Automated probabilistic echo solving: a scalable Bayesian inverse approach for fisheries acoustics

Identifying echo sign is a perennial challenge in fisheries acoustics. Most practitioners classify acoustic backscatter using a combination of direct sampling (such as research trawls) and contrasts between different echosounder frequencies, then estimate abundance by integrating the echo energy at a single frequency. While time-tested, this approach struggles with species mixtures, and discards multi-frequency information when integrating. Inverse methods do not have these limitations, but are seldom used, because their species identifications are often ambiguous and their algorithms complicated to implement. We address these shortcomings with a probabilistic, Bayesian inversion method. Like other inversion methods, it handles species mixtures, uses all available frequencies, and extends naturally to broadband signals. Unlike prior approaches, it leverages Bayesian priors to rigorously incorporate information from direct sampling and biological knowledge, constraining the inversion and reducing ambiguity in species identification. Because it is probabilistic, it can be trusted to run automatically: it should not produce solutions that are both wrong and confident. Unlike some data-driven machine learning models, it is based on acoustical scattering processes, so its inferences are physically interpretable. Finally, the approach is straightforward to implement using existing Bayesian libraries, and is easily parallelized for large datasets. We present examples using simulations and field data from the Gulf of Alaska, and discuss possible extensions and applications of the method.