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DWORSHAK RESERVOIR KOKANEE POPULATION MONITORING

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and

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DWORSHAK RESERVOIR KOKANEE POPULATION MONITORING

Project Progress Report

2001 Annual Report

By

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ABSTRACT

Onsite testing of strobe lights was conducted to determine if they repelled kokanee *Oncorhynchus nerka* away from the turbine intakes at Dworshak Dam. We tested a set of nine strobe lights flashing at a rate of 360 flashes/min placed near the intake of a 90 mW turbine. A split-beam echo sounder was used to determine the effect of strobe light operation on fish density (thought to be mostly kokanee) in front of the turbine intakes. On five nights between December 2001 and January 2002, fish density averaged 110 fish/ha when no lights were flashing. Mean density dropped to 13 fish/ha when the strobe lights were turned on during five additional nights of sampling. This 88% decline in density was significant at the P = 0.009 level of significance based on a paired Student's t test. There appeared to be no tendency for fish to habituate to the lights during the night. Test results indicate that a single set of nine lights may be sufficient to repel kokanee from a turbine intake during the night.

We also used split-beam hydroacoustics to monitor the kokanee population in Dworshak Reservoir during 2001. Estimated abundance of kokanee has continued to increase since the spring of 1996 when high entrainment losses occurred. Based on hydroacoustic surveys, we estimated 3,276,000 kokanee in Dworshak Reservoir in early July 2001. This included 2,069,000 age-0 kokanee (90% CI ± 16.4%), 801,000 age-1 kokanee (90% CI ± 17.8%), and 406,000 age-2 kokanee (90% CI ± 20.5%).

Entrainment sampling was also conducted with split-beam hydroacoustics a minimum of one continuous 24 h period per month. The highest entrainment rates occurred at night with lower discharges and shallower intake depths. Fish movement patterns suggested that they swam "at will" in front of the intakes and may have chosen to move into the turbine intakes.

Based on monthly hydroacoustic sampling in the forebay, we found that kokanee density was low in July and August during a period of high discharge. However, kokanee density was high in late winter when discharge was also high, thus increasing the likelihood of entrainment.

Counts of spawning kokanee in four tributary streams used as an index reached 6,079 fish. This spawner count appeared unusually low considering the high population estimate of kokanee in the reservoir and data collected in previous years.

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INTRODUCTION

Fisheries for kokanee *Oncorhynchus nerka* in the Pacific Northwest are very popular (Wydoski and Bennett 1981; Rieman and Myers 1992). Kokanee feed low on the food chain and may reach densities in excess of 150 harvestable-sized fish/ha even in relatively sterile waters (Maiolie et al. 1991). They also appear to be an ideal fish in fluctuating reservoirs since they rear in the open pelagic zone, and some strains tend to spawn in tributary streams away from the potential impacts of water level fluctuations.

Kokanee, however, can exhibit behavioral tendencies to school and emigrate, resulting in potentially large entrainment losses. Entrainment losses have been documented in Libby Reservoir, Montana (Skarr et al. 1996), Banks Lake, Washington (Stober et al. 1979), and Dworshak Reservoir, Idaho (Maiolie and Elam 1998).

At Dworshak Reservoir, it was estimated that 1.4 million kokanee (95% of the population) were lost through the dam in a period of five months in 1996 (Maiolie and Elam 1998). Thus, entrainment loss of kokanee has been established as the single most important factor contributing to variability in the population in Dworshak Reservoir. In 1996, losses of kokanee were severe enough that they strongly affected the fishery catch success in subsequent years. Years with high discharge have correlated with lower kokanee populations in the reservoir (Maiolie and Elam 1993). When densities are high, Dworshak Reservoir becomes one of the best kokanee fisheries in the state, accounting for a harvest of over 200,000 fish annually. When densities are low, catch rates, harvest, and fishing effort are sharply reduced.

Dworshak Reservoir has also become increasingly important for providing higher river flows to benefit salmon and steelhead. During May, July, and August, large amounts of water are typically released to aid smolt migration and cool water temperatures in the Lower Snake River. This changed operation, however, has the potential to change the number of kokanee that are entrained during the year.

Physically screening Dworshak Dam to prevent fish losses would be very difficult because of high flows (800 m^3/s) and the large amounts of debris within the reservoir. Therefore, one major task of this project is to test behavioral avoidance devices to determine if kokanee and other fish can be deterred from the turbine intakes and effectively decrease entrainment.

Previous studies have achieved good success at affecting the behavior of different species of fish with the use of strobe lights (Patrick 1982; Nemeth and Anderson 1992; Winchell et al. 1994; Ploskey and Johnson 2001). Strobe light testing for this project was first conducted offsite in 1997 in Spirit Lake and Lake Pend Oreille and again in 1998 on Lake Pend Oreille. In 1997, kokanee avoided the strobe lights for the entire night and remained 30 to 136 m away from them in the open water of Spirit Lake (Maiolie et al. 2001b). Lights were found to be even more effective during winter (the season of highest entrainment losses) when water clarity was higher. This report describes our first efforts to test strobe lights on Dworshak Dam. We believed that onsite tests were necessary since the environment near the dam was very different from the pelagic area of natural lakes previously used in the offsite tests. Most notably, these onsite tests were conducted in an area subjected to considerable currents and fish that may be attempting to move downstream.

In addition, we used mobile split-beam hydroacoustics to quantify abundance of kokanee and used kokanee harvested by anglers to obtain samples of fish for aging and population size structure. Kokanee abundance in the reservoir was used to determine the impacts of the current operation of the dam on the kokanee population.

OBJECTIVE

1. To maintain densities of 30 to 50 adult (age-2 and older) kokanee/ha in Dworshak Reservoir by reducing entrainment losses. This should be possible if kokanee entrainment can be reduced by 50% in years of higher than average flows.

DESCRIPTION OF STUDY AREA

Dworshak Dam is located on the North Fork Clearwater River in northern Idaho. At 219 m tall, it is the tallest straight-axis concrete dam in the United States. The U.S. Army Corps of Engineers (USACE) built it in 1971 primarily for power production and flood control. Three turbines within the dam have a total operating capacity of 450 megawatts. The dam can discharge up to 380 m^3/s (10,000 cfs) through the turbines and an additional 420 m^3/s (15,000 cfs) through reservoir outlets and the spillway.

Dworshak Reservoir is 86 km long at full pool (Figure 1). Maximum and mean depths are 194 m and 56 m, respectively. Surface area at full pool is 6,644 ha with 5,400 ha of kokanee habitat (defined as the area over 15 m deep) (Maiolie et al. 1992). Drawdowns for flood control may lower the surface elevation 47 m and reduce surface area by as much as 52%. The reservoir has a mean hydraulic retention time of 10.2 months and a mean annual discharge of 162 m^3/s (Falter 1982). High releases from the reservoir have occurred during spring runoff, during the fall when the reservoir is lowered for flood control, and during late summer when water is released to benefit downstream anadromous fish migrations.

Kokanee were first stocked into Dworshak Reservoir in 1972 (Horton 1981). Four sources of fish were initially used, but the early spawning strain from Anderson Ranch Reservoir, Idaho now populates the reservoir (Winans et al. 1996). These fish spawn during September in tributary streams as far as 140 km above the reservoir. They reach maturity primarily at age-2, although age-1 and age-3 spawners are occasionally found. Adults range in size from 200 to 400 mm total length (TL), depending on the density of fish in the reservoir, but generally average 300 mm during spawning (Maiolie and Elam 1995).

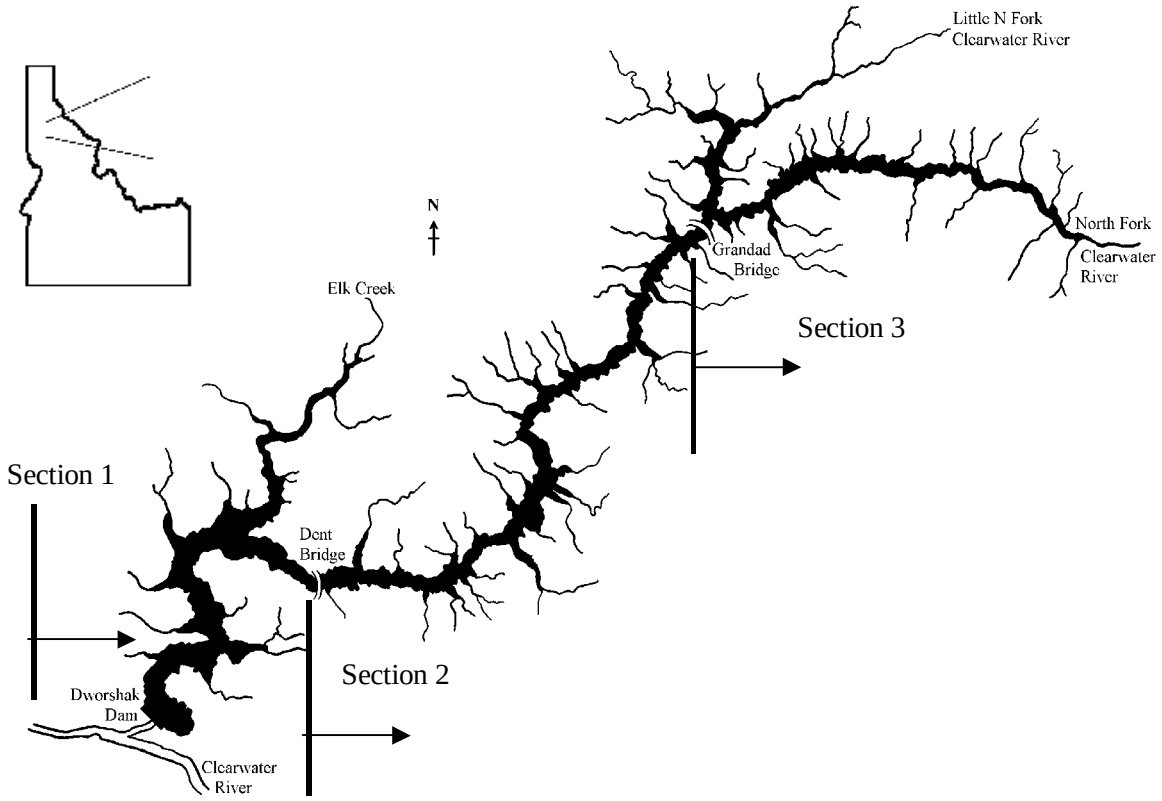

Figure 1. Map of Dworshak Reservoir, major tributaries, and sampling sections, North Fork Clearwater River, Idaho.

METHODS

Strobe Light Testing

Strobe light tests were conducted between December 19, 2001 and January 31, 2002. Two nights were chosen each week: one for a control sample (no strobe lights flashing), and one for a test sample (strobe lights deployed and flashing). A random selection (coin flip) was used to determine which sample (test or control) occurred first each week. On test nights, strobe lights were turned on at dusk and operated until dawn.

Strobe lights were positioned based on the operating condition of the dam. The selector gates on the dam were positioned about 20 m below the surface during our testing ("overshot" mode) (Figure 2). Thus, water was being withdrawn from the surface to a depth of about 20 m. The U.S. Army Corps of Engineers can raise these gates out of the water (undershot mode), which provides a method to withdraw deeper water for temperature control. However, during our tests they remained in the overshot mode. Two whorls of four lights were raised and lowered on a single steel cable. In addition, a single strobe light was pointed directly downward from the lower whorl of lights. Lights in each whorl were pointed horizontally and were positioned 90°

from each other. One whorl of lights was positioned at a depth about 2 m above the selector gate (about 18 m deep) and the second at a depth of about 2 m below the selector gate (about 22 m deep). All lights flashed simultaneously at a rate of 360 flashes/min.

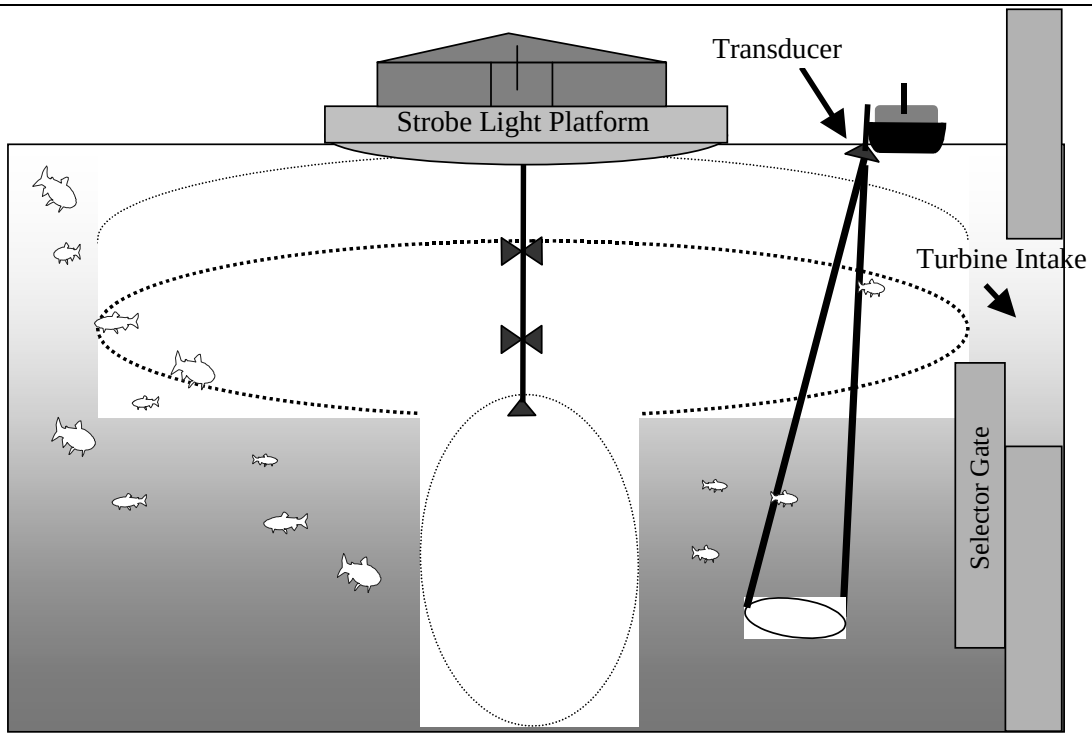

Figure 2. Diagram of strobe light and hydroacoustic equipment setup at Dworshak Dam, Idaho during the testing in 2001 and 2002.

Each hour throughout the night, a single hydroacoustic survey transect was conducted parallel with the face of the dam, about 10-15 m out into the reservoir. Hydroacoustic surveys were conducted using a Simrad EY500 split-beam scientific echo sounder with a 120 kHz transducer. Boat speed was 0.5 to 0.7 m/s. Secchi disc transparencies were also measured for each day of the testing in order to relate strobe light effectiveness to water clarity.

We analyzed the density of fish in an area from 2 m to 50 m deep and 60 m wide directly upstream of the intake of the operating turbine. We configured the echo sounder so that only echoes meeting certain criteria would be regarded as a fish. The length of the returned echo had to be between 0.8 and 1.8 times the length of the echo sounder's ping. The echo could not require more than 4.0 decibels (dB) compensation for being off the acoustic axis, and the target had to be within a 7.1 degree cone. Echoes meeting these criteria were classified as a fish "trace" (a single returned echo from a single fish).

We calibrated the echo sounder at the beginning of the year using a 23 mm copper calibration sphere with a target strength of -40.4 (dB) (at 23°C). We checked the calibration of the echo sounder before each strobe light testing and adjusted the transducer gains if needed (Simrad 1993).

All fish over -45 dB target strength (97 mm TL) were included in the density estimate. Densities were calculated using Simrad's EP500 post processing software, version 5.2. Hourly fish density estimates were averaged for the entire night to comprise one sample. We then used a paired t-test (SYSTAT 2000) of control and test means to determine if differences in fish density existed. Differences were considered significant if $P < 0.05$. Strobe lights were determined effective if fish density were reduced by >50%.

Kokanee Population Estimate

We used a Simrad EY500 split-beam scientific echo sounder with a 120 kHz transducer to document the abundance and distribution of kokanee. Boat speed was 1.5 to 2.3 m/s, and all surveys were conducted at night. The echo sounder was set to ping at 0.7 s intervals, with a pulse width of 0.3 milliseconds. Data were collected with a time varied gain constant of 20 log r (range). Echo sounder calibration and echo recognition criteria were configured as described previously.

Reservoir wide hydroacoustic surveys used a systematic, stratified survey design (Scheaffer et al. 1990). The reservoir was stratified into three sections: from the dam to Dent Bridge (section 1; Figure 1), Dent Bridge to Granddad Bridge (section 2; Figure 1), and Granddad Bridge to the headwaters (section 3; Figure 1). Mean fish density in each section was multiplied by the area of that section and then totaled to obtain population estimates. Ninety percent confidence limits were placed on the total kokanee population estimates using a formula for stratified systematic designs (Scheaffer et al. 1990).

Survey transects were conducted in a "zigzag" fashion from one side of the reservoir to the other, with one transect starting where the previous transect ended. Surveys were conducted on the nights of July 9 and 10, 2001.

Fish density estimates were calculated using EP-500 software, version 5.2. Densities were estimated by echo integration techniques to account for fish within schools that could not be distinguished as single targets. We analyzed only the pelagic region of each echogram, generally from depths of 5 m to 50 m.

We used a target strength frequency distribution to separate kokanee into age classes. The frequency distribution was used to define three peaks that corresponded to the three age classes of kokanee (age-0, age-1, and age-2).

Entrainment

Entrainment sampling was conducted a minimum of one day per month for a continuous 24 h period (Table 1). This monitoring provides baseline information on the time of day fish are entrained, entrainment rate at the different turbine intakes, and the degree of variability in fish entrainment that can be expected between the time of day, seasons, and discharge rate.

A wooden dock was secured to the trash racks of the turbine to be sampled (Figure 3), and the hydroacoustic equipment was set up under a tent on this dock. The echo sounder's transducer was attached to a pole, which was pointed just slightly outward (2-10°) from a line perpendicular with the water's surface. This angle was adjusted for each sampling period depending upon the pool elevation and selector gate mode and depth. The outward angle and

distance from the face of the dam were set to maximize the echogram coverage of the intake opening area yet still ensure that echoes from the face of the dam did not interfere with detecting fish targets.

We used the echo sounder placement and sampling methods described above to document kokanee behavior immediately in front of a single operating turbine intake. Again, echo sounder calibration and echo recognition criteria were configured as described previously.

We analyzed fish movements in a zone from approximately 5.0 m above and below the center of the intake. The center of the intake was considered the depth of the selector gate if in place ("overshot" mode) or the actual center of the intake opening if the gate was removed ("undershot" mode). Fish "traces" were analyzed using EP-500 software version 5.2 with the "Trace Tracking" (pelagic) option. Fish traces were then located within the analysis depth zone to determine the potential number of kokanee entrained. In addition to the aforementioned echo criteria, we set the following "trace tracking parameters." We required a minimum of three detections, a maximum of 30 cm vertical change between detections (consecutive pings), and a maximum of one missing ping per track to qualify targets as a fish "track."

In addition to the software parameters, the following behavioral criteria were also utilized. Fish traces had to continue in a direction towards the intake opening. Specifically, a fish could not head toward the intake for several pings (seconds), then turn away from the intake, then back toward the intake and still be considered entrained. We defined the direction of entrained fish to be a heading >45° off straight parallel with the face of the dam (turbine opening) in either direction. The target strength frequency distribution of "entrained" fish versus "nonentrained" fish was also graphed to determine if size was a factor in fish entrainment.

Fish traces were individually examined with the use of the behavioral window in the EP-500 software. We divided the total number of fish classified as entrained by the number of hours sampled to give us the entrainment rate (fish/h) during each sampling period. This was determined for four time-period strata (dawn, day, dusk, and night). The diameter of the beam (B) at the depth of the intake was calculated with the following equation.

$$\text{Beam diameter (B)} = 2 \times R \times (\text{Tan}\,[\Theta / 2])$$

where: R = range (depth of intake)
Tan = tangent of the angle
Θ = the nominal beam width
(7.1 degrees for the 120 kHz transducer)

The portion (%) of the intake sampled was calculated by dividing the diameter of the beam (B) by the width of the intake (I). The original entrainment estimates were then expanded based on the percent coverage of the acoustic beam during each sample period.

Table 1. Kokanee entrainment sampling conditions, settings, and acoustic beam coverage of and proximities to the turbine intakes of Dworshak Dam, August 13, 2001 through February 26, 2002.

	Turbine Intake						
Date	**#**	**Width (m)**	**Offset Angle (degree)**	**Analysis Depths (top—bottom) (m)**	**Beam Diameter (top—bottom) (m)**	**% of Intake Sampled (top—bottom)**	**Distance From Beam Edge to Dam (m)**
8/13/2001	2	10.6	10.0	11.2—21.2	1.4—2.6	13.10—24.80	3.4—4.5
8/22/2001	2	10.6	5.0	6.8—16.8	0.8—2.1	7.95—19.65	2.3—2.6
11/1/2001	1	10.6	3.0	10.8—20.8	1.3—2.6	12.63—24.33	2.0—1.9
11/19/2001	1	10.6	3.0	11.6—21.6	1.4—2.7	13.57—25.27	2.1—1.9
12/11/2001	1	10.6	4.0	12.4—22.4	1.5—2.8	14.51—26.20	2.3—2.4
1/28/2002	1	10.6	2.0	15.2—25.2	1.9—3.1	17.78—29.48	1.7—1.4
2/7/2002	1	10.6	2.0	14.4—24.4	1.8—3.0	16.84—28.54	1.8—1.4
2/13/2002	3	16.3	2.0	12.4—22.4	1.5—2.8	9.45—17.08	1.8—1.5
2/25/2002	1	10.6	2.0	24.0—34.0	3.0—4.2	28.07—39.77	1.5—1.2
2/26/2002	1	10.6	2.0	24.0—34.0	3.0—4.2	28.07—39.77	1.5—1.2

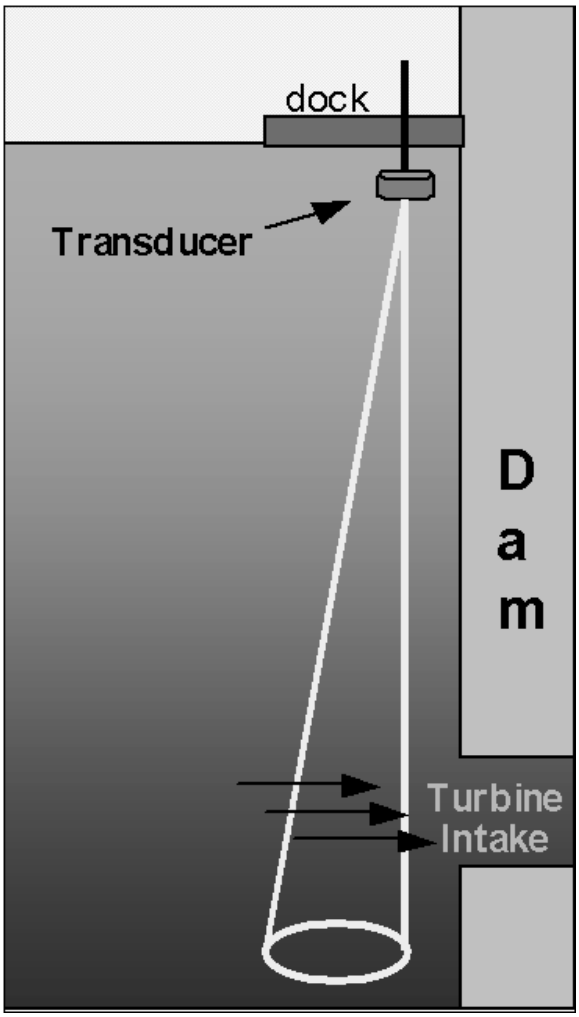

Figure 3. Location of the echo sounding gear used to monitor fish entrainment into turbine intakes of Dworshak Dam, Idaho between August 2001 and February 2002.

Forebay Kokanee Densities

Mobile hydroacoustic surveys were collected along five standardized transects within the forebay of Dworshak Reservoir, one night per month starting in June 2001 (Figure 4). Monthly estimates of kokanee densities in the forebay helped to determine the seasonal changes in kokanee distribution and density near the dam and, therefore, when they may be more susceptible to entrainment. These standardized monthly transects also helped to determine if and when kokanee densities are high enough to statistically test the effectiveness of strobe lights at deterring them from intake areas.

The settings for the echo sounder used in the forebay surveys were identical to those outlined above for the reservoir population estimate. However, only densities were calculated from each month's survey; no population estimates were made. Fish density estimates were also calculated using EP-500 software version 5.2 as previously described for the reservoir population estimate. Only the pelagic region of each echogram was analyzed, generally from depths of 5 m to 50 m over water >15 m deep. Fish density was calculated in each of five transects in the forebay outside of the log boom area and averaged together to obtain a monthly average kokanee density.

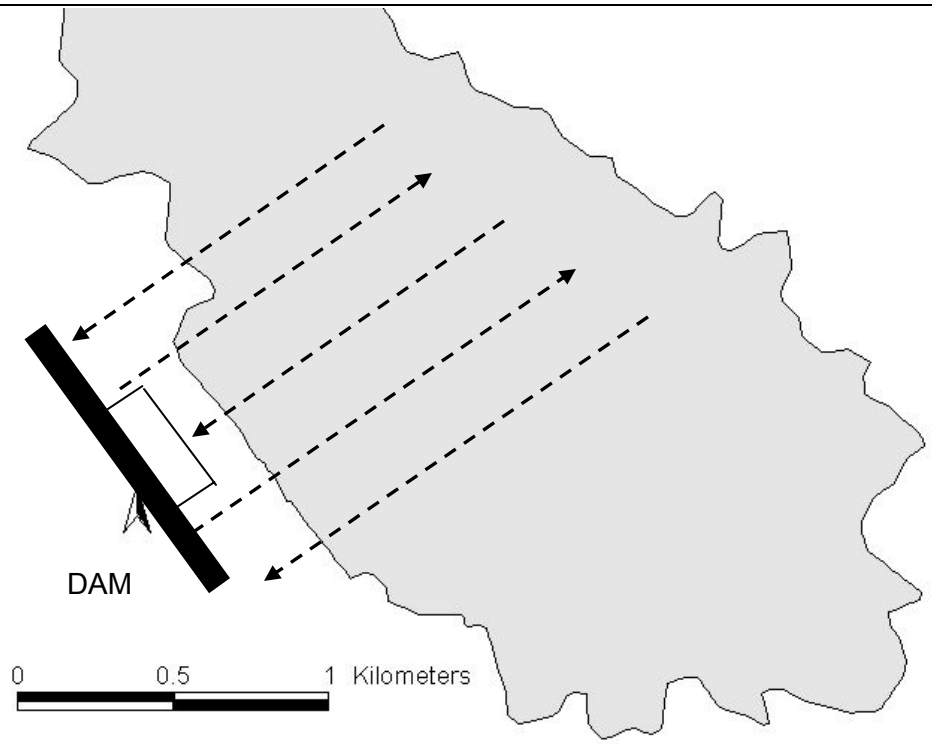

Figure 4. Map of Dworshak Reservoir forebay area and location of forebay density survey transects. Solid black lines represent the dam and log-boomed area; dashed arrows represent direction and location of hydroacoustic sample transects.

Discharge

Data on daily discharge, pool elevation, turbine usage, and spillway operation were obtained from the USACE Dworshak Project Control Room. All discharge values were measured in thousands of cubic feet per second (Kcfs) and were then converted to metric units (m^3/s). Pool elevation is measured as feet above mean sea level (MSL). The time and magnitude of discharge from Dworshak Dam were used to examine correlations between dam operation and kokanee abundance.

Kokanee Aging

Scales from fish caught by anglers were used to determine lengths of age-1 and -2 kokanee. Scales were collected dorsally to the lateral line and posterior to the dorsal fin using techniques described by Nielsen and Johnson (1985). Using a blunt knife, scales were loosened by scraping toward the head. Six to 12 scales were collected from each fish and sealed in a coin envelope labeled with total length and date collected. Scales were prepared by placing them between two glass microscope slides, then taping the sides together. We then aged the scales using a microfiche reader with 24 power lens. Areas of relatively slower growth signifying each winter season or the end of one year's growth (annuli) were counted to determine age. Aging techniques were described by Nielsen and Johnson (1985).

Spawner Counts

We counted kokanee in four tributaries to Dworshak Reservoir on September 24 and 25, 2001. These spawner counts served as an additional relative index of adult population abundance. Spawning kokanee were counted in Isabella Creek, Dog Creek, Skull Creek, and Quartz Creek. We walked these streams from their mouths to the furthest upstream reaches utilized by kokanee. These tributaries have been surveyed annually since 1981 on or near September 25, which was determined to be the peak of kokanee spawning (Horton 1980).

RESULTS

Strobe Light Testing

Fish distribution near the operating turbine changed on nights when the strobe lights were flashing versus nights with no lights (Figure 5). When the lights were off, kokanee tended to form a layer between the depths of 15 m and 50 m near the face of the dam. On nights when the lights were on, kokanee in the area near the turbine intake were fewer in number and showed a more scattered depth distribution.

Fish density was significantly reduced ($P = 0.009$, $df = 40$) when the strobe lights were turned on (test samples) relative to having the lights off (control samples) (Table 2). The mean nightly density of fish near the turbine intakes was 110 fish/ha for control samples and 13 fish/ha for test samples. Individual control samples (a single transect) had fish densities from zero to more than 617 fish/ha, whereas test samples ranged from zero to 91 fish/ha (Figure 6). Thus, strobe lights reduced fish density near the intake by 88%. Secchi transparency values during testing ranged from 5.8 to 6.7 m and averaged 6.2 m.

Table 2. Mean nightly density (fish/ha) of fish in a 48 m by 60 m area directly upstream of the intake to a turbine of Dworshak Dam, Idaho. Test conditions had a set of nine strobe lights flashing at 360 flashes/min, and control samples had no lights flashing. Secchi water transparency (m) was also measured during test periods.

Date	Secchi Transparency (m)	Fish Density (Fish/ha)	
		Control	Test
12/26-28/01	6.7	75	10
1/2-4/02	6.0	129	24
1/17-19/02	5.6	187	13
1/23-25/02	6.3	75	4
1/29-31/02	5.9	84	13
Mean	**6.1**	**110**	**13**

Kokanee Population Estimate

We estimated 3,276,000 kokanee in Dworshak Reservoir in July 2001 based on hydroacoustics. This included 2,069,000 age-0 kokanee (90% CI ± 16.4%), 801,000 age-1 kokanee (90% CI ± 17.8%), and 406,000 age-2 kokanee (90% CI ± 20.5%) (Figure 7). Abundance estimates of fry were highest in section 2 and lowest in section 1 (Figure 8), while estimates of older age classes of kokanee (age-1 and age-2) were similar in sections 1 and 2 but substantially lower in section 3. In contrast to actual numbers of fish present in each section, the densities of kokanee of ages 0, 1, and 2 were highest in Section 3 (1043, 210, and 117 fish/ha, respectively) and lowest in Section 1 (177, 109, and 59 fish/ha) (Figure 9).

Based on a target strength frequency distribution and the lengths and ages of angler-caught kokanee, we defined hydroacoustic echoes between -60 and -47 dB as age-0 kokanee (Figure 10). These were estimated between 25 and 159 mm using Love's (1971) equation. Echoes between -46 and -38 dB were defined as age-1 kokanee (160-249 mm), primarily based on lengths and ages of angler-caught fish (Table 3). Echoes between -37 and -33 dB were defined as age-2 kokanee (250 to 350 mm).

Table 3. Chosen target strengths for each age class of kokanee during the July 2001 hydroacoustic survey in Dworshak Reservoir, Idaho. Table includes length ranges observed for each age class of angler-caught kokanee, as determined by scale aging.

Method	Age-0	Age-1	Age-2	Non-kokanee
Target strength (dB)	-60.0 to -47.0	-46.9 to -38.0	-37.9 to -33.0	> -33.0
Angler catch (mm)	Not sampled	<230	250-340	

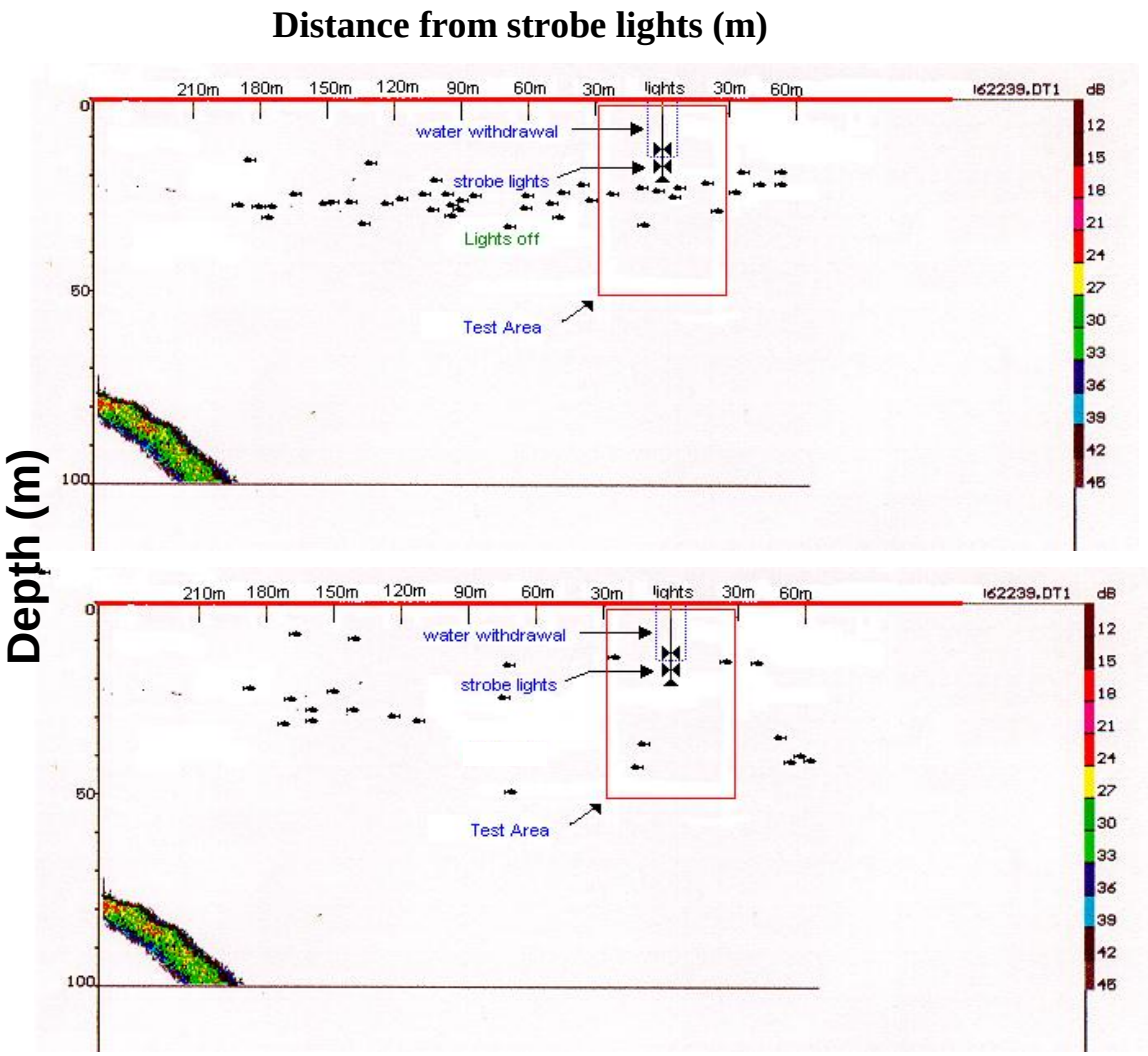

Figure 5. Redrawn echograms showing kokanee distribution in relation to the turbine intakes and strobe lights at Dworshak Dam, Idaho on 10 nights between December 26, 2001 and January 30, 2002. Fish symbols were placed at the location of fish tracks to show the general changes in fish distribution between having the strobe lights off (top echogram) and having the lights on (bottom echogram). Both echograms were compiled from three separate transects. The red box depicts the “test area” in which fish density was calculated. Dotted box indicates the location of the trash racks where water was being withdrawn from the reservoir at the time of the test.

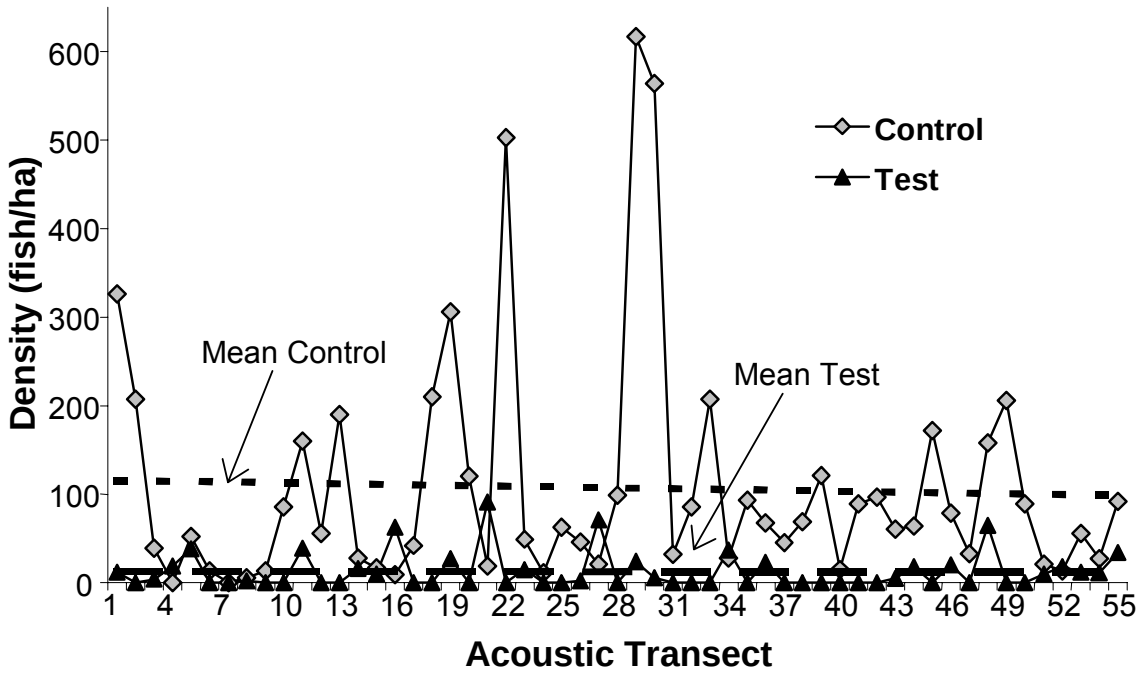

Figure 6. Density of fish in a 48 m by 60 m area near a turbine intake to Dworshak Dam, Idaho. Transects were surveyed by hydroacoustics on 10 nights between December 26, 2001 and January 30, 2002. Diamonds represent fish densities in control samples with the strobe lights turned off and triangles represent test samples when the strobe lights were flashing. Dashed horizontal lines represent the mean of control and test transects.

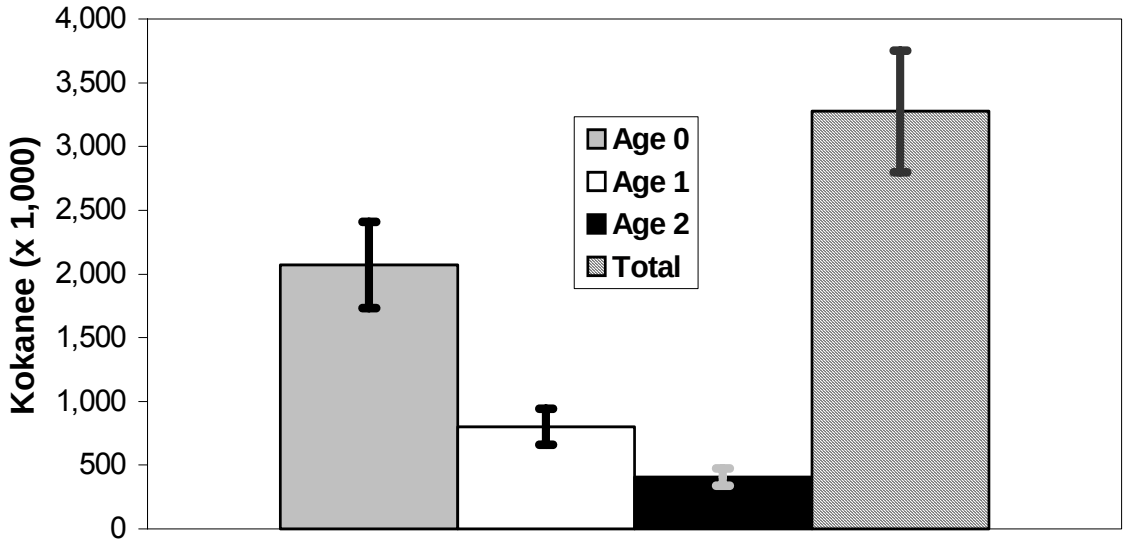

Figure 7. Reservoir-wide abundance estimates for age-0, age-1, age-2, and total kokanee based on hydroacoustic sampling in Dworshak Reservoir, Idaho, July 9 and 10, 2001. Error bars indicate 90% confidence intervals.

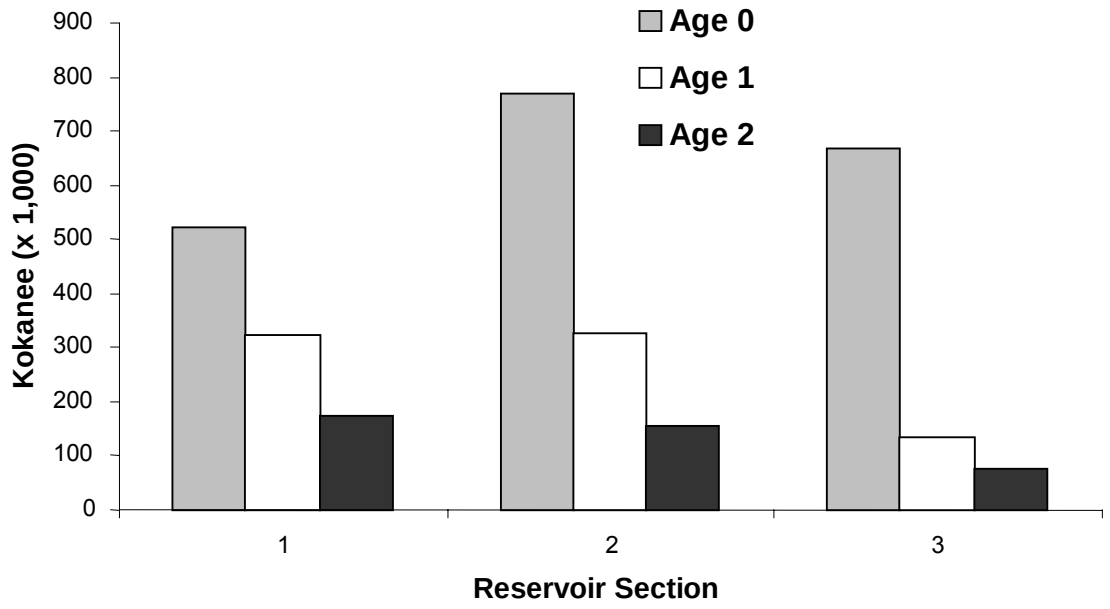

Figure 8. Reservoir-wide abundance estimates for age-0, age-1, and age-2 kokanee, in each reservoir section, based on hydroacoustic sampling in Dworshak Reservoir, Idaho, July 9 and 10, 2001.

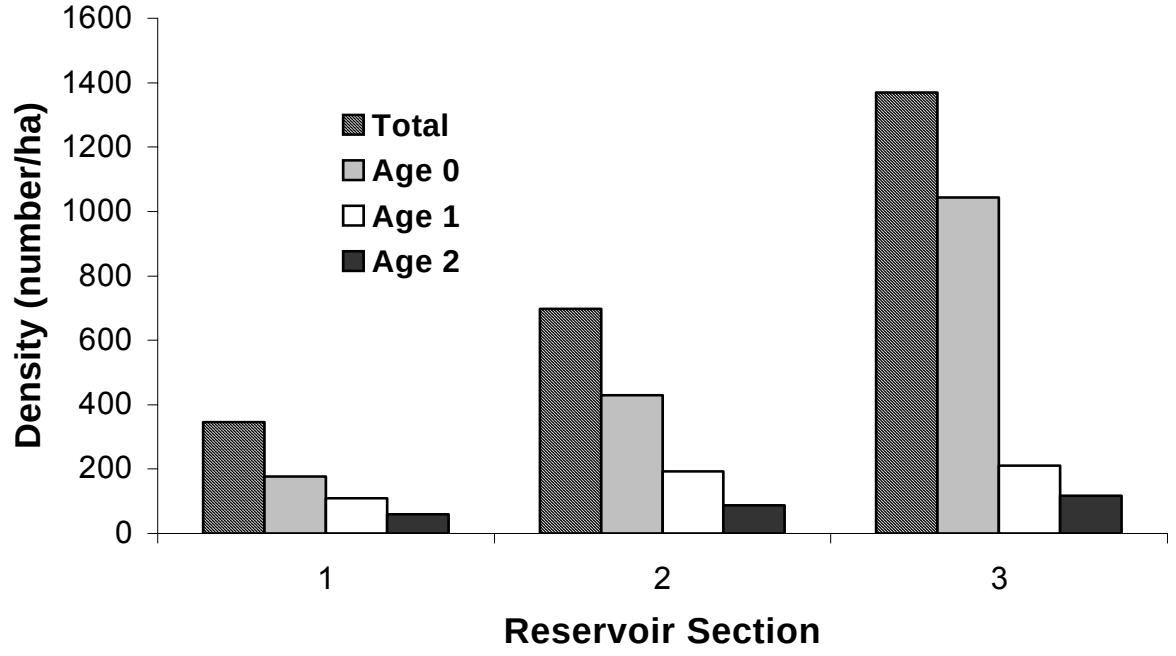

Figure 9. Density of age-0, age-1, age-2, and combined total density of kokanee in each reservoir section based on hydroacoustic sampling in Dworshak Reservoir, Idaho, July 9 and 10, 2001.

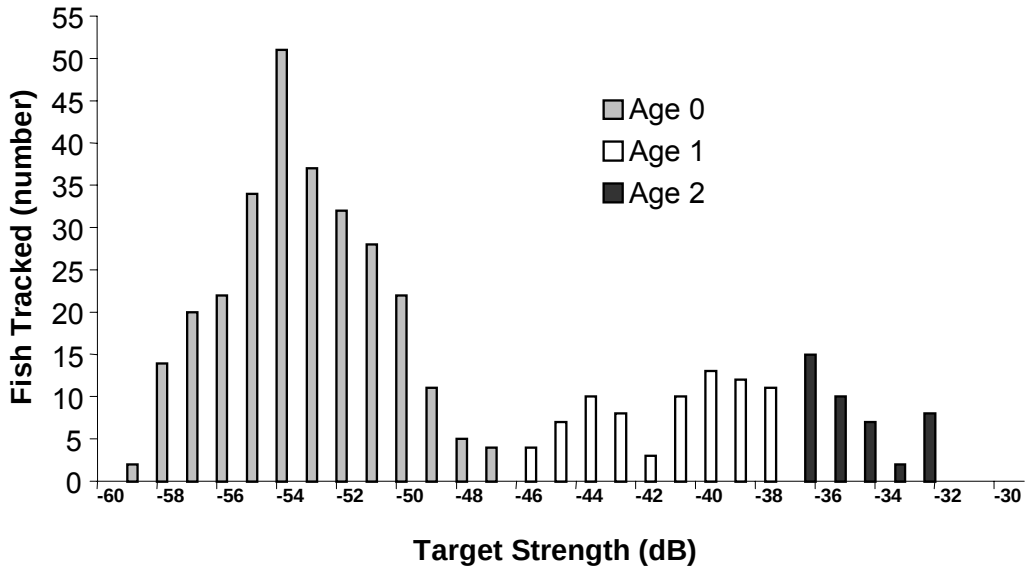

Figure 10. Frequency distribution of fish target strengths sampled with hydroacoustics on Dworshak Reservoir, Idaho, July 9 and 10, 2001.

Entrainment

Low numbers of fish were detected during our entrainment sampling, with even fewer categorized as having been entrained. The highest number of fish were tracked on December 11; however, none were classified as entrained because of their swimming direction. The highest estimate of entrainment (35.7 fish/h) occurred through turbine intake #2 while discharging 65 m^3/s on August 13, 2001 (Table 4). Entrainment estimates of 0 fish/h were obtained for the December, January, and most of February sample periods.

Table 4. Sampling conditions, acoustic coverage, number of tracked fish observed, and expanded entrainment rates from hydroacoustic entrainment sampling, August 2001-February 2002.

Date	Turbine Number	Discharge (m^3/s)	Intake Depth (m)	Acoustic Beam Coverage (%)	Total Fish Tracked	Expanded Mean Entrainment Rate (fish/h)
8/13/2001	2	65	16.2	18.90	135	35.7
8/22/2001	2	65	11.9	13.91	205	29.8
11/1/2001	1	37	15.8	18.54	28	0.6
11/19/2001	1	37	16.5	19.25	50	1.9
12/11/2001	1	40	17.4	20.32	417	0.0
1/28/2002	1	37	20.4	23.89	0	0.0
2/7/2002	1	65	19.5	22.82	1	0.2
2/13/2002	3	167	17.4	13.24	0	0.0
2/25/2002	1	65	29.0	33.87	0	0.0
2/26/2002	1	68	28.7	33.52	0	0.0

The highest mean entrainment (unexpanded) occurred through turbine #2 (5.4 fish/h). Mean entrainment rate through turbine #1 was 0.1 fish/h, while no fish were detected as entrained through turbine #3 (Figure 11) over the days sampled. The highest entrainment also occurred with moderate discharges (Figure 12) and shallower intake depths (Figure 13).

Nighttime sample periods incurred the highest mean entrainment rate (5.1 fish/h), followed by dawn (3.2 fish/h) and day (3.0 fish/h) periods, while no fish were detected as entrained during any of the dusk sample periods (Figure 14).

Analysis of fish traces revealed no consistent behavioral patterns. During every entrainment sampling period, some individual fish (trace tracks) were found to move toward the trashracks, away from the trashracks, or with no particular pattern. Comparison of the frequency distribution of “entrained” fish versus “nonentrained” fish revealed similar size fish in each group (Figure 15).

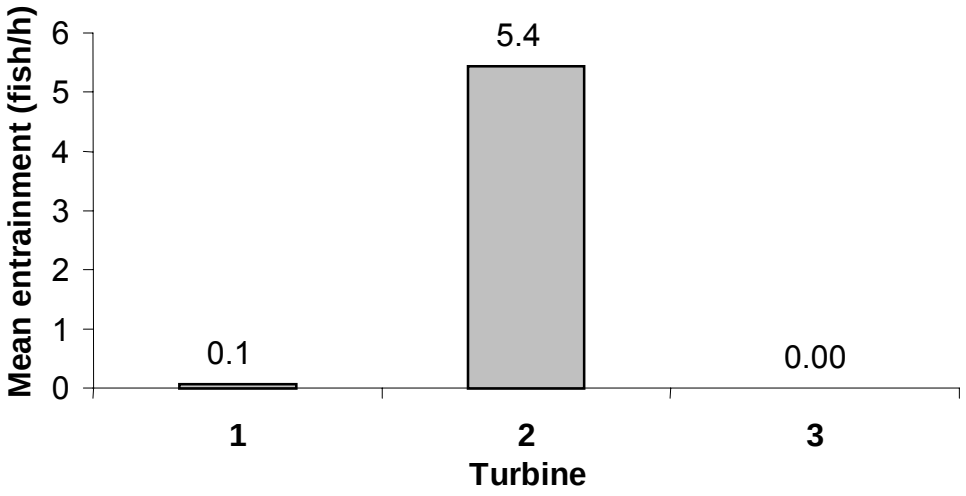

Figure 11. Mean rate of kokanee entrainment (fish/h, not expanded for area of the intake) through each of three turbines of Dworshak Dam, obtained from 24 h hydroacoustic sampling, 2001–2002. Data were collected at different turbines on different days.

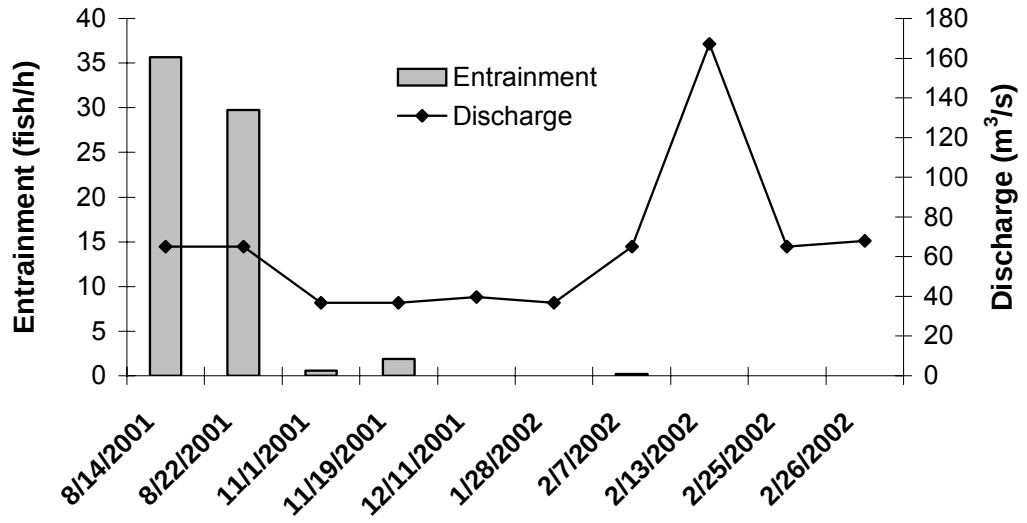

Figure 12. Entrainment rate of kokanee (fish/h) and the discharge rate (m^3/s) of water through the turbines of Dworshak Dam, Idaho. Entrainment data were from 24 h sampling periods and were expanded based upon the percent coverage of the intake openings by the acoustic beam.

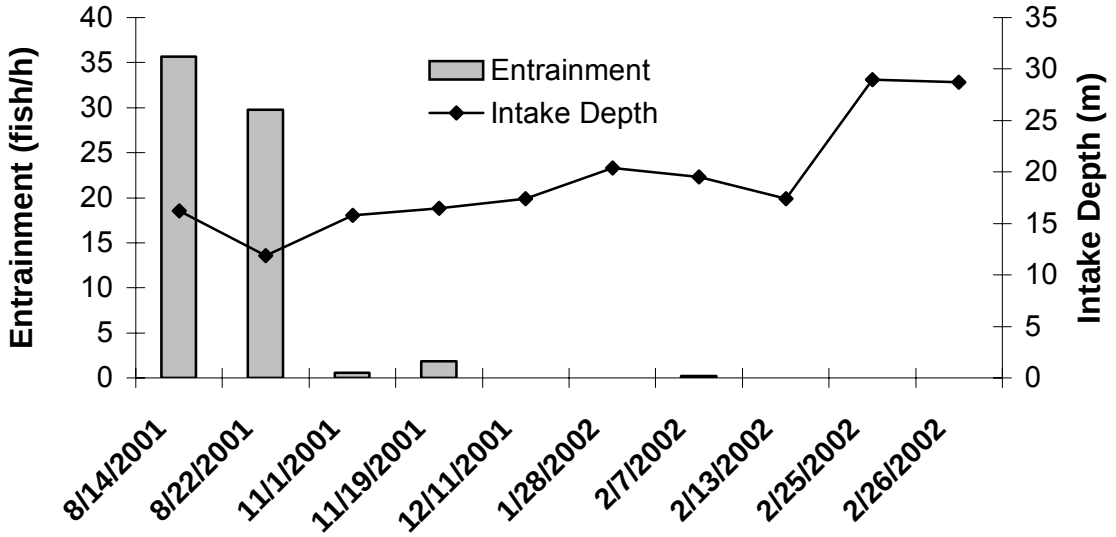

Figure 13. Entrainment rate of kokanee (fish/h) and depth of water discharge (m) through the turbine intakes of Dworshak Dam, obtained from 24 h hydroacoustic sampling, 2001–2002. Rates were expanded based upon the percent coverage of the intake openings by the acoustic beam.

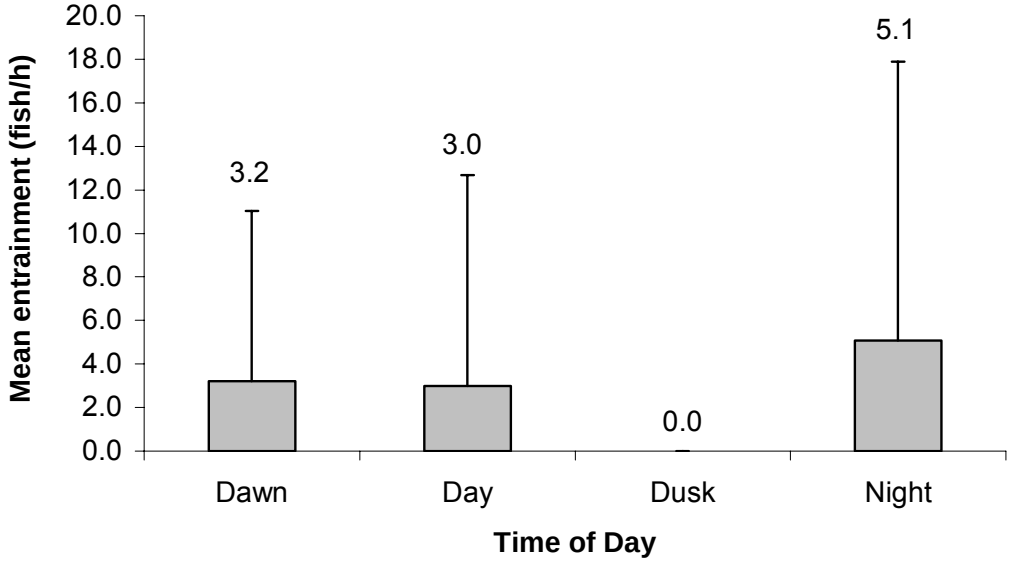

Figure 14. Mean rate of kokanee entrainment (fish/h) through Dworshak Dam for each of four time-of-day strata (dawn, day, dusk, and night), obtained from 24 hour hydroacoustic sampling, 2001–2002. Rates were expanded based upon the percent coverage of the intake openings by the acoustic beam. Vertical bars represent one positive standard deviation of the mean entrainment rates.

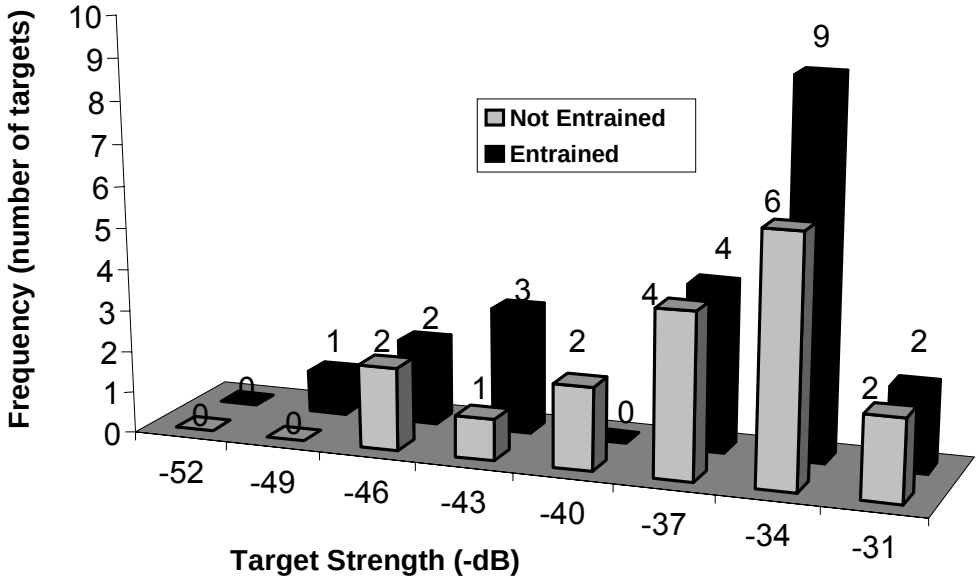

Figure 15. Target strength (fish size) frequency distribution for acoustic targets considered entrained versus not entrained. Target strengths obtained from the July 17-18, 2001 entrainment sample period.

Forebay Kokanee Densities

Fish densities near the dam remained fairly low but stable throughout the summer and fall (Figure 16). During November and December, fish densities in the forebay increased to over 800 fish/ha. The highest density occurred in January when it reached 1,349 fish/ha.

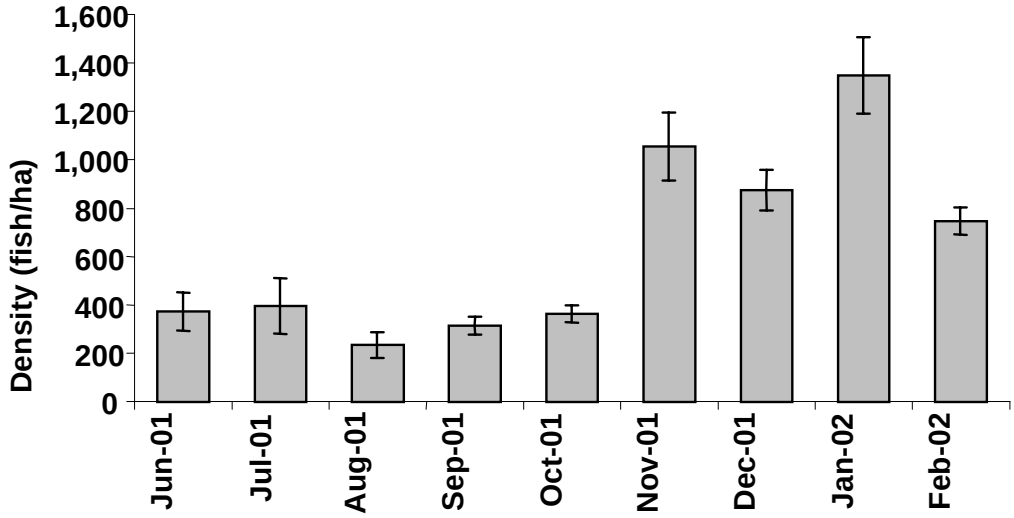

Figure 16. Average fish densities (fish/ha) in the forebay of Dworshak Reservoir, Idaho, obtained from monthly hydroacoustic sampling, 2001 and 2002. Vertical error bars represent 90% confidence intervals.

Discharge

During 2001, mean monthly discharge from Dworshak Dam varied from a low of 34 m^3/s during spring and fall to a high of 303 m^3/s in August (Figure 17). Pool elevation varied with the amount of water discharged according to the USACE operational/rule curve schedule. Pool elevation varied from a low pool of 458 m in late February and early March to a high of 484 m in late June and early July. Dworshak Reservoir did not reach full pool (488 m) during 2001.

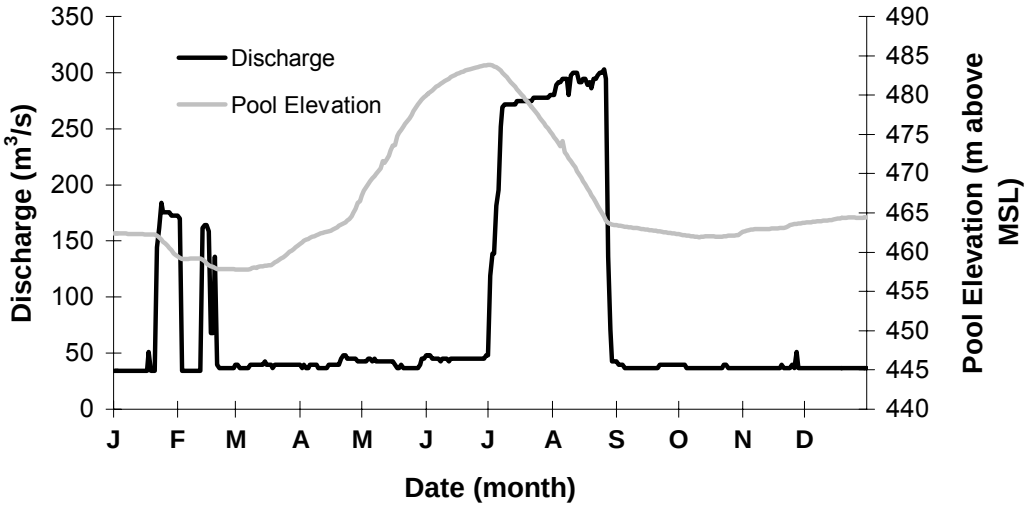

Figure 17. Mean daily discharge rate through Dworshak Dam and Dworshak Reservoir pool elevation (meters above mean sea level) during 2001.

Kokanee Aging

A total of 203 angler caught kokanee were sampled in early July 2001. Creeled kokanee averaged 288 mm TL, with the largest measuring 342 mm (Figure 18). Scale samples and subsequent ages were obtained from a subsample of 54 of the 203 measured kokanee. Scale ages revealed fish were either age-1 or -2. Age-1 kokanee ranged from 188-234 mm TL, and age-2 kokanee ranged from 256-342 mm TL.

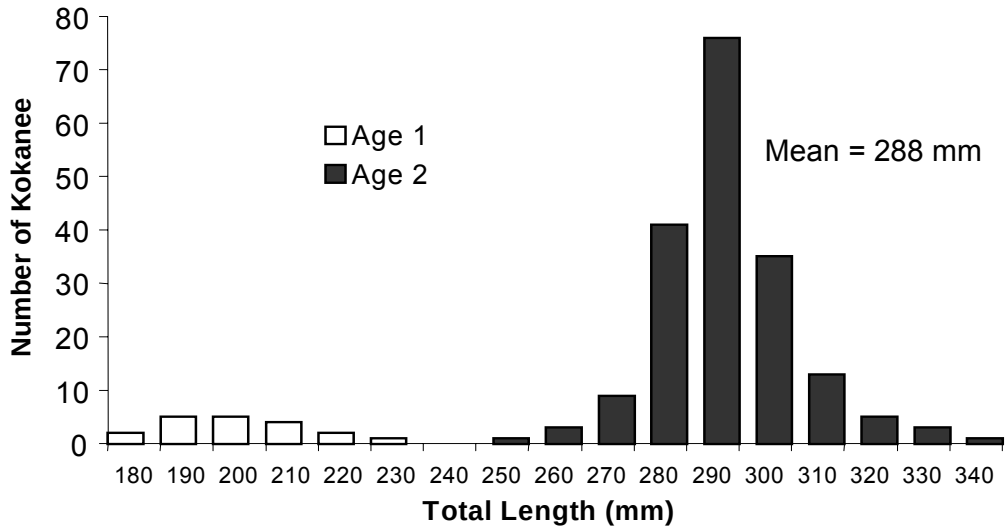

Figure 18. Length frequency of angler caught kokanee from Dworshak Reservoir, Idaho, July 2001. Age classes were based on examination of scale annuli.

Spawner Counts

There was a 29% increase in the number of kokanee counted in spawning tributaries from 2000 (4,465) to 2001 (5,778), and 2001 was the highest year since 1999 (Table 5).

Table 5. Number of kokanee spawners counted in selected tributaries to Dworshak Reservoir, Idaho, during September 1981-2001.

Year	Isabella Creek	Skull Creek	Quartz Creek	Dog Creek	Total (Isabella, Quartz, and Skull)[a]
2001	3751	1305	722	301	5778
2000	3939	402	124	565	4465
1999	10,132	361	827	2,207	11,320
1998	627	20	13	18	660
1997	144	0	0	0	144
1996	2,552	4	13	82	2,569
1995	12,850	20,850	2,780	1,160	36,480
1994	14,613	12,310	4,501	1,878	31,424
1993	29,171	7,574	2,476	6,780	39,221
1992	7,085	4,299	1,808	1,120	13,192
1991	4,053	1,249	693	590	5,996
1990	10,535	3,219	1,702	1,875	15,456
1989	11,830	5,185	2,970	1,720	19,985
1988	10,960	5,780	5,080	1,720	21,820
1987	3,520	1,351	1,477	700	6,348
1986	—	—	—	—	—
1985	10,000	8,000	2,000		20,000
1984	9,000	2,200	1,000		12,200
1983	2,250	135	66		2,451
1982	5,000	4,500	1,076		10,576
1981	4,000	3,220	850		8,070

[a] Total does not include Dog Creek, because it was not censused until 1987.

DISCUSSION

Strobe Light Testing

To our knowledge, the strobe light testing we conducted at Dworshak Dam was the first successful testing that showed kokanee could be repelled from turbine intakes. We can state with a high degree of confidence ($P = 0.009$) that the reduction in fish density while strobe lights were operating was not due to random chance. Even more importantly, the magnitude of the reduction in fish density (88%) was large enough to likely meet our objective of reducing fish entrainment by 50%.

Results from offsite testing conducted on Lake Pend Oreille and Spirit Lake demonstrated excellent effectiveness in repelling kokanee with strobe lights (Maiolie et al. 2001b). We thought this onsite testing was necessary to see if kokanee could be repelled even when there were water currents that could influence fish behavior and when kokanee could be

actively attempting to move downstream (conditions that were not present in the offsite testing). These onsite tests demonstrated success in spite of these factors. Placing the lights 20 m out from the dam effectively deterred fish from entering an area near the turbine intake where water flows were high enough to potentially entrain fish.

Since testing at the turbine intakes was successful, we recommend proceeding with the next phase, which is to test strobe lights at the reservoir outlets on Dworshak Dam. When large numbers of kokanee were entrained in past events, it appeared losses also occurred at the reservoir outlets since we observed dead kokanee near the spillway (the reservoir outlets open onto the spillway). The reservoir outlets present two new challenges. First, they are deeper; 73 m below full pool. Secondly, currents into the reservoir outlets were expected to be much faster because of the increased head. These higher approach velocities could be damaging to strobe lights lowered too close to the dam. Also, at some point as they approach the dam, kokanee may be entrained in the high flows and not be able to move away from the strobe lights. We therefore recommend modeling or measuring water flows near the reservoir outlets before beginning work there.

Strobe light testing to date has been conducted only at night. Effectiveness of strobe lights during the daytime has not been tested but would likely be greatly reduced due to the high levels of background lighting. Daytime testing with our current approach did not appear feasible, because very few fish were seen on the echograms during the day even in control samples. Another limitation of this work was that we only monitored the response of fish over -45 dB, which would consist of kokanee approximately 97 mm TL (Love 1971). Fish below this size were difficult to separate from the ambient noise near the turbine intakes. This was not considered a problem since most kokanee are above this size during January.

Kokanee Population Estimate

Higher abundance estimates in 2001 indicated Dworshak Reservoir kokanee continued to increase since the 95% entrainment losses in 1996 (Maiolie et al. 1999). Adult kokanee densities in 2001 actually exceeded the fish management goal for Dworshak Reservoir of 30-50 age-2 kokanee/ha. It should also be noted that low snowpack since 1997 has resulted in below average water years, with lower than normal average annual discharge through Dworshak Dam and little if any water spilled. Therefore, the opportunity for large entrainment losses has been reduced because of lower discharges.

Stocking 480,000 kokanee fry in 1998 and 890,000 fry in 1999 may have contributed to the increase in kokanee abundance (Stark and Maiolie 2002). These fry were unmarked so the extent to which they helped could not be determined. It was also suggested that stocked kokanee had a different timing of their spawning run, which could have affected the spawner counts. We therefore recommend marking fry if they are needed in the future, so that their benefits can be determined. Techniques such as cold branding of the otoliths during the fry stage were shown to be an effective technique for mass marking large numbers of kokanee fry and tracking their survival (Volk et al. 1990, Maiolie et al. 2002).

Densities of age-0, age-1, and age-2 kokanee (Table 6), as well as spawning kokanee numbers (Table 5), have increased from previous years. In addition, the average fish density is high, yet surprisingly the average size of creeled fish remains large (288 mm; Figure 18). Kokanee growth in 2001 appears to be comparable to recent years with much lower densities.

Growth of this magnitude recruits age-1 fish to the fishery, as evidenced by the length frequency and length at age data (Figure 18 and Table 3).

We are confident that nearly all pelagic fish with target strengths less than -38.0 dB were kokanee based on mid-water trawling from previous years' sampling. However, approximately 127,000 240 mm TL hatchery catchable rainbow trout were stocked into Dworshak Reservoir between March 22 and May 8, 2001. Previous trawl catches of fish ≥250 mm (minimum size of age-2 kokanee) were composed of 33% rainbow trout; therefore, our estimates of age-2 kokanee may include rainbow trout. Currently, kokanee and rainbow trout cannot be differentiated directly with hydroacoustics.

Entrainment

We observed fish moving directly toward the intake openings (perpendicular to the face of the dam), then reversing their course and swimming back towards open water many times during most sampling periods. This behavior suggests fish were moving at will in front of the intakes (milling) and may be voluntarily moving into the turbine intakes at the discharge rates sampled. This would indicate that strobe lights could be fairly effective at repelling kokanee even relatively close to the face of the dam.

Table 6. Estimated abundance of kokanee (thousands) in Dworshak Reservoir, Idaho, 1988-2001.

		Age Classes					
Date	**Sampling Technique**	**0**	**1**	**2**	**3**	**Total**	**Density age-2 & -3 (fish/ha)**
July 2001	Hydroacoustics	1962	781	405	0	3150	75
July 2000	Hydroacoustics	1895	304	199	0	2398	37
July 1999	Hydroacoustics	1143	363	38	0	1544	7
July 1998	Hydroacoustics	537	73	39	0	649	7
July 1997	Trawling	98	0	0	0	65	0
July 1996	Hydroacoustics	231	43	29	0	303	5
June 1995[b]	Hydroacoustics	1635	1309	595	0	3539	110
July 1994	Hydroacoustics	156	984	304	9	1457	69
July 1993	Trawling	453	556	148	6	1163	33
July 1992	Trawling	1043	254	98	0	1043	22
July 1991	Trawling	132	208	19	6	365	5
Sept 1990[a]	Trawling	978	161	11	3	1153	3
June 1989[b]	Trawling	148	148	175	0	471	32
July 1998	Trawling	553	501	144	12	1210	29

[a] September trawling likely resulted in underestimation of the mature fish.
[b] June sampling likely resulted in underestimation of age-0 kokanee.

The entrainment rates of fish were also higher during nighttime sampling periods, as we expected based upon typical kokanee diel depth distribution and movement patterns observed in Dworshak Reservoir. Hydroacoustics has shown a consistent "band" or concentrated "layer" of kokanee during nighttime surveys, whereas during other times, especially during the day, kokanee disperse into lower densities throughout a broader depth range. More importantly

though, this typical nighttime kokanee layer often vertically aligns with the depth range of water withdrawal into the turbine intakes, thereby potentially providing greater vulnerability to entrainment (Figure 19).

The limited data we have to date suggests that kokanee entrainment may be high during summer (Table 4). However, there appears to be a tendency for kokanee density in the forebay to increase during winter (Figure 16). Also, high discharges during winter and spring of 1996 were responsible for large amounts of kokanee entrainment (Maiolie and Elam 1998), suggesting that winter and spring may be more critical. Entrainment rates will continue to be monitored to determine if a seasonal pattern emerges.

Severe noise interference was often encountered while sampling entrainment due to side lobes of the transducer detecting the face of the dam, especially from 15-30 m deep. More efficient coverage of the intakes was obtainable when the reservoir was either near full pool or at low pool, allowing us to sample either below or above the typical band of noise, respectively. Relatively noise free entrainment sampling was attainable when the intakes were quite shallow (<15 m). When the intakes were much deeper (>30 m), we were able to obtain relatively noise-free acoustic recordings and sample a larger area, which was also closer to the face of the dam. In 2002, we purchased an improved transducer designed with smaller side lobes should effectively reduce the amount of noise interference. This new echo sounder and transducer will allow more efficient and closer coverage of the intake opening areas, despite proximity to the face of the dam.

Greater success at determining entrainment rates may be achieved by installing the echo sounder's transducer inside the turbine's penstock, where a greater portion of the water can be acoustically sampled, and water velocities are too high for fish to reverse their course regardless of discharge rate. More consistent entrainment sampling throughout the year and encompassing more operational conditions will provide a better understanding of patterns in kokanee entrainment.

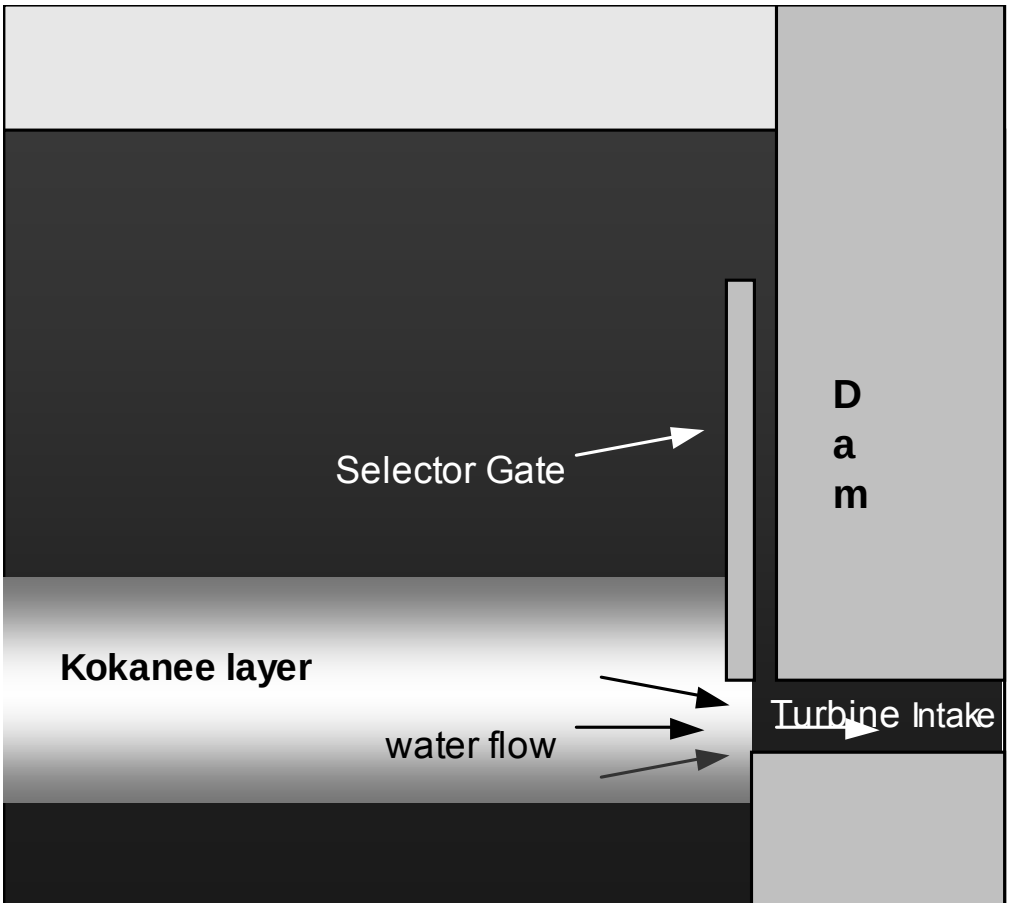

Figure 19. Location of typical nighttime kokanee "layer" and turbine intake opening, illustrating the alignment of fish and discharge distribution and resultant opportunity or susceptibility to entrainment. The selector gate is raised above the turbine intake opening (undershot mode) in this example.

Forebay Kokanee Densities

We found that kokanee densities in the forebay during 2001 were low (Figure 16) during July and August when discharge from Dworshak Dam was increased (Figure 17). High discharge during these months was annually scheduled to aid smolt migration and cool water temperatures in the Lower Snake River. Having fewer kokanee at the lower end of the reservoir during summer would help minimize entrainment losses. Maiolie and Elam (1998) documented a similar pattern. They observed that age-1 and age-2 kokanee moved up the reservoir between April and August of 1995. They also found that age-0 kokanee, which primarily emerge above the reservoir in the North Fork Clearwater River, remained in the upper end of the reservoir until after August of 1995. This pattern of movement would help to explain the low kokanee densities seen in the forebay during the summer of 2001.

We also found that kokanee density was relatively high in the forebay between November 2001 and February 2002 (Figure 16), which coincided with periodic high discharges during January and February (Figure 17). We would expect this to increase the risk of kokanee entrainment, but this was not documented in the February 13, 2002 entrainment sampling.

Discharge

Due to the unusually low snowpack during the winter of 2001-2002, high discharges did not occur during spring runoff (Figure 17). Instead, the highest discharges occurred during July and August when water was released to aid smolt migration. At that time, water was only released through the reservoir outlets and turbines, not over the spillway. Discharge of water from Dworshak Dam during winter and spring of 2001 did not seem to adversely affect kokanee abundance based on the results of the July hydroacoustic surveys (Table 6). The kokanee population in 2001 was at its second highest level since 1988 and showed marked increase over the previous year.

Kokanee Aging

We used kokanee scales and total length measurements from angler-caught kokanee to provide length-at-age data needed for analyzing the hydroacoustic results. However, kokanee less than 180 mm were not present in the creel, and, therefore, did not provide information on the size break between age-0 and age-1 kokanee (Figure 18). We believe a good division between age-0 and age-1 kokanee could be made at –47 dB based on the frequency distribution of target strengths (Figure 10). A recommendation for future work would be to trawl each section of the reservoir to collect representative samples of each age class of fish.

Spawner Counts

We found the percent increase in counts of spawning kokanee (29%) not proportional to the increase in the population estimate of age-2 kokanee (104%) based on hydroacoustic estimates (Figure 20). One concern was that logging activity in these drainages might have reduced the amount of kokanee spawning habitat thus affecting the spawner counts. More kokanee may have been spawning, but they may have gone elsewhere if habitat in these tributaries was reduced. A survey to measure spawning habitat is recommended to document current conditions. Other explanations for the lower than expected spawner count included possible changes in run timing and low water conditions. In particular, the water level in Dog Creek was extremely low, and its streambed was choked with debris; however, Dog Creek was not used in the total spawner counts. Also, it is not known to what extent the hydroacoustic estimate of age-2 kokanee was inflated by the stocking of rainbow trout in the reservoir.

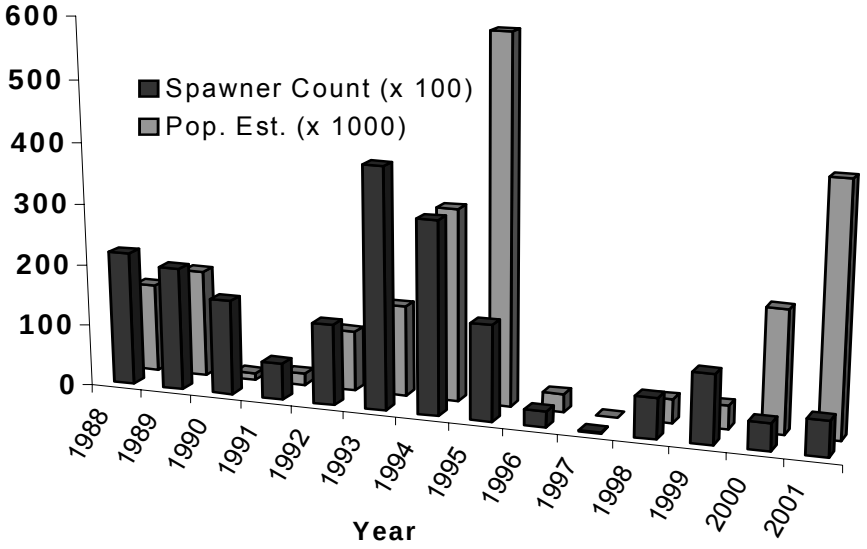

Figure 20. Comparison of annual spawner count (hundreds) and population estimate (thousands) of age-2 kokanee in Dworshak Reservoir, Idaho, 1988-2001.

CONCLUSIONS

Strobe lights can repel kokanee from the area near the intakes to Dworshak Dam during the night. A single set of nine lights appeared to be sufficient to form a barrier in front of one turbine intake. Kokanee density in the reservoir was very high in 2001. Favorable conditions with apparently low entrainment losses in recent years have allowed good growth and survival in Dworshak Reservoir. Adult kokanee (and stocked rainbow trout) densities are above the level needed to maximize catch rates and yield in the kokanee fishery.

RECOMMENDATIONS

1. We recommend the testing of strobe lights at the reservoir outlets to determine if kokanee can be repelled at this location. This testing will require a second set of strobe lights so that a larger area can be illuminated. Greater depths and stronger flows at the reservoir outlets may make them a more difficult location for testing.

2. Detailed measurements of the current velocities near the reservoir outlets should be made before testing. Velocity readings are important to determine at what point fish become entrained by the strong flows and to safeguard the strobe lights.

3. We recommend surveying the spawning habitat within streams used by kokanee to determine condition of the spawning habitat. Low spawner counts this year could indicate that the amount of suitable habitat has declined.

4. If kokanee stocking is required in the future to help recover from large entrainment losses, we recommend newly stocked fish be cold branded or marked in some way to determine benefits and differentiate potentially divergent life history traits.

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