Estimating shifts in squid distribution

To estimate shifts in the distribution of squid between 1998 and 2019 in response to biological (e.g., chlorophyll concentration (xx/mm), *Chl a*) and climate forces (e.g., temperature), we analyzed catch-per-unit-effort (CPUE) data from fisheries independent surveys conducted by the National Oceanic and Atmospheric Association (NOAA) between 1998 and 2019. We used a delta-generalized linear model (delta-glmm) to estimate the probability of encountering squid during a survey, and the probability of positive catches if squid were encountered

Equation .

Where for the ith sample, is observed number of squid captured, is the probability of positive catches, is the expected number of squid captured given positive catches, is the effort offset (i.e., distance fished times the average opening of the net (0.05 km)), is the observed error not explained by biological or environmental covariates, or random variation in the spatiotemporal distribution of the catches, and g is a probability distribution describing the positive catches (e.g., gamma, log-normal, etc.).

We used a variance-autoregressive spatiotemporal (VAST) model implemented in the R package VAST to partition the sources of variability in the catches based on the fixed effects associated with the biological and environmental covariates, and random spatial and spatiotemporal variation for the encounter probabilities and positive catch rates. Analyst implementing VAST models must make numerous decisions based on the type and quality of the data: we followed the recommendations of Thorson (2019).

Because there is both an encounter probability and probability of positive catches in Equation 1, we must define for how the *i*) intercepts, *ii*) covariates, and *iii*) spatiotemporal processes affect each estimate. The estimates of and are the transformations of linear combinations of these three components (Equation 2 and Equation 3).

Equation .

Equation .

The intercept parameters represent estimates of the annual changes in the encounters and catches for category in year . We restricted the categories in our model to ***small and large*** length categories. The parameters describe the change in the catchability of squid based on the kth covariate related to the ith observation . Because the covariates are related to the observation, there is no subscript for the encounter or positive catch models. The spatialand spatiotemporal random effects describe the residual variance not explained by the fixed intercepts or covariates for the location of the ith observation related to factor f. Because our model has categorical size data describing, the loading matrices allow us to estimate the covariance of these two groups as it related to the spatial and spatiotemporal processes. A detailed description of the decision that were made concerning the model formulation are found in Table xx, and the Supplemental XX contains the R script used to build the objects for the VAST wrapper functions.

Results