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Acoustic Imaging Evaluation of Juvenile Salmonid Behavior in the Immediate Forebay of the Water Temperature Control Tower at Cougar Dam, 2010

FINAL REPORT

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GE Johnson
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JS Hughes
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GR Ploskey

April 2012



Pacific Northwest
NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Preface

This study was conducted under the auspices of the Willamette Valley Project Fish Evaluation Program, which is implemented by the U.S. Army Corps of Engineers (USACE) to support management decisions concerning restoration of anadromous fish runs in the Willamette Basin. The study was performed by the Pacific Northwest National Laboratory (PNNL) for the USACE Portland District, whose technical lead was David Griffith (503 808 4773). The PNNL project manager was Fenton Khan (509 371 7230). The related data are archived at PNNL offices in Richland, Washington. This final report is a project deliverable (PNNL Project No. 58030).

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Executive Summary

This report presents the results of an evaluation of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) behavior at Cougar Dam (CGR) on the south fork of the McKenzie River in Oregon in 2010. The study was conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE). The overall goal of the study was to characterize juvenile salmonid behavior and movement patterns in the immediate forebay of the Water Temperature Control (WTC) tower of the dam for USACE and fisheries resource managers use in making decisions about bioengineering designs for long-term structures and/or operations to facilitate safe downstream passage for juvenile salmonids.

We collected acoustic imaging (Dual-Frequency Identification Sonar; DIDSON) data from March 1, 2010, through January 31, 2011, to evaluate juvenile salmonid behavior year-round in the immediate forebay surface layer of the WTC tower (within 20 m, depth 0 to 5 m). From October 28, 2010, through January 31, 2011, a BlueView acoustic camera also was deployed in an attempt to determine its usefulness for future studies and to augment the DIDSON data. A total of 277 days of DIDSON and 65 days of BlueView data were collected during the study period. Because of the large amount of data recorded by the acoustic cameras each day and the cost for analysis, it was not feasible to analyze all of the acquired data. Instead, in consultation with USACE personnel, we processed a total of 45 separate 24-hour periods of DIDSON data covering every month throughout the 11-month study; some months included more sub-sampled days than others to cover special circumstances, such as, different forebay elevations and the presence of large numbers of juvenile fish. Two different 24-hour periods were processed for the BlueView data for the feasibility study. A basic observation of fish, that is, a single fish or a school of fish, in the sample volume was termed an “event.” The data were analyzed to characterize a fish abundance index, fish size patterns, movement direction, diel and seasonal behavior patterns, schooling, and predation.

Juvenile salmonids were present in the immediate forebay of the WTC tower throughout the study (March 2010 through January 2011). The juvenile salmonid (hereafter, called “fish” unless otherwise noted) abundance index was low in early spring (<200 fish per sample-day), began to increase in late April, and peaked on May 19 (6,039 fish). A second peak was observed on June 6 (2904 fish). Screw-trap estimates obtained from the Oregon Department of Fish and Wildlife (ODFW) of juvenile Chinook caught in the tailrace of the dam show comparable numbers, with estimates increasing in the spring and peaking in early June (~2400 fish). The fish abundance index began to decrease in early June and remained low in the summer months (<100 fish per sample-day). During the fall and winter, fish numbers per subsample date varied with a peak on November 10 (1881 fish) and a minimum on December 7 (12 fish). A second, smaller, peak occurred on December 22 (607 fish).

A univariate statistical analysis indicated the fish abundance index (\log_{10} -transformed) was significantly ($P < 0.05$) positively correlated with forebay elevation, velocity over the WTC tower intake gate weirs, and river flows into the reservoir (measured from a gage upstream of the reservoir). A subsequent multiple regression analysis resulted in a model ($R^2 = 0.70$) predicting fish abundance (\log_{10} -transformed index values) using two independent variables of mean forebay elevation and the \log_{10} of the forebay elevation range.

From the approximate fish length measurements made using the DIDSON imaging software, the average fish length for juvenile salmonids during early spring 2010 (March through April) was 214 ± 86 mm (standard deviation). From May through early November, the average fish length remained relatively consistent (132 ± 54 mm), after which average lengths increased to 295 ± 148 mm for mid-November through early December. From mid-December through January the average fish length decreased to 151 ± 76 mm. Measurements provided by the ODFW for juvenile Chinook salmon caught in screw traps below the dam averaged 130 mm from January through May, 93 mm in summer, and 115 mm from September through December. Thus, the sizes of juvenile fish measured using the DIDSON software were comparable to the sizes physically measured on fish caught in the screw traps most of the year, except in November and December.

Analysis of fish behavior indicates milling in front of the WTC tower was the most common behavior observed throughout the study period (>50% of total fish events). The next most common movement patterns were fish traversing along the front of the tower, east-to-west and west-to-east. These juvenile fish did not appear to be entrained in the flow and showed no proclivity to enter the tower. The percentage of fish events showing movement from the forebay to the tower or from the tower to the forebay was generally low throughout the spring, summer, and early fall (0 to 30% for both directions combined, March through early November). From mid-November 2010 through the end of the study (January 31, 2011), the combined percentages of fish moving into and out of the tower were higher (25 to 70%) than during previous months of the study. Furthermore, the net number of fish moving into the tower (i.e., fish moving into the tower minus fish moving out) was highest in the spring and fall months, when more fish were observed going into the tower than swimming back out.

Schooling behavior was most distinct in the spring from late April through early June. Schooling events were present in 30 to 96% of the fish events during that period, with a peak on May 19 (185 events). Schooling events were also present in the summer, but at lower numbers. Total fish events in the summer were low and schooling behavior accounted for 50 to 100% of the fish events during this time. With the exception of some schooling (13 to 44%) in mid-December, few to no schooling events were observed in the fall and winter months, even though total fish events were higher in fall and winter than in summer. Diel distributions for schooling fish during spring and fall months indicate schooling was concentrated during daylight hours and no schooling was observed at night. However, in December, schooling occurred at night, after midnight, and during daylight hours.

Predator activity, most likely bull trout or rainbow trout according to a USACE biologist, was observed during late spring (May 12 to June 7), when fish abundance index and schooling were highest for the year, and again in the fall months when fish events increased from a summer low. No predator activity was observed in the summer, and little activity occurred during the winter months.

For the 2 days of BlueView data analyzed for vertical distribution in the forebay (surface to 30 m deep), a majority of fish (>50%) was present in the middle of the water column, between 10 to 20 m. Small-sized fish (approximately 100 to 150 mm in length) composed 60 to 94% of the fish population at this depth. Between 20 and 41% of total fish abundance index was found in the bottom 10 m of the water column (20 to 30 m deep). These were mostly small- and medium-sized fish (approximately 100 to 350 mm in length). Few fish were observed in the top 10 m of the water column and they were mostly medium-sized fish (approximately 250 to 350 mm in length). Very few large-sized fish (approximately 400 to 450 mm long) were observed in the sampled water column.

The 2010 acoustic imaging study has the following implications for USACE and fisheries resource managers working to design a collection and passage system for juvenile salmonids:

- The occurrence of smolt size targets in the forebay of the WTC tower suggests they would be available to pass at future outlet structures.
- The common presence of predators indicates the need for structural designs that minimize predator safe havens near the outlet(s).
- Schooling behavior should be considered during the design process, e.g., outlet dimensions.
- The high proportion (~0.80) of milling behavior in the immediate forebay of the WTC tower indicates fish were neither entrained nor showed proclivity to enter the tower.
- During the peak in abundance index in mid-May, active movement (right-to-left) along the face of the WTC tower indicated fish could have been searching for an outlet, but entrance conditions at the tower apparently were not conducive to passage.
- Entrance velocities for a surface flow outlet structure will need to be greater than those that currently exist at the intakes of the WTC tower.

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Acronyms and Abbreviations

°C	degree(s) Celsius
CGR	Cougar Dam
cfs	cubic feet per second
d	day(s)
deg	degree(s)
DIDSON	Dual Frequency Identification Sonar
ESA	Endangered Species Act
fps	(foot) feet per second
ft	foot (feet)
h	hour(s)
in.	inch(es)
kcfs	thousand cubic feet per second
kHz	kilohertz
m	meter(s)
MHz	megahertz
msl	mean sea level
MW	megawatt(s)
NMFS	National Marine Fisheries Service
ODWF	Oregon Department of Fish and Wildlife
PNNL	Pacific Northwest National Laboratory
RO	regulating outlet
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
wk	week
WTC	Water Temperature Control

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1.0 Introduction

This report presents the results of an evaluation of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) behavior in the immediate forebay of the Water Temperature Control (WTC) tower at Cougar Dam (CGR) on the south fork of the McKenzie River in Oregon in 2010. The McKenzie River is a tributary of the Willamette River. The study was conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE). The overall goal of the study was to characterize juvenile salmonid behavior and movement patterns in the immediate forebay of the WTC tower to inform USACE and fisheries resource managers' decision-making related to bioengineering designs for long-term structures and/or operations to facilitate safe downstream passage for juvenile salmonids in the Willamette River basin.

1.1 Background

Downstream passage for outmigrating of juvenile Chinook salmon at CGR is limited to two routes: through the turbines and through the regulating outlet (RO). After construction in 1963, the Fish Commission of Oregon conducted studies to evaluate salmonid passage at the dam and found the facility was not suitable for passing either downstream migrating juveniles or upstream migrating adults (Ingram and Korn 1969). Thus, the steering committee at the time decided to cease efforts to safely pass salmonids at the dam and, instead, mitigate the effects on the salmon populations upstream of the dam by transporting these fish (Taylor 2000). In 1998, the Oregon Department of Fish and Wildlife (ODFW) began to use screw traps below the dam to monitor and estimate survival rates of downstream migrating salmon. Taylor (2000) reported that in 2 years of research, 91% of juvenile fish caught in the traps were Chinook salmon, and mortality for these fish ranged between 7 to 32% depending on the route of passage through the dam. Upper Willamette River spring Chinook and bull trout were listed as endangered (or threatened) under the Endangered Species Act (ESA) in 1999 and 1998, respectively.

The 2008 Willamette Project Biological Opinion requires improvements to operations and structures to reduce impacts on Upper Willamette River Chinook and Upper Willamette River steelhead, including evaluations of the feasibility of installing new juvenile collection and bypass facilities (NMFS 2008). As part of these evaluations, the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) required that USACE develop interim operations and investigate the feasibility of using surface flow outlets or other structures to collect and convey fish past the dam to provide safe passage for fish migrating downstream. Accordingly, an understanding of when, where, and how many juvenile salmonids pass into the dams, the relative efficiency of existing routes at passing them, and their behavior in the near forebays will be important components for fisheries managers and the USACE to use in developing operations and structures that pass juvenile salmonids safely and efficiently. Basic information is needed to characterize juvenile salmonid passage efficiencies, temporal and spatial distributions, behaviors, and movement patterns in forebays of USACE dams in the Willamette River basin. The draft research, monitoring, and evaluation plan for the Willamette Valley Project (USACE 2009) included the following management questions: “*What are the continuing effects of the Willamette Valley Project on Willamette ecosystem function and on ESA-listed fish species? What can effectively be done to protect, improve, restore, or mitigate for impacted species, their habitat, and related ecosystem function while also maintaining authorized Willamette Project functions?*” Cougar Dam (Figure 1.1) was

one of the priority projects for research on juvenile salmonid behavior during 2010 under the Willamette Valley Project (WVP) research program.

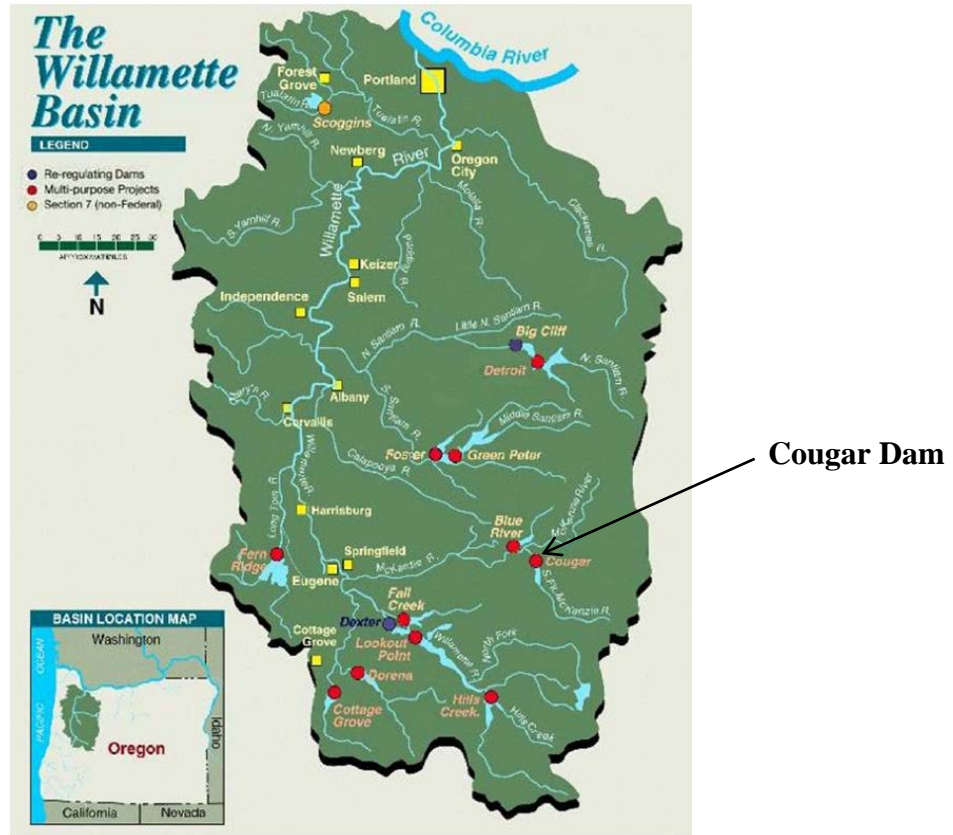


Figure 1.1. Map of the Willamette Basin (Figure 2-1 from NMFS 2008)

1.2 Objectives

This study provides information about juvenile salmonid behavior at CGR that the USACE and fisheries resource managers can use when making decisions about long-term measures to enhance downstream passage. The overall objective of the acoustic imaging evaluation during the year-long study period (February 1, 2011 to January 31, 2011) was to characterize juvenile salmonid behavior and movement patterns in the forebay (within 20 m) of the WTC tower at CGR. Specific study objectives were to use the acoustic imaging data from a Dual-Frequency Identification Sonar (DIDSON) to describe the following:

- daily index of fish abundance
- fish lengths
- fish movements
- fish schooling
- diel distributions
- predator activity.

We also assessed the feasibility of using a BlueView acoustic imaging device to characterize the vertical distribution and movements of fish in the forebay out to 50 m from the WTC tower intakes.

1.3 Study Site Description

Cougar Dam (Figure 1.2) is located on the south fork of the McKenzie River, near Blue River, Oregon. The dam has a powerhouse with two turbine units, a total generating capacity of 25 MW, and a total hydraulic capacity of 1050 cfs. The main purposes of the dam are flood control, irrigation, and power generation. Full pool elevation is rated at 1699 ft above mean sea level (msl) and minimum flood control pool elevation is 1532 ft above msl¹ (<http://www.nwd-wc.usace.army.mil/report/cgr.htm>). Water may pass the dam by either the penstock, which feeds the turbines or the RO, both of which are supplied with water from a common wet well in the WTC tower. Three intakes on the front face of the WTC tower provide water for the wet well. The intakes are equipped with telescoping gates that can be raised or lowered to allow water to enter the wet well from different levels of the reservoir, regulating the temperature of water being discharged through the turbines or RO. This provides suitable water temperature conditions below the dam for Chinook salmon upstream migration, spawning, and the timing for their eggs to hatch. The gates are generally operated for temperature control from late March until the end of October each year. Between November and March, when the reservoir is low, the gates are not used and water flows freely through the intakes into the wet well. Operation of the RO depends on forebay pool elevation and turbine operations. The RO and turbine intakes are located at elevations 1485 and 1426 ft, respectively.



Figure 1.2. Aerial Photograph of Cougar Dam (Courtesy of the USACE)

¹ All elevations in this report are relative to mean sea level.

1.4 Report Contents

In the ensuing sections of this report, we describe the study methods (Section 2.0) and results (Section 3.0), then provide a discussion and conclusions (Section 4.0), and list literature cited (Section 5.0). There are no appendices.

2.0 Methods

The methods section includes descriptions of the general approach, data collection, data processing, and analysis. We collected fish behavior data using a DIDSON—an acoustic imaging camera. The DIDSON bridges the gap between conventional scientific fisheries sonar, which can detect acoustic targets at long ranges but cannot record the shapes of targets, and optical systems, which can record images of nearby fish when not limited by low light levels or turbidity. We also tested a BlueView acoustic camera to determine its feasibility for assessing fish movement, behavior, and vertical distribution.

2.1 General Approach

Acoustic imaging techniques (DIDSON and BlueView¹) were used to sample fish behavior and movement in the nearfield (<20 m) of the forebay surface layer immediately upstream of the WTC tower. Imaging data were collected continuously throughout the study period. Direct capture data from sampling efforts by ODFW in the CGR reservoir and tailrace were used to inform the species composition of acoustic imaging data collected upstream of the intake tower.

2.2 DIDSON Deployment

The DIDSON assembly was deployed and tested between February and early March, 2010, before the start of data collection. A 14-ft floating platform (barge) was designed to accommodate the drastic yearly pool elevation fluctuations of the CGR forebay. The barge was positioned on the southeast corner of the WTC tower (Figure 2.1 and Figure 2.2). The barge was attached to the tower by three engineered brackets anchored to the parapet wall on the roof and paired with brackets at the water surface. A stainless steel cable was attached and tensioned between each pair of brackets and used as a vertical guide for the barge as forebay levels fluctuated. A weak link was engineered into the bracketing system to ensure the link would fail before damage occurred to the tower. A cable spooling system was installed on the barge to ensure telemetry cables would be properly tended on the deck as it ascended or descended with pool elevation fluctuations.

The DIDSON was mounted on a pole suspended from the barge, lowered to a depth of 1.2 m, and aimed horizontally (east to west) across the immediate upstream face of the WTC tower intakes. The DIDSON has 48 individual beams, each 0.6 deg wide by 14 deg deep. The DIDSON frequency was set at “low” frequency (1 MHz) to maximize the range (20 m) across the tower intake for data collection. The resulting sample volume was a “fan” of beams that was 29 deg wide and 14 deg deep. The ping rate was 7 frames per second. We periodically collected small amounts of “high” frequency (1.2 MHz) data to increase resolution to aid in measuring fish targets. At the high-frequency setting, the range is reduced to 10 m and the sample volume is ~5 m wide and 0.5 m deep. Belcher et al. (1999) describe the capabilities of the DIDSON acoustic camera.

¹ We tested a Blue View acoustic camera in late fall 2010. The results of 2 days of the test are presented in this report.

2.2.1 Data Collection

We collected fish behavior data in front of the intake tower 24 h/d, 7 d/wk. A few days of data collection were missed when either the DIDSON or the associated data-collection computer stopped functioning or when the camera was removed for maintenance. A total 277 days of data were collected during the year-long study period.

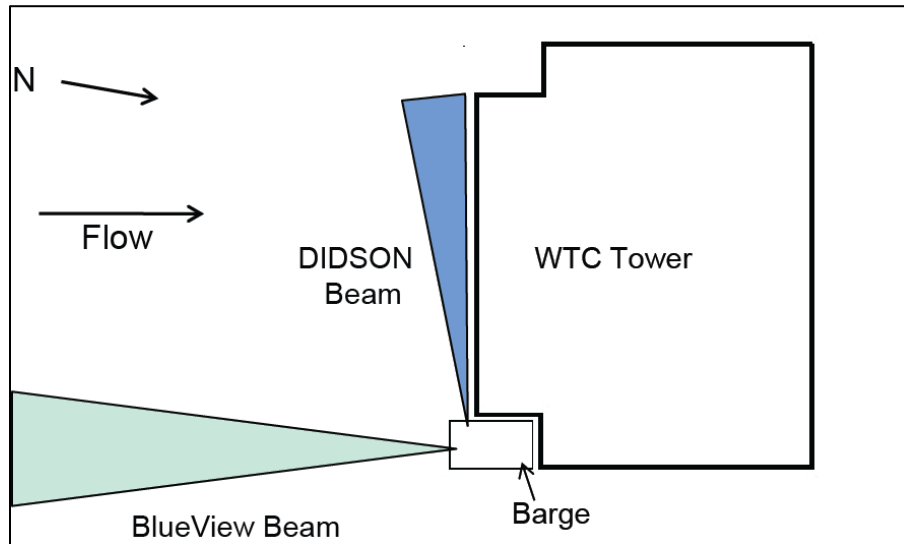


Figure 2.1. Plan View of the WTC Tower at Cougar Dam Showing DIDSON and BlueView Deployments



Figure 2.2. The Floating Platform (barge) Attached to the WTC Tower. The DIDSON and BlueView acoustic imaging cameras are 1.2 m below the water surface.

2.2.2 Data Processing and Analysis

After the data were collected and archived, subsamples were processed. Because of the large amount of data recorded by the DIDSON each day and the cost of data analysis, it was not feasible to analyze all of the data for the year. In consultation with the USACE, we analyzed a total of 45 days (24-hour periods) of data (Table 2.1). These days were selected to account for each month between March 2010 and January 2011, different forebay elevations, when we saw large numbers of fish in June, and during low and high outflow periods in the fall and winter. A subsampled day was from midnight to midnight. Note, for the November 8–9 analysis, the 24-hour period was from noon on November 8 to noon on November 9, when we observed a substantial change in project outflow and wanted to see if it affected fish behavior. Each observation of fish, that is, a single fish or a school of fish, observed in the sample volume was termed an “event.”

Table 2.1. Sample Dates Selected for Analyzing DIDSON Data Collected at CGR, 2010–2011. Forebay elevation, outflow, and WTC tower intake gate weir velocity data were obtained from the USACE. Weir velocity data are the rate of water flowing over the top of intake gates into the wet well.

Date	Avg. Forebay El (ft)	Avg. Outflow (cfs)	Avg. Velocity Over Weirs (fps)
16-Mar	1567.72	394.58	0.00
23-Mar	1570.91	430.00	0.00
14-Apr	1613.95	409.58	1.38
21-Apr	1626.06	403.33	1.24
29-Apr	1638.49	407.08	1.05
05-May	1651.45	415.00	1.31
12-May	1661.50	410.42	1.34
19-May	1670.91	417.92	1.11
26-May	1679.72	422.08	1.23
31-May	1684.61	452.92	1.47
01-Jun	1685.35	1295.83	2.72
02-Jun	1684.57	2637.92	3.90
05-Jun	1691.95	3495.42	3.50
06-Jun	1690.86	3712.92	3.83
07-Jun	1689.61	2717.92	3.11
16-Jun	1688.97	964.58	2.56
30-Jun	1689.14	429.58	1.49
14-Jul	1687.76	406.67	1.56
07-Aug	1669.01	924.17	2.44
11-Aug	1664.70	952.92	3.00
12-Aug	1663.33	958.75	2.67
25-Aug	1655.95	469.58	0.83
08-Sep	1649.68	505.42	1.12
22-Sep	1644.86	497.08	1.16
06-Oct	1638.88	476.25	0.48
14-Oct	1633.25	1036.25	0.00
20-Oct	1623.72	1029.58	0.00
26-Oct	1611.74	1613.33	0.06
30-Oct	1602.44	1605.83	0.00
03-Nov	1592.65	1602.50	0.00
08-09-Nov	1581.16	921.67	0.00
10-Nov	1579.90	1738.33	0.00
17-Nov	1561.95	1654.17	0.00

Table 2.1. (contd)

Date	Avg. Forebay El (ft)	Avg. Outflow (cfs)	Avg. Velocity Over Weirs (fps)
18-Nov	1560.14	1651.67	0.00
07-Dec	1534.73	1684.17	0.00
08-Dec	1533.00	1674.17	0.00
15-Dec	1583.52	991.67	0.00
17-Dec	1586.63	2875.42	0.00
18-Dec	1583.40	2969.58	0.00
22-Dec	1561.04	3822.50	0.00
29-Dec	1542.21	1630.00	0.00
06-Jan	1537.55	1030.00	0.00
12-Jan	1532.48	1053.21	0.00
19-Jan	1607.51	1224.17	0.00
26-Jan	1582.67	3667.50	0.00

DIDSON data were manually processed by replaying the recordings and examining them for fish activities. A standard set of parameters was identified to quantify fish behaviors (Table 2.2). This data processing technique was applied consistently to allow comparisons across different dates and conditions. The results formed the basic database of observations of fish behavior. The basic database was used to compute or characterize the following:

- daily index of fish abundance
- fish lengths
- proportions of various movement behaviors
- proportion of schooling events
- diel and seasonal behavior patterns
- predator activity.

Table 2.2. Processing Parameters for Each Fish Event in the 2010–2011 CGR DIDSON Data Set

Topic	Parameter
Time	Start and end = duration
Abundance index	Approximate count of fish in the observation
Fish Length	Approximate length of typical fish in the event
Movement	MM = Milling TT = Enters sample volume from the tower and then goes back into the tower TF = Moves from the tower through the sample volume and out into the forebay FT = Moves from the forebay through the sample volume and into the tower FF = Enters sample volume from the forebay and then goes back out into the forebay EW = Moves from east to west through the sample volume WE = Moves from west to east through the sample volume
Schooling	0 = no; 1 = yes
Predator Activity	0 = no; 1 = yes

The daily fish abundance index was determined by summing numbers of juvenile fish observed for each subsample date. In instances where fish were densely congregated in a portion of the sample volume or numbers of fish were too large to count, total fish numbers were estimated and therefore total counts

are approximate. Fish lengths were approximated using a measuring tool in the DIDSON imaging software. Standard targets of known measurements were placed in the sample volume during data collection and recorded in the DIDSON video files. These targets were used as an aid in estimating fish lengths with the measuring tool in the software. Not all fish could be measured, especially those in tight groups; therefore, when it was not feasible to measure all fish in a group, some fish were measured and the lengths for the group were approximated. Diel distributions for schooling and total events were calculated by summing all activity that occurs during a specific hour over multiple subsample dates. For example, the cumulative number of schooling events that occurred from 1:00:00 to 1:59:59 was calculated for each date and then summed to generate a total value for 2:00 for a seasonal period. Figure 2.3 displays a screen capture of a frame from the DIDSON video, showing a school of juvenile fish and some larger fish in front of the trashracks of the tower intakes.

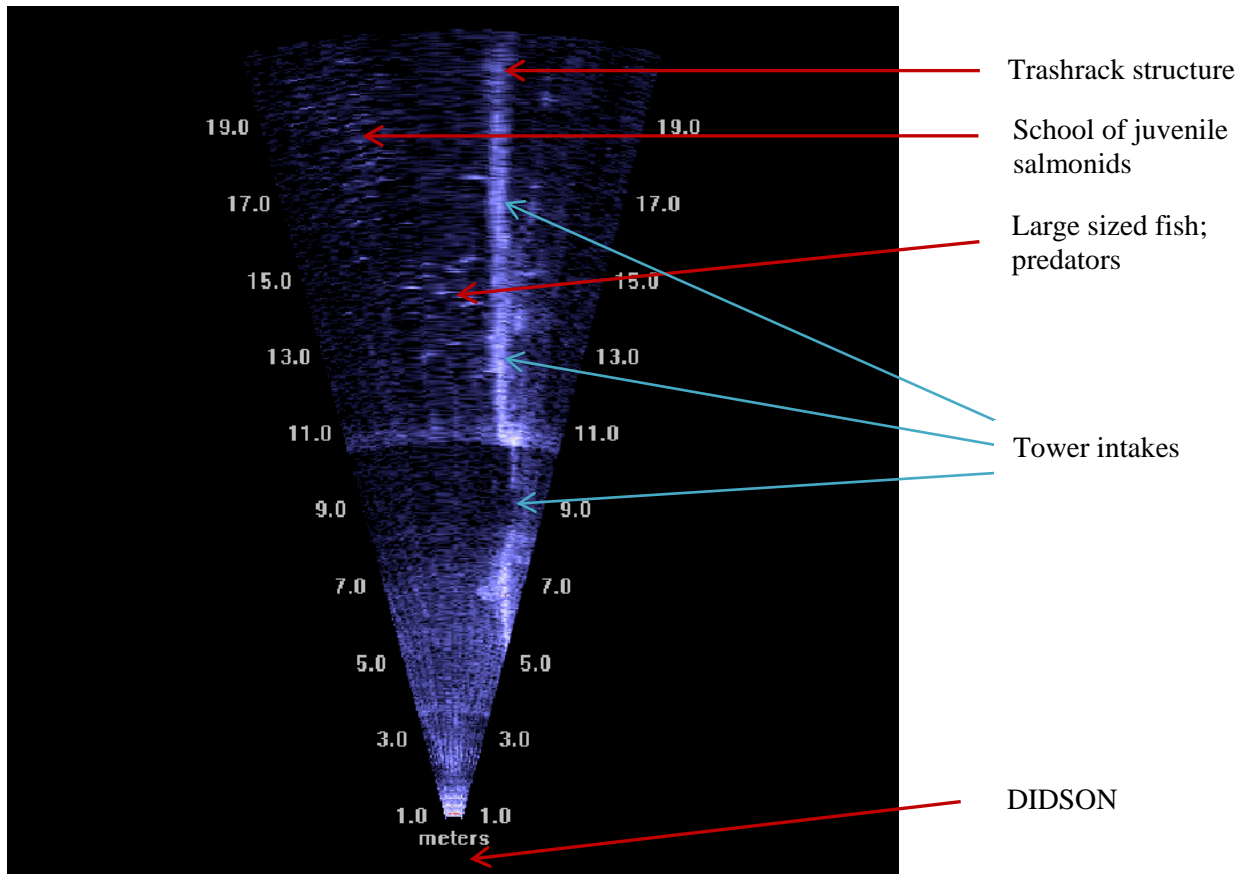


Figure 2.3. Screen Capture of a Frame of the DIDSON Video Showing Small and Large Fish in Front of the CGR WTC Tower. The DIDSON camera is aimed east to west across the intakes.

2.3 BlueView Deployment

On October 28, 2010, a BlueView 900-130 Imaging SONAR was mounted on the barge at the intake tower (Figure 2.1 and Figure 2.2). This device images a sample volume 130 deg wide by 20 deg deep with a fan of 768 individual beams 1 deg wide and 20 deg deep. Based on tests conducted by PNNL, the maximum reasonable range for a 100- to 300-mm target is approximately 50 m (Ploskey and Johnson 2010, unpublished data). The instrument was oriented with the acoustic fan perpendicular to the surface (90 deg from the horizontal plane) to test its feasibility for recording vertical distribution of fish and fish approach behavior in the forebay.

2.3.1 Data Collection

Once the BlueView acoustic camera was deployed, we collected fish behavior data in the forebay in front of the intake tower 24 h/d, 7 d/wk. From October 28, 2010, through January 31, 2011, a total of 65 days of data were collected. This excludes periods when the BlueView camera was stopped for logistical reasons.

2.3.2 Data Processing and Analysis

Processing of BlueView data was similar to the processing of DIDSON data. Data were collected and archived. Because of the large amount of data recorded by the BlueView camera, each day could not be analyzed for the feasibility study. Instead, two separate 24-hour periods were processed in 2010: November 14 (an unsampled DIDSON day) and December 7 (a sampled DIDSON day).

As with the DIDSON data, the BlueView data were manually processed by replaying the recordings and examining them for fish activities. This data processing technique was applied consistently to allow for comparison of the two sample dates and among conditions. The BlueView processing parameters were similar in scope to the DIDSON parameters (see above), but generated different metrics (Table 2.3). The following were characterized:

- daily index of fish abundance
- size class (small, medium, and large)
- proportions of various movement behaviors
- diel behavior patterns
- depth in the water column (surface, mid-depth, and bottom)
- proportion of schooling events
- predator activity

Table 2.3. Processing Parameters for Each Fish Event in the 2010 CGR BlueView Data Set

Topic	Parameter
Time	Start and end = Duration
Abundance index	Approximate count of fish in the observation
Size Class	Small = 100 – 150 mm (measures are approximate) Medium = 250 – 350 mm Large = 400 – 450 mm
Movement	S = Towards the surface B = Towards the bottom M = Milling T = Towards the camera (downstream) A = Away from the camera (upstream)
Depth	Surface (0 – 10 m) Mid-Depth (10 – 20 m) Bottom (20 – 30 m)
Schooling	0 = no; 1 = yes
Predator Activity	0 = no; 1 = yes

The daily fish abundance index was determined by summing numbers of juvenile fish observed for both subsample dates. In instances where fish were densely congregated in a portion of the sample volume, the total fish numbers were estimated and therefore total counts are approximate. The abundance index was then broken down by approximate numbers of fish at different depth bins (surface, mid-depth, or bottom). Fish lengths were approximated using a measuring tool in the BlueView imaging software and fish were classified as small, medium, or large. Finer-scaled estimations were not attempted due to the large depth and range of the BlueView field, which made it difficult to accurately estimate fish location and size. The size ranges for each fish class are approximate. For this feasibility study and because of the orientation of the BlueView camera, we estimated the depth bins for vertical distribution by dividing the total depth of the water column into thirds, each 10 m deep, and labeling each bin as Surface (0 to 10 m), Mid-Depth (10 to 20 m) and Bottom (20 to 30 m). Diel distributions for schooling, total events, and predator activity were calculated using the same methods as for the DIDSON data. Diel distributions for schooling and total events were calculated by summing all activity events that occurred during a specific hour. A screen capture of a frame from the BlueView video is displayed in Figure 2.4.

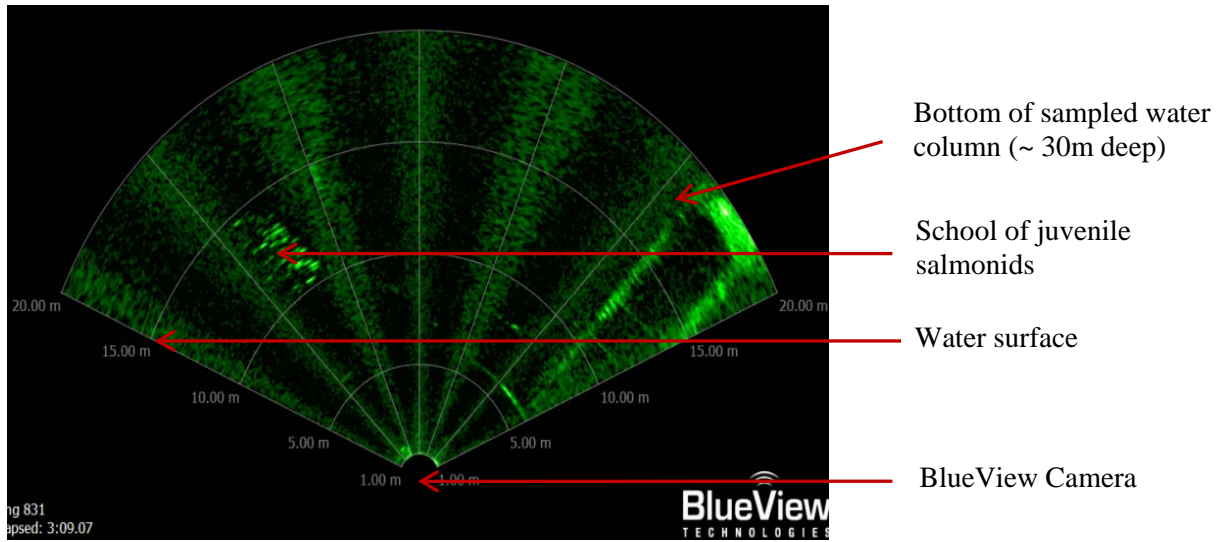


Figure 2.4. Screen Capture of a Frame of the BlueView Video, Showing a School of Juvenile Salmonids in Cougar Dam Forebay. The BlueView is aimed from the tower to the forebay.

3.0 Results

The results from the study are organized into two sections: forebay elevation, dam operations, and temperature; and fish evaluation.

3.1 Forebay Elevation, Dam Operations, and Temperature

The forebay elevation of CGR follows a “rule curve” managed by the USACE Reservoir Control Center. The “rule curve” dictates lowering the forebay pool elevation in the fall and winter months to prepare for storage and flood control in the spring and summer months. Generally, the fall drawdown of the pool begins after September 1, and refill begins on or around February 1.

In 2010, the forebay surface elevation began to increase in early February, peaked on June 5 (1692 ft above msl), slowly decreased from July 4 until late July, and then steadily decreased, for the fall drawdown, until November 28 (Figure 3.1). From late November to the end of the study period on January 31, 2011, forebay elevation fluctuated due to snow and rain from winter storm events. The minimum pool elevation for the study period was on December 9 (1532 ft above msl).

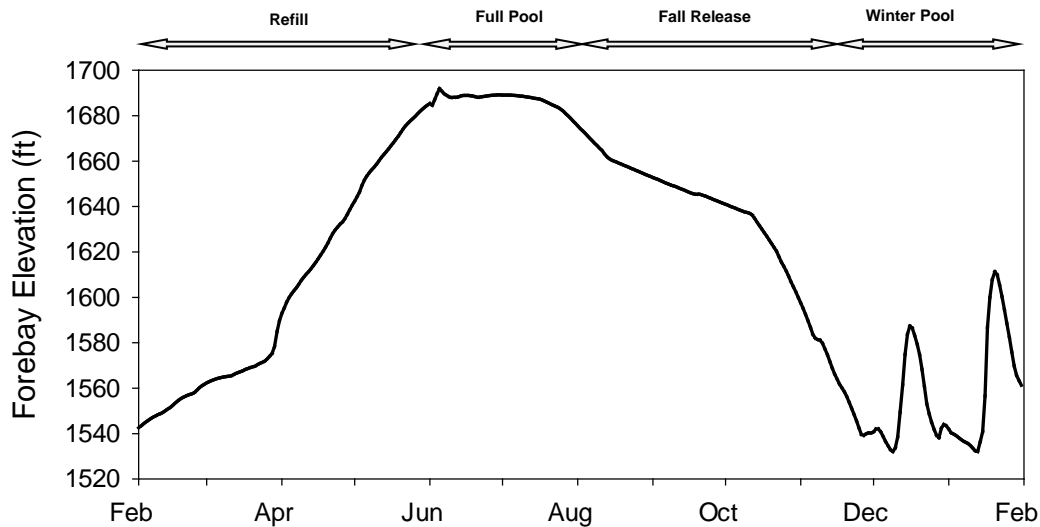


Figure 3.1. Daily Average Surface Elevation (ft above msl) of the Forebay at CGR from February 1, 2010 Through January 31, 2011. Forebay elevation data were obtained from the USACE.

The two turbines at CGR are typically operated 24 h/d, 7 d/wk. The RO is operated as needed. During our study, daily turbine discharge remained fairly constant (~0.40 kcfs) from February to mid-June, except for a few days in March and early June when the turbines were offline and water was passed through the RO (Figure 3.2). From June 1 to July 24, the RO was operated continuously with a discharge peak on June 6 (3.22 kcfs). During this period, turbine discharge decreased, excluding a discharge spike on June 17 when the RO was briefly closed. After July 24, turbine discharge increased (~0.93 kcfs) for 3 weeks before returning to more typical levels (~0.48 kcfs) and remained at those levels until mid-October. Operation of the RO was intermittent during that period. From October 12 onward, turbine discharge was roughly twice the baseline level (~1.05 kcfs) and on October 23 the RO was opened with

an average discharge of 0.53 kcfs. Turbine and RO discharge fluctuated during the late fall and winter months due to rain events. RO discharge had large peaks of ~2.81 kcfs on December 22 and in late January.

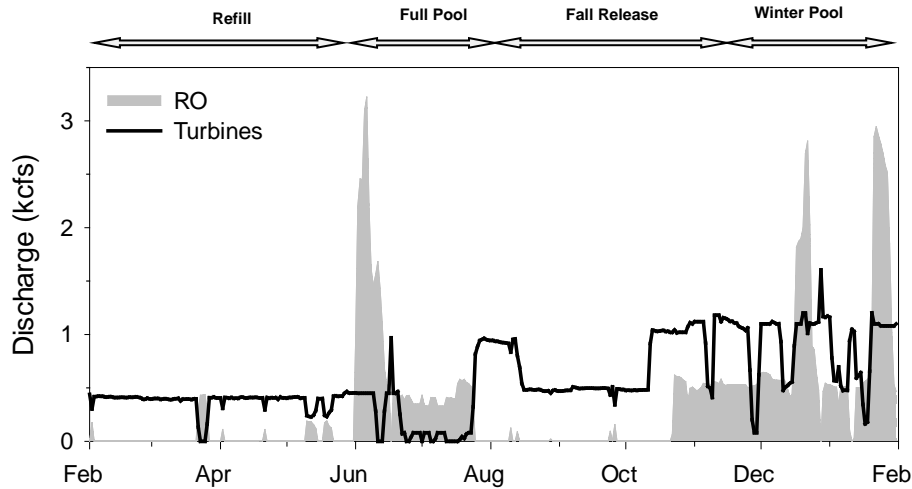


Figure 3.2. Total Daily Discharge (kcfs) for the Two Turbines and the Regulating Outlet at CGR from February 1, 2010 Through January 31, 2011. (Data were obtained from the USACE Willamette Valley Project Operations Office.)

The WTC tower intake gates for temperature control were lowered on March 26, 2010. Temperature control for water passing the dam began on March 31 and ended on October 31, 2010, when the gates were raised. Water temperature data at the WTC tower are available starting in September of 2010 (http://www.nwd-wc.usace.army.mil/tmt/documents/ops/temp/string_by_project.html). The top (surface) depth bin (0–1.8 m), where the DIDSON and BlueView acoustic cameras were deployed, is plotted in Figure 3.3. No temperature data were available at the depths of the RO or turbine intake. The surface water temperature in September was ~17°C and began a steady decline at the start of October. The decline continued through November, ending at 5°C from December through January.

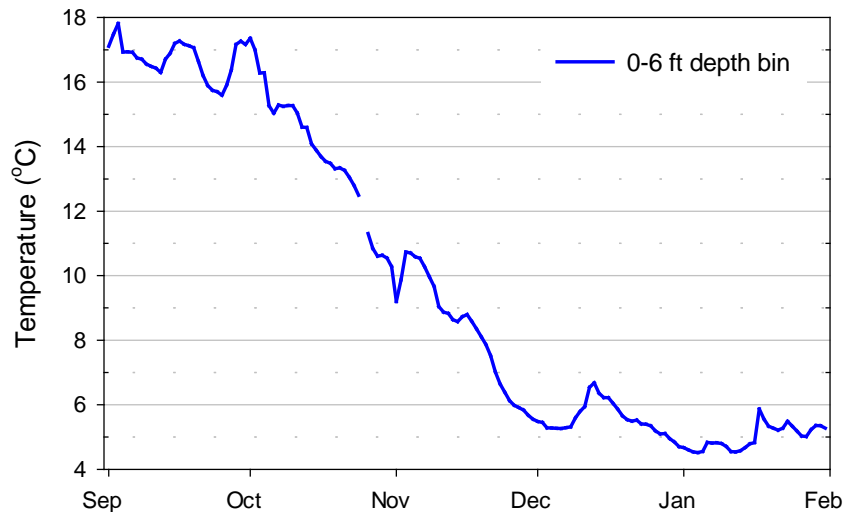


Figure 3.3. Surface (0- to 6-ft depth bin) Water Temperature Data at the WTC Tower from September 1, 2010 Through January 31, 2011 (http://www.nwdwc.usace.army.mil/tmt/documents/ops/temp/string_by_project.html). No data are available from February through August or for October 25, 2010.

3.2 Fish Evaluation

Fish behavior results are presented for the DIDSON and BlueView acoustic cameras. The fish abundance index, lengths, and movement data presented below include 2186 fish events for 45 subsample dates for the DIDSON camera and two subsampled dates for the BlueView camera. Recall, an event is a fish or a school of fish observed in the sample volume. For both data sets, the results are organized into six sections: fish abundance index, fish lengths, fish movements, schooling events, diel distributions, and predator observations. These sections are followed by data from the ODFW screw trap.

3.2.1 DIDSON Data: CGR WTC Tower

3.2.1.1 Fish Abundance Index

The fish abundance index for the top 5 m of the water column in front of the WTC tower was ≤ 200 in the spring (Figure 3.4). The first subsample date on March 16 generated a fish count of seven, which was the minimum for the entire study period. Numbers increased starting April 28 and peaked on May 19 with an estimated 6039 fish. A second peak was observed on June 6 (2904 fish). Numbers steadily decreased through June and remained low throughout the summer, with a local minimum of 15 fish on July 14. From June 16 to October 6, fish numbers were generally low (< 200 fish) per subsample date. During the fall and winter, fish numbers per subsample date varied with a minimum on December 7 (12 fish) and a peak on November 10 (1881 fish). A second, smaller, peak occurred on December 22 (607 fish).

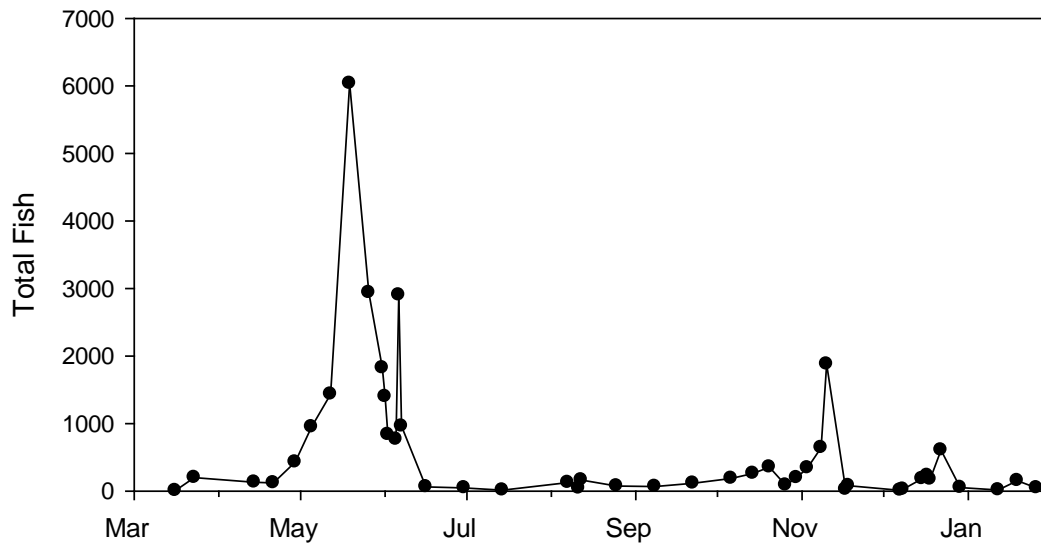


Figure 3.4. Abundance Index (estimated fish counts) in the Forebay (top 5 m of the water column) of the CGR WTC Tower from March 2010 Through January 2011

3.2.1.2 Relationships Between Environmental and Operational Variables and Fish Abundance Index

In addition to variables describing the operation of CGR dam and reservoir, water temperature and flow data from a gaging station on the south fork of the McKenzie River upstream of the CGR forebay were obtained (http://waterdata.usgs.gov/usa/nwis/uv?site_no=14159200) and used as part of this analysis to see if these variables are correlated to fish abundance index in front of the WTC Tower. The fish abundance index (log-transformed) was significantly ($P < 0.05$) correlated with forebay elevation, velocity over the WTC Tower intake gate weirs, and mean gage flows (Table 3.1).

Table 3.1. Univariate Correlations of Environmental and Operational Variables with Log_{10} of Fish Abundance Index. Red font indicates statistical significance ($P < 0.05$)

Variable	Correlation
Day_of_Year	0.036050
Forebay_Elevation_Mean(ft)	0.533725
Log_{10} Forebay_Elevation_range(ft)	0.213732
Forebay_Elevation_Direction	0.272339
Velocity_Over_Weir(ft/s)	0.373089
Log_{10} Total_Outflow(cfs)	0.054532
Log_{10} Mean_Gage_Flow(cfs)	0.308507
Mean_Gage_Temp(C)	0.103865

A multiple regression technique was used to explore multivariate correlations between fish abundance index and the environmental and operational variables listed in Table 3.1. The analysis was conducted using the generalized linear regression module in Statistica version 10 (www.statsoft.com). Stepwise forward selection with Log_{10} of Fish Abundance Index as the dependent variable resulted in a model containing Forebay_Elevation_Mean(ft) and Log_{10} Forebay_Elevation_range(ft) as independent variables (Table 3.2). This model's predictions of fish abundance index fit the observations reasonably well, with an R^2 of 0.70 (Figure 3.5). The scatter of points around the fitted line illustrate the remaining unexplained variation, but there are no unexpected trends in the scatter to suggest another type of model is needed.

Table 3.2. Parameter Estimates for Model of Log_{10} Fish Abundance Index

	Estimate	Wald - Stat.	P
Intercept	-8.29759	35.41380	0.000000
Forebay_Elev_Mean	0.00557	43.32283	0.000000
L_Forebay_Elevation_range	0.42770	20.74257	0.000005
Scale	0.51061		

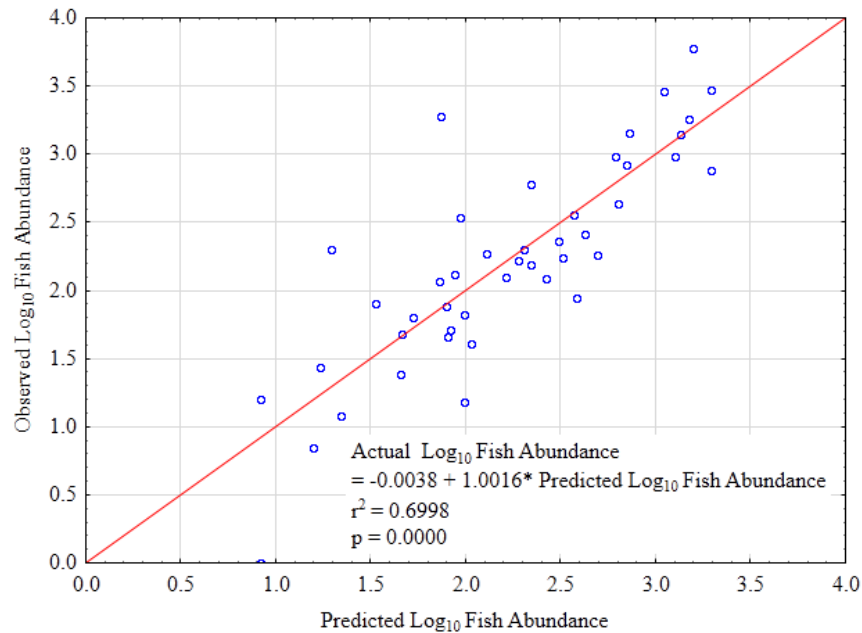


Figure 3.5. Observed Versus Predicted Log_{10} Fish Abundance Index

3.2.1.3 Fish Length

During early spring (March 26 to April 21), fish lengths were variable, averaging 214 ± 86^1 mm (Figure 3.6). The maximum fish length for the entire study was observed during this period (810 mm on April 14). From April 29 to November 8–9, fish lengths were relatively consistent, with an average length of 132 ± 54 mm over this time frame. The average fish lengths on November 17 and December 7 were the highest for the study period at 292 ± 128 and 298 ± 168 mm, respectively. After December 7, 2010, through to the end of the study period in January 2011, fish lengths averaged 151 ± 76 mm.

¹ Mean \pm one standard deviation.

The next most common movement pattern was fish traversing along the front of the tower, either east-to-west or west-to-east (Figure 3.8). Facing upstream, east is the direction of the open forebay (left of the intake tower), west is the direction of the cul-de-sac area (right of the intake tower), which has no outlet. While no traversing occurred on the first subsample date (March 16), traversing in both directions combined accounted for 20 to 50% of all movements from March 23 to May 12, with roughly equal numbers of fish traveling in both directions and no apparent trends. From May 19 to June 1, over half of all fish events involved fish moving from east-to-west, toward the cul-de-sac area. Little to no traversing was observed during the summer (June 2 to September 3) with the exception of June 6 and August 11, when 35 to 50% of the fish events moved west-to-east, from the cul-de-sac area out to the open forebay. Back-and-forth movements in the fall (September 22 to November 3) increased to similar levels and patterns observed during the spring, peaking on November 8–9 (noon-to-noon), when traversing composed 66% of fish movements (both directions equivalent). From November 17 to January 26, little to no traversing occurred; however, on December 17, 29, and January 12, traversing accounted for approximately 20% of total behaviors, with equal percentages traveling in both directions. On January 6, 100% of fish moved from the cul-de-sac area out to the open forebay.

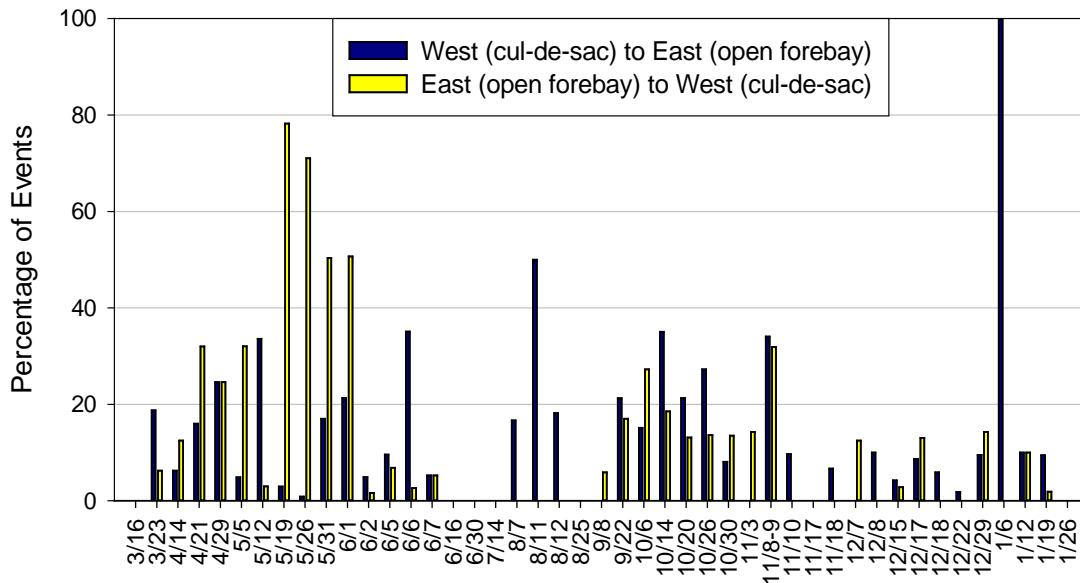


Figure 3.8. Percentage of Total Events Observed That Involved Fish Traversing West-to-East (blue bars) and East-to-West (yellow bars) in Front of the WTC Tower at CGR from March 2010 Through January 2011

The percentage of events in which fish were observed moving into (forebay-to-tower) or out of the WTC tower (tower-to-forebay) was generally low throughout the spring, summer, and early fall (0 to 28% for both directions combined, March 16 through November 8–9) (Figure 3.9). The exception was August 25 when half of all events involved fish moving out of the tower into the forebay. From November 17 through January 26, the combined percentages of fish moving into and out of the tower were relatively high (25 to 70%).

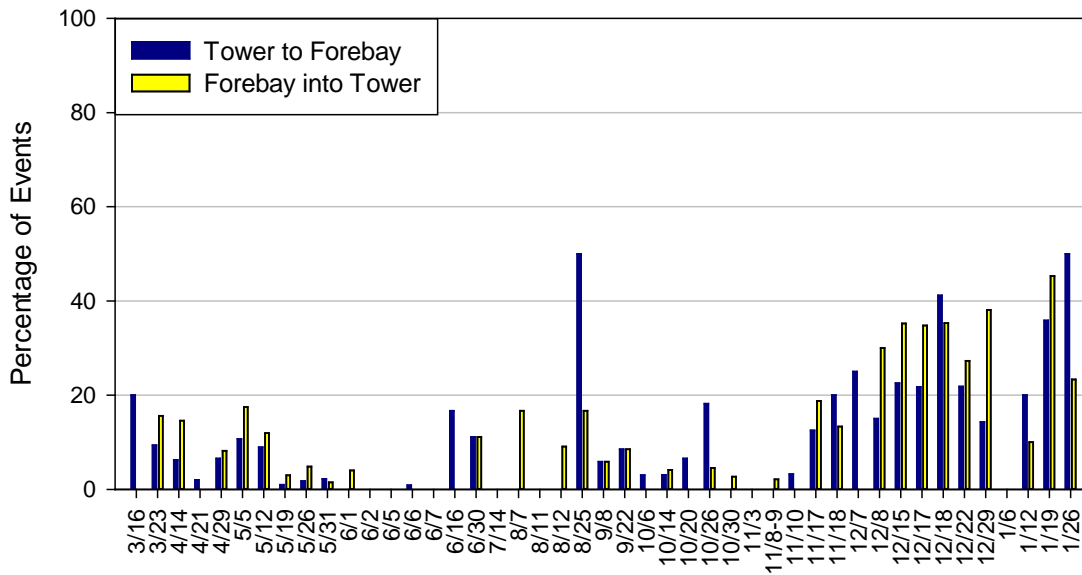


Figure 3.9. Percentage of Total Events Observed That Involved Fish Traversing West-to-East (blue bars) and East-to-West (yellow bars) in Front of the WTC Tower at CGR from March 2010 Through January 2011

Figure 3.10 illustrates the number of fish events that involved fish moving into the tower minus the number that involved fish moving out of the tower to generate net numbers of fish events that involved moving into the tower. A net movement of fish into the tower was observed during the spring and again in December and on January 19. There were six days (June 2, 5, 7, July 14, August 11, and November 3) when no fish moved in either direction.

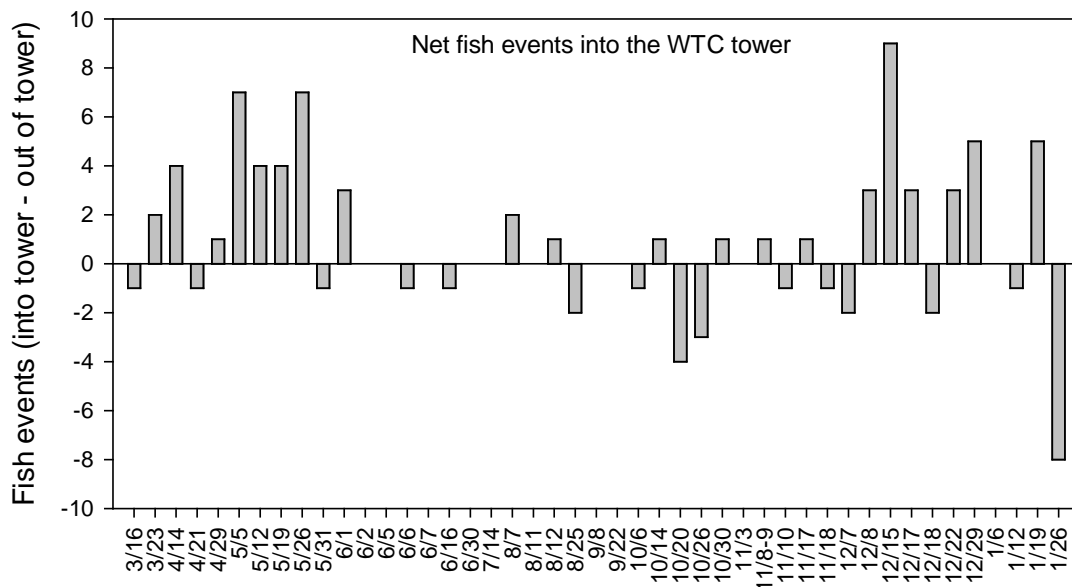


Figure 3.10. Net Movement of Fish into or out of the WTC Tower at CGR from March 2010 Through January 2011

3.2.1.5 Fish Schooling

Schooling behavior was most distinct in the spring from April 29 to June 7 (Figure 3.11). Schooling events were present in 30 to 96% of the fish events during that period, with a peak on May 19 (185 events). Few schooling events occurred during the summer months, and were present in 50 to 100% of the fish events from July 14 to August 25, but due to low fish numbers, total schooling events were low. However, this was not the case during the fall and winter months, where despite robust numbers of fish events, schooling activity was generally low. With the exception of December 22 (44% schooling events), schooling events composed 0 to 30% of the total events from September 8 through January 26.

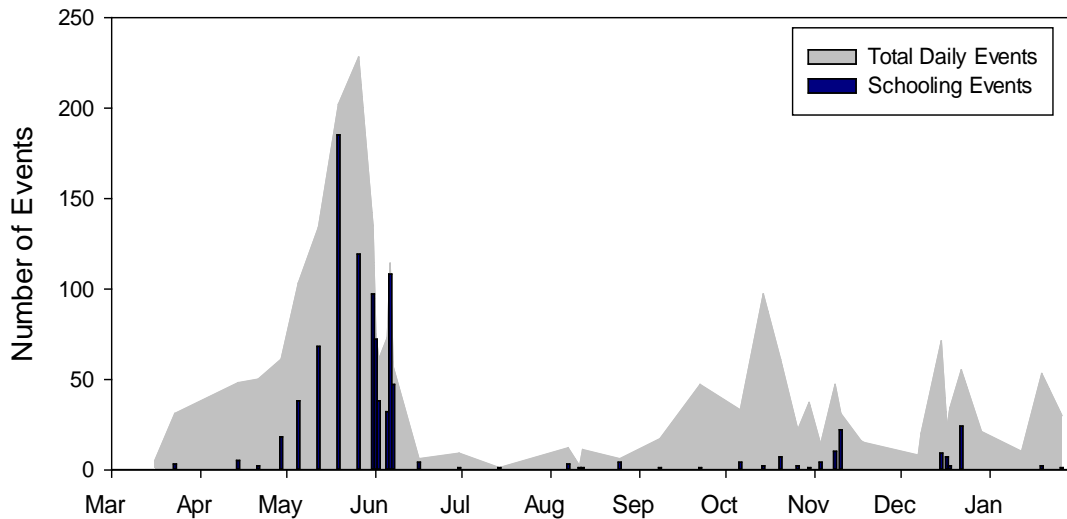


Figure 3.11. Schooling Events (blue bars) and Total Daily Fish Events (shaded region) in Front of the CGR WTC Tower from March 2010 Through January 2011

3.2.1.6 Diel Distributions

Days when schooling was prevalent in spring, fall, and winter were selected to analyze for diel distributions. For events analyzed for schooling behavior (Figure 3.12), schooling was concentrated during daylight hours, except for December when some schooling occurred after midnight hours. Total fish events, although present around the clock, were more prevalent during the day as well. This is most noticeable during the spring period, where two distinct peaks in total fish events were observed; one at 0800 h and one at 1400 h. This bimodal tendency in fish events was also apparent during the fall, but to a lesser degree and the peaks were shifted to later in the day (1000 h and 1600 h), and in December, with a distinct peak at 0800 h and smaller one at 1700 h.

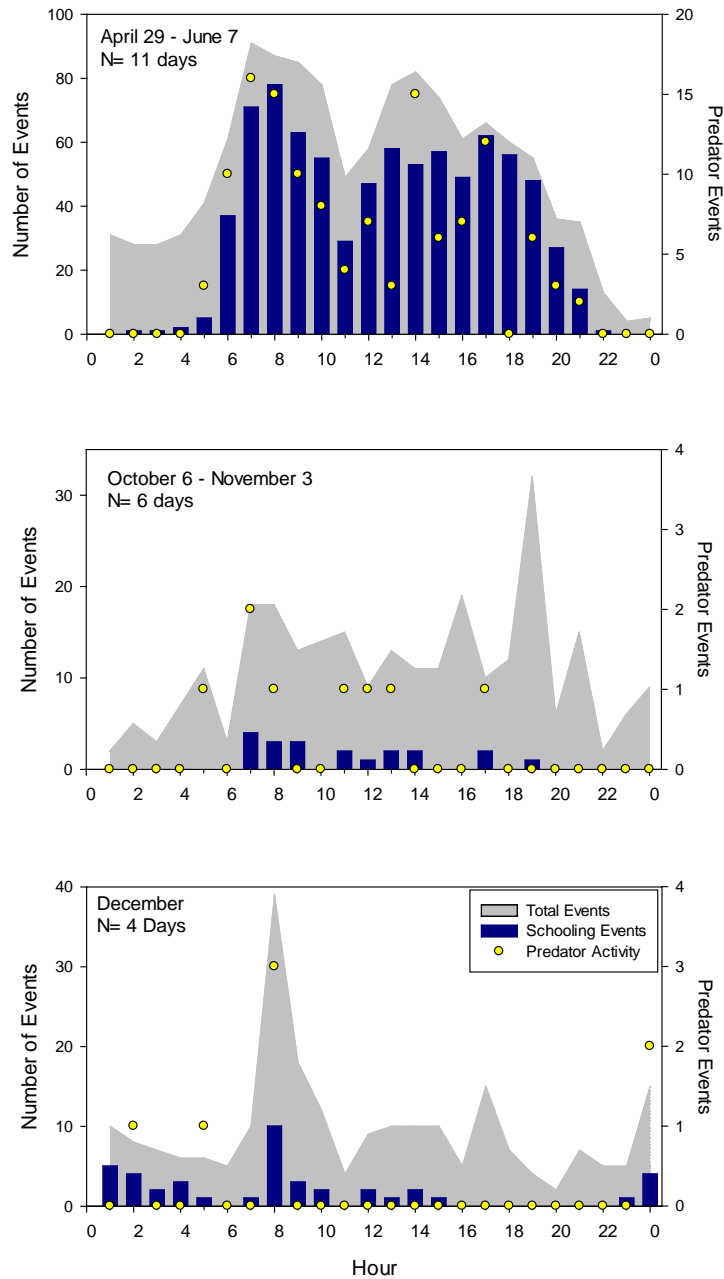


Figure 3.12. Diel Distributions of Fish Events (shaded regions), Schooling Events (blue bars), and Predator Activity (yellow dots) in Front of the CGR WTC Tower for the Spring (top), Fall (middle), and Winter (bottom) of 2010

3.2.1.7 Predator Activity

Predator observations were highest during the spring from May 12 to June 7, when both fish counts and schooling activity were highest (Figure 3.12 and Figure 3.13). Predator activity was also present from September through November, when fish numbers increased but schooling activity was low (Figure 3.12 and Figure 3.13). Few predator events occurred in summer and winter months (Figure 3.13).

3.2.2.2 Fish Length

On November 14, the majority of the fish (>90%) were classified as small (approximately 100 to 150 mm in length), with 6% classified as medium-sized (approximately 250 to 350 mm) (Table 3.3). On December 7, the percentage of small fish decreased to 45%, with medium-sized fish predominating (53%) (Table 3.3). On both sample days, only 2% of the fish population was categorized as large (approximately 400 to 450 mm) (Table 3.3).

3.2.2.3 Vertical Distribution

For both sample dates, the majority of fish (>50%) in the forebay were observed in the middle of the water column, at a depth of 10 to 20 m (Table 2.3 and Table 3.3). Small-sized fish (approximately 100 to 150 mm in length) composed 60 to 94% of the total fish abundance index at this depth. Few fish (1% of total fish abundance index) were seen in the top 10 m on November 14, but on December 7 the number increased to 28% due to a large school of medium-sized fish detected near the surface (Table 3.3). Medium-sized fish were more predominant in the surface layer, making up 22% of the total abundance index on November 14 and 99% on December 7 (Table 3.3). The remainder of fish (20 to 41% of total fish abundance index) was found at the bottom 10 m of the water column (20 and 30 m deep) (Table 3.3). At this depth, small fish composed the majority of the observed fish abundance index (68 to 89%), followed by middle-sized fish (7 to 31%). Large fish never made up more than 3% of the total fish abundance index at any depth, with the exception of the surface layer on November 14 (17%) (Table 3.3).

3.2.2.4 Fish Movements

Approximately 73 to 85% of fish movements in the CGR forebay involved either fish swimming toward the bottom of the sample volume or toward the top, but neither movement was predominant (Table 3.4). Few fish were observed traveling upstream or downstream on November 14, increasing to ~15% each way on December 7 (Table 3.4).

Table 3.4. Fish Movements Observed with the BlueView Acoustic Camera in the CGR Forebay

Movement	14-Nov-10		7-Dec-10	
Towards the bottom	62	34%	45	51%
Towards the surface	73	39%	30	34%
Milling	43	23%	22	25%
Downstream (Towards tower)	5	3%	13	15%
Upstream (Away from tower)	2	1%	15	17%

3.2.2.5 Fish Schooling Events

Schooling events involved all size classes of fish and occurred in all three depth bins. Nine fish events involved schooling activity on November 14 and much of the schooling (56%) occurred in the bottom of the water column (20- to 30-m depth). Sixteen schooling events occurred on December 7 and most (69%) occurred in the middle of the water column (10- to 20-m depth). Schooling in the surface layer (0- to 10-m depth) composed 11 to 19% of total schooling events.

3.2.2.6 Diel Distribution

A diel distribution was created by summing hourly observations for juvenile fish and predators over the two BlueView sample dates (Figure 3.14). Fish presence in the forebay occurred throughout the day and night, but high numbers of fish events were observed between 0200 and 0700 h, 1300 and 1700 h, and 1900 and 2300 h. Schooling events in the reservoir were concentrated during daylight hours (Figure 3.14).

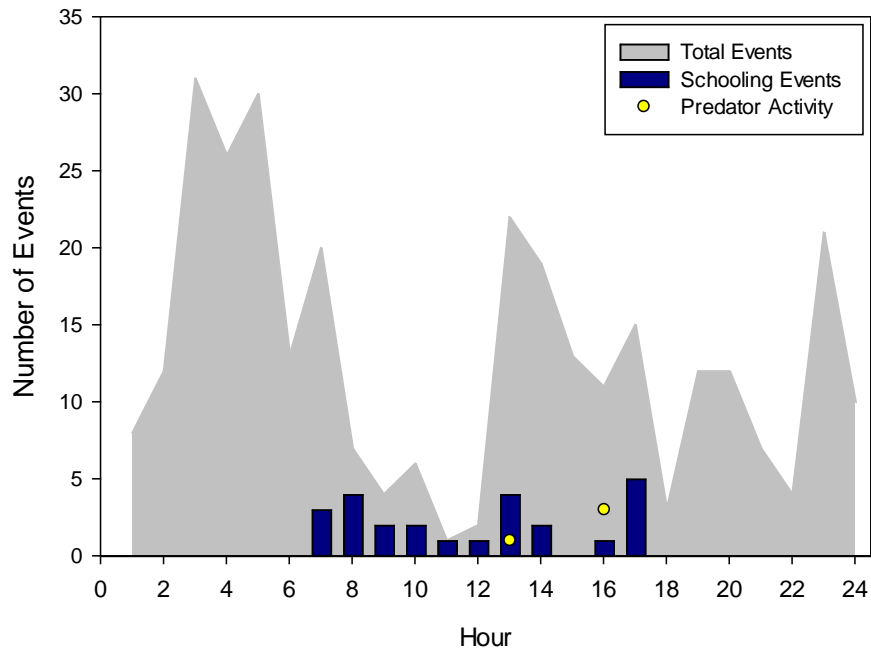


Figure 3.14. Diel Distribution of Fish Events (shaded region), Schooling Events (blue bars), and Predator Activity (yellow dots) in CGR Forebay for the Two BlueView Sample Dates, November 14 and December 7, 2010. No data are available for December 7 from 1000 h to 1200h.

3.2.2.7 Predator Activity

Four predator events occurred on November 14 and no events were observed on December 7. Predator activity was observed in the afternoon hours on November 14 (Figure 3.14); one occurred during the hour ending at 1300 h and three during the hour ending at 1600 h. During both hours, schooling activity was also noted (Figure 3.14).

3.2.3 ODFW Preliminary Screw-Trap Data from CGR Tailrace

Preliminary screw-trap data obtained from ODFW for monitoring activities in the CGR tailrace show juvenile Chinook salmon passed the dam throughout most of the year (Figure 3.15). Preliminary estimates of fish passage indicate higher numbers of these fish were caught in the traps in the spring (May–June) and very large numbers (between 2000 and 3000 each month) in the winter, between November and January. There are some caveats to these preliminary data: the data do not represent daily counts of fish because the traps were not serviced daily, sample sizes are small compared to the total

passage through the dam, and some sampling periods were missed because of flows below the dam and various other reasons.

Average fork lengths for these juvenile salmon averaged 130 mm for January through May and 115 mm for September through December (Figure 3.16). Fish caught in the traps in the summer (June and August; no data available for July) were smaller, with average fork lengths of 93 mm.

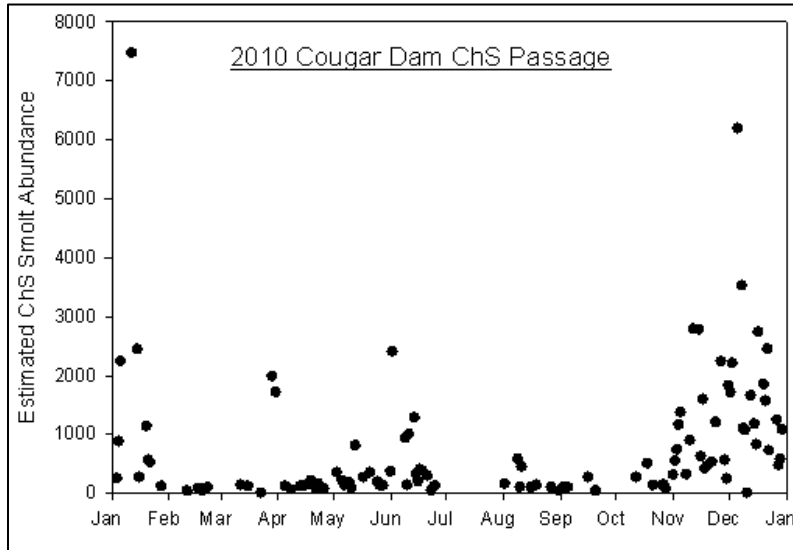


Figure 3.15. Estimate of Juvenile Chinook Salmon Abundance from Screw-Trap Data in the Tailrace of CGR (data courtesy of ODFW)

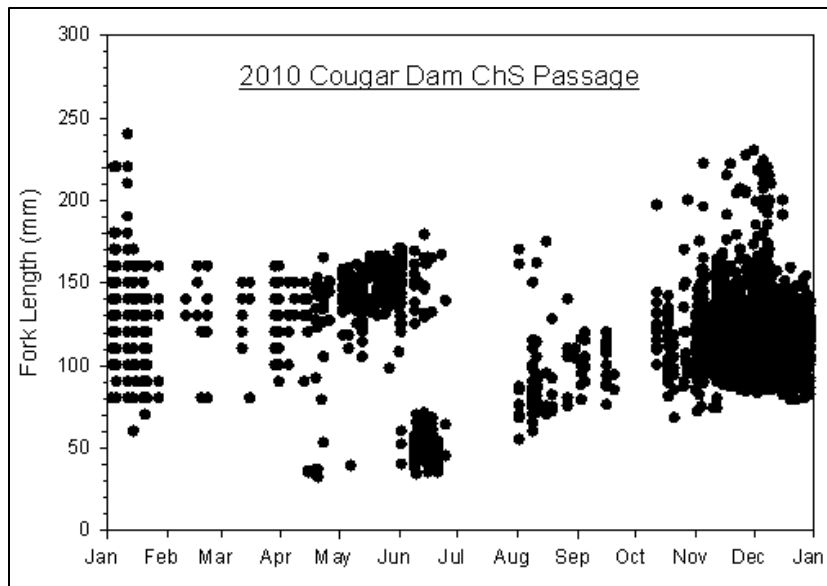


Figure 3.16. Estimate of Juvenile Chinook Salmon Fork Length (mm) from Screw-Trap Data in the Tailrace of CGR (data courtesy of ODFW)

4.0 Discussion and Conclusions

By evaluating juvenile salmonid behavior year-round in the forebay of the WTC tower at CGR, this study provides information for use in making decisions about long-term measures for enhancing downstream fish passage at the dam. Fish behavior data were collected using a DIDSON acoustic imaging camera to sample a ~0.5-m surface layer ~5 m immediately in front of the WTC tower from March 1, 2010 to January 31, 2011. A BlueView acoustic imaging camera aimed directly upstream into the forebay 50 m also was used to collect fish behavior data during October 28, 2010 through January 31, 2011. The BlueView effort began as a feasibility study and, when the instrument's usefulness was demonstrated in the data it produced, we analyzed BlueView data (2 days processed) along with DIDSON data (45 days processed). The key findings are as follows:

- The fish abundance index peaked in late May and early June; there were two small peaks in November and late December.
- A univariate statistical analysis indicated the fish abundance index (\log_{10} -transformed) was significantly ($P < 0.05$) positively correlated with forebay elevation, velocity over the WTC tower intake gate weirs, and river flows into the reservoir (measured from a gage upstream of the reservoir).
- A multiple regression analysis resulted in a model ($R^2 = 0.70$) predicting fish abundance (\log -transformed index values) using two independent variables of mean forebay elevation and the \log_{10} of the forebay elevation range.
- The average fish length was 214 ± 86 mm (\pm s.d.) in March through April; 132 ± 54 mm from the end of April to early November; 295 ± 148 mm for mid-November through early December; and 151 ± 76 mm for the winter (December 2010 through January 2011).
- Milling was the most common behavior we observed except for the following behaviors:
 - mid-May to June 1: fish moving left to right (facing upstream) across the face of the WTC tower intakes
 - August 11: fish moving right to left across the face of the WTC tower intakes
 - August 25 and January 26: fish moving from the WTC tower into the forebay.
- Schooling activity was observed mostly during spring and late fall:
 - May and June had very high levels of schooling activity.
 - There was less schooling in the fall, but persistent predator activity.
- Diel distributions – Fish were present in the immediate forebay of the WTC tower throughout the day/night:
 - Two distinct peaks occurred during the day; morning (0600–1000 h) and afternoon (1400–1800 h)
 - Schooling was observed during daylight, but not nighttime, hours in spring and fall; after midnight and during daylight hours in December.

- Predator activity was observed at times:
 - Predator activity was highest in mid-May to early June when the fish abundance index was highest.
 - No predator activity was observed during summer (July–August) or late winter.
- Forebay vertical distribution (BlueView data):
 - A majority of fish (>50%) were observed in the middle of the water column (10- to 20-m depth).
 - Few fish were observed in the surface bin of the water column (0- to 10-m depth); these were mostly medium-sized fish.
 - Between 20 and 41 % of total fish abundance index for the two sampling days were found in the bottom 10 m of the water column (20- to 30-m depth); these fish were mostly small and medium-sized fish.
 - Few large-sized fish (~400 to 450 mm in length) were observed at any depth.

The main focus of the 2010 study of fish behavior immediately in front of the WTC tower was supplemented with data about fish behavior 50 m into the forebay from the tower. The DIDSON camera was ideally suited for sampling fish behavior in front of the tower intakes because of its high resolution. A disadvantage of the DIDSON camera is its relatively small sample volume (29 deg wide by 14 deg deep with 20-m maximum range), which means it was not well-suited to sample out into the forebay at ranges greater than 20 m. The BlueView camera, on the other hand, has a relatively large sample volume (130 deg wide by 20 deg deep with a 50-m range for the 80-mm and larger targets of interest). We took advantage of this increased sampling volume when the BlueView instrument became available and could be deployed in fall 2010 at CGR.

Experience with the two acoustic imaging devices deployed in this study—the DIDSON and BlueView acoustic cameras—provided an opportunity to examine the strengths and weaknesses of each device for the purpose of characterizing juvenile salmonid behaviors near structures in the forebays of WVP dams. We compared DIDSON and BlueView data collected on the same date, December 7. The fish abundance index from the BlueView samples from the forebay was an order of magnitude higher than the DIDSON fish abundance index found in front of the WTC tower. This could be due to the larger sample volume for the BlueView camera than the DIDSON camera, multiple detections of the same fish, actual fish distribution, or some combination of these factors. The BlueView acoustic camera was definitely able to detect fish at greater ranges than the DIDSON acoustic camera. We did not deploy the BlueView camera to sample immediately in front of the WTC tower intakes; therefore, its performance is unknown in this critical region. Using acoustic imaging technology in future studies to characterize fish behavior in WVP forebays will depend on study objectives and should be optimized for the device (DIDSON or BlueView), acoustic frequency, aiming angles, orientation, range, sampling rate, and other factors affecting data quality for the fish of interest.

The 2010 acoustic imaging study at CGR revealed behaviors typical of juvenile salmonids and other fishes at the face of dams. Juvenile salmonid-sized fish displayed milling behavior in front of the WTC tower. Schooling, a common trait of juvenile salmonids, was prevalent during the day, but not at night, in spring and fall. However, schooling behavior was observed during nighttime hours, after midnight, and daytime in December. There was a diel peak of activity in the morning. Predator fishes, most likely bull

trout or rainbow trout (Chad Helms, USACE Biologist, pers. comm.), were most common when juvenile salmonid-sized fish abundance index was highest. These behaviors were also observed, for example, at The Dalles Dam (Johnson et al. 2009) and Bonneville Dam (Ploskey et al. 2006). The consistency of the 2010 CGR study with other research supports the validity of study method and results.

The fish catch and length data from the screw trap deployed in the CGR tailrace provide useful information for interpreting the acoustic imaging results from the forebay. The peaks in the fish abundance index we observed in May–June, November, and late December coincided with peaks in catch of juvenile Chinook salmon in the screw trap. It is noteworthy, though, that the highest forebay abundance index was in May–June, whereas the highest screw-trap catch was in December–January. The downstream passage peaks during spring and winter are consistent with life-history strategies for Chinook salmon in the Willamette Valley (Keefer and Caudill 2010). At Lookout Point Dam (LOP) on the middle fork of the Willamette River, Keefer et al. (2011) concluded that LOP screw-trap data revealed at least two life-history strategies, and perhaps as many as four. Khan et al. (2011), based on passage peaks from fixed-location hydroacoustic data at LOP, surmised their data indicated there may be at least three and maybe four life-history patterns: spring – yearlings; early summer – yearlings; late fall/winter – subyearlings; and, late fall/winter – yearlings. The multiple life-history strategies evident at CGR provide a basis for salmonid population recovery, but the predominate milling behavior in the immediate forebay of the WTC tower is direct evidence of the need for improved project operations and a collection and passage system for juvenile salmonids.

The 2010 acoustic imaging study has the following implications for USACE and fisheries resource managers working to design a collection and passage system for juvenile salmonids:

- The occurrence of smolt size targets in the forebay of the WTC tower suggests they would be available to pass at future outlet structures.
- The common presence of predators indicates the need for structural designs that minimize predator safe havens near the outlet(s).
- Schooling behavior should be considered during the design process, e.g., outlet dimensions.
- The high proportion (~0.80) of milling behavior in the immediate forebay of the WTC tower indicates fish were neither entrained nor showed proclivity to enter the tower.
- During the peak in abundance index in mid-May, active movement (right-to-left) along the face of the WTC tower indicated fish could have been searching for an outlet, but entrance conditions at the tower apparently were not conducive to passage.
- Entrance velocities for a surface flow outlet structure will need to be greater than those that currently exist at the intakes of the WTC tower.

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