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Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Chief Joseph Kokanee Enhancement Project

Strobe Light Deterrent Efficacy Test and Fish Behavior Determination at Grand Coulee Dam Third Powerplant Forebay

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Prepared for the Bonneville Power Administration
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under Contract DE-AC06-76RL01830

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(a) Colville Confederated Tribes, Nespelem, Washington.

Summary

Since 1995, the Colville Confederated Tribes have managed the Chief Joseph Kokanee Enhancement Project as part of the Northwest Power Planning Council's (NWPPC) Fish and Wildlife Program. Project objectives have focused on understanding natural production of kokanee (a land-locked sockeye salmon) and other fish stocks in the area above Grand Coulee and Chief Joseph Dams on the Columbia River.

A 42-month investigation concluded that entrainment at Grand Coulee Dam ranged from 211,685 to 576,676 fish annually. Further analysis revealed that 85% of the total entrainment occurred at the dam's third powerplant. These numbers represent a significant loss to the tribal fisheries upstream of the dam.

In response to a suggestion by the NWPPC's Independent Scientific Review Panel, the scope of work for the Chief Joseph Kokanee Enhancement Project was expanded to include a multiyear pilot test of a strobe light system to help mitigate fish entrainment. This report details the work conducted during the first year of the study by researchers of the Colville Confederated Tribes in collaboration with the Pacific Northwest National Laboratory (PNNL).

The objective of the study was to determine the efficacy of a prototype strobe light system to elicit a negative phototactic response in kokanee and rainbow trout. Analysis of the effect of strobe lights on the distribution (numbers) and behavior of kokanee and rainbow trout was based on 51, 683 fish targets detected during the study period (June 30 through August 1, 2001). Study findings include the following:

- Analysis of the count data indicated that significantly more fish were present when the lights were on compared to off. This was true for both the 24-hr tests as well as the 1-hr tests. Powerplant discharge, distance from lights, and date were significant factors in the analysis.
- Behavioral results indicated that fish within 14 m of the lights were trying to avoid the lights by swimming across the lighted region or upstream. Fish were also swimming faster and straighter when the lights were on compared to off.
- The behavioral results were most pronounced for medium- and large-sized fish at night. Medium-sized fish, based on acoustic target strength, were similar to the size of kokanee and rainbow trout released upstream of Grand Coulee Dam.

Based on this study and general review of strobe lights, the researchers recommend several modifications and enhancements to the follow-on study in 2002. The recommendations include:

- modifying the study design to include only the 24-hr on/off treatments, and controlling the discharge at the third powerplant, so it can be included as a design variable.
- providing additional data by beginning the study earlier (mid-May) to better capture the kokanee population, deploying an additional splitbeam transducer to sample the region close to the lights, and increasing the number of lights to provide better definition of the lit and unlit region.

Acknowledgments

We sincerely acknowledge the cooperation, assistance and dedication of the following persons:

- Pacific Northwest National Laboratory Staff: Kenneth Ham (scientific input), John Thomas (statistical guidance), Gene Ploskey (scientific input), Misty Nelson (on-site technician), Jake Tucker (mechanical engineering and computer networking), Andre Coleman and Duane Ward (fish distribution maps), Mark Weiland (field calibration), Andrea Currie (technical editor), Lila Andor (text processing), Staci Maloof (public relations)
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- Colville Confederated Tribe: Charlie Joseph (on-site technician), Rod Stensgar (Colville Tribal Hatchery – logistical support)
- Colville Tribal Enterprise Corp.: Lois Wilke (controller) and her staff (provided office space and support)
- Fish Size Data: Gene Smith (Lake Roosevelt Net Pen Coordinator), Mitch Combs (provided fish length data from net pen operations)
- U.S. Geological Service: Dan Feil (currently with U.S. Army Corps of Engineers), Dennis Rondorf, Tim Darland (acoustic tag tracking task)
- BioSonics, Inc.: Jim Dawson (set up DT6000)
- Bluewater Engineering: Tony Petrillo (provided and set up DGPS units)
- Columbia Navigation: Eric Weatherman (setting buoys)
- Terra Byte Systems: Alan Cain and Gabriel Cain (wireless communications and ISP)
- Precision Acoustic Systems: Alan Wirtz (hydroacoustic equipment support)
- Flash Technologies, Inc.: Ron Brown and Kevin Kennemer (provided strobe lights and support)
- Idaho Fish and Game: Melo Maoilie (scientific input; provided light calibration instrumentation).

Abbreviations Used in This Report

ac	alternating current
af	acre-foot, acre-feet
dB	decibel
dc	direct current
DGPS	digital global positioning system
DNA	deoxyribonucleic acid
h	hour
hr	hour
kHz	kilohertz
lx	lux
m	meter
mi	mile
MW	megawatt
NWPPC	Northwest Power Planning Council
PLC	programmable logic controller
PNNL	Pacific Northwest National Laboratory
pps	pings per second
s	second
V	volt

Glossary

anadromous	ascending rivers from the sea for breeding
decibel	dimensionless unit used to express logarithmic ratios of sound intensity; abbreviated as **dB**
diel	involving a 24-hour period that usually includes a day and the adjoining night (e.g., diel fluctuations in temperature)
forebay	a reservoir or canal from which water is taken to run equipment (e.g., a turbine)
hectare meter	the metric unit of volume used to measure the capacity of reservoirs – In the United States, the *acre-foot* is used more commonly. One acre-foot contains 43 560 cubic feet or about 1233.482 cubic meters (0.123 348 hectare meter).
hydroacoustics	the use of transmitted sound to track or count objects (e.g., fish) in water
lumen	SI unit for measuring the flux of light produced by a light source or received by a surface.
lux	SI unit for measuring the illumination of a surface - One lux is defined as an illumination of one lumen per square meter.
penstock	a sluice or gate for regulating flow of water
phototaxis	reflex translational or orientational movement by a freely motile organism in relation to stimulation from a light source
ping	a burst of transmitted sound
target strength	a measure of the proportion of sound (in decibels) reflected back to the transducer from an acoustic target (e.g., fish) – The strength of the return is dependent on the size and orientation of the object.
thermocline	the region in a thermally stratified body of water that separates warmer oxygen-rich surface water from cold oxygen-poor deep water and in which temperature decreases rapidly with depth
tortuosity	the extent to which a fish’s behavior is marked by repeated turns
track	a trajectory associated with a single target

transducer	a pressure-sensitive device that converts electrical energy into sound energy for sound transmission, and sound energy into electrical energy during reception
transect	a sample area of the study site, usually in the form of a long continuous strip
turbidity	the extent to which water is thick or opaque with sediment
wind rose	graphic representation commonly used to present frequency distributions of wind direction – The wind direction frequencies are arranged in “petals” aligned with the wind directions.

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1.0 Introduction

1.1 Background

The construction of Grand Coulee and Chief Joseph Dams on the Columbia River in 1933 and 1956, respectively, resulted in the complete extirpation of the anadromous fishery above these structures. Today, the area above the two dams is totally dependent upon resident fish resources to support local fisheries. Target species in the existing fishery include, but are not limited to, kokanee salmon (*Oncorhynchus nerka*), rainbow trout (*Oncorhynchus mykiss*), white sturgeon (*Acipenser transmontanus*), and walleye *(Stizostedion vitreum*). Kokanee, a land-locked sockeye salmon, is a species of special interest because of its historical significance to native cultures and its role in the functioning ecosystem within the affected area. Factors limiting hatchery kokanee stocks in Lake Roosevelt, the reservoir behind Grand Coulee Dam, are related to annual water regimes, shoreline spawning, fish entrainment, and forage production (Scholz et al. 1985; Peone et al. 1990; Griffith and Scholz 1990).

The Chief Joseph Kokanee Enhancement Project, managed by the Colville Confederated Tribes, was accepted into the Northwest Power Planning Council's (NWPPC) Fish and Wildlife Program in 1995. Project objectives have focused on several critical gaps relating to natural production of kokanee stock or stocks. Specific objectives include

1. assessment of annual adult spawning abundance in tributary habitats

2. micro-satellite analysis of deoxyribonucleic acid (DNA) to determine the specific origin of all kokanee stocks found in Lake Roosevelt, Lake Rufus Woods, and other up-river stocks, including the "free-ranging" up-river kokanee stocks found in the Spokane River/Coeur d'Alene Lake system, the Lake Pend Oreille/Pend Oreille River system, the Arrow Lake system, and the Kootenai Lake/River system of British Columbia

3. use of hydroacoustic technology to determine fish entrainment rates and species composition at Grand Coulee Dam and to quantify fish distributions at the dam relative to hydropower operation and time of day.

A 42-month entrainment investigation concluded that entrainment at Grand Coulee Dam was substantial, ranging from 211,685 to 576,676 fish annually (LeCaire 1999; Sullivan 2000). These studies found that high entrainment was potentially correlated with annual reservoir water regimes, hydropower operations, and reservoir net pen and hatchery releases. Further data analysis determined that entrainment was highest (85%) at the dam's third powerplant (LeCaire 1999; Sullivan 2000).

The Independent Scientific Review Panel of the NWPPC suggested that because entrainment was substantial, something needed to be done to mitigate this loss of resident fish. The panel further suggested that studies conducted at Dworshak Dam and other areas in Idaho by Idaho Fish and Game indicated that kokanee avoided areas illuminated by strobe lights (Maiolie 2001).

There is a long history of using lights to affect the movement of fish. Brett and MacKinnon (1953) examined the use of lights and bubbles to keep migrating juvenile salmon away from turbines. Their results were similar to those found in subsequent studies; that is, the response is species-specific. The response to light can be affected by factors such as turbidity (McIninch and Hocutt 1987) and fish age (Kwain and MacGrimmon 1969; Anderson et al. 1988; Fernald 1988). Strong avoidance response has been noted for chinook salmon smolts during nighttime hours (Amaral et al. 2001; Mueller et al. 2001), while in another study the density of juvenile salmon was lower when lights were on during daylight (Johnson et al. 2001). Juvenile rainbow trout (10 months) showed a preference for darkness when given the choice between light (0.01 lx) and darkness. The minimum threshold was between 0.01 and 0.005 lx (Kwain and MacGrimmon 1969). Younger fish generally show a stronger aversion to light than do adults (Hoar et al. 1957). This is probably related to predator-prey relationships, where younger fish are more vulnerable to predation and so avoid the light, while older fish become the predator and thus are less likely to shun light. Fish not responding to lights include cutthroat trout fry and hatchery-reared trout (Brett and MacKinnon 1953) and eastern brook trout (Mueller et al. 2001). Studies of kokanee exposed to strobe lights showed an immediate avoidance reaction to the lights, with a more pronounced response in winter when turbidity was reduced (Maiolie et al. 2001).

The scope of work for the Chief Joseph Kokanee Project was modified to include a multiyear pilot test of a strobe light system to help mitigate fish entrainment. This report details the work conducted during the first year of the study by researchers affiliated with the Chief Joseph Kokanee Project and the Pacific Northwest National Laboratory (PNNL).

1.2 Study Goal

The goal of the study in 2001 was to assess the efficacy of a prototype strobe light system to elicit a negative phototactic response in kokanee and rainbow trout at the entrance to the forebay adjacent to the third powerplant at Grand Coulee Dam.

1.3 Report Contents

Section 2.0 of this report describes the study site at Grand Coulee Dam. Section 3.0 provides the methods for hydroacoustic techniques and statistical analysis. Results and discussion are presented in Section 4.0. Section 5.0 lists the conclusions and recommendations based on the study results. References are in Section 6.0. Appendices A through E provide supporting information: ancillary data collected during the study, fish distributions from additional hydroacoustic transects, statistical analysis, additional figures supporting the results, and results from the calibration of the strobe lights and hydroacoustic system.

2.0 Study Site Description

The study of the strobe light system was conducted on Lake Roosevelt, the reservoir behind Grand Coulee Dam. Details of the overall study site are presented in this section.

2.1 Grand Coulee Dam

Grand Coulee Dam, located at river kilometer 960.1 (mile 596.6) on the Columbia River, was the second of eight federal locks and dams constructed on the Columbia (Figure 2.1). The dam complex contains four powerplants (pumping plant, left powerplant, right powerplant, and third powerplant), and a spillway (Figure 2.2). Construction of the main dam complex (left and right powerplants and spillway) began in December 1933 and was completed in 1942. Construction of the pumping plant was initiated in 1946 and completed in 1951. Four additional pump/generators were added to the pumping plant in 1983.

Construction of the third powerplant and forebay dam began in 1967, with the first unit (G-19) commissioned in 1975 and the last (G-24) in 1980. The original dam was modified for the third power-plant by adding a 357-m (1170-ft) -long, 61-m (201-ft) -high forebay dam along the right abutment approximately parallel to the river and at an angle of 64 degrees to the axis of Grand Coulee Dam. Each of the six generators at the third powerplant is fed by an individual penstock approximately 12 m (40 ft) in diameter and carrying up to 990 cubic meters per second (35,000 cfs) of water (Figure 2.3).

The 33 generators at Grand Coulee have a total generating capacity of 6809 MW. Table 2.1 shows the distribution of power generation at various locations within the dam. The spillway, situated between the left and right powerplants, is 498 m (1635 ft) long with 11 spill gates. The forebay pool level ranges from 368 m (1208 ft) (minimum pool) to 393 m (1290 ft) (full pool) above mean sea level. The 243-km

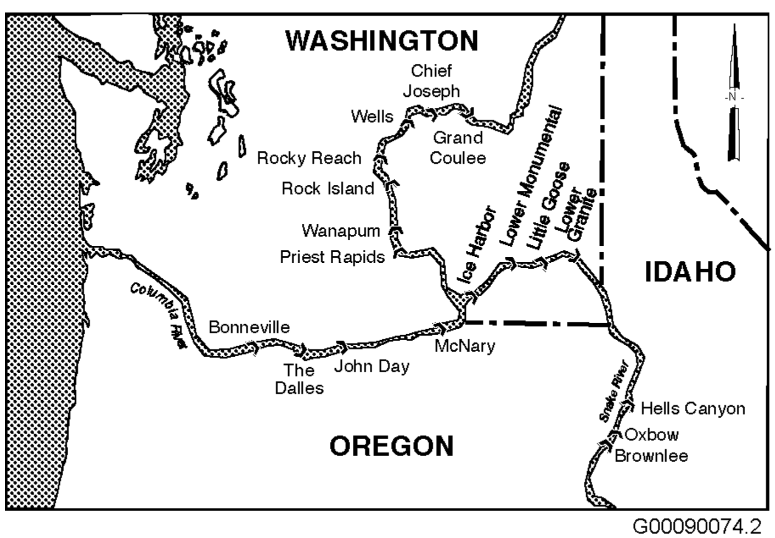

Figure 2.1. Location of Grand Coulee Dam on the Columbia River in Washington State, USA

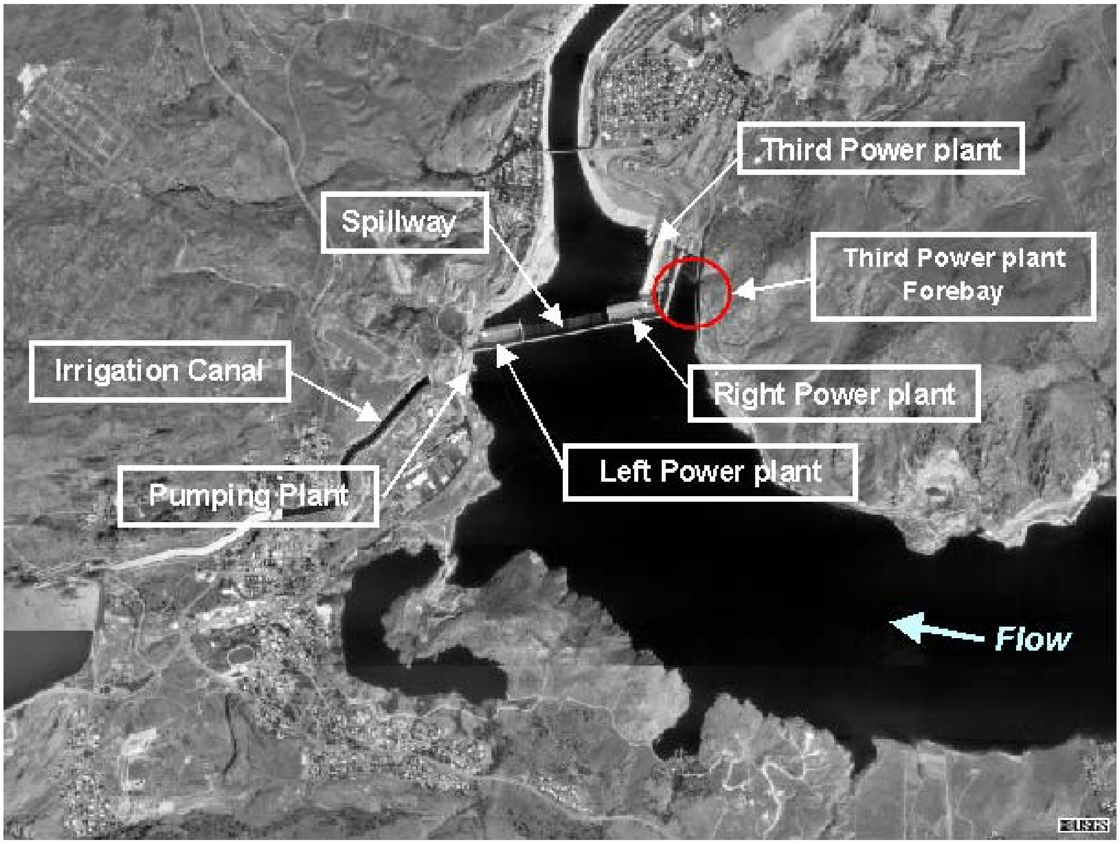

Figure 2.2. Study Site Location (red circle) Near Third Powerplant, Grand Coulee Dam in 2001

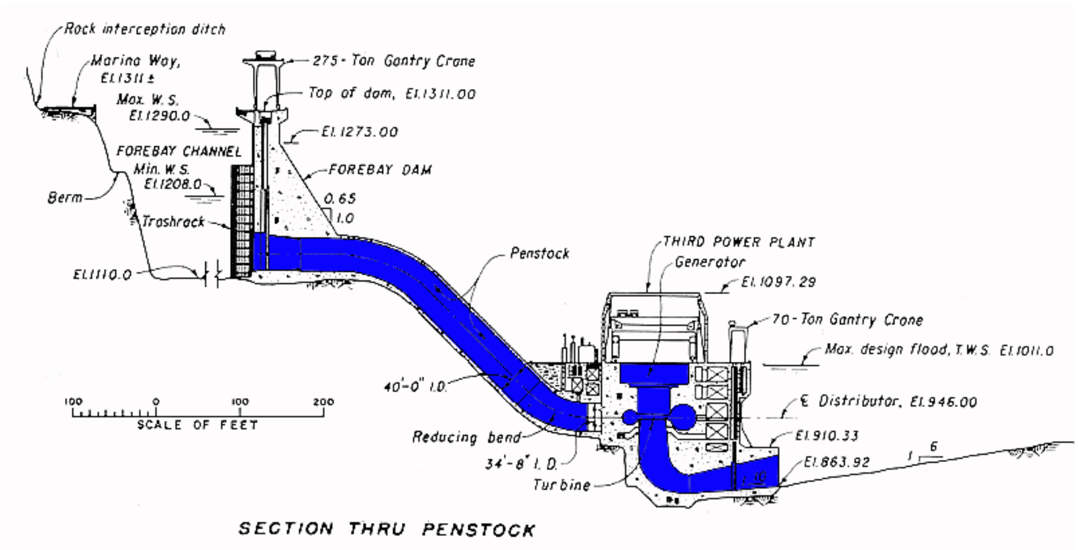

Figure 2.3. Cross Section of Third Powerplant and Forebay Dam at Grand Coulee Dam, Washington (Hubbard 2002)

Table 2.1. Generating Capacity for Grand Coulee Dam (Hubbard 2002)

Location	Description	Number of Generators	Capacity, Each (MW)	Total (MW)
Pumping plant	Pump/generator	2	50	314
		4	53.5	
Left powerplant	Station service generator	3	10	30
	Main generator	9	125	1125
Right powerplant	Main generator	9	125	1125
Third powerplant	Main generator	3	600	1800
	Main generator	3	805	2415
Totals		33		6809

(151-m) -long reservoir created by the dam, Lake Roosevelt, contains approximately 1.2 million hectare-meters (9.5 million acre-feet) of water and serves as a multiple-use body of water for both commercial and recreational uses. In addition to power generation, water from Lake Roosevelt is pumped into adjacent Banks Lake, supplying more than 0.2 million hectares (0.5 million acres) of irrigated land that extends from Coulee City, Washington, in the north to Pasco, Washington, in the south. Grand Coulee Dam also provides flood control for the remainder of the river basin.

2.2 Powerplant Operations

The third powerplant contributes more than 60% of the generating capacity at Grand Coulee and, at times, represents 60% to 70% of the total powerplant discharge (Figure 2.4). During the study period in 2001, much of the third powerplant discharge occurred during the daylight hours (Figure 2.5). We would expect currents in the forebay to follow discharge and be highest during the daylight hours. Current-year operations data were supplied by the Bureau of Reclamation.

Additional data relating to the environmental conditions at Grand Coulee dam are found in Appendix A. These data include forebay elevation, water temperature, turbidity, ambient light levels, wind conditions, and precipitation.

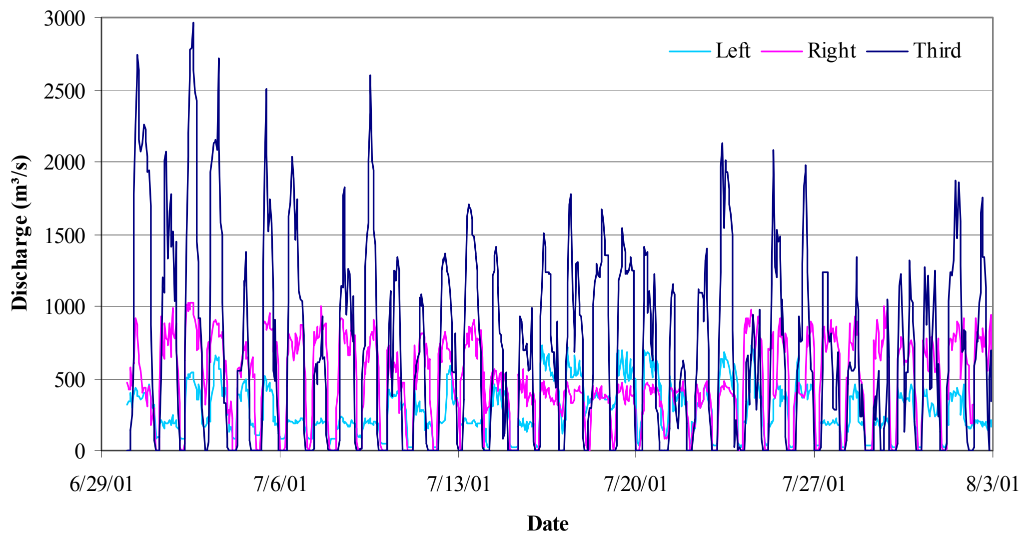

Figure 2.4. Discharge (m³/s) at Grand Coulee Dam from June 30 through August 3, 2001. Data for the average discharge for each powerplant are plotted separately.

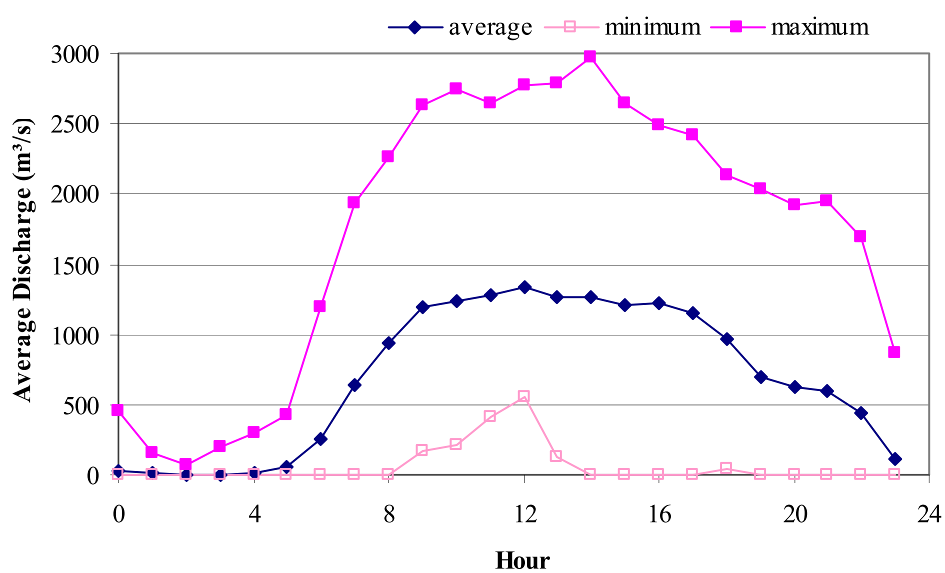

Figure 2.5. Discharge Over 24 Hours at the Third Powerplant at Grand Coulee Dam. Data were averaged over the period June 30 through August 3, 2001.

3.0 Methods

The objective of this study was to determine the efficacy of a prototype strobe light system to elicit negative phototactic response in kokanee and rainbow trout at the entrance to the forebay of the third powerplant at Grand Coulee Dam. The methods used to support that determination are documented in this section.

3.1 Study Design

Strobe light treatment scenarios used in the current study included 24-hr on, 24-hr off and an alternating 1-hr on/1-hr off treatment over 24 hr. To control for possible temporal effects, the experimental period was divided into blocks of 3 days, with the treatment scenarios randomly assigned to 1 of the 3 days. Table 3.1 shows the treatment schedule followed during the study period from June 30, 2001, to August 1, 2001.

3.2 Strobe Lights

Three strobe lights, each producing a maximum of 20,000 lumens-s/flash, were mounted across the center of a 1.3-m^2 aluminum frame (Figure 3.1). The strobe lights, supplied by Flash Technology Inc., Franklin, Tennessee, were sealed specifically for underwater deployment. The frame was deployed from a barge secured in the center of the entrance to the third powerplant forebay (Figure 3.2). The frame was attached to a system of suspension cables that permitted the frame to be nearly vertical in the water column. The orientation of the frame was stabilized in the flow by a dihedral hydrodynamic tow vehicle (v-fin) attached to a bridle at the base of the frame. Data from the strobe lights were collected and transmitted over a RS485 communications line to a personal computer in an equipment trailer on the deck of the dam. There the data were logged by time and date. In addition, two attitude sensors, attached to the frame, monitored any side-to-side or rolling movement. Two light sensors measured light levels above and upstream of the frame (results from the light sensors are presented in Appendix A).

The strobe lights were aimed to illuminate a restricted region directly upstream of the barge location (Figure 3.3). The depth of the lights was approximately 9 m, and the flash rate was set at 360 flashes/minute.

3.3 Hydroacoustic Deployment

To evaluate the effectiveness of the strobe lights in eliciting a negative phototactic response by fish to the lights, four splitbeam transducers were used to track fish entering and within the region illuminated by the lights. The splitbeam hydroacoustic system was supplied by Precision Acoustic Systems (PAS), Seattle, Washington. The system contained a Model PAS 103 Multimode Scientific Splitbeam Echo Sounder operating at 420 kHz, a Model PAS 203 Remote Underwater Quad Multiplexer, four 6°, 420-kHz splitbeam transducers lensed to 10°, and associated power and telemetry cables (Figure 3.4). The four transducers were fast-multiplexed at 20 pings per second (pps). The system was powered by 110–V

Table 3.1. Treatment Design of the 2001 Grand Coulee Dam Study

Date	Strobe	Block
6/30/2001	OFF[(a)]	1
7/1/2001	ON/OFF[(b)]	1
7/2/2001	ON[(c)]	1
7/3/2001	ON	2
7/4/2001	OFF	2
7/5/2001	ON/OFF	2
7/6/2001	ON	3
7/7/2001	OFF	3
7/8/2001	ON/OFF	3
7/9/2001	ON/OFF	4
7/10/2001	ON	4
7/11/2001	OFF	4
7/12/2001	ON	5
7/13/2001	OFF	5
7/14/2001	ON/OFF	5
7/15/2001	ON/OFF	6
7/16/2001	ON	6
7/17/2001	OFF	6
7/18/2001	ON/OFF	7
7/19/2001	ON	7
7/20/2001	ON	7[(d)]
7/21/2001	ON/OFF	8
7/22/2001	ON	8
7/23/2001	OFF	8
7/24/2001	ON	9
7/25/2001	OFF	9
7/26/2001	ON/OFF	9
7/27/2001	ON/OFF	10
7/28/2001	ON	10
7/29/2001	OFF	10
7/30/2001	ON	11
7/31/2001	OFF	11
8/1/2001	ON/OFF	11

(a) OFF = Lights were off for 24 hr.
(b) ON/OFF = Lights were on 1 hr and off 1 hr, alternating for 24 hr.
(c) ON = Lights were on for 24 hr.
(d) Strobe lights were not turned off on July 20.

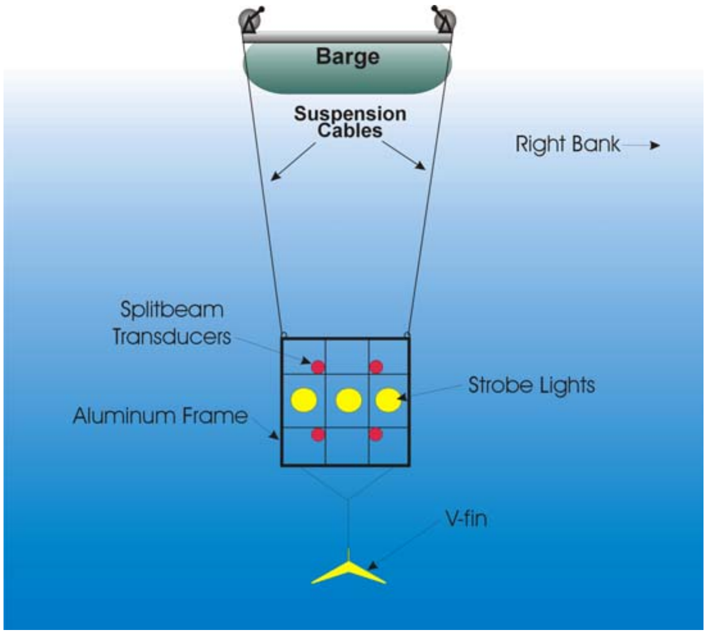

Figure 3.1. Strobe Light and Splitbeam Hydroacoustics Deployment from the Fixed Barge. View from upstream (not to scale).

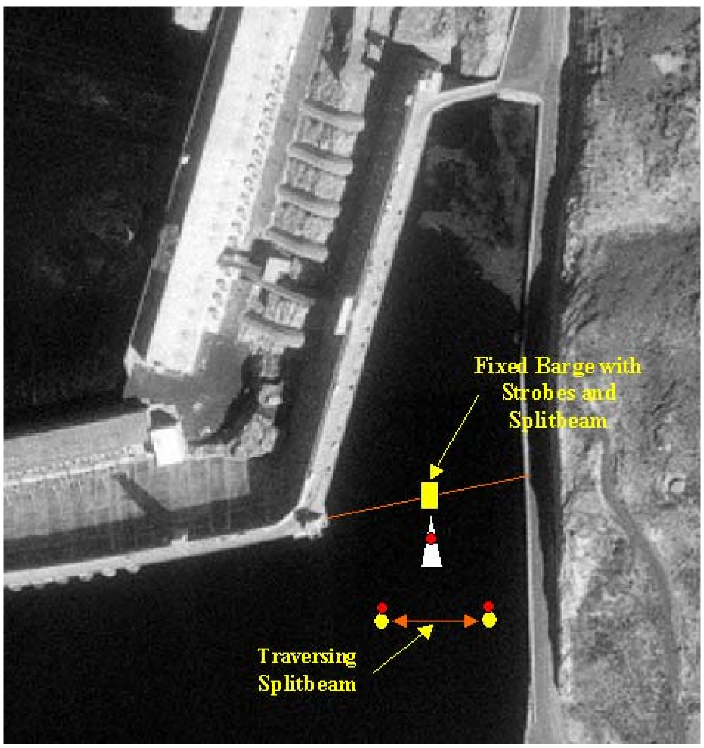

Figure 3.2 Location of Strobe Light Test Site at Third Powerplant Forebay of Grand Coulee Dam. Red dots indicate stationary sampling stations.

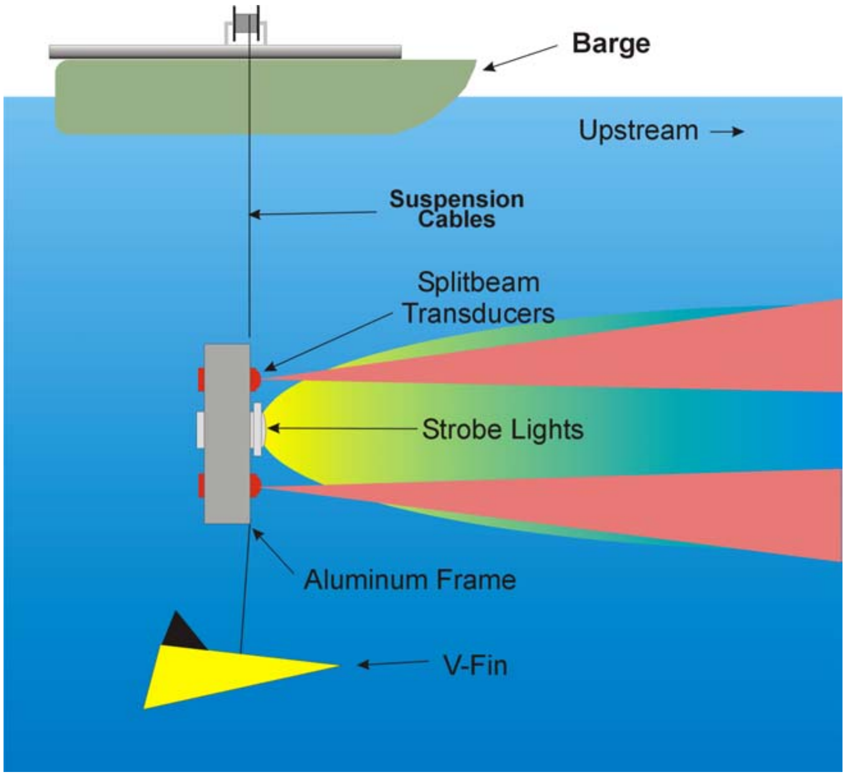

Figure 3.3. Strobe Light and Hydroacoustic Transducer Frame Deployment at Grand Coulee Dam in Spring 2001 as Viewed from the Side Showing Area Illuminated and Ensonified (not to scale)

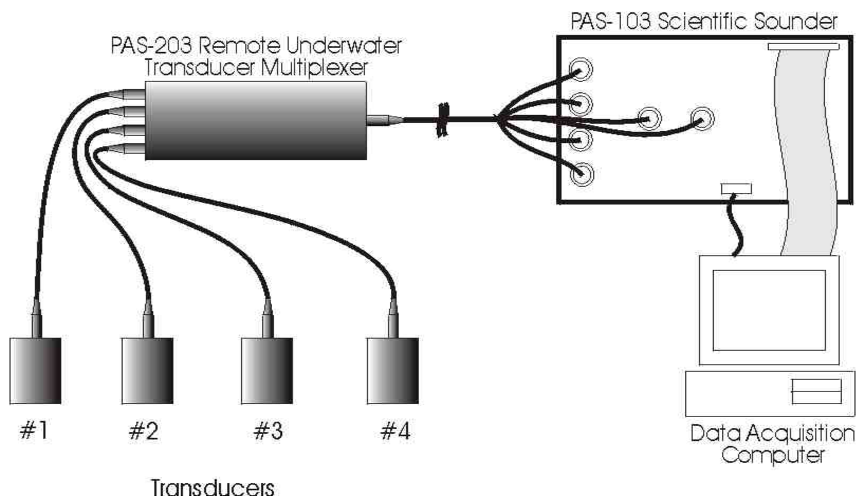

Figure 3.4. Quad-Multiplexed Splitbeam Hydroacoustic System (Precision Acoustic Systems, Seattle, Washington)

alternating current (ac) supplied to the barge from a load center stationed on the dam deck by the Bureau of Reclamation. A personal computer was used for system control and data-logging using the Hydro-acoustic Assessment Research Package (HARP, Hydroacoustic Assessments, Seattle, Washington), a software program for splitbeam data acquisition.

The four splitbeam transducers were mounted to the frame containing the strobe lights (Figure 3.1). The upper two transducers were canted out and upward at approximately 3° and are referred to as the *uplooking* transducers. The lower two transducers were canted out and down at approximately 3°; these are referred to as the *downlooking* transducers. The transducers are also referred to by their placement with respect to whether they were closer to the dam or to the opposite bank—i.e., uplooking dam, downlooking dam, uplooking bank, and downlooking bank. The transducers were aimed to sample as much of the illuminated region as possible with overlap to allow tracking from beam to beam.

Two additional hydroacoustic systems were used during the study to locate fish within the forebay of the third powerplant. Deployment and results for these two additional systems are discussed in Appendix B.

3.4 Data Processing

The data collected at Grand Coulee in 2001 was stored in a centralized location to allow for data transfer, storage, and archiving. The centralized location also facilitated access to data during the processing and analysis phases. A Microsoft® Windows® 2000 server with 300 GB of storage and a digital linear tape (DLT) autoloader were dedicated to this project to serve as the main storage and processing system (Figure 3.5). Several other Windows-based machines provided additional support with processing and analysis. Computers were linked via the Pacific Northwest National Laboratory intranet with an external wireless Internet link to the field site server at Grand Coulee Dam. Raw data and supporting files were downloaded via file transfer protocol (FTP).

Daily backups of data were written to compact disks (CDs) at the field site, then transferred via courier to the main office. All raw and processed data and supporting files were archived to tape for long-term storage.[a]

Data files were processed using in-house software that translated the original data files and used standard tracking algorithms to identify linear traces. The software allowed the user the option of manually choosing tracks (manual tracking) or having the software choose the tracks (autotracking). Initially 10% of the data were manually tracked, with the 10% randomly selected. Manual tracking allowed us to develop the tracking criteria needed for the autotracking and to screen the data for possible noise events. All data collected from the splitbeam transducers were subsequently processed by the autotracking software. Following this initial processing, the tracks were subjected to additional filtering to select targets containing enough information to determine that they exhibited fish-like behavior.

(a) At the completion of the project, a final backup of all data will be made to tape, catalogued, and moved to a permanent storage location.

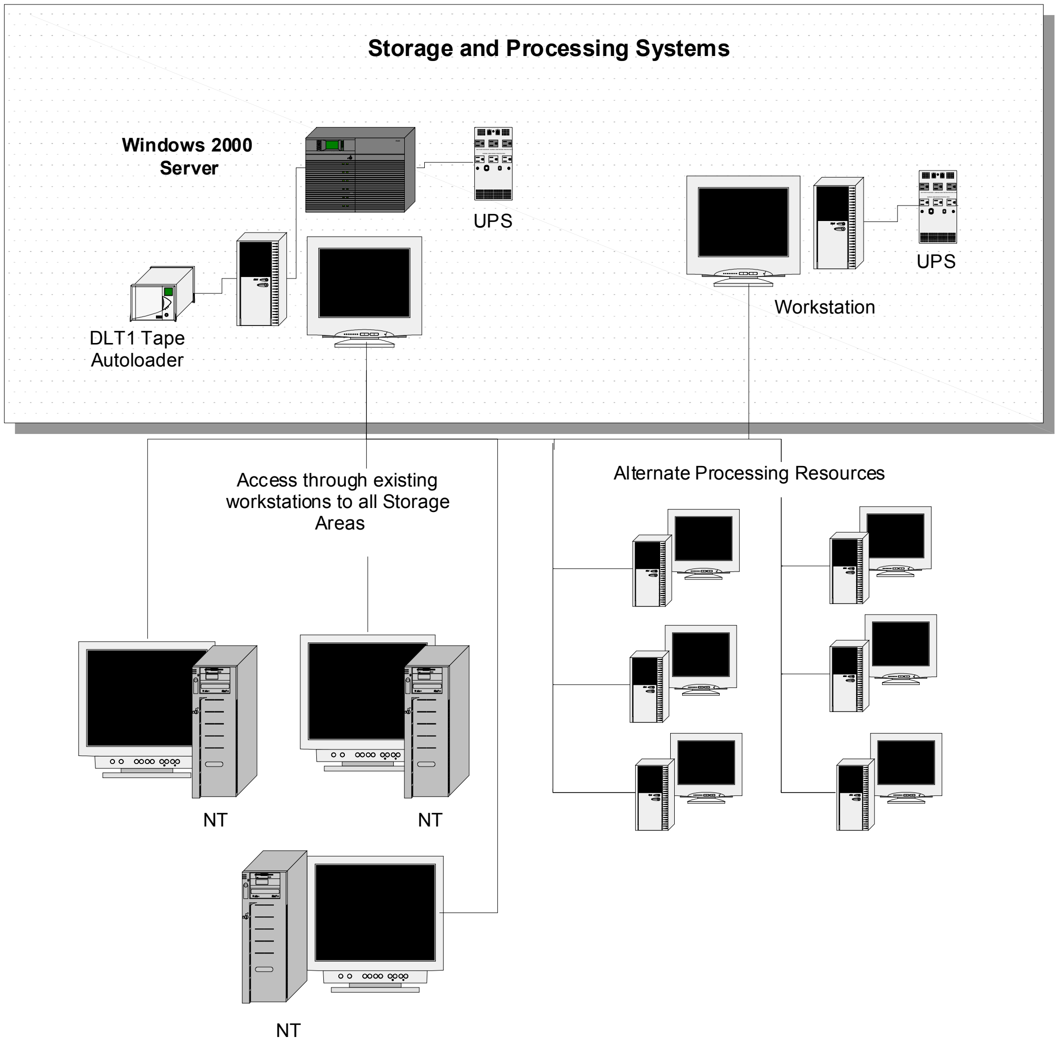

Figure 3.5. Computer Resources in Support of Data Processing Tasks

Criteria for track selection was based on the magnitude of velocity between echo returns (by requiring that each track be adequately described by a constant acceleration for each coordinate location) and on the tracks having a directionality of movement. In addition, short-duration tracks (i.e., less than 9 echo returns) were eliminated because they did not contain enough information to analyze. These filters helped minimize the amount of debris or other non-fish targets included in the analysis.

3.5 Data Analysis

Analysis tested the null hypothesis that there was no effect of the strobe lights on the number of fish within the illuminated region or on their behavior. For fish counts, we were interested in differences in the distribution of fish counts for similar regions and periods of the day. For fish behavior, we were looking at the direction and speed of the fish track and for the presence of milling behavior. If the strobe lights had no effect on swimming behavior, we would expect that the direction and speed of movement and tortuosity (measure of milling) would be independent of the light condition (i.e., on or off).

3.5.1 Fish Track Distribution

Data were analyzed separately for the 24-hr on/off and the 1-hr on/off treatments. The deployment of the four transducers allowed for significant overlap of the sonar beams, which resulted in duplicate counting of some fish targets. Consequently, to minimize any bias caused by the duplicate counting, data from each transducer were analyzed separately.

To statistically evaluate the fish count results for the 24-hr on/off and the 1-hr on/off at hourly treatment conditions, multidimensional contingency tables were constructed. These tables displayed fish counts as a function of date blocks, hour, distance from light source, powerplant discharge, fish size, and strobe light treatment condition. The levels of these factors were defined as follows:

- date block – treatment block from the randomized study design; values from 1 to 10 for the 24-hr on/off and 1 to 11 for the 1-hr on/off treatments. Note that Block 7 was removed from the 24-hr on/off analysis because the 24-hr on treatment was duplicated and there was no 24-hr off treatment.

- hour –1-hr increments (0 to 23)

- distance from lights – 2-m intervals starting near the lights and extending to the limit of the ensonified region (approximately 28 m)

- powerplant discharge
  - 0 (no discharge)
  - 1 (>0 to 707 m^3/s)
  - 2 (>707 to 1415 m^3/s)
  - 3 (>1415 m^3/s)

- Fish size category (based on target strength)
  - 1 (small: target strength ≤-42 dB)
  - 2 (medium: target strength >-42 dB to ≤-32 dB)
  - 3 (large: target strength >-32 dB)

- Strobe light condition (treatment)
  - 0 (lights off)
  - 1 (lights on).

The tables were evaluated statistically using log-linear models because a Poisson distribution and a multiplicative error structure (errors proportional to the count) were postulated. The Poisson regression model and analysis of deviance methods were selected over the more commonly used methods based on a normal error structure and analysis of variance, because the Poisson distribution more adequately reflects the error structure in count data (McCullagh and Nelder 1989, p. 193). Analysis of deviance may be seen as parallel to analysis of variance. A widely accepted method of fitting the models (maximum likelihood) was used. Finally, a weighting factor, 1/volume, was used to reflect the conical shape of the hydro-acoustic beam (observed water volume changes as a function of distance from the beam source). Specific details of the analysis are found in Appendix C.

An additional analysis of the 1-hr on/off data evaluated the change in numbers of fish immediately before and after the strobe light was turned on or off. Only data collected 15 min before or after the hour were used, and a count was made of whether there were more, less, or no change in the number of fish.

3.5.2 Fish Behavior

Fish behavior was described in terms of swimming velocity, which incorporates direction and speed. A fish track consists of a sequence of location vectors, which are echo locations, produced as a function of the sample rate (pps). To describe the direction and speed of a track, we calculated displacement vectors, which are the difference between adjacent location vectors (in sequence). The sum of these displacement vectors, for each fish, is the overall displacement vector pointing from the initial to the final location. Because each track contains random elements resulting from movement of the frame, the fish tracks were smoothed before analysis. For this study, a second-degree polynomial in time was fitted to the echo locations for each track. Thus, the shape of a fish track was interpreted as parabolic in its most complicated form. Generally, fish tracks have only slightly curved trajectories. The end locations estimated by the smoothing were used to determine the displacement vector and the overall displacement velocity. Vectors were calculated for each of the three directions, oriented as follows: laterally or across the light beam, vertical (depth), and upstream/downstream (parallel to the light beam).

Another factor used to describe swimming behavior is tortuosity, which quantifies the amount of turning in a track. The tortuosity index (τ) is defined as

$$\tau = \frac{\left|\vec{r}_n - \vec{r}_0\right|}{\sum\left|\vec{d}\right|} \qquad (3.1)$$

where τ = tortuosity index

$\vec{d}$ = distance between consecutive recorded positions within a fish track

$\vec{r}_0$ = fish's first recorded position

$\vec{r}_n$ = fish's last recorded position.

Note that the variables in Equation (3.1) are vectors, not scalars.

Using Equation (3.1), a fish traveling in a straight line would have a tortuosity index equal to 1. A fish traveling a highly circuitous (i.e., more tortuous) route would have a tortuosity index closer to zero. The tortuosity index indicates whether the fish is swimming straight through an area or is milling. Examples of representative tracks and their associated tortuosity index values are shown in Figure 3.6.

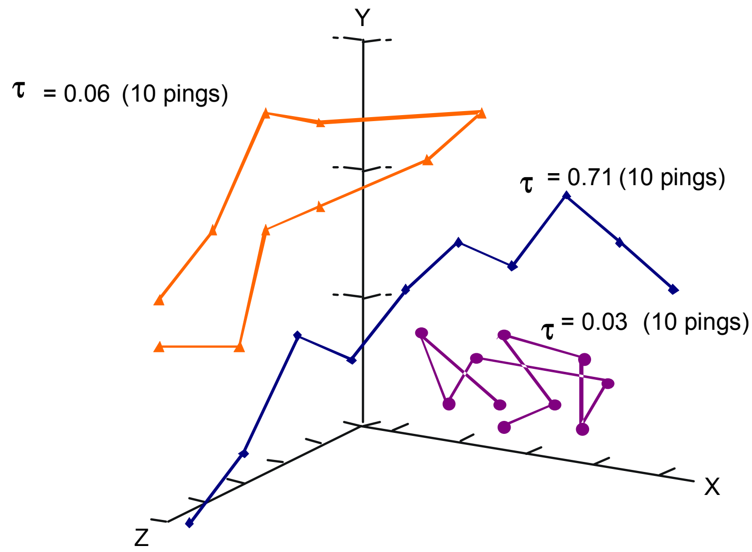

Figure 3.6. Representative Tracks with Associated Tortuosity Index Values and Sample Sizes

For this study, using smoothed tracks, tortuosity was calculated as the ratio of displacement to the distance measured along the fitted parabolic curve in three dimensions. Tracks that do not exhibit much of a parabolic shape or are nearly linear will have a tortuosity index value of nearly 1. If the parabolic curves for each coordinate system begin and end at the same location, then the index will be zero.

Measures of fish behavior, that is, velocity components, velocity magnitude, and tortuosity, were analyzed using probability distributions. A probability distribution is the frequency of occurrence for any particular behavioral metric. Cumulative probabilities indicate what percentage of the population had values less than a give percentile for a particular metric, and the derivative of the cumulative probability is the probability density function (pdf) for the metric. If samples of fish tracks from different treatment conditions (lights on or lights off) have nearly the same pdf for a specific metric, then fish behavior probably was not influenced by the treatment. For this study, we used the chi-square statistic to compare distributions.

4.0 Results and Discussion

Analysis of the effect of strobe lights on the presence and behavior of kokanee and rainbow trout was based on 51,683 fish targets detected between June 30, 2001, and August 1, 2001. The analysis results are presented and discussed in this section.

4.1 Fish Distribution

Fish tracks used in the analysis represent a subset of a larger dataset; selection criteria described in Section 3 were used to ensure that the selected tracks exhibited fish-like behavior.

Hydroacoustic studies provide no information on the species detected. However, data are available in the form of target strength, which can be used to estimate the size of the fish detected (Love 1977). Using data supplied by the Lake Roosevelt Net Pen Program on the sizes of kokanee and rainbow trout released upstream of Grand Coulee Dam in Lake Roosevelt in 2001, we calculated that these fish would have target strengths within the range of -42 to -32 dB (Table 4.1). Figure 4.1 shows the distribution of target strength for fish detected during this study period. More than 50% of the targets detected during the study were within the range calculated for kokanee and rainbow trout. Because response to lights can be dependent on fish species (Mueller et al. 2001; McInich and Hocutt 1987) and on the age of the fish (Kwain and MacGrimmon 1969), and, thus, indirectly related to size, for the analysis we divided the data into three size categories: small (≤-42 dB), medium (>-42 to ≤-32 dB), and large (>-32 dB).

The number of small, medium, and large fish detected over the course of the study were 17,658, 27,328, and 6,697, respectively. Figures 4.2 and 4.3 show the distribution of fish by size category over the study period and over time of day. The number of large-sized fish was fairly constant over the study period, while the number of medium-sized fish decreased from a high count on July 1, 2001. For small fish, detections peaked around July 10. Small fish were generally more abundant during the evening hours (sunset) (Figure 4.3), while medium-sized fish were more abundant during morning and daylight hours.

4.1.1 24-Hour On/Off

Overall, more fish targets were observed with strobe lights on (19,485) than with lights off (15,869). This trend was more evident for the downlooking transducers (those below the strobe lights and canted slightly downward) than the uplooking transducers (above the strobe lights and canted slightly upward) (Figure 4.4). The statistical analysis indicated that for the uplooking transducers, distance from the lights and powerplant discharge had significant effects on the number of fish targets detected. For the down-looking transducers, significant factors in the analysis were block (i.e., 3-day treatment block), distance from lights, and powerplant discharge.

Table 4.1. Estimated Target Strengths (Love 1977) for Fish Released in 2001 in Lake Roosevelt

Rainbow Trout (n=728)	Length (cm)[a]	Estimated Target Strength (dB)[b] Dorsal	Estimated Target Strength (dB)[b] @45 degrees
Mean	32.7	-35.4	-37.9
Minimum	20.7	-39.2	-41.6
Maximum	55.1	-31.1	-33.8
Kokanee (adipose clipped) (n=88)			
Mean	28.6	-36.5	-39.0
Minimum	21.4	-39.0	-41.3
Maximum	43	-33.2	-35.7
Kokanee (non-adipose clipped) (n=97)			
Mean	48.9	-32.1	-34.7
Minimum	30.5	-36.0	-38.5
Maximum	57.5	-30.8	-33.4
Kokanee (3 & 4-yr class) (n=191)			
Mean	39.4	-33.9	-36.4
Minimum	21.4	-39.0	-41.3
Maximum	57.5	-30.8	-33.4

(a) Fish length data from Gene Smith (Lake Roosevelt Net Pen Coordinator) and Mitch Combs (Washington Department of Fish and Wildlife).
(b) Target strengths were estimated for two aspects because fish were approaching the splitbeam transducers head-on.

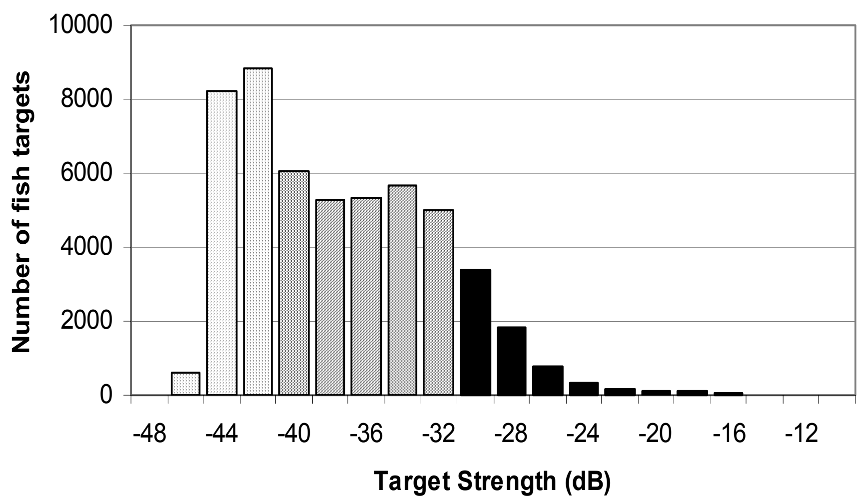

Figure 4.1. Target Strength (dB) for Fish Targets Detected in Third Powerplant Forebay of Grand Coulee Dam in 2001. Bar patterns represent the three size classes used in the analysis (small: ≤-42 dB; medium: >-42 to ≤-32dB; large: >-32dB).

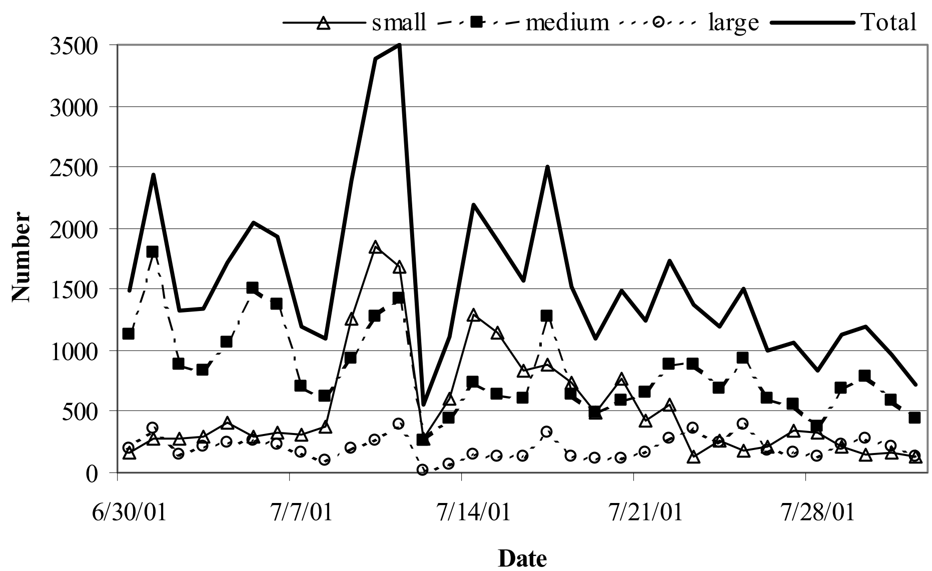

Figure 4.2. Number of Fish Targets Detected During Study Period at Grand Coulee Dam in 2001. Ranges for size categories, based on target strength, were as follows: small ≤-42 dB; medium >-42 to ≤-32 dB; large >-32 dB.

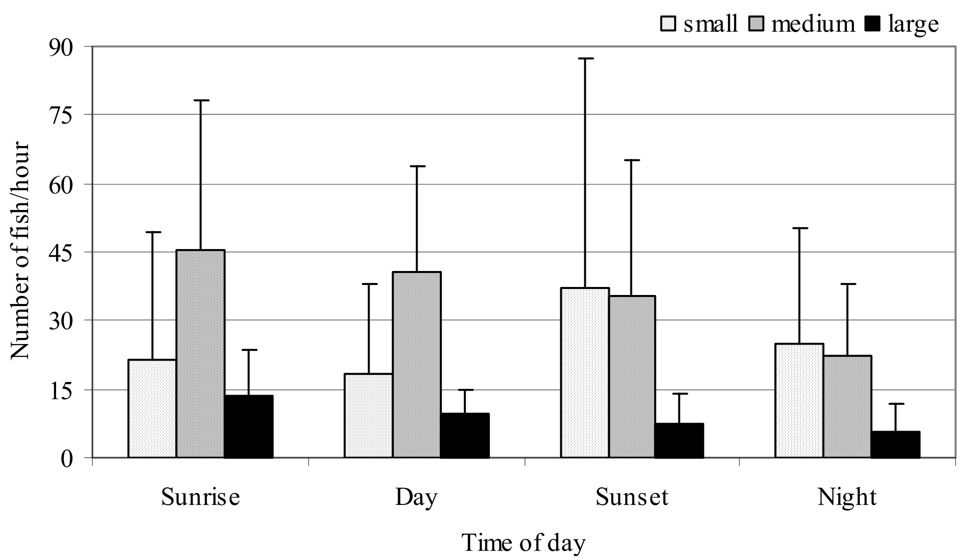

Figure 4.3. Distribution of Fish by Size Category and Time of Day. Bars are ±1 standard deviation (n = 33).

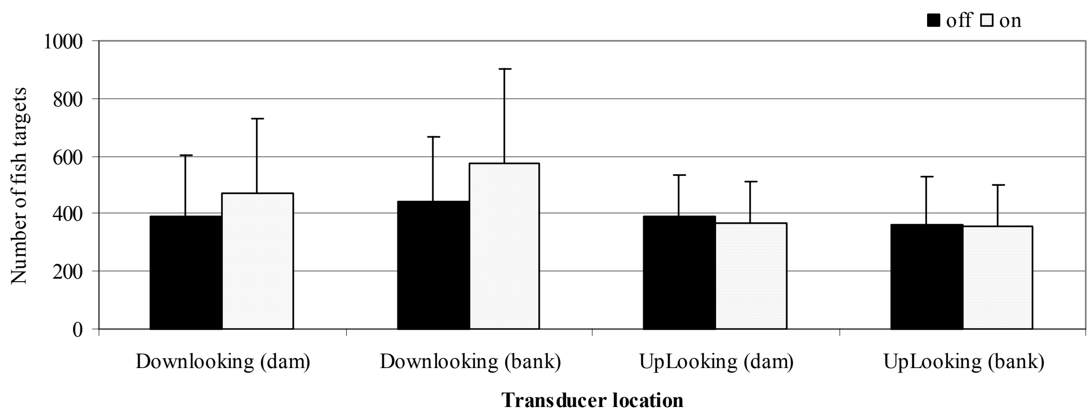

Figure 4.4. Number of Fish Tracks Detected by Each Splitbeam Transducer When Strobe Lights Were Off (24 hr) and On (24 hr). Bars are ±1 standard deviation (n = 10).

For all transducers, distance from the strobe lights was a statistically significant factor in the analysis, with more fish present when lights were on. However, if we examine the distribution of fish in front of the strobe lights more closely (Figure 4.5), we observe that, for all transducers except the downlooking bank-side transducer within 6 m of the lights, it appears that fewer fish were present (<50%) when the lights were on. At mid-distances, between 6 and 18 m, more fish were present when the strobe lights were on, while at distances beyond 18 m, there appears to be little difference in the number of fish when the lights are on or off.

If the avoidance response of fish in our study was within 10 m of the lights, then we may not have been able to detect it because of low fish density and the small sample region directly in front of the transducer. The sonar beam is cone-shaped, with the apex near the transducers and the strobe lights (Figure 3.3), so that the fewer targets will be detected in the near region. Our results suggest the response of fish to the lights occurred within 30 m and is more complex than a simple avoidance observed by Maiolie et al. (2001).

The other factor that significantly affected fish counts was powerplant discharge. For the analysis, discharge was divided into four categories: 0, 0 to 707, 707 to 1415, and >1415 m^3/s. Increasing powerplant discharge (>707 m^3/s) appears to have a negative impact on fish numbers (Figure 4.6). At lower discharges (i.e., less than 707 m^3/s), more fish were detected by the downlooking transducers. With respect to treatment, only the response for fish targets detected by the uplooking (closest to the dam) transducer was significant ($p<0.05$). For all transducers, the trend is for more fish to be present when the lights were on and discharge levels were zero or intermediate (i.e., 707 to 1415 m^3/s) (Figure 4.7). The reason for this is not clear, except that discharge was related also to time of day (Table 4.2). Lower discharge (0 and 0 to 707 m^3/s) was primarily at night, and higher discharge was during the daytime.

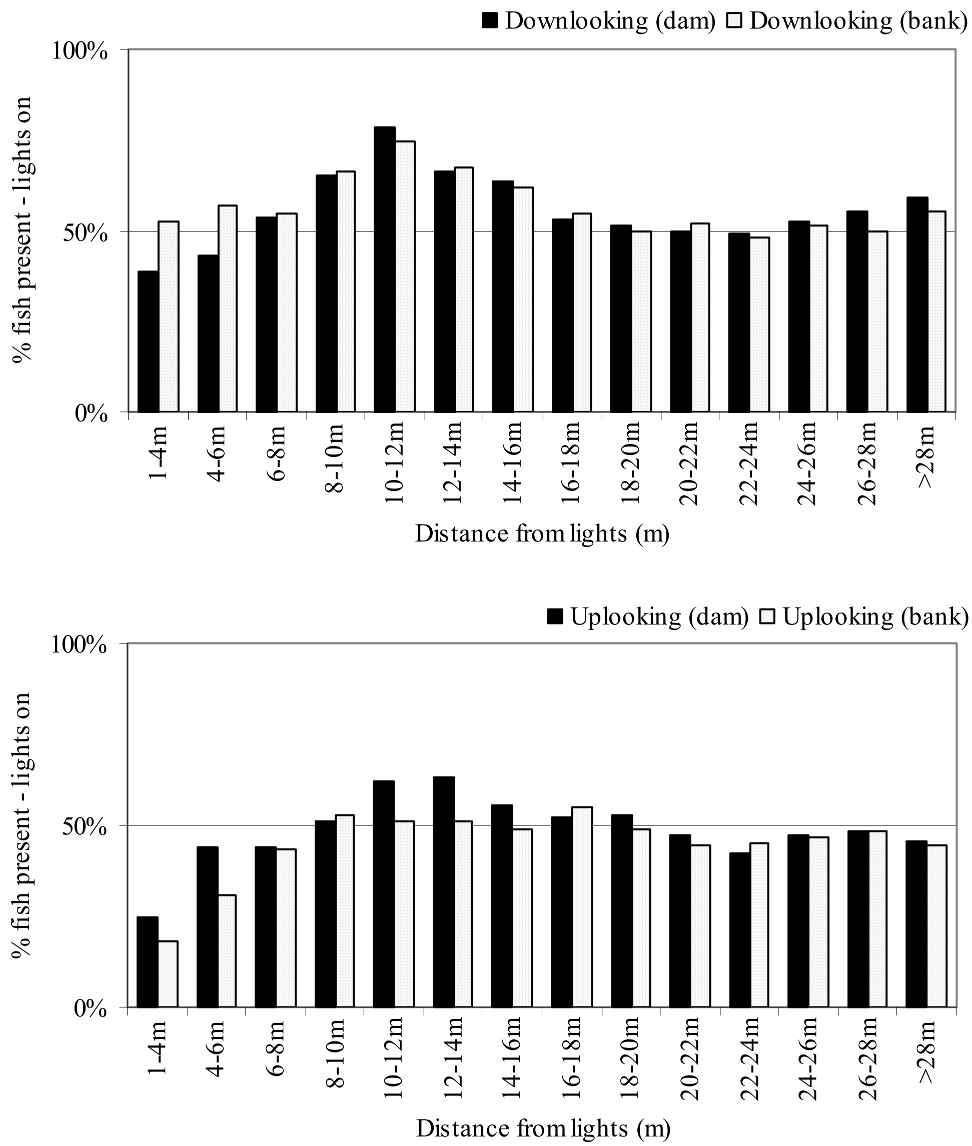

Figure 4.5. Percentage of the Fish Targets Detected When Lights Were On with Distance from the Strobe Lights (24-hr Treatments). Data are presented separately for each splitbeam transducer. Percentages above 50% indicate more fish were detected when the lights were on than off.

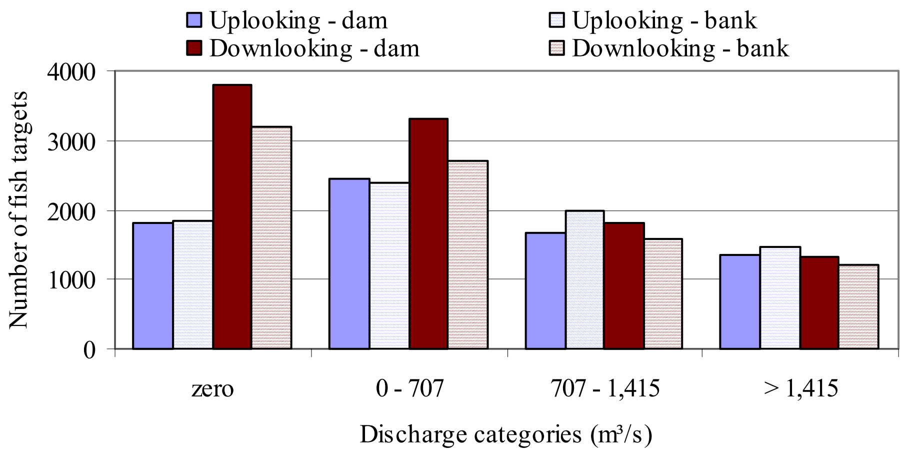

Figure 4.6. Number of Fish Targets Detected with Respect to Discharge from Third Powerplant and Transducer Location

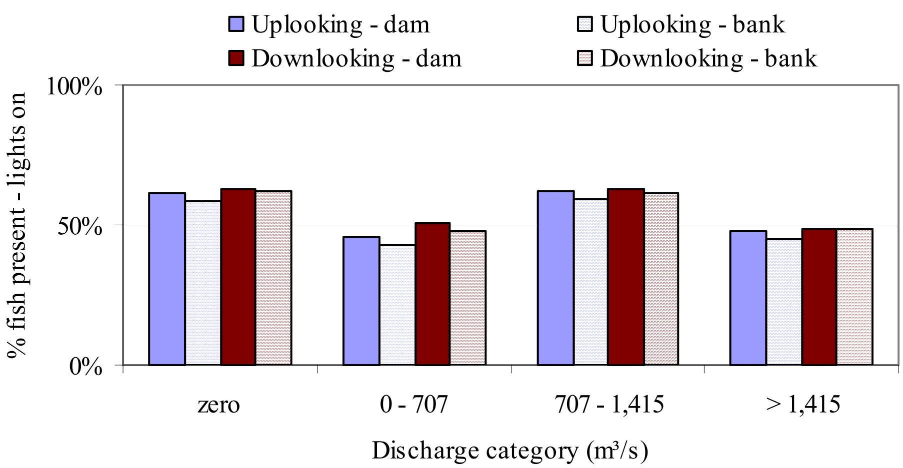

Figure 4.7. Percentage of Fish Targets Present When Strobe Lights Were On at Various Discharge Levels for Third Powerplant and Transducer Location. Percentages greater than 50 indicate more fish were present when lights were on compared to lights off (24 hr).

Overall, results from the density analysis are inconclusive with respect to the efficacy of the strobe lights to elicit a negative phototactic response in fish. The relatively small number of fish tracked immediately in front of the strobe lights contributed to these inconclusive results. The number of fish targets may be related to the low flows in the system due to the abnormally lower water year. It could be argued that the species of interest (kokanee and rainbow trout) may not have been entrained in these low flows as much as in a normal flow year. Although the number of fish targets analyzed was more than

Table 4.2. Distribution (percentage) of Powerplant Discharge by Time of Day for Grand Coulee Dam Third Powerplant, 2001

Time of Day	Powerplant Discharge Categories (m^3/s)			
	Zero	0-707	707-1415	>1415
Day	5.2	27.9	42.1	24.8
Night	63.4	26.1	9.2	1.3

50,000, this represented an approximate fish detection rate of only 1 fish/min. Also, the populations of interest, kokanee and rainbow trout, appeared to have peaked early in the study period (July 1 for medium-sized fish, as indicated in Figure 4.2). We propose to initiate the second phase of this study earlier in 2002 (mid-May) to account for an early peak in the run.

4.1.2 1-Hour On/Off

For the 1-hr on/off strobe light treatment, 15,329 fish tracks were analyzed. Again, more fish targets were detected by the downlooking splitbeam transducers (Table 4.3). From the analysis, distance from the lights was a significant factor influencing the number of fish targets. Over distance from the lights (Figure 4.8), there were generally more fish present when the lights were on. However, there was no trend as was seen for the 24-hr on/off, and generally there was little difference between the on and off condition.

Another way to analyze the 1-hr alternating on/off treatment is to review the data for a 15-min period immediately before and after the lights were switched either off or on, looking for contrast transition behavior. Maiolie et al. (2001) noted that the negative phototactic response of kokanee was instantaneous when strobe lights were turned on or off. In Table 4.4, we see that during the day, the counts increased when the lights were switched between off and on and on to off, while during the night there was no trend in counts across the switch. It is difficult to interpret these results. Several factors may be affecting the results, including distance from the lights and the time interval. In *Fish Passage Technologies* (1995), the authors suggest that responses to strobe lights may be site-specific, so this too could be a contributing factor.

Table 4.3. Number of Fish Targets Detected During the Alternating 1-Hour On/Off Strobe Light Treatment at Grand Coulee Dam, 2001

	Transducer Location	Number of Fish Targets
Uplooking	Dam	3099
	Bank	3174
Downlooking	Dam	4842
	Bank	4214

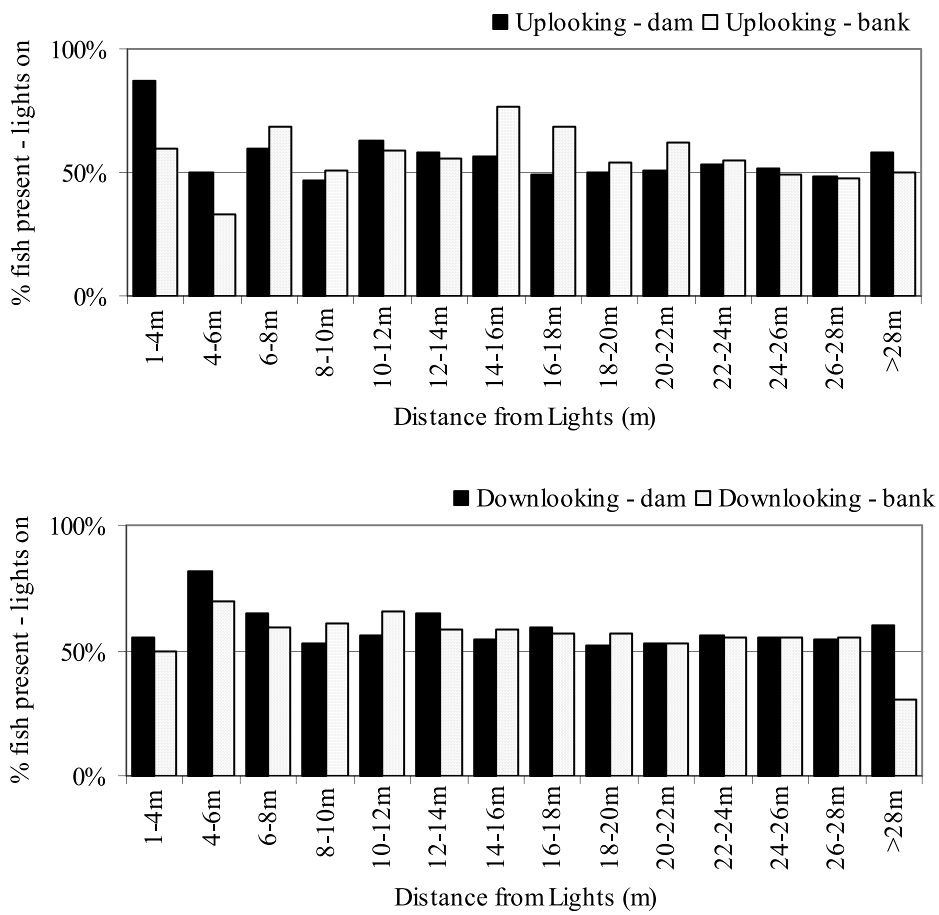

Figure 4.8. Percentage of Fish Targets Present When Lights Were On (1-hr on/off treatment) with Distance from Lights

Table 4.4. Number of Occurrences When Counts Decreased, Increased, or Remained Unchanged After Strobe Lights Were Either Switched On (off ≥ on) or Off (on ≥ off). Change was based on number of fish targets 15 min before and after the switch.

Time	Direction of Light Change	Impact on Fish Target Count		
		Decreased	Increased	No Change
Day	Off ≥ On	28	45	1
	On ≥ Off	24	42	6
Night	Off ≥ On	18	18	9
	On ≥ Off	21	24	1

Unfortunately, in the area where the best response may be occurring (<14 m), there were few targets, and it was difficult to evaluate any response. In 2002, we propose to monitor the near ranges with an alternative deployment that will allow us to evaluate more thoroughly the behavioral response at close range to the lights.

4.2 Fish Behavior (24 hours on/off)

Fish behavior was evaluated using fish swimming speed and the amount of turning behavior. Swimming behavior was analyzed in three directions with respect to the direction in which the strobe lights and transducers were aimed (upstream): 1) laterally or across the light beams, 2) vertically or depthwise relative to the light beams, and 3) upstream/downstream or parallel to the light beams. We also evaluated behavior in two regions, near (<14 m from the lights) and far (>14 m from the lights). The distinction between near and far was based on the total range covered by the splitbeam transducers and on ensuring an adequate sample size in the near region.

Table 4.5 and Figures 4.9 through 4.11 indicate that there were significant differences in fish behavior, at night, between lights on and off with respect to the direction in which the fish were swimming. There was also a difference in behavior between small-sized fish and medium-sized fish.[a] Thus, at night and when the lights were on, medium fish swam either to the right or left of the lights (Figure 4.9) compared to lights off, when there was little movement across the lighted region. For small-sized fish, there was little movement along this axis, with the distribution of velocity components centered on zero. It is also noteworthy that the response for medium-sized fish occurred within 14 m of the strobe lights. Beyond 14 m, an effect was still evident but not as distinct as closer to the lights.

In addition to swimming away from the lights laterally (i.e., across the beam) at night, fish were swimming upstream (Figure 4.10), as seen in the shift of the peak from zero when the lights were off to greater than zero when the lights were on. Again, the response is more distinct for medium-sized fish within 14 m of the strobe lights.

The third directional component to be analyzed was vertical, i.e., up and down in the water column. For this direction (Figure 4.11), there appears to be little response to strobe light state (on or off), suggesting that the fish were not diving to avoid the lights and were thus avoiding potential entrainment in the high velocity water deeper in the channel (McMichael et al. 2000). Only one of the vertical velocity distributions had a significant result (Table 4.5) and may be an artifact of the large number of detected fish targets because visually there is little difference in the distributions.

The behavioral results suggest that medium-sized (and large) fish respond to the lights, at night, by swimming away from the illuminated area. This response was evident within 14 m of the strobe lights but was not evident during the day (Table 4.5 and Appendix D).

(a) The response of large fish was similar to that of medium-sized fish, and results are included in Appendix D.

Table 4.5. Probability Levels for Chi-Square Comparison of Distributions of Velocity Components for Strobe Lights Off and On (24 hr)

Velocity-Direction	Size Range	Distance to Lights[a]	Day	Night
Laterally	Small	near	0.92	**0.04**[b]
(across the lights)		far	0.27	**0.002**
	Medium	near	0.39	**0.0001**
		far	**0.03**	**0.0001**
	Large	near	0.98	**0.03**
		far	**0.0001**	**0.0001**
Vertical (depth)	Small	near	0.27	0.12
		far	0.83	0.12
	Medium	near	0.33	0.21
		far	0.09	**0.05**
	Large	near	0.76	0.65
		far	0.07	0.85
Upstream/Downstream	Small	near	**0.002**	**0.002**
(parallel to lights)		far	**0.0001**	**0.003**
	Medium	near	**0.01**	**0.002**
		far	**0.0001**	**0.0001**
	Large	near	0.11	**0.003**
		far	0.10	0.12

(a) Distance to lights: near = <14 m; far = >14 m.
(b) Bold probabilities indicate that the distribution of counts between lights off and on were significantly different at P = <0.05 level of significance.

Another metric that describes swimming behavior is tortuosity, which is a measure of the straightness of the fish tracks. Fish tracks with a tortuosity index close to 1 are fairly straight, while tracks with a tortuosity index closer to zero contain more turning, which can indicate milling behavior. Analysis of the tortuosity index for different-sized fish during the day and night and at two ranges from the strobe lights (near [<14 m] and far [>14 m]) found that there were significant differences (p = 0.0001) in the amount of tortuous swimming behavior between lights on and off for medium-sized fish at night (Figure 4.12). When the lights were on, fish tracks were straighter, compared to lights off when the tracks contained more turning. These results support the analysis of the velocity components, where zero was the most common component for fish detected when the lights were off. Both these results indicate that, when the lights are off, the fish are milling and not trying to avoid the region.

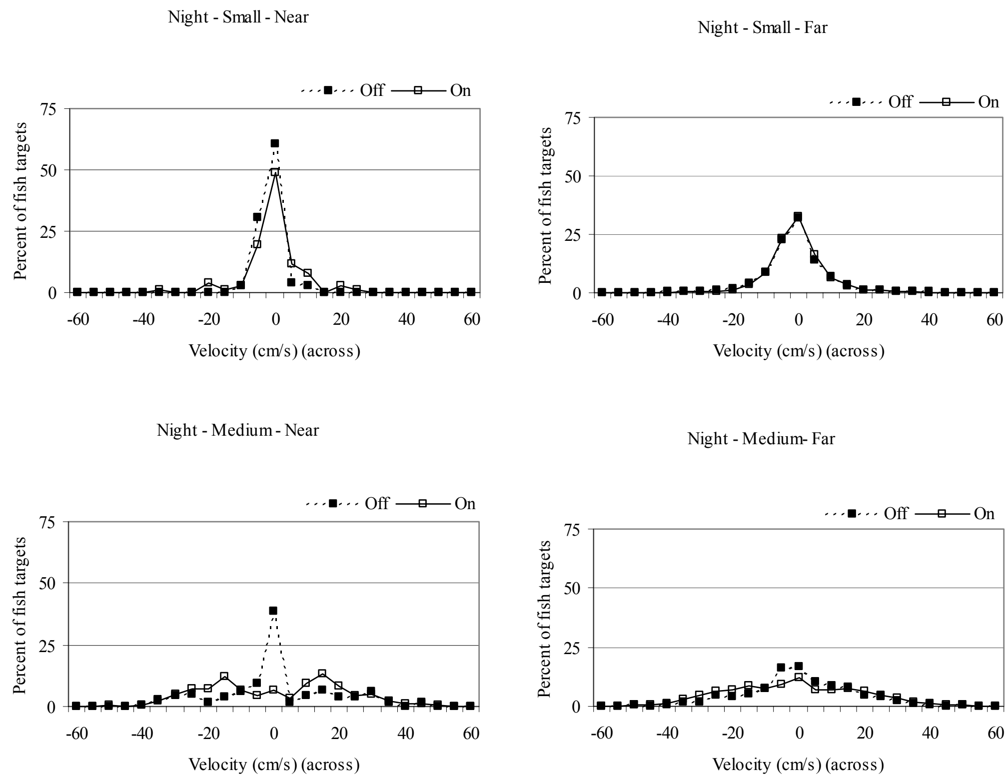

Figure 4.9. Velocity Component in the Lateral Direction Across the Lights for Small (≤-42 dB) and Medium (-42 to -32 dB) Fish Targets at Two Distances from the Lights at Night

Combining the results from the analysis of swimming behavior with those of the distribution of fish targets, we arrive at a somewhat complex picture of the response of fish to the strobe lights. The results indicate that beyond 14 to 18 m, there was little response to the lights; that is, swimming behavior and fish counts were similar, whether the lights were on or off. Closer to the lights (within 14 m), there appeared to be more fish present when the lights were on. However, the behavior data suggests that fish in this region were turning and swimming out of the lighted region in both the lateral and upstream direction. The counts may be influenced by this turning behavior, in that the same fish may be detected more than once. When the lights were off, fish appeared to be spending much of the time in the same location, as seen by the preponderance of zero speeds in all three directions (Figures 4.9 through 4.11) and the greater proportion of more tortuous tracks (Figure 4.12). Thus, the number of fish detected when the lights were on may be an artifact of their behavioral response to the lights.

Light levels beyond 14 m were less than 0.0009 μmol s^{-1} m^{-2} (Appendix E). The minimum threshold for juvenile rainbow trout was between 0.01 and 0.005 lx (approximately 0.000122 to 0.00006 μmol s^{-1} m^{-2}) (Kwain and MacGrimmon 1969). Kokanee in two Idaho lakes appeared to avoid light levels below 0.00016 lx (or 0.296×10^{-5} μmol s^{-1} m^{-2}) at night (Maiolie et al. 2001). Factors that could be influencing

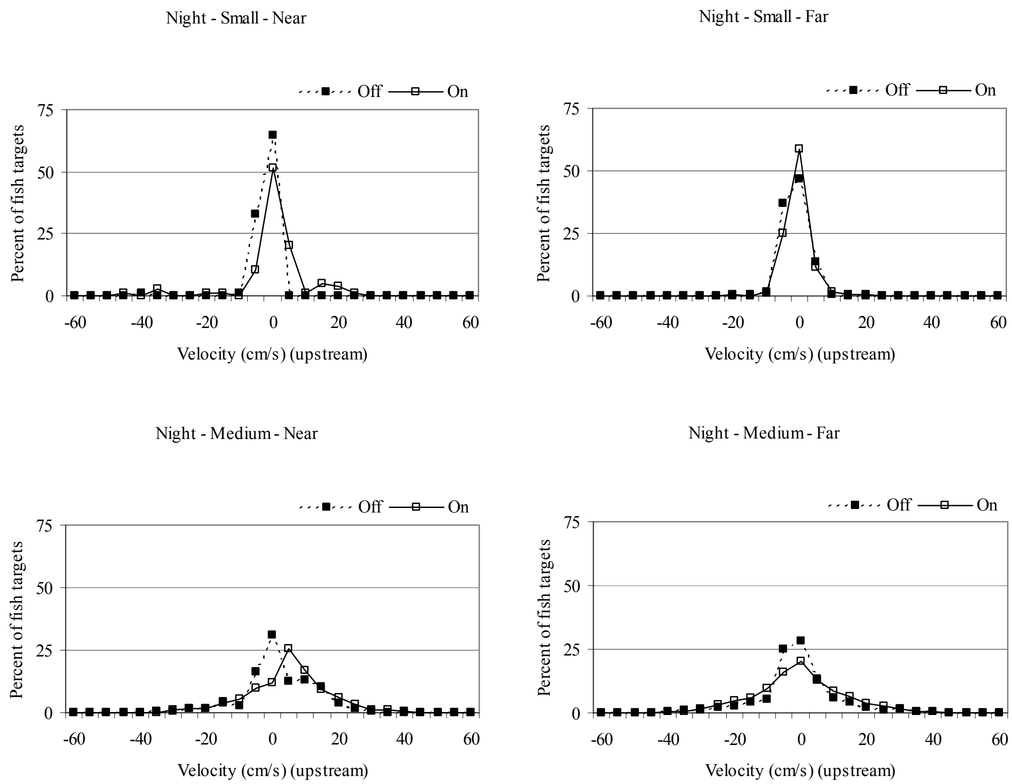

Figure 4.10. Velocity Component in the Direction Away from the Lights for Small (≤-42 dB) and Medium (-42 to -32 dB) Fish Targets at Two Distances from the Lights at Night. Negative components indicate targets going toward the lights, while positive components are in an upstream direction.

the response to lights include fish species. Strobe lights elicited an avoidance response in wild and hatchery Chinook salmon and rainbow trout but none in eastern brook trout (Mueller et al. 2001). The target size of fish detected in this study puts them in the range for kokanee and rainbow trout released into Lake Roosevelt (Table 4.1 and Figure 4.1); however, we have no independent evidence that the fish were kokanee. Hoar et al. (1957) found that young salmon (chum, coho, pink, and sockeye) did not constantly avoid illuminated areas but were continuously passing in and out of the lighted region.

Factors confounding the interpretation of the results include the discharge at the third powerplant, which occurred primarily during daylight hours, resulting in low flows at night. Low flows might be expected to reduce the number of detectable targets in our sample volume. Because the fish of interest (kokanee and rainbow trout) are nonmigratory, they would require the passive transport of the flowing water resulting from turbine operations to accumulate into the sample region. Otherwise, their detection is a matter of random encounter in the area. Past entrainment data suggest that during periods of high flow into the third powerplant forebay, entrainment numbers increased (LeCaire 1999; Sullivan 2000). In fact, there was concern that currents generated in the forebay of the third powerplant might prevent

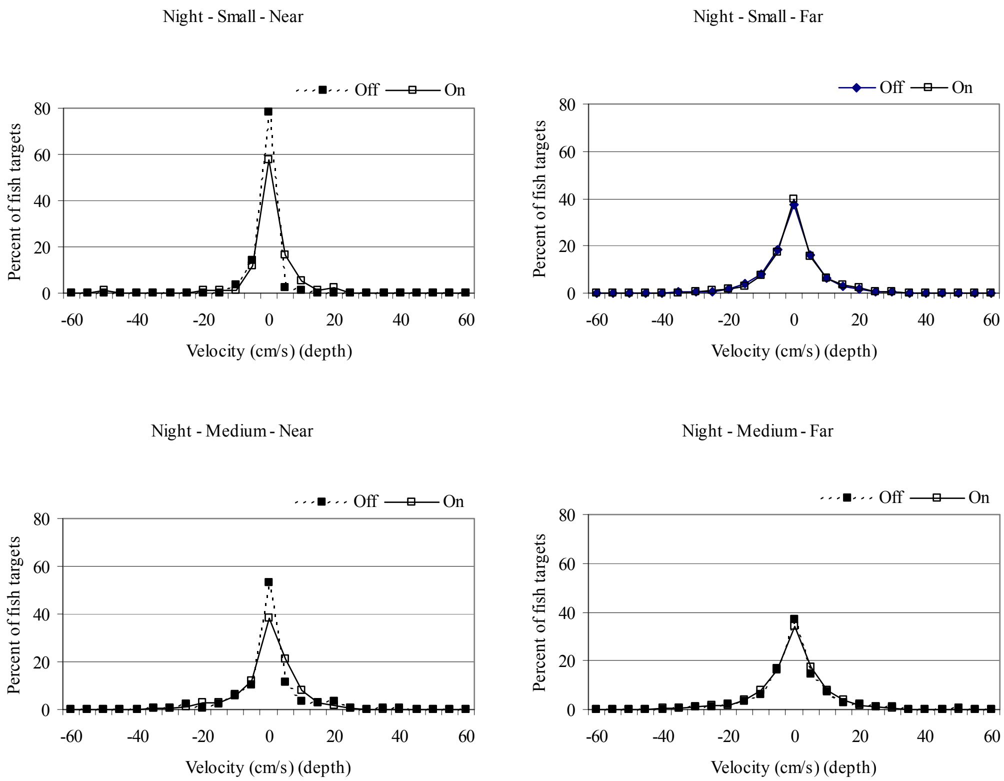

Figure 4.11. Velocity Component in the Vertical Direction for Small (≤-42 dB) and Medium (-42 to -32 dB) Fish Targets at Two Distances from the Lights at Night. Negative components indicate targets going toward the surface, while positive components are going downward in the water column.

salmonid fish from avoiding strobe light stimuli. However, this concern was alleviated after staff of the Chief Joseph Kokanee Enhancement Project and PNNL mapped the water currents and found the currents in the region of the present study would not entrain salmonids (McMichael et al. 2000).

Another complicating factor was that over the study period, the number of fish detections was declining. This may indicate that a change in species or age composition occurred within the detected population. A number of researchers have reported species-specific and age-specific responses to strobe lights (Hoar et al. 1957; Mueller et al. 2001; Kwain and MacGrimmon 1969). Thus, if the behavioral responses observed over the duration of the study came from different species or ages of fish, the effect of strobe lights on kokanee and rainbow trout may have been obscured. Next year, we have proposed that the Colville tribal members conduct a weekly, multiple-mesh gill net test fishery in the vicinity of the study site to ascertain species composition and age.

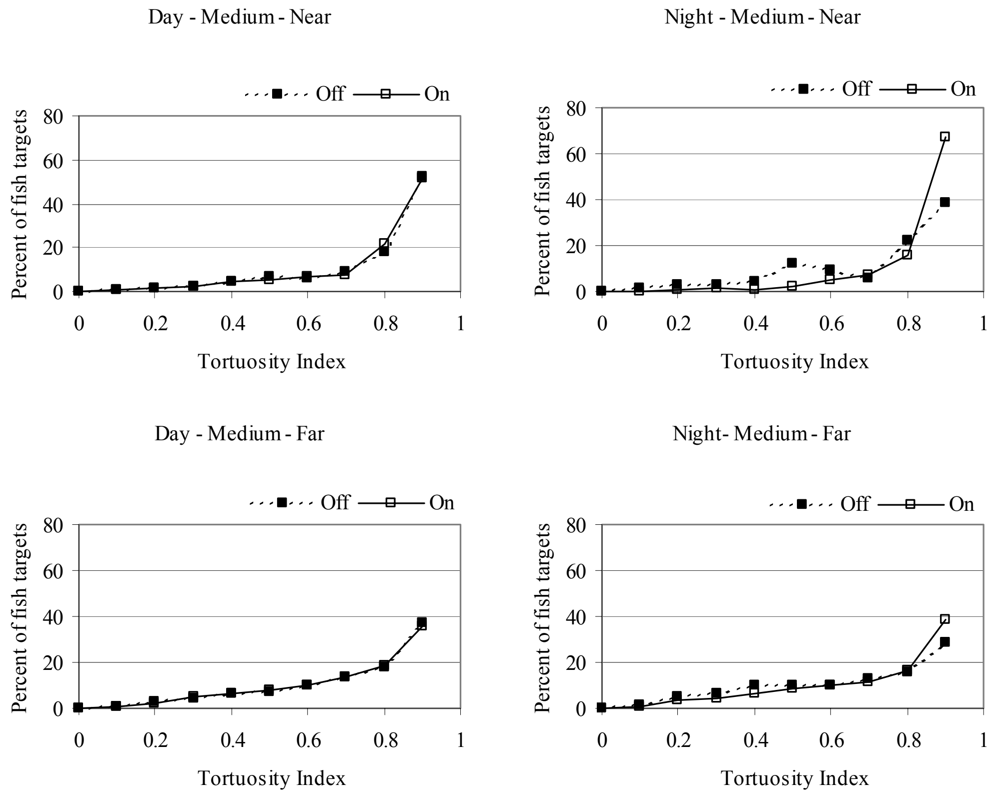

Figure 4.12. Tortuosity Index for Medium (-42 to –32 dB) Fish Targets at Two Distances from the Lights During Day and Night. Indices near 1 indicate a straight track, while indices near zero are turning or milling.

We have undertaken this research with the assumption that strobe lights have no deleterious effect on fish. Studies conducted on human subjects have shown that strobe lights can have adverse effects including spatial disorientation, flicker vertigo, nausea, and in rare cases, epilepsy (Zifkin and Trenite 2000; U.S. Army 2000). It is not known how strobe lights affect fish. If such effects are demonstrated in fish as they are being subjected to passive transport conditions toward the dam, then the result may be to ensure their fate by rendering them incapable of reacting. Additional research should be conducted to determine the effect of strobe lights on kokanee and rainbow trout.

5.0 Conclusions and Recommendations

The response of fish to strobe lights in the forebay of the third powerplant at Grand Coulee Dam in 2001 was based on analysis of the distribution of fish targets and on fish swimming speed and direction. More than 50,000 fish targets were detected by splitbeam hydroacoustics upstream of the strobe lights.

5.1 Conclusions

Based on the results of our analysis, we have drawn the following conclusions:

- Over the entire range (i.e., 28 m) sampled by hydroacoustic system, more fish were detected when the strobe lights were on; however, 50% of these were beyond 22 m.
- There was some indication that close to the lights (<6 m) there were fewer targets when lights were on; however, sample size was inadequate for statistical analysis.
- Distance from the lights, powerplant discharge, and date were significant factors in the analysis of fish density.
- Fish behavioral responses within 14 m of the lights were statistically significant, indicating a negative phototactic response to the lights.
- The behavioral response was strongest for medium- and large-sized fish at night.
- When the lights were on, at night, fish swam away from the lights in the lateral and upstream direction, and at a faster speed.
- There was little tendency for fish to sound (i.e., dive down suddenly) in response to the strobe lights.
- When the lights were off, more fish milled than when the lights were on.

5.2 Recommendations

In 2001, we deployed strobe lights and a complex hydroacoustic monitoring tool for the first time at the third powerplant forebay. Based on this study and general review of strobe lights and their effects on living organisms, we recommend a number of modifications and enhancements to the follow-on study in 2002. The implementation of these recommendations will enhance the study design, provide additional data where data were lacking in 2001, and set the stage for future strobe light installation, should it be deemed efficacious as a fish deterrent.

Our recommendations are as follows:

1. The study should begin earlier (mid-May) to capture the kokanee population as the fish move down the reservoir toward the dam.

2. Additional splitbeam transducers should be deployed at the surface looking down immediately upstream of the strobe lights to sample the region close to the lights.

3. As part of the experimental design, an attempt should be made to increase the flow in the forebay of the third powerplant during the night.

4. The experimental design should be modified to include only strobe light treatments of 24 hr on and 24 hr off.

5. The amount of light should be increased (doubled) to provide better definition of the lit and unlit regions.

6. An acoustic Doppler current profiler (ADCP) should be deployed on the fixed barge to provide flow information that could be used to interpret behavioral results.

7. To determine species composition, Colville tribal members should conduct a multiple-mesh gill net test fishery in the vicinity of the hydroacoustically sampled region.

8. Additional plankton net sampling should be conducted in proximity to the sample region to identify clouds of small targets discovered in 2001.

9. Tests should be conducted on kokanee and rainbow trout to ensure that exposure to intense strobe lights causes no deleterious effects in either species.

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Appendix A

Environmental Conditions at Grand Coulee Dam

Appendix A

Environmental Conditions at Grand Coulee Dam

Environmental factors at the time of the study play a role in data processing and interpretation and are important for year -to-year comparisons. The river conditions (water elevation, temperature, and turbidity) can affect fish distribution (vertical and spatial), immigration, and visual discernment (Levy 1990, Merigoux and Ponton 1999). Light conditions may affect fish distribution and activity levels (Thorpe 1978). Meteorological conditions such as wind and precipitation affect light penetration from the surface and can introduce bubbles into the water column; the bubbles affect data processing and hydroacoustic detectability.

A.1 Forebay Elevation

Forebay elevation data were obtained from the Fish Passage Center DART database(University of Washington 2001). For the 2001 study period, elevation was relatively constant varying by less than 1.5 m (4 ft) (Figure A.1). The forebay elevation during this period was about 1.7 m (5.5 ft) below normal high pool of 393 m (1290 ft). Compared to the previous two years, forebay elevation was slightly below 2000.

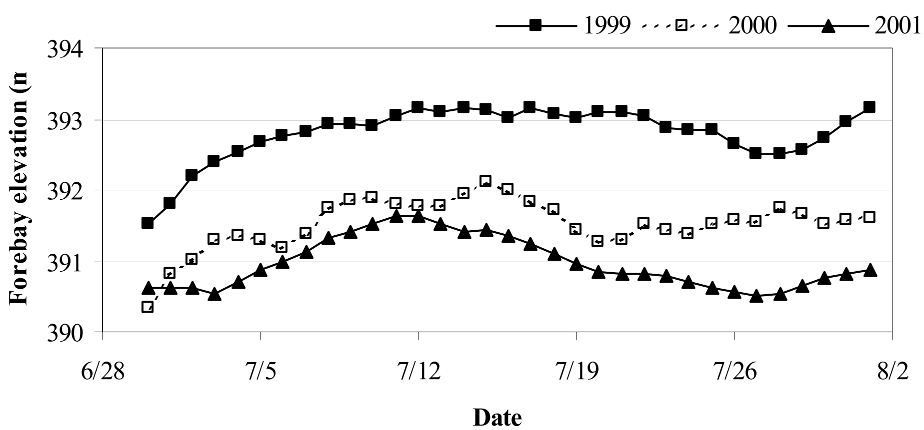

Figure A.1. Forebay Elevation in Front of the Left Powerplant During the Period June 30-August 2 for 1999, 2000, and 2001

A.2 Water Temperature

While light is a well-known stimulus to diel cycles of fish (Thorpe 1978), temperature has also been found to have an effect on their behavioral rhythms (Valdimarsson et al. 1997). For this reason, we examined the seasonal changes in water temperature across depth profiles. Depth-temperature (bathythermograph) data were collected by U.S. Bureau of Reclamation within the forebay of the left powerplant.

Water temperature, at the depth of the light frame (9 m), rose steadily during the study period, from 17°C on June 30 to 21°C at the conclusion of the study on August 1, 2001 (Figure A.2). Water temperature plotted against depth indicated the formation of a thermocline between the surface and 15 m, which was fairly pronounced by mid-July (Figure A.3).

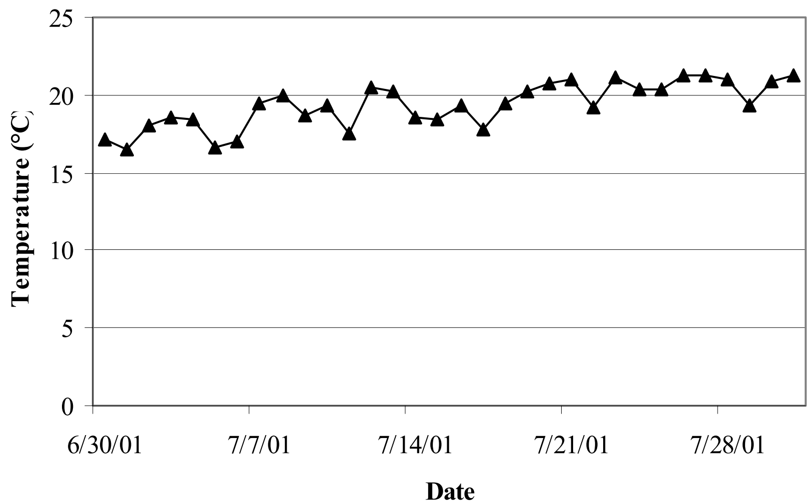

Figure A.2 Water Temperature (°C) at Depth of the Light Frame (9-m) from June 30 to August 1, 2001. Data from the forebay of the left powerplant at Grand Coulee Dam (U.S. Bureau of Reclamation).

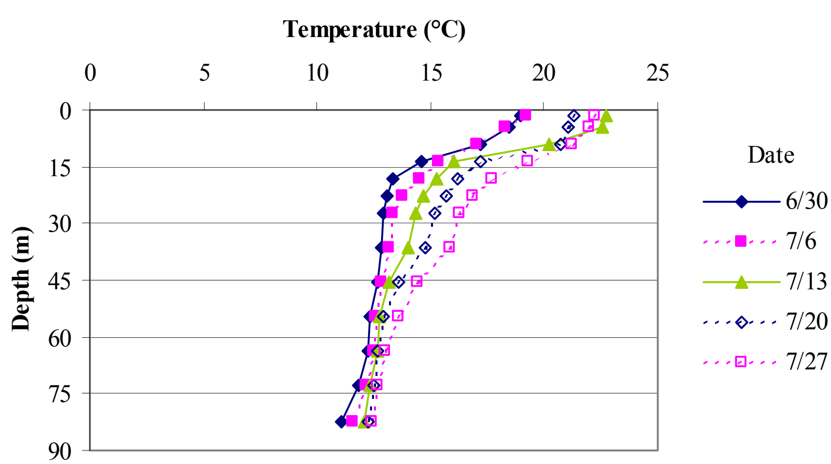

Figure A.3. Water Temperature (°C) at Various Depths from the Forebay of the Left Powerplant at Grand Coulee Dam from June 30 to August 1, 2001. (U.S. Bureau of Reclamation)

A.3 Turbidity

Turbidity can affect the distribution of fish both vertically and spatially (Matthews 1984; Swenson 1978). Turbidity can also limit the effectiveness of the strobe lights by reducing their visible range. Turbidity measurements were taken daily at three depths (surface, 9 m, and 18 m) at three stations in the forebay of the third powerplant (Figure 3.1). The turbidity measurements were taken with Van Doren bottle grab samples and analyzed using a Hach Model 2100P Portable Turbidimeter. Three samples were taken from each depth and station.

Turbidity levels were low throughout the season, with slight increases noted during the latter half of July, particularly near the surface (Figure A.4). Low turbidity was likely a result of the low water flows experienced in 2001.

A.4 Ambient Light Conditions

Ambient light levels have a direct effect on the effectiveness of the strobe light system by providing competing illumination during daylight hours. In addition, the diel light cycle influences fish distribution within the water column (Thorpe 1978).

Light conditions were monitored at the surface and on the frame using Model LI-19SA Underwater Quantum light sensors supplied by LI-COR, Lincoln, Nebraska. Two light sensors were placed on the frame, one aimed upward and one aimed upstream in the same direction as the lights were aimed. Light conditions were monitored 24 hr per day and reported hourly to a data logger on the sensor mast of the fixed barge.

With the shallow deployment of the strobe lights (i.e., 9 m) and the low turbidity, ambient light overwhelmed the illumination produced by the strobe lights during the daylight hours. Light levels for the three sensors shows a strong peak in early afternoon, even for the sensors located on the frame (i.e., Uplooking and Upstream) (Figure A.5). The effect of the strobe lights can be detected only at night (Figure A.6) when background light levels are near zero.

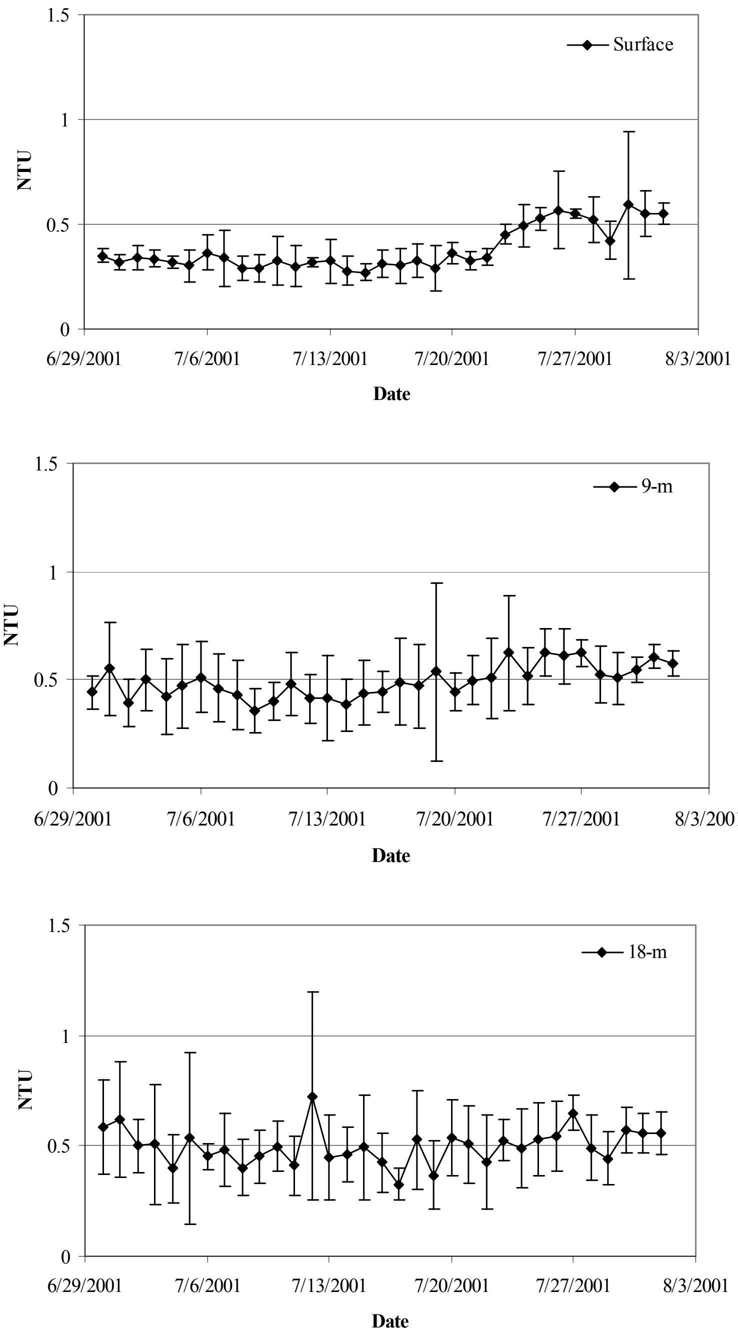

Figure A.4. Turbidity Levels at Grand Coulee Dam from June 30 to August 1, 2001. Bars are ±1 standard deviation (n = 9). Units are Nephelometric Turbidity Units (NTU).

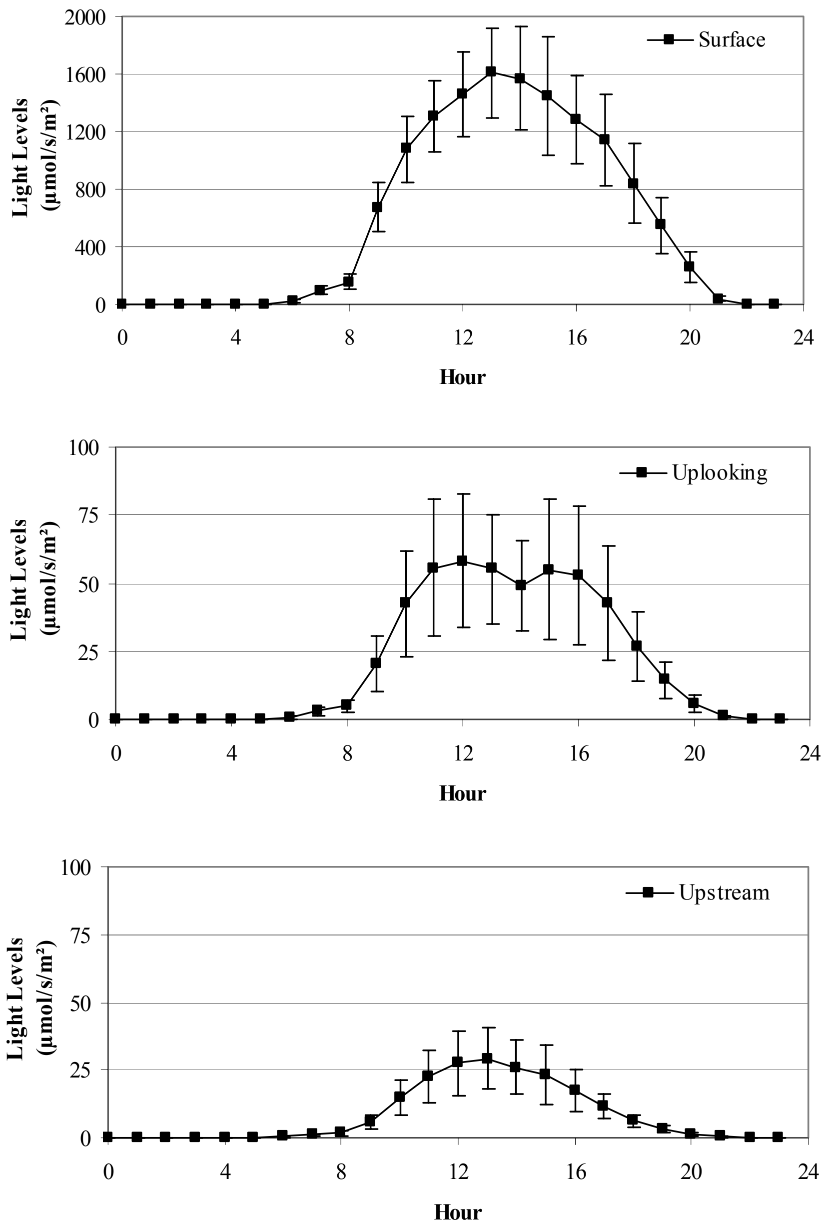

Figure A.5. Hourly Ambient Light Levels Measured at the Waters Surface and by Two Light Sensors on the Strobe Light Frame (9-m depth), One Pointing Toward the Surface (Uplooking) and the Other Upstream. Bars are ±1 standard deviation (n = 33).

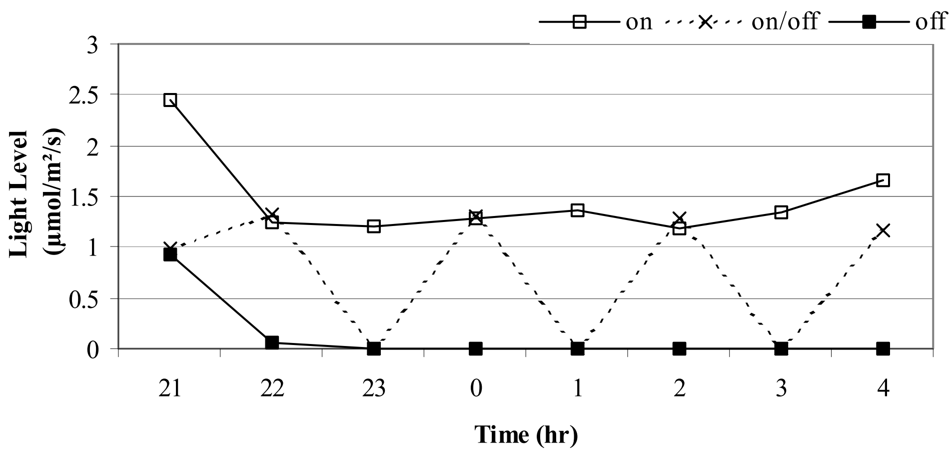

Figure A.6. Hourly Light Levels Measured at the Frame Depth of 9-m During the Night for Each Strobe Light Treatment Scenario (on – lights on for 24-hr; off – lights off for 24-hr; on/off – lights on for 1-hr followed by off for 1-hr).

A.5 Wind and Precipitation

Wind and precipitation disturb the surface of a body of water affecting light penetration. These two events also can introduce bubbles into the water column, which can acoustically obscure fish tracks. Wind speed (hourly average and maximums) and direction were measured during the study period on the fixed barge. A Model 03002V Wind Sentry (R.M. Young Company; Traverse City, Michigan) was secured to the sensor mast on the fixed barge. Wind speed and direction data were input to the LI1400 data logger continuously 24 hr/day and stored as the hourly minimum, maximum, and average speed and direction. On several occasions during the study, gusts were recorded in excess of 64 km/h (40 mph). Average hourly wind speed was generally less than 16 km/h (10 mph) and came predominantly from the south-southwest (Figures A.7 and A.8).

Precipitation data were recorded at the Coulee Dam Airport, Washington, located approximately 8 km southwest of the study site. As expected for this arid region of Washington, precipitation was negligible during July, with <0.05 cm recorded on three separate days. Precipitation was usually associated with sporadic thunderstorms moving through the area.

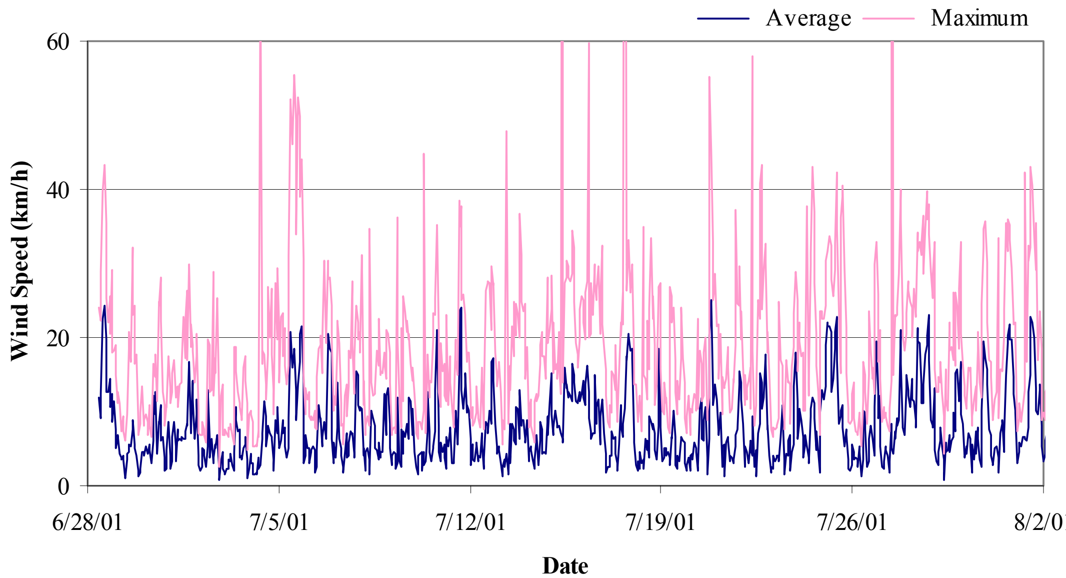

Figure A.7. Wind Speed Measured in the Forebay of the Third Powerplant at Grand Coulee Dam in 2001. Data represent hourly averages of the mean and maximum wind speeds.

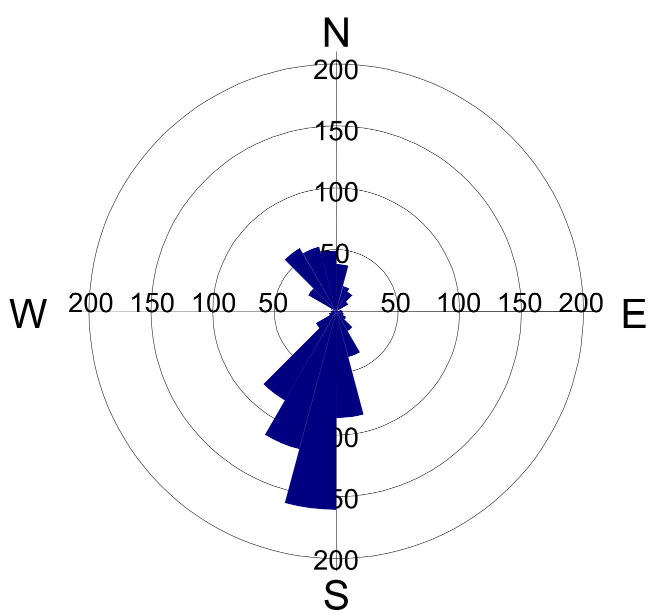

Figure A.8. Wind Rose Showing Predominant Wind Direction in the Forebay of the Third Powerplant at Grand Coulee Dam in 2001

A.6 References

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Appendix B

Distribution of Fish Detected on Mobile Surveys

Appendix B

Distribution of Fish Detected on Mobile Surveys

B.1 Mobile Hydroacoustic Transects

Two additional types of hydroacoustic surveys were conducted at Grand Coulee during the study period to examine the distribution of fish upstream and within the forebay of the third powerplant. One survey was approximately 120 m upstream from the strobe light study area and taken from a mobile platform that covered approximately 70 m across the forebay. The other survey was taken from a boat and covered both the area within the forebay itself as well as upstream from the lights. The upstream surveys were to be used in-season to adjust the depth of the strobe light array to correspond to the highest density of fish; however, densities were too low to accurately gauge the depth distribution in situ.

We used a BioSonics DT6000 splitbeam scientific hydroacoustic system mounted on a small platform (pontoon boat) for the upstream tethered mobile transect. The platform was pulled across the entrance to the third powerplant forebay along a guide rope tensioned between two buoys by a windlass winch controlled by a programmable logic controller (PLC) (Figures 3.2 and B.1). The PLC was programmed to make one crossing between the buoys at the top of each hour, requiring about 10 minutes. It would then "park" and wait for the top of the next hour for the return journey. The splitbeam transducer was oriented vertically from a mount on the upstream end of the pontoon boat, at a depth of 1 m. The hydro-acoustic system operated at a frequency of 200 kHz and a ping rate of 4 pps. A Trimble digital global positioning system (DGPS) was used to provide location data at sub-meter accuracy each second during data collection. The position data were stored in the same file as the hydroacoustic data. Data were stored internally in a battery-powered laptop computer and downloaded periodically for backup and processing. The entire system (winch, DT6000, PLC, and DGPS) was powered by six 12–V dc deep-cycle gel cell batteries that were charged by four solar panels. We had hoped to transfer the data via wireless communication to the deck of the dam, but communication was intermittent so we could not rely on it for real-time data transfer.

Each day during the study, additional mobile transects were conducted using a boat-mounted BioSonics DT6000 splitbeam hydroacoustic system operating at 420 kHz sampling the water column at 3 pps (Figure B.2). Position data again were recorded to the data acquisition software using a Trimble DGPS with sub-meter accuracy at 1-second intervals. Daily mobile transects were located upstream of the mobile barge and downstream of the fixed barge. In addition, we occasionally conducted zigzag transects into the third powerplant forebay to explore for fish that had passed the fixed barge (Figure B.3).

All of the data collected with the BioSonics DT6000 splitbeam hydroacoustic systems were processed using vendor-supplied software.

Figure B.1. Mobile Platform (i.e., traversing) at the Entrance to the Third Powerplant Forebay at Grand Coulee Dam, 2001

Figure B.2. Boat Conducting Mobile Transects in the Vicinity of the Fixed Barge to Supplement the Distributional Data. Fixed barge is on the right.

The locations of the mobile transects are depicted in Figure B.3 along with the overall depth distribution of targets detected during the mobile surveys. It should be noted that the data presented here are in terms of target detections and not fish or fish tracks since the primary purpose of the data was to determine the relative distribution of targets and not to quantify the population. We noted five distinct peaks in the data with depth: at the surface; at about 15 m; at 22-23 m; at about 40 m; and finally, at 46 m. The majority of targets were at the deeper depths (25 to 55 m). When these targets were classified into the three size categories used for the analysis of the fixed barge data (small, ≤-42 dB; medium, >-42 to ≤-32 dB; and large, >-32 dB), we found that the majority of the targets detected below 30 m were small targets with most well below the target threshold (Figures B.4 through B.9). During data processing and analysis, we noted large "clouds" of very small targets appearing periodically at the mobile platform transect. These targets were presumed to be zooplankton due to their small target sizes and large congregations.

The majority of the target detections above 20 m, particularly at the peaks in depth distribution, were medium-sized targets presumed to be the targets of interest, namely kokanee and rainbow trout. This suggests that the region we were illuminating with the strobe lights and sampling with the horizontal-looking splitbeam system at the fixed barge most likely contained the target species.

As a result of these mobile surveys, we concluded that the majority of the targets of interest were located above 20 m depth in the water column. While large numbers of targets were detected below 20 m, these targets had target strengths well below that expected from pen-reared kokanee and rainbow trout. Additional sampling using multiple mesh gill nets and a plankton net should be conducted during future monitoring efforts to determine the species composition of these targets.

Zig-zag boat transects conducted immediately in front of the third powerplant, within the cul de sac, indicated that the target distribution was slightly deeper (20 to 30 m) than that found at the entrance to the cul de sac (Figure B.6). Because these data were collected only periodically, this indication should not be construed as definitive. However, the distribution appeared to be different from that farther upstream and suggests the need to conduct more rigorous boat sampling in the future to determine the extent to which fish utilize that region.

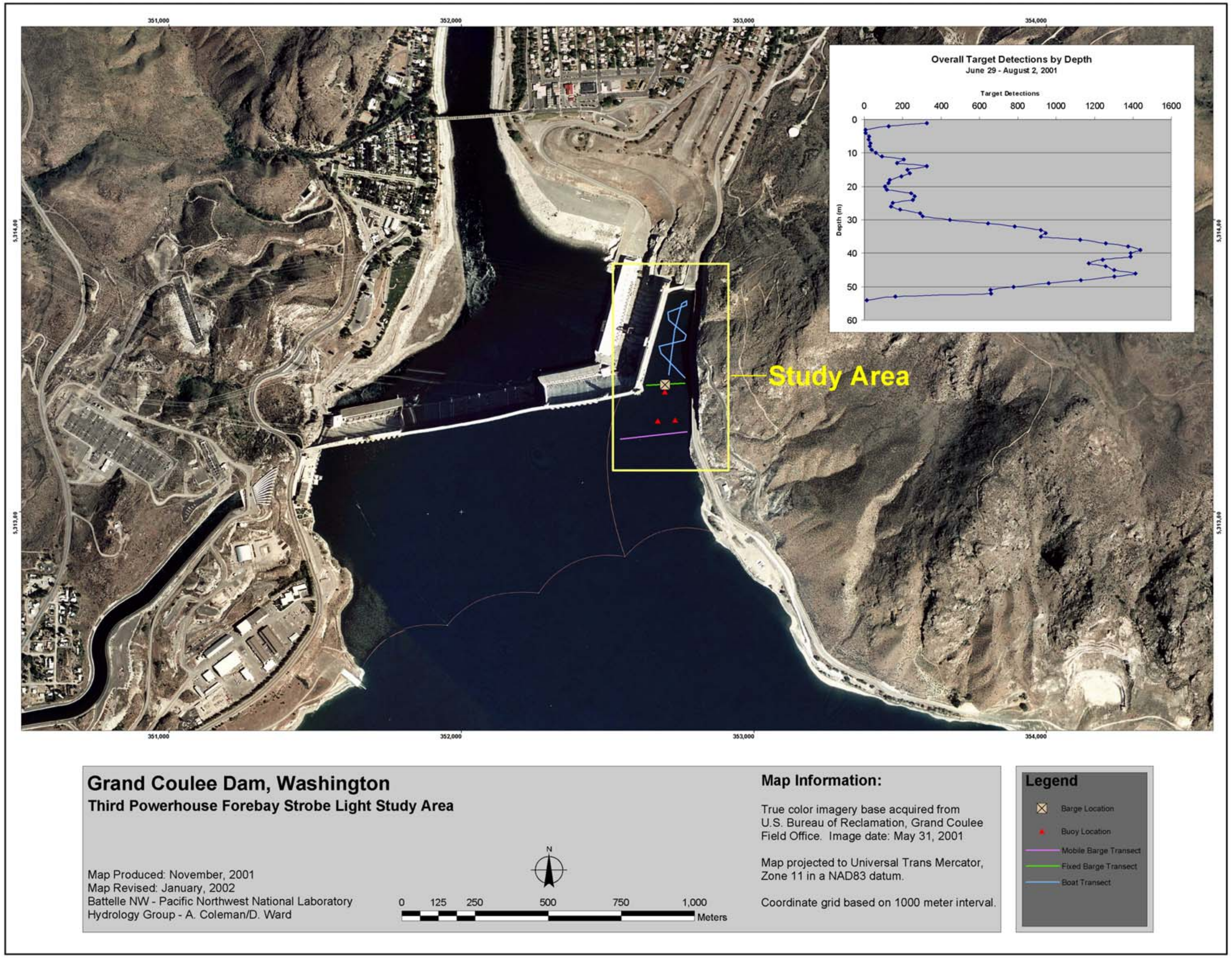

Figure B.3. Overview of the Strobe Light Study Area at Grand Coulee Dam in 2001. Lines indicate transect locations for the mobile hydroacoustic surveys. Graph (upper right) shows the overall distribution of targets with depth from all transects between June 30 and August 1, 2001.

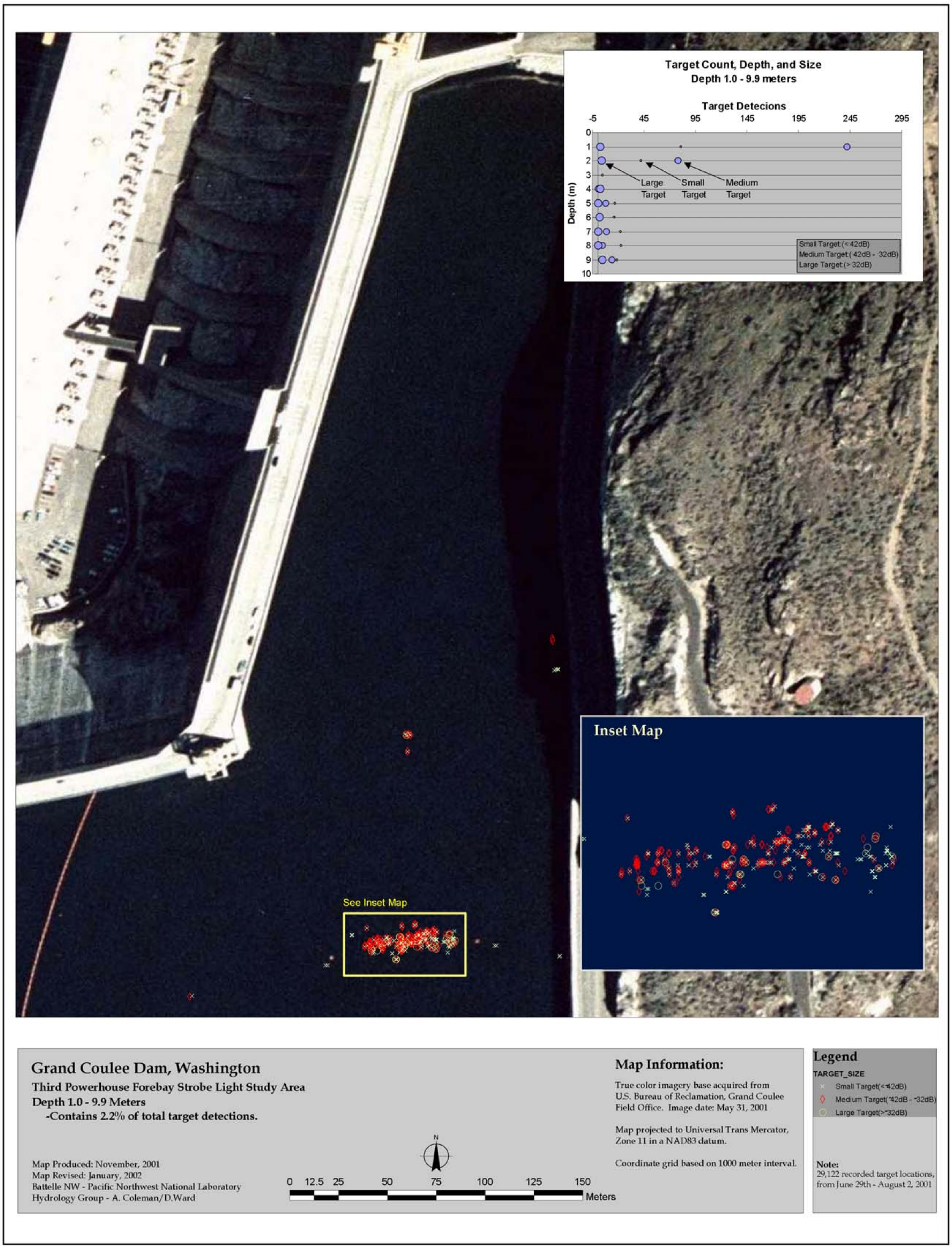

Figure B.4. Location of Targets Within 10 m of the Surface Detected by the Mobile Hydroacoustic Surveys in 2001. Three size-groups of targets are indicated based on target strength (dB).

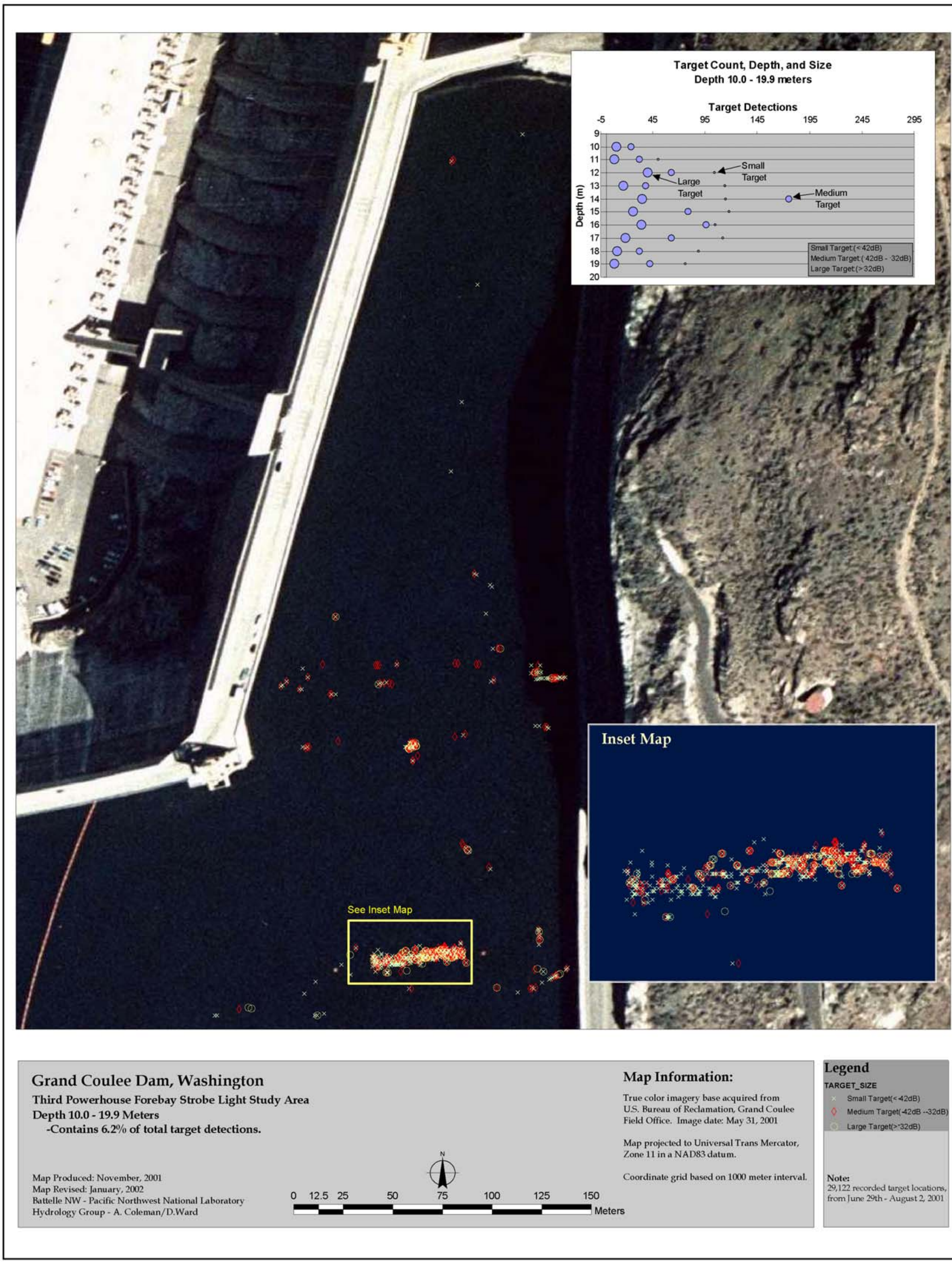

Figure B.5. Location of Targets Between 10-19.9 m from the Surface Detected by the Mobile Hydroacoustic Surveys in 2001. Three size-groups of targets are indicated based on target strength (dB).

Figure B.6. Location of Targets Between 20-29.9 m from the Surface Detected by the Mobile Hydroacoustic Surveys in 2001. Three size-groups of targets are indicated based on target strength (dB).

Figure B.7. Location of Targets Between 30-39.9 m from the Surface Detected by the Mobile Hydroacoustic Surveys in 2001. Three size-groups of targets are indicated based on target strength (dB).

Figure B.8. Location of Targets Between 40-49.9 m from the Surface Detected by the Mobile Hydroacoustic Surveys in 2001. Three size-groups of targets are indicated based on target strength (dB).

Figure B.9. Location of Targets Between 50-54 m from the Surface Detected by the Mobile Hydroacoustic Surveys in 2001. Three size-groups of targets are indicated based on target strength (dB).

Appendix C

Statistical Synopsis

Appendix C

Statistical Synopsis[a]

C.1 Summary

C.1.1 24 hr On/Off

Overall, there were clearly more tracks observed when the lights were on versus off, although the trend was not dramatic. This trend was more evident for the downlooking than the uplooking transducers. Some factors showed statistical significance in the log-linear models that were fit, but this was due primarily to differences in effect-size rather than truly different effects. There was some suggestion of fewer fish when the lights were turned on within 5 to 6 m of the strobe-light array when considering the uplooking transducers alone; however, these were far from conclusive. A more conclusive result showed more fish present when the lights were turned on, from the downlooking transducers. It should be noted that sampling was not sufficient in the closer ranges (within roughly 6 m) to adequately assess the effectiveness of light deterrence. This result is due primarily to the cone-shaped sampling region. Future studies should be set up in such a way as to sample more effectively in the regions nearer the strobe-light array.

C.1.2 1 hr On/Off

The data collected during the 1 hr on/off periods of the study design mostly paralleled those of the 24 hr on/off periods. However, the increase in observed tracks while the lights were on is even more clear. This trend is evident across all levels of the other factors considered in this study.

Note: These data may be viewed in a variety of pivot-tables and other simple charts or graphical summaries. However, conclusions (what few may be drawn) should be drawn from the modeling results only, which more properly incorporate the significant sampling aspects and other sources of variation in this study.

C.2 Methods

C.2.1 Purpose (taken from the Statement of Work)

"The purpose of this analysis is to assess the efficacy of a prototype strobe light system to elicit a negative phototactic response to kokanee and rainbow trout in the entrance to the forebay adjacent to the third powerhouse at Grand Coulee Dam."

(a) This appendix was prepared by Craig A. McKinstry, Pacific Northwest National Laboratory.

C.2.2 Statistical Methods

1.) Data were analyzed separately for the 24 hr on/off and 1 hr on/off treatments defined in the study plan. This analysis is limited to addressing the stated purpose as it pertains to track counts alone. Behavioral components derived from the fish track data are not addressed here.

2.) The four transducers were deployed in such a way that significant beam overlap occurred at distances roughly beyond 5 m from the strobe light-transducer array. This resulted in significant redundant or duplicate counting of fish tracks in the overlapping regions. For this reason, the data from each of the four 4 transducers were analyzed in separate analyses.

   a. Rationale: The overcounting of tracks is treatment-dependent if there is, in fact, a treatment effect. During the treatment condition when more fish are available to be counted (either lights-on or lights-off), they would also be more available to be overcounted. Thus, the overcounting problem would be exacerbated in the presence of a *more-fish-present* effect and would erroneously amplify any true treatment effect. Examining each transducer independently eliminates duplicate counts caused by beam overlap.

3.) Each observed fish track was classified by the following four categorical predictor variables defined as follows:

   a. *Block* - Treatment block from randomized study design: integer values 1 to 11
      i. Note: Block 7 was removed from the 24 hr on/off analysis due to an error in the operation of the strobe-light array.

   b. *Range_bin* - A categorical variable denoting the distance (in 2-m intervals) from the track location to the strobe-light-transducer array. Values: integers 1 to 14 covering distances out to 28 m.

   c. *Discharge* - A categorical variable denoting the level of operation of the third powerplant and coded as follows:
      i. 0 if discharge = 0 (i.e., All third powerplant turbines were off)
      ii. 1 if 0 < discharge <25,000 cfs
      iii. 2 if 25,000 < discharge <50,000 cfs
      iv. 3 if discharge >50,000 cfs.

   d. *Fish_size* - A categorical variable computed from target strength data as follows:
      i. 1 (small) if target strength ≤-42 dB
      ii. 2 (medium) if target strength >–42 to≤-32dB
      iii. 3 (large) if target strength >-32dB.

   e. *Treatment* - Treatment variable coded:
      i. 0 when the strobe lights were off
      ii. 1 when the strobe lights were on.

4.) The results were multidimensional contingency tables as follows:
   a. a 10x24x14x4x3x2 contingency table of track-counts for the 24 hr on/off analysis
   b. a 11x24x14x4x3x2 contingency table of track-counts for the 1 hr on/off analysis.

5.) These tables were analyzed as log-linear models by taking the cell counts from the contingency tables defined above as the response variable and fitting a generalized linear model using maximum likelihood methods. The response variable, *COUNT*, was taken as having a Poisson distribution with multiplicative error structure, and was related to the predictors through a log-linking-function (McCullagh and Nelder 1989, pp. 193-194). The Poisson regression model and analysis of deviance methods were selected over the more commonly used methods based on a normal error structure and analysis of variance because the Poisson distribution more adequately reflects the error structure in count data (McCullagh and Nelder 1989, p.193). Analysis of deviance may be seen as parallel to analysis of variance.

6.) Because the shape of the hydroacoustic beam is roughly a right circular cone, it encompasses an increasing spatial volume with distance from the transducers. The probability of track observation/ detection thus also increases with distance from the transducers, as the sampling volume increases. For this reason, a weighting factor was computed as proportional to the volume of a conic section, 2 m in length, centered at each of the fourteen 2-m conic sections of the beam. The weight used in fitting the model was then computed as inversely proportional to these volumes:

$$weight_i = 1/volume_i$$

where '*i*' goes from 1 to 14, each denoting a 2-meter conic section of beam.

7.) Model fitting was first done with all main effects in the model: *Block, Hour, Range_bin, Fish_size, Discharge, Treatment*.

8.) Model selection was preformed using a backward stepwise procedure based on Akaike's Information Criterion (AIC) (Venables and Ripley 1999), with the *Treatment* effects constrained to remain in the model.

9.) Once a final model was determined and fit, analysis of deviance and analysis of coefficients were performed.

10.) Analysis of first-order interactions between the significant predictors and the treatment effect were also carried out.

C.3 Results

C.3.1 24 hr On/off

1. There were 31,865 tracks used in the 24 hr on/off analysis distributed between transducers as follows:

   i. Upper left[a]: 6,890
   ii. Lower left: 9,541
   iii. Upper right: 7,273
   iv. Lower right: 8,161
2. Stepwise regression of main effects was performed with the *Treatment* factor constrained to remain in the model. This yielded the following significant factors:
   i. Uplooking Transducers: *Range_bin, Fish_size, Discharge* were retained in the model as significant predictors of the observed counts.
   ii. Downlooking Transducers: *Block, Range, Fish-size, Discharge,* were retained in the model as significant predictors of the observed counts.

3. Analyses of deviance and parameter estimates were performed on the final models arrived at in item 1b. These are summarized below:
   i. Uplooking Transducers: *Range_bin, Fish_size, Discharge, Treatment*
      1. Analysis of deviance found all factors to be to be statistically significant at the p = 0.01 level. This would suggest that each of these factors was significantly related to the observed cell counts in the log-linear model. Next, the nature of this relationship will be explored. These factors will be assessed only in how they relate to the *Treatment* effect.
      2. For both uplooking transducers, the T*reatment* effect was found to show <u>fewer fish observed when the lights were on.</u>
         a. The parameter estimate was statistically significant for the upper left transducer (p <0.0001), but not statistically significant for the upper right (p = 0.13)
      3. Cursory analysis however has shown the uplooking transducers are subject to more noise due to bubbles created from wind on the lake surface. This noise makes identification and discrimination of fish tracks more difficult, according to scientist Mary Ann Simmons.
   ii. Downlooking transducers: Model Factors: *Block, Range_bin, Fish_size, Discharge, Treatment*
      1. Analysis of deviance found all factors to be to be statistically significant at the p = 0.001 level
      2. For both downlooking transducers, the *Treatment* effects were found to have parameter estimates <u>indicating more fish observed when the lights were on.</u>
         a. These parameter estimates were statistically significant (p <0.0001) for both the lower right and left transducers.

4. Stepwise regression of first-order interactions was then carried out.
   i. These interactions were formed by pairing the significant main effects from the previous analysis with the *Treatment* effect.
   ii. The stepwise model selection was constrained to retain the significant main effects identified in item 1b above for each transducer.

(a) Left is *dam* side; right is *bank* side.

iii. Results: (24 hr on/off cont.)
1. Uplooking transducers:
   a. Upper Left: significant interaction terms
      *i. Fish_size*Treatment*
         1. The *Fish_size*Treatment* interaction was shown to be significant; however, the only clear trend shows slightly more than 50% of tracks were observed during the lights-on phase across all levels of the fish_size factor.
      ii. Discharge*Treatment
         1. Discharge level shows no clear trend. Relatively more fish were seen during lights-off when discharges were from 0 to <25,000 cfs, and >50,000cfs
   b. Upper Right:
      i. No significant interaction terms
2. Downlooking Transducers:
   a. Lower Left: significant interaction terms
      i. Fish_size*Treatment
         1. The trends noted for the Upper Left transducer are repeated here.
   b. Lower Right: significant interaction terms:
      i. Range_bin*Treatment
         1. From *Range_bin=3* (6 to 8 m) and greater, more tracks were observed during the lights-on phase of treatment. <u>At less than 6 m, there are significantly more tracks during the lights-on phase of treatment</u>.

C.3.2 1hr On/Off

1. There were 15,329 tracks used in the 1 hr on/off analysis distributed between transducers as follows:
   i. Upper Left[(a)]: 3,099
   ii. Lower Left: 4,842
   iii. Upper Right: 3,174
   iv. Lower Right: 4,214

2. Stepwise regression of main effects was performed with the Treatment factor constrained to remain in the model. This yielded the following significant factors:
   i. For both Uplooking and Downlooking Transducers: Range_bin, Fish_size were retained in the model as significant predictors of the observed counts.

(a) Left is *dam* side; right is *bank* side.

3. Analyses of deviance and parameter estimates were performed on the final models arrived at in item 2b. These are summarized below. Final factors in the model were Range_bin and Fish_size for all transducers.
   i. Uplooking Transducers
      1. All factors were statistically significant at $p = 0.05$.
      2. Parameter estimates for the treatment factors suggested the following:
         a. Upper-Left Transducer - <u>fewer fish when the lights were on (p = 0.03)</u>.
         b. Upper-Right Transducer - <u>more fish when the lights were on</u>. (p = 0.002).
   ii. Downlooking Transducers
      1. The treatment factor was not shown to be statistically significant for both transducers in the analysis of deviance.
      2. Parameter estimates for the treatment factor were not statistically significant, but <u>both suggested fewer fish present when the lights were on</u>
         a. Lower Left (p = 0.53)
         b. Lower Right (p = 0.24).

4. Stepwise regression of first-order interactions was then carried out.
   i. These interactions were formed by pairing the significant main effects from the previous analysis with the *Treatment* effect.
   ii. The stepwise model selection was constrained to retain the significant main effects identified in item 2b above for each transducer.
   iii. Results:
      1. Uplooking Transducers:
         a. Upper Left: No significant interaction terms
         b. Upper Right: No significant interaction terms
      2. Downlooking Transducers:
         a. Lower Left: No significant interaction terms
         b. Lower Right: No significant interaction terms.

C.4 References

McCullagh, P., and J. A. Nelder. 1989. *Generalized Linear Models.* 2nd ed. Chapman & Hall, Boca Raton, Florida.

Venables, W. N., and B. D. Ripley. 1999. *Modern Applied Statistics with S-plus*. 3rd. ed. Springer-Verlag Inc., New York.

Appendix D

Swimming Response to Lights 24-hr On/Off

Appendix D

Swimming Response to Lights 24-hr On/Off

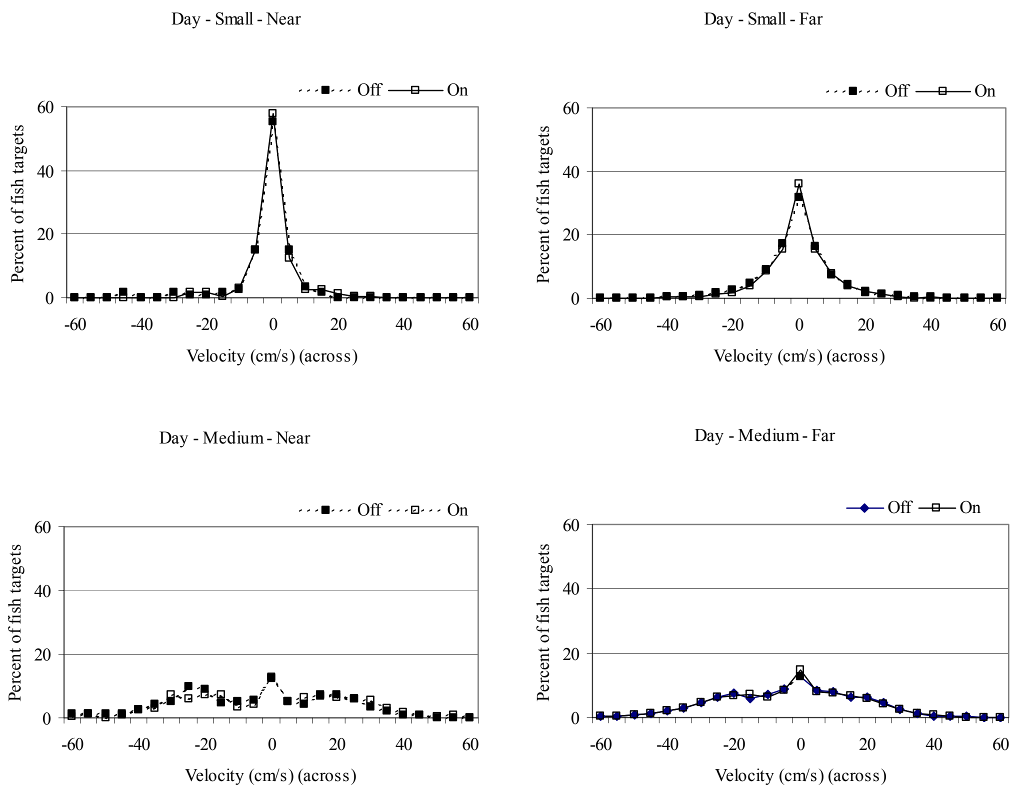

Figure D.1. Velocity Component in the Direction Across the Lights for Small (≤-42 dB) and Medium (>-42 to ≤-32 dB) Fish Targets at Two Distances from the Lights During the Day. Positive and negative components indicate fish swimming away from lights laterally.

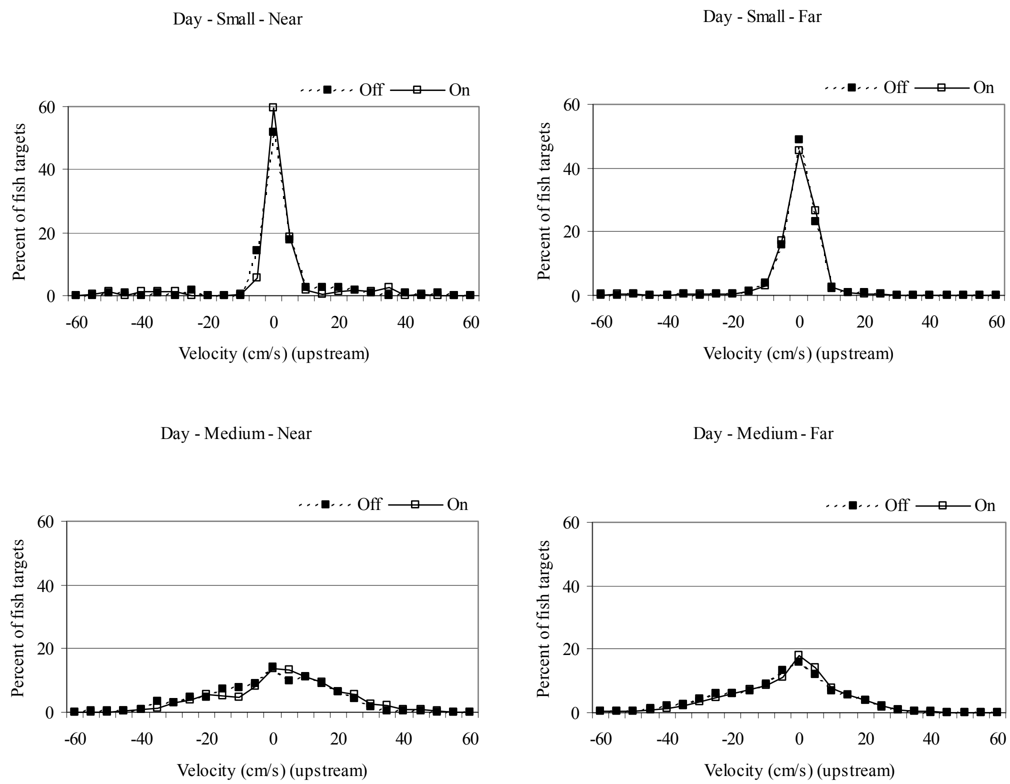

Figure D.2. Velocity Component in the Direction Away from the Lights for Small (≤-42 dB) and Medium (>-42 to ≤-32 dB) Fish Targets at Two Distances from the Lights During the Day. Negative components indicate the fish targets going toward the lights, while positive components are in an upstream direction.

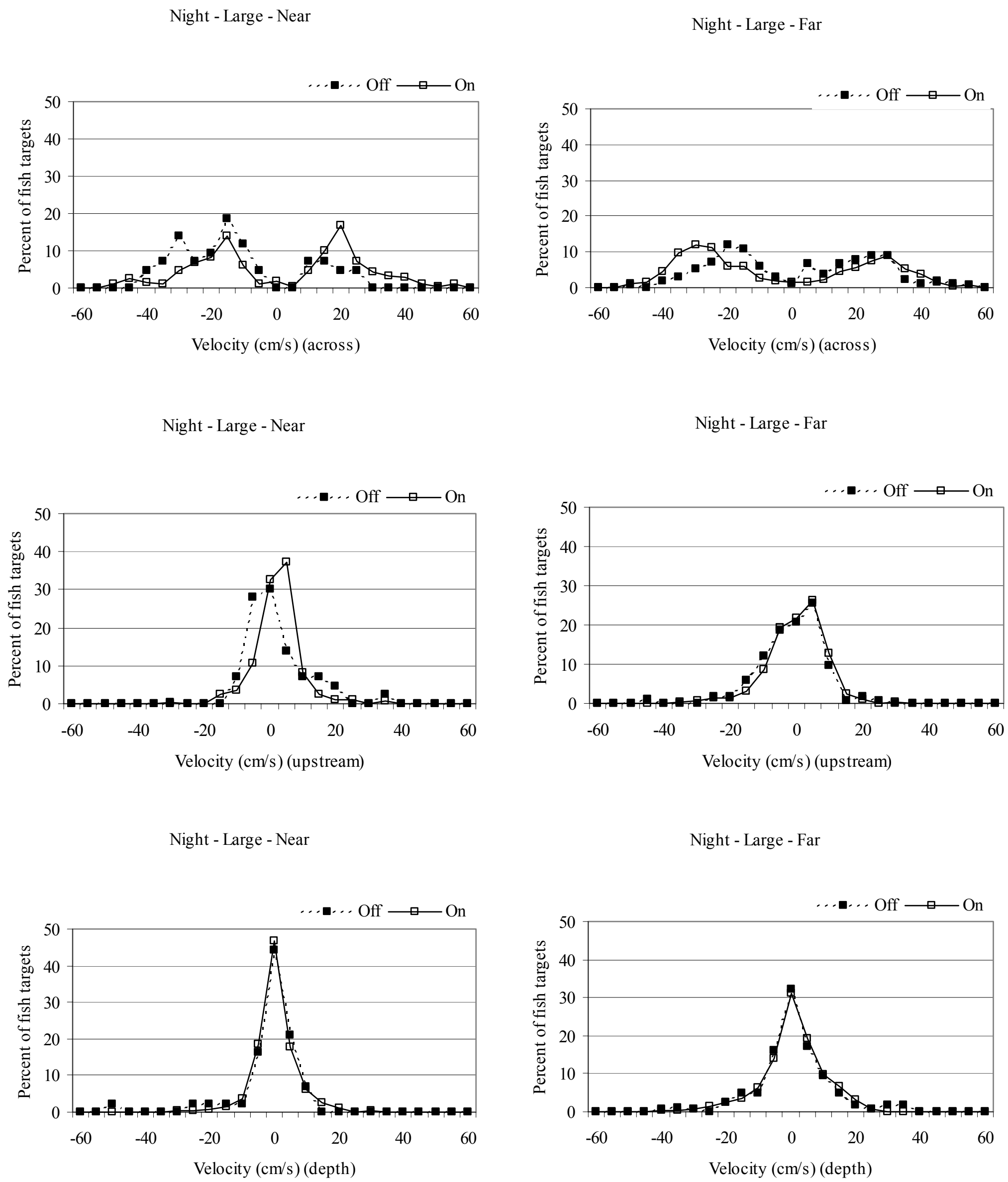

Figure D.3. Velocity Components for Large Fish Targets (>-32dB) at Two Distances from the Lights (near: <14m; far: >14 m) During the Night. Velocities greater than zero for the component across the light indicate that fish are swimming away from the lights. For the upstream component, velocities greater than zero are indicative of fish swimming upstream, while negative components are in the downstream direction. Positive velocities along the depth component indicate fish swimming downward, while negative components indicate the fish are swimming toward the surface.

Appendix E

Strobe Light and Transducer Mapping

Appendix E

Strobe Light and Transducer Mapping

Following completion of the data collection effort, we measured the strobe light illuminance and transducer sample volume. The aluminum frame containing the strobe lights and splitbeam transducers was secured to a floating frame and suspended approximately 0.3 m below the water surface (Figure E.1). An International Light IL1700 photometer was used to determine the illuminance per flash from the strobe light array. The IL1700 provides a cumulative measure of illuminance over a user-selected time period (approximately 30 s), which, when divided by the number of flashes (approximately 180), yields illuminance (μmol s^{-1} m^{-2}). Light and hydroacoustic measurements were conducted simultaneously. The light sensor was used as the acoustic target to map the hydroacoustic sample volume. Vertical centerline measurements were conducted at 1-m intervals from 1 to 30 m. In addition to the centerline measurements, a second set of measurements was taken at approximately 10 m depth. These measurements were taken at 45-degree intervals around the entire frame (Figure E.2). Along each of the 45-degree radii, measurements were taken at 0.2-m intervals from 1 to 3.2 m from the center of the frame.

Results from the vertical mapping demonstrated that light levels were approximately 0.0009 μmol s^{-1} m^{-2} at 14 m depth (Figure E.3). Radial measurements conducted at 10 m demonstrated that light levels were greater than 0.0015 μmol s^{-1} m^{-2} within the areas ensonified by the hydroacoustic array at that range (Figure E.4).

Figure E.1. Position of the Floating Calibration Frame During the Calibration Effort at Grand Coulee Dam in 2001

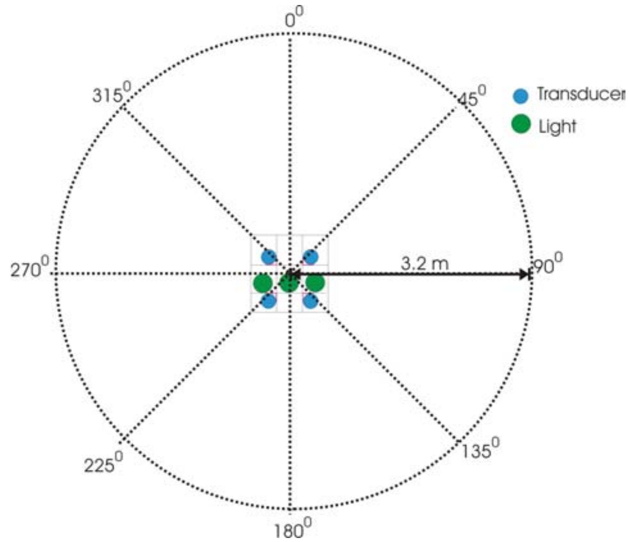

Figure E.2. Calibration Frame Depicting 45-Degree Radii Sampling Transects at Grand Coulee Dam in 2001

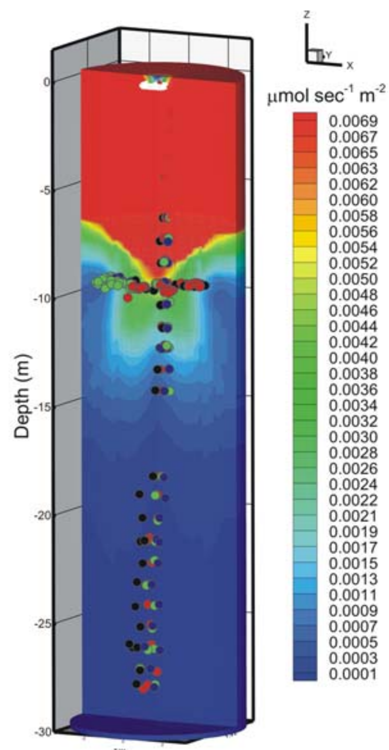

Figure E.3. Contour Plot of Strobe Light Illuminance (µmol s^{-1} m^{-2}) and Scatter Plot of Hydro-acoustic Targets. Light frame is depicted in white at top of image.

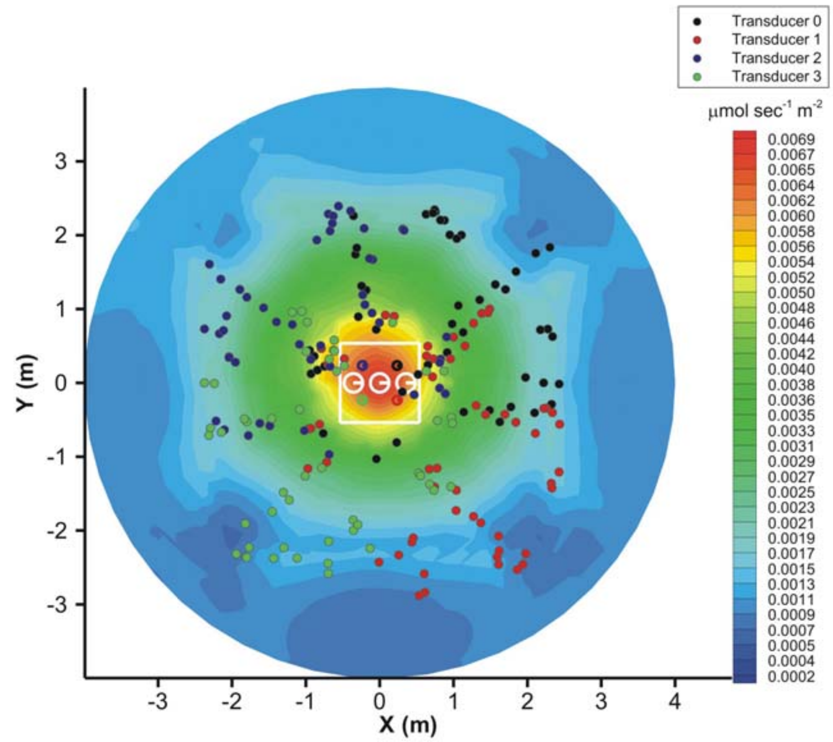

Figure E.4. Contour Plot of Strobe Light Illuminance (μmol s^{-1} m^{-2}) and Scatter Plot of Hydroacoustic Targets. Strobe lights (white) and transducers (various colors) are depicted within light frame (white).

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