IMPACTS OF NOISE ON THE ESTIMATION OF DOWNRIVER MIGRATING SALMONIDS

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INTRODUCTION

Acoustic techniques have been used since 1979 to enumerate juvenile salmonid migration past hydroelectric dams on the Columbia River in the northwestern United States. The initial techniques for estimation of fish passing through turbines used bottom-mounted transducers on the outside of trash racks, oriented toward the surface and slightly upriver. This deployment was logistically simple, but the data were subject to error from noise and target misclassification.

An alternate deployment is to mount transducers inside of trash racks, oriented in various modes inside the turbine gallery. This deployment reduces misclassification problems since most of the fish are committed to passage through the turbine gallery at this point. However, even this deployment is subject to uncertainties caused by lack of knowledge about the acoustic properties of the fish targets and the interactions of those properties with echo-counting thresholds. As pointed out by Johnson and Wright [1], the accuracy of acoustic techniques is sensitive to the relationship between the acoustic target strength of the fish and the echo-counting threshold when noise is a limiting factor.

We collected acoustic data at Bonneville Powerhouse I on the Columbia River to determine effective transducer deployment and monitoring techniques for routine collection of fish passage data. The investigation centered on the relationship between acoustic target strength and noise thresholds since this was the most critical factor. As a measure of the effectiveness of the acoustic application, the study was conducted in conjunction with netting operations by the U.S. National Marine Fisheries Service (NMFS). The net study was designed to evaluate the fish guiding efficiency (FGE) of submersible traveling screens (STS) which had been installed within the intakes as a mechanism to guide fish away from the turbines and up into a bypass system.

METHODS

Transducers were installed and tested at Turbine Unit 3 of Bonneville Powerhouse I, June 28–30, 1988. Data were then collected at this location in conjunction with the FGE studies by the NMFS for 16 evenings during July 6–27. The daily monitoring period began at 2000 h and continued until an adequate sample was obtained for the net study, which was typically just after 2200 h.

Transducers were deployed at two locations within the turbine unit (Figure 1). A new style of transducer mount was designed to attach to the horizontal bars of the trash rack. These mounts were deployed by divers. The mount for the lower transducer was attached to the deepest horizontal trash rack bar. The transducer was oriented upward and slightly downstream so that it looked toward the end of the STS. The mount for the upper transducer was attached to the top of the third trash rack, approximately the same depth as the bottom (upstream edge) of the STS. Again, the transducer was oriented upward and slightly downstream, approximately normal to the intake ceiling.

The acoustic equipment consisted of a 420 kHz BioSonics Model 101 Echo-Sounder, a BioSonics Model 151 Multiplexer/Equalizer, BioSonics 15° transducers, a Raytheon Model LSR 910M Chart Recorder and a recording system. The recording system was comprised of a BioSonics Model 171 Tape Recorder Interface and a Sony PCM and VCR. All acoustic equipment was fully calibrated at BioSonics before and after the data collection period, using a U. S. Navy standard transducer.

The pulse length of the echo-sounder was 0.4 ms and the pulse rate was 15 pings/s . Data collection alternated between upper and lower transducers at 5-min intervals. Real time data were obtained with the Raytheon chart recorder at a threshold of -59 dB. Additional echograms were subsequently created from the VCR-recorded data using BioSonics Model 111 Thermal Chart Recorders at thresholds of -65 dB and -51 dB. These three thresholds provided the basis to examine the impact of noise on the various estimates.

Data analysis consisted of three phases. The first phase was target strength measurement. The second and major phase was analysis of the chart records of fish passage at the various noise thresholds. The third phase was comparison between the acoustic and net catch data.

Target strength analysis was made on data collected July 6, 1988. We used a modification of the Craig and Forbes [2] technique for single beam target strength extraction. The modification uses the maximum echoes from each fish rather than each individual echo [3]. Echo strengths were measured by means of a storage oscilloscope. The target strength information was extracted from the echo strength data by sequentially removing the effect of the transducer directivity pattern, beginning with the largest fish echoes.

For the second phase of the analysis, all echo traces from the chart recordings at each of the three thresholds were coded for quality (high and low) and fish type (juvenile salmonid or adult shad/squawfish) and entered into a data base by bitpadding. A high quality trace (QC 1) was a distinct target (black trace with multiple pings) with a pronounced short-to-long range shift. Adult shad/squawfish targets were distinguished on the basis of echo size and change of direction. All other probable fish targets were assigned a low quality code (QC 2). Data analysis programs provided weighting for range and beam angle. Beam angles for each transducer and threshold were obtained from the transducer directivity patterns and a mean target strength assumption based on the phase 1 target strength analysis. The resulting calculated beam angles were 22°, 17° and 10° for the upper transducer for thresholds 1, 2 and 3 respectively, and 20°, 16° and 9° for the lower transducer.

The analysis of trends was conducted on both the uncorrected echo counts and the range-weighted counts. The range-weighted counts use the beam angle information and the range of the targets to calculate the effective sampling width of the acoustic beam at that range. Observations were then weighted the by the ratio of the width of the turbine slot to the width of the sampling beam at range. The range-weighted counts divided by the sampling interval (min) are estimates of the fish passage rate (#fish/min). For both the uncorrected and range-weighted counts, the FGE was estimated simply from the upper transducer detection rates divided by the total detection rates (upper + lower transducers). Diel variation within the monitoring period was examined by dividing the monitoring period into two parts, 2000 h to 2130 h ("Dusk") and 2130 h to termination ("Evening").

NMFS used fyke nets to sample behind the STS at Turbine 3. Nets were arrayed on a vertical frame which was installed in the intake bulkhead slots. This positioned the nets just behind the STS (Figure 1). Fish that were successfully guided by the STS were collected in the gatewell above using a gatewell dip net. Unguided fish were caught in the fyke nets. FGE was calculated by dividing the number of fish caught in the gatewell by the total number of fish caught in both gatewell and fyke nets.

RESULTS

<u>Target Strength Measurement</u>

A total of 101 fish were detected and measured for target strength from the July 6, 1988, Turbine 3 data recorded in conjunction with FGE studies. Only fish from the first 4-6 m (depending on noise levels) of range were included to minimize the effect of noise on the measurements (maximum range was about 9 m). The target strength range was from -28 to -63 dB (Figure 2). There was a clear separation between two size modes at -41 dB. All of the larger targets (those with echo strengths greater than - 40 dB) had been coded as adult shad/squawfish during the echogram analysis of this data. Most of these large fish echo traces also showed some upstream movement against the water flow. The mean target strength of the smaller size fish was -50.1 dB.

Fish Passage

The number of targets detected at threshold 1 (-65 dB) varied by date from 76 to 312. Corresponding daily acoustic FGE estimates ranged from 2% to 28%. The overall acoustically estimated FGE was 11% for threshold 1. Detections showed a strong diel trend even within the limited monitoring period. The detection rate (fish/min) was 0.90 for the dusk period and increased substantially to 2.16 fish/min for the evening period.

The number of targets detected each day for threshold 2 (-59 dB) varied from 42 to 172. Corresponding daily acoustic FGE estimates ranged from 3% to 28%. The overall acoustically estimated FGE was 15% for threshold 2. Again a diel trend was noticeable with fish/min rates of 0.45 for dusk and 1.53 for evening.

The number of targets detected at threshold 3 (-51 dB) varied among dates from 45 to 148. Daily acoustic FGE estimates ranged from 0% to 21% Overall acoustically estimated FGE was 11% for threshold 3. The detection rates for dusk and evening were 0.38 fish/min and 1.58 fish/min respectively.

The weighted (by range) data resulted in slightly higher estimates of FGE, partly because the lower transducer had slightly greater range than the upper transducer. The weighted FGE estimates were 13%, 19% and 12% for thresholds 1, 2 and 3 respectively.

Comparisons with Fyke and Gatewell Net Catches

The relation between the net estimates of FGE and those from the threshold 1 and 3 acoustic data for each date are shown in Figure 3. The average of the daily FGE values from the net catches is 15%, which compares with the weighted acoustic estimates of 13%, 19% and 12% for thresholds 1, 2 and 3 respectively.

The daily fish passage rates from the quality code 1 acoustic data for thresholds 1 and 3 over the study period are compared with those from the net catches in Figure 4. With some exceptions, the data are comparable in both magnitude and trend. The relationship between the two estimators was determined using ratio estimation [4]. In this case the relationship between the acoustic estimates of fish passage rate and those from the nets are 1.13 +/- 0.31, 1.07 +/- 0.26 and 1.44 +/- 0.31 for thresholds 1, 2 and 3 respectively. The estimates for thresholds 1 and 2 are not significantly different from one-to-one.

DISCUSSION AND CONCLUSIONS

While noise is potentially a problem in acoustic studies of downstream migrants at hydroelectric dams, its impact depends primarily on the type of application. For relative measures, such as FGE, diel variation or run timing, noise does not appear to be a major problem for the in-turbine transducer deployment used in this study. The acoustic estimates of FGE from a broad range of thresholds were consistent and in good agreement with those from the nets. The thresholds ranged from -65 dB, which was below virtually all fish target strengths, to -51 dB, which would have excluded about half of the salmonid targets. The results show that if the threshold is set to include a reasonable proportion of the targets (probably at least half) and has reasonable range detection (so as to not severely interact with variable vertical distributions), then FGE values should be accurate.

The results also show that misclassification of noise or nonfish targets (such as debris) is not a serious problem. The estimates of FGE from all three thresholds were essentially the same for both quality code one (definite fish targets) and quality code 2 (probable fish targets). In addition, the same diel trends were seen in both quality codes. These results show that concerns for target misclassification because of leaves, branches, etc., have been greatly exaggerated.

While research in fisheries acoustics has concentrated on the relationship between mean target strength and fish length, of equal or even greater importance, especially in echo-counting, is the target strength distribution. The mean target strength (or more properly, the target strength equivalent to the mean acoustic backscattering cross section) is important in echo-integration, since it determines the scaling factor for absolute estimation. The mean target strength is also used to estimate the effective transducer sampling volume of an echo-counting process. However, as pointed out by Thorne [5], the estimates of fish density from echo-counting are relatively insensitive to error associated with the estimation of the mean target strength. The major possibility of error in echo-counting, such as in the estimation of downstream migrating salmonids, occurs when smaller target strengths are below noise thresholds, allowing fish to pass undetected.

The target strength analysis indicated a 20–23 dB spread for the juvenile salmonids. This width is in good agreement with other observations for juvenile salmonids [3, 6 and 7]. Both this width and the shape (near-normal) of the distribution argue that the total range is included in the measurement. The one-to-one relationship between the threshold 1 acoustic estimates and those from the nets offers additional evidence that no significant numbers of fish were below the lowest detection threshold used in this study. However, the fact that the highest threshold produced the highest estimates, although some fish were clearly thresholded out at this level, suggests that the assumed mean target strength was too high. The highest threshold would be the most sensitive to error because of the shape of the transducer directivity pattern. In fact, the differential sensitivity of different thresholds to error associated with the mean target strength assumption and the corresponding beam angle estimation may be a powerful tool for error detection, or even for estimation of the true mean target strength.

The net catches were used in this study to ground-truth the acoustic estimates of passage rate. While the net catches provided valuable insight into the acoustic data, there were several aspects of the comparison that added variability and error. One was simply the small daily sample size, but the biggest problem was an apparent lack of real synopticity that was caused by the uncertain effect of turbine startup and shutdown on the net operations, combined with dramatic diel changes in passage rates. A major improvement in such comparisons would be to conduct the experiment during a diel period with more stability in fish passage rates. While net operations are very important for ground truth, and particularly for species composition, the acoustic techniques have advanced to the point that the biases of the acoustics are better understood than those of the nets, and there is little to be gained from the nets in terms of absolute calibration of acoustics. The same evolution in the relationship between acoustics and direct capture techniques that has been seen in marine and limnetic applications, that is, a change from calibration to species composition [8 and 9], is appropriate for FGE and fish passage assessments.

The multiple threshold analysis used in this study was laborious because of the reliance on chart recorders. These techniques could be easily implemented on automatic processors, such as the BioSonics Echo Signal Processor (ESP). Additional advantages of automatic processors include much greater flexibility to implement new processing schemes, such as single beam deconvolution, direct target strength measurement, trace type analysis and confidence interval calculations.

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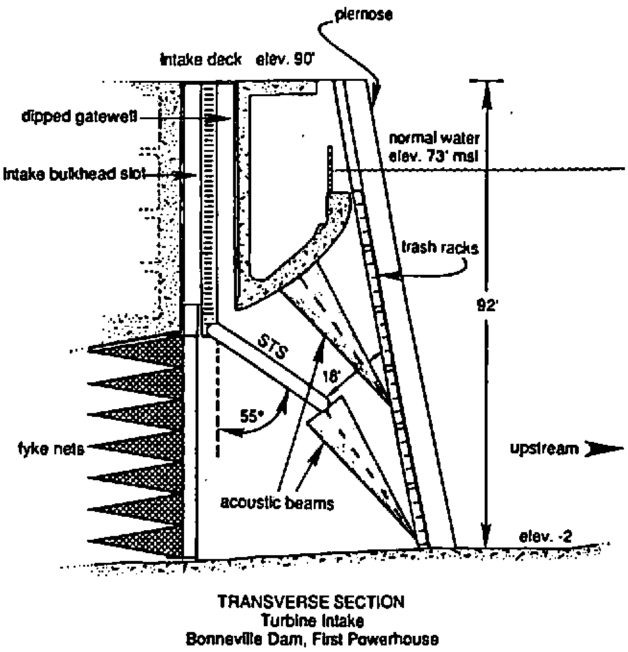

Figure 1. Sampling locations for 15° transducers at Bonneville Powerhouse I, 1988.

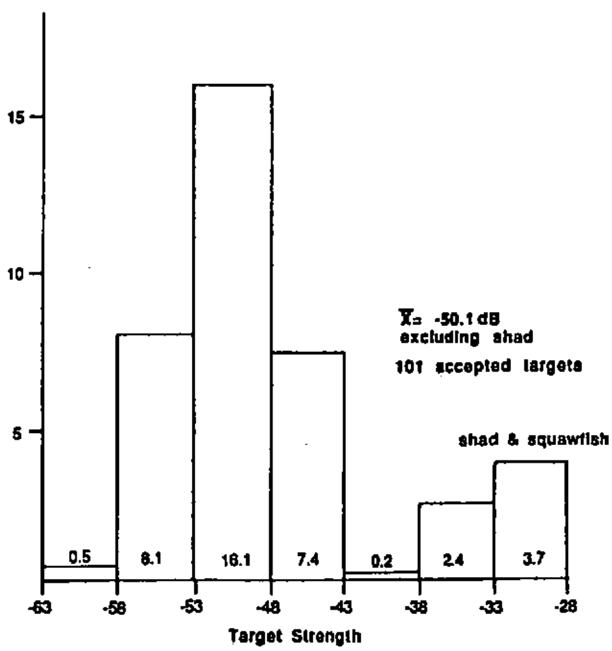

Figure 2. Frequency histogram of target strengths calculated manually using storage oscilloscope. The 2 h of data were collected at Bonneville Powerhouse I on July 6, 1988.

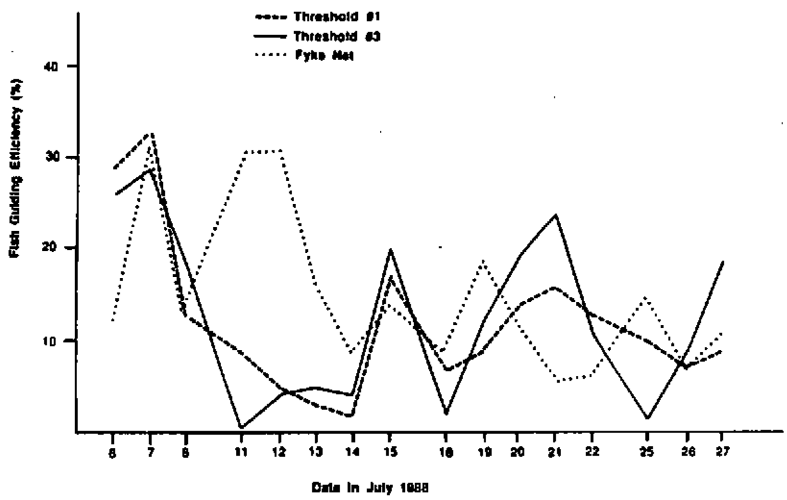

Figure 3. Comparison of daily FGE estimates from acoustic and catch data.

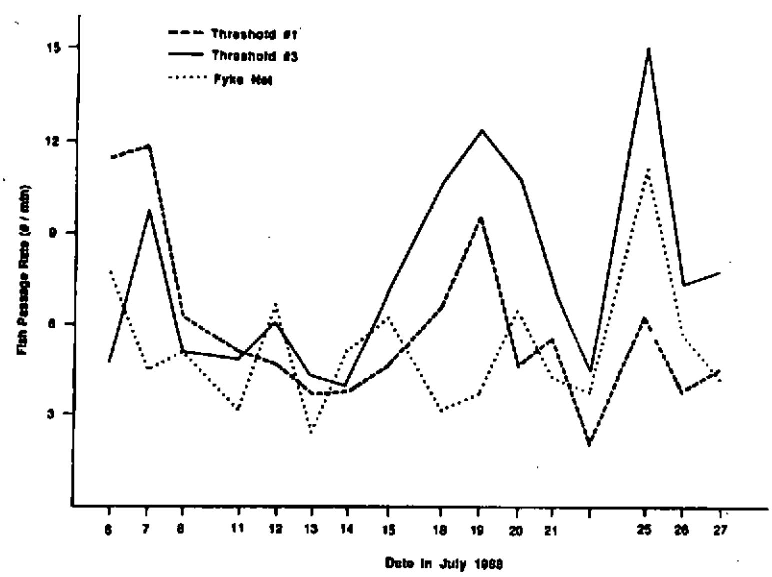

Figure 4. Comparison of daily estimates of fish passage rate from acoustic and catch data.