Quantifying Intra-Species Variation in Acoustic Backscatter Models

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Abstract: Fisheries researchers are increasing the use of acoustic backscatter models in estimates of fish and zooplankton abundance. Target strength models based on measurements from a few fish may be applied to all individuals of the same species at frequency. The choice of carrier frequency combined with morphological and behavioral differences among organisms will influence amplitudes and variability of backscattered echoes. We quantified variability in backscatter of Atlantic cod (*Gadus morhua*) and brook trout (*Salvelinus fontinalis*) using data from digitized x-rays and Kirchhoff-ray mode models. Backscatter means and variances were combined to map the probability of discriminating cod from trout backscatter over a range of aspect angles, fish lengths, and acoustic frequencies.

INTRODUCTION

Acoustic technology is an accepted and increasingly important part of aquatic research and resource management. Precise conversion of acoustic data to estimates of organism size, distribution, and abundance requires quantification of variability associated with acoustic measurements. Measurements of target strength have been widely used to relate fish length and aspect to backscatter amplitude (1). Variability in backscatter amplitude is traditionally treated as noise. This study uses an anatomically-based model to quantify variance in factors influencing acoustic backscatter and to estimate the probability of classifying targets in mixed species ensembles.

METHODS

Digitized x-rays from surface adapted cod (n=9, range 156 to 418 mm) and trout (n=10, range 98 to 149 mm) were combined with a Kirchhoff-ray mode (KRM) model (2) to estimate acoustic backscatter. The KRM model coherently sums backscatter from a set of fluid-filled cylinders representing the body and a set of gas-filled cylinders representing the swimbladder. The model is parameterized for each fish and lengths are scaled for comparison. Model backscatter values have been shown to match field measurements (2,3) and the model has been applied to other species at numerous frequencies (3).

Intra- and inter-species backscatter was examined as a function of acoustic wavelength (λ), fish length (L), and fish aspect (θ). For each fish, backscatter was calculated at a fish length of 200 mm, over a frequency range of 12 kHz to 420 kHz, and over an aspect range of 70° to 110° (angles > 90° are head up). The L/λ range (1.6 to 57.6) mimics frequencies used by fisheries acousticians. Intra-species variability was examined by calculating the mean and variance in reduced scattering lengths (L_{bs}/L) of fish for all θ and L/λ combinations. Inter-species variability was examined by contouring the probability of detecting a difference in mean cod and trout backscatter amplitudes (t-test of means, variances assumed unequal, coded positive (cod) or negative (trout) by the larger mean in a cell).

RESULTS

General shapes of mean backscatter surfaces for cod and trout are similar (Fig. 1). Mean reduced scattering lengths for both species peaked (L_{bs}/L =0.08) when fish are orthogonal to the acoustic wave front and decrease as the aspect angle deviates from 90°. The width of the peak indicates the range of tilt-angles formed by the swimbladder relative to the sagittal axis of the fish body. Interference nodes and nulls regularly cycle along the L/λ axis for both species. Variance in backscatter amplitude is proportional to L/λ values for both species at head-down aspects (i.e. <90°). This increase in variance with increasing frequency occurred over a narrower band of angles in trout compared to variances observed in backscatter from cod. At head down aspects, reduced scattering lengths varied little within or between species across the L/λ range examined.

A total of 2653 (62.8%) mean reduced scattering lengths in the θ and L/λ matrix were significantly different ($p<0.1$, df~17 adjusted for variance in each cell). A greater number of cells had significantly higher reduced

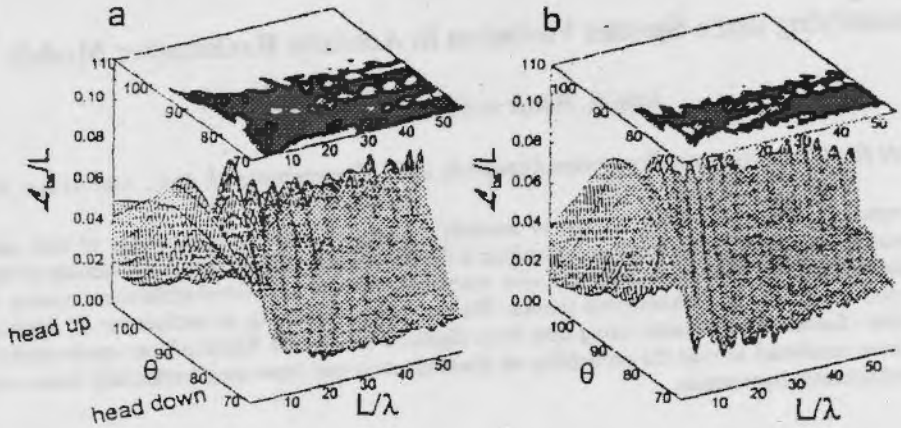

FIGURE 1. Mean (lower surface) and variance (upper contour) of reduced scattering length (RSL) plotted as a function of fish aspect (θ) and the ratio of fish length to acoustic wavelength (L/λ) for Atlantic cod (a) and brook trout (b).

scattering amplitudes from cod than from trout (Fig. 2). 'Cod' cells (white) form a band of angles roughly centered on 90° and extend across all L/λ's. 'Trout' cells (black) dominate head down aspects and were found on the margins of the scattering matrix. Grey cells indicate no significant difference between backscatter means. If aspects and lengths of species are known, a suitable frequency can be chosen to maximize the probability of detecting and discriminating between species.

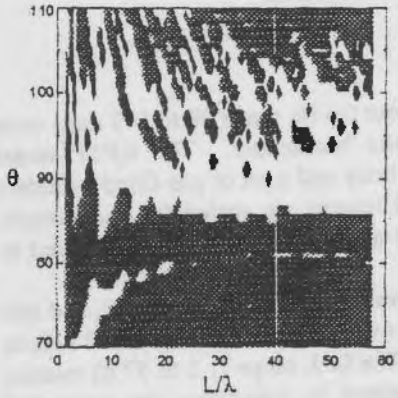

FIGURE 2. Probability ($p < 0.9$) of detecting trout (black) or cod (white) as a function of fish aspect (θ) and the ratio of fish length to acoustic wavelength (L/λ). Grey indicates no significant difference.

DISCUSSION AND CONCLUSIONS

Examining variability in backscatter amplitudes is not new (1). Recent numeric models include organism anatomy, and exploit increased computing power. It is naive to believe that single variables will accurately characterize backscatter at rather high frequencies ($1 > L/\lambda < 20$). Application of model results allow us to quantify the relative contributions of backscatter variability and make intelligent hardware choices. Probability and Bayesian (4) approaches quantify the uncertainty of detecting and distinguishing among target types.

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