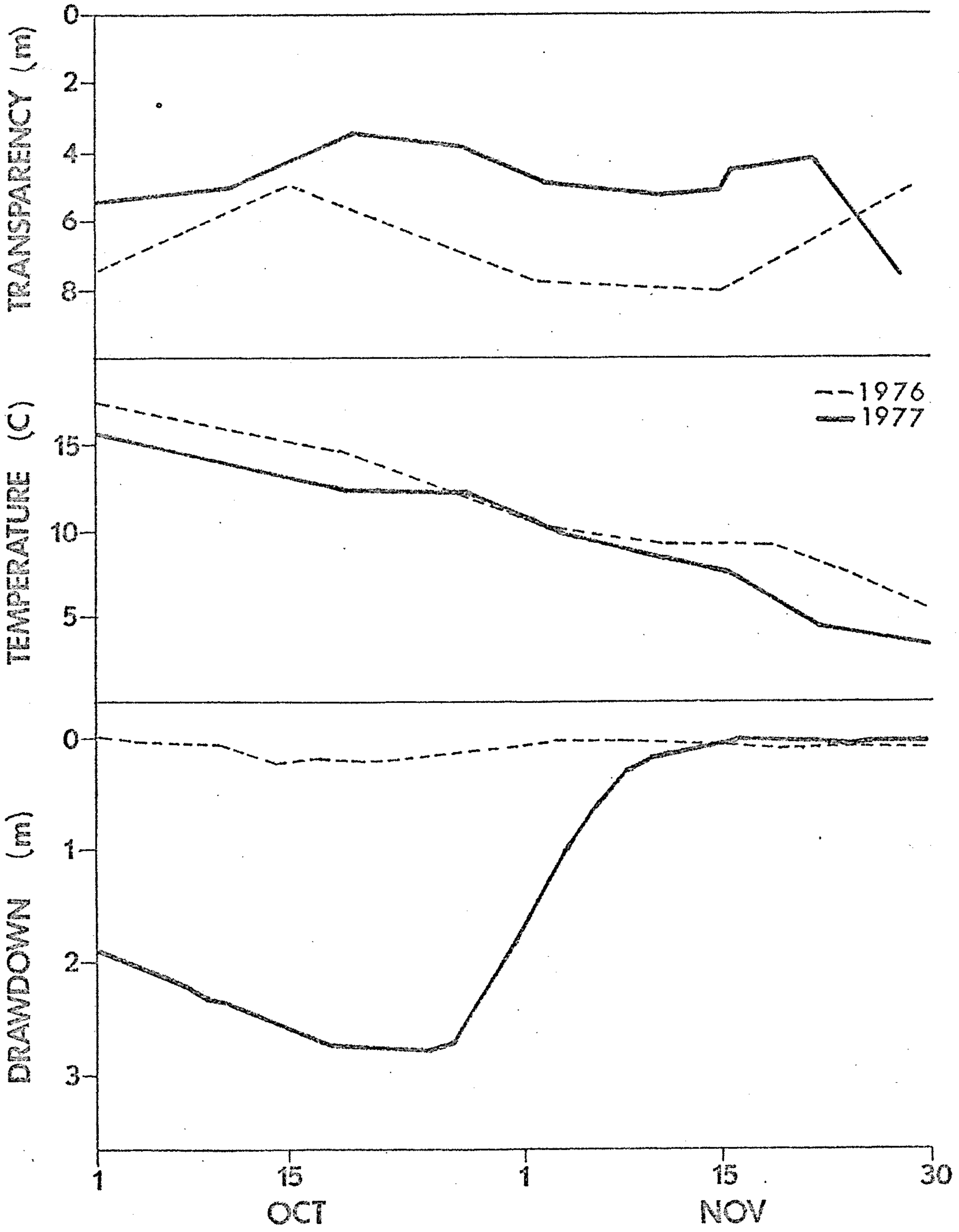

Fig. 20. Reservoir drawdown and water temperature and transparency for Banks Lake during the kokanee spawning seasons in 1976 and 1977.

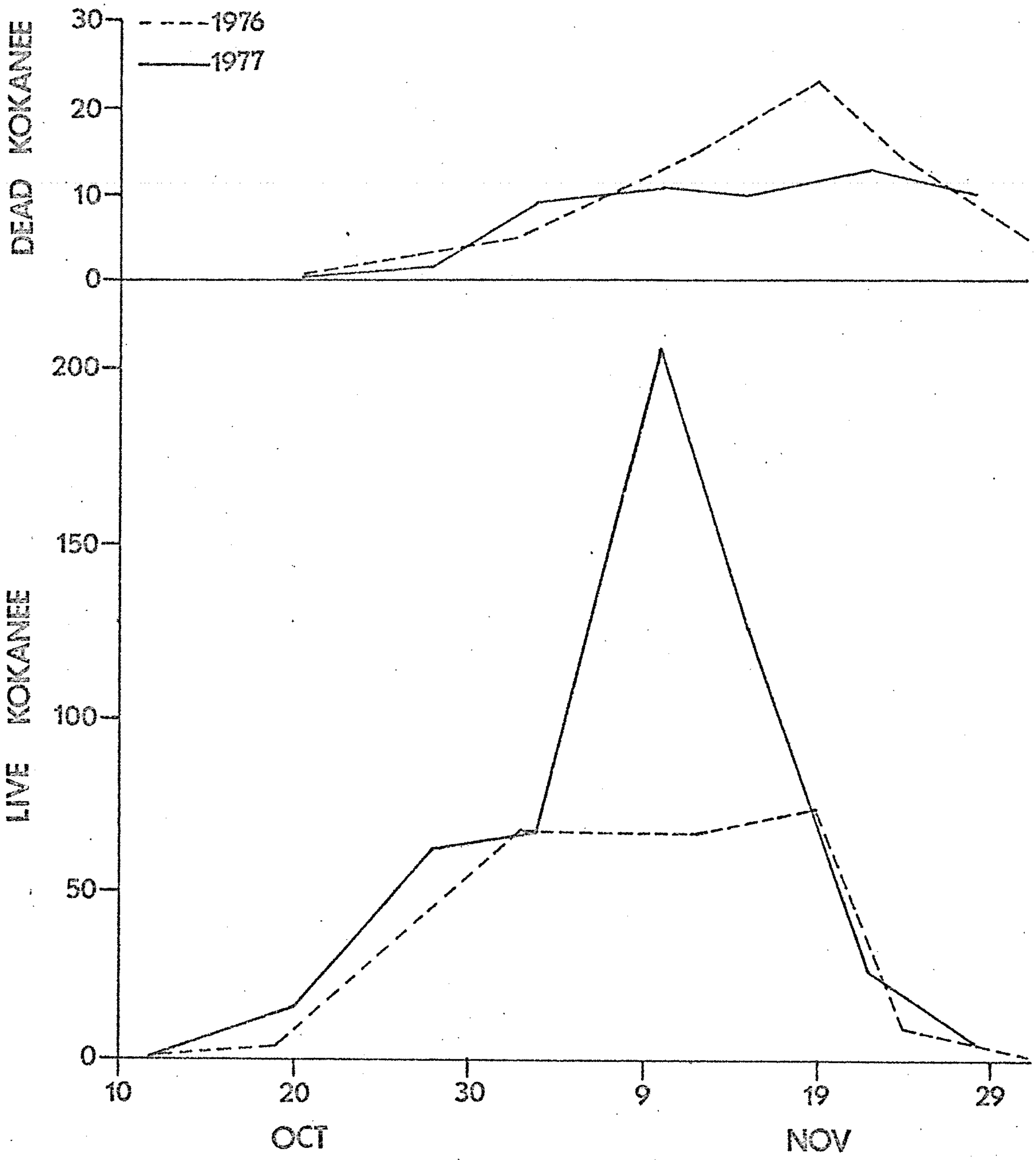

Fig. 21. Number of live and dead kokanee observed during glass-bottomed pram surveys in primary spawning area in Banks Lake during 1976 and 1977.

that dead kokanee were usually located downslope, away from the concentrated spawning area at a depth greater than 5 m.

The majority of spawner observations in the primary spawning area occurred in a 113-m stretch of talus shoreline containing smaller, cleaner gravel (prime gravel section). Spawner count density (no./m) from the glass bottom pram was two orders of magnitude higher for the prime gravel section (1.5/m, maximum) than for the remainder (0.01/m, maximum) of the primary spawning area in 1977 (Fig. 22). The prime gravel section was surveyed biweekly by a SCUBA team, in addition to the weekly surveys by glass-bottom pram. Spawner counts obtained by SCUBA were at least 4.5 times higher than those obtained by the glass-bottomed pram (Fig. 23) and were considered to be close to the actual number of spawners. Kokanee shied from the glass-bottomed pram early in the season, but became less wary as the season progressed. Thus, early season pram counts underestimated the actual number by more than a factor of 4.5. The disparity between pram counts and SCUBA counts became less as the season progressed, and the visibility improved due to reduced turbidity. The width and depth of area viewed through the glass-bottomed pram increased with visibility. Turbidity was not a problem during the 1976 survey, and the spawner counts more closely approached the actual number of spawners.

Kokanee spawning was most concentrated in locations with smaller, clean gravel. In the prime gravel section, the smaller gravel was located primarily at shallow depths where wave action had excavated the larger gravel and decreased the slope of the talus shoreline. Slope of the shoreline increased from 16° to about 36° below the 3-m depth (Table 3). Gravel size tended to increase with depth, especially below 7 m.

Spawning area utilized in the prime gravel section was measured on two occasions in 1977 (Fig. 24). The area of concentrated spawning was 339 m^2 at the beginning of peak spawning (November 4) under conditions of a 1-m drawdown. On November 16, when full pool was reached and during peak of spawning, the area had increased to 568 m^2. The entire increase in area was to the shallow side of the spawning bed. The

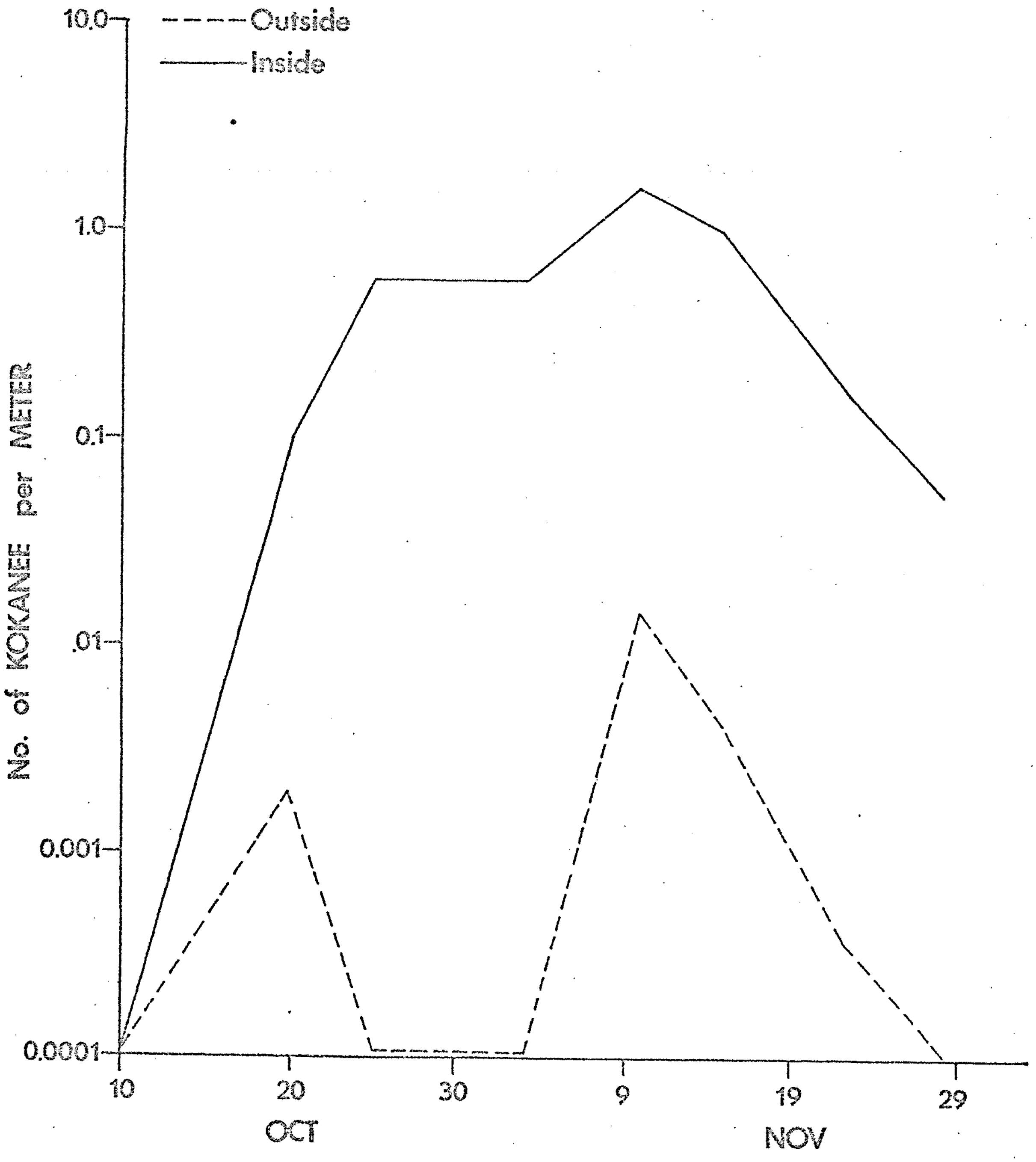

Fig. 22. Number of kokanee per meter observed by glass-bottomed pram inside and outside the prime gravel section of the primary spawning area in Banks Lake, 1977.

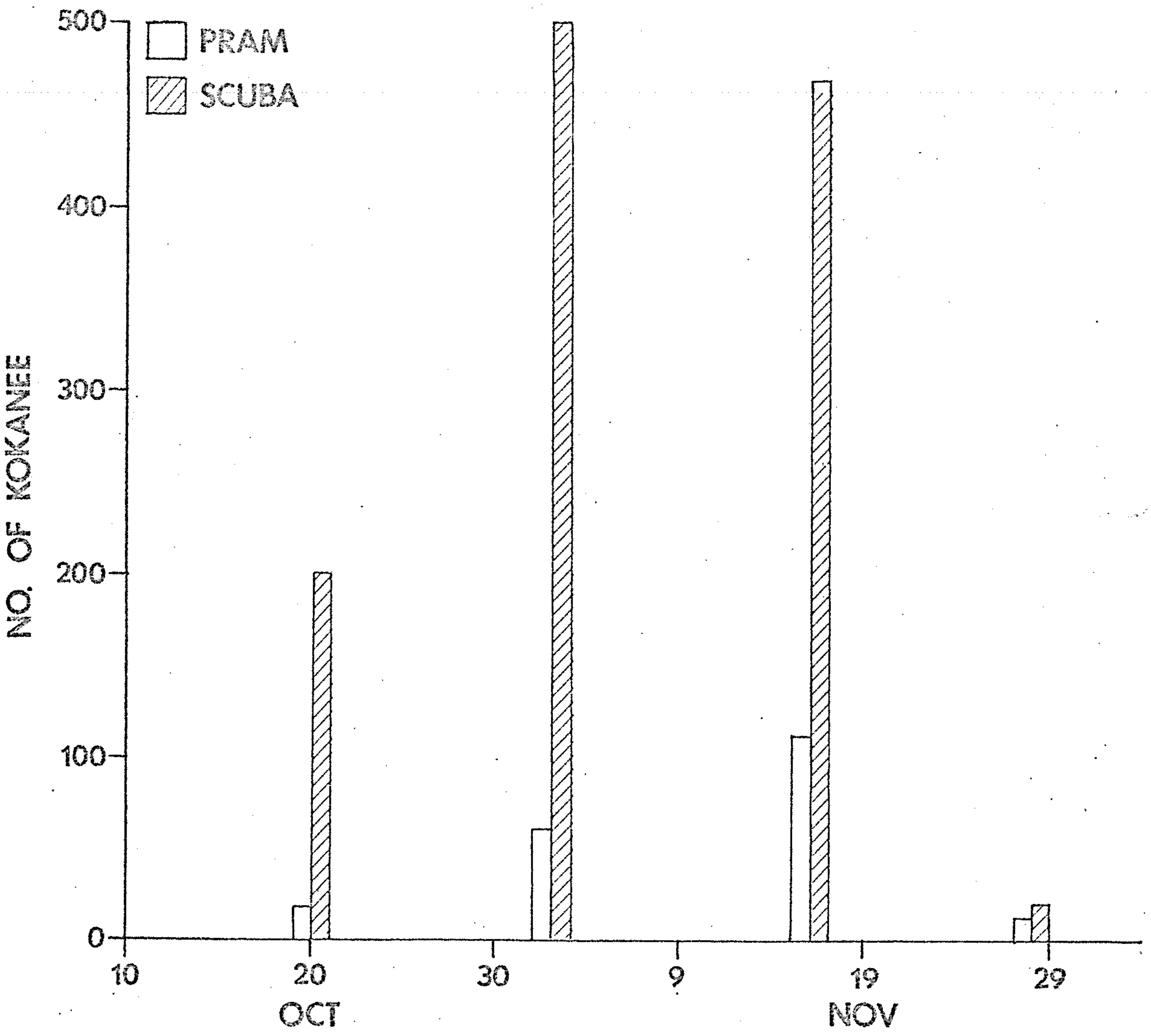

Fig. 23. Comparative spawner counts in the prime gravel section of Banks Lake using glass-bottomed pram and SCUBA in 1977.

Table 3. Mean slope and gravel size (% composition by area) by depth increment in the prime gravel section, Banks Lake, 1977.

Depth (m below full pool)	Mean Slope	Gravel size* (% Composition by Area)						
		<7.9 mm	7.9-13.5	13.5-26.7	26.7-53.4	53.4-106.8	106.8-214.6	>214.6
0-3	16°		0.4	4.2	21.1	46.1	20.3	7.9
3-5	35°		0.4	5.1	25.5	47.8	21.2	
5-7	37°		0.5	5.5	26.4	29.5	29.9	8.2
7-9	37°		0.1	1.0	4.8	11.1	43.6	39.4
9-11	36°			1.3	11.4	27.7	5.3	54.3
11-13	37°				3.8	42.5	53.7	
13-15	26°		0.2	2.0	12.7	21.8	25.3	38.0
>15	27°			1.1	10.9	40.0	28.7	19.3

*Gravel size measured from substrate photographs. Composition of smaller size classes probably underestimated.

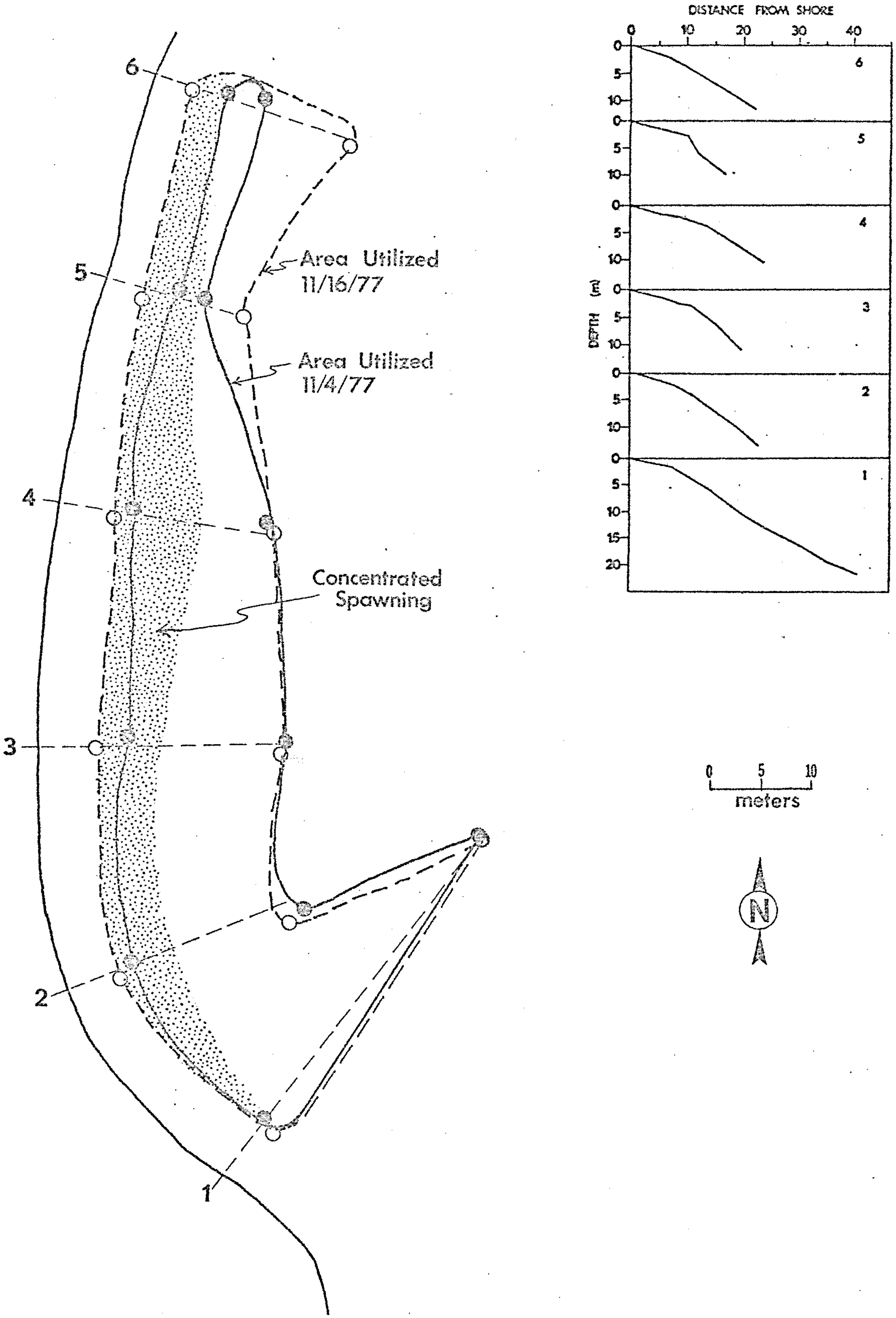

Fig. 24. Spawning areas utilized and areas of concentrated spawning in the prime gravel section of Banks Lake on 11/4/77 and 11/16/77.

increased spawning population in 1977 utilized a larger area than in 1976, when only 165 m^2 was used.

Much less kokanee spawning activity was observed below the 5-m depth. Spawning was observed at depths greater than found in 1975 and 1976. During 1977 surveys, redds were located as deep as 20 m. The total area utilized was much greater than the area of concentration (1,198 m^2 and 1,579 m^2 for November 4 and 19, respectively), but redd density was apparently very low in the deeper part of the spawning bed.

6.2.2.3.2 Other areas. The kokanee spawner count, measured by glass-bottomed pram counts, was increased twofold at Million Dollar Mile in 1977 over 1976, in spite of the reduction in visibility from 7.0 m to 3.0 m. A spawner count of 32 was recorded in 1977, as opposed to 17 in 1976 (site 5-02, Fig. 25). The talus shoreline at Million Dollar Mile has similar gravel and slope to that at the primary spawning area, however, the available spawning area was much less since much of the shoreline was a vertical cliff. No count by SCUBA observation was made in either 1976 or 1977 at this site.

A far greater number of kokanee spawned along the jetty entrance to the Coulee City boat harbor in 1977 than in 1976 (site 6-04, Fig. 25). Maximum spawner count in 1977 using the glass-bottomed pram was 2.5 times that observed in 1976. Two-hundred fifty-seven kokanee were observed along the jetty by snorkeling in 1977.

Spawning kokanee have been observed in two general types of areas in Banks Lake: natural talus shorelines and gravel fill along roadbeds or jetties. In 1977, only one site was found, other than those noted previously, that attracted a concentration of spawners. Ninety kokanee spawners were observed by SCUBA at 3- to 5-m depths (5-7 m below full pool) along the South Dam, just east of the basalt outcrop adjacent to the barrier net (Fig. 3). Based on their proximity to the barrier net, which had been removed 5 days earlier, these fish may have been trapped by the barrier and thereby forced to spawn inside the net. No surveys had been conducted in this location during previous years, so it is not known whether these fish were an established subpopulation of spawners.

A small concentration of mature kokanee was found along the talus shoreline south of the primary spawning area in 1976 (site 6-02, Fig. 25), but the site was not used in 1977. No evidence of actual spawning was observed by inspection with SCUBA during either year.

No other concentrations of spawning kokanee were observed during either 1976 or 1977. There were a few isolated locations along roadbed fill areas which were used by spawning kokanee in 1976 (Fig. 25) that were unavailable in 1977 due to the 2.7-m fall drawdown.

6.2.2.3.3 Spawner estimate. The maximum number of kokanee on the spawning grounds at the peak of spawning in 1977 was estimated from spawner counts at 1,000. Of these, 500 spawners utilized the primary spawning area, 250 at Coulee City Harbor, 100 along the South Dam (all actual counts by SCUBA) and 150 at Million Dollar Mile (an expanded count utilizing the ratio of 4.5 for SCUBA counts to pram counts). In total, these numbers represent an increase of 6.7 times over the 1976 kokanee spawning population.

The total spawning population was probably much greater than 1,000 fish because of turnover on the spawning grounds. Actual turnover time was not determined for Banks Lake kokanee since no fish were tagged. Pfeiffer (unpublished M.S. thesis) found that female kokanee in Lake Stevens, Washington, spent an average of 15.4 days on spawning grounds in a tributary stream. This value was adopted for this study.

The total spawning population was estimated from a method presented by Lewis (1972) where the total number was equal to the quotient of the area under the curve of the number of spawners present throughout the spawning season and mean length of time spent on the spawning grounds.

The area under the curve of number of spawners present throughout the spawning season at the primary spawning area (Fig. 21) was measured planimetrically. The estimated total spawning population in the primary area was 940. It was not possible to make frequent SCUBA counts at other spawning locations to derive a curve. Therefore, the total spawning population outside the primary area was estimated based on the ratio of estimated total population at the primary area (940) to the maximum number observed at the primary area (500). By this method, the estimated total Banks Lake kokanee spawning population in 1977 was 1,880.

6.2.2.3.4 Egg deposition. A comparison of egg deposition in 1976 and 1977 was made for the primary spawning area and for the entire

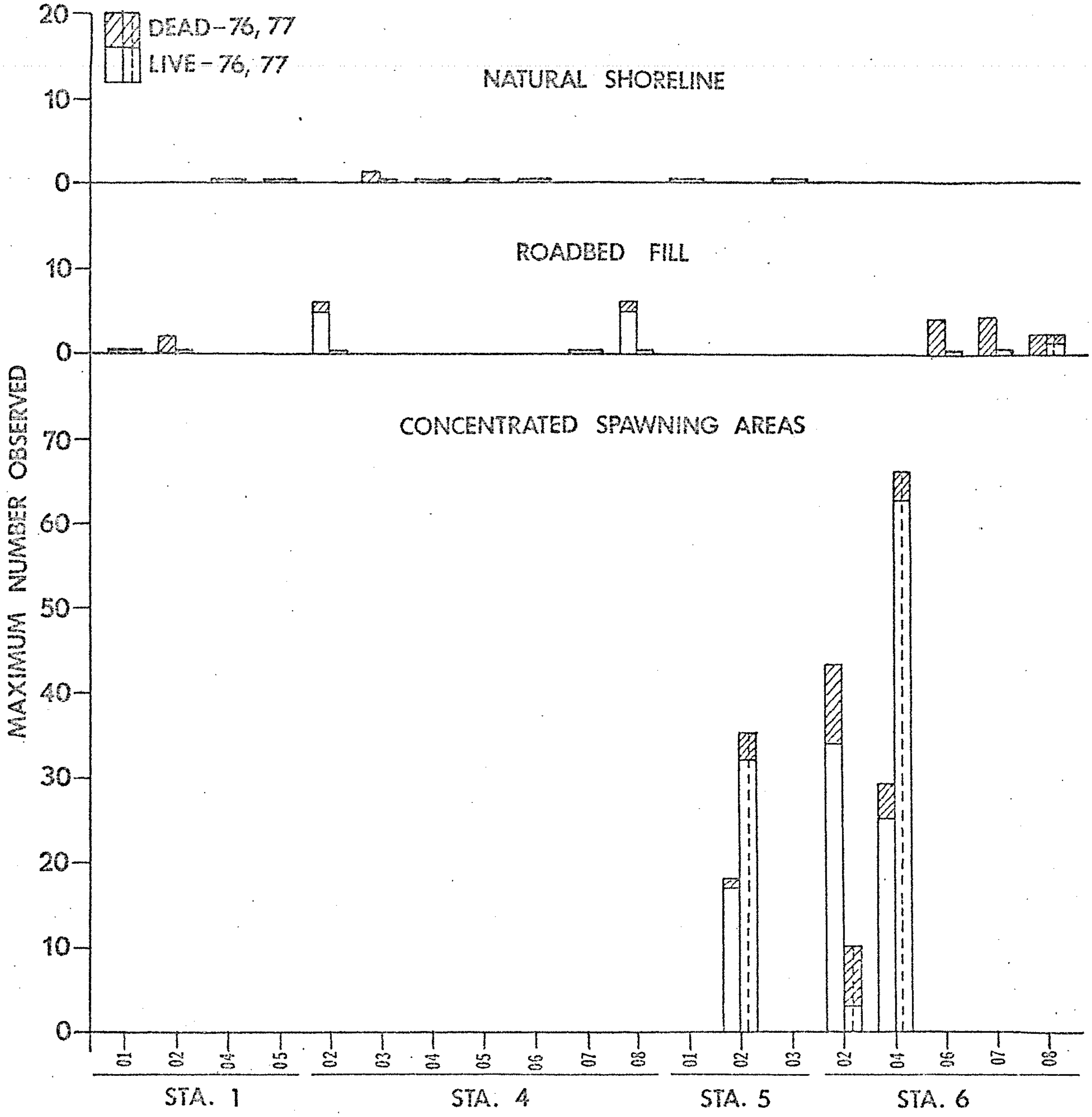

Fig. 25. Maximum number of live and dead kokanee observed by glass-bottomed pram in the concentrated spawning area (excluding primary site), roadbed fill areas, and natural shoreline areas in 1976 and 1977.

lake. Egg deposition was estimated by the multiplication of numbers of female kokanee by the average fecundity. A 50:50 sex ratio for spawners was assumed; thus, the number of females was half the total spawner population. The average fecundity of Banks Lake kokanee had previously been determined to be 1,222 eggs per female (Stober et al. 1976). Incomplete spawning was not considered to be an important source of error in the calculation of egg deposition because 10 dead, spent kokanee examined during November 1976 had spawned completely. Undoubtedly, eggs were lost during spawning to predators; namely, the abundant spiny sculpin (Moyle 1977). Because this loss was not measured, an arbitrary value of 10 percent was assumed. This value is far less than an average predation loss, but was chosen because of the low density of spawning which probably reduced the chance for superimposition of redds, which contributes to the loss of eggs.

Egg deposition in the primary spawning area was estimated to be 516,906 in 1977 and 56,419 in 1976. Respective egg densities (number of eggs per sq m) were 910 and 342. Estimated egg deposition for the entire lake was 1,033,817 in 1977 and 84,135 in 1976. Although these estimates are based on somewhat arbitrary constants, they are the best presently available for Banks Lake kokanee. The differences between annual egg deposition in 1976 and 1977 were primarily due to the increase in 1977 spawner density. Based on the increase in kokanee egg deposition in 1977 it can be concluded that sufficient numbers of spawners were retained in the lake to consider operation of the barrier net a success.

6.2.2.4 Effect of Drawdown on Spawning. Strong evidence exists that kokanee year-class strength in Banks Lake is affected by drawdowns greater than 4.6 m (15 ft) between time of egg deposition and emergence (Stober et al. 1977). At the beginning of the 1977 spawning season, water level was 2.7 m below full pool and may have forced some early spawners to lower than normal depths on the talus slopes. This may have provided far greater egg and fry survival of these deeper spawners because they may be able to emerge prior to spring drawdown. Full pool was reached in mid-November and spawning kokanee were observed to follow the rising water level during the peak period of spawning. Most spawning in 1977 was therefore shallower than 4.6 m below full pool and the eggs and fry are vulnerable to spring drawdown. The extent to which each kokanee year-class could be protected from spring drawdown by maintaining low pool throughout the spawning season is unknown because the best spawning substrate is relatively shallow. It is possible that wave action during drawdown could create favorable spawning beds by excavating the larger gravel that covers the preferred finer material at depths greater than 5 m. However, intentional water level manipulation to 5 m would probably not be an effective means of creating spawning beds at greater depths in the lake.

All spawning substrate along the jetties of Coulee City Harbor is less than 4.6 m (15 ft) below full pool and therefore survival of eggs and larvae may be poor under conditions of 3.0- to 4.6-m spring drawdowns. Because spawning at the beginning of the 1977 season was entirely at the 3.4- to 4.6-m (below full pool) level, the potential fry survival and production from this area may have been enhanced. Peak spawning by kokanee along the jetty was slightly earlier than at the primary spawning site because of more rapid cooling in the harbor. This area may also warm earlier in the spring which could result in emergence before spring drawdowns occur. Spawning areas along jetty and roadbed fills are very vulnerable to drawdown at any time during egg and larval development because of the shallow depth of these locations.

6.2.3 Gilling Rate

The species and size of the fish gilled by the barrier net was determined throughout the period of operation. Fish were recovered principally during cleaning operations, however, a few which had dropped out of the net were recovered from the bottom by divers during routine SCUBA inspections of the net. Some fish were difficult to identify because they had gilled early in the 2-week period between net-cleaning operations and decomposed. The decomposition rate was greatest during July and August when water temperatures were warmest.

The gilling rate of all species was low and unimportant relative to the losses due to entrainment. In all, 13 species were identified (Table 4). Kokanee were by far the most abundant (194), accounting for 68 percent of the 287 total number of all fishes. Chinook (26) and

Table 4. Species composition, number, and length of fishes gilled in the barrier net.

Species	Scientific Name	No.	Mean[1] Length (mm)	n	Length Range	
					Min. (mm)	Max. (mm)
Kokanee salmon	*Oncorhynchus nerka*	194	371.6	103	288	505
Chinook salmon	*Oncorhynchus tshawytscha*	26	301.3	20	280	350
Rocky Mt. whitefish	*Prosopium williamsoni*	24	319.4	12	281	406
Yellow perch	*Perca flavescens*	13	224.4	12	100	290
Peamouth	*Mylochelius caurinus*	9	348.0	5	325	394
Longnose sucker	*Catostomus catostomus*	8	293.3	4	218	327
Rainbow trout	*Salmo gairdneri*	5	305.3	3	299	312
Lake whitefish	*Coregonus clupea formis*	2	–	0	–	
Black crappie	*Pomoxis nigromaculatus*	2	192	1	–	–
Brown bullhead	*Ictaluras nebulosus*	1	238	1	–	–
Carp	*Cyprinis carpio*	1	200	1	–	–
Largemouth bass	*Micropterus salmoides*	1	287	1	–	–
Pumpkinseed sunfish	*Lepomis gibbosis*	1	168	1	–	–
TOTAL		287				

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[1] Measured from tip of snout to fork of tail.

Rocky Mountain whitefish (24) ranked second and third in abundance. Surprisingly few yellow perch (13) were gilled despite their vast numbers and strong tendency to concentrate along the net. Schools of perch numbering in thousands were observed passing freely through the meshes. The number of lake whitefish (2) and carp (1) gilled also was low relative to their abundance in Banks Lake. Carp were often observed near the net by divers and were occasionally seen to attempt to force themselves through the net by ramming. Apparently, their large size and somewhat truncated form prevented gilling. This effect was probably true for mature lake whitefish, as well.

The kokanee which gilled in the barrier net were substantially smaller than the kokanee entrained in the irrigation canal. This difference was 70 mm during August and 20 mm during September and October. The difference resulted primarily from the gilling selectivity of the barrier net for smaller kokanee and became less with advancing maturity because the males, which were larger, tended to become entangled in the mesh more easily due to their elongated snouts and protruding teeth. The kokanee gilled in October were mostly spawning males. Only two kokanee were identified as immature age II.

The seasonal gilling rates of kokanee, chinook and Rocky Mountain whitefish which were most commonly gilled in the barrier net were 1.19, 0.09, and 0.14 fish/day, respectively, in the south net and 0.41, 0.11, and 0.06 fish/day, respectively, in the east net (Table 5). Only eight kokanee were gilled during the first 2 months of net operation, while 186 were gilled during the second 2 months. The increased gilling rate during September and October was probably due to increasing effort of maturing kokanee to follow the irrigation flow, it may also have resulted in part, from closure of the gaps in the south net. The greatest increase in gilling rate was observed in the south net, which appeared to be the main avenue of escape.

Chinook were gilled in small numbers primarily during June and July. Their mean length of 301.3 mm and size range from 280 to 350 mm indicated that most were age II from a plant in 1976.

The gilling rate of Rocky Mountain whitefish was high relative to the low abundance of this species in Banks Lake and in the entrainment

Table 5. Number and seasonal rate of gilling by kokanee, chinook, and Rocky Mountain whitefish in the barrier net.

South Net

			Number				Rate (No./day)			
	Period	Days	Kokanee	Chinook	RMW[1]	Total	Kokanee	Chinook	RMW[1]	Total
	6/23-7/6	13	0	2	0	2	0	0.15	0	0.15
1	7/8-7/14	6	3	5	2	14	0.50	0.83	0.33	2.33
9	7/14-7/26	12	2	2	3	9	0.17	0.17	0.25	0.75
7	7/26-8/10	15	2	0	0	5	0.13	0	0	0.33
7	8/10-8/23	13	0	0	1	3	0	0	0.08	0.23
	8/23-9/6	14	15	2	6	26	1.07	0.14	0.43	1.86
	9/6-10/24	48	122	0	5	141	2.54	0	0.10	2.94
		121	144	11	17	200	1.19	0.09	0.14	1.65

East Net

			Number				Rate (No./day)			
	Period	Days	Kokanee	Chinook	RMW[1]	Total	Kokanee	Chinook	RMW[1]	Total
	6/24-6/30	6	0	6	0	9	0	1.00	0	1.50
1	6/30-7/14	14	0	7	1	11	0	0.50	0.07	0.79
9	7/14-8/2	19	1	0	2	10	0.05	0	0.11	0.53
7	8/2-8/18	16	0	0	0	12	0	0	0	0.75
7	8/18-9/7	20	15	0	4	28	0.75	0	0.20	1.40
	9/7-10/25	48	34	0	0	42	0.71	0	0	0.88
		122	50	13	7	112	0.41	0.11	0.06	0.92

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[1] Rocky Mountain whitefish

catches from the irrigation canal. All individuals gilled were large and maturing and apparently of ideal size and body shape for gilling in the mesh of the barrier net.

The greater water depth of the south net apparently was more attractive to fish than was the shallower depth of the east net. No fish were gilled in the 183-m (600-ft) portion of the east net which traversed water less than 3 m (10 ft) deep. The gilling rate appeared to be related to depth, with the highest rate occurring within 3 m (10 ft) of the surface. Few fish were gilled deeper than 7.6 m (25 ft). This difference may have resulted from variation in water current which was fastest at the surface and almost negligible below 7.6 m, or it may have been the preferred swimming depth of fish irrespective of current.

Gilling rate did not appear to be related to differences in water current along the net. The fastest water currents were encountered midway along the east net in water depths ranging from 6.1 to 7.6 km. The gilling rate in this section of net was no greater than in adjacent net sections of equal or greater depth.

In general, the loss of fishes of all species by gilling in the barrier net was inconsequential compared to their population sizes and to entrainment losses. If these fishes had not been gilled, they would very likely have been entrained into the irrigation canal and lost from the lake.

6.2.4 Gillnet Catches Adjacent Barrier Net

The relative abundance of fishes inside (near irrigation canal outlet) and outside (adjacent barrier, main lake basin) the barrier net and seasonal abundance was determined semiweekly by comparative gillnet sampling. These results were also compared with gillnet catches from midlake at stations 4, 5 and 6.

Kokanee were caught in approximately equal numbers inside and outside the barrier net during the entire period of barrier net operation (Fig. 26). The catches of kokanee in the barrier net vicinity were approximately equal to the catches at stations 4, 5, and 6 until September, when the catches became larger at the barrier net. The age composition of kokanee gilled at the barrier net was almost entirely age III,

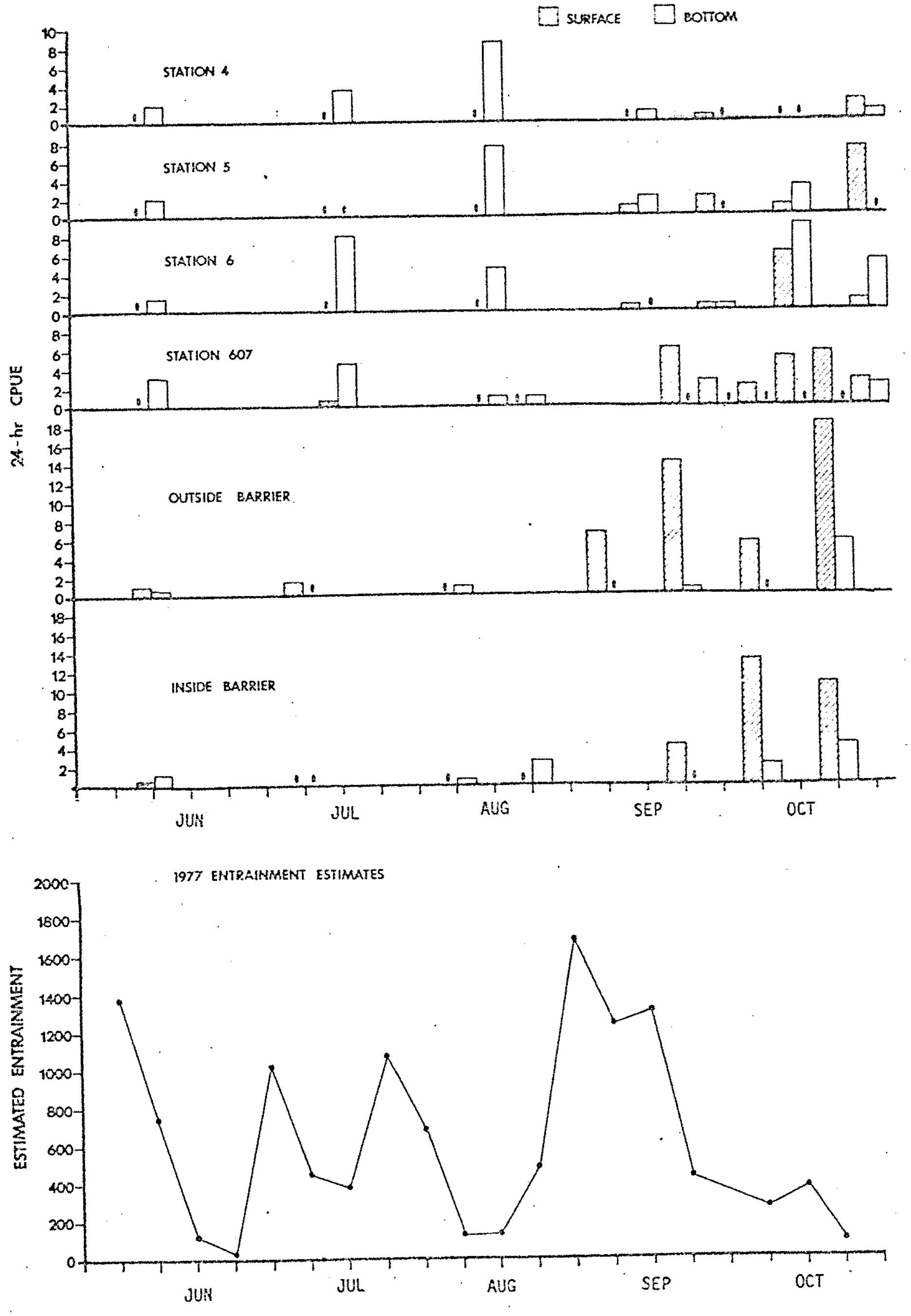


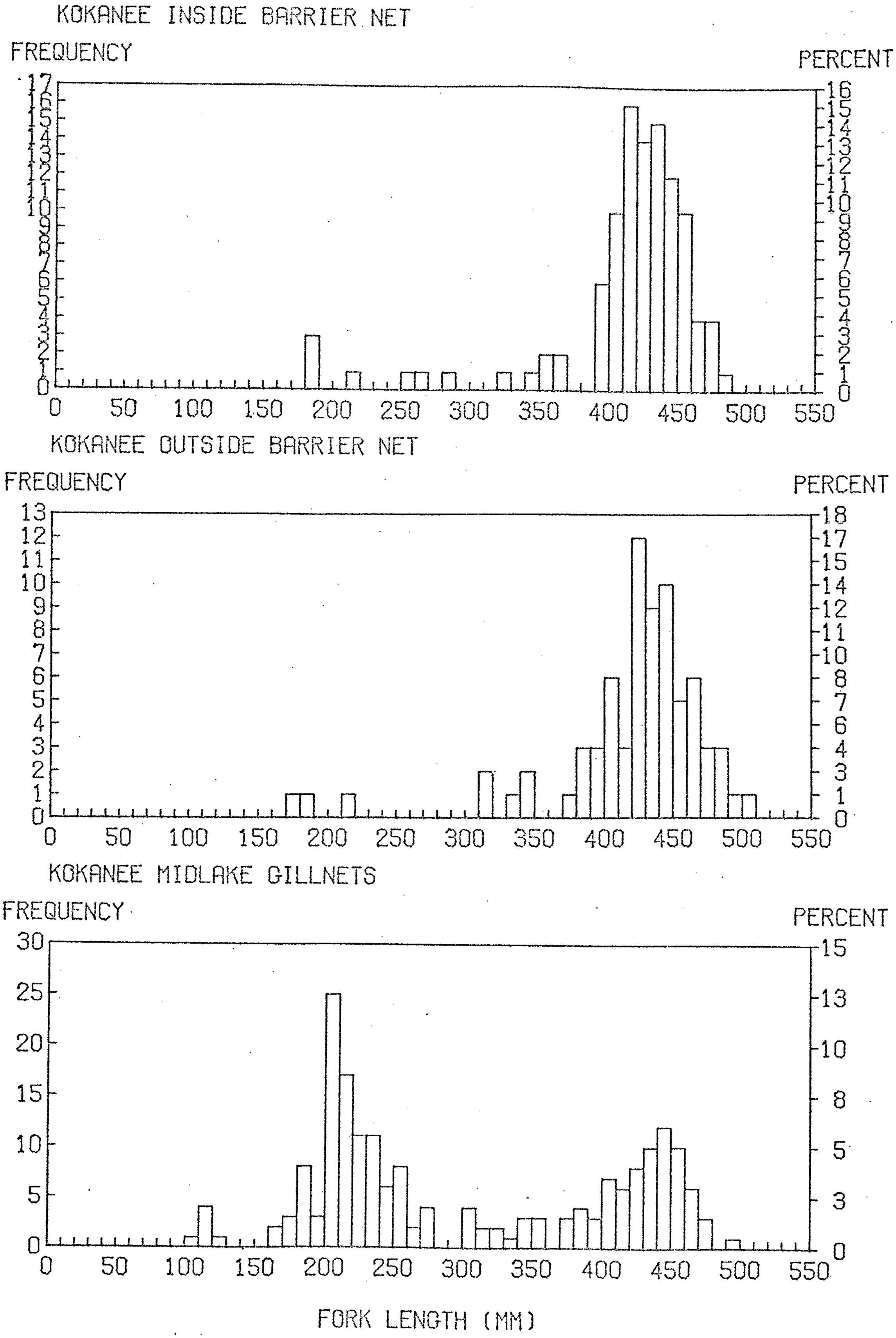
Fig. 26. Surface and bottom gillnet 24-hr catch per unit effort of kokanee inside (near irrigation canal outlet) and outside (adjacent barrier main lake basin) barrier net compared with main basin sampling stations and estimated irrigation canal entrainment during 1977.

with very few age II, whereas at Stations 4, 5, and 6, the composition was nearly equally divided between II's and III's (Fig. 27).

Unlike kokanee, the gillnet CPUE of lake whitefish was dramatically lower inside the barrier net than outside (Fig. 28). This difference was not obvious until September, at which time lake whitefish became abundant near the barrier. The low abundance inside the barrier net was consistent with the canal sampling data which showed a low entrainment of lake whitefish during operation of the barrier net. Comparisons of length-frequency distributions for lake whitefish indicated a higher proportion of juveniles in the catch inside the barrier net than outside or at transects 4-6 (Fig. 29). Apparently, the barrier net effectively screened the adults but was less effective in screening the smaller juvenile lake whitefish.

The yellow perch population was apparently not affected by the presence of the kokanee barrier net. Numerous observations were made throughout the study of schools of yellow perch swimming through the net in both directions. Catches of yellow perch inside the barrier net were larger than outside or at transects 4-6 (Fig. 30). This was probably related more to habitat preference than to presence of the barrier. Comparison of length-frequency distributions of yellow perch caught by gillnets inside and outside the barrier net indicated a higher proportion of juveniles than the catch at transects 4-6 (Fig. 31).

Relative abundance of fish populations inside and outside the barrier net in 1977 was determined by gillnet sampling. Kokanee catches, primarily maturing age III fish, were similar inside and outside the barrier net. Kokanee apparently actively followed the irrigation flow and successfully found the gaps along the south barrier net. Lake whitefish catches were lower inside the barrier net than outside, which suggested that lake whitefish were effectively screened out of the irrigation canal. Yellow perch were apparently unaffected by the presence of the barrier net and were observed swimming through the mesh of the net on numerous occasions.



KOKANEE INSIDE BARRIER NET

KOKANEE OUTSIDE BARRIER NET

KOKANEE MIDLAKE GILLNETS

Fig. 27. Length frequency analysis of kokanee caught in gillnet samples inside (near irrigation canal outlet) and outside (adjacent barrier main lake basin) barrier net compared with midlake stations in 1977.

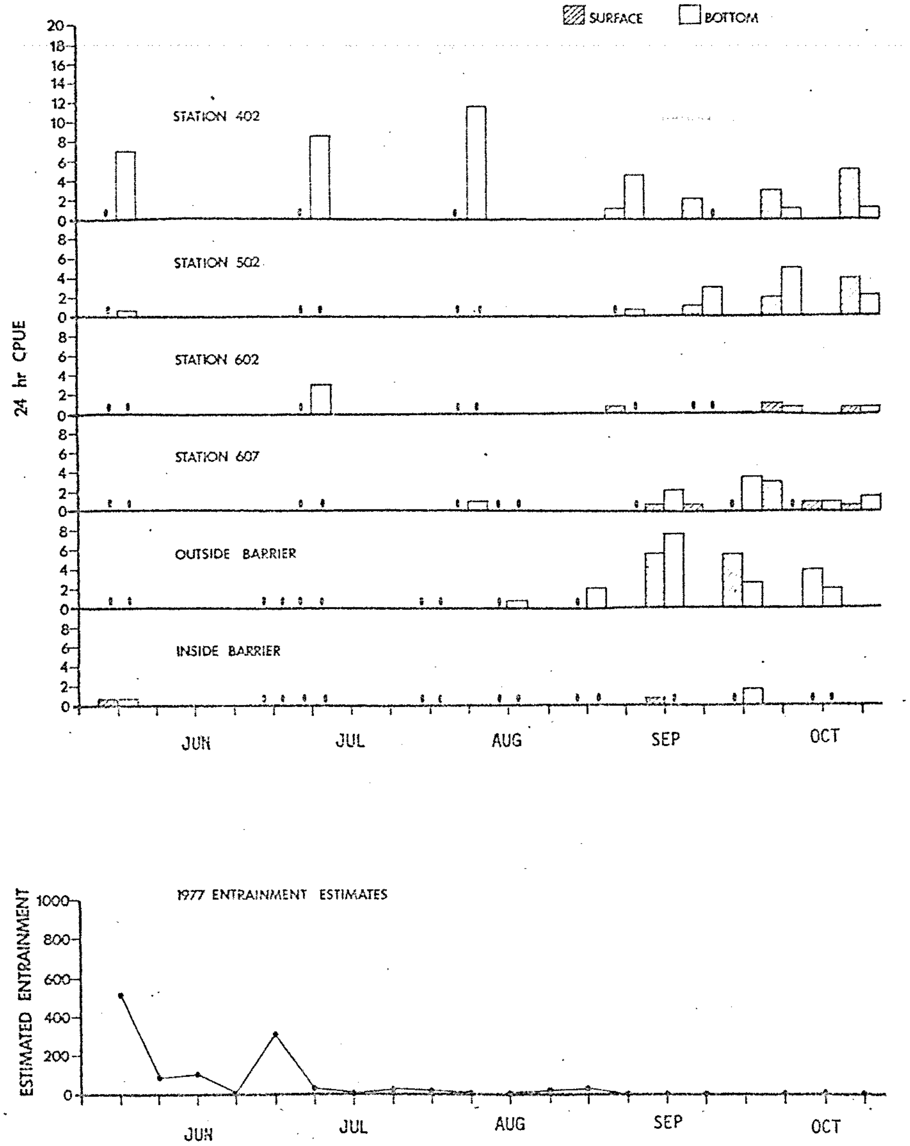


Fig. 28. Surface and bottom gillnet 24-hr catch per unit effort of lake whitefish inside (near irrigation canal outlet) and outside (adjacent barrier main lake basin) barrier net compared with main basin sampling stations and estimated irrigation canal entrainment during 1977.

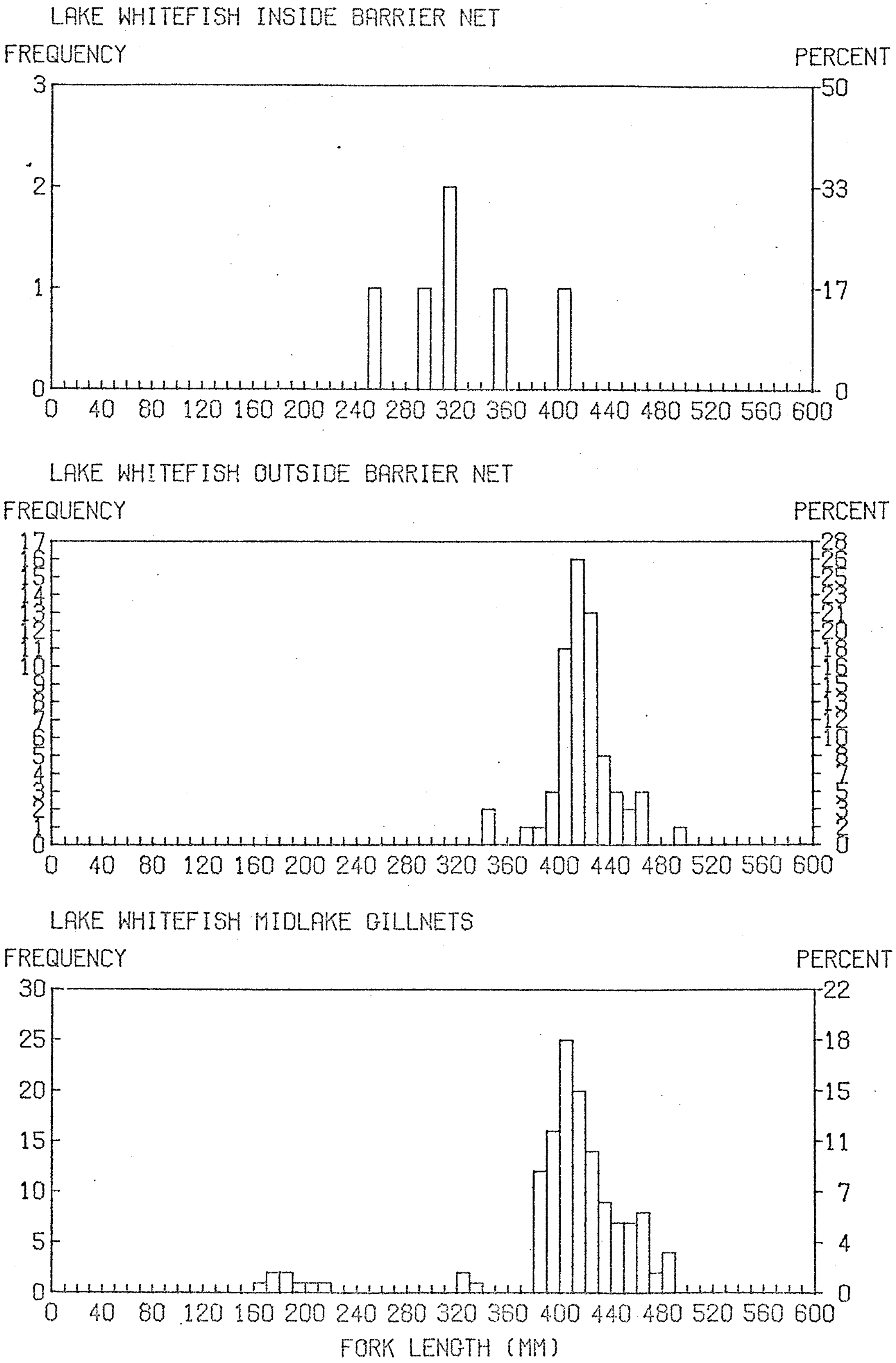


Fig. 29. Length frequency analysis of lake whitefish caught in gillnet samples inside (near irrigation canal outlet) and outside (adjacent barrier main lake basin) barrier net compared with midlake stations in 1977.

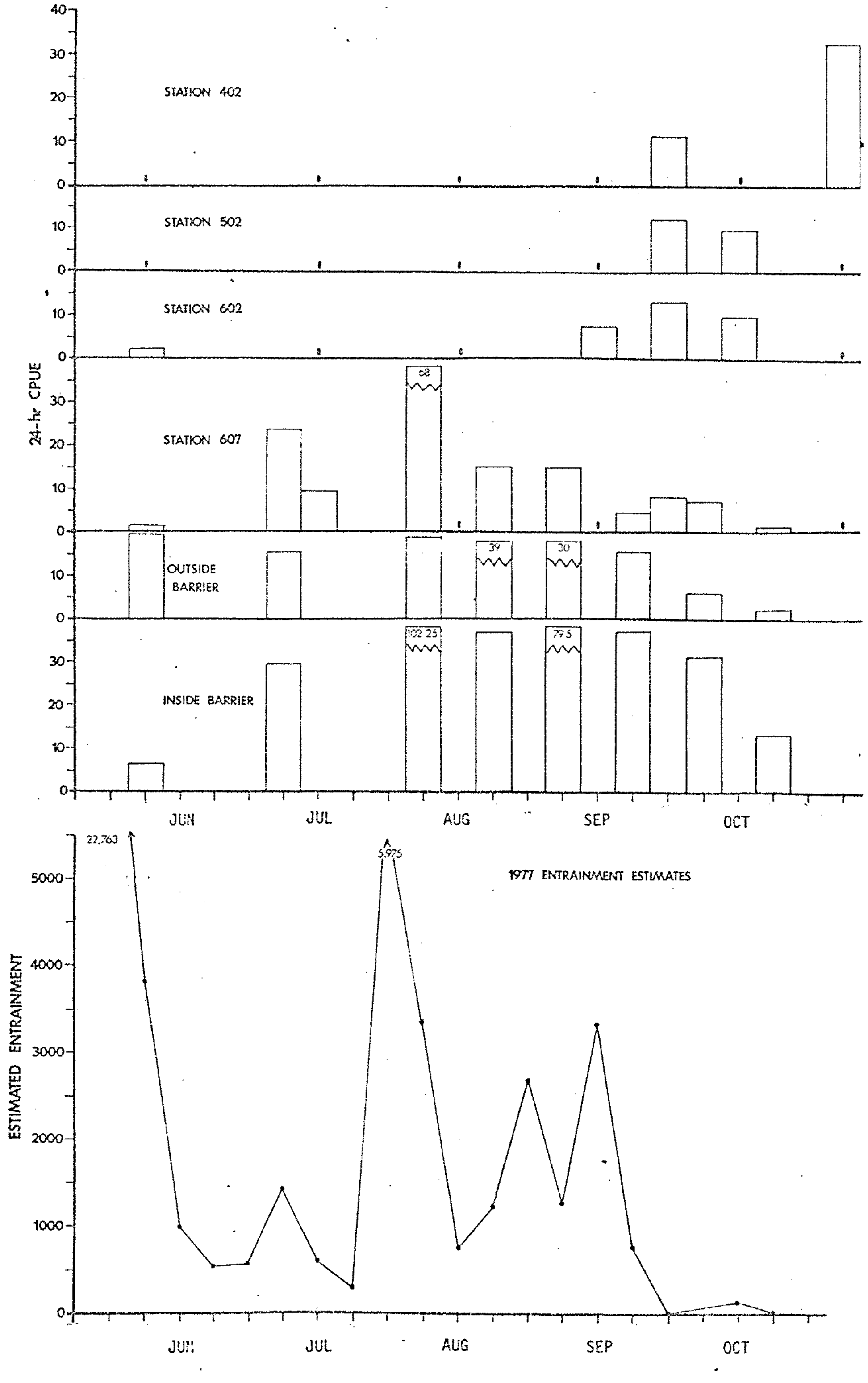


Fig. 30. Surface and bottom gillnet 24-hr catch per unit effort of yellow perch inside (near irrigation canal outlet) and outside (adjacent barrier main lake basin) barriet net compared with main basin sampling stations and estimated irrigation canal entrainment during 1977.

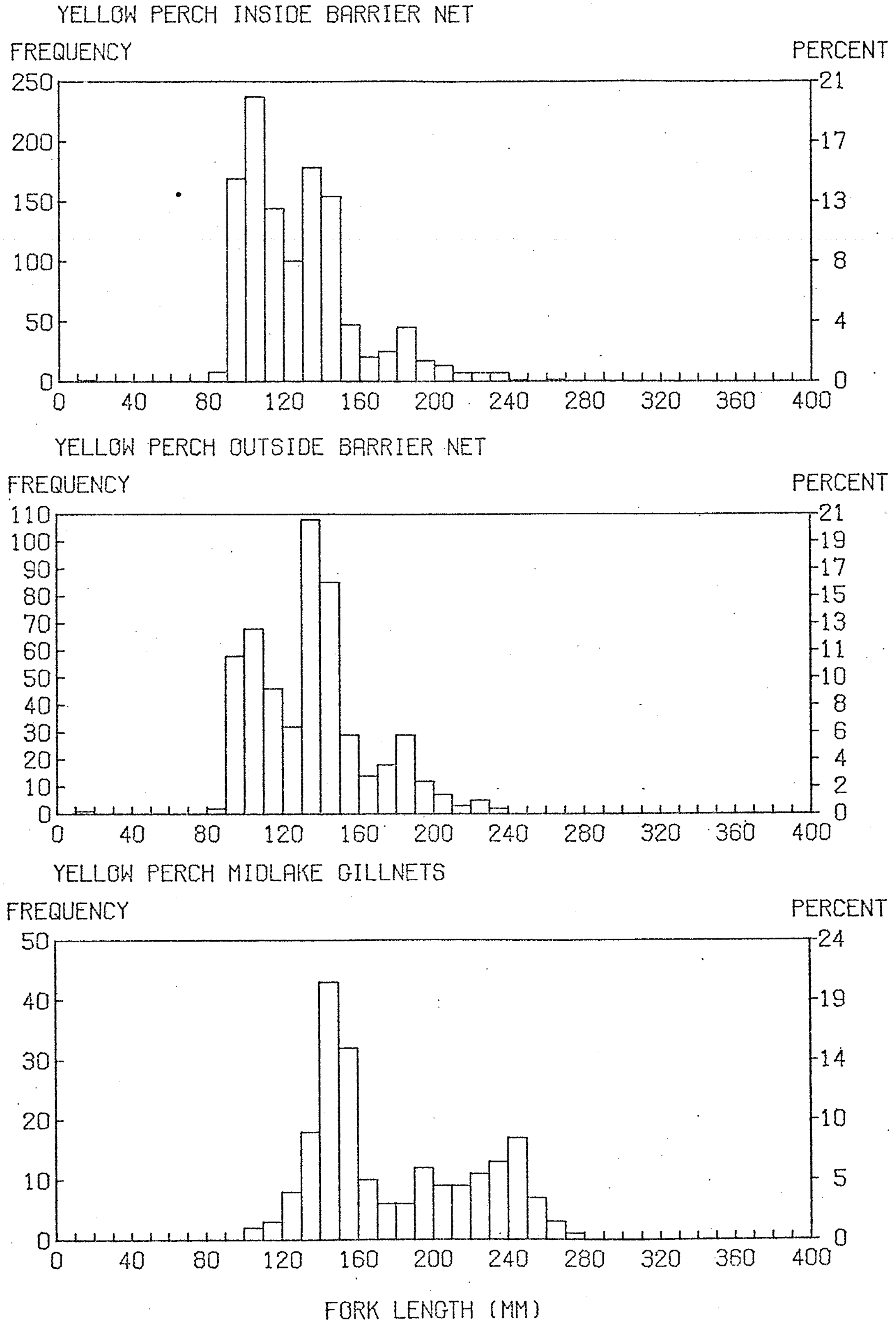


Fig. 31. Length frequency analysis of yellow perch caught in gillnet samples inside (near irrigation canal outlet) and outside (adjacent barrier main lake basin) barrier net compared with midlake stations in 1977.

6.2.5 Acoustic Surveys

Acoustic surveys of fish densities were made monthly inside and outside the barrier net as a supplemental means of evaluating the fish-screening effectiveness of the barrier net and to determine whether areas of fish concentration or avoidance could be detected. While acoustic surveys near the barrier net were not included in the contract proposal, they were considered sufficiently important to add without additional cost.

In the analysis of the echograms, large targets were separated from small targets and the depth distribution was divided into three strata: surface to 9.1 (30 ft), 9.1 to 18.3 m (30 to 60 ft) and 18.3 m (> 60 ft) (Appendix Table 4). Analysis of the echogram target strengths revealed that the targets were readily separable into two distinct size groups, large targets being about 30 times larger than small targets. Because the species and size composition of fishes near the barrier net was well known from SCUBA observation, gillnetting, and canal sampling, the small targets were assumed to be age I perch. Age I perch were abundant and distributed narrowly about a mean size of 90 mm (15 g). The large targets were a combination of species probably including kokanee, carp, chinook, whitefish, and suckers which ranged in size from 250 mm (200 g) to 550 mm (3,500 g). This separation of targets persisted strongly during all acoustic surveys, enabling perch to be excluded from the analysis.

The acoustic data were analyzed in an effort to identify the possible effects of the following variables: 1) seasonal period; 2) diel period; 3) depth; 4) inside versus outside the barrier net; 5) distance upstream from the barrier net; and 6) target size. In general, the survey results were irregular and did not show significant differences between the variables compared. No consistent diel variation existed in either the vertical or horizontal distributions of targets or in the absolute number of targets irrespective of distribution. Acoustic assessments of fish populations customarily show greater densities at night and a greater proportion of targets at shallower depths, but these effects were not observed in the transect areas near the barrier net.

A Friedman's two-way analysis of variance test (Siegel 1956) was used to test for differences in target densities between transects inside the barrier net (transects 1-3) and transects outside the barrier net (transects 4-7, 8-11). There was no significant difference at the 5 percent level. The density of large targets in the vicinity of the barrier net appeared unaffected by the presence of the net.

The seasonal variation in target density was determined by comparing the mean target density of all transects outside the barrier net (transects 4-10) for each survey. Target density tended to be higher in July and September than in August and October, but monthly differences were not significant at the 5 percent level.

Target densities outside the south barrier net were greatest at transects nearest the net and lowest at transects farthest from the net (Fig. 32). This difference occurred consistently during the nighttime surveys but never during the daytime surveys. Interpretation of these results is speculative but nighttime stratification of fishes suggests that screening occurred at night, perhaps because the openings under the lead line were not visible. This effect, however, was not observed outside the east net. Target density inside the barrier net was lower than outside.

6.2.6 Fish Population Monitoring

Continuation of the standard gillnet sampling at transects 4, 5, and 6 initiated in 1973 maintained the baseline monitoring of the relative sizes of the populations of: kokanee, lake whitefish, and yellow perch in Banks Lake. Determination of the relative abundance was necessary as a means of evaluating the effect of the barrier net on entrainment of principal species, and on the size of these populations in the lake. If substantial numbers of kokanee were prevented from leaving Banks Lake, an increase in their relative numbers might be detected particularly at the south sampling sites.

6.2.6.1 Kokanee. Gillnet catches of kokanee monitored primarily the abundance of age II- and III-year-olds. The relative abundance of kokanee in the gillnet catches since 1973 is shown in Fig. 33. Generally, catches have been largest at station 6 through the summer period. Much

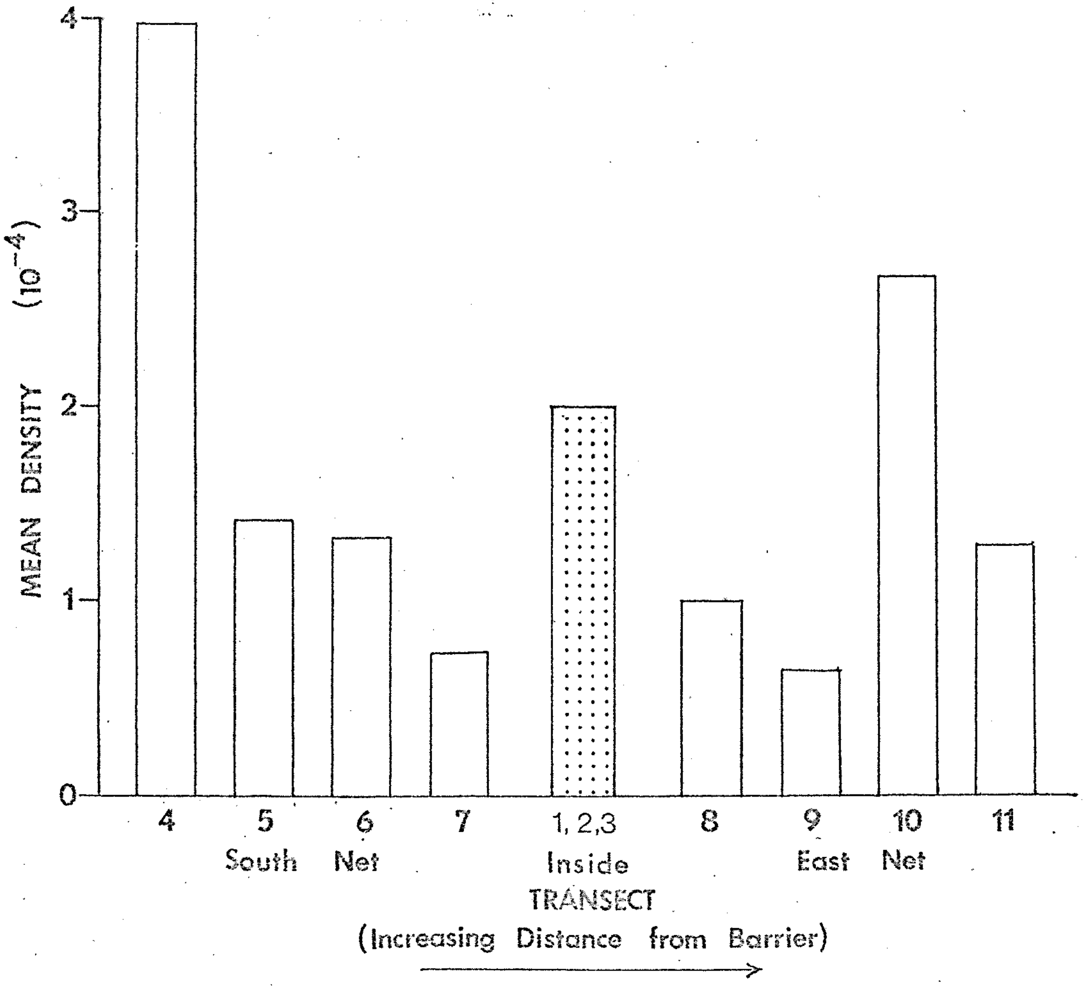


Fig. 32. Mean acoustic target density (night only) by transect at increasing distance from south and east barrier nets compared with mean of inside transects.

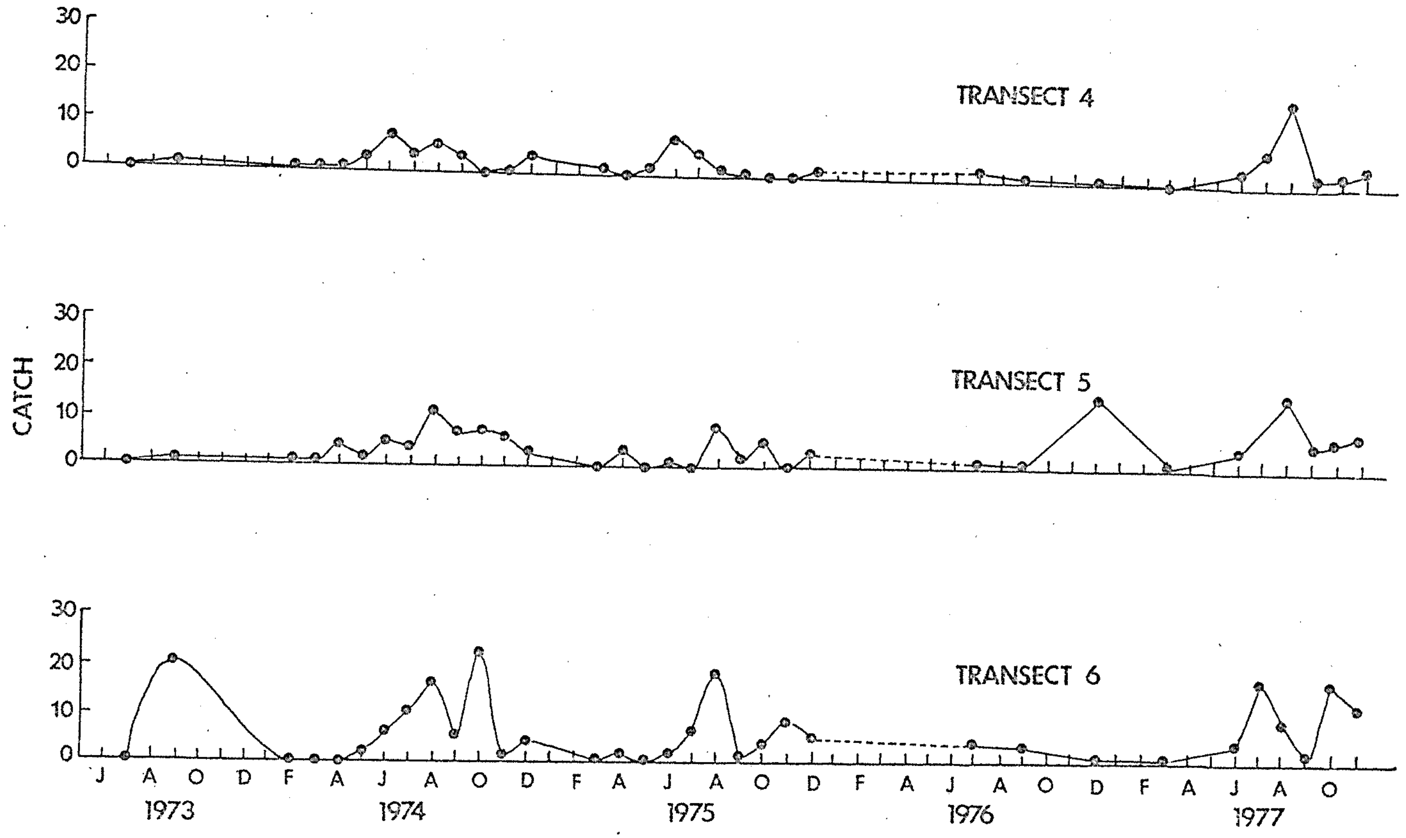


Fig. 33. Horizontal distribution of kokanee. Each point represents the catch from three 24-hr horizontal variable-mesh gillnet sets: 2 on the bottom and 2 on the surface.

of the variability between stations has been attributed to seasonal and operational changes which influence temperature, food and spawning behavior (Stober et al. 1977). The variation between years can be attributed to changes in the year-class strength.

A summary of the length frequencies of kokanee since 1973 is shown in Fig. 34. Individuals of the 1971, 1972 and 1976 year classes were relatively numerous, while those of the 1970, 1973 and 1974 year classes were small in number (year class identified by year of fry emergence).

A decline was apparent in the offshore catch of age II kokanee (roughly < 300 mm) in 1975 and of age III kokanee (> 300 mm) in 1976 (Fig. 35). A comparable decline of age II kokanee was noted in 1976 and of age III kokanee in 1977. Thus, it appears that the sizes of the 1973 and 1974 year classes (age III in 1976 and 1977, respectively) were roughly comparable, even though data points varied widely between sampling. Both the 1973 and 1974 year classes were subjected to large spring drawdowns prior to emergence of the fry from the gravel.

A comparison of the numbers of age II kokanee between years also showed a pronounced increase in 1977 over 1976, which suggests a larger year class and improved sport fishing in 1978.

It is also apparent in Fig. 35 that the sample catches of maturing kokanee (> 300 mm) increased during late fall 1977. Until then, the 1977 catches had been relatively small and comparable to those obtained in 1976. This was anticipated in view of previous sampling of immatures which indicated similar population sizes of the 2 yr. The increased catches were unusual because they occurred during spawning when mature kokanee normally concentrate along the shoreline. While their identity was unknown, it seems possible that they may have been individuals which spent considerable time in an unsuccessful attempt to pass the barrier net, and when irrigation flow ceased, were forced to recirculate in Banks Lake in a belated attempt to find suitable spawning sites.

6.2.6.2 Lake Whitefish. Gillnet catches of lake whitefish have shown a general decline since 1974 (Fig. 36). Generally, the largest catches have occurred at transect 4. Offshore catches of lake whitefish decreased in midsummer during most years when adults estivated in the metalimnion of the deepest part of the lake (Devil's Hole, near station 3)

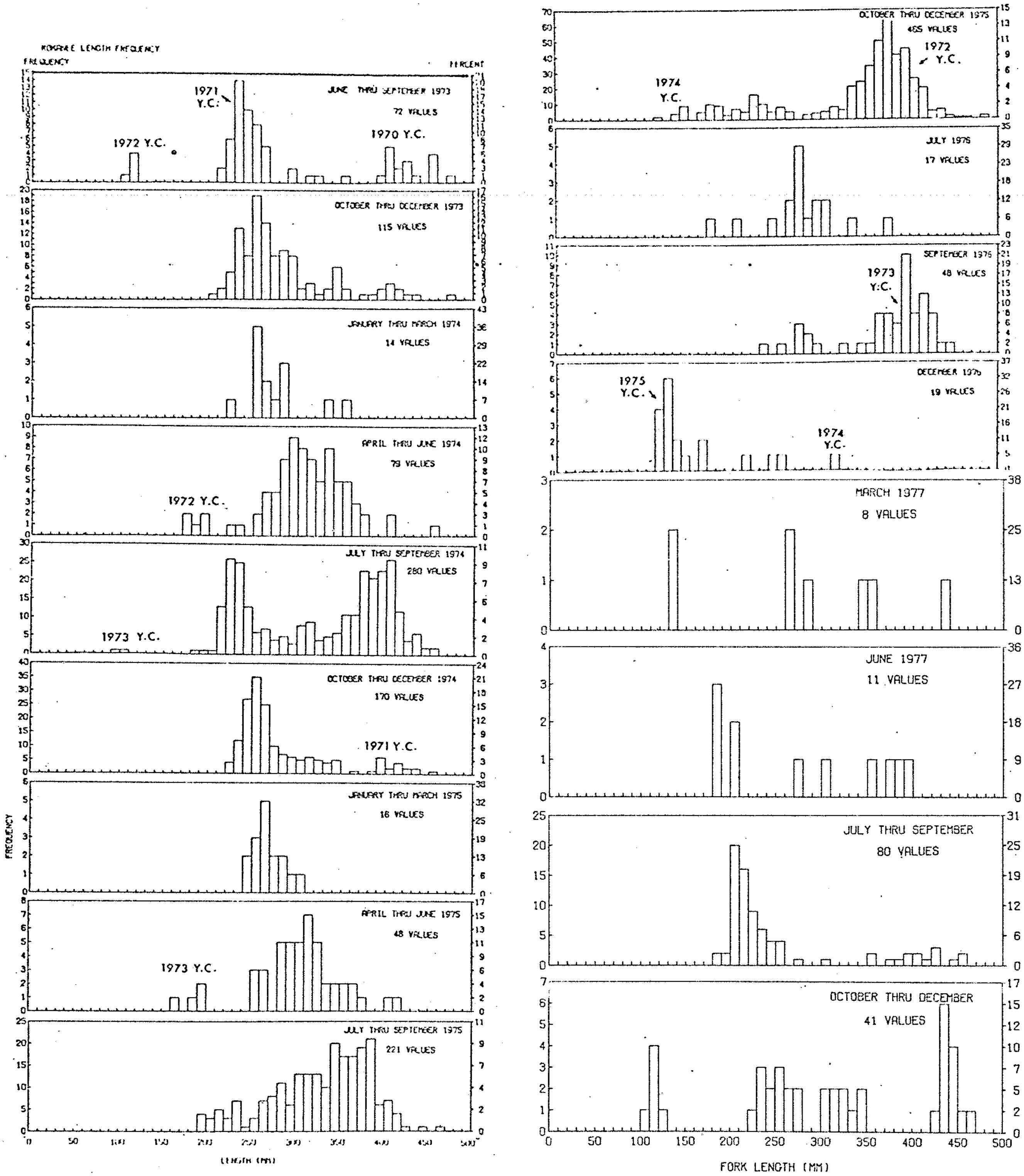


Fig. 34. Length distribution and year class of kokanee caught in monthly and quarterly gillnet samples from 1973 to 1977 grouped by quarter.

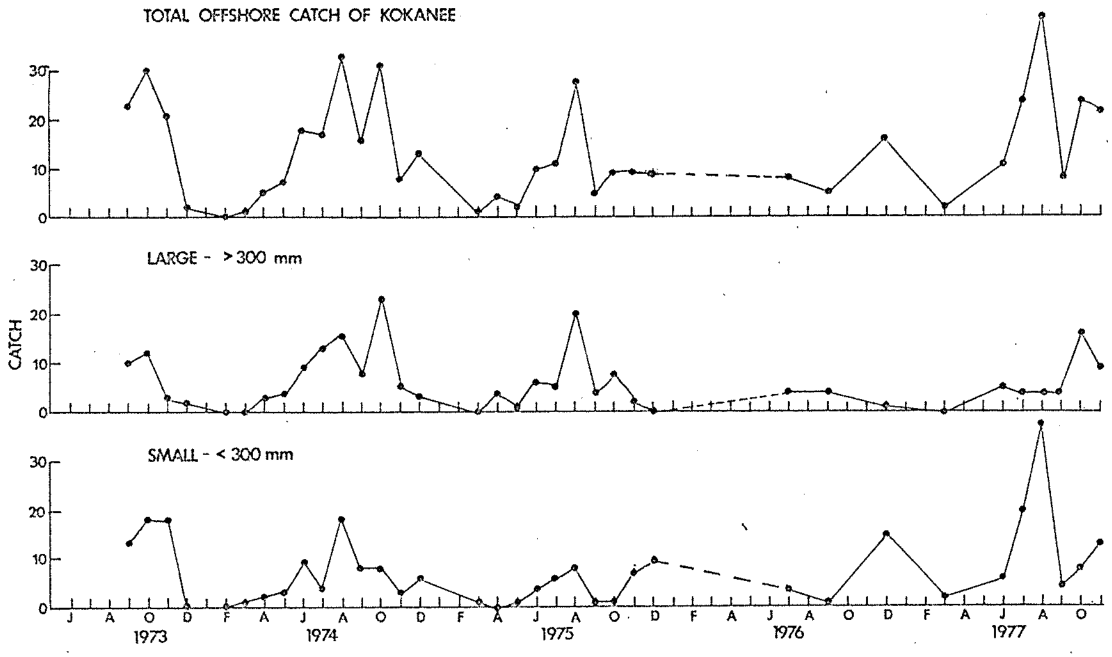


Fig. 35. Total offshore gillnet catch of kokanee salmon, representing combined catches from two days' sampling at surface and bottom at Stations 4, 5 and 6.

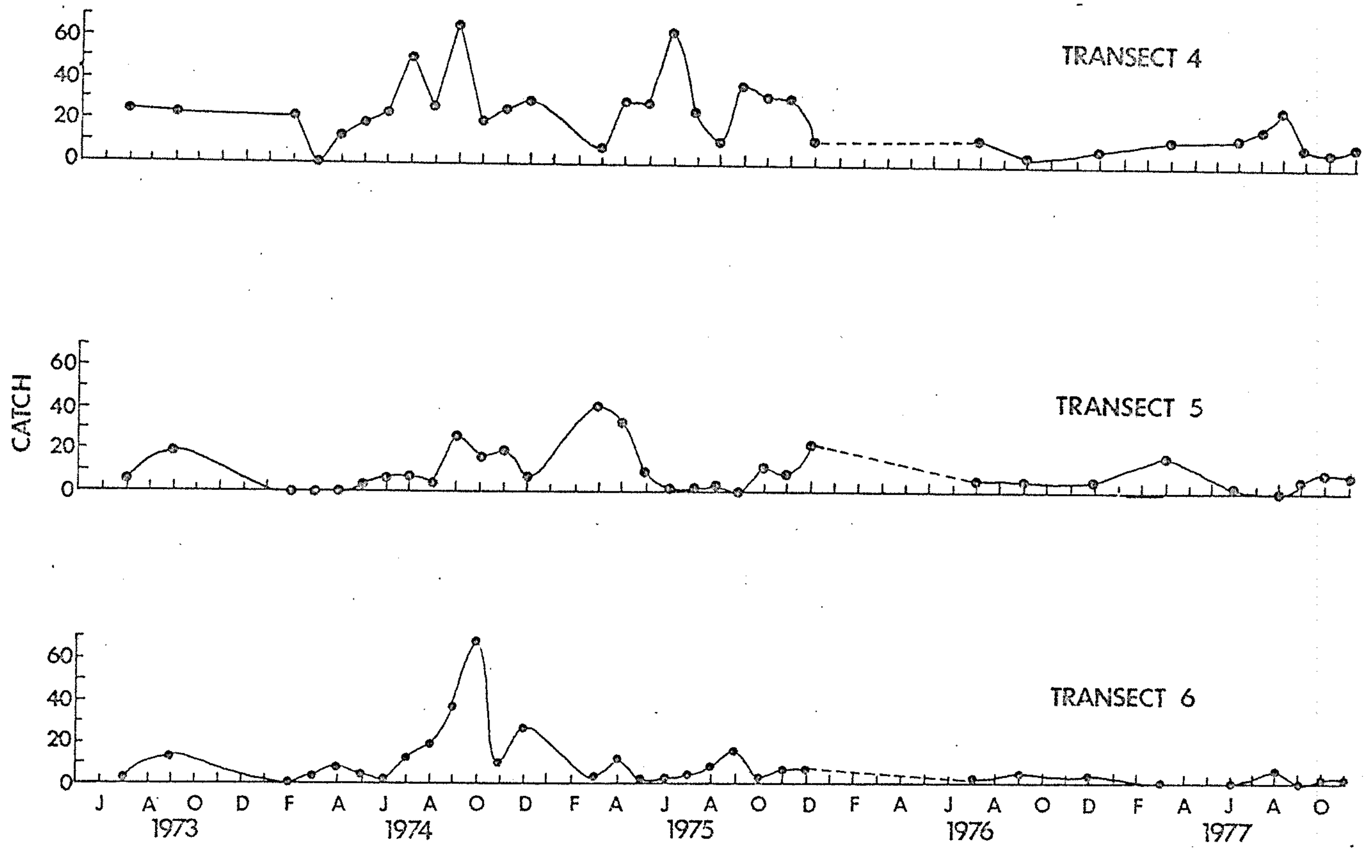


Fig. 36. Horizontal distribution of lake whitefish. Each point represents the catch from three 24-hr horizontal variable-mesh gillnet sets: 2 on the bottom and 2 on the surface.

when epilimnetic water temperatures exceeded 18° C throughout the remainder of the lake (Stober et al. 1977).

Length frequencies indicated that the larger gillnet catches in 1974 and 1975 resulted from the recruitment of the large 1974 year class to the sample gear (Fig. 37).

Abundance of large lake whitefish (> 400 mm) has remained relatively stable since 1973 (Fig. 38). The decline of small fish (< 400 mm) in the catch since 1974 was attributed to the fact that only one strong year class in the gillnet catch began in summer 1974 and numbers declined due to mortality until 1976 when average size approached 400 mm.

6.2.6.3 Yellow Perch. Yellow perch abundance, as measured by gillnet catches at transects 4, 5, and 6, declined in 1976 and 1977 (Fig. 39). This decline may have been partially the result of reduced recruitment of the 1973 and 1974 year classes due to dessication of incubation habitat in the spring of 1973 and 1974 (Stober et al. 1977).

A comparison of length-frequency distributions over the period 1973 to 1974 (Fig. 40) indicated a decline in the catch of larger individuals (> 200 mm) during 1976 and 1977. Generally, a comparison of length-frequency distributions would show growth increment of the year classes with time, however, at least two factors, sex and location of capture were known to have introduced wide variability into the samples and thereby masked size increment due to growth (Stober et al. 1977).

In summary, the relative abundance of kokanee, lake whitefish and yellow perch populations in Banks Lake have been monitored by means of gillnet sampling since 1973. Kokanee year-class strength has fluctuated seasonally and annually over the period 1973 to 1977. The 1971, 1972 and 1976 year classes were relatively strong, while the 1970, 1973 and 1974 year classes were relatively weak (year class identified by year of fry emergence). These fluctuations resulted in poor kokanee sport fishing in 1976 and 1977, however, recent samples indicate an increase in abudance of age II kokanee suggesting an improvement in the 1978 sport fishery.

Gillnet catches of lake whitefish have shown a general decline since 1974, primarily due to lack of subsequent recruitment of an abundant year class. Catches of large lake whitefish have not shown as much

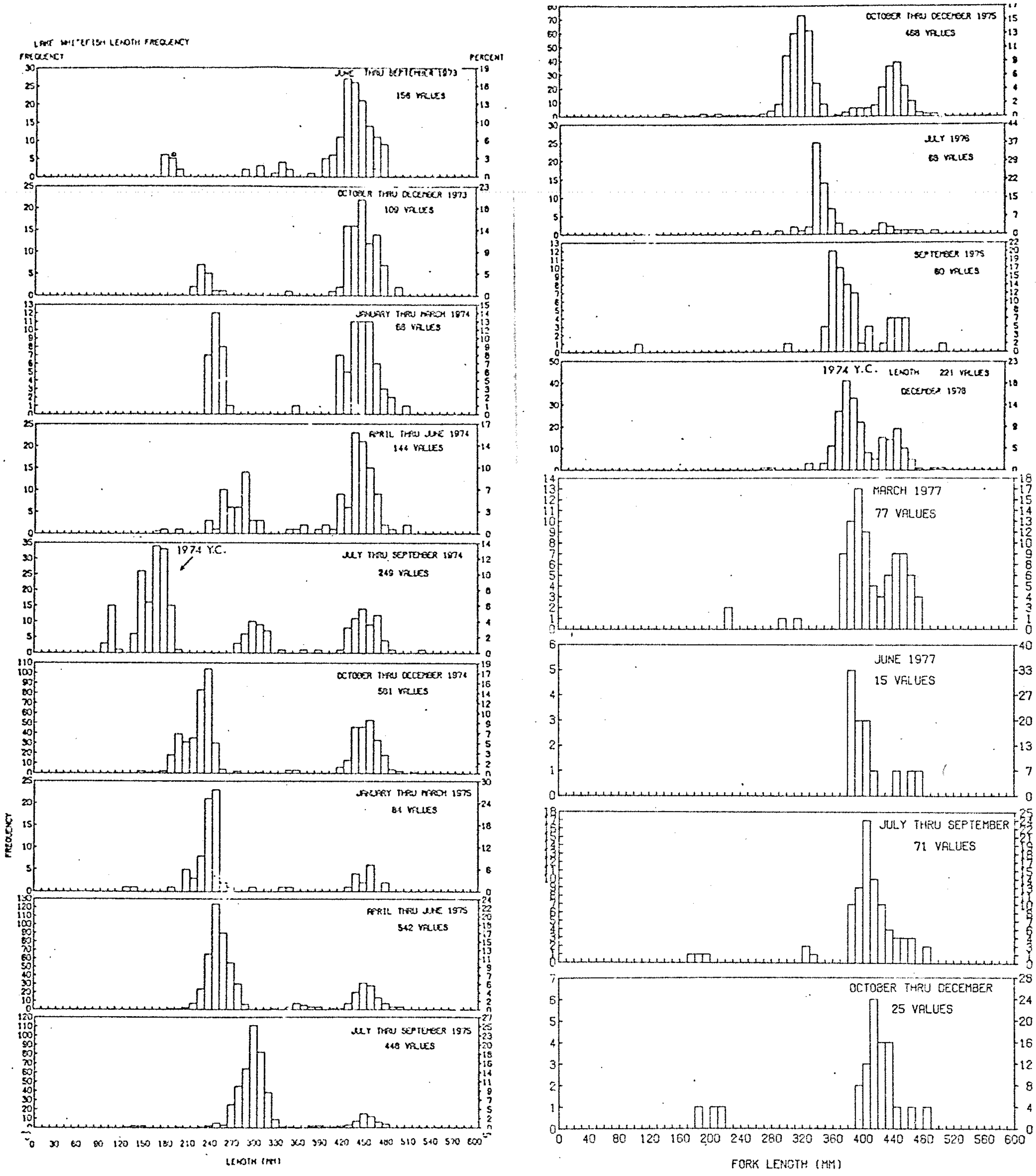


Fig. 37. Length distribution and year class of lake whitefish caught in monthly and quarterly gillnet samples from 1973 to 1977 grouped by quarter.

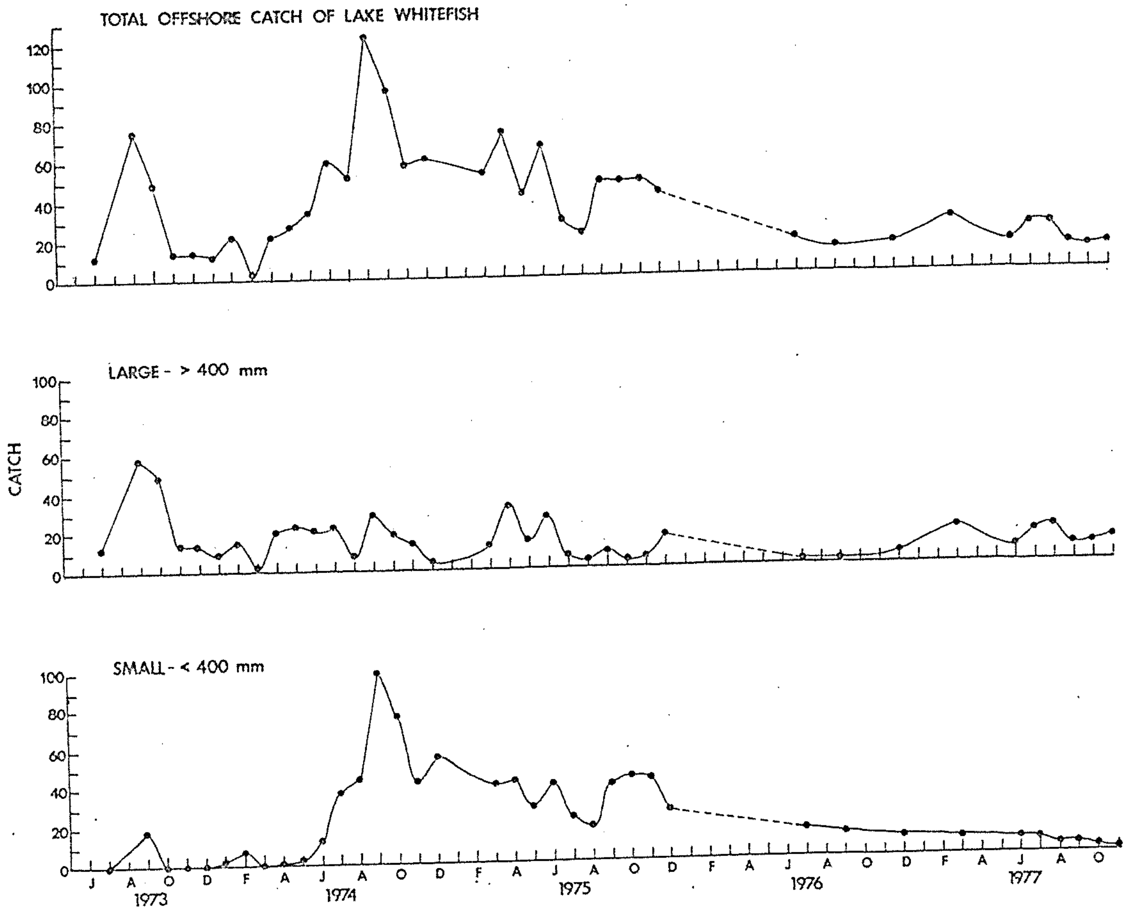


Fig. 38. Total offshore gillnet catch of lake whitefish, representing combined catches from two days' sampling at surface and bottom at Stations 4, 5 and 6.

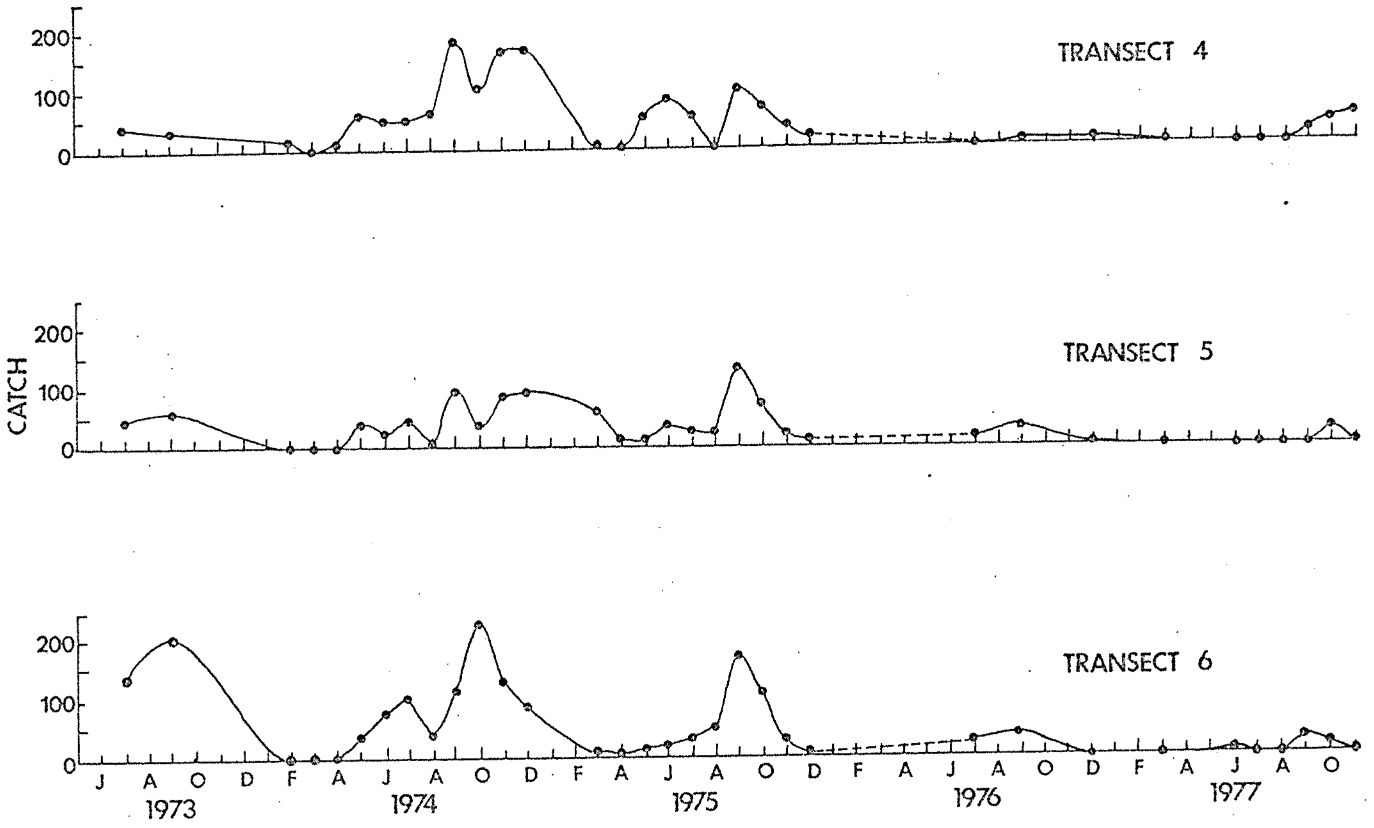


Fig. 39. Horizontal distribution of yellow perch. Each point represents the catch from three 24-hr horizontal variable-mesh gillnet sets: 2 on the bottom and 2 on the surface.

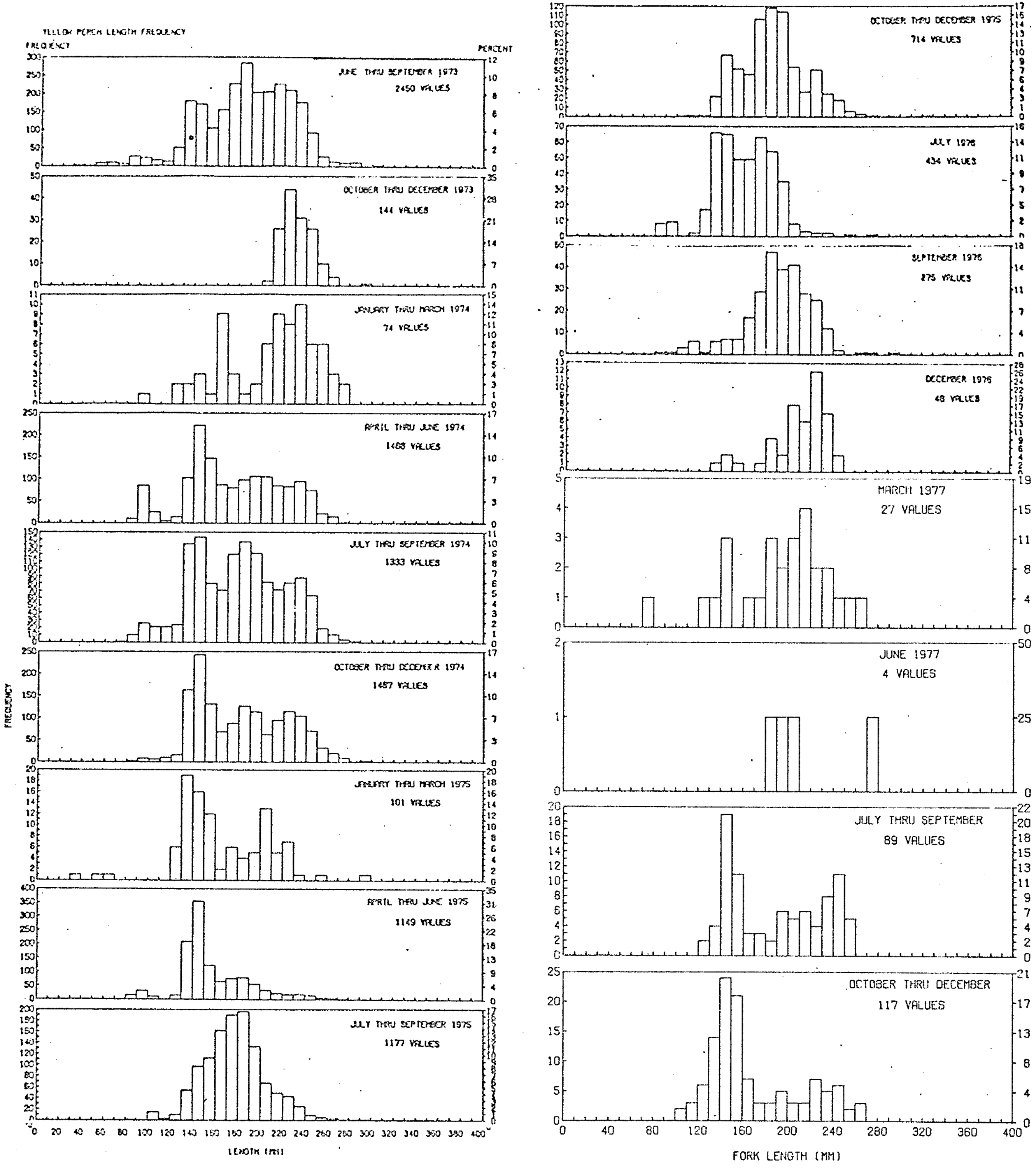


Fig. 40. Length distribution and year class of yellow perch caught in monthly and quarterly gillnet sampling from 1973 to 1977.

decline as catches of small individuals. Yellow perch abundance declined in 1976 and 1977, probably partially due to reduced recruitment of the 1973 and 1974 year classes.

6.2.7 Creel Census

A limited creel census to determine sport fishing effort and catch, specifically for kokanee, was conducted in late summer and fall 1977. The study was limited in scope because it was conducted before and after regular working hours. The primary goal was to determine angler CPUE in a year with a low population of age III kokanee (1977) which could be compared to the 1975 creel census.

The census results were based on boat counts on 66 occasions between August 9 and October 23, 1977, and on returns of 68 questionnaires representing 171 anglers who expended 1,246 angler-hr.

The 1977 weekday boat counts declined steadily during the census period from an average of 17 in early August to 0.1 for the month of October. The angler-effort for the south end of Banks Lake for the period August through October was 65 percent less in 1977 than in 1975 (Table 6). The kokanee catch per angler/hr was poor in 1977, ranging from 0.1 in late August to 0.02 in October. During a corresponding period in 1975, the kokanee catch per angler/hr was 5.6 times greater.

The kokanee sport fishery in 1977 was very poor as recounted by anglers during interviews and in the questionnaires. Some 68 percent of the creel census questionnaires returned contained a comment regarding the poor fishing. Many comments also referred to poor fishing in 1976.

The kokanee sport fishery depends primarily on age III fish, although immature age II fish are also creeled during the summer months (Stober et al. 1977). The 1974 year class (age III in 1977) was very weak prior to barrier net operation and any benefit to the sport fishery could not be detected by this limited study.

6.3 Artificial Spawning Beds

6.3.1 Natural Spawning on Artificial Gravel

Artificial spawning beds described in this section were developed by the Northwest Steelhead and Salmon Council of Trout Unlimited, with

Table 6. Angler-effort for south end of Banks Lake and kokanee catch per unit effort for the period August through October, 1975 and 1977.

	1975		1977	
	Effort south end	Kokanee CPUE	Effort south end	Kokanee CPUE
August	29,900	0.275	13,175	0.105*
September	19,657	0.217	4,177	0.030
October	224	1.519	195	0.022
	49,781	0.263	17,547	0.047

*August 1977 CPUE based on data from 8/27-31 only.

the aid of FRI, University of Washington. This effect was initiated to test the feasibility of establishing artificial spawning beds in Banks Lake below the level of minimum drawdown. Maintaining a stable, abundant kokanee population in the lake which would be unaffected by drawdown was the principal objective of the test. It has been found that lowering the lake level during late winter and early spring for irrigation causes lethal exposure of a portion of the lakeshore eggs and larvae. Most kokanee spawning occurs in a depth range of 1 to 8 m below full pool, since suitable spawning substrate exists in only limited amounts at deeper depths. In the future, spring drawdown will have an increasingly adverse effect on stock stability as the magnitude of drawdown increases with increasing irrigation demand. With the eventual doubling of irrigation flow and increased drawdown of the lake level, egg exposure will increase, possibly resulting in severe reductions in fry survival such as that seen in the 1973 and 1974 year classes (Stober et al. 1977). However, if fish can be induced to spawn at deeper depths, this effect may be mitigated.

Artificial spawning beds may be one means of inducing spawning at greater depth. The beds may be utilized to attract spawning fish, or they may be planted with eggs for the development of a spawning stock which would return to the same bed to spawn annually. If artificial spawning beds were successful, self-sustaining populations of kokanee may be developed which would be unaffected by operational changes in lake level.

The beds were placed at a depth below that of maximum drawdown and both received 38.2 m^3 (50 yd^3) of gravel distributed in a 10.2-cm (4-inch) to 15.2-cm (5-inch) layer. The gravel was selected so that it was large enough to allow adequate interstitial water movement and small enough for the fish to excavate.

There are a number of factors which can influence the success of the artificial spawning beds. Most obvious among these are: 1) intergravel DO; 2) siltation rate; 3) gravel size; 4) water depth; 5) gravel depth; and 6) egg density. Since each one of these factors is critical to egg survival, a study was initiated to determine their effects on eggs planted in two artificial beds and one gravel incubation box.

Neither artificial bed was utilized by kokanee for spawning. A number of small disturbances were observed on the south bed which may have been caused by kokanee, but no redds were found. The only fish found on the beds were dead (season total: north site, one dead; south site, 27 dead).

6.3.1.1 Gravel Analysis. The gravel placed at the north and south sites and the gravel box was analyzed (Table 7) to determine percent composition by size. Gravel placed at the south site was 49.88 percent in the size range from 6.7-13.2 mm with the next largest component (40.44 percent) ranging from 13.2-26.9 mm. Gravel placed at the north site was composed of 89.04 percent in size range from 13.2-26.9 mm followed by 10.27 percent which ranged from 6.7-13.2 mm. Gravel sizes in the incubation box were 78.68 percent 13.2-26.9 mm and 10.31 percent 6.7-13.2 mm. The percentage of pan silts (< .85 mm) was 1.21 percent or less in all three gravel types utilized.

6.3.1.2 Dissolved Oxygen. Dissolved oxygen concentration was relatively high in the two artificial beds, and the primary spawning area. The lowest mean DO of the two sampling periods was 9.2 ppm at the north site and the highest was 11.6 ppm found at the south site. There was little variation between the artificial sites, and the primary spawning area which averaged 11.2 ppm and 10.7 ppm, respectively, for the two sampling periods (Table 8). Little variation occurred between intergravel DO measurements and ambient DO measurements taken above the substrate.

6.3.1.3 Sedimentation Rate. The mean sedimentation rate at the north site (.071 mm/day) was greater than that at the south site (.057 mm/day), and both were greater than the mean rate at the primary spawning area (.016 mm/day) (Table 8). Divers observed a thin layer of silt accumulating on the surface of the north bed with less on the south bed, while the primary spawning area remained bare. However, 1 month after the silt jars were removed, both artificial sites were bare of silt. The only silt observed during egg planting was within the beds, and this amount appeared to be small and of little consequence to survival of the planted eggs.

Table 7. Percent size composition by volume of gravel placed at two artificial gravel beds and one gravel box in Banks Lake, 1977.

Gravel Size (mm)	Percent Composition Gravel Box	South Site	North Site
>26.9	8.77	0.00	0.00
13.2 - 26.9	78.68	40.44	89.04
6.7 - 13.2	10.31	49.88	10.27
3.35 - 6.7	1.45	7.48	.30
1.70 - 3.35	.04	.47	0.00
.85 - 1.70	.02	.61	0.00
pansilts (<.85)	.72	1.21	.38
Total sample volume (ml)	4560	2139	3650

Table 8. Measurements of dissolved oxygen and sedimentation rates in artificial gravel beds and primary spawning site.

		Dissolved Oxygen (ppm)			
		Mean	Range		Above
Bed	Date	D.O.	Low	High	Substrate
South	11/17	9.8	8.8	10.6	10.1
North	11/17	10.0	9.8	10.1	10.0
Primary	11/17	11.2	10.6	12.3	10.6
South	11/30	11.6	11.0	12.0	11.8
North	11/29	9.2	7.6	11.3	11.6
Primary	11/30	10.7	10.0	11.1	11.1*

	Sedimentation Rates (mm/day)		
	Mean	Range	
Bed	Rate	Low	High
South	.057	.055	.060
North	.071	.066	.070
Primary	.016	.004	.026

*Mean of two samples.

6.3.2 Planting of Eyed Eggs

Natural spawning did not occur on the artificial beds; therefore eyed eggs were planted in an effort to establish a spawning population which may utilize the beds in the future. If studies continue, the survival of the planted eggs could be monitored to determine the potential of the gravel beds as an incubation medium and to test the success of these plants.

Measurements which were made of DO and siltation rates in the gravel beds determined that the intergravel DO concentrations before egg planting compared favorably with optimum conditions, as described in the literature (Koski 1975). Some of the redds observed in the primary spawning area were dug in cobble at least twice the size of the gravel in the artificial bed. Therefore, the natural spawning potential of the artificial bed should be improved by the composition selected.

Siltation is of greatest concern since silt can filter down into the gravel beds and eventually fill in the interstitial gravel spaces. This would render the beds unsuitable for spawning since it would reduce water movement and the exchange of DO around the eggs. If the north site, south site and primary site accumulated silt at the rates determined in the siltation rate experiment (Table 7), the three sites would accumulate 25.9 mm, 20.8 mm, and 5.8 mm of silt per year, respectively. Such accumulations would render the beds unsuitable in a short time. However, several observations indicated that these rates may not be representative of annual rates. During October 1977, the lake level was dropped 2.7 m (9 ft) to force kokanee spawning at lower elevations. The level was returned to full pool around mid-November. During the period of drawdown, divers observed increased turbidity. The siltation rates on the artificial beds, while high during the period of drawdown, ceased almost entirely after the lake returned to full pool. Thus the drawdown probably caused the sedimentation by exposing lakeshore sediment deposits to wave action. One month after the experiment was concluded, the artificial beds were bare of silt, indicating a sharp decline in the siltation rates. Reasons for the disappearance of the silt deposits are unknown.

Sampling with emergent fry traps will be used to determine whether production can be obtained from the beds. The effects of egg plants at various gravel depths on hatching success could be determined. If monitored through emergence, the two densities of eggs planted in the gravel box would provide preliminary information on the effect of egg density on survival.

The absence of kokanee spawners on the artificial beds does not necessarily indicate that such beds will not be utilized. Reasons why spawners were not attracted to spawn are not known, but can be inferred based on well-established behavior patterns which are true for all salmonid species. The instinct of salmon to return to natal spawning gravel is well documented. Stream-spawning salmon return to a particular tributary and even to a particular reach within the tributary with a remarkable degree of reliability. The 1977 kokanee spawners resulted from lakeshore spawning by parent stock in 1973. Thus, it is likely that the 1977 spawners were returning to specific locations from which they emerged as fry. The introduction of gravel beds of different chemical composition just prior to spawning may not have allowed sufficient time for straying to occur. The beds may well attract kokanee spawners in future years when larger spawning populations result in increased straying to the artificial beds, or after the beds have had sufficient time to age in the lake water. It may be that each bed will require artificial seeding for 3 yr following placement of the gravel in the lake to establish a subpopulation which returns to each bed to spawn.

7.0 SUMMARY AND CONCLUSIONS

A net barrier was established in the southeast sector of Banks Lake to reduce the entrainment of mature kokanee into the main irrigation canal. The area of the outlet was enclosed by three nets totaling 1,365 m (4,200 ft) in length. The net, constructed of 83-mm (3 1/4-inch) stretched-measure dacron, was chosen because it retained salmonids greater than 25 cm, presented low resistance to current and was less encumbered by fouling when compared with smaller mesh. The nets were installed on July 9 and maintained until termination of the irrigation season on October 25, 1977.

Maintenance equipment was designed and constructed and included an engine, hydraulic pump, power block and roller, and a high-pressure water pump. This equipment was mounted aboard a small boat-barge combination which traversed the length of the nets during cleaning to remove aquatic weeds and algae with high-pressure water jets. Cleaning intervals were biweekly through the maximum summer growth period to control fouling and maintain net visibility. Maximum irrigation flow of 223.7 m^3/sec (7,900 cfs) resulted in neglibible force on the net. Calculation of the forces due to increase in the irrigation canal discharge and reduction of the lake level indicated the barrier net can be operated under conditions more rigorous than those encountered in 1977.

The escapement of fishes past the barrier net was measured directly by sampling irrigation canal entrainment, using methods developed during 1975 and 1976. The estimated kokanee entrainment rates for the period from July 9 to October 25, 1975, 1976 and 1977 were 100,908, 32,119 and 7,031, respectively. Maximum entrainment occurred later in 1977 than during the previous 2 yr, indicating that the barrier may have delayed escapement. Some escapement in 1977 was expected due to the difficulty in fitting the south net to irregularities in bottom contour. This problem was not encountered with the east net. A breakdown of the cleaning gear in early September on the south net allowed an increase in escapement. The screening efficiency of the south net could be improved with further modification.

An estimated 96 lake whitefish were entrained after July 9, 1977, compared to 11,825 during 1975, and 4,998 in 1976. During the 4 weeks preceding installation of the barrier net, the entrainment of lake whitefish was 1,016. These data demonstrate that lake whitefish were effectively screened.

Yellow perch were not screened by the barrier net due to their small size. Perch constituted 55.9 percent of the total number of fish entrained into the irrigation canal in 1977. SCUBA observations confirmed that schools of small perch near the barrier net passed freely through the mesh. The net was constructed to allow passage of yellow perch to avoid potential gilling of large numbers. The entrainment of all species combined was lowest in 1977 at 39,392. Comparable entrainment for 1975 and 1976 was 149,664 and 53,880 fish, respectively.

The number of kokanee spawning in 1977 was monitored weekly from mid-October to the end of November to estimate the population size and for comparison with 1975 and 1976. About half the spawning occurred in one area along the southwest shoreline and at three other smaller areas. Most spawning occurred from 2 to 5 m subsurface and was observed as deep as 20 m. Spawner counts, from a glass-bottomed pram, were two to three times higher than in 1976. Spawner counts using SCUBA were at least 4.5 times higher than pram counts and were considered to be close to the actual number. The maximum number of kokanee on spawning grounds at the peak of the season in 1977 was estimated to be 1,000, a 6.7-fold increase over 1976. The total kokanee spawning population was estimated to be 1,880 in 1977.

An estimated deposition of 1,033,812 eggs in 1977 compared favorably with the estimated 84,135 eggs from 153 kokanee spawners during 1976. This indicates the net was successful in retaining spawners and increasing the potential recovery of the weak 1977 year class. The mature kokanee population of 8,911 in 1977, based on entrainment catches and spawner counts, was the lowest of the 3 yr observed. This compares with the combined estimate for 1976 of 32,272. Operation of the barrier net during 1977 is considered to have retained about 21 percent of the population, while in 1976 without a barrier net, only about 0.5 percent of the kokanee population remained in the lake. These estimates of retention are not strictly comparable because the total population in 1977 was only about one-third as large as that in 1976.

The gilling rates of fishes in the barrier net were monitored to determine whether gilling loss significantly impacted the populations. The number of gilled fish was insignificant relative to the numbers lost by entrainment. A total of 312 fish was gilled during 4 months of net operation. Included were 194 kokanee, 26 chinook and 24 Rocky Mountain whitefish. Most fish were gilled within 3 m of the surface where currents were strongest.

Gillnet and acoustical sampling adjacent to both sides of the barrier net was conducted to determine if differences in abundance and size composition occurred. These data indicated that no significant differences existed except for lake whitefish which were effectively screened. Acoustical surveys showed a consistent increase in fish targets immediately outside the south net during the night, but this was not evident during the day. This suggested that the barrier was most effective during the night when the gaps under the south net were less visible. Gillnet and acoustical sampling were ineffective in assessing the efficiency of the barrier net because these techniques do not account for the behavioral response of the fish to the barrier. These techniques would require nearly complete barrier net efficiency or as an aid to sampling a known marked fish population.

Baseline monitoring with gillnets in the main lake basin showed an increase in the abundance of age II kokanee, indicating that fishing should improve in 1978.

A creel census conducted during late summer was a basis for comparing the kokanee sport catch per effort during 1977, with census data obtained in 1975. The catch per angler-hr ranged from 0.1 in late August to 0.02 in October. During a corresponding period in 1975, the kokanee catch per angler-hr was 5.6 times greater. The angler effort in 1977 was approximately one-third of the angler effort in 1975.

Whether the barrier net benefited the sport fishery in 1977 is unknown. Seasonal distribution of kokanee from gillnet sampling conducted since 1973 provides some evidence that the likelihood of screened kokanee reentering the sport fishery is greatest during the spring months (March through June) when the kokanee are feeding actively and are distributed randomly throughout the south pool of Banks Lake. Random movement should tend to return many fish to the fishery, particularly during May and June when peak fishing effort and catching success occurs.

Two artificial spawning beds were placed in the lake during fall 1977 to test the feasibility of creating kokanee spawning habitat below the level of maximum lake drawdown. Each bed was composed of 38.2 m^3 of washed, graded gravel distributed in a layer averaging 25 cm deep and located about 8 m subsurface. Natural spawning did not occur on the beds this year, however, spawners may be attracted during subsequent years when larger spawning populations exist. Intergravel DO was measured in the beds and found to be adequate through December 1977. An experiment to test the survival of eyed kokanee eggs in the beds was initiated by planting 100,320 eyed eggs. Fry sampling on the artificial beds as well as on the natural spawning areas will determine the potential of the artificial spawning areas.

The use of a barrier net to reduce the loss of kokanee brood stock from the lake and the establishment of spawning and incubation habitat below the level of maximum lake drawdown could ensure a viable kokanee fishery sustained by a wild kokanee population. Management of the fishery in this manner would maintain the high quality of the existing fishery at the lowest cost and may isolate the wild kokanee population from the annual impacts imposed by irrigation and pumped-storage power generation.

8.0 RECOMMENDATIONS

1. Future operation of the barrier net should be accompanied by evaluation measures until the screening efficiency under seasonal drafting rates, lake level combinations, weather variations and increased kokanee abundance prove the system reliable. Minimum evaluation should include irrigation canal entrainment sampling, weekly SCUBA inspection of the barrier, and indexing of the spawning population.

2. The screening efficiency of the south net should be improved by addition of a curtain of additional netting along the lead line to insure a better fit with the irregular lake bottom.

3. The south net should be relocated between Dry Falls Dam and the large island to bypass the steep, irregular bottom contour encountered at the present site. This would simplify the installation by elimination of the third net.

4. The safety and efficiency of the cleaning operation would be facilitated by replacing the present vessel with a barge measuring approximately 4 x 8 m; modification of the bow roller to prevent binding of the corks during net hauling; and a series of small diameter rollers, lattice or screen should be installed on the deck to improve the effectiveness of the spray in removing aquatic weeds.

5. The following items are necessary to improve the management of the kokanee fishery: determine the portion of screened kokanee which reenter the sport fishery; determine the portion of screened kokanee which spawn effectively in the lake; determine the general circulation pattern and response to irrigation flow of kokanee in the south pool during the irrigation season; determine the diel and seasonal behavior of kokanee encountering the net barrier.

6. The survival of kokanee eggs planted in the artificial beds and of naturally spawned eggs should be determined by trapping emergent fry during March, April and May 1978. These data would be of major importance to the cooperative management of both fish and water in Banks Lake.

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10.0 APPENDIX

A comprehensive study of the limnology of Banks Lake was conducted from July 1973 through November 1976 as reported in Stober et al. (1977). Monthly monitoring of selected physical and chemical parameters was continued from April through October of the present study.

Measurements of temperature, conductivity, DO, and pH were made, in situ, at stations 1-6 by means of a Hydrolab Model 6D.

Appendix Table 1. Temperature in degrees Celsius for selected depth strata for Banks Lake from April through October 1977.

Station	Depth Strata	April	May	June	July	August	Sept	Oct
1	0	7.0	11.2	12.5	17.9	19.6	18.6	13.5
	4	6.5	10.1	11.4	17.3	18.6	18.5	13.5
	8	6.5	10.0	11.2	17.2	18.5	18.5	13.5
	12	6.5	10.0	11.1	17.0	18.5	18.5	13.5
	16	6.5	+	+	+	18.4	18.5	13.5
2	0	8.0	12.5	16.0	20.0	23.5	18.5	12.0
	4	7.5	11.0	13.5	17.8	19.5	18.4	12.0
	8	7.0	10.9	13.0	17.5	18.5	18.4	12.0
	12	7.0	10.9	12.8	17.1	18.4	17.9	12.0
	16	+	+	+	+	18.4	17.9	12.0
3	0	9.0	13.5	17.9	20.6	23.9	18.5	12.0
	4	8.5	12.0	14.5	19.1	20.0	18.4	11.6
	8	8.2	11.5	12.9	18.0	18.8	18.3	11.5
	12	7.3	11.0	12.7	17.2	17.6	18.0	11.5
	16	+	+	12.7	+	17.6	18.0	11.5
4	0	8.5	13.5	17.9	19.8	23.1	18.0	+
	4	8.2	12.5	15.9	18.9	21.9	17.7	+
	8	8.0	11.5	13.8	18.5	19.0	17.5	+
	12	8.0	10.6	12.6	17.8	18.0	17.5	+
	16	8.0	9.7	12.3	15.0	16.5	17.5	+
5	0	+	+	15.5	17.5	21.8	17.6	10.5
	4	+	+	15.5	17.0	21.2	17.4	10.5
	8	+	+	14.9	16.5	20.0	17.3	10.5
	12	+	+	14.9	15.6	18.0	17.3	10.3
	16	+	+	14.0	15.1	16.6	17.3	10.3
6	0	6.9	11.4	16.0	17.4	23.8	17.3	10.5
	4	6.9	11.3	15.8	16.9	23.5	17.0	10.8
	8	6.9	11.0	15.8	16.9	21.7	17.0	10.8
	12	6.9	10.7	15.6	6.8	18.6	17.0	10.8
	16	6.9	10.6	13.5	16.5	17.5	17.0	10.8

+ = no samples taken

Appendix Table 2. Average percent dissolved oxygen saturation by depth strata for Banks Lake from April through October 1977.

Station	Depth Strata	April	May	June	July	August	Sept	Oct	Mean for each depth strata
1	*0-6	109	108	103	108	103	109	103	106
	**B4	110	111	108	106	100	107	101	106
	***W.C.	109	109	105	107	101	108	102	106
2	0-6	115	112	122	122	118	116	115	117
	B4	116	113	111	110	101	101	108	109
	W.C.	115	113	117	117	109	109	112	113
3	0-6	117	115	122	116	117	111	119	117
	B4	113	115	107	107	94	103	111	107
	W.C.	115	115	115	112	107	107	116	112
4	0-6	110	111	113	111	114	104	+	111
	B4	110	103	100	69	57	102	+	90
	W.C.	110	107	106	98	90	103	+	102
5	0-6	+	+	114	109	106	102	116	109
	B4	+	+	95	82	56	99	106	88
	W.C.	+	+	107	97	85	100	111	100
6	0-6	110	112	113	110	110	105	113	110
	B4	106	105	90	88	63	98	106	94
	W.C.	108	108	105	103	90	102	100	104
High		122	117	131	127	127	117	129	-
Low		106	89	80	57	40	91	101	-
Monthly mean	0-6	112	112	115	113	111	108	113	112
	B4	111	109	102	94	79	102	106	100
	W.C.	111	110	109	106	97	105	110	107

*0-6 = mean of surface to 6 meters
**B4 = mean of bottom 4 meters
***W.C. = mean of water column
\+ = no samples taken

Appendix Table 3. Average pH by depth strata in Banks Lake from April through October 1977.

Station	Depth Strata	April	May	June	July	August	Sept	Oct	Mean for each depth strata
1	*0-6	11.3	9.0	8.6	8.3	8.6	8.4	8.1	8.9
	**B4	10.0	8.6	8.2	8.2	8.3	8.3	8.1	8.5
	***W.C.	10.9	8.8	8.4	8.3	8.5	8.3	8.1	8.8
2	0-6	8.8	8.6	8.7	8.7	8.9	8.7	8.7	8.7
	B4	8.7	8.3	8.2	8.4	8.4	8.4	8.4	8.4
		8.7	8.4	8.5	8.6	8.7	8.5	8.6	8.6
3	0-6	8.9	8.7	8.6	8.7	8.9	8.7	8.5	8.7
	B4	8.7	8.3	8.2	8.3	8.5	8.5	8.3	8.4
	W.C.	8.8	8.5	8.4	8.5	8.7	8.6	8.4	8.6
4	0-6	9.2	8.8	8.7	8.4	9.0	8.5	+	8.8
	B4	8.7	8.1	8.0	7.9	8.2	8.3	+	8.2
	W.C.	8.9	8.5	8.3	8.2	8.6	8.4	+	8.5
5	0-6	+	+	8.7	8.5	8.8	8.4	8.5	8.6
	B4	+	+	8.1	8.1	8.1	8.2	8.0	8.1
	W.C.	+	+	8.4	8.3	8.4	8.3	8.3	8.3
6	0-6	8.7	8.5	8.7	8.5	8.8	8.4	8.8	8.6
	B4	8.5	8.1	8.1	8.2	8.2	8.1	8.2	8.2
	W.C.	8.6	8.3	8.4	8.3	8.5	8.3	8.5	8.4
High		11.4	9.1	8.9	8.8	9.2	8.8	9.1	-
Low		8.5	8.1	8.0	7.8	8.1	8.1	8.0	-
Monthly mean for each depth strata	0-6	9.4	8.7	8.7	8.5	8.8	8.5	8.5	8.7
	B4	8.9	8.3	8.1	8.2	8.3	8.3	8.2	8.3
	W.C.	9.2	8.5	8.4	8.4	8.6	8.4	8.4	8.6

*0-6 = mean of surface to 6 meters
**B4 = mean of bottom 4 meters
***W.C. = mean of water column
\+ = no samples taken

Appendix Table 4. Mean conductivity (μmhos/cm^2) for Banks Lake for 1977.

	Stations						
	1	2	3	4	5	6	Mean
April	147	148	139	124	+	119	113
May	115	109	121	116	+	118	116
June	110	110	112	120	123	121	116
July	127	126	125	140	134	130	130
August	120	119	123	128	133	133	126
Sept	111	110	110	112	114	114	112
Oct	115	118	117	+	113	112	115
High	147	148	139	140	133	133	-
Low	110	109	110	112	113	112	-
Mean	121	120	121	123	123	121	122

+ = no samples taken

Appendix Table 5. Acoustic target densities by target size and depth.

			Target Density (per 1000 m^3) and Sample Volume (m^3)								
			Surface to 30 ft (9.1 m)			30 ft (9.1 m) to 60 ft (18.3 m)			>60 ft (18.3 m)		
Date	Diel Period	Transect No.	Large	Small	Volume m^3	Large	Small	Volume m^3	Large	Small	Volume m^3
July	Day	1	0	1.01	3950	0	0.48	2112			0
		2	0	0.33	3073	0.91	0	2189			0
		3	0.28	0.83	3596	0	0	1816			0
		4	0	0	195	0.26	0.80	3742			0
		5	0	0	1032	0.09	0.09	34234			0
		6	1.37	1.37	731	0.14	0.09	21089			0
		7	0	0	2802	0.10	0.07	29933			0
		8	0.48	1.45	4127			0			0
		9	0	0.70	4285			0			0
		10	0.80	0.53	3746			0			0
		11	0	0	795	0.08	0	12955	0.05	0.01	95131
	Night	1	0.27	0	3686	0	0	1795			
		2	0	0	2927	0	0	1724			
		3	0	0	4001	0	0	2252			
		4	0	0	242	0	0.30	3377			
		5	0	0	586	0	0.05	18854			
		6	1.75	0	1140	0.20	0	14843			
		7	0	0	599	0.13	0.13	22877			
		8	0	0	3746			0			
		9	0	0	4239			0			
		10	0	0	4239			0			
		11	0.53	0.27	3746	0.12	0	41666	0.04	0	83047

Appendix Table 5. continued

			Target Density (per 1000 m^3) and Sample Volume (m^3)								
			Surface to 30 ft (9.1 m)			30 ft (9.1 m) to 60 ft (18.3 m)			>60 ft (18.3 m)		
Date	Dicl Period	Transect No.	Large	Small	Volume m^3	Large	Small	Volume m^3	Large	Small	Volume m^3
Aug	Day	1	0	0	3393	0	0	1478			
		2	0	0	2007	0.27	0	14710			
		3	0	1.00	997	0.14	0.14	14074			
		4	0	0	640	1.02	0.61	4885			
		5	0.56	0.56	1797	0.06	0	34078			
		6	0	0	1325	0.11	0.03	37055			
		7	0	0	2738	0.04	0	22527			
		8	0	0	3174			0			
		9	0	0.46	4345			0			
		10	0	0	5456			0			
		11	0	0.46	2141	0.15	0	13527	0.01	0	80179
	Night	1	0.35	0.69	2875	0.98	0	3076			
		2	0.38	0	2632	0	0	1737			
		3	0	0	1810	0.11	0	8728			
		4	0	0	698	0.20	0	5120			
		5	0	.50	1994	0.22	0.04	22593			
		6	0.74	0	2698	0	0	24437			
		7	0.12	0.25	8143	0	0.13	7898			
		8	0	0.62	3211			0			
		9	0.40	0.20	4982			0			
		10	0	0	5619			0			
		11	0	0	2610	0	0	8673	0.33	0.02	85498

Appendix Table 5. continued

Date	Diel Period	Transect No.	Surface to 30 ft (9.1 m) Large	Surface to 30 ft (9.1 m) Small	Surface to 30 ft (9.1 m) Volume m^3	30 ft (9.1 m) to 60 ft (18.3 m) Large	30 ft (9.1 m) to 60 ft (18.3 m) Small	30 ft (9.1 m) to 60 ft (18.3 m) Volume m^3	>60 ft (18.3 m) Large	>60 ft (18.3 m) Small	>60 ft (18.3 m) Volume m^3
			Target Density (per 1000 m^3) and Sample Volume (m^3)								
Sept	Day	1	2.01	0	1986	0.66	0	1517			
		2	0	0	1882	0	0	1285			
		3	0	0	3405	0.15	0	6784			
		4	0	0	472	1.16	0	3437			
		5	1.02	0	1954	0.34	0.04	26100			
		6	0	0	1263	0.36	0	27863			
		7	0	0	977	0.04	0.12	25298			
		8	0.44	0	2290			0			
		9	0	0	3562			0			
		10	0.25	0.25	3967			0			
		11	0	0	1844	0.23	0.11	8743	0.05	0	77553
	Night	1	0	0.56	1800	0	0	1030			
		2	0	0	2984	0	0	1529			
		3	0	0	2524	0	0	9465			
		4	1.84	0	543	0.19	0	5252			
		5	0	0	1133	0.22	0	27722			
		6	0	0	1308	0.07	0	30357			
		7	0.29	0	6974	0.10	0	31129			
		8	0	0	2190			0			
		9	0	0	3722			0			
		10	1.14	0	3511			0			
		11	0.32	0.32	3091	0.33	0	9040	0.25	0.04	79339

Appendix Table 5. continued

Date	Diel Period	Transect No.	Surface to 30 ft (9.1 m) Large	Surface to 30 ft (9.1 m) Small	Surface to 30 ft (9.1 m) Volume m^3	30 ft (9.1 m) to 60 ft (18.3 m) Large	30 ft (9.1 m) to 60 ft (18.3 m) Small	30 ft (9.1 m) to 60 ft (18.3 m) Volume m^3	>60 ft (18.3 m) Large	>60 ft (18.3 m) Small	>60 ft (18.3 m) Volume m^3
			Target Density (per 1000 m^3) and Sample Volume (m^3)								
Oct	Day	1	0.87	8.75	2286	0	0.78	1277			
		2	1.85	4.17	2158	0	0	1429			
		3	0.70	0.70	4289	0	0	5048			
		4	0	0	556	0.27	0.82	3644			
		5	0	0	1948	0.04	0.32	24810			
		6	0	0.43	2341	0.10	0.10	19285			
		7	0	0	1391	0.11	0.11	26190			
		8	0	0.83	2421			0			
		9	0	0.29	3426			0			
		10	0	0.60	3333			0			
		11	0	0.48	2073	0.31	0.20	9784	0.15	0.06	80681
	Night	1	0	1.67	2399	0.64	0.64	1574			
		2	1.38	0	2907			1608			
		3	0.18	0.18	5713			8092			
		4	0	0	629	0.24	0.48	4203			
		5	0	0	1122	0.11	0.11	28509			
		6	0	1.86	1074	0.06	0.31	31926			
		7	0	0	4144	0.20	0.59	5055			
		8	0	1.57	3181			0			
		9	0.20	0.40	4996			0			
		10	0.23	0.46	4379			0			
		11	0	0.51	1979	0.27	0.54	11201	0.29	0.42	94664