U.S. Army Corps of Engineers
Portland District

Splitbeam Evaluation of Near-Field Fish Behavior at Bonneville Dam First Powerhouse, Unit 8

FINAL REPORT

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February 2001

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Executive Summary

Pacific Northwest National Laboratory (PNNL) conducted this study for the U.S. Army Corps of Engineers (Corps). The purpose of the study was to evaluate fish behavior in front of Turbine Unit 8 of the First Powerhouse at Bonneville Dam and determine if this behavior could be attributed to the presence of a modified extended-length submersible bar screen (ESBS) installed at the dam in 2000.

To characterize the behavior of juvenile, migrating salmonids (smolts), we used two stationary splitbeam transducers and one traversing transducer upstream of the streamlined trash racks at the B-slot of Unit 8. We analyzed smolt behavior characteristics from May 4 to July 15, 2000, with respect to time of day, season (spring and summer), sample region in front of the trash rack, and whether the turbine was on or off.

Based on the results of this study we conclude that:

- because the fish population immediately upstream of the trash racks was high in the water column, the majority of fish would not have been entrained under the tip of the ESBS from the sample region.
- there was a substantial degree of milling upstream of the trash racks.
- only one region was identified that potentially could contribute to fish entrainment, but that occurred at night, when relatively few fish were detected. At that time, fish were still relatively high in the water column away from the tip of the ESBS.
- the majority of tracked fish were located in the center region of the slot opening with lower numbers to the north and south sides. This raises concerns about center slot hydroacoustic sampling for passage estimation at this location.

Based on these conclusions, we recommend that:

- the traversing splitbeam transducer be redeployed on a lower trash rack (#2 or #3) to concentrate effort at the tip of the ESBS, to assess the dynamics of that region
- for future fish bypass design efforts, the mechanisms that cause milling in front of an unobstructed turbine intake be modeled. Improved mitigation technologies may become apparent by understanding these delay mechanisms.
- further research be conducted to establish the validity of our finding that the majority of tracked fish were located in the center region of the slot opening with lower numbers to the north and south sides.

Acknowledgments

We gratefully acknowledge the cooperation, assistance and dedication of the following people and organizations that contributed to the success of this study (listed in alphabetical order).

U.S. Army Corps of Engineers, Portland District personnel:
Dennis Schwartz

U.S. Army Corps of Engineers, Bonneville Dam
Jennifer Sturgill
Operations and Maintenance crews at first powerhouse ("The Professionals")

U.S. Army Corps of Engineers, Waterways Experiment Station and contract personnel:
Larry Lawrence
Deborah Patterson
Carl Schilt
Mark Weilen

USGS (Cook, WA)
Derrek Faber
Shaun Zimmerman

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Abbreviations and Terms

τ	Tortuosity index
λ	Loopyness index
ANOVA	Analysis of variance
CFD	Computational fluid dynamics
cfs	Cubic feet per second
cm	Centimeter(s)
collector	Prototype surface collector
Corps	U.S. Army Corps of Engineers
DART	Data access in real time
dB	Decibel
displacement fraction	The proportion of fish traveling in a particular direction; page 3.9
ensonify (ensonification)	Subjected to sound field
echo	Single energy return from an object (fish or debris)
ESBS	Extended-length submersible bar screen
FFU	Fisheries field unit
FGE	Fish guidance efficiency
FPC	Fish passage center
fps	Feet per second
ft	Feet
kcfs	1,000 cubic feet per second
kHz	Kilohertz
km	Kilometer
loopyness index	λ; an index of the maximum displacement in a fish's track; page 3.11
MAF	Million acre-feet
m	Meter(s)
m^3	Cubic meter(s)
m/s	Meters per second
MW	Megawatts
NMFS	National Marine Fisheries Service
N_{PSC}	Collector (PSC) entrance efficiency
NTU	Nephelometric turbidity unit(s)
observation	Individual echo location within a fish track
ping	Sound pulse transmitted and received by a transducer
PNNL	Pacific Northwest National Laboratory
potential entrance efficiency	A measure of the proportion of fish estimated to pass into a collector
pps	Pings per second
Q	Volume water discharge (ft^3/s)
s	Second(s)
STS	Submerged traveling screens
tortuosity index	τ; an index of efficiency of progress in overall displacement in space; page 3.10
track	Fish track (comprised of multiple echo observations)
WES	Waterways Experiment Station
x-axis	Parallel to, or along, the collector; North/South direction
y-axis	Depth in the water column
z-axis	Perpendicular to, the dam; upstream/downstream

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1.0 Introduction

1.1 Background

The passage of juvenile salmonids down the Columbia River has been the subject of numerous studies, some involving enhancement or modifications to hydroelectric dam structures to facilitate fish movement. One way to measure the success of these new structures is to determine the fish guidance efficiency (FGE). The FGE is a count of the number of fish guided around a turbine by submerged traveling screens divided by the total number of fish entering the turbine intake. At Bonneville Dam's First Powerhouse, the FGE traditionally has been very low. It improved in 1998, however, when the U.S. Army Corps of Engineers (Corps) installed an extended-length submersible bar screen (ESBS) at the powerhouse.

Since 1998, the perforated plate behind the ESBS has been redesigned to reduce vibrations that had resulted in extensive problems with plate attachment at other hydroelectric projects. In 1999, the Corps asked Pacific Northwest National Laboratory (PNNL) to test the new design at Little Goose Dam on the Snake River (Anglea and Skalski 2000). Our researchers found that the new design had no significant effect on FGE. However, the results noted that the measurement of FGE was dynamic and not constant for an intake or plate type. Therefore, in 2000, the Corps asked PNNL to conduct a monitoring study at Bonneville Dam when a redesigned ESBS was installed in the B-slot of Turbine Unit 8 at that dam.

1.2 Goals and Objectives

The purpose of our spring and summer 2000 study at Bonneville Dam was to evaluate fish behavior in front of B-slot of Turbine Unit 8 of the First Powerhouse at Bonneville Dam and determine if this behavior could be attributed to the presence of the modified ESBS installed at the dam.

1.3 Report Contents

Section 2.0 of this report describes the study site at Bonneville Dam. Section 3.0 provides methods for hydroacoustic techniques and statistical analyses. Results are provided in Section 4.0, discussion in Section 5.0. Section 6.0 lists our conclusions and recommendations. Supporting information is provided in Appendices A-F on turbine operations at Unit 8, statistical analyses, background noise, quality control, fish behavior statistics, and sample sizes for the vector plots.

2.0 Study Site Description

2.1 Bonneville Dam

Bonneville Dam, located on the Columbia River at river mile 146.1 was the first of eight federal locks and dams constructed by the U.S. Army Corps of Engineers (Figure 2.1) on the lower Columbia and Snake rivers. The dam comprises two powerhouses (First Powerhouse and Second Powerhouse), a spillway, and two navigation locks interconnected by three islands. Construction of the First Powerhouse began in 1933, and was completed in 1937. The second powerhouse was constructed on the Washington side of the river between 1974 and 1981. A larger navigation lock was completed in 1993 to replace the original (circa 1938) lock.

The First Powerhouse comprises 10 generators and has a total generating capacity of 526,700 kW. The Second Powerhouse comprises eight generators and has a total generating capacity of 558,200 kW. The spillway, located between the two powerhouses, is 442 m long with 18 spill gates. The forebay pool level ranges from 21.8 to 23.3 m above mean sea level.

The Corps chose the B-slot of Unit 8 on the First Powerhouse of Bonneville Dam as the site to test the extended-length submersible bar screen (ESBS) (Figure 2.2). The trash rack at the entrance to Unit 8 had been modified to incorporate the streamlined design. The design incorporated structural vanes to guide the flow and create less turbulence behind the trash rack.

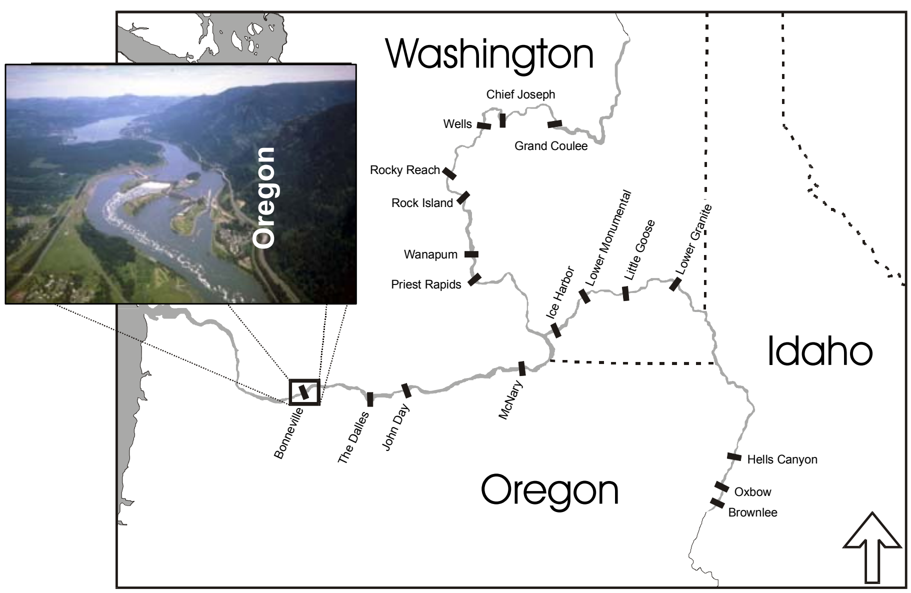

Figure 2.1. Location of Bonneville Dam on the Columbia River Between Washington and Oregon

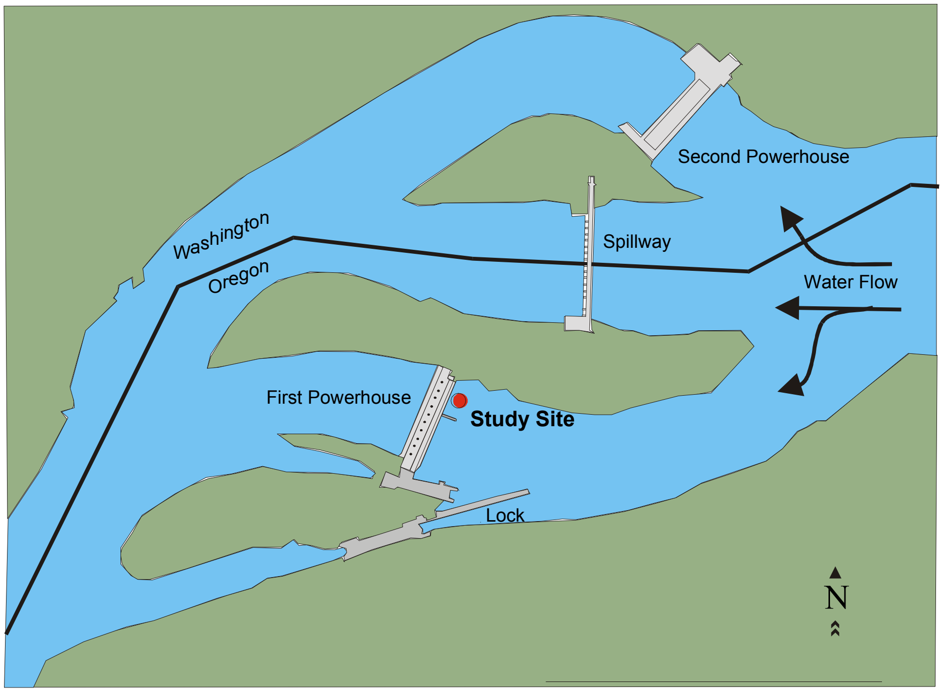

Figure 2.2. Study Site Location (red dot) at Unit 8, First Powerhouse, Bonneville Dam in 2000

2.2 Hydraulic and Environmental Conditions

To draw conclusions about fish behavior at Bonneville Dam, it is important to understand hydraulic and environmental conditions existing at the dam during the study period.

2.2.1 River Discharge

This section provides information on the hydraulic conditions (in-season flows and dam operation), for April 15 through July 15, 2000. River discharge and dam operations data were obtained from the Fish Passage Center (http://www.fpc.org). Water discharge was relatively constant at the First Powerhouse in May and June with one anomalous peak around May 4 (Figure 2.3). Figure 2.3 also shows the discharge from the spill and Second Powerhouse. Second Powerhouse discharge was sacrificed to maintain mandatory spill and First Powerhouse loading.

2.2.2 Turbidity and Temperature

Turbidity and temperature may play important roles in salmon smolt behavior with respect to visual cues and the condition of the migrating salmon. Data are provided on turbidity and temperature for reference when examining the seasonal behavior data later in this report. The turbidity in 2000 ranged from 2.0 secchi units to a high of approximately 6.8 secchi units (Figure 2.4). Levels remained relatively low (2-4 secchi units) during the spring peak migration and only began to rise significantly in mid-June.

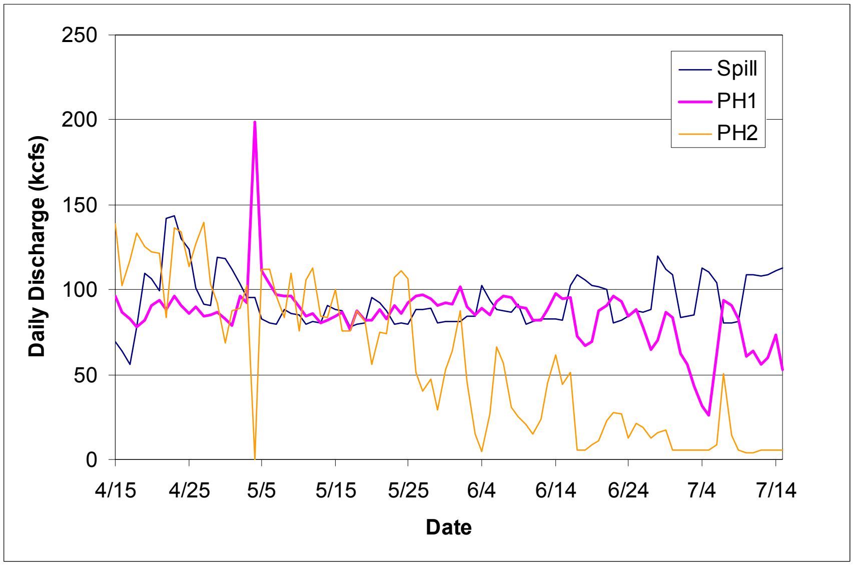

Figure 2.3. River Discharge (kcfs) at Bonneville Dam from April 15 - July 15, 2000. Data from the Fish Passage Center web page (http://www.fpc.org). (Spill - Spillway discharge, PH1 - First Powerhouse, PH2 – Second Powerhouse)

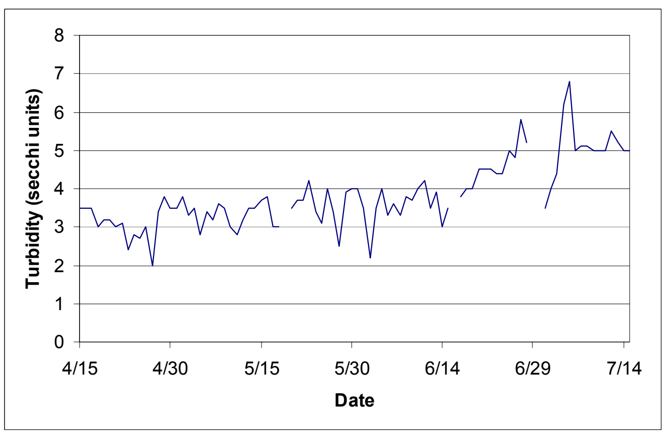

Figure 2.4. Turbidity (secchi units) at Bonneville Dam from April 15 - July 15, 2000. Data from the Fish Passage Center web page (http://www.fpc.org).

The water temperature rose steadily during the study period starting at 10.1°C and ending at 19.3°C (Figure 2.5). It is reasonable to expect that fish subjected to warmer waters might swim more slowly and be less able to maintain their swimming performance in the face of increasing flows near the dam.

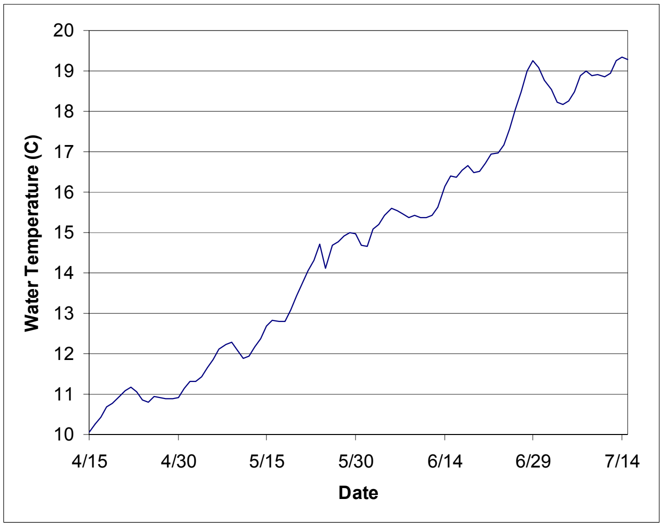

Figure 2.5. Water Temperature (°C) at Bonneville Dam from April 15 - July 15, 2000. Data from the Fish Passage Center web page (http://www.fpc.org).

2.2.3 Weather Conditions

Wind and rain are primarily a concern when trying to extract fish tracks from the raw dataset. Both weather events cause small bubbles to be driven into the water column. This is particularly true of the region near turbine intakes such as the sample region in front of Unit 8. As the water is pulled downward toward the turbine opening, so are the bubbles. This results in increased background noise levels, which complicates fish track detection. Our detailed analysis of fish tracks has isolated a number of instances where noise was associated with fish tracks and resulted in “false” track segments. When examining fish behavior on a fine scale, these false track segments can bias the results since the bubbles are moving in a particular direction (usually with the flow). The wind and precipitation data included here are for Skamania, Washington (approximately 11 miles west of Bonneville Dam).

Wind and rain were most prevalent from the start of the study through June 14 (Figure 2.6). The remainder of the study was only affected by wind conditions. The poor weather conditions overlapped the peak of the smolt run, complicating the track selection process for the splitbeam hydroacoustic dataset. The majority of the wind events originated from the west or southwest (Figure 2.7). Because the dam provides a shelter for westerly wind events, they did not directly affect the sample region. However, wind-driven waves upstream of the dam can also cause large clouds of bubbles to drift into the region. At times, the bubble masses entirely masked the upper water column, preventing fish track detection during those events.

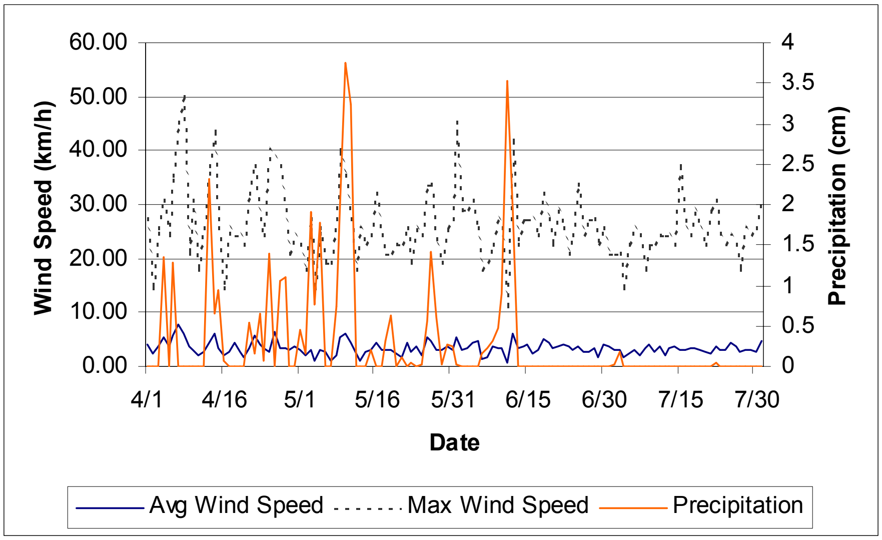

Figure 2.6. Wind Speed (kmh) and Precipitation (cm) at Bonneville Dam from April 15 - July 15, 2000. Data from the National Weather Service (NOAA).

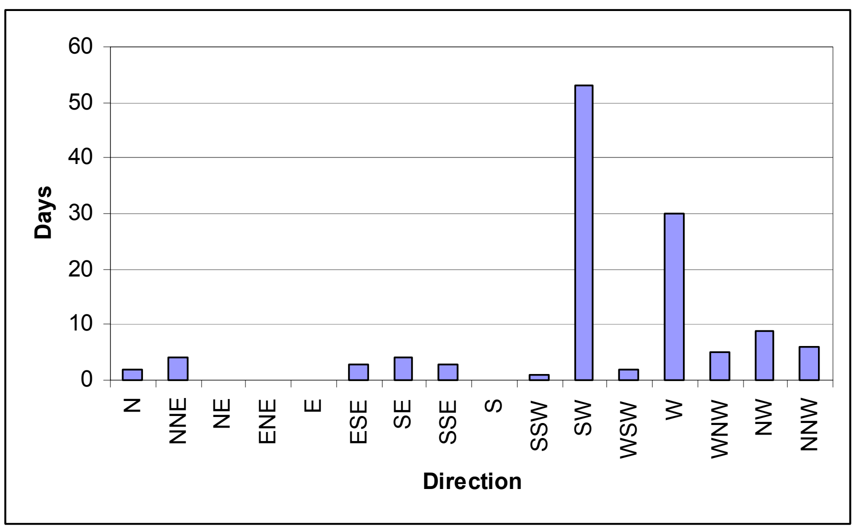

Figure 2.7. Wind Direction at Bonneville Dam from April 15 - July 15, 2000. Data from the National Weather Service (NOAA).

2.3 Salmon Smolt Migration

Run timing and species composition data were obtained from the Columbia Basin Research home page of the University of Washington (http://www.cqs.washington.edu/dart/). During the study period, the principal components of the salmonid run at Bonneville Dam were age-0 and 1 chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), sockeye (*O. nerka*), and steelhead (*O. mykiss*). The relative distribution of these species is shown graphically in Figure 2.8.

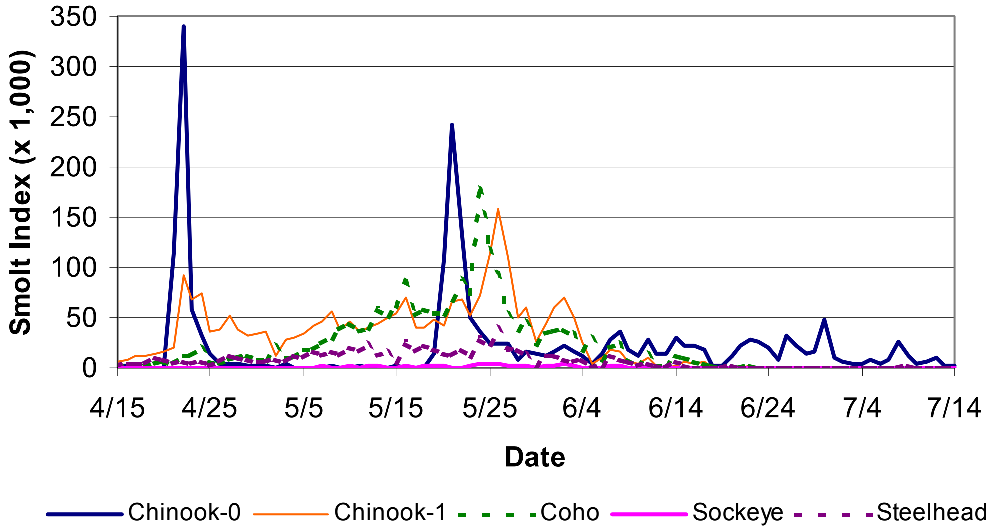

Figure 2.8. Smolt Run-Timing Index at Bonneville Dam in 2000

There were two distinct peaks in the 0-age juvenile chinook run in 2000. The first occurred between about April 18 and April 26 and the second between May 17 and May 27. Yearling chinook had corresponding runs, lagged by a few days, as did coho smolts. The runs dropped off significantly after the first week of June with only occasional small pulses of 0-age chinook moving through the area from June 7 through July 15.

3.0 Methods

3.1 Hydroacoustic Deployments

Three splitbeam systems, two stationary and one traversing were used to evaluate fine-scale smolt behavior on the upstream side of streamlined trashracks at the B-slot of Unit 8, First Powerhouse during spring and summer sampling periods 2000. The multiplexed splitbeam system (Figure 3.1) consisted of a PAS-103 Scientific Sounder (200 kHz) connected to a PAS-203 Remote Underwater Transducer Multiplexer and controlled by a data acquisition computer system. Four 12° (nominal beam width at -3 dB) splitbeam transducers are normally attached to the multiplexer. Because of a cracked element in one of the transducers, discovered at the time of final calibration, only three transducers were delivered and used for the study. The remaining transducer, delivered in June, was used to evaluate noise conditions emanating from the turbine units. Of the three deployed transducers, two were mounted to the trash rack, while the third was attached to a mount containing a chain-driven traversing system which allowed the single transducer to cover the entire opening (Figure 3.2). A narrow footprint Acoustic Douple Current Profiler (ADCP) was used alongside the traversing splitbeam transducer.

3.1.1 Fixed Transducers

Two up-looking, fixed-location transducers were attached to the fifth panel of the modified trash racks located on the B slot of Unit 8 by divers contracted by the Corps (Figure 3.2). The 12° transducers were designed to sample from near the center of the rack to either side of the slot. Throughout the sample period we experienced exceptional noise from the up-looking transducers. Part of the noise was assumed to be due to the structure associated with the traversing transducer and part from volume reverberation produced by increased beam coverage of the 12° beams. Upon recovery of the transducers, it was discovered that the transducers had been misplaced on the trash rack, as illustrated in Figure 3.3. Therefore, some noise may have resulted from structure interference. Additionally, we conducted ad hoc measurements of the forebay ambient noise levels using a broadband hydrophone and concluded that some of the noise may have been inherent with the environment at our operating frequency of 200 kHz (Appendix A).

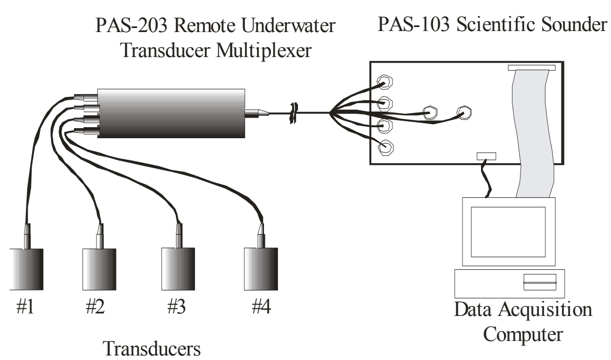

Figure 3.1. PAS-103 Multimode Scientific Splitbeam System with Four Transducers Attached (only three were used in this study).

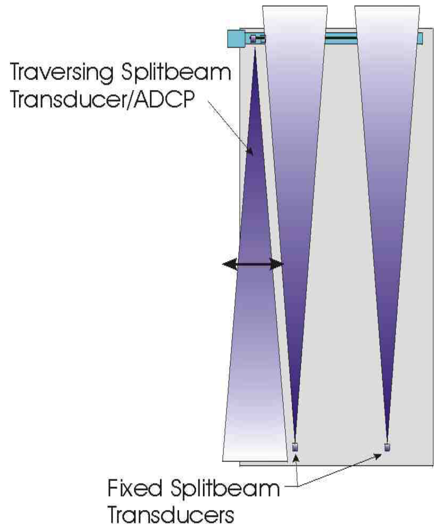

Figure 3.2. Orientation of Splitbeam Transducers Relative to the Streamlined Trash Rack (gray area) at Unit 8, Bonneville Dam First Powerhouse in 2000. A narrow footprint ADCP was used alongside the traversing splitbeam transducer.

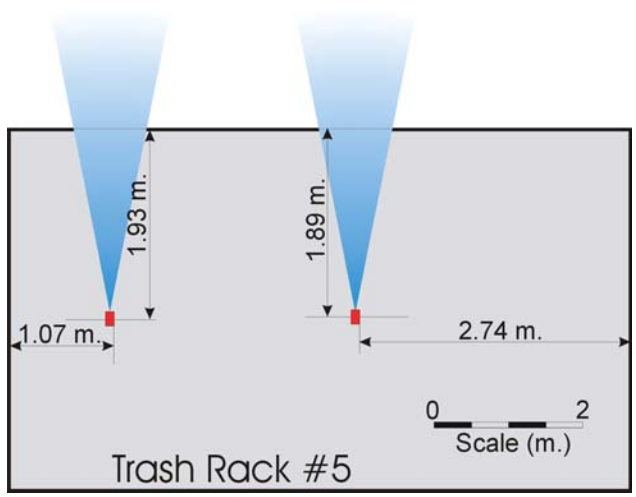

Figure 3.3. Actual Placement of the Up-Looking Splitbeam Transducers Attached to the Fifth Panel of the Streamlined Trash Rack at Slot B, Unit 8, Bonneville Dam First Powerhouse in 2000

3.1.2 Traversing Transducer

A single down-looking traversing transducer was deployed near the bottom of the top panel of the trash rack (Figures 3.2, 3.4, and 3.5). The transducer sampled from near the bottom of the top panel to the forebay floor and across the entire entrance. Opposing pairs of transducers (down-looking and up-looking) were sampled in a "fast-multiplexing" mode. That is, they were sampled on alternate pings at 20 pings per second resulting in an effective ping rate of 10 pings per second for each transducer.

3.2 Data Processing and Quality Control

Splitbeam sonar data were collected at the B-slot of Unit 8, Bonneville Dam First Powerhouse from May 4 through July 15, 2000. Archive copies of the data were made at the site before shipment to PNNL, and again upon arrvial. The splitbeam data were collected as binary files, with each file containing multiplexed data from two sonar transducers (the traversing splitbeam and one of the fixed, up-looking splitbeams). The data went through several processing steps before final anlysis. In the first step, transducer calibration data were combined with the binary data to produce files with the proper format for the tracker program. The resulting files contained the data for a single transducer. The files were checked for data integrity; incomplete files were removed and gaps in the data were identified. Next, the files were filtered

Figure 3.4. Deployment of the Traversing Splitbeam Transducer on the Top Panel of the Trash Rack of the B-Slot of Unit 8, First Powerhouse, Bonneville Dam in 2000. During the study the trash rack was lowered into the water.

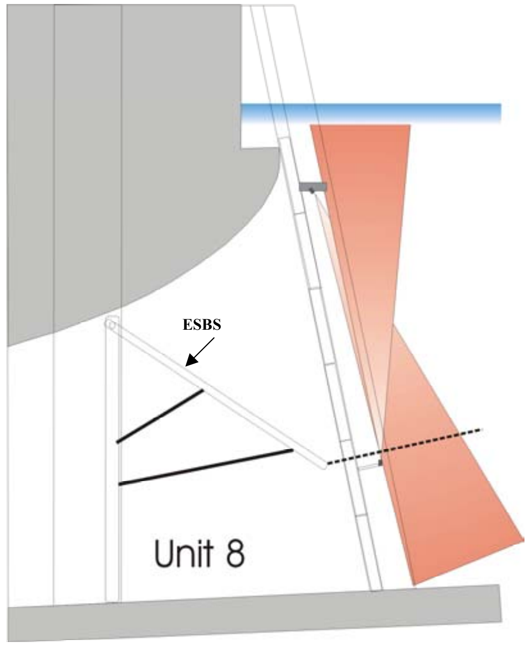

Figure 3.5. Orientation of the Traversing and Stationary Splitbeam Transducers (as viewed from the south side) at the B-Slot of Unit 8, Bonneville Dam, First Powerhouse in 2000

to remove noise and targets which did not meet standards set for the sonar and for smolt detection. The filter removed horizontal lines, set limits on the range for the uplooking transducers to avoid surface interference, removed targets with mechanical angles larger than the beam angle, and restricted target strengths to those associated with smolt-size targets.

After filtering, the Pacific Salmon Commission's Splitbeam Fish Tracker software (release for PNNL March 14, 2000, Xie [2000]) was used to select fish tracks. The program allowed both auto- and manual-processing of the data. Initially, the data were manually processed to develop and evaluate the input parameters needed for auto-processing. Fish tracks were selected based on target strength, location in the beam, direction, and general shape and distinctiveness. Tracks that were highly intertwined or were obscured by acoustic noise were deleted from the files. Approximately 18% of the data files were processed manually.

Files for manual processing were randomly selected from each hour's worth of data and from the multiplexed pairs to ensure adequate spatial and temporal coverage. In addition, the files chosen for manual tracking were randomly divided among the processing technicians (the number varied between 2 and 5 through the season). To ensure uniformity/consistency of track selection by data processing technicians a quality control (QC) procedure was used. From each day of data, a file was randomly selected from one of the processor's lists of files. This file was copied, renamed, and then both the original and the copy distributed to all the technicians (in essence, each technician processed each QC file twice). This provided a uniformity check between different technicians and within each individual.

Re-training was performed during the data processing period when the QC files showed discrepancies in track selection. Analysis of the QC files showed high variability between processors which continued even with retraining (Appendix B). It was decided that auto-tracking the data would provide more consistent results.

To facilitate autotracking the data through the PSC Fish Tracker software, we used a windows robot (SQA[1]). Automatic processing eliminated the error associated with tracker bias and through repeated checks of the track selection parameters, yielded acceptable tracks for subsequent analysis. The track selection parameters are listed in Table 3.1. One hundred percent of the data were autoprocessed.

The PSC Fish Tracker software was developed to track upstream migrating adult salmon where fish are moving across the beam in the horizontal plane. For our application, the fish were moving across the vertical plane of the beam. While the underlying algorithms worked well, this difference in orientation required additional filtering and smoothing of the selected fish tracks.

The target selection parameters in the PSC Fish Tracker were set so as not to exclude reasonable tracks. However, this led to the inclusion of some tracks which had behaviors not associated with a fish target (e.g., excessively high swimming speeds). Additional processing, using a modification of the original tracking algorithm was used to remove tracks that did not exhibit any movement, exhibited excessively high speeds, or remained in the beam for an unreasonable length of time. After the post-tracking filtering, the remaining tracks were smoothed to remove unreasonable rapid movements between echoes. Intertrack varability in swimming speed results from several factors, including water flow, fish movement and measurement error. The smoothing was designed to remove velocities that exceed

Table 3.1. Input Parameters for the Pacific Salmon Commission Splitbeam Fish Tracker Software Package for Processing Splitbeam Hydroacoustic Data at Bonneville Dam in 2000

Vertical Velocity	Max Delta Vx,y, m/s	2.0
	Max Delta Vy, m/s	2.5
Track Validation	Minimum Number of Echoes	10
Filter Settings	Mean Target Strength, min dB	-57
	Mean Target Strength, max dB	-40
Displacement	Total X min, m	0.1
	Total X max, m	50
	Delta X max, m	0.4
	Total Y max, m	20
	Total Z max, m	20
	Max Delta Z, m	0.4

[1] SQA Robot is a product of Rational Software Corporation, Burlington, Massachusetts.

reasonable fish swimming speeds. The smoothing algorithm works by projecting toward future locations based on the present location at each observation. It is an adaptation of a forward-looking time series averaging procedure. The first and last locations within the track are maintained by the smoothing algorithm as a constraint, so not to alter the overall track displacement.

Final processing of the fish tracks included converting track locations to geo-coordinates (Oregon State Plane, North, feet, NAD27), adding designators for day, night, and forebay elevation. The data were then ready for analysis.

3.3 Study Design

No explicit experimental design was proposed at the onset of this project. The objective was to examine the spatial and temporal aspects of fish behavior. Turbine operation was added as a factor during the study. Generally, between 1700 to 2000 hrs and from 2200 to 2400 hrs, the turbine at Unit 8 was shut down. However, there was quite a bit of variability in timing and there were also other periods when the turbine was off (Appendix C).

Two time factors were examined: seasonal and diurnal. The study period was divided into spring (May 4, 2000 - May 31, 2000) and summer (June 1, 2000 - July 15, 2000). The spring period includes the majority of the salmonid run. The diurnal periods were sunrise, day, sunset and night. Sunrise and sunset were each 2 hrs, day was 12 hrs, and night 8 hrs. For some of the analysis, sunrise was combined with day, and sunset with night.

The volume sampled by the transducers was divided into five contiguous regions for the purpose of the analysis (Figure 3.6). These analysis regions were based on the distribution of fish tracks. The division between upper and lower regions at 10 m reflected a change in the distribution of targets with the upper 10-m of the water column containing most of the fish targets detected by the splitbeam systems. The division of the lower region reflect the positions of the two stationary transducers, while the density of tracks in the upper region allowed us to divide that region into three parts. The regions are referred to as: 1) top/south, 2) top/mid, 3) top/north, 4) bottom/south, and 5) bottom/north.

The analysis was based on fish and not the individual echoes within a track. Tracked fish positions were average positions. All statistical analyses were performed using the SAS® software system, version 8. A statistical synopsis is contained in Appendix D.

Where possible, we examined fish behavior based on the following factors:

Factor	Levels	df
1. Turbine Operation	ON, OFF	1
2. Time of Day	Day, Night	1
3. Seasonal	Spring, Summer	1
4. Spatial	Top/South, Top/Mid, Top/North, Bottom/South, Bottom/North	4

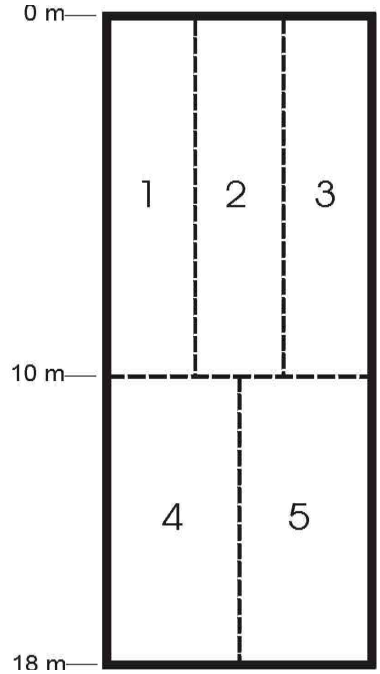

Figure 3.6. Sample Regions Associated with Splitbeam Data from Unit 8, First Powerhouse, Bonneville Dam in 2000 (0-m is at the forebay surface). Regions 1 and 4 are on the south side of the opening, regions 3 and 5 are on the north side. Regions are referred to as 1:top/south; 2:top/mid; 3:top/north; 4:bottom/south; 5:bottom/north.

Four null hypotheses follow from these treatments:

1. Operation of the turbine at Unit 8 will not affect migrant smolt behavior upstream of the trash racks.

2. Time of day will not affect migrant smolt behavior upstream of the trash racks at Unit 8, Bonneville Dam

3. Spring and summer seasons will not affect migrant smolt behavior upstream of the trash racks at Unit 8, Bonneville Dam

4. Migrant smolt behavior upstream of the trash racks at Unit 8, Bonneville Dam is not affected by position in front of the opening.

3.4 Data Analysis

The analysis of fish behavior is presented in three sections: fish distribution, fish behavior, and vector plots. The first section includes analysis of the number and location of the fish within the splitbeam region and changes in the proportion of fish related to time of day, season, and turbine operation. The second sub-section describes the behavior or movement characteristics of the tracked fish. These characteristics include analysis of displacement direction, displacement velocity and milling behavior. Finally, vector plots describing fish movement are given for the area sampled by the splitbeam sonar. In that area, the actual swimming effort of tracked fish is found by subtracting modeled water flow velocity from the observed fish velocity vector field.

The numbers of tracked fish used in the analysis are the result of several filtering processes, which eliminated short-duration fish tracks and, when there were large time gaps within a track, separated single long tracks into two or more tracks. Also, the number of detected targets was related to the size and shape of the sampled region in the sonar beam. The purpose of the filtering was to select targets containing enough information to describe behavior, and not an attempt to accurately count fish. By selecting fish tracks with similar characteristics, we can compare their behavior over time and space. By selecting longer fish tracks, we eliminated tracks that go through the sampled area quickly or where the sampled volume was small (near the transducers). Because of these track selection criteria, which removed many indefinite tracks, the analysis was based on the sampled fish track population by using a probability viewpoint. Using this viewpoint we evaluated the percentage of the population expressing a particular behavior in the region ensonified by the multibeam sonar.

3.4.1 Fish Track Distribution Analysis

The analysis of fish track distribution was based on the proportion of tracks present rather than on actual numbers because of the target selection procedures described in the previous paragraph. This section discusses the distribution of fish track detections over the sample period, over time of day and with depth. The fish tracks are also presented as scattergrams for the three perspectives, plan (top) view, side view and front view.

3.4.2 Fish Behavior Analysis

Four metrics for measuring movement are used to describe fish swimming behavior. First, the displacement fraction describes the direction of movement. A fish track consists of a sequence of location vectors, which are echo locations, produced as a function of sampling rate (pings/s). The displacement vectors 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. A displacement (distance) is the length of a displacement vector, so the total length of a track is the sum of all the displacements between echo locations. Displacement fraction is then the fraction of movement in a particular reference direction along a chosen coordinate. Each fish track in the analysis is described by three displacement fractions; one for each of the three location coordinates. The three location coordinates (orthogonal directions) are north/south across the opening, upward/downward in the water, and upstream/downstream from the dam. The reference directions were chosen as north, upward and upstream (these are the positive directions of the fish track coordinate system, respectively). At any position in the splitbeam sample region, the direction of movement for the sampled fish population detected there is described by the distribution of associated displacement fractions. This distribution of displacement fractions describes a probability of movement in a particular direction. The mid-point (1/2) of the displacement fraction is used to determine the dominant direction of movement. The percent of fish with displacement fractions greater or less than the mid-point indicates the dominant direction of movement for that local population for a particular direction. Note that there is no net movement (in a direction) for a displacement fraction equal to the mid-point.

A precise definition of the displacement fraction (f), for the north-south direction (x) is defined as:

$$f_x = \frac{1}{L_x} \sum \Delta x_i \ (\text{where } \Delta x_i > 0)$$

where $\Delta x_i = x_i - x_{i-1}$

$L_x = \sum |\Delta x_i|$

x_i = location at observation i (i = 1…n).

Displacement fractions in the other two directions were calculated by substituting y (upward/downward) or z (upstream/downstream) for x in the above equations.

These displacement fractions are then used to find the percent of fish tracks headed in a particular direction. The fractions were statistically analyzed to determine which factors (time of day, season, region, or turbine operation) contributed to observed fish behavior. The statistical results are shown as contrasts across factor levels. Displacement fractions, for each movement direction, were first analyzed in contingency tables with likelihood-ratio chi-square tests (Fleiss, 1981; SAS). All statistical analyses were preformed using the SAS® software system. A detailed description of the statistical tests is in Appendix D.

In addition to the displacement direction, a second metric, the displacement velocity vector was also calculated and evaluated. Displacement velocity characterizes both the speed and direction of a fish as it moves from its initial to final location. The displacement velocity is the overall displacement vector divided by the observation time for a fish track. This metric differs from the average swim speed for a fish track, which is the track length divided by the observation time. The displacement velocity incorporates information about how tortuous the track is in space (tortuosity is defined below as the third metric). Displacement vectors were analyzed to evaluate which factor(s): time of day, season, region, or turbine operation contributed to the observed speed. These displacement vectors were modeled against the covariates through Multivariate Analysis of Variance (MANOVA) and Univariate analysis for each of the three orthogonal directions of movement. Univariate tests of significance were based on standard methods of ANOVA and F-tests. Multivariate tests were carried out using Wilk’s Lambda, Pillai’s trace, Hotelling-Lawley trace, and Roy’s maximum root tests with F approximations (SAS) (Appendix D).

The third metric includes two indices that describe the straightness of a fish track. These indices are tortuosity and loopyness. These indices are used to categorize fish tracks as milling or directed. The tortuosity index (τ) measures the degree of non-linear fish movement as defined by the equation:

$$\tau = \frac{|\vec{r}_n - \vec{r}_0|}{\sum|\vec{d}|}$$

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.

Using this equation, a fish traveling in a straight line would have a tortuosity index equal to 1. A fish traveling a highly circuitous (e.g., more tortuous) route would have a tortuosity index closer to zero. The tortuosity index measures how efficiently a fish makes progress in its overall displacement in space. In order to standardize with other measures described below, the tortuosity index was defined between zero and 1. Examples of representative tracks and their associated tortuosity and loopyness index values are shown in Figure 3.7.

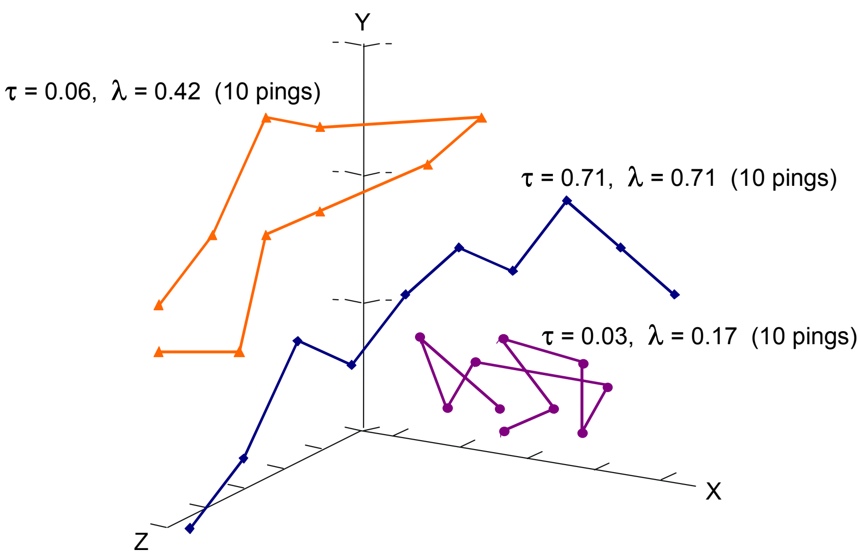

Figure 3.7. Representative Tracks with Associated Tortuosity and Loopyness Index Values and Sample Sizes

The loopyness index (λ) is similar to the tortuosity index. However, because the tortuosity index could be small even though a track did not actually exhibit a great deal of winding around (see upper left track in Figure 3.7), the loopyness index was defined. The loopyness index gives the relative maximum displacement of a fish in its track and is described by the equation:

$$\lambda = \frac{\left|\vec{r}_i - \vec{r}_0\right|}{\sum\left|\vec{d}\right|}$$

where λ = loopyness index

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

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

$\vec{r}_i$ = fish's maximum distance from initial position.

The loopyness index is always greater than or equal to the tortuosity index. As with the tortuosity index, a fish traveling in a straight line will have a loopyness index equal to 1 and a fish that stays in a confined area will have a loopyness index close to zero. However, a fish that swims out from the starting position and then returns to near the starting position (i.e., makes a loop) will have a loopyness index larger than the tortuosity index (e.g., $\lambda \geq \tau$). Only when both the tortuosity and loopyness indices are close to zero is a track highly wound up in space. In Figure 3.7, the tortuosity and loopyness indices would be similar for all the tracks except for the track in the upper left. For this track the starting and ending positions are very close, while, the maximum distance the fish traveled is large.

Tortuosity and loopyness indices were statistically evaluated through a non-parametric analysis based on median scores. The test statistic has an asymptotic chi-square distribution with r-1 degrees of freedom, where r is the number of class levels in the covariate factors (i.e., time of day, season, region or turbine operation). (Appendix D)

Potential entrance efficiency is the final metric. This metric is an attempt to predict or project where a fish is going as it passes through the sonar beam. Without actual observations of fish passing through the opening, we can only estimate where the fish is going while it is in the beam. To calculate the potential entrance efficiency, each segment in a fish target track is projected from its initial position and assessed by whether it projects into the opening. The number of track segments projected into the opening divided by the total number of track segments gives an estimate of the probability of a given fish target entering the opening. If all track segments for a fish track project into the opening, then its entrance probability is 100%; it is zero, if none project into the opening. The estimate of entrance efficiency for a population was obtained by counting the number of fish at a location with a projection percentage greater than some limit (we used 50%) divided by the total number of fish at that location. Thus, the likelihood that a fish track projects into the opening is estimated, then the percent of the population that is aiming toward the opening at least 50% of the time is calculated. Fish, that tend to turn away from the opening for most of the track length will have a low probability of entering the opening. We cannot estimate how many of the fish heading away from the opening turn on the final segment of the track and enter the opening. However, in terms of behavior, this is another indication of where the fish are heading in a particular region. It should not be compared to efficiencies, which are based on counting fish as they go through an opening.

Potential entrance efficiencies were analyzed through contingency table analysis and likelihood ratio chi-square tests (Fleiss 1981). Individual tests were performed for each of the test factors (i.e., time of day, season, region and turbine operation). The effects of the test factors were comparatively assessed through analysis of deviance from a logistic model (McCullagh and Nelder 1989).

3.4.3 Vector and Flow Plots

The vector plots were generated from the observed average fish swimming activity (displacement velocity) within 1-m bins and from the CFD flow model (Rakowski et al. 2000). The observed average fish swimming activity is a function of the fish's swimming effort plus the flow field velocity in which it was detected. Swimming effort is the fish's velocity relative to a reference frame traveling with the local water flow velocity. The fish's swimming effort is calculated by removing (subtracting) the effect of the flow field velocity from the observed swimming activity (displacement velocity) by vector arithmetic. Plots of swimming effort reveal a fish's actual behavior because these vectors indicate whether a fish was actively swimming with the flow, against the flow, or crossing flow lines. Because the flow field used for this analysis was based on a CFD model, and not measured at the same instant as the fish track data, the results are suggestive of only the combined swimming behavior for the population during the study. The CFD model was run under two sets of operational conditions (i.e., Unit 8 on and Unit 8 off) and fish tracks were compared to model results for the same study period, so to reflect the typical relationship between flow and fish behavior.

3.5 Hydraulic Data

3.5.1 CFD Model Data

Two CFD models were developed to model water flow at Bonneville Dam (Rakowski et al. 2000). Both models were three-dimensional (3D) and based on numerical solutions to the Reynolds Averaged Navier-Stokes equations. The first CFD model simulated hydrodynamics for the Bonneville First Powerhouse forebay, turbine intakes, and the prototype surface collector system. The second CFD model encompassed the Second Powerhouse, spillway channel, First Powerhouse forebay, and a portion of the upstream river.

Simulation output from the First Powerhouse CFD model was used to calculate flow corrected fish movements. Two simulations were used, corresponding to turbine operating conditions.

3.5.2 ADCP In Situ Data

A narrow footprint 600kHz RD Instruments[1] ADCP was used to measure the near-field flow field during the time fish were tracked. The ADCP was deployed next to the traversing splitbeam transducer (Figure 3.2) and aimed so it sampled the same volume of water sampled by the splitbeam transducer. A minimal beam width of 6° from vertical was used so the ADCP could be positioned close to the turbine intake. However, a minimal beam width results in a large theoretical standard deviation. To reduce the overall variation in the velocity measurements, velocites were averaged over 3 min or 0.5 m. Results are presented in a separate report [2].

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[1] RD Instruments, San Diego, California.
[2] Cook, C.B., and R.L. Johnson. 2001. Analysis of observed water velocities at Bonneville Dam. Letter Report. U.S. Army Corps of Engineers, Portland District. Portland, Oregon.

4.0 Results

4.1 Fish Distribution

Analysis of fish behavior was based on nearly 124,000 tracked fish with an average track length of 1 m and average observation time of 2.9 s. The fish tracks used in the analysis represent a subset of a larger dataset; selection criteria, described in the methods section, were used to ensure that the selected tracks contained enough information to describe behavior. No attempt was made to accurately count fish because tracks cannot be uniquely identified with specific fish targets sampled over indefinite periods. Figure 4.1 shows the distribution of selected fish tracks detected between May 4 and July 15 by the splitbeam system compared to the smolt run-timing index (DART http://www.cqs.washington.edu/dart). The peak count of tracked fish was on May 22, within one day of the peak of the run. Some of the low counts from the splitbeam data may have been due to problems with the traverse system (May 15-16 and June 12-15). Differences between the smolt index and tracked fish counts may be the result of our selection process and, during the summer period, other species such as American shad may have been detected.

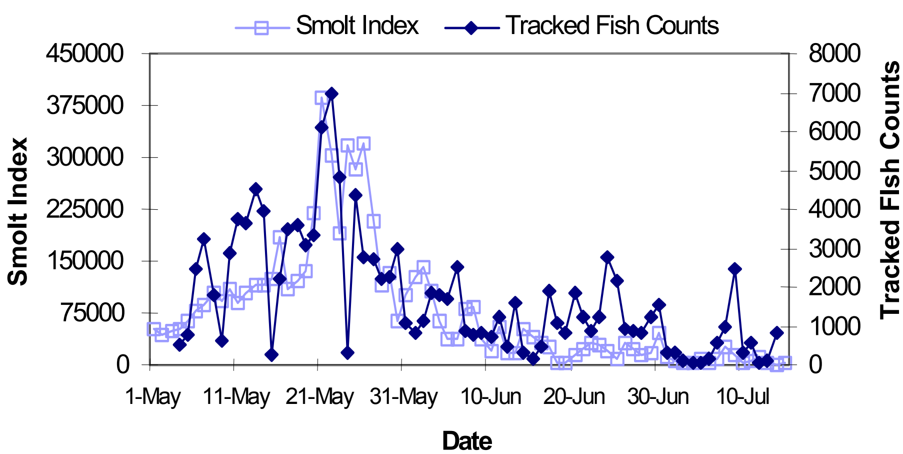

Figure 4.1. Comparison of Tracked Fish Counts from the Splitbeam Sonar and the Smolt Run-Timing Index for Bonneville Dam in 2000

Large differences exist in the number of fish detected in front of Unit 8 between spring and summer, and day and night (Table 4.1). Sixty-four percent of the fish were detected during the spring sampling period; and, for both seasons, the majority of the tracked fish were detected during the day, 89% in spring and 78% in summer. A similar diurnal pattern was noted for fish detected in front of Unit 3 during the same sampling period (Johnson et al. 2001). This is in contrast to detections at Lower Granite Dam on the Snake River, where there was no difference between day and night counts (25% for both sunrise and day, 12% at sunset and 38% at night) (Anglea et al. 2001).

Table 4.1. Tracked Fish Counts for Spring (May 4-June 1) and Summer (June 1-July 15) Sampling Period at Unit 8, First Powerhouse, Bonneville Dam in 2000

Counts	Day	Night	Total
Spring	70,629	8,847	79,476
Summer	34,650	9,871	44,521

Figures 4.2 through 4.4 show the distribution of fish relative to the Unit 8 structure. Fish were distributed relatively high in the water column (from 5-16 m depth) above the area potentially affected by the ESBS. The data have undergone considerable filtering to remove most track or target ambiguity. Since the acoustic and volume backscatter noise increased with range, fewer targets would have been selected at longer ranges with these filters in place. However, pre-filtered, auto-tracked data and manually tracked data did not yield substantial numbers of fish at longer ranges either. Therefore, it appears there were few fish tracks outside the distribution range indicated by these figures. Note that the fish detections in Figures 4.2 through 4.4 are represented by a single point, which is the average position of each tracked fish and not the entire track. This was done to simplify the graphic since the details of an entire fish track would not be distinguishable at presentation scale.

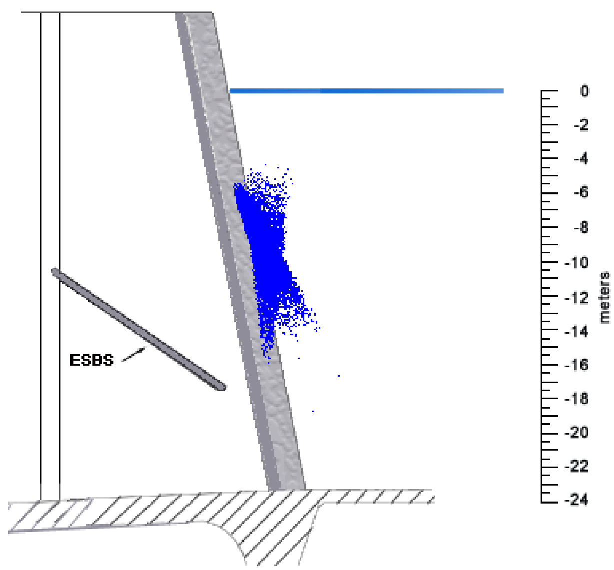

Figure 4.2. Side-View of Unit 8, First Powerhouse, Bonneville Dam Showing the Distribution of Fish Tracks Detected by two Stationary and one Traversing Splitbeam Transducer in 2000. Blue horizontal line is the average water level. Location of the ESBS is shown to the left. (Approximately to scale.)

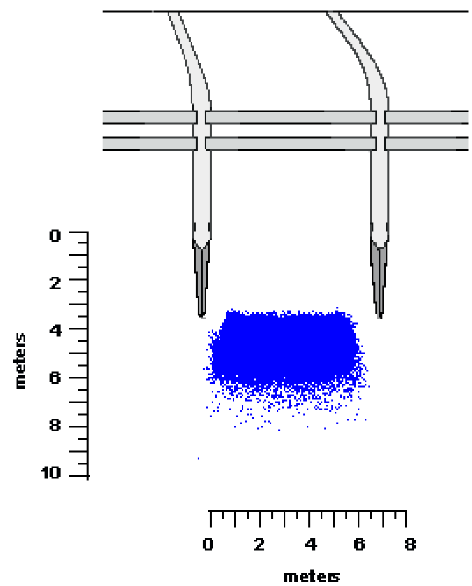

Figure 4.3. Plan-View (top) of Unit 8, First Powerhouse, Bonneville Dam Showing the Distribution of Fish Tracks Detected by two Stationary and one Traversing Splitbeam Transducer in 2000. (Approximately to scale.)

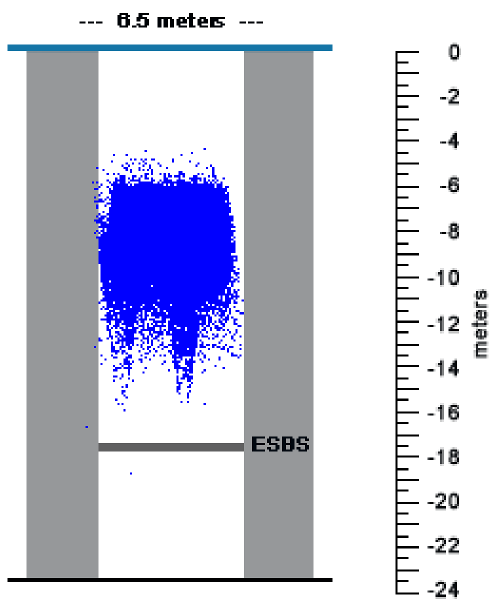

Figure 4.4. Front-View (from upstream) of Unit 8, First Powerhouse, Bonneville Dam Showing the Distribution of Fish Tracks Detected by two Stationary and one Traversing Splitbeam Transducer in 2000. Solid line shows the location of the toe of the ESBS relative to the fish distribution. (Approximately to scale.)

When we examined the number of fish detected in the five sample regions (Figure 4.5), we again noted that most fish were detected in the upper half of the opening (above 10 m) with the highest detection occurring in the top center opening (Figure 4.5). Few targets were detected during the night in any region. Significantly more fish were detected in the top north and middle regions than in the south or lower regions (p >0.001). This would imply that a center-mounted transducer might over estimate passage if that count is expanded across the entire opening. The reader is cautioned that the results may be biased by our target selection process and/or by the placement of the up-looking transducers (see Figure 3.3 in the Methods section). The south transducer was close to the intake wall and structural interference may have affected our ability to detect fish in this area. Also, placement of the north transducer was more central, thereby reducing coverage in the north region.

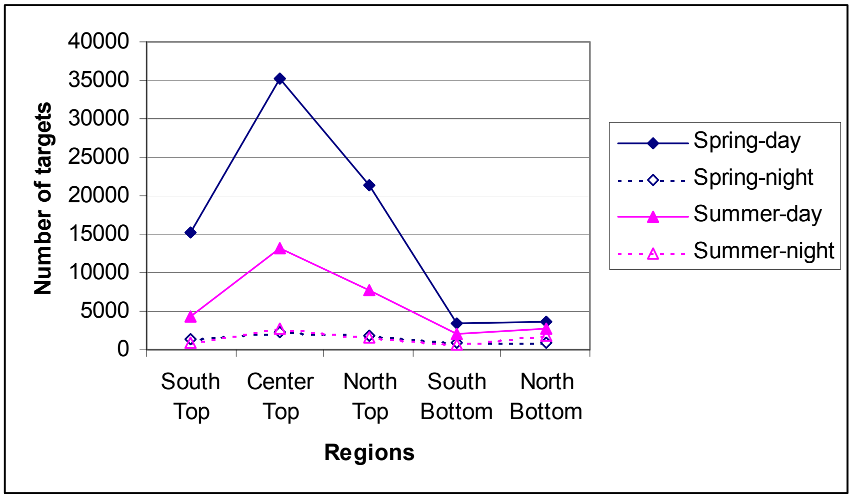

Figure 4.5. Number of Targets by Region for Spring (May 4-June 1) and Summer (June 1-July 15) Sampling Periods at Unit 8, First Powerhouse, Bonneville Dam in 2000

At different times during the sample period, the turbine at Unit 8 was shut down (Appendix C). This was done primarily at night (1700-2000 hrs and 2200-2400 hrs) and during the summer sample period. For purposes of the analysis, the turbine was considered off if it was shut down for anytime within a one hour period. For the spring season, the turbine was off approximately 12% of the time, while it was down approximately 34% during the summer. Because there was little consistency in turbine operation it would be difficult to detect differences in fish distribution or behavior influenced by turbine operation. Observed seasonal and diurnal differences confound any observed effect due to turbine operation. To effectively evaluate turbine operation, the down times for the turbine should have been distributed more uniformly across the time period.

From our sample of 124,000 fish, about 2,000 were associated with the turbine off condition. Since the turbine was off primarily at night, this number probably reflects both the turbine operation as well as reduced number of fish detected at night. The proportional diurnal distribution of targets was strongly skewed toward the daytime for both the turbine on and off conditions (Figure 4.6). During the day, a

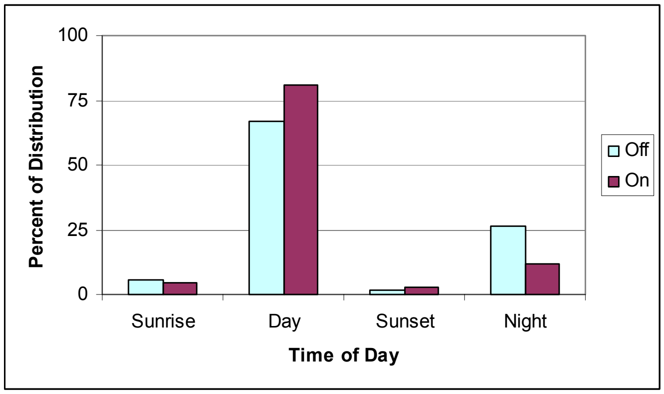

Figure 4.6. Diurnal Distribution of Tracked Fish as a Percentage of the Total for Turbine Unit 8 Off and On at First Powerhouse, Bonneville Dam in 2000

slightly higher percentage of fish (10%) was detected with the Unit 8 on as off. At night, more than twice the percentage of fish was detected with Unit 8 off as on. However, in terms of absolute numbers, the number of targets detected when the turbine was off represents less than 2% of all targets.

Figures 4.7 and 4.8 show the change in distribution of fish with depth in front of Unit 8 between day and night for spring and summer sample periods. During the day, approximately 90% of the fish were detected between 6 and 9 m, with the peak at 7 m in the spring and 8 m in the summer. During the night, the distribution of fish was more dispersed, with approximately 76% of the fish detected between 6 and 9 m in the spring and 65% in the summer. Fish distribution when the turbine was off was similar to the summer distribution; 80% of the fish detected when the turbine was off were detected in the summer.

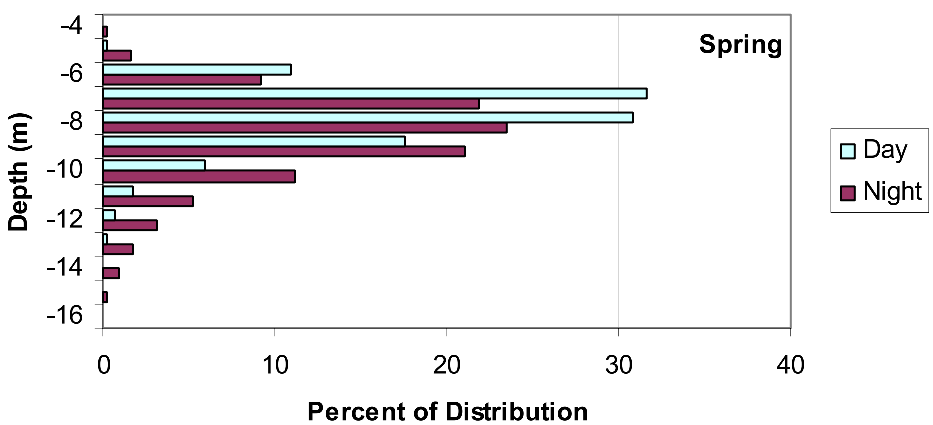

Figure 4.7. Depth Distribution of Tracked Fish During Spring 2000 Upstream of Unit 8, First Powerhouse, Bonneville Dam for Day and Night

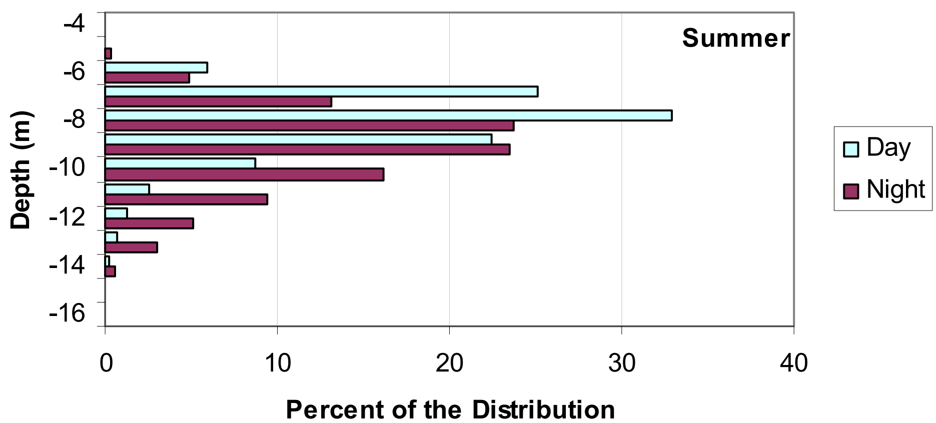

Figure 4.8. Depth Distribution of Tracked Fish During Summer 2000 Upstream of Unit 8, Bonneville Dam, First Powerhouse for Day and Night

4.2 Fish Behavior

Approximately 124,000 fish tracks met the selection and filtering criteria. The original statistical analysis included all the tracks, and the large sample size resulted in statistical over-sampling with nearly every test indicating significant differences. To compensate for the large sample, the data were sub-sampled. The analysis presented in this report represents a 10% random subsampling of the data. In addition, the random sampling was stratified to achieve a balance between factor levels, allowing a more valid comparison of behavioral metrics between factor levels (Netter et al. 1990). In one case, the data were not sufficient to achieve the balanced sampling objectives for the turbine operations factor. Bootstrapping methods were used to achieve the desired level.

4.2.1 Direction of Fish Movement

The first behavioral metric we analyzed was the displacement fraction or direction of movement. All analyses were significant ($p < 0.001$) except for the north/south movement direction over regions ($p = 0.09$) (Statistical tables are in Appendix E). Figure 4.9 illustrates the direction of movement for fish with respect to a) time of day, b) season, c) region, and d) turbine operation. It is apparent from this figure that the predominant direction of fish movement was downward. The largest percentage of fish was headed down during the day, in the summer, in the upper regions of the opening and when the turbine was off. Movement in the north/south direction parallel to the front of the opening was evenly divided between those fish headed north and those headed south. Surprisingly, the analysis revealed that fish in front of Unit 8 were generally headed upstream, except at night when slightly more than 50% where headed downstream. This upstream direction of fish movement was more pronounced during the day, in summer, when the turbine was off and for fish detected in the top south region of the opening.

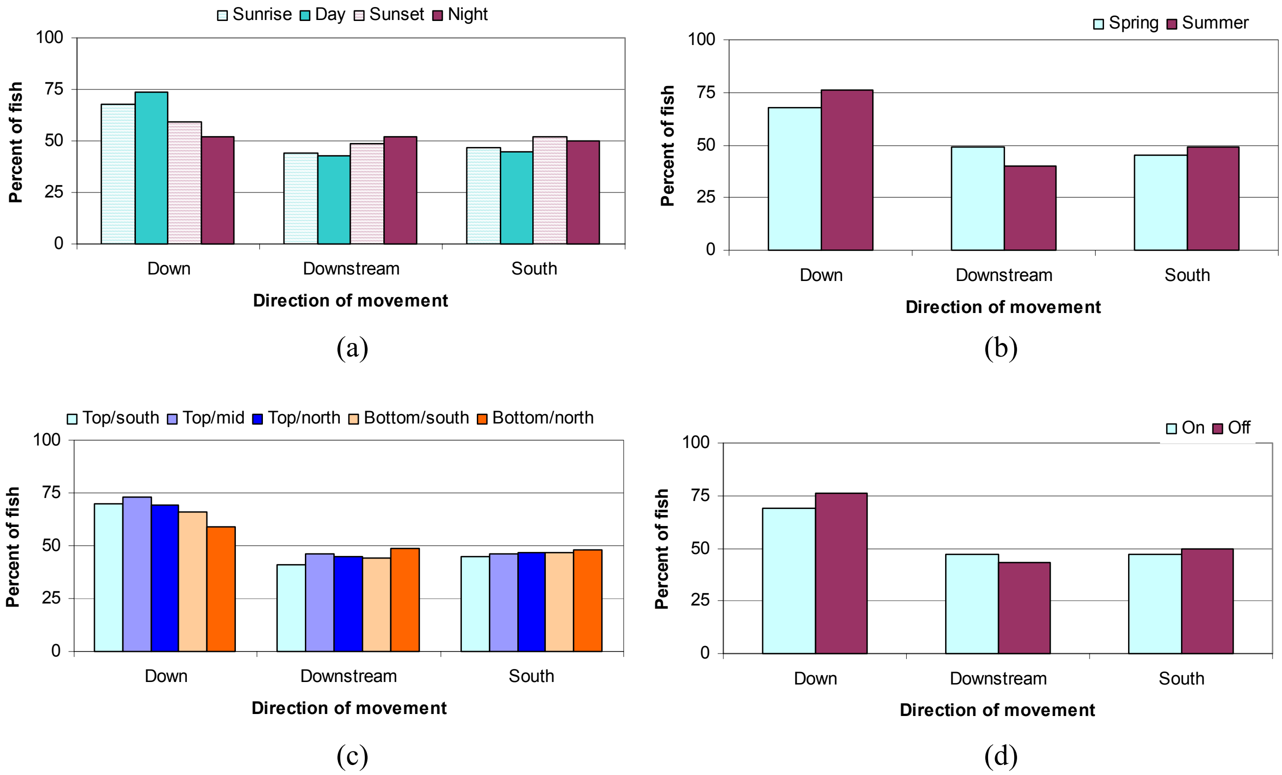

Figure 4.9. Direction of Movement for Fish Detected by Splitbeam Sonar in Front of B-Slot, Unit 8, Bonneville Dam First Powerhouse in 2000. Down, downstream, and south are the directions of flow.

When the turbine was off, fish were primarily headed in a downward direction (Figure 4.10). There was no preference for north or south movement and a larger proportion of fish were headed upstream. Similar to turbine-on conditions, more fish were headed down during the day than during the night. Over regions, fish in the bottom part of the opening were generally headed more north and downstream; there was little difference in downward movement (Figure 4.11).

4.2.2 Displacement Vector/Swimming Speed

Analysis of displacement velocities confirmed the results of the displacement fractions: the dominant direction of travel was downward. Figure 4.12 shows the net displacement velocities for the five regions in front of Unit 8. The net velocities are the direct sum of positive and negative velocities, and were calculated so that the resulting velocity components were not influenced by the unequal sample sizes of fish moving in opposite directions. We note that on the south side of the opening the net displacement velocity is to the north, and in all areas, velocity in the north-south direction dominates. The magnitude of the downward velocity is similar and indicates that the fish are headed downward. The velocity component in the downstream direction is nearly zero, indicating that the fish are opposing the flow.

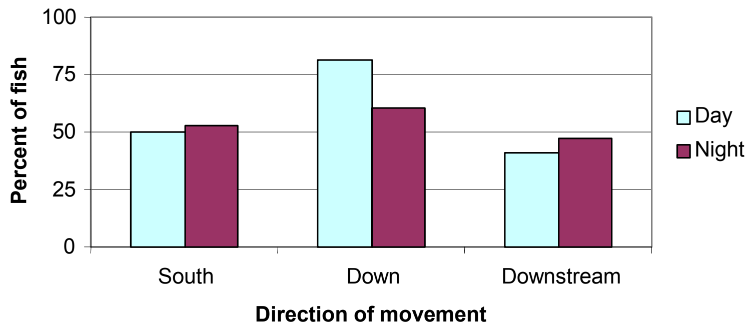

Figure 4.10. Direction of Tracked Fish Movement for Day and Night When Turbine Unit 8 was Off at First Powerhouse, Bonneville Dam in 2000

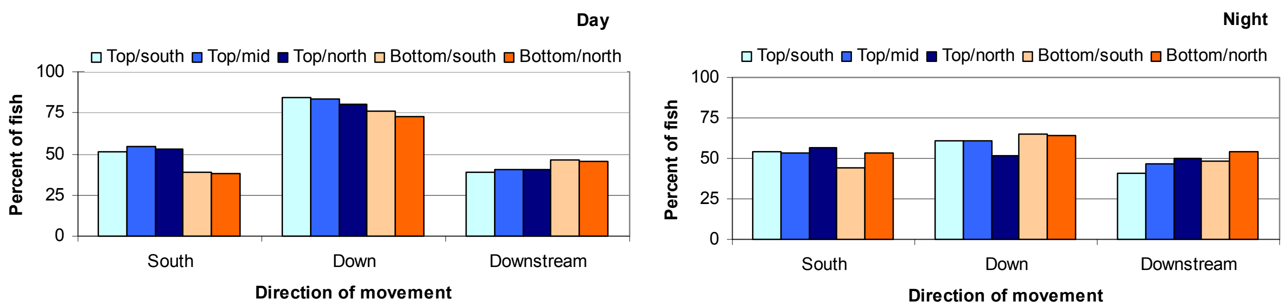

Figure 4.11. Direction of Movement for Tracked Fish Targets in Different Regions at Unit 8, First Powerhouse, Bonneville Dam in 2000, When the Turbine was Off

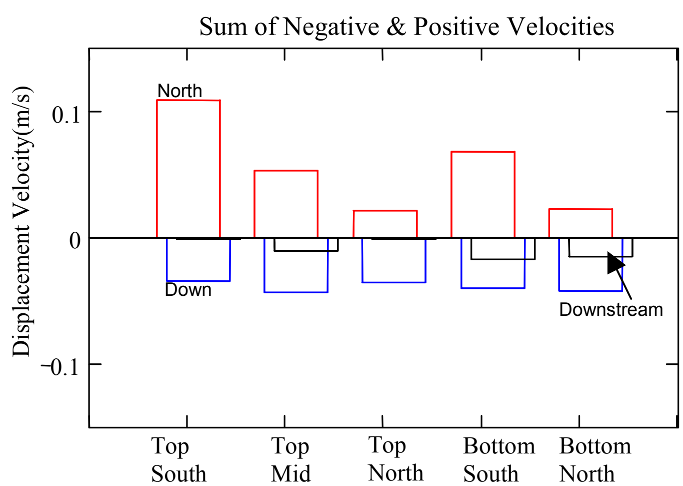

Figure 4.12. Net Displacement Velocities for Non-Milling, Directed Fish in 5 Regions in Front of Unit 8, Bonneville Dam, First Powerhouse, 2000

4.2.3 Potential Entrance Efficiencies

Given that fish are predominantly headed parallel to and slightly away from the dam, it is not surprising that the potential entrance efficiencies are fairly low – 18% to 25%. The highest overall potential passage values occurred during the spring season (24% compared to 20% for the summer) and during the night (24% compared to 20% during the day). Statistical tests indicated that only turbine operation was not statistically significant ($p = 0.47$), while seasonality and time of day had the strongest effects on passage values.

4.2.4 Milling Behavior

In all the analyses conducted so far, no attempt has been made to categorize behavior. The metric that we use to do that is tortuosity. The tortuosity index is used here to characterize fish swimming behavior as directed (>0.5) or milling (<0.5). The selection of 0.5 as the cutoff between directed and milling fish was based on examination of the data. Fish tracks on one side of the cutoff were not necessarily straighter than those on the other side. There were, however, distinct differences in the direction of movement between these two groups, that allows for a more detailed understanding of fish behavior in this region.

The tortuosity index was plotted against depth for day and night (Figure 4.13). During the day, it appears that more fish were milling near the surface and between 8 to 10 m. Fish tracks were more directed as depth increased below 10 m and also around 6 m. The increase in directed tracks with depth, was also noted at night, however there was no pronounced, secondary peak around 6 m.

Across the opening at Unit 8, fish tracks were more directed along the sides compared to the middle (Figure 4.14), while there was more milling behavior in the center of the opening. This behavior was similar in both the top and bottom regions. When the turbine was off, there was little change in the tortuosity index across the top of the opening (Figure 4.15), and too few fish present in the bottom to plot.

To further refine our analysis of behavior, we separated milling fish tracks (tortuosity index <0.5) from those with a more directed track. Directed tracks are straighter and have a larger displacement relative to the track length. About 38% of the fish tracks at Unit 8 were classed as milling, while the remaining 62% of the fish tracks were classed as directed. When we looked at the direction of movement for the directed fish, we found they were either headed north (34%) or south (28%). In fact, the north-south displacement fraction distribution for directed fish was bimodal, with modes on both sides of the middle value (0.5). That is, for non-milling fish, the displacement in the north-south direction was either zero (south-directed) or one (north-directed). The north-south displacement fraction for the milling population was approximately 0.5, indicating that the milling population equally likely to be headed north as south. We used these three groups: milling fish, north-directed fish, and south-directed fish to examine in more detail fish behavior across the opening. Table 4.2 shows the percentage of fish in each behavior class in each region. In each region, most fish were either milling or north-directed. The percentages are fairly constant over region and time of day. The highest percentage of milling fish was found in the bottom section, and at night in the top/mid section.

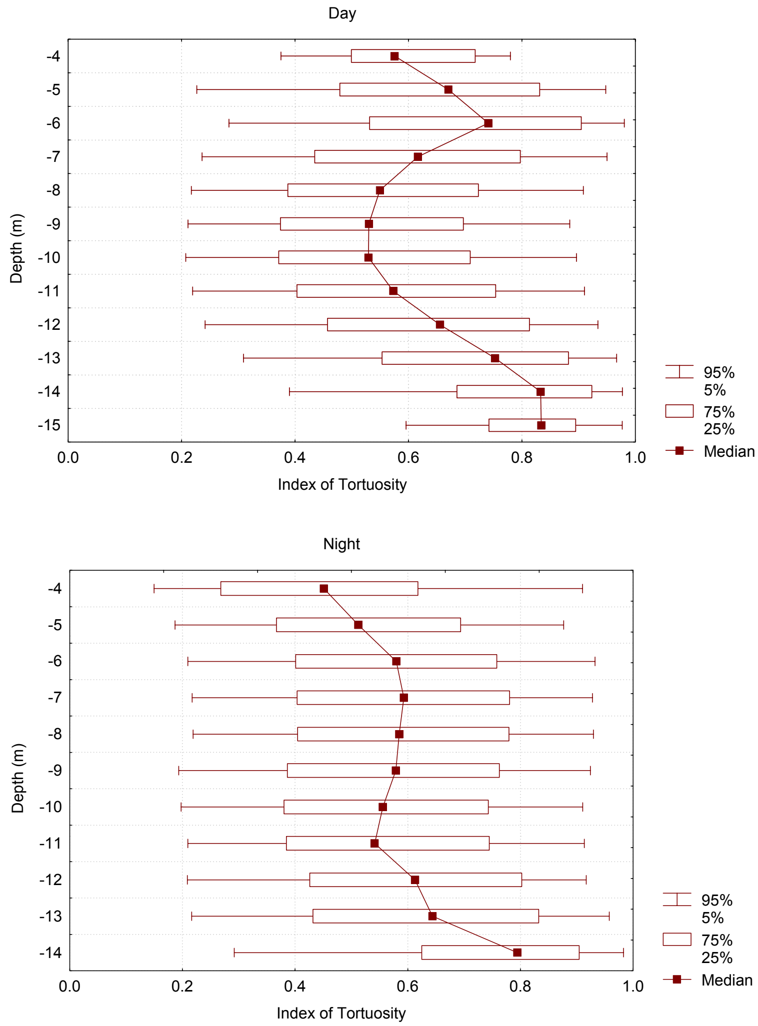

Figure 4.13. Index of Tortuosity Versus Depth for at Unit 8 (turbine on), First Powerhouse, Bonneville Dam in 2000. (Minimum sample size was 15.)

With respect to direction of movement, south-directed fish were headed downstream, although only by a few percent (Figure 4.16) and primarily when in the north regions. Downstream movement was more pronounced at night.

All fish in all areas exhibited downward movement (Figure 4.17) especially during the day. There were no major differences between the three groups with respect to downward movement.

Another metric associated with tortuosity is displacement velocity. Displacement velocity is the distance between the first and last track segment divided by the observation time. Displacement velocity ignores the path between the first and last segment. If we compare displacement velocities for milling

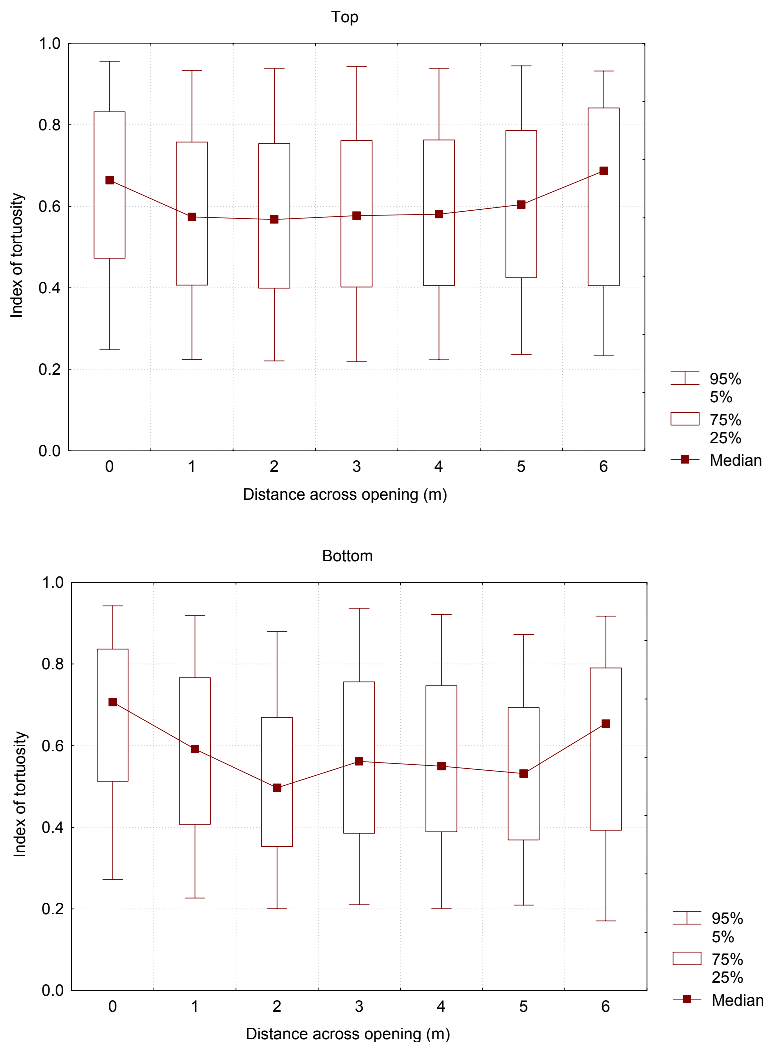

Figure 4.14. Index of Tortuosity Across the B-Slot at Unit 8, First Powerhouse, Bonneville Dam in 2000. The top figure is for the upper 10 m of the opening, the bottom figure for 10 to 18 m. (Minimum sample size was 15.)

and directed fish (Figure 4.18), we note that displacement velocities are constant for milling fish over the sampled depth. For directed fish, the displacement velocity was highest near the surface, decreased to a minimum around 7-m and then increased with depth. This pattern is similar to that seen for the tortuosity index (Figure 4.13). Given that the track lengths are nearly the same over depth and the observation times are comparable, the displacement velocity reflects the tortuosity index trend with depth.

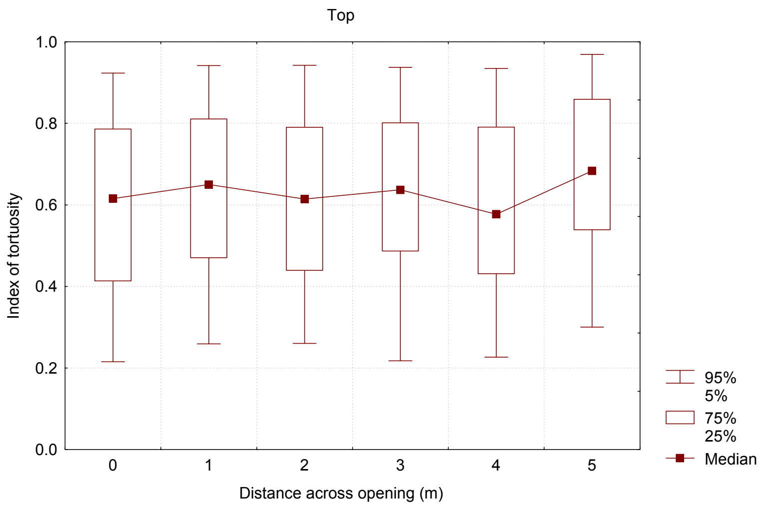

Figure 4.15. Index of Tortuosity When the Turbine was Off, Across the B-Slot of Unit 8, First Powerhouse, Bonneville Dam in 2000. Index calculated for fish in the top 10 meters of the water column.

Table 4.2. Percentage of Tracked Fish Target in Each of the Five Sample Regions, that were Milling, North-Directed, or South-Directed for Day and Night at Unit 8, First Powerhouse, Bonneville Dam in 2000

<table>
<tr><th colspan="6">Day</th><th></th><th colspan="6">Night</th></tr>
<tr><td colspan="2">36.4</td><td colspan="2">39.3</td><td colspan="2">36.7</td><td>Milling</td><td colspan="2">34.0</td><td colspan="2">40.1</td><td colspan="2">38.4</td></tr>
<tr><td colspan="2">36.8</td><td colspan="2">34.1</td><td colspan="2">37.0</td><td>North Directed</td><td colspan="2">36.1</td><td colspan="2">32.0</td><td colspan="2">24.8</td></tr>
<tr><td colspan="2">26.8</td><td colspan="2">26.6</td><td colspan="2">26.3</td><td>South Directed</td><td colspan="2">29.9</td><td colspan="2">27.9</td><td colspan="2">36.8</td></tr>
<tr><td colspan="3">40.2</td><td colspan="3">41.2</td><td>Milling</td><td colspan="3">33.0</td><td colspan="3">44.1</td></tr>
<tr><td colspan="3">33.6</td><td colspan="3">31.0</td><td>North Directed</td><td colspan="3">36.1</td><td colspan="3">24.6</td></tr>
<tr><td colspan="3">26.2</td><td colspan="3">27.8</td><td>South Directed</td><td colspan="3">30.9</td><td colspan="3">31.3</td></tr>
</table>

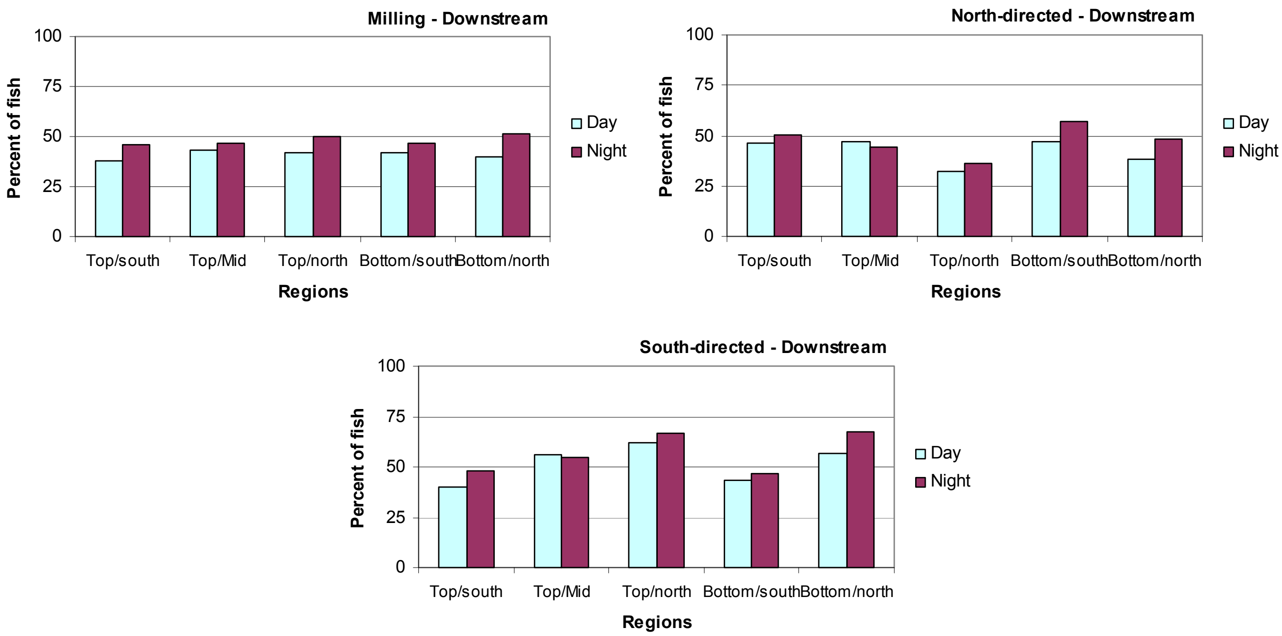

Figure 4.16. Percent of Tracked Fish Headed Downstream by Region in Front of Unit 8, Bonneville Dam in 2000. Percentages are shown for the three behavioral groups: milling (tortuosity index <0.5), north-directed (tortuosity index >0.5; north/south displacement = 0), and south-directed (tortuosity index >0.5; north/south displacement = 1).

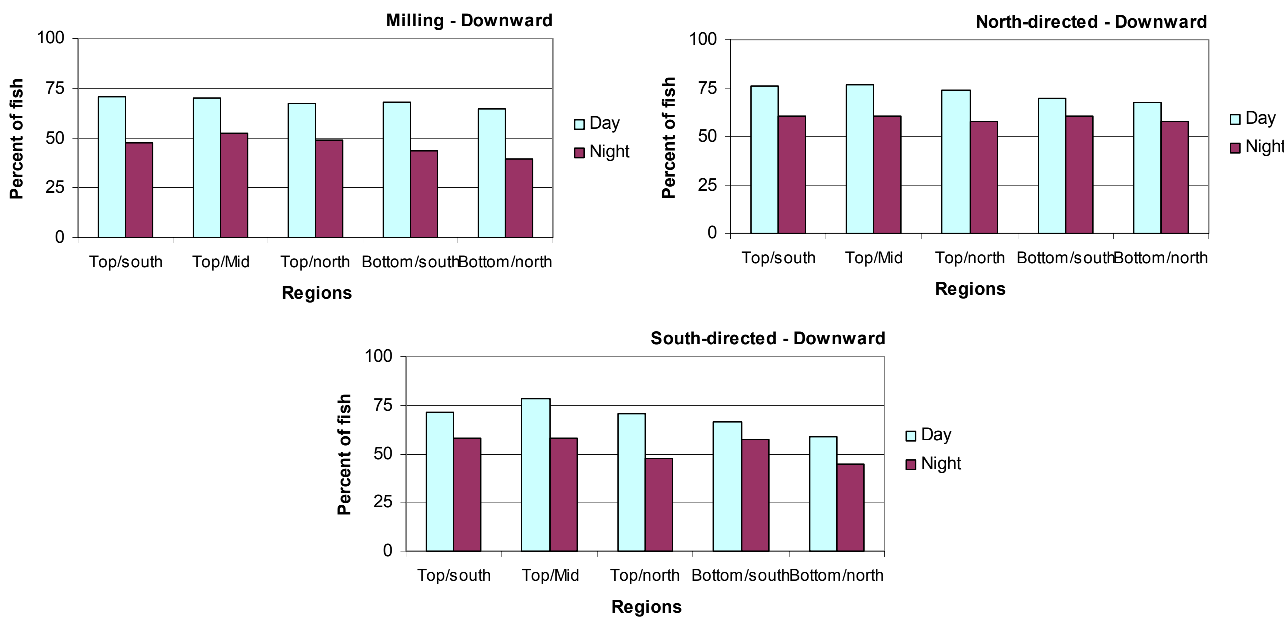

Figure 4.17. Percent of Tracked Fish Headed Downward by Region in Front of Unit 8, Bonneville Dam in 2000. Percentages are shown for the three behavioral groups: milling (tortuosity index <0.5), north-directed (tortuosity index >0.5; north/south displacement = 0), and south-directed (tortuosity index >0.5; north/south displacement = 1).

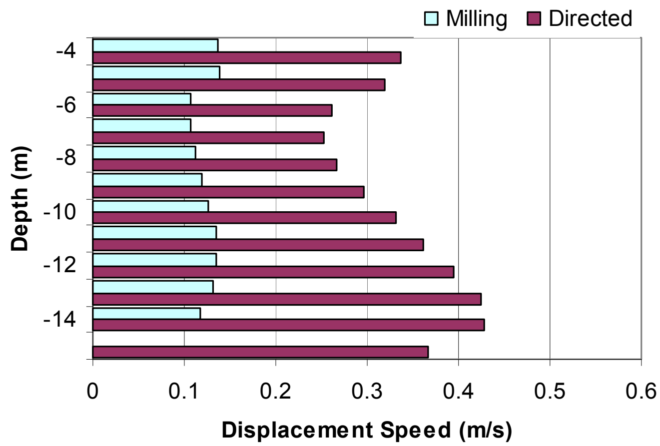

Figure 4.18. Displacement Speed Versus Depth for Directed and Milling Fish Tracks in Front of Unit 8, First Powerhouse, Bonneville Dam in 2000

As a comparison, Figure 4.19, shows the average swimming speed, which is the length of the fish track divided by the observation time. Note this is not the actual swimming speed in flowing water, because water velocity was not removed from the motion of each fish. There is little difference (~0.1 m/s) between swim speed and displacement speed for directed fish. However, milling fish have a swimming speed similar to that of directed fish, indicating that they are expending a lot of energy to maintain their position.

Lastly, we can compare potential entrance efficiencies for directed versus milling fish (Table 4.3). The milling fish had almost identical potential entrance efficiencies throughout the five regions of the opening regardless of day/night period. Recall that this quantity reflects aiming more than the actual propensity for entry into the opening. South-directed fish exhibited the highest potential entrance efficiencies on the north-top for both day and night. The lowest efficiencies for south-directed fish were for those in the south-bottom region at night. Conversely, the north-headed fish had the highest values at night in the south-bottom region and the lowest value in the north-top during daylight hours.

When the turbine was turned off, the fish behaved in a somewhat consistent manner throughout the five sample regions with only slightly higher values at night on the north side of the opening (Table 4.4).

4.2.5 Vector Plots/Swimming Effort

Another way to look at fish movement is using vector plots. Vector plots have the advantage of carrying speed information along with the directional information. Swimming effort is defined as the vector difference of displacement velocity and local water velocity. Effort is the remaining fish displacement velocity relative to the flowing water. The vector plots (Figures 4.20 through 4.22) show that fish

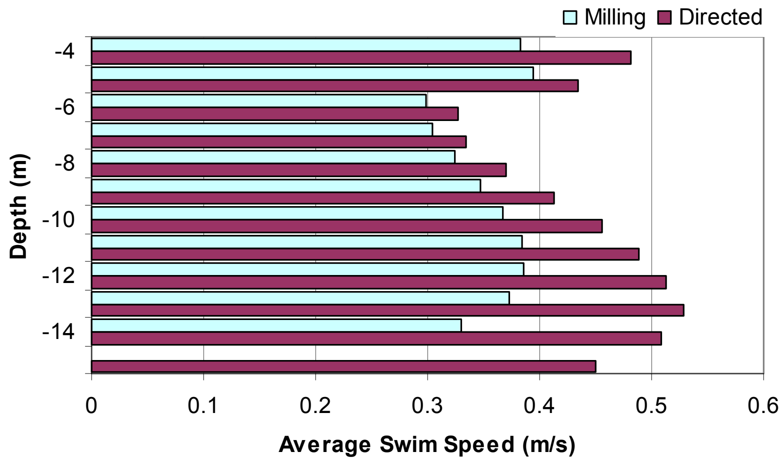

Figure 4.19. Average Swim Speed Versus Depth for Directed and Milling Fish Tracks in Front of Unit 8, First Powerhouse, Bonneville Dam in 2000

Table 4.3. Potential Entrance Efficiencies for the Three Classes of Targets with Turbine Unit 8 On (cells are arranged to display the five sample regions, left side of the table is south)

Milling Targets

Day	21.6	26.3	24.2
Night	24.9	26.8	27.4
Day	21.8		20.7
Night	21.0		27.3

South-Headed Targets

Day	12.4	27.9	40.9
Night	14.3	24.6	38.2
Day	11.3		28.4
Night	9.9		35.1

North-Headed Targets

Day	22.4	17.0	6.3
Night	24.5	14.9	8.1
Day	20.1		9.7
Night	29.7		14.7

Table 4.4. Potential Entrance Efficiencies with Unit 8 Off (cells are arranged to display the five sample regions, left side of the table is south)

<table>
<tr><td>Day</td><td colspan="3">15.2</td><td colspan="2">12.7</td><td>10.7</td></tr>
<tr><td>Night</td><td colspan="3">13.4</td><td colspan="2">18.3</td><td>19.0</td></tr>
<tr><td>Day</td><td colspan="4">15.5</td><td colspan="2">12.4</td></tr>
<tr><td>Night</td><td colspan="4">17.3</td><td colspan="2">20.7</td></tr>
</table>

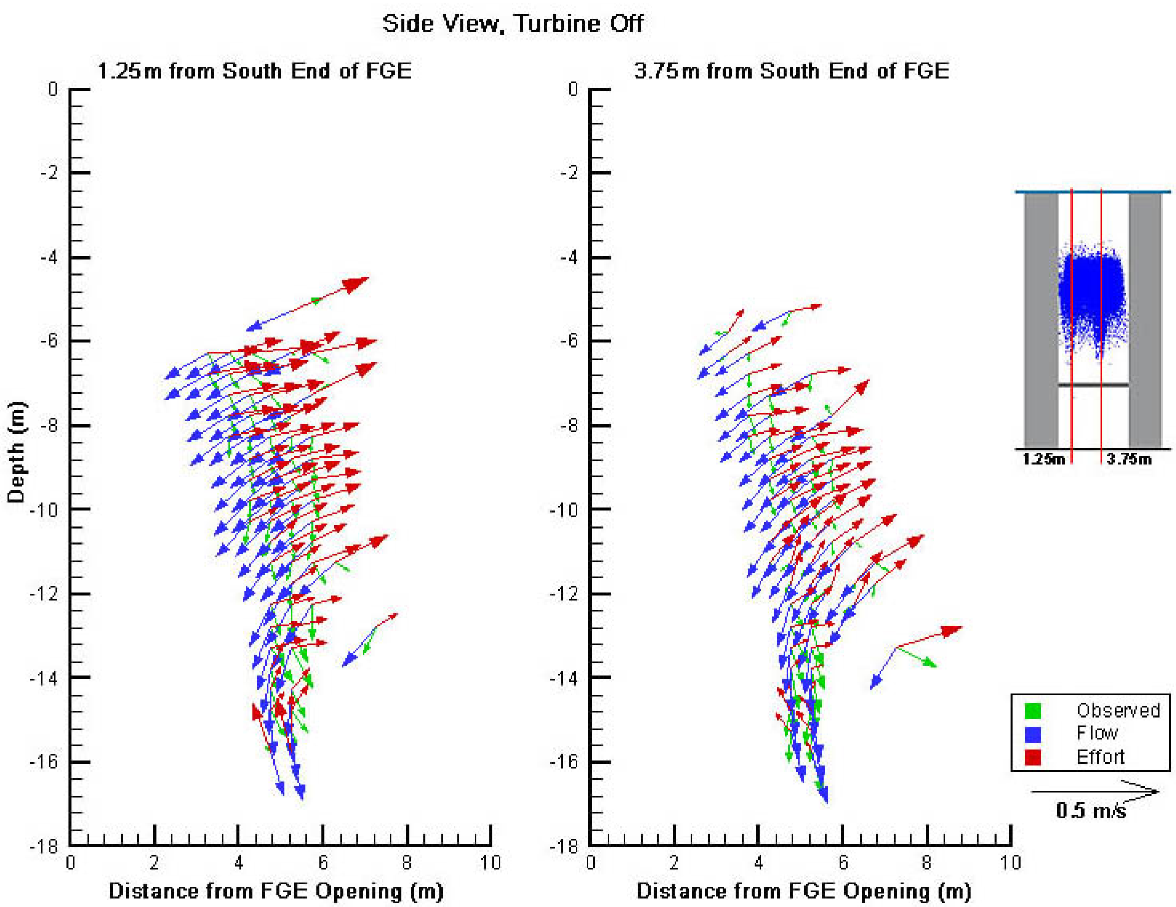

Figure 4.20. Swimming Field Vectors (Side View) Based on 1 m Bins with Unit 8 Off at First Powerhouse, Bonneville Dam in 2000. Note that Reference Vectors are Different Between Unit 8 On and Off.

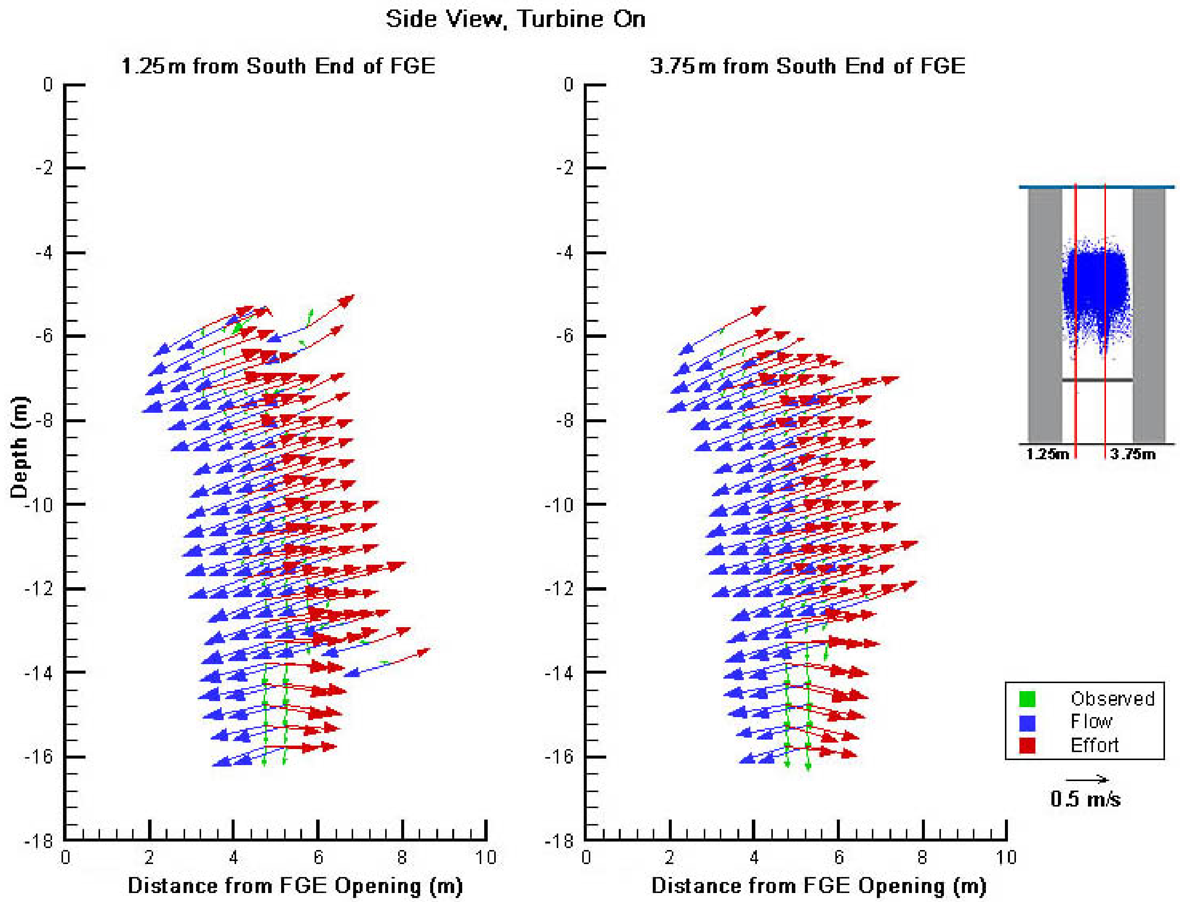

Figure 4.21. Swimming Field Vectors (Side View) Based on 1 m Bins with Unit 8 On, First Powerhouse, Bonneville Dam in 2000. Note that Reference Vectors are Different Between Unit 8 On and Off.

effort was away from the structure in all areas (Sample sizes associated with these figures are in Appendix F). Because positive and negative directed movement tends to balance over time, the resulting average displacement velocity (green arrow) at each location tends to be small compared to the magnitude of the flow. As a result, the effort vector (red arrow) tends to point opposite to the downstream pointing flow vector (blue arrow).

Vector plots map the average effort for a spatial or volumetric bin. We have seen that in each area sampled by the splitbeam sonar, there is a heterogeneous population of fish, some of which are milling, while the rest are moving in a more directed manner. The average obscures this information. Another way to consider swimming effort is to look at the difference in the fish track displacement velocity along the water flow vector, and the flow velocity magnitude. In other words, calculate effort by projecting the fish displacement velocity onto the flow. A relative effort is then calculated by dividing by the water

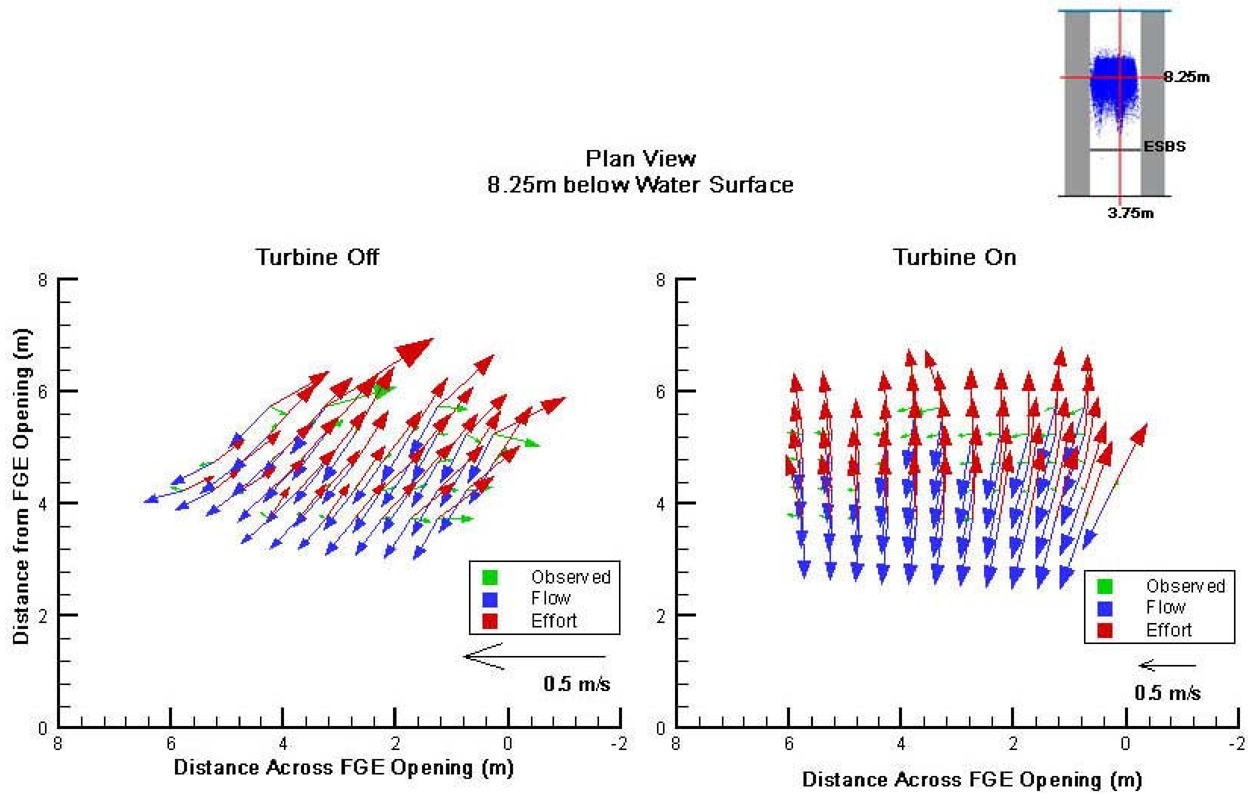

Figure 4.22. Swimming Field Vectors (Plan View) Based on 1 m Bins with Unit 8 Off and On, First Powerhouse, Bonneville Dam in 2000. Note that Reference Vectors are Different Between Unit 8 On and Off.

flow. A relative effort of unity (1) is associated with a fish that is holding its position in the current. An effort greater than one, indicates that the fish is swimming upstream against the flow, and a relative effort less than one is associated with fish that are being pulled along with the flow. Fish with effort equal to or less than zero are going downstream with or faster than the flow. For fish swimming in front of Unit 8 (Figure 4.23), we see the population is composed of two large groups. On large group of fish was going upstream against the flow (upper right in figure), while the remaining fish were being pulled downstream (lower left, effort <1). Within the group of fish going downstream, most were still making an effort to go against the flow, but with limited success. Finally, there were only a few fish in our sample that had a displacement velocity similar to or exceeding the flow (lower left, effort < 0).

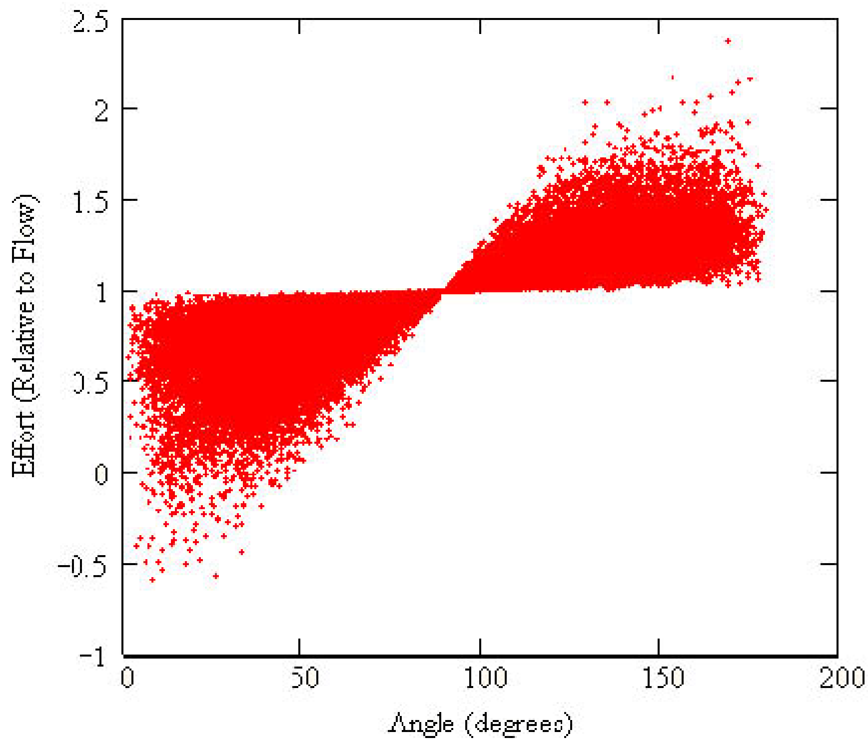

Figure 4.23. Relative Fish Swimming Effort Versus the Angle Between Water Flow and Fish Displacement Vector. Angles less than 90˚ are in the same plane as water flow, angles greater than 90˚ are opposite flow.

5.0 Discussion

5.1 Background Data

Bakshtansky et al. (1993) suggests that "hydroacoustic methods probably offer the greatest promise in providing non-invasive information about free-ranging downstream migrants." They further suggest that while hydroacoustics can provide new information on fish distribution, it is more difficult to determine fish movement, orientation and behavioral response. This has been true in this and former studies conducted using traditional and novel hydroacoustic techniques (Angela et al. 2001; Johnson et al. 1999, 2000, 2001). Therefore, it is not enough to discuss behavioral results from this study; we must also discuss the challenges, and solutions employed to overcome those challenges, while acknowledging that hydroacoustic sampling may not be appropriate to measure every aspect of fish behavior.

The overall goal of the study was to evaluate fish behavior in front of B-slot of Unit 8 and determine if this behavior could be attributed to the presence of the modified ESBS installed in 2000. The evaluation of fish behavior was motivated by the variability in FGE during tests conducted in 1997 (Hanks and Ploskey 2000) and in 1998 at this unit (Ploskey et al. 2000). We used hydroacoustic techniques which were comprised of three splitbeam transducers, two stationary, and a third attached to a robotic mount which allowed it to move back and forth across the opening of the streamlined trash racks at the B-slot of Unit 8. This configuration permitted us to evaluate fine-scale smolt behavior immediately upstream of the trash racks.

Smolt behavior can be affected by a number of environmental and physical factors aside from those attributed to the ESBS. The same is true of hydroacoustic tools used to evaluate the smolts. One of the most problematic factors that we have had to deal with in past evaluations was constantly changing hydraulic conditions within the study area, usually driven by needs in the hydropower system. This year, a concerted effort was made to keep the First Powerhouse operations as constant as possible. The effort met with reasonable success. The river discharge stayed between 90-100 kcfs from mid-April until mid-June with the exception of one unexplained peak around May 4 when Second Powerhouse apparently was not operating and the First Powerhouse took up the slack, peaking at about 200 kcfs. Despite this one anomaly, the overall project operations probably did not contribute significantly to variation in smolt behavior during the spring study period. However, after mid-June, powerhouse operations began to fluctuate substantially, which may have contributed, to some extent, to smolt behavior. However, most of the fish tracks that we collected were before mid-June. There were also periods, especially in the evening when Unit 8 was shut down for short periods to conduct fyke-netting operations.

Environmental conditions such as temperature and turbidity can have an effect on both hydroacoustic instrument performance and smolt behavior. Temperature affects the speed of sound in water and particulates in the water in sufficient quantity and size can contribute to volume reverberation or volume scattering in the same way that plankton do in the sea (Urick 1975). Although temperature constantly increased throughout the season (10°C to 19.3°C), and the turbidity increased by 2-3 secchi units, these were not significantly large changes to affect the performance of the hydroacoustic instruments, particularly at the relatively short ranges that we were operating. However, both of these factors could have had an effect on salmon smolt behavior by affecting their swimming performance and limiting their ability to use visual cues for finding or avoiding structures and openings.

The most troublesome environmental conditions for hydroacoustic evaluations at Bonneville Dam have been the wind and rain. Both of these conditions create bubbles in the water column. When clouds of bubbles were drawn toward a powerhouse, they were drawn into the water column by the hydraulic forces associated with turbine operation creating excessive background noise. Rain may also directly contribute to increased ambient acoustic noise levels through the impact of rain on the water (Urick 1975). Although the majority of the noise is associated with the frequency range of 10-100 kHz, some effects have been observed as high as 200 kHz. Both of these noise sources can compound to excessive levels and totally mask the presence of fish swimming in our relatively shallow sampled region of the water column. During this study, there were a number of rain events in April and May with peak precipitation of about 4 cm per day (Figure 2.6). In early June, there was only one period with excessive wind and rain (4 cm). Late June and July were relatively rain free with occasional windy days. The prevailing winds were typically from the west or southwest. The powerhouse provided shelter from direct wind affects. However, any time the wind blows upstream of the dam in the Columbia Gorge, bubbles are transported downstream by the river flow into our sample region. Why is this important? We were attempting to isolate the fine-scale behavior of fish using a sonic device that was highly susceptible to this type of background noise in terms of frequency (200 kHz) and beam width (12°). While it was possible to detect and isolate fish in this noise, the noise often becomes part of the track. Extensive filtering and track smoothing was required to remove the noise and reconstruct original fish movement. This careful track scrutiny was a substantial part of the effort needed to arrive at a sample of tracks that represented the behavior of the targeted fish population. Another reason to be concerned with the wind and rain generated noise was the effect that it potentially could have on the behavior of migrating salmon smolts. The extent of this behavioral effect is unknown. In addition, rain events are usually accompanied by an obscured sky that decreases the amount of available light. Little is known about how salmon smolts might react to these low light conditions near hydropower structures.

During our study, we also encountered acoustic noise emanating from the turbines. The hydroacoustic system that was deployed at Unit 8 was a 200 kHz splitbeam echo sounder with 12° beams. This frequency was chosen to avoid conflict with the 420 kHz system operated by Waterways Experiment Station inside the unit for passage estimation and direct evaluation of the ESBS (fish guidance efficiency). In a post-season evaluation of the acoustic background noise using a broadband hydrophone, we discovered that a component of the turbine noise at 200 kHz resulted in as much as a 23 dB increase in background noise levels above those measured at 420 kHz. This added to the environmental noise level making it increasingly difficult to extract clean targets from the water column. The acoustic noise is not likely to have affected fish behavior since it is well beyond their hearing capability. However, the noise that we encountered may have been a component of lower frequency sources that could have had a contributing effect on juvenile salmon behavior.

The splitbeams used in this study covered different areas on front of Unit 8. The two stationary transducers were mounted on fixed steel mounts and aimed up in the water column to just graze the traverse frame on the top trash rack. The down-looking traversing (moving) transducer crossed the opening twice within 1 hour. It was aimed down to just graze the up-looking transducer mounts. The majority of the fish tracks detected were in the overlap region between the two sets of transducers (stationary/traversing).

When the raw autotracked data was filtered, most of the targets beyond the range of the overlap region were removed because of ambiguities in their ping-to-ping spacing. These ambiguities were assumed associated with noise as described above, and in fewer cases, with multiple targets. Therefore, we feel confident that our beam coverage was from surface to bottom. Therefore, the majority of the targets were deemed in the region between the two mounts. This is further substantiated by noting the decreased density, not only in the lower part of the down-looking beam, but also at the apex end of the up-looking beams. This further suggests that the majority of fish were located above the tip of the ESBS. The depth distribution histograms indicated that the majority of fish were in the 7-10 m range during the day and 1-2 m deeper at night.

5.2 Tracked Fish Summary

We successfully tracked close to 0.4 million targets between May 4 and July 15, 2000. Of that population, we selected 124,000 targets that could reasonably be classified as fish tracks. Of these, approximately 2,000 were associated with the turbine 'off' condition. The majority of the fish were tracked during daytime (89% in spring and 78% in summer). Since we tracked fish well in front of the turbine intake, we may have tracked individuals more than once over the course of a day. Therefore, these numbers cannot be used to calculate an index of abundance. But despite this, the distribution of tracked targets over the spring season closely followed the run timing curves from the smolt-monitoring program with the exception of down-times in our data collection system. Typically, during the summer season, the number of salmon smolts decreases while the number of non-salmonids such as shad increase. Thus late season behavioral evaluations should be used with some caution as these "other" species may dominate the tracked population.

Both the spring and summer periods had similar distributions relative to our arbitrary sample regions (3 regions above 10 m, and 2 regions below 10 m). Of particular note, however, was the abundance of targets in the center top region. Although these data include both the up-looking transducers and the down-looking traversing transducer, it raises the question of distribution in front of the opening. If these results hold true, it could have serious implications about sampling in the center of turbine intake slots near the trash racks. Additional research will be necessary to substantiate this finding.

5.3 Fish Behavior

Fish behavior was defined by: 1) the direction and speed of travel; and, 2) by the straightness of the track, as measured by the tortuosity index. We used the tortuosity index to look both at spatial changes in the index, as well as to categorize different behavioral groups. When we looked at the change in the index over depth (Figure 4.13), we noted substantial differences between day and night. Both day and night showed increasing values (straighter tracks) with depth. This was as expected since the sampled fish tracks might become more directed with depth because of increasing influence of the turbine intake hydraulics. However, we also noted a greater preponderance of directed tracks at 6 m compared to 4 and

8 m during the day. This pattern was not noticed at night. We have no explanation for this pattern, but note there is a similar, but reversed, pattern in the swim speed (Figure 4.19). Additional study will be necessary to understand this phenomena.

The tortuosities across the opening (Figure 4.14) are more explainable, with the fish tracks at the edges of the opening more directed and those at the center, more tortuous. The edges of the opening might be expected to provide guiding cues and higher velocity as the water moves around the pier nose. Fish caught in these regions might be expected to follow the flow or swim against it, but be guided by the structure nevertheless.

Because the majority of the tracked fish targets were located well above the tip of the ESBS, it was important to consider the direction that they were moving to ascertain whether they might have an opportunity to be entrained into the turbine. Because there was a range of behaviors in front of Unit 8 with some fish tracks being relatively straight, while other tracks were indicative of milling, we divided the fish into groups based on the tortuosity index to determine if there were differences in other behavioral attributes associated with milling and non-milling behavior. Milling fish were defined as those with a tortuosity index value <0.5; this group contained approximately 38% of the tracked population. The remaining 62% of the tracked fish tracks were classed as directed (τ >0.5), with 28% headed in a southerly direction and 34% headed in a northerly direction.

The predominant directional component for all fish was downward in the water column especially during the day. At night, downward movement was less pronounced for north and south-directed fish, while a similar percent of milling fish were going down as up. Movement in the upstream-downstream direction was similar for milling and north-directed fish, with more fish heading upstream during the day, than at night. Only south-directed fish were headed downstream. If the fish detected upstream of Unit 8 are to be entrained they would have to maintain rigorous swimming upstream and downward for an extended period. If that were the case, we most certainly would have tracked them down to the tip of the ESBS and perhaps beyond. Since we did not see a large number of fish in that region, it is highly unlikely that they would have expended the effort to become entrained below the ESBS. The only way that we would have missed them with the acoustic system was if they were shunted through the streamlined trash rack and under the tip of the ESBS behind the trash rack. However, the splitbeam system placed behind the trash rack detected fewer fish during the day than during the night (Ploskey 2001). It is unclear what happened to all the fish that we detected during the daytime hours and why we did not see more fish at night. Unit 8 was generally down for part of the night, so turbine noise was not a factor in our ability to detect fish. A possible scenario, based on the observed upstream movement of many of the fish, is the fish moved upstream during the day using visual clues and turbine noise to avoid the opening. At night, when these clues were minimized, the fish were entrained into the turbine. It is apparent that the additional hydroacoustic coverage at Unit 8 has highlighted the complexity of fish behavior in front of dams.

We also looked at the turbine-off condition to see if the data would be reasonable based on slack water. We found that there was a strong downward component during the day with virtually no directed movement laterally or downstream/upstream. At night, the fish tracks appeared stalled in all directions with only moderate downward movement in the bottom regions. This was expected for the slack water scenario directly in front of the B-slot intake. Fish farther from the intake (not detected by our sampling instruments) may have had a much different behavior associated with operating units adjacent to Unit 8.

5.4 Potential Entrance Efficiency

Potential entrance efficiencies were computed for the three classes of targets described earlier: milling, north-directed, and south-directed. The efficiencies quantify the propensity for aiming at the opening over the three populations of directed movement, and do not indicate actual counts of passage, as might be provided by some other arrangement of deployed splitbeam systems. This acoustic system was, instead, deployed to measure mainly transverse movements across the face of the trash rack. It could also measure movements perpendicular to the face, but only over the angular range of one splitbeam. In other words, the spatial range of measurements of the tracked population was greater over the transverse direction, and much less in the longitudinal direction of flow. Thus, the system is not able to count directly passage of fish into the opening, only a potential for entrance can be estimated here.

The maximum efficiency was 40.9 and lowest was 9.7. The highest values were on the north side of the slot among south moving targets. In the remainder of the regions, the values were relatively low considering the size and depth of the opening. Since we are tracking fish directly in front of a turbine opening, we would expect the entrance efficiencies would be relatively high. Our data, based on the direction that fish were aiming, suggests this was not true. However, even fish that are predominantly aimed away from the opening, could quickly turn and head back through the trash rack, and disappear from our sample volume.

The potential entrance efficiency metric described in this report should not be confused with the efficiency metric used for fish passage evaluations (Ploskey 2001). First, the potential entrance efficiency is not a count of fish going through an opening. This metric is merely a way to determine the *overall heading of a population of fish*. When we evaluate displacement fraction we are looking at the direction of movement in a single plane (north/south, upstream/downstream or upward/downward), the potential entrance efficiency provides a metric to describe the overall direction of travel. We can also use this metric to estimate how long it might take a fish to go through the opening given it's present displacement direction and speed.

We were also concerned with the possible random nature of the tracks we were measuring. Figure 5.1 shows the potential entrance efficiency for randomly directed targets having the same location and swimming speed as our population of fish. The mean and standard deviation were produced from 20 simulations of randomly distributed angular directions. [Note: if the angular direction is parallel to the dam, the efficiency is zero, whereas, if the fish were passive and followed the water flow, then the efficiencies would approach 100%.] The results show that the potential entrance efficiencies for our population of fish are less than would be expected if movement was purely random and definitely not passive. The error bars for the randomly simulated potential entrance efficiencies (Figure 5.1) are very small, and indicate that these efficiency values are highly reproducible over the population of original fish track locations distributed in front of the trash rack at Unit 8. The interception of the opening by the projection of actual fish displacement vectors occurs within a very narrow horizontal band, whereas, the randomly oriented projections produce a much greater coverage, and thus have a greater efficiency. This

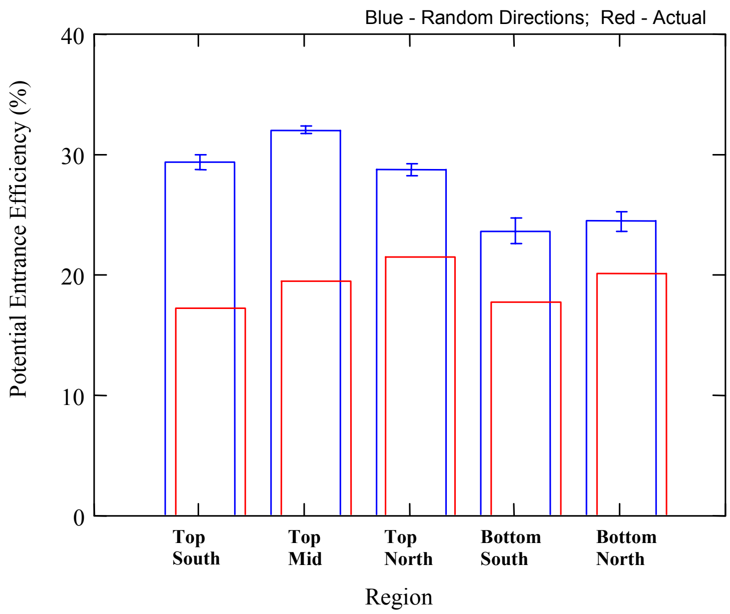

Figure 5.1. Comparison of Potential Entrance Efficiencies Calculated from a Population of Targets with Randomly Determined Angular Directions to Fish Detected by Splitbeam Sonar in Front of Unit 8, Bonneville Dam First Powerhouse in 2000. The mean and standard deviation are for 20 random simulations.

supports the observation that fish are avoiding the opening, at least for the typical observation period. Thus, potential entrance efficiencies provide us with behavioral information about the fish and should not be compared to those efficiencies calculated from fish counts.

Results from Ploskey et. al (2001) indicate that fish passage at Unit 8 was low compared to Unit 9 (units 7 and 10 were also low). Fish passage efficiency was between 60% and 90% for the spring season and between 30% and 60% for the summer. Our efficiencies, as measured by the potential entrance efficiency, were also significantly higher in spring than summer, however these efficiencies (~22%) were much lower than those calculated by Ploskey et al. (2001). We can also extrapolate efficiency from our analysis of swimming effort (Figure 4.23). If we assume that fish with a relative swimming effort of less than unity (1) are less resistant to the local flow, and therefore, are more likely to go through the opening, then potentially 56% of the fish would pass through the opening in spring, compared to 51% in summer. These two metrics may be referred to as an aiming efficiency and swimming efficiency.

Data from the ADCP indicated that there were three flow regions in front of Unit 8 (Cook and Johnson[1]). The flows in the first region, from near the surface to 10 m, were constant and fairly low, around 1 m/s. Below this region, from 10 to 15 m, flows were still around 1 m/s, but much more variable. Finally, the region below 15 m was characterized by flows greater than 1.5 m/s and headed strongly

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[1] Cook, C.B., and R.L. Johnson. 2001. Analysis of observed water velocities at Bonneville Dam. Letter Report. U.S. Army Corps of Engineers, Portland District. Portland, Oregon.

downward. Most of the fish detected by the splitbeam hydroacoustic system were above 10 m. When we examined the acoustic data, there was more noise below 10 m than above. This could be the result of background noise (Appendix A) from turbine operation. The noise did not entirely block out tracks, and although our processing programs were not able to extract targets from the noise, examination of the acoustic data indicates that there were few targets in this area.

Fish behavior in front of Unit 8 (and perhaps all units) is extremely complex, with most fish high in water column and headed away from the opening. Fish in front of Unit 8 did not appear to be following flow. This was apparent from both potential entrance efficiencies, one based on aiming angle, the other on swimming effort. In fact, only a small proportion of the fish analyzed for this report were following flow. While our selection criteria may have biased our sample against fish heading straight into the opening, the number of fish detected indicates there were a lot of fish attempting to avoid the opening. The behavioral complexity we see in front of Unit 8 is probably not unique to this area and indicates a strong need to better understand the factors influencing migrant fish population behavior in these environments. Increased understanding of behavior will ultimately lead to increased effectiveness in design of structures to safely pass fish by hydropower dams.

6.0 Conclusions and Recommendations

6.1 Conclusions

Based on our results we conclude:

- The majority of fish detected by the splitbeam sonar would not have been entrained under the tip of the ESBS.
- There was a substantial degree of milling immediately upstream of the trash racks.
- Only one region was identified to potentially contribute to fish entrainment (bottom-north), but that was at night when relatively few fish were detected. The fish were also still relatively high in the water column away from the tip of the ESBS.
- The majority of fish were located in the center region of the slot opening.

6.2 Recommendations

Based on this study we recommend:

- further research be conducted to establish the validity of using results from center-oriented hydroacoustics to estimate passage efficiency and find a sampling remedy to account for the variation across the slot opening.
- that the mechanisms responsible for milling behavior in front of an otherwise unobstructed turbine opening be studied. Through understanding of what contributes to milling and thereby delays fish passage, improved mitigation technologies may become apparent.
- the traversing splitbeam be redeployed on a lower trash rack (#2 or #3) to concentrate effort at the tip of the ESBS to assess the dynamics of that region.

7.0 References

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Appendix A

Background Noise

Appendix A

Background Noise

A noise factor that we encountered at Unit 8 was the prevalence of 200 kHz acoustic noise emanating from the turbine unit. Since our hydroacoustic system was operating at 200 kHz, the increase noise levels from turbine operation added additional background noise to our data stream. We were able to substantiate the presence of the noise by using a broadband hydrophone and passively collecting noise data in a post-season test. The data was collected from a boat tied to the trash rake cable that crosses the forebay about 25 m upstream of the turbines. Figures C.1 through C.3 show the relative noise levels in dB volts from 50 kHz to 500 kHz with different aiming schemes (30°-down toward turbine, horizontal toward turbine, and 30°-down away from turbine). These measurements resulted in 23 dB, 13.5 dB, and 5 dB differentials between turbine on and off for the three aiming schemes, respectively. These results clearly demonstrate the presence of 200 kHz noise associated with turbine operation. The other factor that appeared to affect our ability to detect fish at longer ranges unambiguously was the volume backscattering levels associated with 12° beams. While the increase volume provides a greater horizontal range of detection, it was also more susceptible to volume backscattering noise (small bubbles and particulate in the water). This coupled with the 200 kHz noise emanating from the turbines made it difficult to extract targets from the noise in an unambiguous manner.

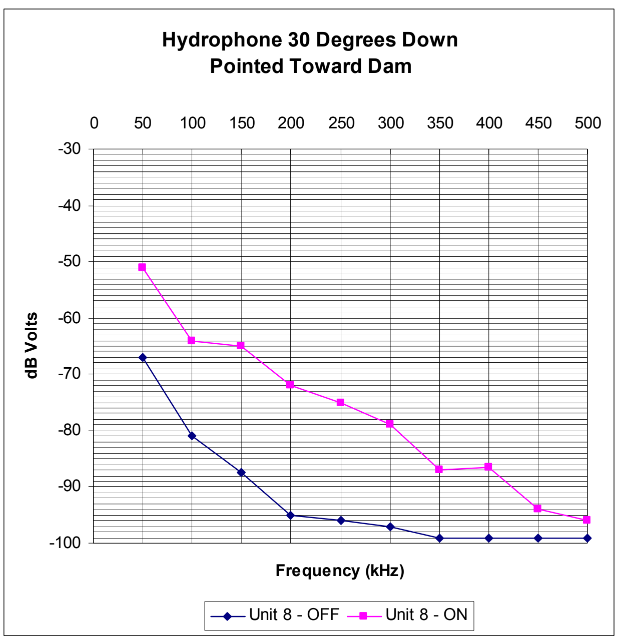


Figure A.1. Background Noise Levels in Front of Unit 8, First Powerhouse, Bonneville Dam in 2000 with Unit 8 OFF and ON. Hydrophone pointed 30° down and toward the dam.

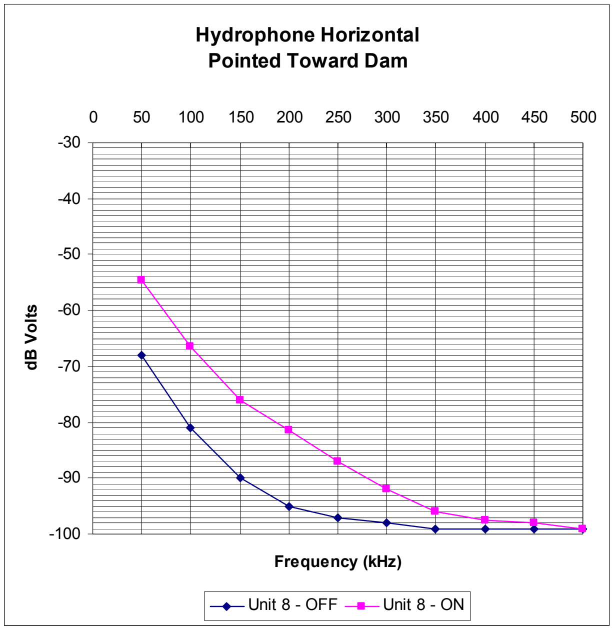


Figure A.2. Background Noise Levels in Front of Unit 8, First Powerhouse, Bonneville Dam in 2000 with Unit 8 OFF and ON. Hydrophone pointed horizontally toward the dam.

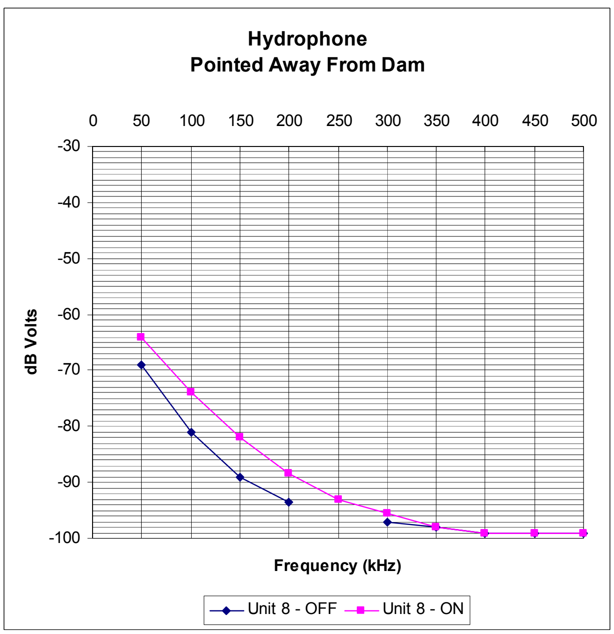


Figure A.3. Background Noise Levels in Front of Unit 8, First Powerhouse, Bonneville Dam in 2000 with Unit 8 OFF and ON. Hydrophone pointed away from the dam.

Appendix B

Quality Control Analysis

Appendix B

Quality Control Analysis

Quality Control Analysis

by Craig A. McKinstry
Battelle Statistical Resources Division

Introduction

Internal and external quality control (QC) measures were implemented to assess the consistency of fish track selection by the data processing technicians. On a weekly basis, files were randomly selected, then twice renamed and added to each technician's workload, without their knowledge. Through this procedure, each QC file was processed twice by each technician. This procedure was implemented to assess the internal and external consistency between data processing technicians in identifying fish tracks.

Consistency is addressed at two levels:

1. The synchrony of the fish tracks identified. This measure is used to address the question: Do the technicians select the same fish tracks in a file, each time the file is processed?

2. The number of fish tracks identified in each pass through a particular file. This measure is used to address the question: Do the technicians select the same number of fish tracks each time they process the same file?

Methods and Results

Track Synchrony Analysis

In this report, synchrony is defined for a data file each time each time it is processed as the proportion of fish tracks identified of all fish tracks identified every time the file was processed. This measure is best illustrated in the graphical example below. In Figure B.1, a file has been processed twice; Processor 1 identified 3 tracks, while Processor 2 identified 4 tracks, for a total of 5 distinct tracks. Processors 1 and 2 could represent different technicians or 2 passes through the file by one technician. The former would be a measure of external synchrony while the latter would be a measure of internal synchrony. If each processor identified zero targets in a file, the synchrony score would be 1.0 or 100% synchronized.

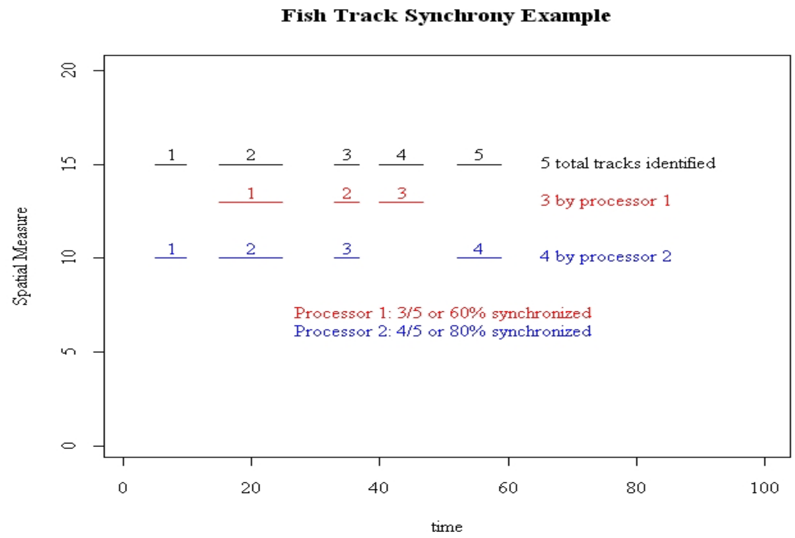
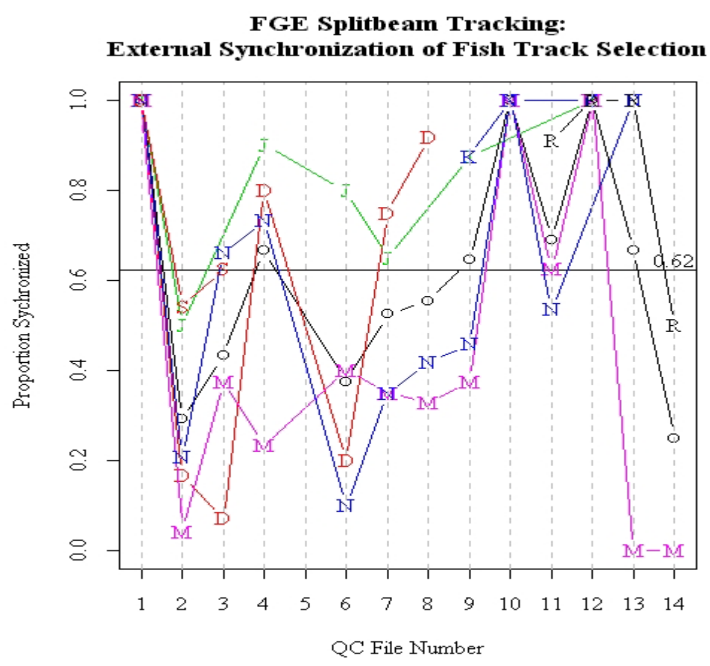


Figure B.1. Example of How the Synchrony Measure is Computed. Each set of vertically aligned tracks represents the same fish track or same set of 'echoes' occupying the same time and space.



File Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Technicians	5	5	4	4	*	4	4	3	4	3	3	4	3	2
Total Targets	1	12	28	15	*	5	10	55	12	0	28	0	1	1

* File number 5 was excluded from this analysis due to an unresolved problem with the data.

Figure B.2. External Synchrony Summary P-Chart of 14 QC Files Processed Through the Season

The sequence of files in Figure B.2 follows chronological ordering from left to right. The black horizontal line shows the overall mean while the black line segments with circular points show the mean values by file for those technicians who process the file. Seven data processing technicians were involved at different times through the season and are represented by letters: D, J, K, M, N, R, and S. The table below the plot shows the number of technicians involved in QC processing, and the total number of targets (fish tracks) identified by all technicians processing the file.

Figure B.3 shows a comparison of external synchrony of 7 data processing technicians for the FGE splitbeam data files processed this year. This graphical summary shows that technicians selected the same fish in a file 62% of the time on average across all QC files processed. The number of technicians participating varied between 2 and 5 through the season. The plot shows high variability in the external synchrony between files. The overall mean synchrony score of the FGE system was 62%.

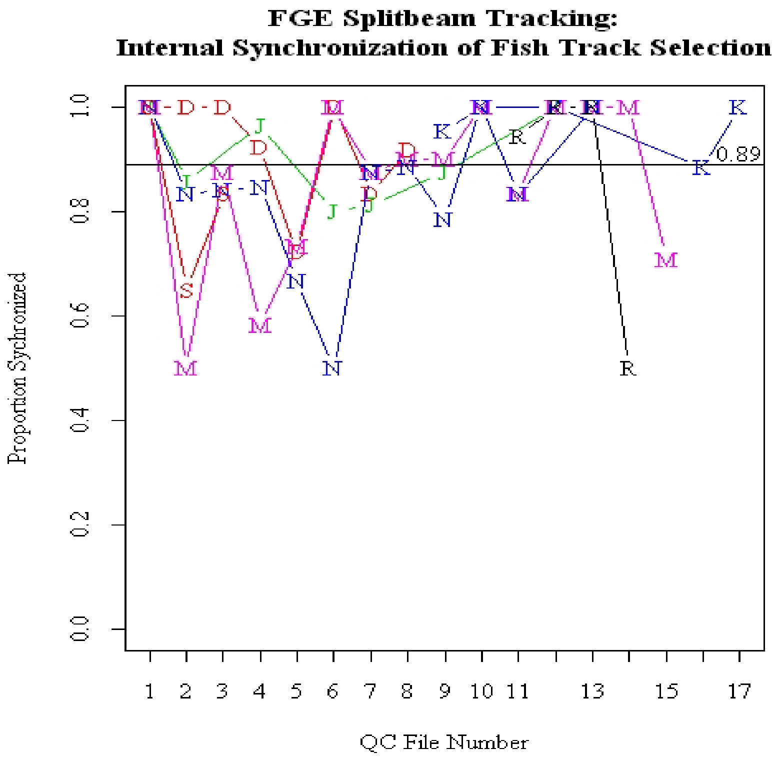


Figure B.3. P-Chart of Internal Synchrony for the FGE Splitbeam System. In this plot each technician is synchronized only to themselves through two passes through each file. Files are in chronological order from left to right. Seven data processing technicians were involved at different times through the season and are represented by letters: D, J, K, M, N, R, and S.

The figure above shows each of 7 technicians internal synchrony through the season. This plot shows that each technician chose the same targets in each file 89% of the time on a fairly consistent basis through the season.

Track Count Analysis

The track counts for each time a QC file was processed were analyzed using analysis of deviance from a Poisson model. As previously stated, each technician (called 'Observer' in the models below) made two passes (called 'Pass' in the models below) through each QC file to measure the internal observer error-variance. 'Pass' however, is likely highly correlated with 'Observer.' In each of the Analysis of Deviance Tables 1-6, each factor ('Observer' and 'Pass' both nested and un-nested) is added sequentially to the model from first to last. By adding 'Pass' to the model already containing 'Observer,' this correlation is accounted or controlled for, and the significance test on 'Pass' in not confounded by its multicolinearity with 'Observer.' From the analyses on track synchronization in previous sections of this report, it was evident that inter-observer variation was greater than intra-observer variation. Put another way, technicians were themselves reasonably consistent in track selection but showed much higher variability between technicians. For this reason, 'Observer' is always added into the model before 'Pass.'

FGE Splitbeam Track Count Analysis

Analysis of track counts was performed on the FGE splitbeam QC files. In the FGE splitbeam summary (Tables B.1 and B.2), a trend appears, whereby variation attributed to inter-observer count is not detected as significant until the track-count variation among QC files is controlled for in the nested analyses.

Table B.1. FGE Splitbeam Analysis of Deviance Table

Model	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL			113	1489.60		
Observer	6	74.07	107	1415.53	0.77	0.5913
Pass	1	0.24	106	1415.29	0.02	0.9019

Table B.2. FGE Splitbeam Analysis of Deviance Table for Factors Nested Within Each File

Model	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL			113	1489.60		
Observer in file	56	1452.72	57	36.89	34.73	<0.0001
Pass in file	18	5.42	39	31.47	0.4	0.9794

Summary

It is apparent from this analyses that improving consistency in track selection is a major issue that needs to be addressed and could greatly aid in our analyses of smolt behavior from the splitbeam hydroacoustic sampling data. Care must be taken in interpreting file synchrony scores, particularly those for external synchrony, as there are no criteria for the quality of targets selected by any technician. It may be the case that one technician selects more marginal targets than another, thus biasing the formers synchrony score higher than the latter's.

It is highly unlikely that any amount of training could rectify these consistency problems, given the large volume of data files processed, the variable level of noise in the image files, and the subjective nature of manual track selection. Combining auto-tracked targets with manual-tracked targets for any systems would surely exacerbate this problem of consistency. However, using auto-tracking alone may help the problem of consistency.

Additional research in an experimentally controlled setting needs to be done. This research should be directed at determining a 'signature' echo pattern for a juvenile salmonid, and in determining the effective range and other limitations for both the splitbeam and multibeam hydroacoustic sampling gear in detecting and monitoring the movements of juvenile salmon.

Appendix C

Turbine Operations at Unit 8

Appendix C

Turbine Operations at Unit 8

Turbine operations at Unit 8 for study period. 1 – indicates Unit 8 was on; 0 – indicates Unit 8 was off. If turbine was off at any time during an hour, it was assumed to be off for the entire hour. Hour 1 was from 0000 to 0100. Gray areas highlight times when Unit 8 was off.

		Hours																							
Month	**Day**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
May	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
	2	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	15	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	0
	16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
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	19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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	22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	1
	23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	24	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
	25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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	27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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	29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	30	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	31	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
June	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
	3	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Month	Day	Hours 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
June	10	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
	12	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0
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	17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	18	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
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	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	0
	21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	23	1	1	1	1	1	1	1	1	1	1							0	0	0	0	1	1	0	0
	24	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
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	27	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	1	1	0	0
	28	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
	29	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0
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July	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0
	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	1	0	0
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	10	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1
	11	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
	12	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
	14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									

Appendix D

Statistical Synopsis

Appendix D

Statistical Synopsis

Fish Behavior Statistical Synopsis
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Contingency Table Analysis

The Pearson chi-square statistic for two-way tables involves the differences between the observed and expected frequencies, where the expected frequencies are computed under the null hypothesis of independence. The chi-square statistic is computed as

$$Q_p = \sum_i \sum_j \frac{(n_{ij} - e_{ij})^2}{e_{ij}}$$

where $e_{ij} = [(n_{i.} \cdot n_{.j})/n]$

When the row and column variables are independent, QP has an asymptotic chi-square distribution with (R-1)(C-1) degrees of freedom. For large values of QP, this test rejects the null hypothesis in favor of the alternative hypothesis of general association (Fleiss 1981; SAS).

The likelihood-ratio chi-square statistic is based on the natural logarithm of the ratios between the observed and expected frequencies. The statistic is computed as

$$G^2 = 2 \sum_i \sum_j n_{ij} \ln\left(\frac{n_{ij}}{e_{ij}}\right)$$

When the row and column variables are independent, G2 has an asymptotic chi-square distribution with (R-1)(C-1) degrees of freedom (Fleiss 1981; SAS).

The continuity-adjusted chi-square statistic for 2×2 tables is similar to the Pearson chi-square, except that it is adjusted for the continuity of the chi-square distribution. The continuity-adjusted chi-square is most useful for small sample sizes. As the sample size increases, the statistic becomes increasingly like the Pearson chi-square. The statistic is computed as

$$Q_c = \sum_i \sum_j \frac{\left[\max(0, \left|n_{ij} - e_{ij}\right| - 0.5\right]^2}{e_{ij}}$$

Under the null hypothesis of independence, QC has an asymptotic chi-square distribution with (R-1)(C-1) degrees of freedom (Fleiss 1981; SAS).

Multivariate Analysis of Variance

Multivariate analyses were conducted based on a model of the form

$$Y = X\beta + \varepsilon$$

where Y is n ×p matrix of n observations on p response variables, X is n×k matrix of covariates, β is k×p matrix of parameter estimates, and ε is n ×p matrix of residual error. Each of the p models can be estimated and tested separately (SAS).

Multivariate tests were carried out by first constructing the matrices H and E. The H and E matrices correspond to the numerator and denominator of a univariate F-test (Rencher 1995; SAS). These are used to construct tests of the Multivariate General Linear Hypothesis of

$$L\beta M = 0$$

Where L is the test matrix, M is the pxp identity matrix, and β is k ×p matrix of parameter estimates. The matrices H and E are defined as follows

$$H = M'(L\beta)'(L(X'X) - L')^{-1}(L\beta)M$$
$$E = M'(Y'Y - \beta'(X'X)\beta)M$$

Four multivariate test statistics are computed which are all functions of the eigenvalues of $E^{-1}H$ (or $(H+E)^{-1}H$):

Wilks' lambda = det(E)/det(H+E)
Pillai's trace = trace($H(H + E)^{-1}$)
Hotelling-Lawley trace = trace($E^{-1}H$)
Roy's maximum root = largest eigenvalue of $E^{-1}H$

All four are reported with F approximations (SAS).

Non-Parametric ANOVA

Tortuosity and loopyness factors were assessed through non-parametric analysis based on median scores. The test statistic has an asymptotic chi-square distribution with r-1 degrees of freedom, where r is the number of class levels (SAS).

Appendix E

Fish Behavior Statistical Tables

Appendix E

Fish Behavior Statistical Tables

Displacement Fractions

Displacement Fractions by Time of Day

Movement in the North-South Direction

Time of Day	Count Moving South	% Moving South
Sunrise	1463	47.19%
Day	1389	44.81%
Sunset	1621	52.29%
Night	1561	50.35%

Likelihood Ratio Chi-Square: 41.05; df=3; P-val<0.0001

Movement in the Upward-Downward Direction

Time of Day	Count Moving Downward	% Moving Downward
Sunrise	2094	67.55%
Day	2288	73.81%
Sunset	1838	59.29%
Night	1617	52.16%

Likelihood Ratio Chi-Square: 360.84; df=3; P-val<0.0001

Movement in the Upstream-Downstream Direction

Time of Day	Count Moving Downstream	% Moving Downstream
Sunrise	1368	44.13%
Day	1344	43.35%
Sunset	1531	49.39%
Night	1601	51.65%

Likelihood Ratio Chi-Square: 60.68; df=3; P-val<0.0001

Displacement Fractions by Season

Movement in the North-South Direction

Season	Count Moving South	% Moving South
Spring	2800	45.16%
Summer	3026	48.81%

Likelihood Ratio Chi-Square: 16.54; df=1; P-val<0.0001

Movement in the Upward-Downward Direction

Season	Count Moving Downward	% Moving Downward
Spring	4203	67.79%
Summer	4689	75.63%

Likelihood Ratio Chi-Square: 94.12; df=1; P-val<0.0001

Movement in the Upstream-Downstream Direction

Season	Count Moving Downstream	% Moving Downstream
Spring	3019	48.69%
Summer	2497	40.27%

Likelihood Ratio Chi-Square: 89.09; df=1; P-val<0.0001

Displacement Fractions by Turbine Operation

Movement in the North-South Direction

Turbine Operation	Count Moving South	% Moving South
Off	3090	49.84%
On	2899	46.76%

Likelihood Ratio Chi-Square: 11.78 ; df=1; P-val=0.0006

Movement in the Upward-Downward Direction

Turbine Operation	Count Moving Downward	% Moving Downward
Off	4721	76.15%
On	4274	68.94%

Likelihood Ratio Chi-Square: 81.07 ; df=1; P-val<0.0001

Movement in the Upstream-Downstream Direction

Turbine Operation	Count Moving Downstream	% Moving Downstream
Off	2674	43.13%
On	2929	47.24%

Likelihood Ratio Chi-Square: 21.17; df=1; P-val<0.0001

Displacement Fractions by Region

Movement in the North-South Direction

Beam Region	Count Moving South	% Moving South
Bottom North	1202	48.47%
Bottom South	1174	47.34%
Top South	1111	44.80%
Top Mid	1137	45.85%
Top North	1165	46.98%

Likelihood Ratio Chi-Square: 7.926; df=4; P-val=0.09

Movement in the Upward-Downward Direction

Beam Region	Count Moving Downward	% Moving Downward
Bottom North	1471	59.31%
Bottom South	1627	65.60%
Top South	1725	69.56%
Top Mid	1822	73.47%
Top North	1701	68.59%

Likelihood Ratio Chi-Square: 124.703; df=4; P-val<0.0001

Movement in the Upstream-Downstream Direction

Beam Region	Count Moving Downstream	% Moving Downstream
Bottom North	1219	49.15%
Bottom South	1079	43.51%
Top South	1024	41.29%
Top Mid	1142	46.05%
Top North	1119	45.12%

Likelihood Ratio Chi-Square: 34.427; df=4; P-val<0.0001

Summary Tables of Displacement Velocities by Analysis Factors

Univariate Displacement Velocities by Time of Day

Direction of Velocity	RSquare	CV	Root MSE	Predicted Mean Velocity	DF	SS	MS	FValue	ProbF
North-South	0.0036	1395.63	0.2113	0.0151	3	1.9709	0.6570	14.72	<0.0001
Up-Down	0.0102	-290.78	0.1216	-0.0418	3	1.8832	0.6277	42.42	<0.0001
Upstream-Downstream	0.0038	4525.98	0.1307	0.0029	3	0.8164	0.2721	15.94	<0.0001

Multivariate Displacement Velocities by Time of Day

Statistic	Value	FValue	NumDF	DenDF	ProbF
Wilks' Lambda	0.9824	24.48	9	30164	<0.0001
Pillai's Trace	0.0176	24.41	9	37188	<0.0001
Hotelling-Lawley Trace	0.0178	24.52	9	19473	<0.0001
Roy's Greatest Root	0.0126	52.22	3	12396	<0.0001

Univariate Displacement Velocities by Season

Direction of Velocity	RSquare	CV	Root MSE	Predicted Mean Velocity	DF	SS	MS	FValue	ProbF
North-South	0.0030	804.12	0.1903	0.0237	1	1.3654	1.3654	37.71	<0.0001
Up-Down	0.0075	-199.13	0.0998	-0.0501	1	0.9344	0.9344	93.87	<0.0001
Upstream-Downstream	0.0069	1066.50	0.1168	0.0110	1	1.1768	1.1768	86.28	<0.0001

Multivariate Displacement Velocities by Season

Statistic	Value	FValue	NumDF	DenDF	ProbF
Wilks' Lambda	0.9806	81.59	3	12396	<0.0001
Pillai's Trace	0.0194	81.59	3	12396	<0.0001
Hotelling-Lawley Trace	0.0197	81.59	3	12396	<0.0001
Roy's Greatest Root	0.0197	81.59	3	12396	<0.0001

Univariate Displacement Velocities by Turbine Operation

Direction of Velocity	RSquare	CV	Root MSE	Predicted Mean Velocity	DF	SS	MS	FValue	ProbF
North-South	0.0021	1034.74	0.2039	0.0197	1	1.067233	1.067233	25.68	<0.0001
Up-Down	0.0066	-195.06	0.1041	-0.0534	1	0.897434	0.897434	82.85	<0.0001
Upstream-Downstream	0.0006	1237.46	0.1275	0.0103	1	0.127653	0.127653	7.85	0.0051

Multivariate Displacement Velocities by Turbine Operation

Statistic	Value	FValue	NumDF	DenDF	ProbF
Wilks' Lambda	0.9902	40.85	3	12396	<0.0001
Pillai's Trace	0.0098	40.85	3	12396	<0.0001
Hotelling-Lawley Trace	0.0099	40.85	3	12396	<0.0001
Roy's Greatest Root	0.0099	40.85	3	12396	<0.0001

Univariate Displacement Velocities by Turbine Operation

Direction of Velocity	RSquare	CV	Root MSE	Predicted Mean Velocity	DF	SS	MS	FValue	ProbF
North-South	0.0042	800.86	0.2080	0.0260	4	2.2675	0.5669	13.11	<0.0001
Up-Down	0.0030	-250.29	0.1166	-0.0466	4	0.5149	0.1287	9.46	<0.0001
Upstream-Downstream	0.0022	1263.92	0.1280	0.0101	4	0.4416	0.1104	6.74	<0.0001

Multivariate Displacement Velocities by Turbine Operation

Statistic	Value	FValue	NumDF	DenDF	ProbF
Wilks' Lambda	0.9907	9.71	12	32786	<0.0001
Pillai's Trace	0.0094	9.70	12	37182	<0.0001
Hotelling-Lawley Trace	0.0094	9.72	12	21682	<0.0001
Roy's Greatest Root	0.0066	20.42	4	12394	<0.0001

Potential Passage Efficiency

Potential Passage Efficiency by Time of Day Factor

Time of Day	Count Projected into FGE Slot	% Projected into FGE Slot
Sunrise	656	21.16%
Day	636	20.52%
Sunset	696	22.45%
Night	756	24.39%

Likelihood Ratio Chi-Square: 15.62; df=3; Pvalue=0.0014

Potential Passage Efficiency by Seasonal Factor

Season	Count Projected into FGE Slot	% Projected into FGE Slot
Spring	1514	24.42%
Summer	1234	19.90%

Likelihood Ratio Chi-Square: 36.70; df=1; Pvalue<0.0001

Potential Passage Efficiency by Turbine Operation

Turbine Operation	Count Projected into FGE Slot	% Projected into FGE Slot
Off	1303	21.02%
On	1410	22.74%

Likelihood Ratio Chi-Square: 5.40; df=1; Pvalue=0.0201

Potential Passage Efficiency by Beam Region

Beam Region	Count Moving South	% Moving South
Bottom North	574	23.15%
Bottom South	467	18.83%
Top South	495	19.96%
Top Mid	565	22.78%
Top North	574	23.15%

Likelihood Ratio Chi-Square: 24.51; df=4; Pvalue<0.0001

Analysis of Deviance on Table on Potential Passage Efficiencies

Source	Deviance	NumDF	DenDF	FValue	ProbF
Intercept	90294.44				
Season	90114.35	1	12390	24.88	<0.0001
Time of Day	89757.16	3	12390	16.45	<0.0001
Turbine Operation	89753.37	1	12390	0.52	0.4694
Beam Region	89681.17	4	12390	2.49	0.0409

Tortuosity Factor

Krustal-Wallis Rank Sum Tests Based on Chi-Square Statistic

Hypothesis tests are for H0: Tortuosity values were different over the levels of the factor vs. Ha: Tortuosity values did not differ

Effect	Factor Levels	Chi-Square Statistic	DF	P value
Time of Day	4	9.2830	3	0.0258
Season	2	1.4247	1	0.2326
Turbine Operation	2	0.7459	1	0.3878
Beam Region	5	5.6298	4	0.2286

Loopyness Factor

Krustal-Wallis Rank Sum Tests Based on Chi-Square Statistic

Hypothesis tests are for H0: Loopyness values were different over the levels of the factor vs. Ha: Loopyness values did not differ

Effect	Factor Levels	Chi-Square Statistic	DF	P value
Time of Day	4	9.6424	3	0.0219
Season	2	0.8987	1	0.3431
Turbine Operation	2	0.8734	1	0.3500
Beam Region	5	6.0669	4	0.1942

Appendix F

Sample Sizes for Vector Plots

Appendix F

Sample Sizes for Vector Plots

Sample sizes used to generate the vector plots presented in Figures F.1 through F.3 are presented here. The number of fish tracks at the edges of the sample region is often small, so that there is more uncertainty in the direction and magnitude of these vectors.

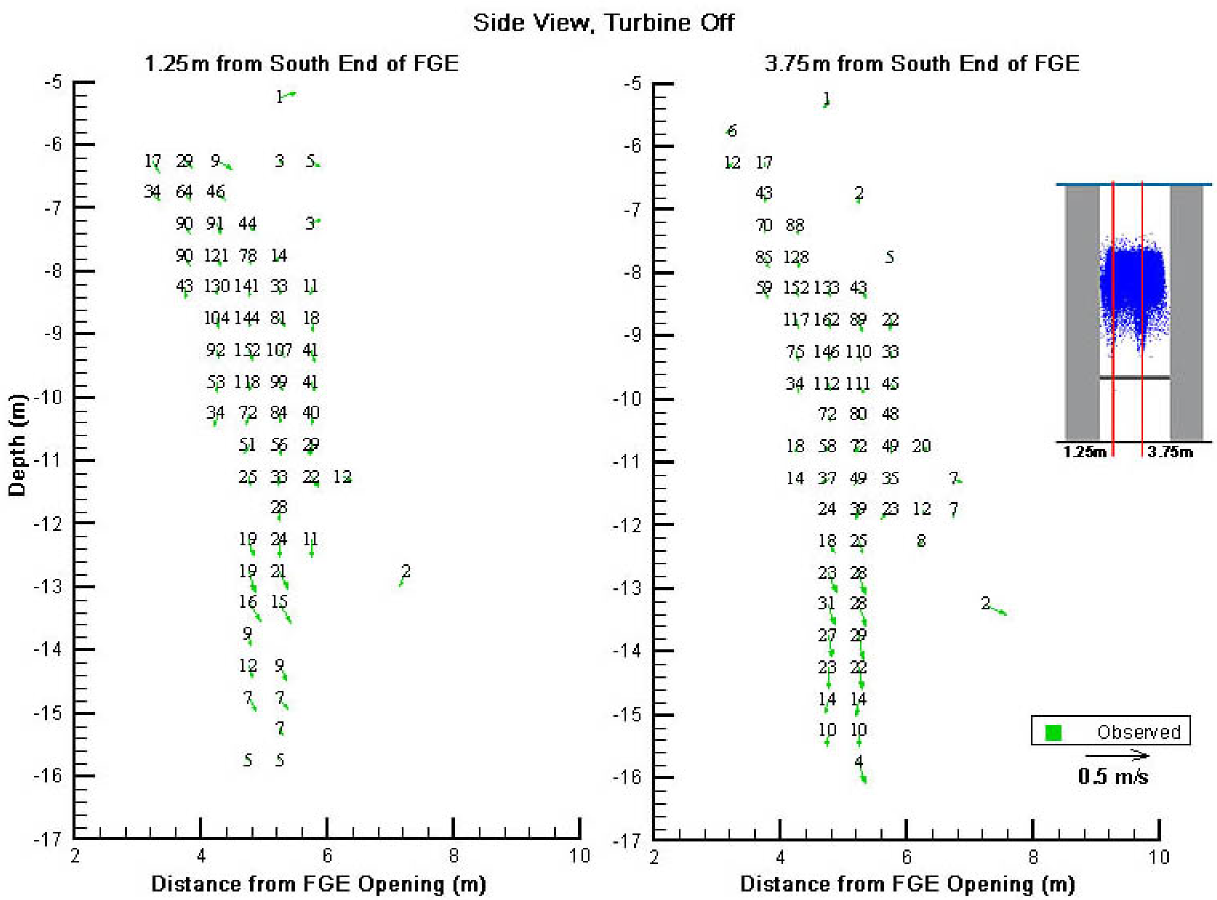

Figure F.1. Sample Size for Swimming Field Vectors (Side View) Based on 1 m Bins with Unit 8 Off at First Powerhouse, Bonneville Dam in 2000. Note that Reference Vectors are Different Between Unit 8 On and Off.

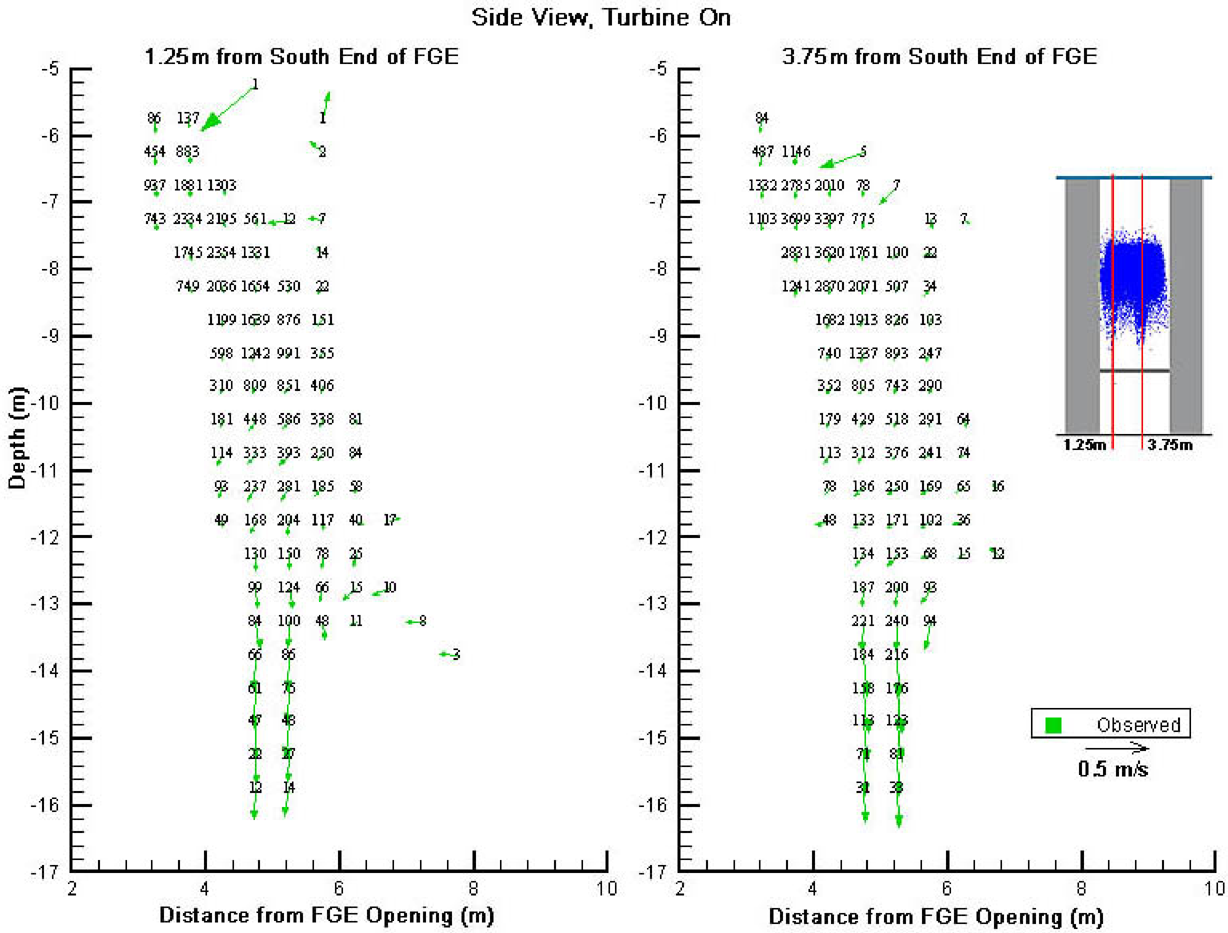

Figure F.2. Sample Size for Swimming Field Vectors (Side View) Based on 1 m Bins with Unit 8 On at First Powerhouse, Bonneville Dam in 2000. Note that Reference Vectors are Different Between Unit 8 On and Off.

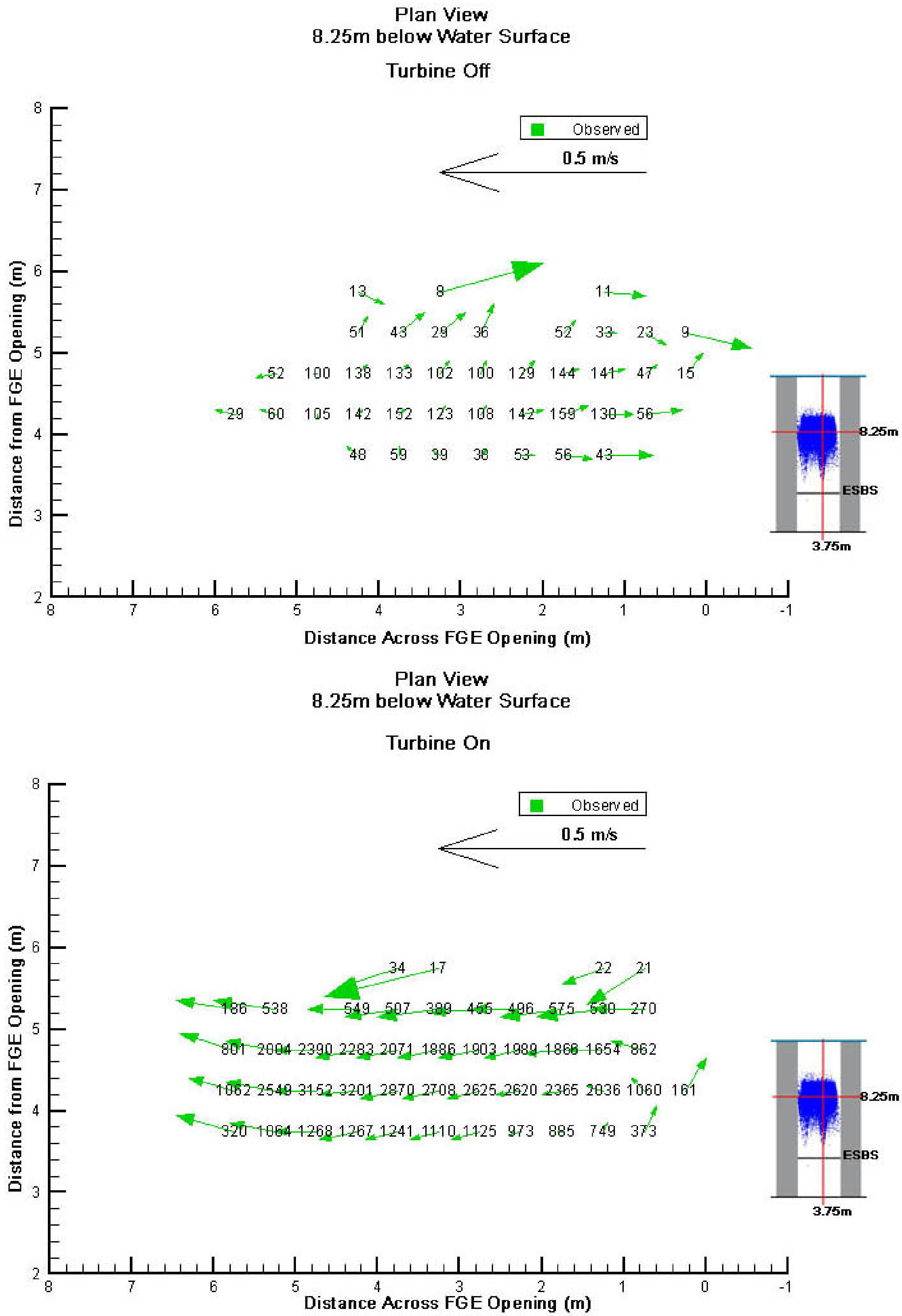

Figure F.3. Sample Size for Swimming Field Vectors (Plan View) Based on 1 m Bins with Unit 8 Off (a) and On (b) at First Powerhouse, Bonneville Dam in 2000. Note that Reference Vectors are Different Between Unit 8 On and Off.