

Unobserved Detection Heterogeneity in Distance Sampling: Bias, Robustness, and Gamma Frailty Models

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Abstract

Distance sampling estimates abundance by modeling detectability as a function of distance. Unobserved heterogeneity among survey sites or transects can alter the detection process and, when inadequately represented by the fitted detection function, bias abundance estimation. We introduce a Gamma frailty into the detection hazard, providing a tractable random-effects formulation for point- and line-transect surveys. We develop a joint maximum likelihood estimator and a computationally efficient marginalized pseudo-likelihood estimator paired with cluster-robust standard errors. For a class of single-parameter survival-form detection functions, we show analytically that ignoring Gamma frailty inflates the fitted detection scale and consequently underestimates abundance. This establishes a direct mechanism through which this form of unobserved heterogeneity produces negative abundance bias when a homogeneous detection model is fitted. Simulations show that incorporating random effects can reduce bias when relevant detection covariates are omitted. Moreover, such models may provide useful flexibility by absorbing some of the effects of omitted detection-function structure, including conventional cosine adjustment terms. Two empirical applications illustrate how accounting for unobserved heterogeneity affects abundance estimation and uncertainty quantification in practice.