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Point-source violations: split-beam tracking of fish at close range

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Abstract − Split-beam positional estimates of fish detected in a river at close range often do not correspond to the actual position of the target. These inaccuracies create problems in determining whether a fish is moving upstream or downstream. We hypothesize that these positional estimates are degraded by two factors: size of target relative to beam diameter, and the complex scattering of the fish. These parameters create a near-field effect, within which the phase measurements of the returning echoes are corrupted. Examples of fish tracks from near and far range fish detected by a split-beam echo sounder are provided to illustrate these inaccuracies. Experimental data from tethered spheres and complex targets show increasing distortion with target complexity and proximity to the transducer. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

split-beam / point-source / fish tracking / positional estimates

Résumé − Dépassements du point-source : suivi des mouvements des poissons à « petite échelle » au sonar. Les estimations de positionnement des poissons au sonar, à petite échelle, souvent ne correspondent pas à la position réelle de la cible. Nous prenons pour hypothèse que l'énergie acoustique du poisson a un effet sur le champ proche qui altère la phase des échos en retour et dégrade les estimations de positionnement. Des exemples de suivis de poissons à petite ou grande échelle au moyen d'un écho-sondeur corroborent cette hypothèse, ainsi que des résultats sur des sphères attachées et des cibles complexes. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

faisceau double / point-source / suivi de poissons / estimations de positionnement

1. INTRODUCTION

Scientists that utilize split-beam echo sounders to count anadromous salmonids in rivers now have a means to observe aspects of fish behavior (BioSonics Inc., 1998; 1999), specifically direction of travel. These observations typically degrade with range as volume and boundary reverberation levels increase (Dahl, 2000). Fish that move downstream through the sonar beam may now be distinguished from fish migrating upstream and removed from fish passage estimates. However, some species of salmon travel close to the edge of the river and close to the transducer. We have observed that split-beam estimates of position for these fish are often highly variable, and direction of travel does not consistently correspond to visual observations. We hypothesize that such error is primarily due to the complex scattering properties and close range of the fish. Additionally, we hypothesize that selection of a transducer with a beam shape cross section (elliptical) that mimics the cross sectional shape of the fish may improve positional

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estimates at close range. Our goal is to document these observations and empirically test the hypotheses.

2. MATERIALS AND METHODS

2.1. In situ methodology

Study sites were located in Alaska, at river mile 8.6 on the right bank of the Kenai River and 1.5 miles downstream from Lake Aleknagik on the right bank of the Wood River. Observations were made in June and July of 1999 on chinook salmon (*Onchorhynchus tshawytscha*) in the Kenai River and sockeye salmon (*O. nerka*) in the Wood River. A 420 kHz DT6000 scientific echo sounder manufactured by BioSonics, Inc. was used to collect data. Position of echoes within the sound field was estimated using the split-beam technique (Ehrenberg, 1981). Pulse width was set at 0.2 ms and the pulse rate between 4–15 pulse$\cdot$s^{-1}. The split-beam transducers were mounted on dual-axis rotators, which were supported by an aluminum 'T' mount. The mount was placed about 25 m offshore at the transition between the muddy bank and the gravel bottom substrate of the channel in the Kenai River. This site was tidally influenced, with mid-channel water depths varying from 2–4 m in depth. In the Wood River, the mount was located about 1 m from shore. The river bottom was about 0.5 m deep at the transducer and sloped down to a depth of 2 m at a range of 5 m. Chinook salmon in the Kenai River typically travel in the main channel, while the sockeye salmon in the Wood River travel in a band 2–3 m wide, and at a range of 1–4 m from the river bank. Bottom substrate at both sites was characterized as fist-sized cobble.

A pitch/roll sensor manufactured by Jasco Ltd. was mounted adjacent to the transducers. The output of the sensor was incorporated into the sonar display and files, allowing precise linkage of aiming angles and acoustic data. The transducer was aimed approximately perpendicular to the riverbank to maximize the side aspect returns from fish. Since the salmon are typically bottom-oriented, vertical aiming was adjusted carefully to achieve a balance between maximum fish detectability and minimal phase corruption from the bottom substrate. Acoustic data were collected over a –50 dB threshold and saved to binary and database files.

2.2. Experimental methodology

To further evaluate our in situ observations, we designed an experiment to position a sphere and a complex target at different ranges from the transducer. The sphere was a 33 mm tungsten carbide target, while the complex target consisted of a long balloon, 2 cm diameter by 28 cm long installed in a plastic housing 5 cm tall by 3 cm thick by 28 cm long. Three lead weights were attached to the floor of the housing to add scattering complexity and provide negative buoyancy. This target, which we defined as the 'complex' target, is depicted in *figure 1*. It was constructed to roughly emulate the scattering properties of an adult salmon.

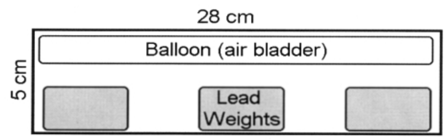

Figure 1. Configuration of complex target.

The measurements were taken in a low noise lakeshore environment with minimal current. The sphere and the complex target were suspended from a float to maintain a constant depth. A pulley arrangement was constructed to move the float toward or away from the transducer. This assembly, shown in *figure 2*, allowed the selected target to be moved along the acoustic axis with minimal aspect change. The complex target was hung perpendicular to the axis to provide a side aspect.

Each target was positioned on the acoustic axis at the desired range, and the sound field was rotated across the target in the X coordinate to simulate the target moving through the acoustic sound field. Data from these sweeps were analyzed to isolate the X component of the target trajectory. We first collected data using a 2° circular transducer, and then repeated the measurements with a 2° × 6° elliptical transducer with major axis parallel to the water surface.

3. RESULTS AND DISCUSSION

3.1. In situ observations

At the Kenai site, fish were detected at a considerable range. *Figure 3* shows the track, expressed as a time series of x and y angles from the 2° circular split-beam system, of a salmon at a range of 41 m. The track of a fish at 3 m range from the 2° circular transducer is observed in *figure 4*. Although there is some variability in the track in *figure 3*, it is clear that the fish is moving from one side of the beam to the

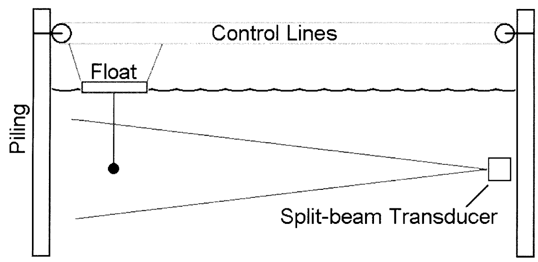

Figure 2. Illustration of experimental assembly.

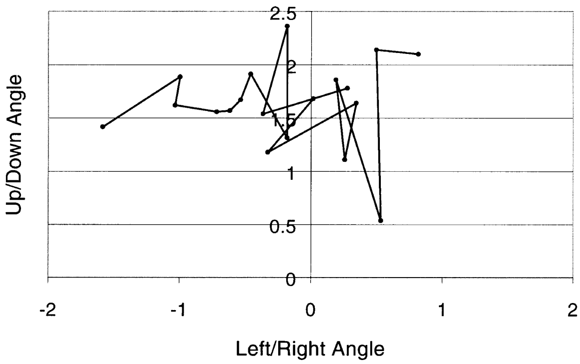

Figure 3. Plot of X and Y Split-Beam angles from a fish target at 41 m.

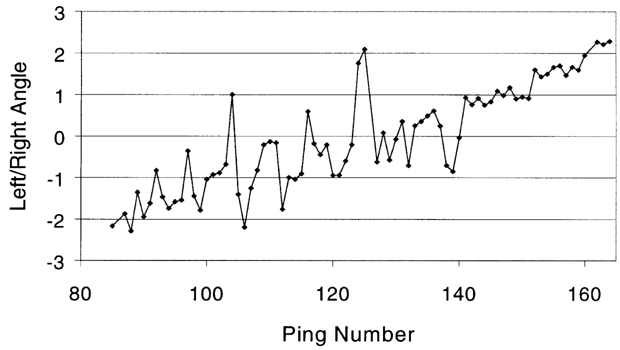

Figure 6. Movement of complex target through circular sound field, range 8 m.

other. The direction of travel for the fish at close range is not well characterized, however, due to the high variability in positional estimates.

At close range, the size of the target is actually larger than the nominal beam diameter. This violation of the point-source scattering assumption is illustrated in *figure 5*.

3.2. Experimental observations

Figures 6 and *7* show the sweep of the 2° circular beam across the complex target at 8 m and 2 m ranges respectively. Although both target tracks are highly variable in the X coordinate, the direction of movement is clear when the target is at 8 m, but is ambiguous when at 2 m. *Figures 8* and *9* demonstrate tracks through the circular sound field for the sphere at 8 and 2 m respectively. Both data sets from the sphere show a smooth progression of X positional estimates as the sound field is rotated across the targets. These observations were not unexpected in the low noise environment of the lakeshore environment. Some low frequency oscillations visible in *figure 9* are likely due to movement in the target support apparatus.

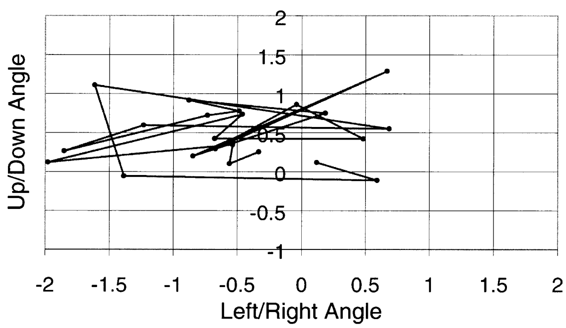

Figure 4. Plot of X and Y Split-Beam angles from a fish target at 3 m.

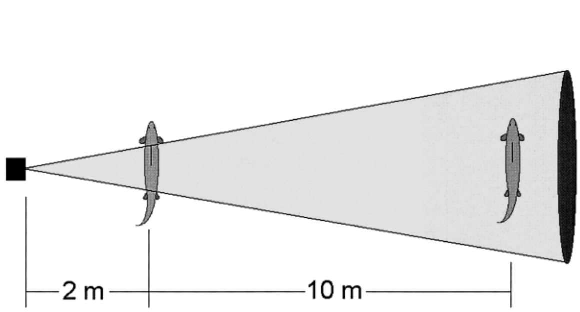

Figure 5. Graphical representation of point source violation.

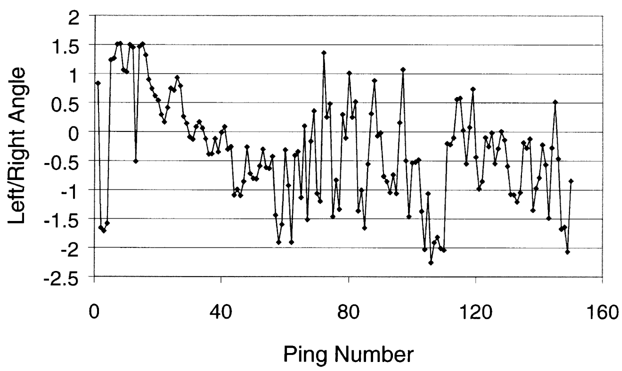

Figure 7. Movement of complex target through circular sound field, range 2 m.

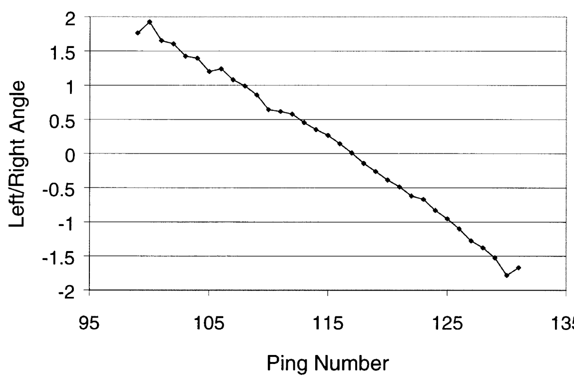

Figure 8. Movement of sphere through circular sound field, range 8 m.

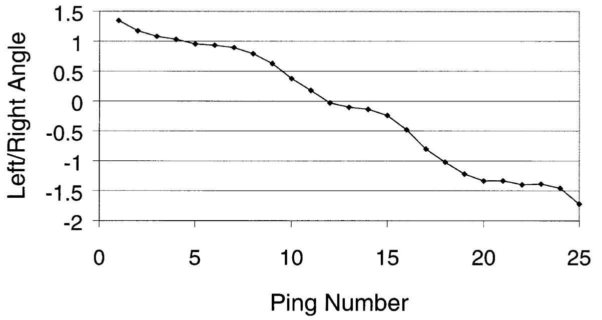

Figure 9. Movement of sphere through circular sound field, range 2 m.

The target track created as the complex target passed through the elliptical sound field at ranges 6 and 2 m are shown in *figures 10* and *11*. The elliptical beam encountered some aquatic vegetation at range 8 m, confounding the measurement of the targets at that range. Although variability increases with range, the overall direction of travel of the complex target through the elliptical sound field is unambiguous. Analysis of the sphere data in the elliptical beam (not shown) showed smoother trajectories and provided unambiguous directional estimates.

Since we were able to visually observe degradation of the split-beam positional data as range decreased, we examined a variety of ways to quantify these patterns. One of the most simple and intuitive ways was to run a linear regression through the trajectory, as shown in *figure 12*. The R^2 value from the regression served as an index of measurement precision. The R^2 values are plotted as a function of range and transducer beam shape in *figure 13*.

The R^2 value for the sphere approached a value of 1 for all measurements on the sphere. This suggests that the sphere acted as a point source target at all locations, as expected. The R^2 values for the complex target generally decreased with range.

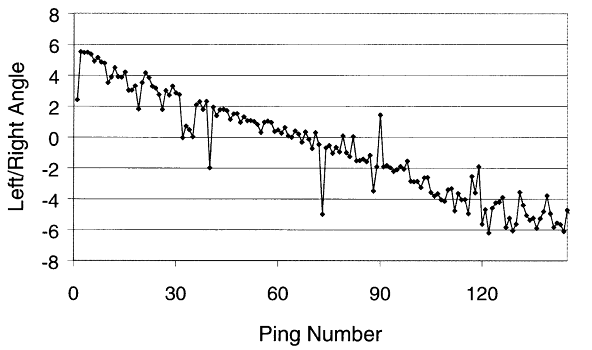

Figure 10. Movement of complex target through elliptical sound field, range 6 m.

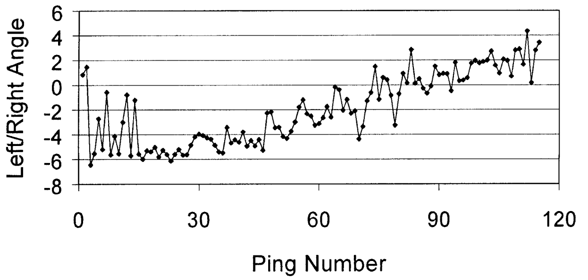

Figure 11. Movement of complex target through elliptical sound field, range 2 m.

3.3. CONCLUSION

From these observations, we suggest that fish targets have what may be considered a near-field, that is, they do not act as a point source scatterer within some range. Salmon are complex targets and generate considerable variability into the positional estimation

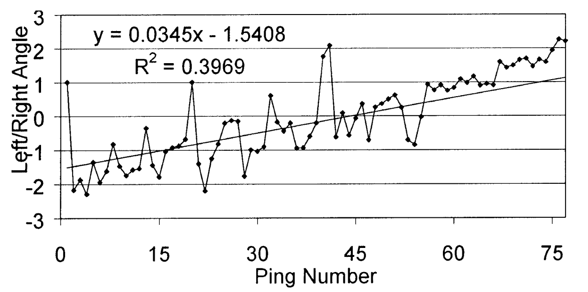

Figure 12. Linear regression through a fish trajectory data set.

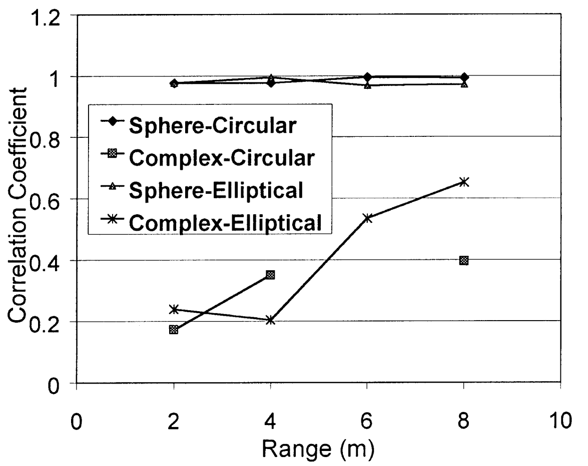

Figure 13. Plot of R^2 values by range for target and transducer type.

algorithms of a split-beam system. This problem may be alleviated to some degree by shaping the sound field cross-section to match the cross-sectional shape of the fish through use of elliptical transducers. Calculation of this near-field range using standard near-field formulae produces unrealistically large estimates. We believe that substituting a live fish for the complex target, and repeating this experiment with a variety of transducer shapes and acoustic frequencies can empirically measure the near-field of a fish. From this type of study, it should be possible to develop a model to predict the fish near-field, taking into account the fish length, transducer shape, and acoustic frequency. This model would be useful for specifying the transducer parameters to count fish at specific sites, as well as for developing range-dependent tracking parameters.

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