Population simulation operating model

The parameter values and equations governing the model are given in Tables 1 and 2, respectively. The population model runs for 100 years, with a fishing time series beginning in year 26 (years 26-100 experience fishing). The fishing time series was simulated as a two way trip with a linear increase from 0 in year 25 to a fully selected fishing mortality that was >*F*msy () and achieved 85% of maximum sustainable yield (MSY, at equilibrium) in year 85 of the time series, followed by a linear decrease to a fully selected fishing mortality that was <*F*msy () and also achieved 85% of MSY at equilibrium.

One hundred simulation iterations were run for each population model specification (Table 3), with stochasticity included using log-normal draws for recruitment deviations in each year. A sampling model then sampled from that population and fishery exploitation model to simulate the data collection process.

Sampling model

Annual landings were simulated using a log-normal distribution with a standard deviation (SD) of 0.05. A fishery index was simulated using a lognormal distribution where the SD was specified as a treatment within the simulation design, taking values of 0.25 or 0.5 (Table 3). The catch age-composition available for select years throughout the time series was simulated using a multinomial distribution. Age composition data was simulated from years 26, 36, 46, 51, 56, 61, 66, 71, and consistently from year 76 to 100. The number of samples began at *n*=30 in year 26 of the model (first year with fishing), increasing by 10 each decade until year 51, and then increasing by 10 every 5 years until year 76 where it was fixed at *n*=100 for the rest of the time series. This composition specification was similar to that used in Ono et al., (2015). Once the true observed age composition was simulated, ageing error was included by drawing from a multinomial distribution with probabilities defined using an ageing error matrix (the probabilities any specimen with true age *a* will be read as age 0, 1, …, *A*).

Estimation model

The estimation/assessment models were identical in structure to the population operating model. They began in year 26 of the time series (first year with data). The fixed-effect parameters estimated within the model included the unfished recruitment, the recruitment SD, a natural mortality parameter, two logistic selectivity parameters, catchability of the fishery index (if the index is included in assessment), and annual fully selected fishing mortality levels in each year (Table 1). Recruitment deviations in each year and those that make up the initial unfished abundance were treated as random effects. All other parameters were fixed at their true values from the operating model. The assessment models also fit the data using the same likelihoods used to generate data in the sampling model.

Model Fitting

Models were fit in a mixed-effects context in Template Model Builder (TMB, Kristensen et al., 2016) with recruitment deviations specified as random effects and the remainder of the fixed effect parameters identified in Table 1. TMB calculates the marginal negative log-likelihood given the fixed effect parameters using the Laplace approximation to integrate over random effects. Fixed effect parameters are estimated via minimizing the marginal negative log-likelihood within the program R using the nlminb function. Random effects and derived quantities are then predicted using empirical Bayes (Kristensen et al., [2016](javascript:;)). Starting parameter values for each simulation iteration were chosen by sampling from a uniform distribution with the bounds specified as 35% below and 35% above the true parameter value. Standard errors of parameter estimates were extracted in addition to those of derived quantities using the generalized delta method built into TMB.