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**STROBE LIGHT TESTING AND KOKANEE POPULATION  
POPULATION MONITORING, DWORSHAK  
ASSESSMENT DAM IMPACTS AND  
FISHERIES INVESTIGATION PROJECT, 87-99**

Annual Progress Report for 1998



DOE/BP-35167-9



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**Strobe Light Testing  
and  
Kokanee Population Monitoring**



**DWORSHAK DAM IMPACTS ASSESSMENT AND  
FISHERIES INVESTIGATION PROJECT, 87-99**

Annual Progress Report  
for 1998  
Contract Number 87BP35167

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The 1998 annual report for the Dworshak Dam Impacts Assessment and Fisheries Investigation Project is provided in the following manuscript. According to our Bonneville Power Administration contract, a journal manuscript may be submitted in lieu of an annual report upon the COTR's request. This request was received and the following manuscript will be sent to the American Fisheries Society for review and publication. Not all of the data collected during 1998 was appropriate to include in this manuscript. Therefore additional data are provided in appendices after the manuscript.

## Response of Free-Ranging Kokanee to Strobe Lights

**Abstract.**-We tested the response of kokanee *Oncorhynchus nerka* to strobe lights. Testing was conducted on wild, free-ranging fish in their natural environment (i.e., the pelagic region of two large Idaho lakes). Split-beam hydroacoustics were used to record the distance kokanee moved away from the lights as well as the density of kokanee in the area near the lights. In control tests, where the strobe lights were lowered into the lake but kept turned off, kokanee remained within a few meters of the lights. Once the lights began flashing, kokanee quickly moved away from the light source. Kokanee were found to move an average of 30 to 136 m away from the lights in waters with Secchi transparencies from 2.8 to 17.5 m ( $p=0.00$  to  $p=0.04$ ). Kokanee densities near the lights were significantly lower ( $p=0.00$  to  $p=0.07$ ) when the lights were turned on than in control samples with no lights flashing. Flash rates of 300, 360, and 450 flashes/min elicited strong avoidance responses from the fish. Kokanee remained at least 24 m away from the lights during our longest test that lasted for 5 h 50 min. Kokanee appeared to be responding to flashes that were well less than 0.00016 lux above background lighting.

Entrainment losses of fish through large hydroelectric facilities is an all too familiar problem. Kokanee *Oncorhynchus nerka* seem particularly susceptible to entrainment. High losses of kokanee have been documented at Libby Dam in Montana (Skaar 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 5 months (Maiolie and Elam 1998). These losses of kokanee were severe enough that they strongly affected the fishery in subsequent years.

Physically screening Dworshak Dam to prevent fish losses would be very difficult because of the high flows ( $800 \text{ m}^3/\text{s}$ ), and the large amounts of debris within the reservoir. Our hope was that strobe lights could be used as a behavioral barrier to prevent fish losses, while avoiding the problems associated with a physical screen. Strobe lights appeared to have potential for affecting the behavior of a number of fish species, including coho salmon *Oncorhynchus kisutch* and chinook salmon *O. tshawytscha* (Nemeth and Anderson 1992), silver salmon *O. kisutch* (Fields and Finger 1956), American shad *Alosa sapidissima* (Taft 1990), alewife *A. pseudoharengus*, smelt *Osmerus mordax*, gizzard shad *Dorosoma cepedianum*, white perch *Morone americana*, spot *Leiostomus xanthurus*, and menhaden *Brevoortia tyrannus* (Patrick and Christie 1985).

We therefore tested the response of kokanee to strobe lights to determine its potential as a behavioral deterrent capable of reducing entrainment losses. Testing was conducted off-site in Spirit Lake and Lake Pend Oreille where kokanee densities were relatively high. All testing was conducted in the pelagic area of these lakes on wild, free-ranging fish.

## DESCRIPTION OF STUDY AREA

Spirit Lake is a natural lake located in the northern panhandle of Idaho near the town of Spirit Lake (Figure 1). It is approximately 526 ha and contains a strong population of kokanee; nearly 1,000 fish/ha based on mid-water trawling. Water depth in the lake where strobe light testing occurred was 20-25 m. The lake's Secchi transparency varied from 3.7m to 4.7 m at the time and location of testing.

Lake Pend Oreille is also located in the northern panhandle of Idaho between the towns of Sandpoint and Bayview (Figure 1). It is a natural lake of about 38,000 ha with a maximum depth of 350 m. Kokanee densities based on trawling were approximately 200 fish/ha, however, concentrations of kokanee were found where densities exceeded 1,000 fish/ha. These areas with higher density were used during our testing. All tests were conducted in the south end of the lake where depths exceeded 100 m. Secchi transparency in Lake Pend Oreille varied from 2.7 m to 17.5 m at the time and location of testing.

We felt confident that nearly all pelagic fish in these lakes were kokanee based on mid-water trawling at night from 1987 to 1994. Trawl catch in the pelagic zone of both lakes was composed of >99% kokanee. These kokanee were the late spawning strain similar to Lake Whatcom kokanee based on their allozyme variability (Winans et al. 1996).

## METHODS

Strobe lights used in these experiments were built by Flash Technologies, Franklin, Tennessee. Four flash heads were supported in the water by a vertical steel cable with the lights pointed horizontally at 90° angles. We could not synchronize the flash heads so that they flashed at the same time. A concrete weight held the lights down (Figure 2). Power was supplied by a 5,000 watt portable generator. During testing, we set the strobe lights to flash rates of 300, 360, or 450 flashes/min.

One boat, which was equipped with hydraulic winches, raised and lowered the lights. This boat was either allowed to drift, or was anchored during testing. A second boat was equipped with hydroacoustic gear. This boat conducted surveys past the first boat to determine the distribution of kokanee in the vicinity of the lights, and to estimate fish densities in the area of the lights (Figure 2). We used a Simrad EY500 split-beam scientific echosounder with a 120 kHz transducer to conduct the hydroacoustic surveys. Boat speed was 1 to 1.5 m/s and all surveys were conducted at night. The echosounder was set to ping at 0.5 to 1.0 s intervals, depending on water depth, with a pulse width of 0.3 milliseconds. We calibrated the echosounder at the beginning of each year using a 23 mm copper calibration sphere with a target strength of -40.4 dB (decibels) (at 23°C). We checked the calibration of the echosounder prior to each test and adjusted the transducer gains if needed. Fish density estimates were calculated using EP-500 software, version 4.5 or 5.2. All fish larger than -60 dB were included in the density estimates. Densities were based on echo integration techniques to account for fish within schools that could not be distinguished as single targets.

We estimated the density of fish within 30 m on either side of the lights and 5 m above and below the lights in most tests. The exception to this was on the October 29, 1998 testing

on Lake Pend Oreille where fish densities were analyzed within 70 m of the lights because of their wider dispersion on this date. We also estimated the distance from the lights to the first group of fish. Distances to the left and right of the lights on each transect were averaged and recorded as the distance for that transect. We used paired Student's t tests to determine significance of changes between the control and test samples. Calculations were made using Systat version 5.03 software.

First, control information was collected at each site. The lights were lowered to the desired depth and the generator was started, but the lights were kept turned off. The hydroacoustic boat then conducted surveys past the strobe lights to record kokanee density and distribution data. One to five surveys were run at different angles past the strobe lights. All of the control transects were averaged and used as a single sample since they were collected at the same location.

Testing was conducted with the strobe lights set at 300, 360, or 450 flashes/min. Hydroacoustic surveys were then conducted past the lights in a similar fashion. We used the boat's radar to keep the transect straight and to insure the transect length was at least 200 m on each side of the strobe lights. The boat was then moved to a different location and the testing was repeated with controls and test samples. Again, all survey transects conducted at the same location were averaged and considered to be a single sample.

All testing was conducted at night. Attempts to test the lights during the day failed because kokanee formed tight schools during the day and were only infrequently seen on the echograms, even in our control samples.

Lights were manufactured so that the brightness of the flash was reduced as the flash rate increased. This was done to prolong the life expectancy of the flash heads, but it meant that two variables (flash rate and brightness) changed during our testing.

During the strobe light testing, we recorded several additional variables to determine their effect on the outcome of our test. These included water clarity (measured by Secchi transparency), water depth, and date.

Tests were also conducted to see if kokanee became habituated to the lights during the night. The boat with the strobe lights was anchored at a single location on Spirit Lake on July 30, 1997. Lights were lowered to the 12 m depth, which was the middle of the kokanee layer. Four control transects were surveyed past the lights during the first 20 min of the test with the lights turned off. Then the lights were turned on at a flash rate of 360 flashes/min. Over the next 5 h 50 min, 16 transects were surveyed past the lights; four at the start of flashing, two each hour during the night, and four at daybreak. A separate analysis to look at the response of larger kokanee was conducted on this test. In addition to analyzing the echograms for all fish over -60 dB (approximately 20 mm), we also analyzed them for fish over -48 dB (approximately 100 mm) (Love 1971).

On June 18, 1997 strobe light testing was conducted on Lake Pend Oreille, Idaho. Testing was conducted in water of >100 m depths to eliminate the effect of light reflecting off of the lake bottom. The boat which held the strobe lights was not anchored and continually drifted during the testing. Thus, each hydroacoustic transect was at a new location and was considered a separate sample for statistical analysis. Twelve control samples, eight tests with the lights flashing at 300 flashes/min, and five tests with the lights flashing at 450 flashes/min

were conducted between 2130 and 0240 hours.

We conducted strobe light testing on February 25, 1998 and October 19, 1998 in Lake Pend Oreille to explore seasonal effects of strobe lights. Secchi transparency at these times were 17.5 m and 9.9 m, respectively.

The brightness of the strobe lights was measured using an International Light Radiometer, Model IL1700. We used this light meter to integrate the amount of light received for one minute, and then we divided the total by the number of flashes to obtain the brightness of light per flash. Light measurements were made at all three flash rates in waters of 9.5m and 6.0 m Secchi transparencies.

## RESULTS

The first test was conducted on May 29, 1997 in Spirit Lake. We tested the response of kokanee to a flash rate of 450 flashes/min. Secchi transparency was 3.7 m, water depth was about 22 m, and the strobe lights were 12 m deep. At each of three sites, density of fish within 30 m of the lights and the distance to the first group of fish was compared between controls (lights off) and test groups (lights flashing). In control samples the mean distance to the fish was 7 m and the mean density was 814 fish/ha. Once the lights were flashing, the distance to the first group of fish increased significantly to a mean of 39 m ( $P=0.036$ ,  $df=2$ ). Fish densities within 30 m of the lights dropped significantly to 138 fish/ha on average ( $P=0.023$ ,  $df=2$ ).

Strobe light testing continued on June 17, 1997 in Spirit Lake. Water depth was about 20 m, and the strobe lights were placed 12 m deep. The mean density of fish was reduced from 1200 fish/ha in control samples to 235 fish/ha when the strobe lights were turned on with a flash rate of 300 flashes/min ( $p=0.071$ ). This was an 80% reduction in fish densities within 30 m of the lights. Fish were repelled from the lights an average distance of 30 m, which was a significant increase from the control samples ( $p=0.006$ ).

On July 30, 1997 a test was conducted in Spirit lake to determine if kokanee would become habituated to the strobe lights. The boat holding the lights was anchored at a single location for the entire night. In four control samples with the lights turned off, fish averaged 1.4 m away from the lights and densities within 30 m of the lights averaged 1,551 fish/ha. Density of larger fish over -48 dB (approximately 100 mm total length) was 1,160 fish/ha within 30 m of the lights in these control samples.

Horizontal distance to the first group of fish increased to 52 m once the lights began flashing. Density of all fish within 30 m of the lights dropped to 343 fish/ha and density of larger fish (over -48 dB) decreased to 0 fish/ha. During the 5 h 50 min of testing, there was a slight tendency for fish to move closer to the lights (Figure 3). However, the last three samples (5 h 36 min to 5 h 50 min) showed that kokanee greater than -60 dB remained an average of 30 m away from the lights, with fish densities of 125 fish/ha within 30 m of the lights (Figure 3). For the entire test, fish were repelled an average of 40 m and densities within 30 m of the lights declined 94% for all fish and 95% for fish larger than -48 dB, (Table 1).

We found during our testing on Lake Pend Oreille, June 18, 1997, that kokanee remained close to the strobe lights in the control samples (lights off). Mean distance to the

first group of fish was 5 m and densities within 30 m of the lights averaged 711 fish/ha. When the lights were flashing at a rate of 300 flashes/min, the mean distance to the fish was 46 m and densities dropped to 139 fish/ha. The distance to the first group of fish was 45 m and densities were 120 fish/ha when the lights were flashing at a rate of 450 flashes/min. The probability that the change in distance and density was due to random chance was  $p = 0.000$ . Secchi transparency during this test was 2.75 m, (Table 1).

We tested a flash rate of 360 flashes/min in Lake Pend Oreille on February 25, 1998. Water had a Secchi transparency of 17.5 m. During this winter test, kokanee moved an average of 119 m away from the lights; significantly further than the mean distance of 13 m seen in control samples ( $p=0.000$ ). Density of fish within 30 m of the lights dropped from 372 fish/ha in control samples to 4 fish/ha once the lights were turned on ( $p=0.002$ ) (Table 1).

Our last test was conducted on Lake Pend Oreille on October 29, 1998. Secchi transparency was 9.9 m. The average distance from the light to the first group of fish was 0 m in the control samples since fish were found directly above and below the lights in all control samples. Once the lights were turned on to flash rates of 360 and 450 flashes/min, fish moved away from the lights a mean distance of 136 m ( $p=0.004$ ). Density of fish within 70 m of the lights dropped from 816 fish/ha to 0 fish/ha once the lights began flashing ( $p=0.015$ ), (Table 1).

Prior to this test, brightness measurements were recorded for the strobe lights in water of 9.5 m Secchi transparency. Flash heads produced a mean brightness of 59 and 56 lux at about 2 cm from the lights at a flash rates of 360 and 450 flashes/min, respectively. Brightness declined logarithmically with distance from the light. At 44 m from the flash head, brightness had decreased to a mean of 0.00016 lux at the 360 flashes/min rate and 0.00019 lux at the 450 flashes/min rate.

## DISCUSSION

We found no response from kokanee during our control (lights off) sampling. The lowering of strobe lights, running the generator, movement of people on the boats, use of boat lights, and repeated hydroacoustic surveys over top of the fish did not affect the distribution or density of kokanee in the vicinity of the lights (Figure 4). Densities of fish near the lights and the densities of fish >200 m away appeared very similar with no apparent change in density or depths.

Kokanee showed a marked change in their distribution almost immediately after the lights were turned on in each and every test (Figure 4). Kokanee appeared to quickly leave the area around the lights, resulting in lower densities. Changes in the distance from the lights to the first group of fish, as well as the reduction in density of fish within 30 m of the lights, were significant at the 95% confidence level in all but one test.

Kokanee responded in both deep (>100 m) and shallower (<25 m) water tests. Thus, the reflection of light off of the lake bottom did not appear to trigger the avoidance response of kokanee. We concluded that the lights would work equally as well if they were positioned over deep water. Little difference was seen between flash rates of 300, 360 and 450 flashes/min, however this was not extensively tested.

Considerable, and statistically significant, reductions in kokanee densities were found in winter as well as spring testing (Table 1). This is important since high entrainment losses at Dworshak Reservoir often occur during winter. Strobe lights proved to be even more effective during winter, most likely because of the clearer water. Water transparency was found to be an important variable in the response of kokanee and explained nearly 70% of the variation in the distance kokanee moved away from the lights (Figure 5).

Kokanee appeared to be responding to light levels well below 0.00016 lux in our tests. This was the brightness at a distance of 44 m from the lights, whereas kokanee avoided the area within 135 m of the lights in tests at similar water clarity. Brightness at 135 m from the lights was below our ability to measure.

The response of kokanee to strobe lights in our study was much more pronounced than the response of many other fish species tested with behavioral deterrent devices. Low frequency sound evoked spontaneous avoidance responses from Atlantic salmon *Salmo salar* if they were within a distance of 2 m (Knudsen et al. 1992). Carlson (1994) summarized an extensive literature base and concluded that salmonids response to sound occurred at less than a few meters in range. The extent of influence of a single pneumatic poppers appeared to be approximately 10 m in repelling adult alewife *Alosa pseudoharengus* (Haymes and Patrick 1986). Other studies which tested strobe lights were conducted in raceways or enclosures where the full effect of distance could not be realized (Nemeth and Anderson 1992, Patrick 1982, Patrick and Christie 1985). Our tests on free-ranging fish allowed us to see that kokanee would react negatively to strobe lights at distances up to 136 m under the right conditions.

This study had several limitations. All testing was conducted at night. The authors suspect that daytime avoidance of the lights would be less since background levels of light would be much higher. Our tests were conducted in the relatively calm waters of lakes. As such, they may not be indicative of kokanee responses in the moving water near the face of a large dam. Our longest test was 6 h. Installation on dams may require the lights to be on for much longer periods of time. Habituation to the lights for periods greater than 6 h has not been tested. Lastly, all testing was conducted in water with Secchi transparencies of 2.8 to 17.5 m. Trends in our data suggest the effectiveness of the lights would be reduced in more turbid water (Figure 5).

Kokanee were lost in very high numbers from Dworshak Reservoir during some years (Maiolie and Elam 1998). Our hope was to find a way to minimize these losses in the future. Strobe lights were shown to reduce total fish entrainment at the Milliken Station at Cayuga Lake, New York (Homa 1994). Results on individual species, however, were mixed. Some species or life stages were repelled while others were attracted at certain times of the year. Kokanee were not present in their study. Strobe lights appeared to show promise for repelling kokanee in our off-site tests. All age classes responded during each season of the year. Further testing, preferably on-site, appears warranted.

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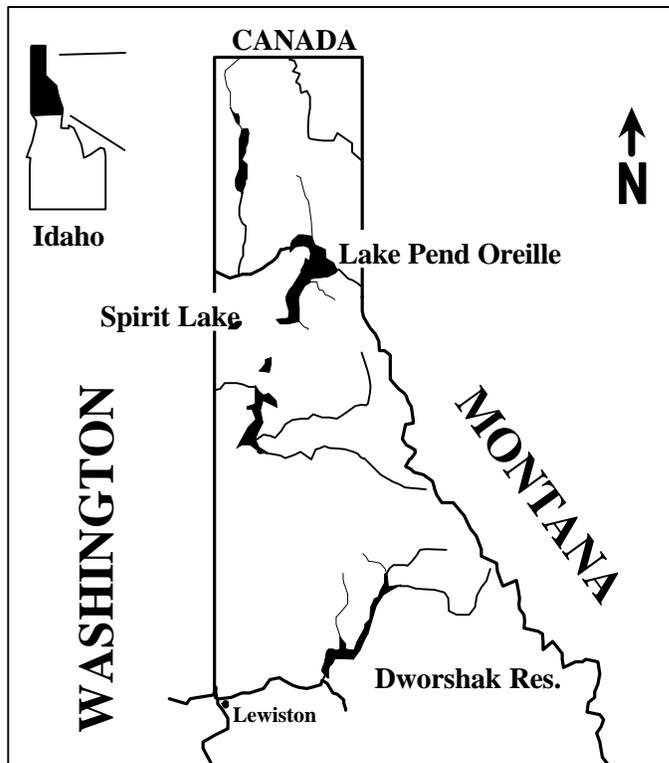


Figure 1. Map of northern Idaho showing the location of the three bodies of water discussed in this study.

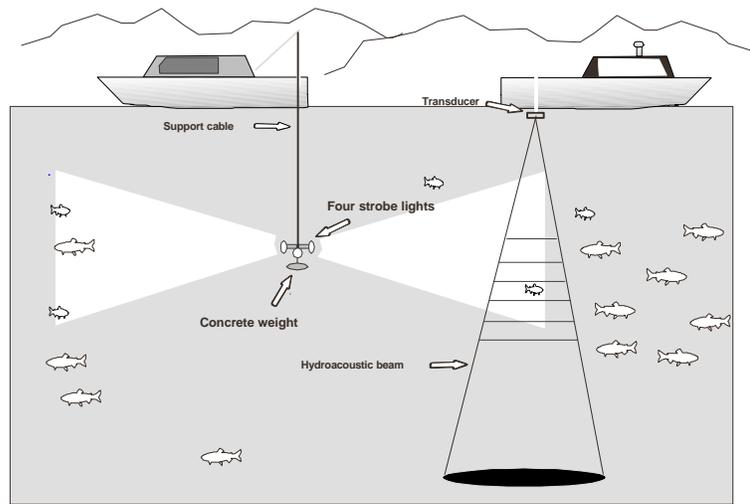


Figure 2. Arrangement of boats in the strobe light tests. One boat raised and lowered the lights while a second one conducted hydroacoustic surveys.

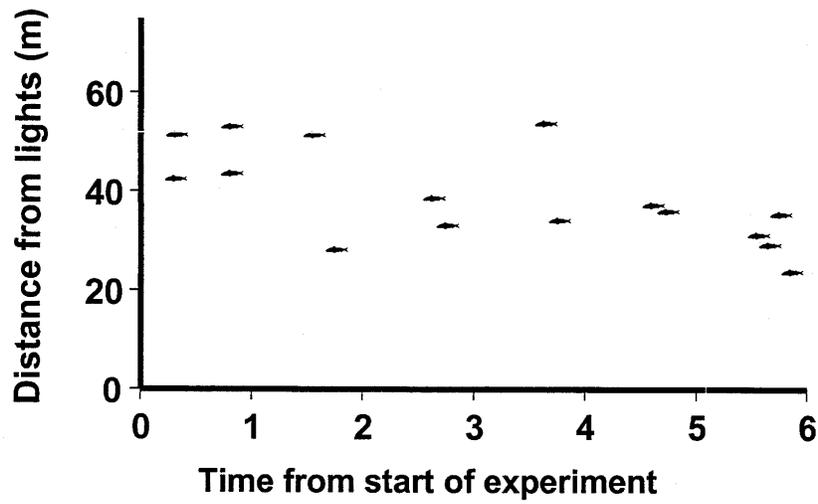


Figure 3. Distances fish moved away from strobe lights during a 6 hour long test. All fish larger than -60 dB were included.

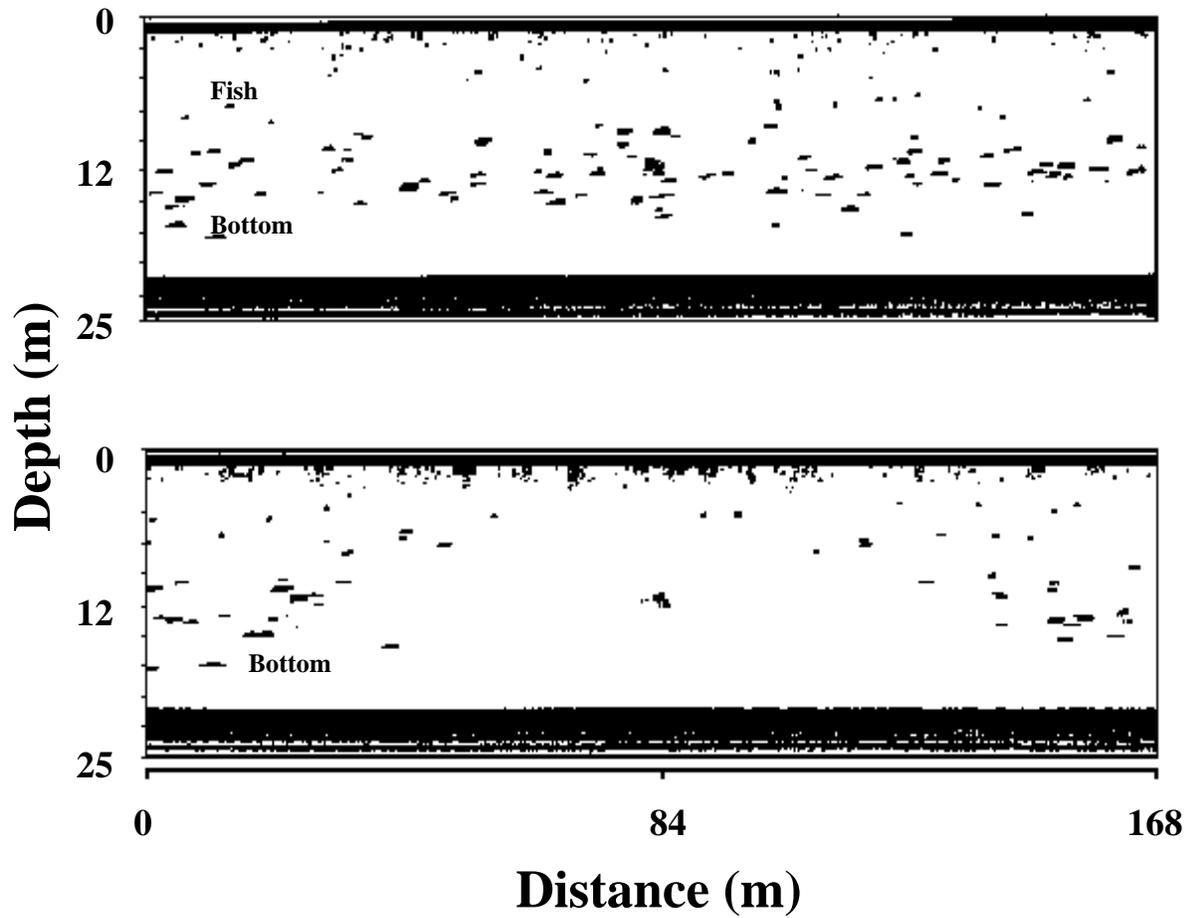


Figure 4. Example echograms of strobe light testing on Spirit Lake, July 1997. Lights were turned off in the top figure (control sample), and were flashing at 450 flashes/min in the lower figure. Circles indicate location of strobe lights

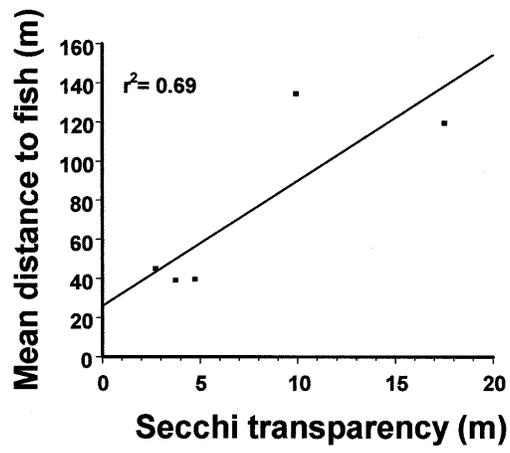


Table 1. Results of testing strobe lights in Spirit Lake and Lake Pend Oreille, Idaho. P-values are given for t-tests between control and test groups.

Lake	Date	Secchi Depth (m)	Flash Rate (flashes/min)	Mean distance to first group of fish (m)	Reduction in fish density within 30 m
Spirit Lake	5/29/97	3.7	450	39, p=0.036	83%, p=0.023
Spirit Lake	6/17/97	-	300	30, p=0.006	80%, p=0.071
Spirit Lake	7/30/97	4.7	360	40, p=0.000	94%, p=0.000
Lake Pend Oreille	6/18/97	2.75	300	46, p=0.000	80%, p=0.000
Lake Pend Oreille	6/18/97	2.75	450	45, p=0.000	83%, p=0.000
Lake Pend Oreille	2/25/98	17.5	360	119, p=0.000	99%, p=0.002
Lake Pend Oreille	10/29/98	9.9	450 and 360 (combined)	136, p=0.004	100%, p=0.015 <sup>a</sup>

<sup>a</sup> Kokanee density estimates were analyzed within 70 m of the lights.

Appendix A.

Number of kokanee spawning in selected tributaries  
to Dworshak Reservoir, 1981 to 1998.

Appendix A. Number of kokanee spawning in selected tributaries to Dworshak Reservoir during September 1981-1999

Year	Isabella Creek	Skull Creek	Quartz Creek	Dog Creek	Total (Isabella, Quartz, and Skull) <sup>a</sup>
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

<sup>a</sup> Total does not include Dog Creek because it was not counted until 1987.

Appendix B.

Estimated abundance of kokanee in Dworshak Reservoir,  
1988 to 1998.

Appendix B. Estimated abundance (thousands) of kokanee in Dworshak Reservoir, Idaho, 1988-1998.

Year	Sampling Technique	Age Class				Total	Density Age-2 and -3 (fish/ha)
		0	1	2	3		
Jul 1998	Hydroacoustic	537	73	39	0	649	7
Jul 1997	Trawling	65	0	0	0	65	0
Jul 1996	Hydroacoustic	231	43	29	0	303	5
Jun 1995 <sup>b</sup>	Hydroacoustic	1,635	1,309	595	0	3,539	110
Jul 1994	Hydroacoustic	156	984	304	9	1,457	69
Jul 1993	Trawling	453	556	148	6	1,163	33
Jul 1992	Trawling	1,043	254	98	0	1,043	22
Jul 1991	Trawling	132	208	19	6	365	5
Sep 1990 <sup>a</sup>	Trawling	978	161	11	3	1,153	3
Jun 1989 <sup>b</sup>	Trawling	148	148	175	0	471	32
Jul 1988	Trawling	553	501	144	12	1,210	29

<sup>a</sup> September trawling likely resulted in underestimation of the mature fish.

<sup>b</sup> June sampling likely resulted in underestimation of age-0 kokanee.