Fish Exclusion and Monitoring of a Blast Containment Area using Electrofishing Techniques, Electrical Barrier and Hydroacoustic Techniques on the Rogue River near Medford, Oregon

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1.0 Introduction

Smith-Root, Inc. was responsible for overseeing all aspects of fish protection and monitoring of fish community impacts during a blasting project in the Rogue River on July 15, 2000. This project called for the removal of riverine bedrock near the Regional Water Reclamation Facility for the City of Medford, Oregon. A team of scientists from Smith-Root, Inc. was responsible for limiting accidental mortality of protected salmonids caused by the project.

1.1 Objectives

Objectives of the project were as follows:

a) Determine abundance of fish before fish exclusion.
b) Exclude fish from the effective blast area.
c) Determine efficiency of fish exclusion.
d) Document blast-caused fish mortality.

1.2 Schedule of Events

Table 1. Lists planned timeline of events and the actual timing of events. All times are given in 24 hour convention.

Event	***Planned***	***Actual***
Begin mobile surveys	07:00	07:09
Fetch hatchery fish	07:00	06:58
Conduct preliminary snorkel survey	08:30	08:30
Begin stationary survey	09:00	09:36
Begin fish herding measures	09:00	09:30
End fish herding measures	11:00	10:55
Activate electric barrier	11:00	10:58
Place caged fish in position	11:30	11:30
Conduct final snorkel surveys	11:45	12:45
End stationary survey	12:30	12:29
Detonation	13:00	18:13
Begin fish retrieval	13:10	18:16
Retrieve caged fish	14:00	18:55

The greatest deviation from planned timing of events was the delay of detonation from 13:00 hours to 18:13 hours. Events preceding and following this delay proceeded as planned. This delay was the result a mistake made at the origin of the munition shipment. The shipment was incomplete and forced the on-site munitions officer and thus all other parties to wait for the arrival of the shorted munitions. Safety concerns voiced by the munitions officer prevented further fish herding measures during the delay.

2.0 Methods

2.1 Site Description

At the time of sampling, the Rogue River was approximately 30 m (100") wide and 2.5 m to 4.5 m (8' to 15') deep at the thalweg (Fig 1.) On the north side of the river, across from the Water Reclamation Facility, a shallow shelf extended about 6 m (20') into the river. On the south side of the river, especially near the blast area, the drop off was relatively steep. A deep hole about 2.8 m (15') deep was located just east of the blast area. West of the blast area, a shallow shelf extending 6 m to 9 m (20' to 30') out in the river began 60 m (200') downstream.

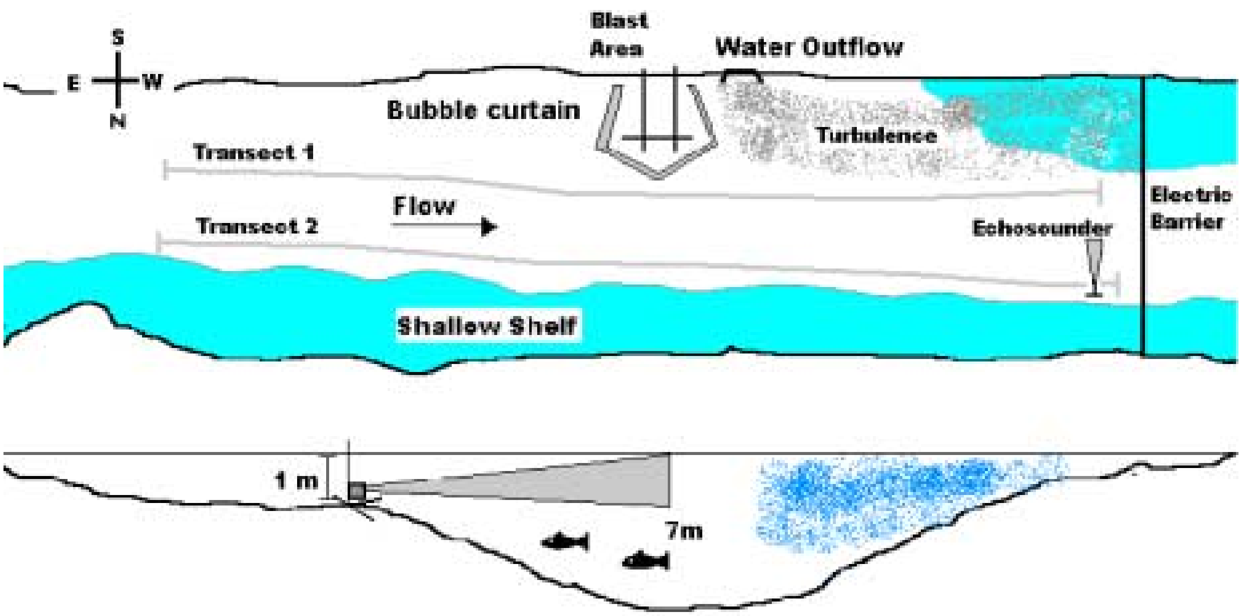

Figure 1. Plane view of site (top) and cross sectional view of stationary survey sampling (bottom). "Transect 1" and "Transect 2" represent mobilehydroacoustic survey transects and snorkel survey transects. Schematics are not to scale.

2.2 Fish Exclusion

The strategy to lessen the likelihood of adverse effects to fish in the blast area included three measures. Application of these measures was intended to exclude fish from the effective blast area.

2.2.1 Herding measures

The primary fish removal measure was use of an electrofishing boat to herd or chase fish to a safe distance from the blast area. Boat electrofisher settings were 7.5 Hz pulsed direct current at 500 volts on the initial exclusion pass and 7.5 Hz pulsed direct current at 1000 volts for the final pass. Technicians drove the electrofishing boat in a zigzag pattern, first working the immediate blast area and then starting 100 feet upstream of the blast area and continuing downstream to a distance of 300 feet below the blast area. We conducted two passes, one beginning at 09:30 hours using the 500 voltage setting and the second beginning at 10:25 hours using the 1000 voltage setting.

2.2.2 Electric Fish Barrier

We used a Smith-Root, Inc. Electric Fish Barrier (EFB) in an attempt to keep adult fish from reentering the effective blast zone. The EFB consisted of a SRI BP-1.5 P.O.W. Pulsator, a 4000w portable generator and two 9.5 mm (3/8") steel cables strung across the width of the river (76 m, 250') 3.2 m (10') apart. The EFB array was deployed 300 feet downstream of the blast area and was activated immediately following completion of fish herding measures (10:58 hours). The pulsator was set to 276 volts and 2 Hz resulting in a graduated electrical field (fig 2). Power density of the field was highest directly adjacent to each electrode and diminished toward the center of the barrier and water surface.

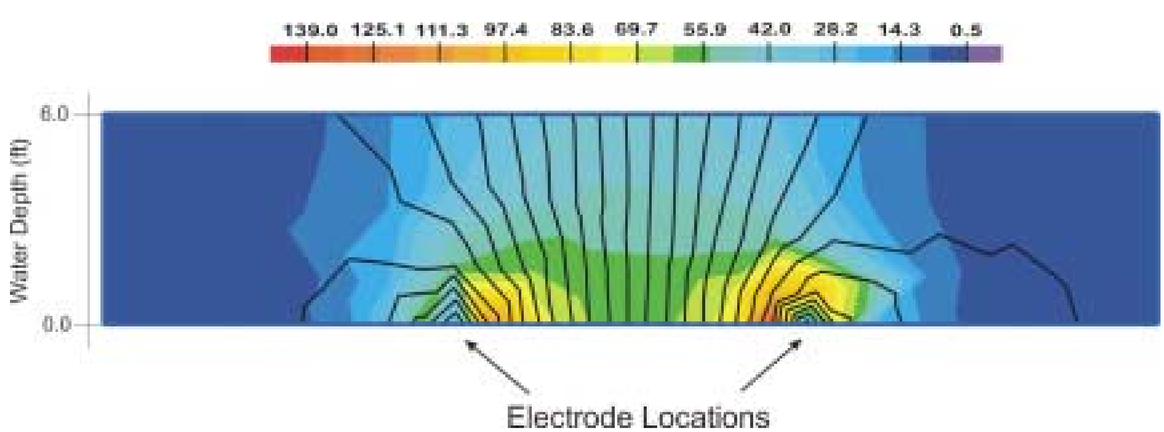

Figure 2. Map of fish barrier electric field. Top color bar indicates power gradient (V/m). Equipotential lines are in 10 volt increments.

2.3 Monitoring

2.3.1 Snorkel Surveys

Prior to exclusion measures, two snorkel surveys were conducted (beginning 08:30 hours) to estimate numbers and species of fish and determine where fish are located. We conducted these surveys starting 15 m (50’) upstream of blast area downstream to the electric barrier. After concluding exclusion measures, four snorkel surveys were conducted (beginning 12:45 hours) to determine effectiveness of exclusion measures. These final surveys began 30 m (100’) upstream of the blast area and continued downstream to the electric barrier.

2.3.2 Hydroacoustic surveys and locations

A mobile survey was completed from 07:09 to 07:28 hours in order to assess the abundance of fish in the containment area before the electrofishing began. A stationary survey was completed from 09:36 to 12:29 hours. From 09:30 to 10:58 hours, the time in which Smith-Root was electrofishing, data were collected to assess the success of excluding fish using electrofishing techniques. At 10:58, the electrofishing ended and the electric barrier was turned on. From 10:59 to 12:29 hours, data were collected to determine whether the electric barrier was able to prevent fish from entering the containment area.

2.3.2.1 Mobile survey

A 420 kHz, 6° split-beam DT transducer was mounted to the Smith-Root electrofishing boat. The transducer was placed at a depth of 0.6 m (2’), aimed about 1 degree down from horizontal and pointed toward the shore to gain maximum sample volume. At 07:09 hours two East-West oriented transects were completed to sample both sides of the river, sampling at a speed of about 1.5 m/sec (5 ft/sec). Each transect extended from the electric barrier, 91 m (300’) downstream of the blast area, to about 150 m (500’) upstream of the blast area. When possible, the boat was navigated at the edge of the thalweg nearest to the shore that was being sampled.

The mobile survey was conducted with a threshold of –50dB at a pulse rate of 10 pings per second.

2.3.2.2 Stationary Survey

The same transducer that was used for the mobile survey was mounted on a T-mount (Fig 1) in the river on the north bank, about 9 m (30’) upstream of the electric barrier, and at a depth of 0.75 m (2.5’) (Fig 2). The transducer was placed on the edge of a shallow shelf in 1 m (3’) of water, about 6 m (20’) from the shore, and pointed towards the opposite bank. The angle was adjusted to attain the maximum sampling distance with the least amount of noise (about 5-6° up from horizontal). Sampling began at 09:36 hours and continued until 12:29 hours.

The stationary survey was conducted with a threshold of –50dB. From 09:36 to 10:36 hours, a pulse rate of 5 pings per second was used. For the remainder of the sampling period, a pulse rate of 10 pings per second was used.

2.3.3 Acute Mortality Experiment

As a further measure of the effects of the blast, we placed caged Summer Steelhead (*Oncorhynchus mykiss*, 100 fish/lb) supplied by Oregon Department of Fish and Wildlife, Cole Rivers Hatchery in four locations in the vicinity of the blast area. Cages were fabricated of plastic frame and nylon netting. We placed cages (11:30 hours) immediately within the bubble curtain (BC), immediately outside the BC and both 25 and 50 feet north of the blast area. Each cage contained four fish.

3.0 Hydroacoustic Data Analysis

3.1 Echo Selection, Trace Formation and Filtering

3.1.1 Introduction

The discussion of the analysis of split-beam data must be preceded by an evaluation of both objectives and quality assurance. For this study, split-beam data were used for both fish detection and behavioral determination. Often, these two objectives require selection of analysis parameters that are at least different, and perhaps mutually exclusive at times. For example, selection of all echoes inside a fish trace increases the likelihood that some echoes with corrupted phase will be included. Although fish detectability is optimized, positional estimation, and therefore fish behavior may be corrupted. Conversely, if definition of echoes and formation of fish traces are selective processes with many echoes and traces rejected, fish passage estimates will be underestimated.

The approach to the analysis of the split-beam data is based in part on experience gained in the analysis of data from Alaska Rivers, which used horizontally aimed split-beam transducers to count adult sockeye salmon, where it was observed that the effects of noise added ambiguity to the fish behavioral data. In the riverine study, large targets (mean TS –30 dB) were observed in a high noise environment.

In the Rogue River, we expected to measure a range of fish in an environment that is generally characterized by moderate to high noise conditions. Given the sampling objectives and quality of data, the strategy for data analysis was to define criteria for echo selection and trace formation that select against the effects of noise.

3.1.2 Echo Selection

The DE/DT scientific echo sounder can write raw acoustic data, as well as echo data, to file. The raw data consists of the quadrature digital samples providing amplitude and phase. This digital data stream must be run through an echo formation algorithm to form or select echoes. The echo selection is a 5-stage process. 1) the candidate digital samples must fall between user-input minimum and maximum amplitude levels. 2) the samples surpassing threshold are correlated to a replica of the transmit pulse shape (after bandpass filtering) to evaluate pulse shape. This correlation scheme is also used to determine the range (Z) of the echo, which is defined as one half pulse width before the correlation peak. Echoes that do not surpass the correlation threshold are rejected. 3) the pulse width of the echo is measured at a user-selected level (such as –6 or –12 dB) relative to peak amplitude. Echo pulse width is tested against user-selected minimum and maximum pulse width limits; echoes outside the limits are rejected. 4) the split-beam algorithm calculates the X and Y angle for each digital sample in the echo. The echo X and Y angle is the mean of these individual angle estimates. The standard deviation about the mean is also calculated. This standard deviation of the angle must be below a user-selected value for both X and Y-axes. 5) the echoes must fall within user-selected angular limits on the X and Y-axes to be accepted.

3.1.3 Trace Formation

The tracking or trace formation algorithm is a 4-dimensional algorithm using time (ping number) and distance information from the three coordinates (X = left/right, Y = fore/aft, and Z = range). Based on a user-entered velocity parameter, a spherical volume is placed around the last echo in a fish trace. Echoes from the next ping that fall inside this spherical volume are considered as candidates for this fish trace. A timeout or "ping gap" parameter is used to define the termination of the fish trace.

3.1.4 Trace Filtering

When traces are formed, a variety of mathematical parameters are calculated, such as slope and linearity. These parameters are tested against user-selected thresholds to filter out false or corrupted traces. False traces are formed from noise, and corrupted traces include noise echoes. We call this process trace filtering. While a variety of filters exist, we selected two filters that were particularly effective. The first is a "number of echoes" filter. Traces with too few or too many echoes were rejected. The second is called a "ping concentration" filter. Ping concentration is defined as the quotient of the number of echoes over the total possible number of echoes. Traces formed in high noise events tend to have low ping concentration values, and valid fish traces tend to have higher values.

The choice of echo selection and trace formation and filter parameters requires an evaluation of how these processes interact. For example, a choice of very selective echo formation criteria results in traces that have more missing echoes, resulting in lower ping concentration values. In contrast, a relaxation of echo selection criteria produces traces with high ping concentration values but increases the potential for corruption of direction of travel and velocity estimates. Selection of parameters was an iterative process. We chose a data set, analyzed it, and then evaluated the behavioral data. This process was repeated several times to evaluate and fine-tune the analysis parameters.

The VTRACK software displays an echogram that indicates the trace formation process. A red line is drawn at the leading edge of each echo in a trace to indicate the success of the trace formation algorithm. During analysis, we were able to observe the performance of the algorithm to confirm the choice of trace formation and filtering parameters. Table 2 provides the parameters used in echo selection, trace formation, and trace filtering for each sampling period during the stationary survey.

Table 2. Echo selection, trace formation and trace filer parameters for the stationary survey. “PW” = pulse width, “SD” = standard deviation.

Echo Selection Parameters	
Shape Correlation	0.8
PW Measurement Level	-6 dB
Minimum Normalized PW	0.75
Maximum Normalized PW	2.0
Minimum Echo Strength	-70 dB
Maximum Echo Strength	-10 dB
Minimum Left/Right Angle	-6.0
Maximum Left/Right Angle	6.0
Minimum Fore/Aft Angle	-6.0
Maximum Fore/Aft Angle	6.0
SD Left/Right Angle	1.5
SD Fore/Aft Angle	1.5
Trace Formation Parameters	
Maximum Fish Velocity	3.0
Maximum Ping Gap	10.0
Trace Filtering Parameters	
Minimum Number of Echoes	3.0
Maximum Number of Echoes	150.0
Minimum Ping Concentration	75.0
Maximum Ping Concentration	100.0

3.2 Data Calculations

3.2.1 Time

The VTrack software did not calculate time for each fish properly and therefore time was calculated in an Excel worksheet (Eq. 1). The first ping number for each fish traced in VTrack was converted to an elapsed time (in minutes) by dividing it by the number of pings per second, divided by 60. The elapsed time was added to the recorded start time for each sample to derive a time of sampling for each fish.

Elapsed Time (in minutes) = First Ping Number/Pulse Rate/60 sec per minute
Equation 1

3.2.2 Direction of Movement

For the samples from the stationary survey, VTrack identified fish moving upstream or downstream based on the X-axis values (the axis moving left and right of the transducer). VTrack compares the X value of the first and last pings and, depending on which value is greater, assigns it a value of left (upstream) or right (downstream).

3.2.3 Target Strength Estimation

The target strength of each echo was calculated using split-beam algorithms. Mean target strength of each tracked fish was calculated by averaging the target strength values of the component echoes.

4.0 Results and Discussion

4.1 Snorkel Surveys

Snorkel surveys conducted before exclusion began showed that the water clarity was not favorable for visual fish detection beyond one meter range in the main channel (south side of river near blast area) and two meters range on the north side shelf. No fish were observed during these preliminary surveys.

Final snorkel surveys conducted after exclusion were more productive possibly due to the use of two snorkelers. Juvenile salmonids were witnessed by both observers 30 meters upstream of the blast area on the north shelf in one meter depth. Determination of fish species was compromised by low water clarity. No fish were observed near the blast area or downstream of the blast area.

4.2 Mobile Survey

Mobile surveys conducted before exclusion began showed that the Rogue River at the blast area was not favorable for mobile hydroacoustic sampling. The distinct, shallow shelves on both the north and south sides of the river (Fig 1) limited sampling distance. The deep channel in the middle of the stream was difficult to sample for fish near the bottom due to the narrow angle and orientation of the transducer. The outflow for the treated wastewater, located immediately downstream of the blast area, created a large zone of turbulence that extended 8 m to 12m (30-40') out into the river and downstream to the electric barrier.

The large amounts of noise recorded by the transducer effectively masked any distinct fish signals. Altering the trace formation parameters in VTrack yielded widely varying results without being able to exclude traces created from noise, or "false fish". Thus, no reliable estimates of fish abundance could be obtained from the mobile survey data.

4.3 Stationary Survey

The maximum range of the transducer was 7 m (23') for stationary surveys during and after electroshocking. The range was limited due to reverberations off the bottom and turbulence created by the wastewater outflow. Also, it was impossible to sample the deep channel in the middle of the river due to the angle of the shelf (Fig 1). Frequent boat passage through the sampling area produced frequent noise in the data, although VTrack was successful in filtering nearly all of the noise produced from boat wakes.

4.3.1 Fish Location

Most fish sampled were observed at 3 to 5 m (10 to 16') from the transducer (Fig 3). This distance corresponds to a relatively deep channel (1.5 to 2.5 m) that was located in the middle of the river (Fig 1). No relationship between time and range was observed during either stationary survey.

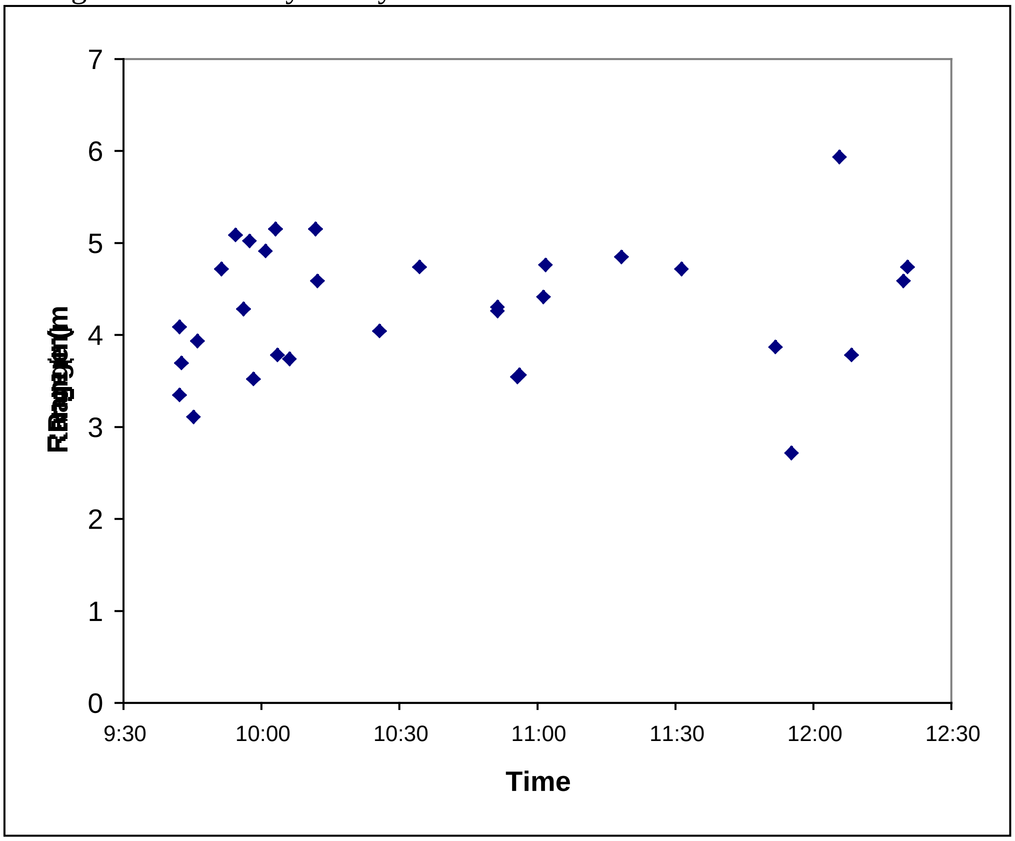

Figure 3. Range from transducer of fish sampled during stationary sampling both during (09:36 to 10:58 hours) and after electroshocking occurred (10:58 to 12:29 hours).

4.3.2 Frequency of Fish

The number of fish sampled during the electrofishing (1.5 hours) decreased over time (Fig 4). For the data analysis, the sampling periods were divided into half-hour intervals. From 09:30 to 11:00 hours, there was a sharp decline in the number of fish sampled per half-hour. By 11:00, almost 70% of the total fish sampled had been counted (Fig 5). At 10:58, the electrofishing stopped and the electric barrier was turned on. From 10:59 to 12:30 hours, the number of fish sampled per half-hour was low (3 to 4 per half-hour) and fairly constant.

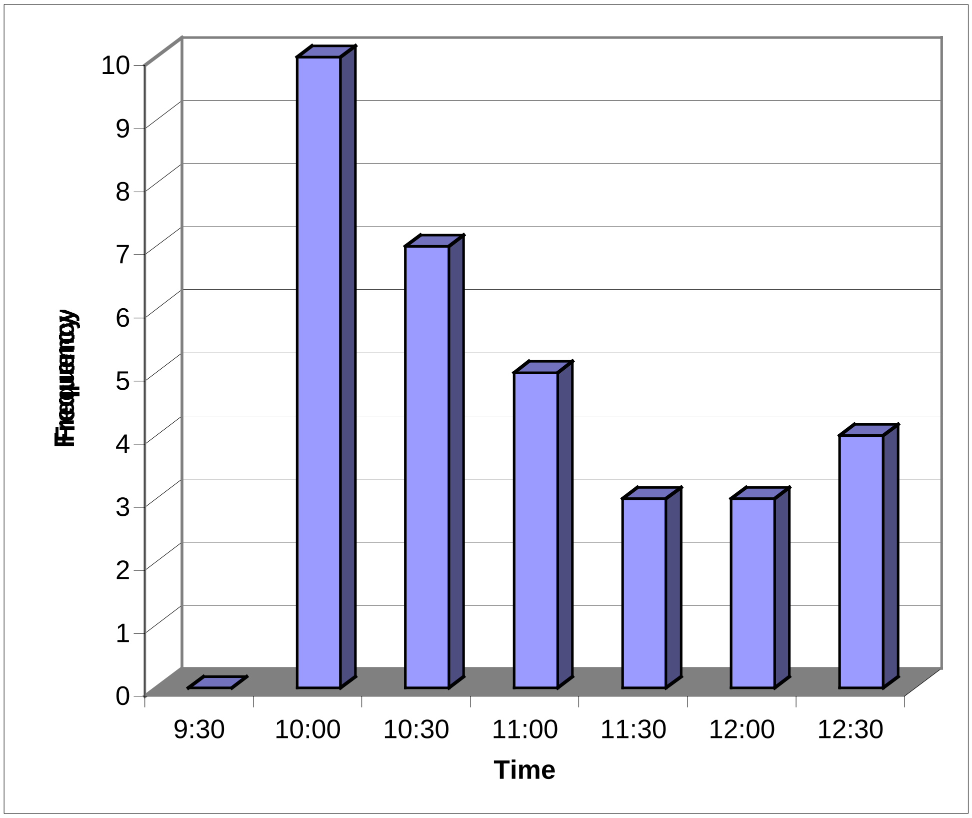

Figure 4. Number of fish sampled per half-hour during stationary sampling. "10:00" represents those fish sampled from 09:30 to 10:00 hours, "10:30" those fish from 10:00 to 10:30 hours, and so forth. Sampling began at 09:36 and finished at 12:29 hours.

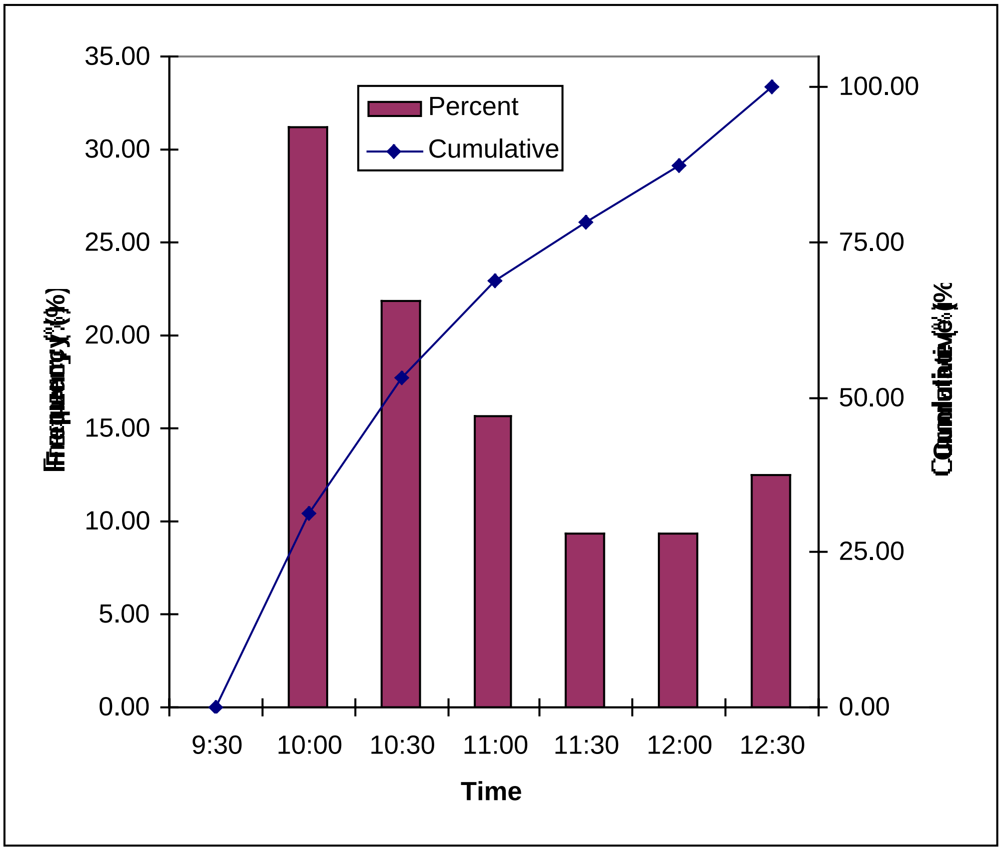

Figure 5. Frequency and cumulative percent of fish sampled per half-hour during stationary sampling. "10:00" represents those fish sampled from 09:30 to 10:00 hours, "10:30" those fish from 10:00 to 10:30 hours, and so forth.

4.3.3 Direction of Fish Movement

A random subsample of traces from the stationary sample data was analyzed by plotting the traces along the X and Y angles to verify that VTrack was correctly identifying fish direction (left or right). Vtrack correctly identified the direction of all of the fish subsampled.

Before the electric barrier was turned on (10:58 hours), almost all of the fish sampled were moving downstream (Fig 6). The average distance traveled was 0.36 m (1.2'). The two fish moving upstream during this period traveled a greater distance, 0.70 m (2.3') and 0.76 m (2.5'). After the electric barrier was turned on, all of the fish sampled were moving upstream. The average distance traveled was 0.43 m (1.4').

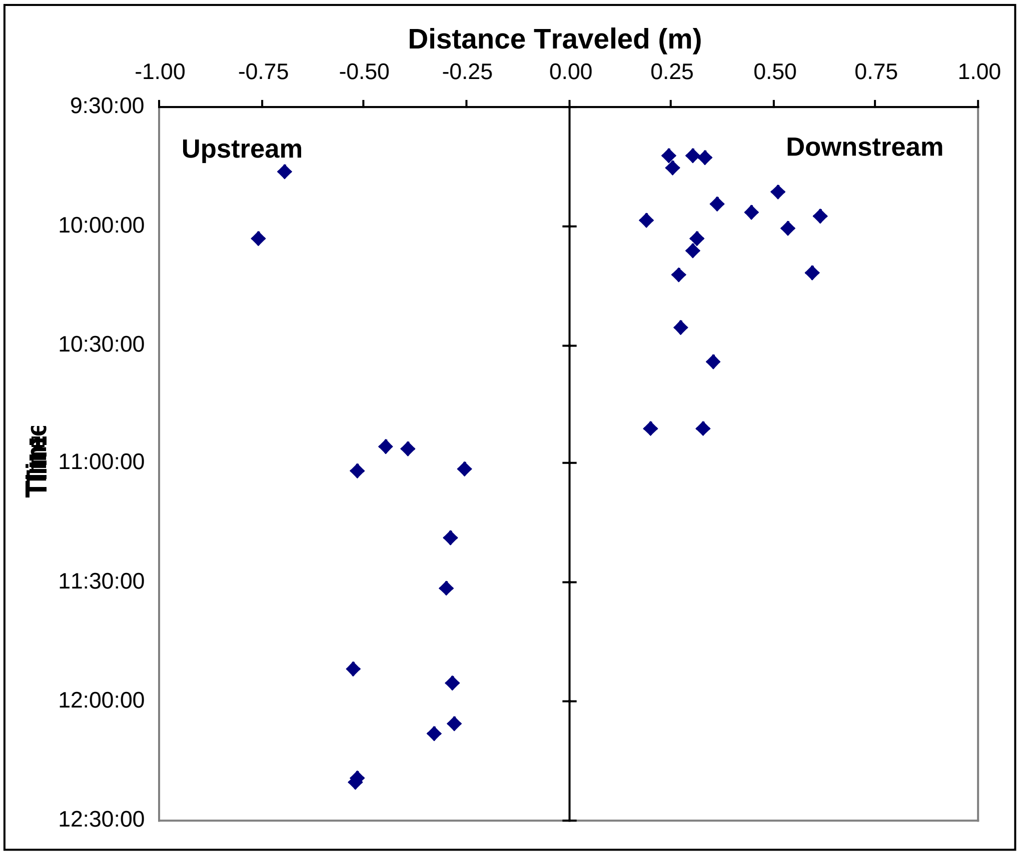

Figure 6. Direction of movement and distance traveled of fish sampled per half-hour during stationary survey.

4.3.4 Average Target Strength and Size

The combined average target strengths for all fish (N=32) had a unimodal distribution that was slightly left-skewed (Fig 7). The average target strength for all fish was –30.5 dB, ranging from –38.0 dB to –22.5 dB. However, a sample of at least 100 fish is required to form a reliable target strength distribution.

In general, higher average target strengths correlate to larger size. Target strengths for fish observed in side aspect were converted to fish size using the following algorithm (Love, 1971; Eq. 2):

$$TS = 22.8 \log L - 2.8 \log \lambda - 22.8 \qquad \text{Equation 2}$$

Where TS represents target strength, L the fish length and λ the wavelength.

Thus, a fish with average target strength of –36 dB would be 0.13 m (5.1"), -20 would be 0.67 m (26.4"). The average fish size sampled during the stationary survey was 0.23 m (9.1").

The size distribution was unimodal with a peak at 0.20 m (7.9”) (Fig 8). The size distribution, however, is only presented to show a general trend, not to provide absolute sizes of individual fish. Size calculations can be skewed due to normal variance in the target strengths of the component echoes of a fish. For fish with few component echoes, a high or low target strength associated with one of the component echoes can skew the mean target strength of the fish, thereby affecting the size calculation. For the four largest fish in the sample, removing the highest target strength from the component echoes in computing the average target strength altered the overall fish length 0.06m to 0.16m.

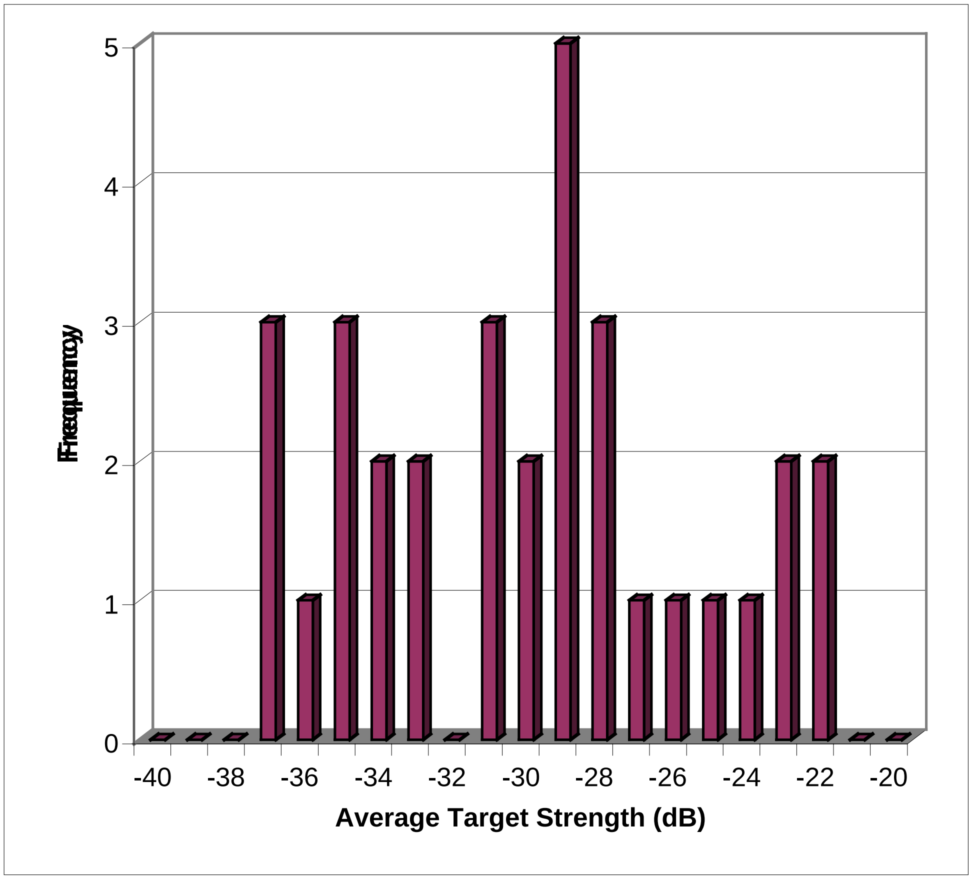

Figure 7. Distribution of average target strength of fish sampled during stationary survey. “-36” represents all fish with average target strengths of –36.99 to –36.00.

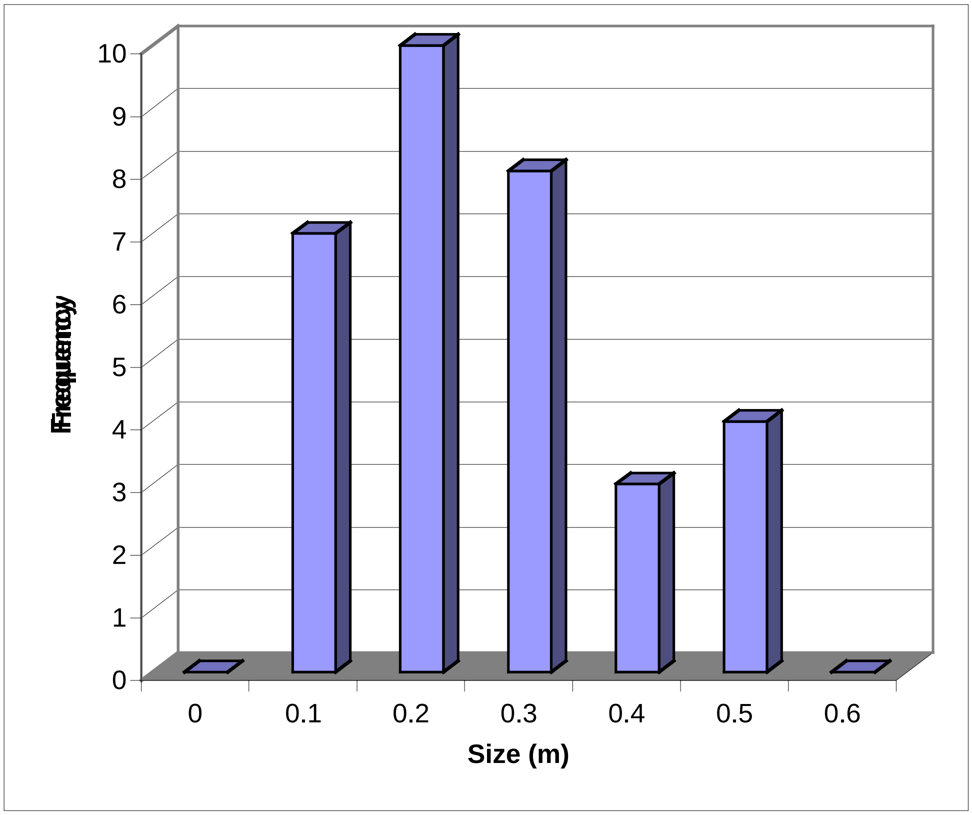

Figure 8. Distribution of fish size calculated from the average target strength of each fish. "0.1" represents all fish 0.05 to 0.15 m in length.

4.4 Acute Mortality Experiment

We were able to observe fish caged in the enclosure at fifty feet from the blast area during final snorkel surveys. These fish were maintaining position in the current and appeared to be feeding on drifting material. All appeared to be strong and healthy.

All cages were retrieved within one hour after detonation. Surprisingly, only two of the sixteen caged fish had died between time of cage deployment and retrieval. These two individuals were enclosed in the cage within the bubble curtain and showed no obvious external damage or discoloration. All other fish were energetic and appeared healthy and unharmed.

4.5 Blast Mortality of Wild Fish

We began collection of dead or dying fish immediately after munitions personnel gave the "all clear" signal. A silt plume caused by the blast made collection of fish very difficult on the south half of the river. We witnessed approximately four fish near the surface in the plume but we were only able to collect one individual. This one individual was a 15-inch Rainbow trout (*Oncorhynchus mykiss*) that was floating with its head partially out of the water. Due to the low visibility of the water, we would not have witnessed this fish if it were not visibly above the water. The other three fish that were witnessed in the plume (*Oncorhynchus* sp.) darted away when we attempted to net them and were apparently unharmed.

Due to low visibility in the plume, we began collecting fish on the north side of the river where the water visibility was more conducive to collection. Over the next twenty minutes, we collected an additional 12 fish (table 3). Few of these fish floated to the surface and were thus collected at mid-depth (salmonids) or from the riverbed (catostomids).

Table 3: Fish identification and length of blast induced mortalities. Fork Length is reported in centimeters (inches).

Species	Common Name	Fork Length
Oncorhynchus mykiss	Rainbow trout	38 centimeters (15 inches)
Oncorhynchus mykiss	Rainbow trout	15 (6)
Oncorhynchus mykiss	Rainbow trout	15 (6)
Oncorhynchus mykiss	Rainbow trout	14 (5.5)
Oncorhynchus mykiss	Rainbow trout	14 (5.5)
Oncorhynchus mykiss	Rainbow trout	13 (5)
Oncorhynchus mykiss	Rainbow trout	10 (4)
Oncorhynchus mykiss	Rainbow trout	10 (4)
Oncorhynchus tshawytscha	Chinook salmon	9 (3.5)
Catostomus rimiculus	Smallscale sucker	35.5 (14)
Catostomus rimiculus	Smallscale sucker	35.5 (14)
Catostomus rimiculus	Smallscale sucker	30.5 (12)
Richardsonius balteatus[a]	Redside shiner	7.5 (3)

5.0 Conclusions

- Electrofishing was successful in greatly reducing the number of fish at the site, and in moving fish downstream past the electric barrier. By the time the barrier had been turned on, 70% of all fish counted had moved downstream, away from the containment area.
- The electric barrier was 100% successful in keeping adult salmonids from reentering the containment area. Small fish were observed in the site moving upstream after it was turned on. Those fish were moving though the deepest part of the river, where the power from the barrier was weakest.
- A range of fish was excluded from the site, from about 0.1 m (4.3”) to 0.5 m (19.8”) in length. The mean length of 0.20 m (7.9”) was slightly higher than would be expected if the majority of the fish excluded were juvenile salmonids. It is possible, however, that the sample is biased toward larger fish because noise would have masked smaller fish with lower target strengths and fewer numbers of echoes.