Reconstruction of Acoustic Exposure on Orcas in Haro Strait

D.M. Fromm
Acoustics Division

Introduction: On 5 May 2003, USS *Shoup* (DDG 86), an *Arleigh Burke*-class Navy Guided Missile Destroyer, transited from the Naval Station Everett via the Strait of Juan de Fuca and the Haro Strait to the Canadian Forces Maritime Experimental Test Range at Nanoose Bay on the eastern side of Vancouver Island, British Columbia. While underway, a sonar training exercise was executed from 10:40 to 14:40 (local time). During the exercise, unusual behavior was observed in one of the resident pods of orcas, raising the question of the sonar's impact on them. Due to two coincidental activities, this question can be addressed in detail.

Coinciding with *Shoup's* transit, a marine mammal class from Friday Harbor Labs led by Dr. David Bain was observing a pod of Southern Resident killer whales (*Orcinus orca*) (J pod).[1] The class shadowed the J pod from their boat, recording its behavior, the GPS location of the boat, and the time of day. Figure 1 shows the tracks of USS *Shoup* and Dr. Bain's boat shadowing the J pod overlaid on the bathymetry.

Additionally, acoustic recordings were made on monitoring hydrophones deployed by Dr. Val Veirs of Colorado College for his Orca Vocalization and Localization (OVAL) project.[2] More than 370 recordings on four hydrophones were made, spanning the time period that *Shoup* was transmitting for its long-range sonar operations.

Modeling Analysis: A detailed reconstruction of the event that related the locations of *Shoup*, the J pod, and the monitoring hydrophones during the time period of *Shoup's* long-range sonar operations was constructed. By combining high-fidelity predictions of the acoustic field with the in situ acoustic recordings, the reconstruction provides a moment-to-moment picture of the events of May 5.

Figure 2 shows an example of the reconstruction at a representative time in *Shoup's* transit. The map plots the positions of *Shoup*, the J pod, and the monitoring hydrophones over the bathymetry contours. (The ellipses are explained later.) The straight red lines indicate the direct path from the acoustic source to the J pod or to the monitoring hydrophones.

Acoustic field predictions were executed along the direct paths using the state-of-the-art, bench-marked, underwater acoustic propagation model RAM, developed at NRL.[3] A high-resolution, 3D description of a complex and highly range-dependent environment was assembled from databases, models, and inputs provided by experts at various Navy laboratories. The two plots of Fig. 3 show transmission loss in dB vs range and depth from *Shoup* to the hydrophones (a) and to the J pod (b).

Due to the complexity and range-dependence of the environment, a small shift in *Shoup's* location causes the details of the acoustic field to change while the mean acoustic field remains fairly stable. Therefore, it was appropriate to use histograms to quantify the received sound pressure levels (SPLs) in the vicinity of the phones and the J pod.

Dr. Val Veirs' acoustic recordings constituted a key part of the analysis for two reasons. First, because the recordings were calibrated, the predicted SPLs from *Shoup* to the monitoring phones could be validated for those times that the recording hydrophones were not overloaded. Second, through a spectral analysis of the recordings, the mode of operation of *Shoup's* sonar, which had not been logged, could be determined. Specifically, it could be proven that the first half of the transmission was directed to the port side of the ship (away from the hydrophones) and the second half of the transmission was directed to the starboard side of the ship (toward the hydrophones).

After receiving the direct path acoustic energy, the hydrophones recorded the reverberation, i.e., sound energy that scattered from interactions with the ocean surface and bottom. The time series showed up to 19 s of reverberation. The received intensity of reverberation from the port-side transmission is comparable to or greater than that in the starboard-side transmission despite the fact that it was directed away from the hydrophones.

Data Interpretation: To understand this, consider the ellipses plotted on the map in Fig. 2. The orange/dark-green ellipses have *Shoup* and the phones as their foci, while the yellow/light-green ellipses have *Shoup* and the J pod as their foci. These are approximate "travel time" ellipses for 1, 3, 5, … 17, 19 s from the smallest to the largest. That is, if the moment in time when the sound arrives along the direct radial path from *Shoup* to the phones (J pod) is time t = 0 s, then reverberation from locations covered by the smallest ellipse arrives 1 s later, and reverberation from the next smallest ellipse arrives 3 s later (from t = 0) and so on.

For the *Shoup*-phone ellipses, the orange/dark-green shows the portions of the travel time ellipse that are not blocked by land and can actually contribute to the reverberation. The yellow/light-green ellipses illustrate the same thing for the J pod. Finally, the green (dark or light) portion of the ellipses corresponds to the reverberation due to the port-side transmission, and the orange/yellow portion of the ellipses corresponds to the reverberation due to the starboard-side transmission. It is evident that a significant amount of acoustic energy from the port-side transmission could

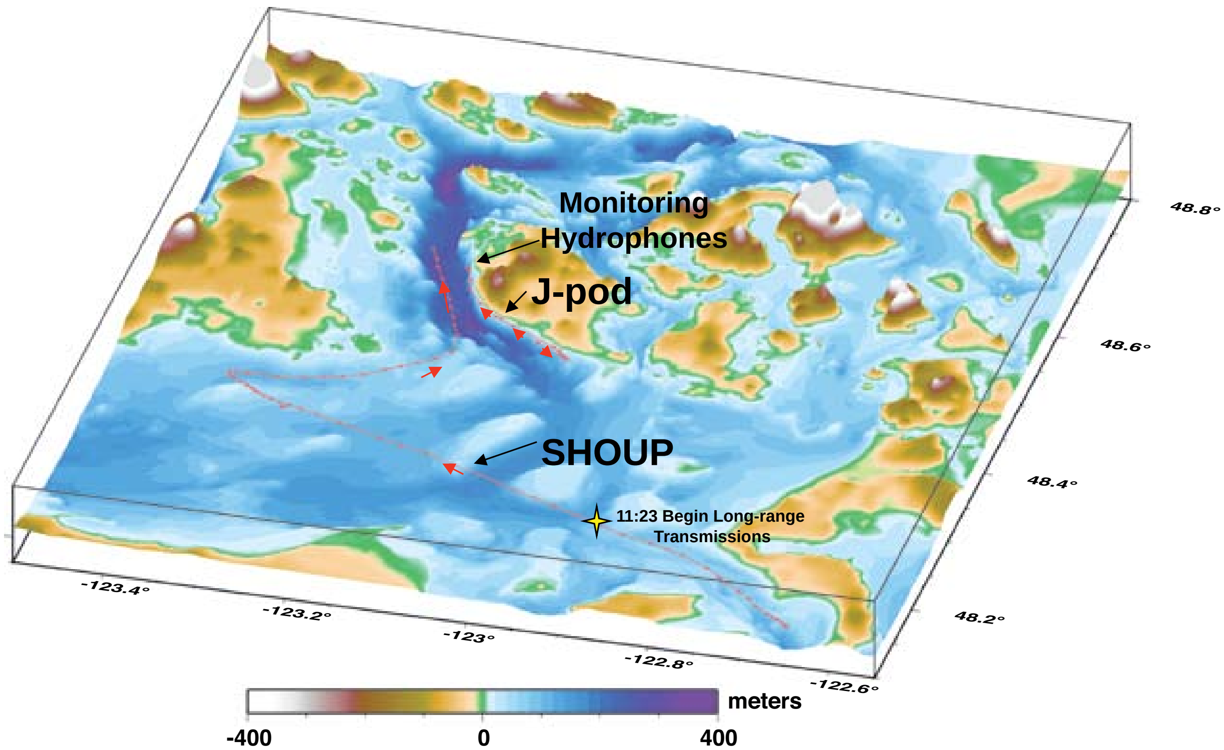

FIGURE 1
Three-dimensional image showing bathymetry and topology of the Haro Strait (deep blue) and surrounding region. The topology above 400 m elevation is in gray. The track of USS *Shoup*, corresponding to times when its sonar was active, proceeds from the lower right-hand corner at time 10:40 and ends at time 14:41 (all times local). The reported track of the boat containing Dr. David Bain and his students, who shadowed the J pod, proceeds from the center of the figure at time 10:47, heading initially southeast, and concludes at time 14:43 heading northwest. The monitoring hydrophones of Dr. Veirs are located shoreward of this last location. *Shoup*'s sonar was initially configured for short-range (less than 2.5 km) operations. From 11:23 until 14:40, it was configured for long-range operations (from 5 to 20 km). The first hydrophone recording available for analysis was from time 11:39.

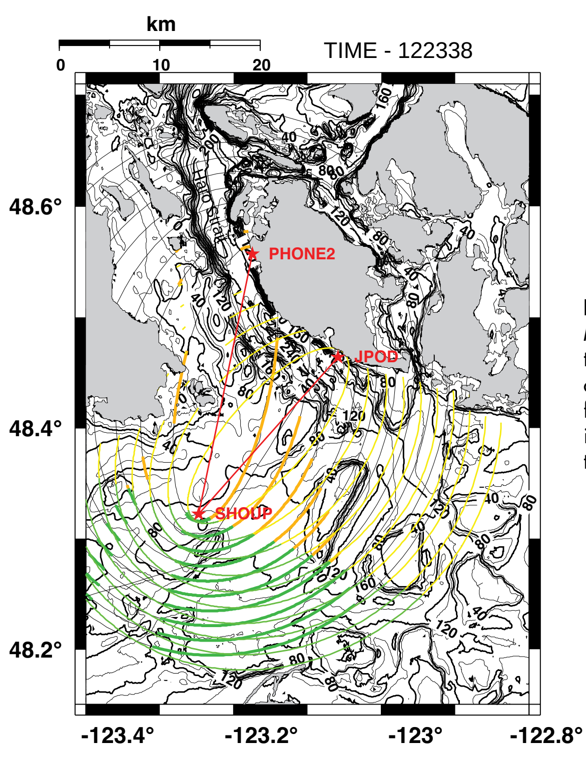

FIGURE 2
Map showing the positions of *Shoup*, the J pod, and the monitoring hydrophones over the bathymetry contours. The straight red lines indicate the direct path from the acoustic source to the J pod or to the monitoring hydrophones. The ellipses indicate location and timing of reverberation (see text).

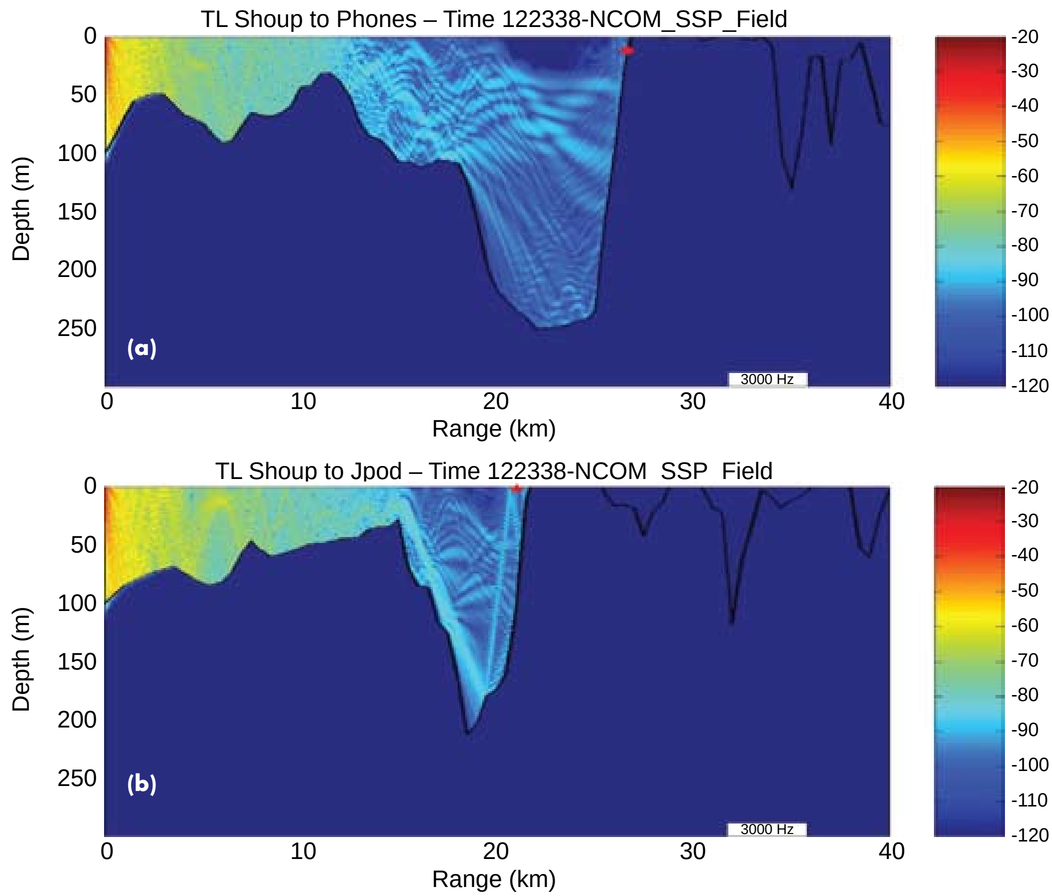

FIGURE 3
Bathymetry and RAM-predicted transmission loss as a function of depth and range for the direct-path radial lines from *Shoup* to the monitoring hydrophones (a) and to the location of the J pod (b).

be scattered from the ocean surface and bottom and received on the hydrophones.

Summary and Conclusions: The comparison of the predicted and measured direct path SPLs on the hydrophones indicated that the model was tending to predict levels ranging from 1 to 10 dB higher than those recorded. Improving the acoustic predictions would require an actual in situ measurement of the sound speed field and a much more detailed description of the bottom properties throughout the region. The predicted SPLs were considered to be an overestimate of the mean SPL received at the monitoring hydrophones and experienced by the J pod.

By combining the model predictions with the acoustic recordings, a time series of the SPL received by the J pod could be created for the entire event that became more accurate as the J pod and *Shoup* both approached the locations of the hydrophones. By integrating this time series a total energy exposure for the J pod could be calculated. From these results, the National Marine Fisheries Service (NMFS) determined that the J pod's exposure levels did not reach the levels for a temporary threshold shift in hearing, let alone a permanent threshold shift. Without the evidence of the directionality of the sonar's mode of operation, the total predicted exposure would have been approximately twice as high and NMFS's conclusion might have been different.

The results of this reconstruction were also used in the development of a risk continuum function to relate acoustic exposure levels to the probability of a behavioral response. This risk continuum function was used in the analysis supporting the recent Environmental Impact Statement for the Hawaii Range Complex.

[Sponsored by COMPACFLT]

References

[1] D. Bain, Field notes provided to the National Marine Fisheries Service NorthWest Region (NMFS NW); subsequently made available to U.S. Navy by NMFS NW for the express purpose of completing this acoustic analysis (2003).
[2] V. Veirs, Acoustic recordings made under the OVAL program and provided to NMFS NW; subsequently made available to U.S. Navy by NMFS NW for the express purpose of completing this acoustic analysis (2003).
[3] M.D. Collins, "A Split-step Pade Solution for Parabolic Equation Method," *J. Acoust. Soc. Am.* **93**, 1736–1742 (1993).