Description of the process model for NEA cod age-structured population dynamics

The following provides a description of the process model for the NEA cod age-/stage-structured population dynamics. Further details are available online open access (Ohlberger et al. 2014). The model describes changes in abundance over time, and consists of a dynamic age-structured population model with lognormal process noise, which refers to stochasticity in the survival process due to environmental effects. Spawning stock biomass (SSB) in a given year (y) is calculated from age-specific abundance ($N_{a,y}$), weight-at-age ($W_{a,y}$), and the probability of being mature ($P_{a,y}$): $SSB_y = \sum_{a=1}^{a=A} N_{a,y} P_{a,y} W_{a,y}$, where a denotes age and A is maximum age. The number of eggs (N_e) is calculated from spawning stock biomass and fecundity: $N_{e,y} = SSB_y \tau e^{\varepsilon_{sp}}$, where τ is mean fecundity (eggs kg^{-1}), and $\varepsilon_{sp} \sim N(0,\sigma_{sp})$ is a Gaussian error term with mean zero and variance σ_{sp} describing stochasticity in the spawning process. The number of larvae (N_l) is calculated from egg abundance and mortality (M_e) during the period between egg and larval surveys (t_e): $N_{l,y} = N_{e,y} e^{-t_e M_e}$. The number of 0-group fish (N_z) is calculated from larval abundance and mortality (M_l) during the period between larval and 0-group survey (t_l), and a temperature effect ($\varphi_l T_l$) based on a proxy of the thermal conditions during the larval stage (June-August): $N_{z,y} = N_{l,y} e^{-t_l M_l + \varphi_l T_l}$. We further considered intercohort density dependence in the survival of the 0-group due to predation from older cod, and intracohort density dependence in the survival of age 1-3 juveniles based on Beverton-Holt relationships (Ohlberger et al. 2014). The number of age 1 fish (N_1) is thus calculated from 0-group abundance the previous year, an intercohort interaction ($\gamma N_{3+4,y-1}$) describing the increase in mortality with abundance of older cannibalistic cod, and mortality (M_z) during the period between 0-group and age 1 survey (t_z):

$N_{1,y} = N_{z,y-1} e^{-t_z M_z} \frac{1}{1+\gamma N_{3+4,y-1}} e^{\varepsilon_{M_z}}$, where $\frac{1}{1+\gamma N_{3+4,y-1}} e^{\varepsilon_{M_z}}$ was restricted to be < 1. The term $\varepsilon_{M_z} \sim N(0,\sigma_{M_z})$ accounts for variability in survival of the 0-group. The number of age 2-4 fish is calculated from the abundance of the previous age-class in the previous year, juvenile mortality (M_j), and an intracohort interaction ($\beta_a N_{a-1,y-1}$) describing the increase in mortality with abundance: $N_{a,y} = N_{a-1,y-1} \frac{1}{1+\beta_a N_{a-1,y-1}} e^{-M_j}$, for 2 ≤ a ≤ 4. Cod are recruited to the fishery at age 4, and fishing mortality on age 3 is assumed to be negligible (ICES 2013). The number of age 5-9 fish ($N_{a,y}$) is thus calculated from the abundance of the previous age-class in the previous year, natural mortality of adults (M_{4+}), and fishing mortality on that age-class the year before ($F_{a-1,y-1}$): $N_{a,y} = N_{a-1,y-1} e^{-(F_{a-1,y-1}+M_{4+})}$, for 5 ≤ a ≤ 9. This formulation assumes that natural and fishing mortality both occur throughout the year. Fishing mortality for a given age and year is modeled based on the age-selectivity of the fishery (f_a), and a year effect to account for temporal changes in fishing effort (f_y): $F_{a,y} = e^{f_a+f_y}$, where f_a represents the mean relative proportion by age of fish caught in the fishery, and f_y is a measure of fishing effort that is unknown and estimated in the model. We allowed for effort to change gradually over time due to changes in fisher's behavior, investments or regulations (Aanes et al. 2007). It was modeled as a random walk process following a normal distribution according to $\varepsilon_{f_y} \sim N(0,\sigma_{f_y})$: $f_y = f_{y-1} + \varepsilon_{f_y}$. For identifiability, effort in the first year was set to 0 (Gudmundsson 1994, Aanes et al. 2007). Finally, the catch for a given age and year ($C_{a,y}$) is related to age-specific abundances through: $C_{a,y} = \frac{F_{a,y}}{F_{a,y}+M_{4+}} N_{a,y}(1-e^{-(F_{a,y}+M_{4+})})$, which defines the true catch as the fraction of the total removal of individuals from the population due to fishing.

LITERATURE CITED

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