NORTH AMERICAN JOURNAL OF FISHERIES MANAGEMENT

A PUBLICATION OF THE *AMERICAN FISHERIES SOCIETY*

1983

VOLUME 3

NUMBER 4

North American Journal of Fisheries Management 3:331–354, 1983
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Barrier Net to Reduce Entrainment Losses of Adult Kokanee from Banks Lake, Washington[1]

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ABSTRACT

A barrier net 1,341 m long was developed to reduce the entrainment of mature kokanee (*Oncorhynchus nerka*) into the main irrigation canal intake of Banks Lake in Washington. The dacron net was constructed of 83-mm mesh (stretch measure) and relied on the visual avoidance response exhibited by salmonids. The net was hauled by machine and cleaning was done with high-pressure water jets. The screening efficiency of the barrier was evaluated by numerous methods including sampling the fishes entrained in the irrigation canal with large nets, mark and recapture of adult kokanee in the reservoir, estimates of the number of beach spawners, sonic tracking near the barrier, census of the sport fishery, and mortality of kokanee gilled in the barrier. The annual canal entrainment of kokanee declined from an average of 64% before installation of the net to 10% afterwards, based on 4 years of catch data. An estimated 35,391 adult kokanee, based on mark-and-recapture estimates, were retained in the lake during the fall of 1978 when 96% retention of the population was achieved. Sonic-tracked kokanee were turned back by the barrier and, during October, "homed" to beach spawning sites. From a creel census, it was estimated that anglers caught 46,427 kokanee in 1978. The catch of kokanee per angler-hour remained stable at 0.216 while the catch of all other species declined from 0.372 to 0.042 from 1972 to 1978. The barrier net enhanced the sport fishery and the spawning population in the reservoir. The number of kokanee gilled in the barrier net was small relative to the population retained, and the net provided an economical means of reducing the entrainment loss of adult kokanee through a spillway.

Fishery management efforts to sustain naturally reproducing kokanee (*Oncorhynchus nerka*) populations are frequently in conflict with water management strategies designed to maximize hydroelectric and irrigation demands. The management of resident fish populations in large hydroelectric and irrigation reservoirs is complicated by attrition of the population downstream through spillways and turbines (Huston and Vaughan 1968). Although this is a common problem in reservoir fisheries management, it is well documented only where passage of anadromous fish is concerned (Bell et al. 1976; Ebell et al. 1979). Little attention has been given to quantifying the loss of resident fishes and developing solutions for screening large water volumes passing out of a reservoir. Multi-level discharge openings can be an effective means of retaining resident reservoir fish populations by discharging water from depths other than where the fish are concentrated (May et al. 1979). Few dams in northwestern United States were designed with multi-level openings or are managed to retain resident fish populations. The fishery manager may only anticipate high losses and overstock in an effort to maintain a short-term fishery.

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Pelagic species like the landlocked kokanee, an important sport fish in the northwestern United States and western Canada, can be severely depleted from reservoirs by entrainment downstream. This species is unique among salmonids in that it can be self-sustaining by spawning either along reservoir shorelines or in tributary streams. To provide a consistent benefit, however, sufficient numbers must be retained in the reservoir to support a sport fishery and an adequate spawning escapement.

A naturally reproducing kokanee population in Banks Lake was influenced annually by two major water managemeot impacts (Stober et al. 1977). Large numbers of age–III+ kokanee leave the reservoir each year thereby substantially reducing the reservoir sport catch as well as the spawning population, and drawndown of the reservoir caused a loss of eggs and alevins in shoreline spawning areas (Stober and Tyler 1982). The loss of adult fish became most important when it occurred in a year class which had previously been depleted by drawdown. The value of the sport fishery on Banks Lake was estimated at about $3 million aoually.

In this paper, we report on the developmeot and evaluation of a practical and economical method of reducing the entrainmeot of adult kokanee from Banks Lake. A barrier net was designed, constructed and operated to contain adult kokanee in the reservoir. This approach was selected as a less costly alternative to physical modifications of the existing dam and outlet structures.

Description of Banks Lake

Banks Lake is located in east central Washington immediately south of Grand Coulee Dam (Fig. 1) and functions as the equalizing reservoir for the Columbia Basin Irrigation Project. The reservoir was created in 1951 by flooding 11,008 hectares along a 46.5-km section of the upper Grand Coulee between two earth-filled dams (Wolcott 1964). A pumping plant located in the left end of Grand Coulee Dam supplies Columbia River water from Franklin D. Roosevelt Reservoir. Nearly all of the water that enters Banks Lake is pumped by six pumps up 111.2 m into a 2.5-km-long feeder canal at the combined rate of 271.8 m^3/second. Two pump-generating units were added in 1974, each rated at 49.6 m^3/second in the pumping mode, and have occasionally been used to increase the rate of water supply. Natural runoff to the reservoir is small and intermittent.

Between late March and October, irrigation water is withdrawn from Banks Lake through the main canal headworks in the south dam to supply the agricultural requirements on about 202,000 hectares of land in the Columbia Basin. The maximum rate of irrigation withdrawal was 224 m^3/second at the peak of the growing season (Fig. 2) during 1975–1978. The 1975 and 1978 withdrawal curves were generally unimodal while the 1976 and 1977 withdrawal peaked in late April or early May and again in July in a bimodal pattern. The seasonal withdrawal regime before and after barrier installation was equally distributed.

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 south pool to the irrigation canal headworks and allows for irrigation withdrawal at maximum drawdown. The presence of the dredged channel and two offshore islands were important features that had to be considered in the design and site selection for the net barrier. The main irrigation canal intake is 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 3.4 km where it leads into the Bacon Siphons and Tunnels.

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

The limnology of Banks Lake is influenced by a two-pool system. The north pool, which extends from the north dam to the Steamboat Rock area (Fig. 1), is directly affected by the pumped input of water from Lake Roosevelt. During the summer irrigation season, the north pool had lower water temperatures, less transparency, shorter retention time, and lower zooplankton abundance than the south pool. However, during winter when the pump generators were operated, water temperatures were warmer in the north pool and the water column was thoroughly mixed. In addition, greater concentrations of plant nu-

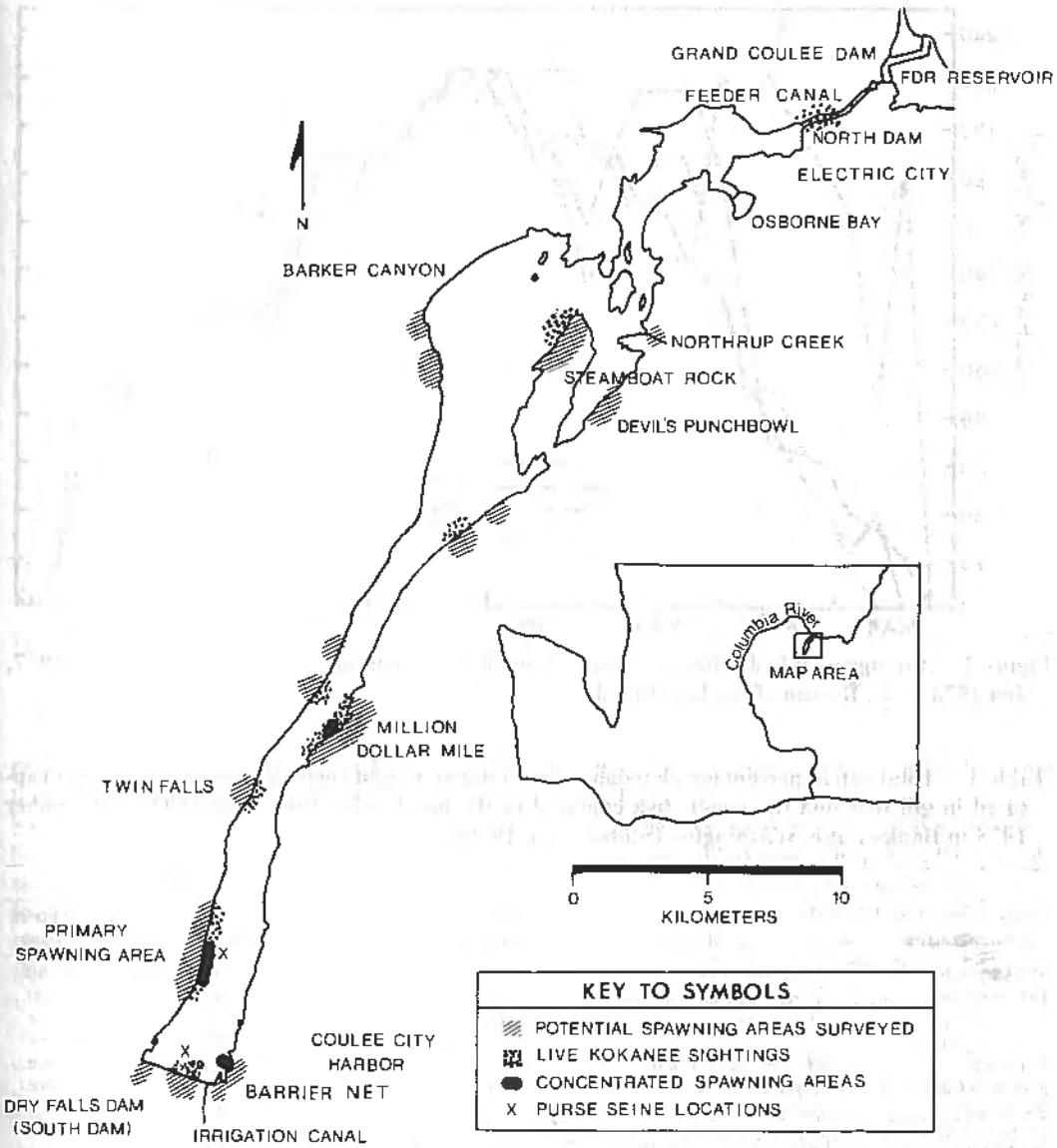

Figure 1. Geographical location and features of Banks Lake, Washington and locations of sampling sites.

trients (nitrates and phosphates) and a correspondingly greater phytoplankton production occurred in the north pool. A nitrate deficiency occurred throughout the lake after pumping and drafting had ceased for a period of time. Zooplankton development was greater in the south pool, the larger and more stable portion of the lake. In general, the lake was classified as a nitrate-limited oligotrophic system (Stober et al. 1977).

Twenty-three species of fish have been identified in Banks Lake by Stober et al. (1976 and 1977) and are listed in Table 1. Yellow perch, lake whitefish, and kokanee comprised about 90% of the sample catch. Responses of the three major species indicated general avoidance of the north

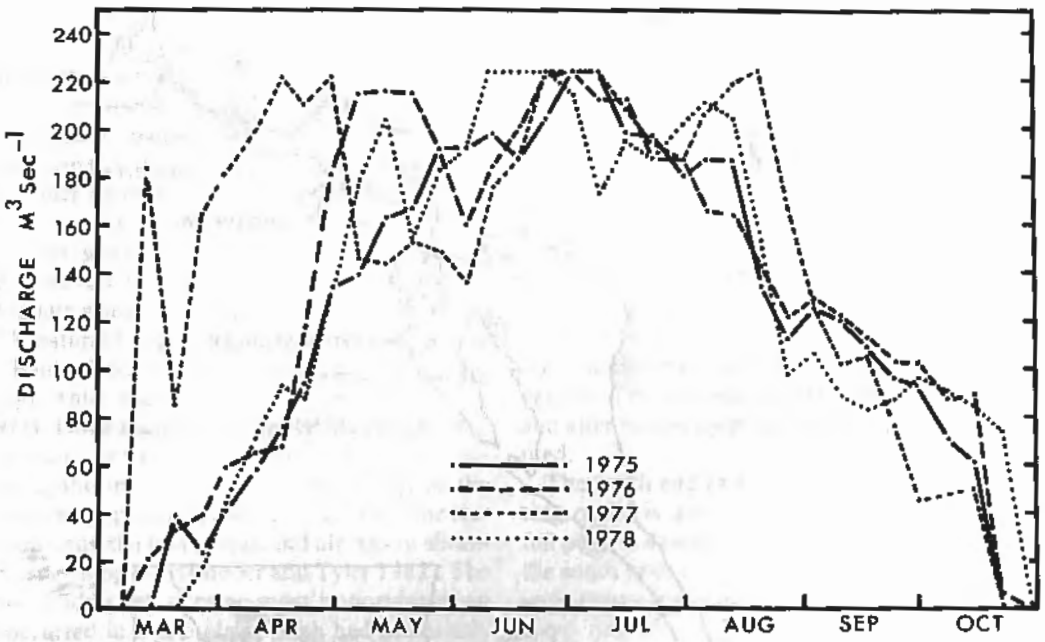

Figure 2. Average weekly discharge of water through the irrigation canal during 1975, 1976, 1977, and 1978 (U.S. Bureau of Reclamation data).

Table 1. Total catch, percentage abundance, and relative weight (percent) for the age-I⁺ fish captured in gill nets and the age-0⁺ fish captured in the beach seine from June 1973 to December 1975 in Banks Lake, Washington (Stober et al. 1976).

		Gill nets			Beach seine		
Common name	Scientific name	Number caught	Relative abundance	Relative weight	Number caught	Relative abundance	Relative weight
Yellow perch	*Perca flavescens*	9,764	63.88	25.89	130,134	95.60	95.60
Lake whitefish	*Coregonus clupeaformis*	2,760	18.01	40.00	2,941	2.10	2.00
Kokanee	*Oncorhynchus nerka*	1,131	7.40	11.48	2	Trace	Trace
Longnose sucker	*Catostomus catostomus*	424	2.77	8.86	1,470	1.05	Trace
Peamouth	*Mylochelius caurinus*	491	3.21	3.00	975	0.70	Trace
Common Carp	*Cyprinus carpio*	88	0.58	3.38	217	0.15	Trace
Rainbow trout	*Salmo gairdneri*	240	1.57	3.70	31	Trace	Trace
Chinook salmon	*Oncorhynchus tshawytscha*	80	0.52	0.38	0	0.00	0.00
Black crappie	*Pomoxis nigromaculatus*	38	0.25	0.20	853	0.61	Trace
Largemouth bass	*Micropterus salmoides*	46	0.30	0.64	890	0.63	0.30
Mountain whitefish	*Prosopium williamsoni*	91	0.60	0.77	10	0.01	Trace
Pumpkinseed	*Lepomis gibbosus*	35	0.23	Trace	70	0.05	Trace
Brown bullhead	*Ictalurus nebulosus*	13	0.09	Trace	13	0.01	Trace
Walleye	*Stizostedion vitreum*	24	0.16	0.59	1	Trace	Trace
Burbot	*Lota lota*	3	Trace	Trace	0	0.00	0.00
Brown trout	*Salmo trutta*	1	Trace	Trace	0	0.00	0.00
Largescale sucker	*Catostomus macrocheilus*	35	0.23	1.11	[a]	Trace	Trace
Northern squawfish	*Ptychocheilus oregonensis*	10	0.07	Trace	3	Trace	Trace
Prickly sculpin	*Cottus asper*	3	Trace	Trace	2,667	1.90	2.00
Bridgelip sucker	*Catostomus columbianus*	1	Trace	Trace	[a]	0.00	0.00
Dolly Varden	*Salvelinus malma*	[b]					
Cutthroat trout	*Salmo clarki*						
White sturgeon	*Acipenser transmontanus*						

[a] Not separated from age-0 longnose sucker.
[b] Taken in irrigation canal.

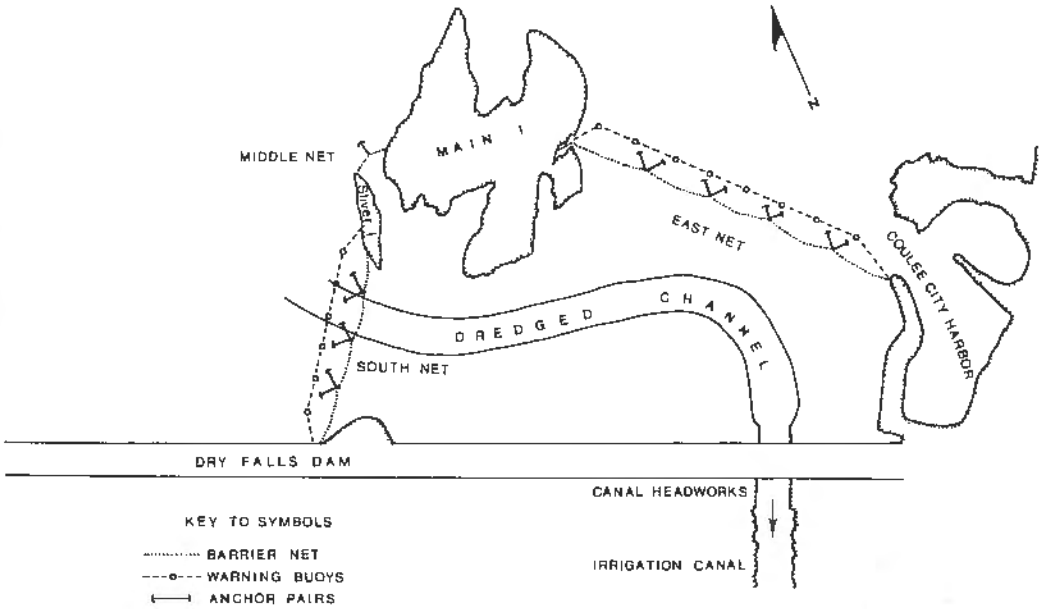

Figure 3. Southeast sector of Banks Lake showing locations of barrier nets, anchors, and warning buoys.

pool during the summer either due to the reduced temperature, food supply, or increased water velocities. Yellow perch in the north pool exhibited lower growth rates and poorer condition. All three species were dependent on daphnia as the major food source (Thomas 1978). Daphnia were concentrated in the south pool of the reservoir (Knutzen 1977).

Barrier Net Development and Operation

Site Selection

The selection of the site for the barrier net in Banks Lake was a compromise among numerous factors, some which favored a distant and others a closer location to the main canal intake. Setting the barrier at the greater distance meant contending with less current, a more uniform bottom contour, and better anchoring security. Those factors that favored a closer siting were decreased cost of the net and less interference with boat traffic and shoreline anglers. The final choice was made on the basis of anchoring security, which was afforded by interconnecting the net with two offshore islands, and was done by dividing the net into three segments—east, middle, and south (Fig. 3).

The cross-sectional bottom contour between specific attachment points for each net site was sounded through the ice during February 1977 to obtain an accurate series of length and depth measurements (Fig. 4). Detailed drawings were made of each site for use in the design and construction of the nets to fit each cross-sectional opening. The nets were designed to be approximately 10% larger in depth and width than the cross-sectional openings to allow a slight downstream sagging between anchor points. The south net measured 379 m long by a maximum depth of 24 m; the middle net, 126 m long by a maximum 8 m deep; and the east net, 859 m long by 12 m deep. The south net was the most difficult to fit due to steep slopes near each shore and at the sides of the excavated channel.

Shoreline anchorage for the ends of the barrier nets in Dry Falls Dam and the islands consisted of holes drilled into bedrock at 478.5 m elevation into which 20-cm eye bolts were set with epoxy plastic. The anchorage on the jetty at Coulee City Harbor consisted of a deadman embedded in the east shore of the jetty with a cable running through the jetty and emerging on the opposite slope.

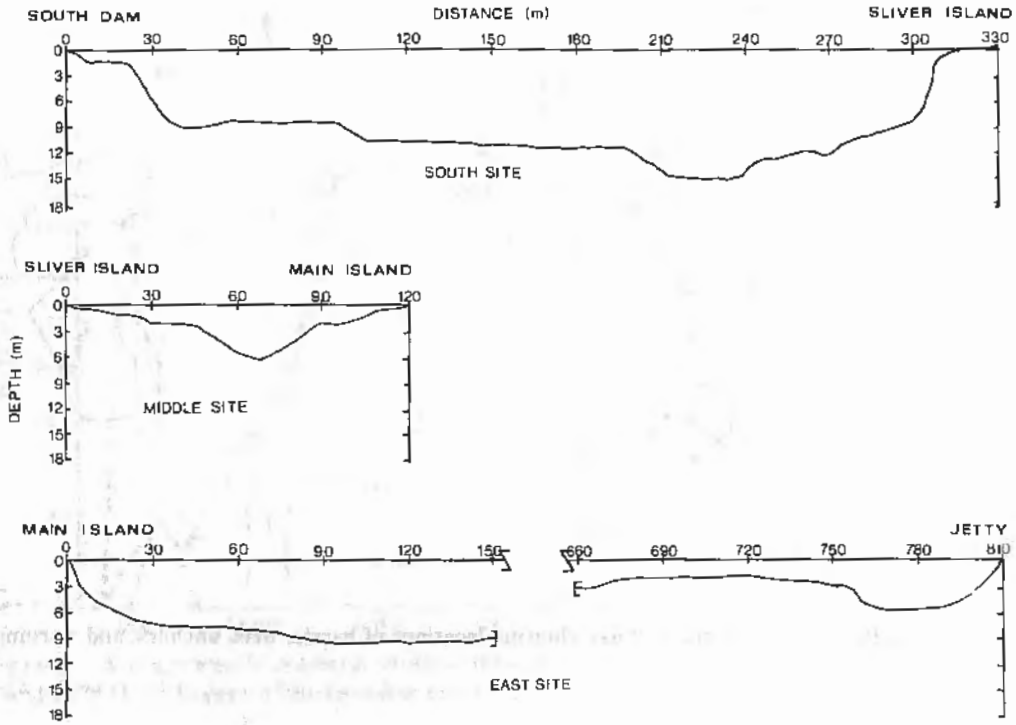

Figure 4. Channel cross-section where the south, middle, and east barrier net sites were located in Banks Lake. The middle 1,700 ft. of gradual sloping bottom was not illustrated for the east site.

Design and Construction

Body depth and girth measurements of kokanee were compared with various mesh sizes to determine the largest mesh that would physically prevent passage of adult kokanee. From these comparisons, we determined that the largest of age-II and age-III+ kokanee (25-cm fork length) could not physically pass through 83-mm stretch-measure 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 fibers with a clear varnish to retain the white color of the material. After installation, visibility was maintained by cleaning the mesh at regular intervals.

The net material selected for construction was 16-thread, knotless dacron with a breaking strength of 34 kg per strand. This mesh presented a relatively low resistance to current, a moderate fouling rate compared with smaller mesh sizes, and allowed the passage of numerous yellow perch. The expected life of the net material was 3 years; however, the same net has been deployed for 7 consecutive years with annual repairs of the mesh. Dacron material was selected because it does not deteriorate as rapidly as nylon in direct sunlight; however, it has lower tensile strength and less stretch. Chafing material was incorporated into the ends of the net exposed to rocky areas during drawndown. The chafing material was No. 72 polypropylene, measuring 76 mm stretch.

The net was hung with 13-mm diameter, double-braid nylon cork and lead lines with a breaking strength of 3,402 kg. Weight was added by attaching 5-mm chains along the entire length of the lead line. Polystyrene corks measuring 76 mm in diameter by 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

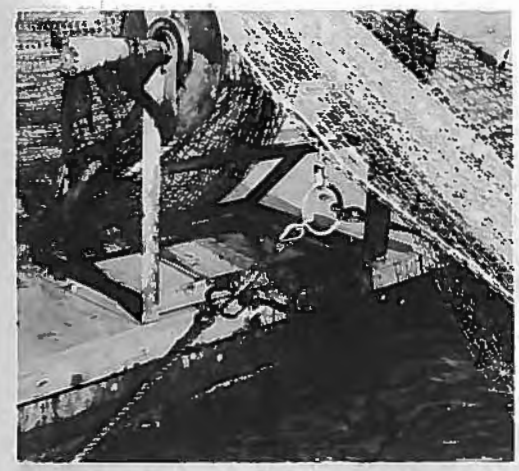

Figure 5. Stern of the net cleaning barge showing the hydraulically powered roller, the cleaned net, and the connecting ring that coupled a pair of anchors to the chain lead line.

that spanned the dredged channel. Corks in this section were spaced on 15.2-cm centers to provide extra flotation where the strongest current was expected.

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 26-kg kedges placed in pairs, initially with one of each pair upstream and the other downstream from the barrier and joined by 27-mm diameter polypropylene lines. Eventually all anchors were placed upstream. The joining lines varied in length from 30 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. 5). 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). Each anchor was 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.

During the first year of net deployment in 1977, the principal loss of adult kokanee and other species occurred through gaps under the leadline of the south net. The tension that caused the leadline to lift was relieved by adding 25 m of net near the middle. Gaps that remained at the edges of the dredged channel and at the steep slopes near each shore were closed by attaching another net curtain (6 m wide × 365 m long) to the lead line of the south net. The attachment point of the south net to the offshore island was changed so that the net approached the vertical shoreline tangentially rather than perpendicularly. This tangential abutment of the net with the shore presented fish leading along the net with a gradual change in direction and they were less inclined to attempt to pass through the net. In 1978, the ends of the barrier nets were carefully positioned by divers and left undisturbed by stopping the cleaning operations at least 50 m from each shore.

The drawndown level in 1978 exceeded the depth to which vinyl chafing material had been added to the ends of the south net. The dacron netting abraded easily on the sharp basalt during wave action and required frequent repairs. Modifications to minimize this problem were devised but could not be accomplished prior to termination of the project.

A separate 1,450-m corkline strung with 20-cm polystyrene floats that were 15 cm in diameter was stretched between large visible buoys from shore to shore to keep boaters away from the net barrier.

The total cost of the net barrier, including modifications, was $19,400 in 1977–1978. The combined cost of the equipment used for hauling and cleaning the net, excluding the boat and barge, was $10,325. The annual installation, removal, and maintenance costs were about $15,000. However, this can increase by $2,000–$3,000 per year depending on the amount of net requiring replacement and repair. These costs were compared with a minimal estimate of about $4,000,000 plus operation and maintenance costs for construction of a permanent, fixed screening system.

Cleaning the Net

The net-cleaning procedure was mechanized to minimize labor requirements. The cleaning gear was mounted on a flat-bottom fiberglass boat 8 m long, equipped with a mast and boom (Fig. 6) mounted on the port side 3 m from the bow—

Figure 6. Apparatus used to lift and clean the barrier net in Banks Lake.

which required design modification during construction of the hull. A 2.8-m × 4-m raft constructed of wood and styrofoam was attached to the stern of the 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 energized a power block suspended from the boom and could be lowered and raised with a hand winch on the mast. The power block was used to lift the net and pull the work boat and raft along the net. A second hydraulic motor powered a wide stern roller mounted on the raft which pulled the net down the length of the work boat and raft to the stern where it was released to fall back into position. Near the ends of the steru roller, two ridges were built by wrapping the roller with used polypropylene line cemented in place with epoxy. These ridges increased friction between the roller and the net, and separated the cork and lead lines to spread apart the mesh for cleaning. A third hydraulic motor powered a piston water pump that delivered water under 63.2 kg/cm^2 pressure to two hand-operated spray nozzles used to remove aquatic weeds and algae from the net. Spray removal of algae was further aided by using an elevated screen platform down the center of the raft to raise the net above the deck.

Additional net-guiding rollers were mounted on the bow and stern of the boat and two intermediate guide rollers were positioned atop the net fore and aft of the power block. With the power block raised in operating position, these rollers increased the contact of the net on the power block, reducing slippage and lowering the center of gravity.

The net-cleaning barge was towed by an outboard skiff into starting position within 50 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 and the barge was moved backward to the starting position near shore by reversing the rotation of the power block and power roller. After cleaning began, the power block control valve was adjusted to move the barge forward along the net at the rate of approximately 2 m/minute. 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 inspected the net for holes and removed large debris and fish. Two other 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 unshackled from the lead line and released. The cleaning was continued for one barge length, after which the connecting ring was retrieved by pulling up the dropline and the ring was reshackled to the leadline off the stern (Fig. 5). An average of about 10 minutes was required to pass an anchor point. Minor difficulty was experienced in re-joining the net to the connecting ring of the anchor line at anchor points situated in relatively high current velocity 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 eased by towing the barge and net upstream with an outboard skiff. The direction of travel of the cleaning gear along the net was reversed each time a net was cleaned in order to avoid shifting the net to one side of the channel.

Drag on the Barrier

The theoretical force acting on the barrier net due to irrigation withdrawal was calculated for the conditions prevailing during 1977 and 1978 and for increased withdrawals expected to occur in the future. The calculations were based on net porosity, wetted cross-sectional area of the net, and maximum discharge for drawdown from full pool to 6.1 m according to the formula:

$$F = (Q/A)^2/2g(WaPn)$$

where:

F = force on net,
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%) and large cross-sectional area of the net site (8,141 m^2 at full pool; 2,275 m^2 at the 6.1-m drawdown). The force increased with the level of drawdown. Under the present irrigation regime in which maximum flows reach 223.7 m^3/second, a drawdown of 6.1 m will produce a force of 101 kg. Under the future regime in which maximum flows may reach 566 m^3/second, a drawdown of 6.1 m will result in a force of 623 kg. This force was divided among four main shoreline attachment points and seven intermediate anchor points. The distribution of this force was unequal because of unequal currents through the two major channel openings. The largest drag 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 leadline 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 connecting the anchor pairs during the net-cleaning operation.

In practice, fouling by periphyton increased the frictional drag of the net. During a 3-week period in August, streamers of periphyton hanging from the meshes grew to lengths of 10–20 cm. The additional drag created by periphyton growth probably far exceeded the force of water current on the net. The greatest tension in 1977 was encountered during rapid fouling of the net following a windstorm that caused large quantities of rooted aquatic plants to break loose and accumulate on the east net. This tension was estimated at about 181 kg. The construction and anchoring of the barrier net was adequate to withstand forces considerably greater than were encountered during the 1977 operation.

During June 1978, the anchors holding the middle half of the east barrier net were dragged downstream approximately 30 m because of the excessive force caused by a combination of strong current and fouling of the net. This strong current resulted from a high irrigation flow (224 m^3/second) and a drawdown of 2.4 m which reduced the cross-sectional channel opening. The fouling resulted from an accumulation of periphyton during the first 35 days of net operation when the net was not cleaned. The drag on the net was largely due to fouling because tension was relieved after cleaning. Until this occurred, one anchor of each pair had been set upstream and

Figure 7. Irrigation canal sampling net lifted for removal of catch.

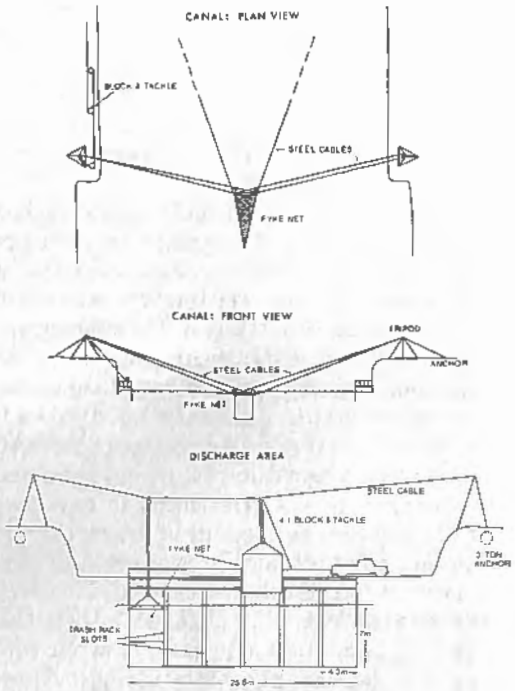

Figure 8. Sampling apparatus for fish entrained through the irrigation canal discharge at Dry Falls Dam (South Dam), Banks Lake.

one downstream to hold the net in place against current and wiod. It was obvious that single upstream anchors at the center of the net were inadequate and the downstream anchors were unnecessary. This situation was corrected by hauling the net back into position with a boat and setting the paired anchors upstream from the net. The net was cleaned at 3-week intervals during July and August.

Io future operations of the barrier net when tension on the lead or cork lines may approach the breaking strength or results from handling problems during net cleaoiog, the tension on a single point can be relieved either by adding additional anchors and lengthening the net to create more sag, or by more frequent cleaning. If the net becomes clogged with debris, it sinks.

Sampling Fish Entrained in the Irrigation Canal

Large sampling nets (Fig. 7) were developed (Stober et al. 1977) to capture fish entrained in the water moving through the irrigation canal intake structure. Smaller nets and various suspension designs (Fig. 8) were employed on the downstream side of the discharge structure depending on the change in volume drafted throughout an entire irrigation season (Fig. 2). These nets were used to determine the number of fish entrained before (1975 and 1976) and after (1977 and 1978) deployment of the barrier net.

The primary net used each year sampled an area 3.7 m square (Fig. 8). It was constructed of 25-mm stretch mesh with No. 252 four-stitch knotless nylon and was suspended from a 4.3-m × 3.8-m rigid frame of closed channel steel. 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 suspended from an overhead cable. Lifting power was provided by attaching the lift to a motor vehicle. Two nets were fished simultaneously in gates 1 (outside) and 4 (inside) in the 6-gate outlet structure. During the early and late irrigation season when the velocity increased near the gates due to reduction in volume below 100 m^3/second, sampling was conducted with smaller nets downstream at the edge of the white-water zone. Sample effort varied from 2 to 4 days per week and the catch was removed every 12 hours. The volume of the sample was calculated from U.S. Bureau of Reclamation discharge data. The total entrainment of each species except kokanee

Table 2. Estimated number of fish entrained in the irrigation canal, the 95% confidence limits, and percent composition by species July 9 through October 25, 1975–1978.

Species	1975		1976		1977		1978		Percent of total number			
	Estimated number entrained	Confidence limits	Estimated number entrained	Confidence limits	Estimated number entrained	Confidence limits	Estimated number entrained	Confidence limits	1975	1976	1977	1978
Kokanee	100,908	±6,013	32,119	±5,450	7,031	±2,513	726	±298	67.4	59.6	17.8	2.5
Yellow perch	16,408	±4,409	3,516	±3,223	22,022	±29,290	9,148	±4,275	11.0	6.5	55.9	31.1
Lake whitefish	11,825	±3,533	4,998	±2,870	96	±159	264	±281	7.9	9.3	0.2	.9
Common carp	6,055	±5,506	1,763	±668	3,228	±1,964	3,249	±1,074	4.0	3.3	8.2	11.1
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	2,229	±1,163	1.5	9.3	5.0	7.6
Mountain whitefish	2,009	±1,049	1,058	±523	841	±928	2,218	±615	1.3	2.0	2.1	7.5
Prickly sculpin	1,789	±1,109	3,578	±2,501	2,062	±1,901	7,315	±2,939	1.2	6.6	5.2	24.9
Rainbow trout	1,659	±549	385	±202	94	±251	227	±23	1.1	0.7	0.2	.8
Peamouth	903	±747	928	±585	1,591	±1,524	1,204	±187	0.6	1.7	4.0	4.1
Pumpkinseed	553	±445	105	±171	9	±42	657	±136	0.4	0.2	T	2.2
Black crappie	129	±263	36	±118			1,158	±180	0.1	0.1		3.9
Walleye	80	±172	30	±68	84	±184	408	±15	T*	0.1	0.2	1.4
Largemouth bass	56	±96	20	±65			85	±119	T	T		.3
Brown bullhead	38	±61	30	±90	52	±130	512	±248	T	0.1	0.1	1.7
Burbot												
Largescale sucker			13	±44						T		
Dolly Varden												
White sturgeon					12	±58					T	
Total	149,664		53,880		39,392		29,400					

* T = trace.

(number and biomass) was estimated at weekly intervals according to the statistical procedures presented in the Appendix.

The number of each species of fish entrained into the irrigation canal was estimated using the same procedures each year. Seasonal variations in number and age compositions of each species were compared. The entrainment estimates for 1975 and 1976 prior to barrier net installation were derived from sampling conducted during nearly the entire irrigation season, whereas the 1977 and 1978 estimates were based on shorter sampling periods beginning June 9, 1977 and April 24, 1978 and ending October 25 each year. Estimates of the escapement of fishes past the barrier net were based on canal catches that occurred on July 9, 1977 and on May 18, 1978 following the complete installation of the net. Comparisons between years were made by considering similar time periods from July 9 to the end of the irrigation season (Table 2).

Barrier Net Evaluation

The screening efficiency of the barrier net, the effect on the fish populations, and reactions of fish to the net were evaluated by (1) monitoring the entrainment of fish into the irrigation canal, (2) tagging kokanee in the vicinity of the barrier net to provide a marked population to monitor the rate of return to the sport fishery and the spawning grounds, (3) sonic tracking of kokanee near the barrier net to determine behavioral responses during feeding and maturation, (4) surveying the number of kokanee spawners, and (5) estimating the size of the sport fishery.

The estimated entrainment of kokanee after July 9, 1975 and 1976 was 100,908 and 32,119, respectively (Table 2). The entrainment of kokanee during the entire 1975 and 1976 irrigation seasons was 128,397 and 50,007, respectively (Stober et al. 1977). The estimated entrainment of kokanee during operation of the barrier net in 1977 and 1978 was 7,031 and 726, respectively. Total entrainment was 7,031 and 3,592 in 1977 and 1978, respectively. The mean relative abundance of kokanee in the irrigation canal declined from 64% before installation of the barrier to 10% afterwards. The barrier was most efficient in 1978 when kokanee abundance was reduced to 2.5% of the total entrainment. The net was

least efficient in 1977 due to the difficulty in fitting the south net to the irregularities in the bottom contour. The weekly entrainment rate of kokanee was erratic. Seasonal variations were due primarily to variation in the volume of irrigation water withdrawn, feeding movements in the south pool, and maturation of the adults.

A comparison of length-frequency distributions of entrained kokanee over the 4 years showed a predominance of age-III+ fish during most of the irrigation season. The mean fork length for entrained kokanee was 360, 375, 425, and 380 mm in 1975, 1976, 1977, and 1978, respectively. The number of age-II+ kokanee entrained were negligible except during June and July in 1977 when the rate was substantially higher. The reason for this difference was determined the following year from mark-recapture studies which showed that the population was relatively larger.

Adult lake whitefish were screened by the barrier net more efficiently than all other species. The pelagic nature of this species caused them to shy away from the net. In the years preceding establishment of the barrier net, lake whitefish constituted the largest quantity, by weight, of fish entrained in the irrigation canal. Their seasonal entrainment pattern was strongly influenced by intolerance to warm surface water which isolated them from the outlet during the summer. Consequently, entrainment was high during the spring and fall and low during the summer. Prior to net deployment, 11,825 and 4,998 lake whitefish were entrained after July 9, 1975 and 1976, respectively. After establishment of the barrier net, entrainment declined to 96 and 264 in 1977 and 1978, respectively (Table 2). Fall out-migration was almost completely blocked, and out-migration during the spring was effectively blocked during the period the net was installed.

The entrainment of yellow perch in the irrigation canal has tended to be very large in the spring, moderate in the early summer, and low during the late summer and fall. Operation of the barrier net in 1977 and 1978 altered this pattern only slightly because the net was installed both years after the period of high entrainment and because most yellow perch were too small to be screened by the barrier. The principal effect of the barrier net on the yellow perch population has been to retain yellow perch larger than 160 mm (age III+) in Banks Lake. By reducing the entrainment of other species, the barrier net has effectively changed the relative numerical importance of yellow perch in the canal catch. Yellow perch comprised 11 and 6.5% of the canal net catches in 1975 and 1976; 55.9 and 31.1% of the catches in 1977 and 1978, respectively.

The entrainment of longnose suckers in the irrigation canal was largest during the May and June spawning period, moderate during July and August, and lowest during April, September, and October. The barrier net reduced the entrainment of adult longnose suckers because of their large size which prevented passage through the mesh. However, many succeeded in passing the net during May and early June 1978 by wiggling under the leadline. Scuba inspection revealed that hundreds of longnose suckers were caught under folds of the barrier net curtain which was lying on the bottom beside the leadline. Many had passed under the leadline and several meters of netting before being gilled or trapped in the folds. This action revealed the different behavior pattern and persistence of the longnose sucker and explained why an estimated total of 8,506 were entrained during the spawning season in 1978.

The entrainment of longnose suckers during comparable periods of barrier net operation (after July 9) in 1977 and 1978 was 1,978 and 2,229, respectively (Table 2). During similar periods in 1975 and 1976, there were 2,247 and 4,987 fish entrained, respectively. Longnose suckers comprised 5.0% of the 1977 entrainment and 9.8% of the 1978 entrainment. The length-frequency distribution of longnose sucker in the canal catches ranged from 250 to 450 mm and a single mode occurred at about 385 mm.

The barrier net apparently had little effect on reducing the entrainment of common carp. The canal catches have shown no decline after the dates of installation in 1977 and 1978. Adult carp were seen frequently ramming the webbing of the barrier net and jumping over the cork line in both directions. This behavior was not interpreted as attempts to enter the canal because the numbers of carp inside the net appeared to equal those outside.

Many schools of 5 and 10 common carp were seen cruisiog continually along both sides of the barrier net, apparently feeding on the periphyton growing on the net. The stomach of one fish was examined and contained mostly zooplankton, predominantly daphnia. Carp seemed to reduce the fouling of the barrier by dislodging the streamers of periphyton during feeding activities.

Mountain whitefish were entrained in small numbers, chiefly from mid-June to mid-September, and the net had little obvious effect on reducing their entrainment due to their small size and slender body.

The estimated entrainment of rainbow trout during the comparative periods in 1975 and 1976 was 1,659 and 385, respectively, as compared to 94 and 227 in 1977 and 1978 (Table 2). The barrier net may have caused some reduction in the entrainment of rainbow trout, but the catches in the canal were too small to show this conclusively. The abundance of rainbow trout in the reservoir was dependent on stock which was reduced during the study period.

The effect of the barrier net on the entrainment of chinook salmon was difficult to ascertain. The abundance of chinook salmon in the reservoir depended on stocking and this was discontinued in 1976. In 1978, chinook were entrained at a moderate rate for the 3 weeks immediately preceding installation of the barrier, then stopped completely for 3 weeks after the barrier net was installed. A second period of moderate entrainment occurred during 4 weeks in late June and July. In 1977, the entrainment rate dropped from very high to very low, coincident with the installation of the net.

Other species were entrained (Table 2) but, due to their low abundance or small physical size, these data were not useful in evaluation of the barrier net.

Kokanee Abundance

A mark-and-recapture experiment was implemented in 1978 to estimate the adult kokanee spawning population and determine general movements near the barrier net. A purse seine 183 m long × 14 m deep was used from June 16 through October 19, 1978 in the vicinity of the barrier net west of the Main Island and near the primary spawning area about 5 km north. Setting and hauling the purse seine was done from the boat and barge designed to haul and clean the barrier net by using essential hydraulic equipment and two outboard skiffs.

Adult kokanee were anesthetized in a solution of tricaine methane-sulfonate, measured, and tagged with a color-coded, numbered, Dennison spaghetti tag. Tagged kokanee were recovered from a variety of sources including purse-seine and gill-net catches, removal from the barrier net, spawner surveys, and a creel census. The numbers of tagged and untagged kokanee from purse-seine and gill-net catches were used to estimate population size.

The population of mature kokanee was estimated using the Schumacher and Eschmeyer multiple-census technique (Ricker 1975). The method requires that the population being estimated remains constant with no mortality or recruitment. The estimate was calculated for the adult kokanee population after Labor Day (September 5–October 19) when a very limited sport fishery existed because the drawdown limited boat access.

The population estimate was calculated from the mark/unmarked ratio of adult kokanee in the purse-seine catches according to the formula

$$\frac{1}{N} = \frac{\Sigma\,(M_t R_t)}{\Sigma\,(C_t M_t^2)}$$

where

N = population size,
M_t = total marked fish at large at the start of the tth day,
C_t = total sample taken on day t,
R_t = number of recaptures in the sample C_t,
m = number of catches examined.

The standard deviation of 1/N was calculated as

$$S(1/N) = \sqrt{\frac{s^2}{\Sigma\,(C_t M_t^2)}}$$

where

$$s^2 = \frac{\Sigma\,(R_t^2/C_t) - (\Sigma\,R_t M_t)^2/\Sigma\,(C_t M_t^2)}{m - 1}$$

Confidence limits for 1/N were calculated by multiplying the standard deviation by the appropriate t-value corresponding to m − 1 degrees of freedom. The population size (N) was estimated by inverting the value obtained for 1/N; the 95% confidence limits for N were computed as the inverse of the confidence limits for 1/N.

The confidence limits are not symmetrically distributed around N, because the calculation relies on inverting the estimate and confidence limits of 1/N. The value of 1/N is the slope of the line R_t/C_t plotted against M_t and passing through the origin—its confidence limits are symmetrically distributed.

A total of 1,824 fish of 6 species was caught in 144 purse-seine hauls. The total catch by species was 1,121 kokanee, 434 lake whitefish,

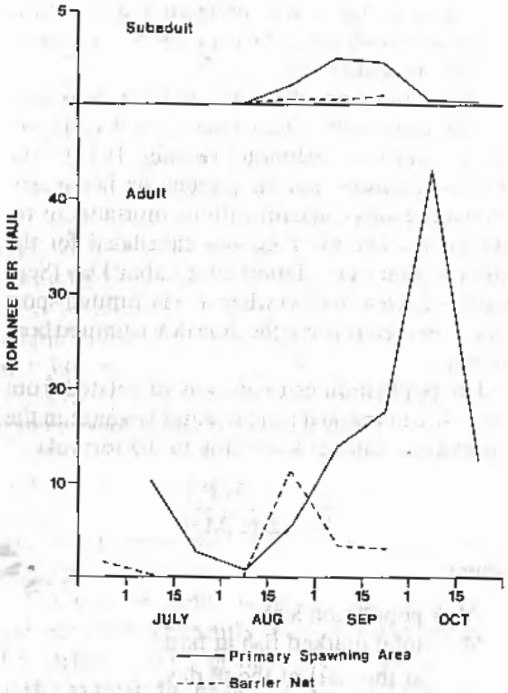

Figure 9. Semi-monthly catch of adult and subadult kokanee per purse-seine haul in the vicinity of the barrier net and primary spawning area, Banks Lake, 1978.

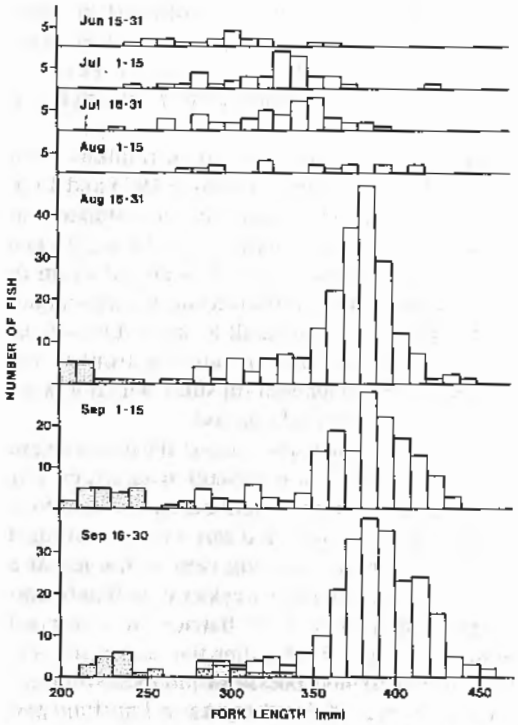

Figure 10. Semi-monthly, length-frequency distributions of kokanee caught by purse seine in Banks Lake, 1978. Stippled areas indicate fish identified as subadults.

215 mountain whitefish, 27 rainbow trout, 26 common carp, and 1 chinook salmon.

Seasonal and weekly variations occurred in the abundance of adult kokanee (Fig. 9) due to either feeding behavior, maturation, or avoidance of warm surface water. Few adults occurred in the vicinity of the barrier net from June until mid-August. Catches increased substantially in late August and then declined. Catches near the spawning area were moderate to large in July and declined as the water temperature reached a maximum of 23.3 C on August 8. Adult kokanee were present in the hypolimnion during this period, as evidenced by the gill-net catches. Catches increased at both sites after August 17 as the water temperature declined below 19 C and continued to increase near the spawning area through early October, whereas a decline was observed near the barrier net. No kokanee were caught in late October because the spawners moved onshore and were inaccessible to the purse seine.

Subadult kokanee began to appear in the seine hauls in late August (Fig. 9), contributing 15.5, 12.5, and 0.6% of the total kokanee catch in August, September, and October, respectively.

The length-frequency distribution of kokanee in the seine hauls at semi-monthly intervals showed that adults (age III+) grew from an average of 300 mm in June to about 380 mm in late August (Fig. 10). Immature kokanee were first recruited into the purse-seine catch in late August and were generally less than 300 mm long.

The sex ratio for seine-caught kokanee was calculated for the period September 1–21. A total of 76 males and 87 females was captured during this period and this ratio did not vary significantly ($P \leq 0.05$) from a 1:1 ratio by chi-square test (Steel and Torrie 1960).

A multiple-census population estimate requires that fish are marked and added to the population over a period of time while samples are taken concurrently and examined for recap-

tures (Ricker 1975). The conditions that must be met include random mixing of marked and unmarked fish, randomly distributed fishing effort, limited mortality, and limited recruitment to the population being sampled. The population estimate was conducted entirely at the south end of the lake near the major spawning area and the barrier net. The tagging and recapture operations could not be randomized geographically; however, the assumption that the marked fish were distributed randomly with the unmarked seemed acceptable based on the distribution of tag returns from gill-net samples, the sport catch, and tracks of sonic-tagged fish. Many of the latter moved rapidly back into the main body of the south pool. Fishing mortality was insignificant because the estimate was made during a period when sport fishing pressure was low. The estimated total catch of kokanee for this period was 780. Natural mortality was probably low because water temperature had declined and feeding and growth had ceased. An estimated 63 kokanee were entrained into the irrigation canal and 425 were known to have been gilled in the barrier net during this period. Neither unequal mortality of tagged fish vs. untagged fish nor loss of the Dennison tags was detected. The possibility of systematic error due to recruitment, which would bias the estimate upwards, was slight because it was calculated only for adult kokanee. Recruitment of subadults into the samples was unlikely because the adults had assumed spawning coloration and were sexually dimorphic.

The systematic errors that can seriously bias such an estimate were, for the most part, avoided. The population estimate of age–III$^+$ kokanee for the period September 5–October 19, 1978 was 35,381, with a 95% confidence interval of 26,360–53,812.

Tag recoveries indicated marked kokanee were distributed over the entire south pool of Banks Lake. Two were recovered as far north as Streamboat Rock and the remainder were recovered south of Million Dollar Mile (Fig. 1). The recovery of tags in the sport fishery and on the spawning grounds demonstrated conclusively that retention of kokanee in the lake by the barrier net both improved the fishery and increased the spawning population.

Kokanee Spawner Surveys

Estimates of the kokanee spawning population in Banks Lake were made in 1975 and 1976 along with general life-history studies. These observations were continued in 1977 and 1978 to determine whether or not kokanee diverted from the irrigation canal by the barrier net contributed significantly to the population.

Two methods were used to survey the 96.5 km-long shoreline for identifying locations and numbers of spawning kokanee. A pram measuring 2.4 × 1.1 m was fitted with a 60 × 60 cm plexiglass window (Stober et al. 1977) and was moved parallel to the shoreline at selected sites each week at the rate of about 0.6 m/second. Scuba surveys of intensively spawned areas were conducted each week by towing divers on a diving plane to depths of 5 m at a rate of about 1 m/second. All surveys were conducted between 1000 and 1500 hours, the period of best light penetration.

The scuba surveys were the most accurate and gave substantially higher counts but were slow and therefore practical only for a small area. They were used in areas of high spawning density. Boat surveys from a glass-bottom pram were less accurate but were capable of covering longer distances and were used in areas of medium to low spawning density.

It was necessary to correct the counts obtained from the pram surveys because the number of spawners was consistently underestimated. The degree of underestimation was inversely related to spawner density. The correction factors were derived by simultaneously surveying areas of high to medium spawning density by both methods and comparing the counts. Correction factors were applied to all survey data for the spawner estimate. The estimate also was corrected by the average time spawners occupied the grounds (redd life) according to Lewis (1972) and Pfeifer (1978).

Scattered spawning occurred along the west shoreline and roadbed fill along Highway 155. These areas were subsampled once by glass-bottomed pram. The basis for correcting pram counts in these areas with low spawner density was provided by a comparative survey along the South Dam which indicated that at low spawner density, scuba counts were twice as large as pram counts. The pram counts from the Highway 155 and west shoreline sites were corrected by a factor of two and also corrected for the distance of potentially spawned shoreline vs. distance sampled.

Mathematically, the population estimate (N) was computed by

$$N = A_1 t^{-1} + A_1 t^{-1}\left(\frac{C_2}{C_1}\right) + \frac{A_1 t^{-1}}{C_{max}} \cdot (\Sigma C_s + \Sigma C_a + C_{ch} + C_{cw})$$

where

A_1 = area under the curve of weekly scuba counts in high-density spawning area plotted against time and measured planimetrically (49,318),

t = average time of an individual spawner on the grounds (redd life),

c_1 = maximum count by pram in the high-density spawning area,

c_2 = maximum count by pram in the medium-density spawning area,

C_{max} = maximum count by scuba in the high-density spawning area (3,000),

C_s = scuba counts in medium-density spawning areas (Million Dollar Mile, South Dam, Coulee City Harbor),

C_a = aerial counts in low-density spawning concentrations (Twin Falls, Steamboat Rock),

C_{ch} = expanded pram count for Highway 155,

C_{cw} = expanded pram count for West talus shoreline.

The expanded pram counts (C_{ch} and C_{cw}) were calculated as

$$C_e = (\Sigma c_p / \Sigma d_p)(C_{sd}/c_{sd})D$$

where

c_p = pram count for representative survey site,

d_p = distance of survey site covered by pram,

C_{sd} = scuba count for South Dam comparison area,

c_{sd} = pram count for South Dam comparison area (C_{sd}/c_{sd} = 2.0),

D = distance of shoreline (4.0 km for Highway 155 and 14.3 km for west shoreline).

Systematic observations of beach-spawning kokanee were conducted each year from 1975 to 1978. The spawning season extended over the months of October and November, reaching a maximum around November 1. During this time, the water temperature declined from about 16 to 4 C. The transparency of the water averaged about 6 m. The reservoir was filled prior to the peak of spawning each year and drawdown had little effect on the depth distribution of spawners. Preferred spawning depths ranged from 1.5 to 4.6 m below full pool; up to 13.7 m when high population densities occurred. Redd density declined rapidly below the depth of 4.6 m and little spawning occurred above 1.5 m.

Kokanee spawners selected talus shoreline areas. The largest concentration of spawners occurred each year along the primary spawning area—the southwest shore of the reservoir (Fig. 1). Five additional areas with smaller numbers of spawners were located at Million Dollar Mile, Coulee City Harbor, South Dam, Twin Falls, and Steamboat Rock (Fig. 1). A greater quantity of fine clean substrate along the talus shorelines, especially in the primary spawning area, was considered the reason for the concentration of spawners.

An intense effort was made to survey a 2,400-m long section of shoreline, including a 113-m length of primary spawning area, each week. Surveys conducted from the glass-bottom pram yielded counts approximately 10 times lower than scuba observations due to depth limitations of visibility. The differences in the counting methods were less with small populations and greater with large populations. As the density of spawning increased, the depth of spawning increased and this resulted in less accurate pram counts.

The area of high density spawning was measured by divers and plane-table survey to be 165, 568, and 863 m² in 1976, 1977, and 1978, respectively. The variation in area spawned was related to number of spawners. The total area spawned in the primary spawning area was 165, 1,579, and 1,690 m² in 1976, 1977, and 1978, respectively.

Certain limitations were evident in the spawner survey methods. The scuba surveys were limited in area coverage by the endurance of the divers (about 1 hour) and the counts were somewhat variable because each diver estimated school size differently. Even with this variability, the counts were more reliable than those obtained from the glass-bottom pram, especially at high spawner densities because many fish were below visibility range. The counting rates of different observers were compared using the pram over the same area and group of fish, and the rates were equivalent. Kokanee also tended to shy away from the pram during the early part of the spawning season, increasing the difficulty of counting.

Table 3. Estimated number of kokanee spawners from surveys and mark-recapture data from purse seines, potential egg deposition, and egg density for all of Banks Lake and the primary spawning area, 1976–1978. Spawner-survey estimate range was based on turnover times of 5.7 and 15.4 days.

	Spawner-survey estimate			Purse seine mark-recapture
	1976	1977	1978	1978
Lake-wide				
Population estimates	346–944	2,084–5,630	6,717–18,111	35,381
Egg depositions	190,265–519,106	1,145,991–3,095,937	3,693,678–9,959,239	19,456,011
Primary spawning area				
Population estimates	115–311	940–2,539	3,202–8,652	
Egg depositions	63,239–171,019	516,906–1,396,196	1,760,780–4,757,735	
Egg density per m²	383–1,036	327–884	1,042–2,815	
Total area utilized (m²)	165	1,579	1,690	

The accuracy of the pram counts varied inversely with spawner density. The pram counts were most accurate during a year of small spawning population (1976), were less accurate during a year of moderate spawning population (1977) and were least accurate in the year of large spawning populations (1978). The ratio of scuba count to pram count during these years was 1, 4.5, and 12.9, respectively.

Estimates of redd life were not made for kokanee spawners at Banks Lake. To correct for spawner succession in making population estimates, it was necessary to use "literature" values of 5.7 days (Lewis 1972) and 15.4 days (Pfeifer 1978). Using these values, 1978 spawner estimates were 6,717 and 18,111 for the entire lake; 3,202 and 8,652 for the primary spawning site (Table 3). Population estimates for 1976 were 346 and 944; 2,084 and 5,630 in 1977. The estimate of potential spawners from September 5–October 19, 1978 by the Schumacher-Eschmeyer treatment of tagging data was 35,381, with a 95% confidence interval of 26,360–53,812. The estimate based on tagging, considered the most accurate, was approximately double the highest estimate from the spawner survey. Although the spawner surveys did not accurately assess the population, the data obtained were useful in that they reflected the relative annual abundance of the population.

Information on the quantity and depth at which eggs were deposited by kokanee was of value for two reasons: (1) to determine the effect on natural kokanee production of reservoir water management for irrigation and pump-generation; (2) determine the spawning success of large kokanee populations retained by the barrier net.

Potential egg deposition in the primary spawning area was calculated from the spawner estimates by multipying one-half of the estimate (assuming a 1:1 sex ratio) by the average fecundity (1,222 eggs) (Stober et al. 1976). Spawning was assumed to be complete each year, although a few unspawned female carcasses were observed along shorelines after the spawning season. Undoubtedly, eggs were lost during spawning to predators like the abundant sculpins (Moyle 1977). Because these losses were not measured, an arbitrary value of 10% was assumed. Predation loss in 1978 may have been greater than in previous years due to superimposition of redds. The estimates of potential annual egg deposition are presented in Table 3. Egg densities at the primary spawning sites were 383 and 1,036/m² in 1976, 327 and 884/m² in 1977, and 1,042 and 2,815/m² in 1978. Egg densities in the shallow parts of the spawning bed were much greater than the above values because spawning was concentrated at depths between 1.5 and 4.6 m. The relative density of redds by depth could not be measured because redds were indistinct due to superimposition and shifting substrate.

Sonic Tracking

The movements of age–III⁺ kokanee in the south end of Banks Lake were studied to determine their behavior patterns during feeding and pre-spawning activities. Of special interest was their reaction on encountering the barrier net; i.e., degree of persistence in attempting to pass

the net and extent of return to the main body of the lake.

Fourteen sonic-tagged adult kokanee were released between July 18 and October 3, 1978; six were released near the primary spawning area, five near the south barrier net, and three near the east barrier net. All kokanee captured for tagging were obtained by purse seining, tagged without anesthetization, and released within 20 minutes.

The tracking system consisted of a Model TA-25 (Smith Root) sonic receiver coupled with a Model SR-70-H hydrophone. A PC-74 pulse counter was used to distinguish the pulse rates of individual fish tags. Sonic transmitters (Model SR-69 tags) emitted a frequency of 74 kHz with a pulsed repetition rate between 0.5 and 8.0 pulses per second. The sonic tags were attached externally by inserting a loop of hollow vinyl tubing through the skin under the dorsal fin and then attaching it to a metal swivel eye glued to each tag. The kokanee were tracked continuously during daylight on the first day of release. After the first day of tracking, the lake was searched daily at intervals to locate individual fish and plot their locations by using a sextant to sight landmarks.

Movements of sonic-tagged kokanee during the months of July and August were related to feeding; during September and October, to spawning. Six of the 14 fish tracked encountered the barrier net and all turned back into the reservoir with little delay at the net. None of the tracked fish passed the net. The last four kokanee tracked after mid-September moved to beach spawning sites along the southwest shore of the reservoir.

Sport Fishery

A creel census of the sport fishery was conducted in 1978 to provide comparative data of the first full year of barrier net operation against previous years without a net barrier. The recovery of tagged kokanee in the catch also was facilitated by the creel census. The census was designed to be comparable with earlier censuses by Duff (1973) and Stober et al. (1976). The principal angler access sites on Banks Lake were visited to check angler use and fishing success. Sampling days were apportioned equally between two weekends per month and two pairs of weekdays per month. The census was directed at the primary kokanee fishery conducted offshore by trolling during April–September. Sampling was done on 58 days during the period April 10–October 28, 1978 and during the hours of 1300–1800. The census data included angler interviews and counts of boat trailers and car-top carriers.

Estimation of the boat fishery was hindered by the difficulty in obtaining interview data because boat anglers could only be contacted within a few minutes of their return to a launch ramp. The non-interview data were an important supplement. It was assumed that all empty boat trailers and car-top racks represented boats on the water. In order to avoid bias in these data, considerable effort was spent in developing correction factors. Counts of empty boat trailers were an unknown fraction of the total boats launched for a day. Thus, it was necessary to establish a rate of boat exchange. Since a variety of boating activities occurred on the lake, it was necessary, also, to determine the percentage of boats actually engaged in fishing.

The rate of boat exchange was estimated each month from the change in 2-hour recordings of license numbers on all vehicles at the launch ramps throughout the day. The boat exchange rate was not significantly different between areas, therefore a mean of 2.0 was used. The percentages of fishermen and water skiers (the only other boating activity) were calculated by direct counts of the boats on the lake engaged in each activity. Water skiing accounted for 11% of the launchings from June through September.

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

$$E_e = BRAT$$

where

E_e = estimated fishing effort in angler hours,
B = estimated boats fishing during surveys,
R = mean daily exchange rate of boats,
A = mean anglers per boat,
T = mean angler fishing time.

The estimated total catch (C_e) = $E_e \times$ (CPUE), where

C_e = estimated total catch,
CPUE = observed catch per angler hour.

A limited creel census was conducted during August 9–October 21, 1977 to determine angler effort in the south one-third of Banks Lake based on boat counts. Estimates of catch per angler-hour were derived from voluntary angler returns of creel census questionnaires that requested the

date, number in party, hours fished, and catch by species.

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

$$E_e = B_{wd} \times E_t/E_{wd} \times A \times T$$

where

E_e = estimated fishing effort in angler-hours,
B_{wd} = number of boats fishing during week-day surveys in 1977,
E_t/E_{wd} = ratio of total effort to week-day effort (based on 1975 census),
A = average number of anglers per boat (2.7) (based on 1977 data),
T = average fishing time in hours (6.3, based on 1977 data),

and

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

where

CPUE = catch per angler-hour,
C_r = catch reported by anglers on creel census questionnaires,
E_r = effort in angler-hours reported on creel census questionnaires.

These statistics were calculated monthly. Effort statistics for 1975 and 1978 were adjusted to include only the south end of Banks Lake from the North Million Dollar Mile access southward, to enable comparisons between years. No census was conducted in 1976.

The 1978 census takers contacted 898 anglers who fished a total of 214,768 hours to catch 55,465 fish of all species, or about 0.26 fish per angler-hour. The species composition in decreasing order of abundance was: kokanee, 83.7%; yellow perch, 5.9%; rainbow trout, 4.0%; chinook salmon, 2.7%; black crappie, 2.3%; largemouth bass, 0.8%; pumpkinseed, 0.2%, and brown bullhead, 0.2%. Lake whitefish and walleye also were taken but comprised less than 0.2% of the total catch.

Kokanee were caught exclusively by trolling offshore April–September. Observations of the boat fishery indicated 89% were engaged in fishing for kokanee. The peak monthly catch of kokanee was 14,651 and occurred in July. This equated to a CPUE of 0.303.

A comparison of the sport fishery for the months of April–September 1972, 1975, and 1978 is shown in Table 4. The CPUE for all other species was 0.372, 0.234, and 0.042 for 1972, 1975, and 1978, respectively. The decline in the CPUE for all other species indicated a general decline in the fish stocks. The CPUE for kokanee probably was improved by operation of the net barrier.

Table 4. Catch statistics for the kokanee sport fishery in 1972, 1975, and 1978 in Banks Lake, Washington.

	1972	1975	1978
Angler-hours	245,239	332,076	214,768
Kokanee catch (number)	70,119	73,631	46,427
Kokanee CPUE	0.286	0.222	0.216

A limited creel census based on boat counts and a questionnaire was conducted during the latter part of the 1977 season. The effort expended during August–October in 1975 and 1978 in the south end of Banks Lake was found to be about 15% of the season's total (April–September). The 1977 effort was, therefore, expanded by 85% to obtain a total estimate of 116,980 angler-hours. The August 1977 CPUE (0.105) was applied to this effort to obtain a total catch of 12,283 kokanee. The average CPUE (0.047) for the August–October period in 1977 was not utilized because it was considered less representative of the early part of the season when catches were normally higher. Due to the impact of extreme reservoir drawdown on kokanee eggs and alevins during the spring of 1973 and 1974, the catch of the age-III+ year class in 1976 was considered equally as poor as in 1977. This was confirmed by interviews during the 1976 season. For comparative purposes, a catch of about 15,000 kokanee was arbitrarily selected for the 1976 season.

Gilling Mortality in the Barrier Net

A record was kept of fish gilled in the barrier net to evaluate mortality resulting from the use of a relatively large mesh. Gilled fish were removed principally during cleaning operations; however, a few that had dropped out of the net were recovered from the bottom by divers during routine inspections.

Thirteen of 23 species present in Banks Lake were gilled (Table 5). Kokanee were gilled most frequently, accounting for about 70% of the total

Table 5. Species composition, number, and length of fish gilled in the barrier net during 1977 and 1978.

	1977					1978				
				Length range (mm)					Length range (mm)	
Species	Number in catch	Mean length (mm)	Number	Min.	Max.	Number in catch	Mean length (mm)	Number	Min.	Max.
Kokanee	194	372	103	288	505	465	377	181	227	480
Chinook salmon	26	301	20	280	350	72	351	60	305	397
Mountain whitefish	24	319	12	281	406	20	324	6	276	370
Yellow perch	13	224	12	100	290	19	264	10	212	284
Peamouth	9	348	5	325	394	0		0		
Longnose sucker	8	293	4	218	327	13	332	6	272	379
Rainbow trout	5	305	3	299	312	8	334	8	300	360
Lake whitefish	2		0			1	461	1		
Black crappie	2	192	1			2	280	1		
Brown bullhead	1	238	1			1		0		
Common carp	1	200	1			16	268	12	175	600
Largemouth bass	1	287	1			2	282	2	241	322
Pumpkinseed	1	168	1			0		0		
Prickly sculpin	0		0			1		0		
Walleye	0		0			1		0		
Total identified	287					621				
Unidentified	12					75				
Total catch	299					696				

each year, followed by chinook salmon and mountain whitefish. Despite their large numbers, few yellow perch were gilled because of their small size. Also, lake whitefish were gilled in small numbers owing to their large size, hypolimnetic distribution during the summer, and wariness of the net. Common carp were gilled in small numbers because of their large size and truncated shape. Although a few large individuals (550–600 mm) were entangled by their serrated dorsal spines, most of the gilled carp were small (175–240 mm). Carp often were observed near the net by divers and occasionally were seen to ram the net.

The seasonal gilling rates of kokanee, chinook salmon, and mountain whitefish in the barrier net were 1.60, 0.19, and 0.19 per day, respectively, in 1977; 2.78, 0.43, and 0.12 per day, respectively, in 1978. Very few kokanee were gilled prior to mid August (8 in 1977, 40 in 1978); however, the incidence increased markedly from late August through October. A total of 425 was caught during this period in 1978, compared to 186 in 1977.

A comparison of the mean lengths of kokanee gilled in the barrier net with kokanee caught in the irrigation canal nets is presented in Table 6. During the early portion of the season (May to late June), the barrier net selectively gilled the large members of the kokanee population because the mean length of the population was near the minimum size for gilling. Canal net catches during this period indicated that many small kokanee passed through the mesh of the barrier net. The mean lengths for kokanee from the irrigation canal were 254.1 mm and 288.9 mm in 1977 and 1978, respectively, while the three kokanee gilled in the barrier net during May and June had a mean length of 340.0 mm (Table 6). This indicated that the barrier net was selective for the largest individuals and accounted for the low gilling rate during this period.

During the following 2-month period from late June to late August, the mean lengths of fish taken from both nets in both years were similar (Table 6). As kokanee grew during the summer, their mean length increased to a size which made them more susceptible to gilling in the barrier net (368.2 mm in 1977 and 340.7 mm in 1978). Because of the reduced efficiency of the barrier net in 1977, more kokanee escaped into the irrigation canal (9,198). The smaller population in 1977 resulted in fewer kokanee being gilled (8). In 1978, however, the improved fit of the barrier reduced the number of kokanee caught in the canal nets in midseason (16) from the number caught during the earlier part of the season (56).

During the last 2 months of operation (Sep-

Table 6. Mean length of kokanee gilled in the barrier net and caught in the irrigation canal nets in 1977 and 1978.

		Irrigation canal				Barrier net			
				Length range (mm)				Length range (mm)	
Year	Period	Mean length (mm)	Number	Min.	Max.	Mean length (mm)	Number	Min.	Max.
1977	5/18–06/24	254.1	75	152	392				
	6/24–08/24	368.2	198	143	551	349.2	8	315	377
	8/24–09/15	402.8	362	222	564	341.9	18	288	420
	9/15–10/24	419.2	84	290	495	389.7	81	292	505
1978	5/18–06/24	288.8	56	135	362	340.0	3	318	352
	6/24–08/24	340.7	16	228	425	349.7	24	286	390
	8/24–10/04	386.9	10	325	415	370.2	30	210	455
	10/04–11/01	381.0	1			384.1	123	227	480

tember and October), kokanee from the canal nets were larger, on the average, than kokanee gilled in the barrier net. This difference in lengths was 60.9 mm between August 24 and September 15, and 29.5 mm between September 15 and October 24 in 1977. A 16.7-mm difference was found between August 24 and October 4, 1978. This difference resulted primarily from the gilling selectivity of the barrier net for smaller kokanee that were within the susceptible gilling size range—which became less with advancing maturity because the males tended to become entangled in the mesh more easily due to their protruding teeth and elongated snouts. The increased gilling rates during September and October probably were due to increasing persistence of maturing kokanee to follow the irrigation flow. The highest gilling rate occurred in the south barrier net, indicating that the channel was the main avenue of movement.

Similarly, chinook salmon were gilled at a greater rate in 1978 than in 1977 (2.3 times greater), but also increased in mean length from 301 to 351 mm. This growth rate made them more susceptible to gilling and increased the gilling rate even though their population decreased.

The gilling rate of mountain whitefish was high relative to their low abundance in Banks Lake and in the entrainment catches from the irrigation canal. All individuals gilled were large, maturing, and apparently of ideal size and body shape for gilling in the mesh of the barrier net.

In general, the loss of fishes of all species by gilling in the barrier net was of little consequence compared to their population sizes and to potential losses that would have occurred due to entrainment. If these fish had not been gilled, they very likely would have moved into the irrigation canal and lost to Banks Lake.

Benefit to the Kokanee Fishery

The benefits to the kokanee population resulting from the reduction in the entrainment of adults by the barrier net are summarized in Table 7. Population estimates based on entrainment, sport catch, and spawner count enabled comparisons of the populations during 2 years before (1975 and 1976) and after (1977 and 1978) deployment of the barrier net. The percentage of kokanee among all species entrained was reduced by the barrier net from 64% before to 10% after deployment.

The estimate of spawners in 1978 by the mark-recapture method was two times greater than by spawning-ground survey and was considered more accurate. Therefore, as a basis for comparing spawner counts during 1975–1978, the counts in 1976 and 1977 were approximately doubled to 1,851 and 11,039, respectively. Spawner counts in 1975 were estimated to range from 5,000 to 10,000; the upper estimate was used to assess the population. The percentage of kokanee retained was calculated from the sport catch and spawner count.

The 1975 population was the largest observed during the 4 years. Forty percent of this population remained in the lake and provided a good sport fishery and spawning escapement without a barrier. However, what might the sport catch and spawning escapement have been had a barrier prevented the entrainment of an estimated 128,297 kokanee? In 1976, with a smaller population, only 25% remained in the reservoir. The 75% lost severely depleted the spawning escape-

Table 7. Estimated kokanee entrainment, sport catch, spawner count, population index, and percent retained in Banks Lake, Washington.

Year	Total annual irrigation canal entrainment	Percent of all species entrained	Sport catch	Spawner count	Population index	Percent retained
1971			72,885			
1972						
1973						
1974						
1975	128,397	67.4	75,035	10,000[a]	213,432	40
1976	50,007	59.6	15,000[a]	1,851	66,858	25
1977	7,031	17.8	12,283	11,039	30,353	77
1978	3,592	2.5	46,427	35,381[b]	85,400	96

[a] Approximate value.
[b] Mark-recapture estimate.

ment. A small number of fry were expected from this year class. With increased screening efficiency in 1977 and 1978, the retention of adult kokanee increased from 77 to 96%. The barrier net served to enhance the sport fishery as well as to increase the spawning population in the reservoir, ensuring that an adequate number were available for natural reproduction.

Discussion

Several factors contributed to the success of the barrier net. The relatively shallow maximum depth (17 m) of the reservoir near the irrigation canal outlet structure made it possible to fit the nets to the entire opening. Because nearly all of the water in the reservoir is pumped from deep intakes in Lake Roosevelt, there is a lack of heavy debris (i.e., logs, limbs, and other terrestrial matter) being pumped from the Columbia River. A general lack of woody vegetation in the surrounding arid basin also reduced the amount of debris. The clogging rate by periphyton was minimized by utilizing relatively large mesh. The location of offshore islands provided anchoring security at a distance sufficient from the discharge structure to maintain low water velocities through the barrier at maximum discharge rates. The need to retain only adult kokanee and not the juveniles was a definite advantage. The behavioral tendency of salmonids to lead along a visible net barrier was the primary factor that led to this approach. In order to maximize the benefit from this leading behavior, cul-de-sacs were minimized in order to avoid leading fish into trap-like situations.

The major force on the net from flow was transmitted to the lead line and then to seven anchor points. In fluctuating reservoirs, an advantage can be gained by allowing maximum flexibility in a barrier net, whereas a fixed rigid structure might be destroyed if subjected to drawdown or wave action. The major disadvantage of net barriers is the amount of attention required for cleaning and repairing.

The application of net barriers should be explored in other reservoirs where the entrainment or passage of fish can pose a variety of problems. It is possible to deploy net barriers in several configurations (angles to flow, depths, and mesh sizes) to provide a reservoir fishery manager with a means to improve fish retention or guidance away from spillways or turbine intakes during critical migratory time periods. Utilization of the barrier net since 1977 to retain adult kokanee, in conjunction with the management of water levels that follow rule curves developed to allow egg-to-fry survival (Stober and Tyler, 1982), should stabilize the valuable Banks Lake sport fishery in the future.

Acknowledgments

This research was supported by the U.S. Bureau of Reclamation Contract Numbers 14-06-100-7794 and 7-07-10-S0023. Cooperation received from the Washington State Department of Game and the U.S. Fish and Wildlife Service is greatly appreciated. We sincerely thank Michael Pease, C. F. Cowman, Jr., J. Wilcock, S. Quinnell, D. Gaudet, and D. Van Wyck for their assistance in the field.

References

Bell, M. C., Parkhurst, Z. E., Porter, R. G., and Stevens, M. 1976. Effects of power peaking on survival of juvenile fish at lower Columbia and Snake River dams. U.S. Army Corps of Engineers,

North Pacific Division, Contract No. DACW 57-75-C-0173, Portland, Oregon, USA.

DUFF, R. L. 1973. 1971–72 Banks Lake creel census. Unpublished report, Washington Department of Game, Region 2, Ephrata, Washington, USA.

EBEL, W. J., TANONAKA, G. K., MONAN, G. E., RAYMOND, H. L., AND PARK, D. L. 1979. Status report–1978; the Snake River salmon and steelhead crisis: its relation to dams and the national energy shortage. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington, USA.

HUSTON, J., AND VAUGHAN, T. 1968. Temporal movement of rainbow trout in reservoirs. Proceedings of the 48th Annual Conference of the Western Association of State Game and Fish Commissions, Reno, Nevada, USA.

KNUTZEN, J. A. 1977. Operational effects of irrigation and pumped storage on the limnological characteristics of Banks Lake, Washington. Master's thesis. College of Fisheries, University of Washington, Seattle, Washington, USA.

LEWIS, S. L. 1972. Life history and ecology of kokanee in Odell Lake. Oregon State Game Commission, D-J Progress Report F-71-R-8, Portland, Oregon, USA.

MAY, B., HUSTON, J., AND MCMULLIN, S. 1979. Lake Koocanusa post impoundment fisheries study. Montana Department of Fish and Game, Fisheries Division, in cooperation with U.S. Army Corps of Engineers. Contract Number DACW-67-75-C-0004 Completion Report January 1, 1969 to September 30, 1978, Libby, Montana, USA.

MOYLE, P. B. 1977. In defense of sculpins. Fisheries (Bethesda, Maryland) 2:20–23.

PFEIFER, R. L. 1978. Evaluation of the natural reproduction of kokanee (*Oncorhynchus nerka* Walbaum) in Lake Stevens, Washington, as related to the lake limnology and basin hydrology. Master's thesis. University of Washington, Seattle, Washington, USA.

RICKER, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 119, Fisheries Research Board of Canada, Ottawa, Canada.

STEEL, R. C. D., AND TORRIE, J. H. 1960. Principles and proceedings of statistics with special reference to the biological sciences. McGraw-Hill Book Co., New York, New York, USA.

STOBER, Q. J., TYLER, R. W., THOMAS, G. L., JENSEN, L., KNUTZEN, J. A., SMITH, D. L., AND NAKATANI, R. E. 1976. Operational effects of irrigation and pumped/storage on the ecology of Banks Lake, Washington. Third Annual Progress Report, June 1975 to May 1976, U.S. Bureau of Reclamation, Contract Number 14-06-100-7794. University of Washington, College of Fisheries, Fisheries Research Institute, FRI-UW-7610, Seattle, Washington, USA.

STOBER, Q. J., TYLER, R. W., KNUTZEN, J. A., GAUDET, D., PETROSKY, C. E., AND NAKATANI, R. E. 1977. Operational effects of irrigation and pumped storage on the ecology of Banks Lake, Washington. Final Report, REC-ERC-77-5, U.S. Department of Interior, Bureau of Reclamation, Engineering and Research Center and Pacific Northwest Region, Contract Nnmber 14-06-100-7794. University of Washington, College of Fisheries, Fisheries Research Institute, Seattle, Washington, USA.

STOBER, Q. J., AND R. W. TYLER. 1982. Rule curves for irrigation drawdown and kokanee salmon (*Oncorhynchus nerka*) egg to fry survival. Fisheries Research, Elsevier, Amsterdam, The Netherlands.

THOMAS, G. L. 1978. The comparative responses of kokanee, lake whitefish and yellow perch to hydrological perturbations in Banks Lake, Grant County, eastern Washington. Doctoral dissertation. College of Fisheries, University of Washington, Seattle, Washington, USA.

WOLCOTT, E. E. 1964. The lakes of Washington: Vol. II, eastern Washington. State of Washington, Division of Water Resources, Water Supply Bulletin 14, Olympia, Washington, USA.

APPENDIX

The average daily catch ($\bar{C}_i$) in the canal nets was calculated for each week and species using the following procedure

$$\bar{C}_i = \frac{C_{ij}}{\Sigma H_i}(24) \qquad (1)$$

where

C_{ij} = j^{th} catch in the ith week,
H_i = number of hours fished for each catch.

Weekly entrainment rates were estimated for each species by the expression

$$T_i = \frac{\bar{C}_i Q_i n_i}{Qs_i} \qquad (2)$$

where

T_i = estimated weekly entrainment rate,
Q_i = average daily canal discharge rate (cfs) for weekly period,
Qs_i = weekly rate of flow through nets in cfs.
n_i = number of days in the week (usually 7).

The point estimate for the total (32-week maximum) seasonal entrainment of each species through the irrigation outlet structure was calculated from

$$T_e = \sum_{i=1}^{32} a_i \bar{C}_i = \sum_{i=1}^{32} T_i \qquad (3)$$

where

T_e = estimated total number entrained by species,

$$a_i = \frac{Q_i n_i}{Qs_i}$$

The variance about the mean was calculated from the expression

$$\mathrm{Var}(\bar{C}_i) = \frac{\sigma^2}{n} = \frac{Si^2}{n} = \frac{Si}{\sqrt{n}} \tag{4}$$

The variance about the weekly estimated catch (T_i) was estimated from

$$\mathrm{Var}(T_i) = \left(a_i^2 \frac{Si}{\sqrt{n}}\right) \tag{5}$$

Assuming C_i are independent random variables, then the $\mathrm{Var}(\hat{T}_c)$ can be estimated from

$$\mathrm{Var}(\hat{T}_c) = \sum_{i=1}^{32} a_i^2 \mathrm{Var}(\bar{C}_i)$$

$$= \sqrt{\mathrm{Var}(\hat{T}_c)} = \sqrt{\sum_{i=1}^{32} a_i^2 \frac{S_i}{\sqrt{n}}} \tag{6}$$

The interval estimate was then obtained from

$$\hat{T}_c \pm Z_\alpha \sqrt{\mathrm{Var}(\hat{T}_c)} \tag{7}$$

where

Z_α = 95% probability.

Use of the Friedman two-way analysis of variance established that the kokanee was the only species that showed any significant difference in rate of entrainment between the six outlet tunnels. Entrainment through the two outside tunnels was found to be significantly higher than entrainment through the four inside tunnels. To establish the greatest precision in the calculation of T_c for kokanee, a weighted weekly average was calculated in the following manner:

$$\bar{C}w_i = \frac{1}{3}\left[\sum_{i=1}^{N_{oi}} Co_{ij}/N_{oi} + 2\sum_{i=1}^{N_{bi}} Cb_{ij}/N_{bi}\right] \tag{8}$$

where

Cw_i = weighted average daily catch for week i,
N_{oi} = number of daily catches in the ith week for outside gates,
N_{bi} = number of daily catches in the ith week for inside gates,
Co_{ij} = j^{th} daily catch in i^{th} week for outside gates,
Cb_{ij} = j^{th} daily catch in i^{th} week for inside gates.

The weekly estimated entrainment rates (T_i) were then calculated from

$$T_i = a_i \bar{C}w_i \tag{9}$$

Assuming that Co_{ij} and Cb_{ij} are independent random variables, an unbiased estimate of the weekly variance was then calculated by

$$\mathrm{Var}(a_i\bar{C}w_i) = \frac{1}{9}\left[\frac{\sum_{i=1}^{N_{oi}} Co_{ij}^2 - N_{oi}\bar{C}o_i^2}{N_{oi-1}}\right] + \frac{4}{9}\left[\frac{\sum_{i=1}^{N_{bi}} Cb_{ij}^2 - N_{bi}\bar{C}b_i^2}{N_{bi} - 1}\right] \tag{10}$$

If N_{oi} or N_{bi} = 1, then E (Var) = 0; however, this was not the case. The estimated seasonal entrainment was calculated in the same manner as before

$$T_c = \Sigma T_i \tag{11}$$

The estimated total variance of the catch was found by

$$\mathrm{Var}(T_c) = \sum_{i=1}^{32} a_i^2 \mathrm{Var}(\bar{C}w_i) \tag{12}$$

Assuming Cw_i are independent random variables, the variance can then be used to calculate the interval estimates about T_c

$$T_c \pm Z_\alpha \sqrt{\sum_{i=1}^{32} a_i^2 \mathrm{Var}(\bar{C}w_i)} \tag{13}$$

where Z_α = 95% normal probability.

The random variable C_{ij} can be modeled by the Poisson distribution with parameter (λV) where λ = the average occurrence of fish in V, the volume of water filtered through the sampling nets each day. The value of V is very large, ranging from 169.8×10^3 cm to 1.542×10^6 cm per day. This caused the value of the parameter (λV) to become extremely large and the Poisson was closely approximated by the normal distribution. Because sample catches were used to calculate the point estimate T_c, the central limit theorem applies and an even closer approximation to the normal distribution was obtained. Therefore, the assumption that the catches ($\bar{C}_i$) are independent random variables appears reasonable.