**Simple Age-structured Operating Model**

1. **Stage I - Current structures of a simple operating model** 
   1. Life history schedules

The length-at-age () is modeled following a von Bertalanffy growth model (E1.1) and the weight-at-age () is obtained from the weight-length relationship by the power function (E1.2). The maturity-at-age () is used to define the proportion of the mature female population at age and it follows a logistic function (E1.3). The sex ratio is assumed 1:1.

* 1. Stock-recruitment relationships (B-H based on mature female biomass)

The unfished equilibrium spawning biomass per recruit () is modeled as shown in E2.1 and the virgin recruitment () is 1,000,000. Expected annual recruitment of age 1 fish is computed from the Beverton-Holt stock-recruitment model (E2.2).

* 1. Initial condition

The number of fish in age group in the initial year is modeled by considering fishing mortality in spawning biomass per recruit (E3.1-E3.5). The spawning biomass of fish in year 1 is calculated based on mature female biomass (E3.6).

* 1. Basic abundance dynamics

The abundance of fish at age 1 () corresponds to annual recruitment of age 1 (E2.2) with recruitment deviations (E4.1). The abundance of each subsequent age of each year is modeled assuming exponential decay (E4.2-E4.4). The spawning stock biomass of fish in each year is calculated based on mature female biomass (E4.5). The abundance and biomass of fish in each year are calculated as shown in E4.6-E4.7.

* 1. One fleet (logistic selectivity)

Time-invariant logistic selectivity function is assumed for the fishery (E5.1). The landings-at-age during year is determined using the Baranov catch equation (E5.2). The landings in weight is calculated as shown in E5.3.

* 1. One survey (logistic selectivity)

Time-invariant logistic selectivity function is assumed for a fishery-independent survey (E6.1). The fishery-independent survey index () is scaled to the mean over time (E6.2-E6.4).

* 1. Time series of Fmult

The fully selected fishing mortality rate in each year is modeled with linear increase of and its lognormal deviates (E7.1). Currently, the first year of is defined as 0.01 and the last year of is defined as 0.4.

* 1. Observed data

Observed landings are modeled with a lognormal observation error (E8.1). Proportion-at-age data for landings are simulated using random draws from multinomial distributions with a sample size of 200 (E8.2-E8.3).

Time series of relative abundance (in numbers) of survey is modeled with a lognormal observation error (E8.4). Proportion-at-age data for surveys are simulated using random draws from multinomial distributions with a sample size of 200 (E8.5-E8.6)

* 1. Output data

The general flow of operations in the simple age-structured operating model is presented in Figure 1. The output data include simulated data from the population, such as spawning stock biomass (mt) per year, abundance (in number) per year, biomass (mt) per year, abundance-at-age (in number) per year, landings-at-age (in number) per year, landings (×1000 in number and mt) per year.

The output data also include true reference points calculated from the simulated data, such as maximum sustainable yield (MSY), fishing rate at MSY (FMSY), spawning stock biomass at MSY (SSBMSY), equilibrium recruitment at MSY (RMSY), biomass (both male and female) at MSY (BMSY), exploitation rate at MSY (EMSY), spawners per recruit at MSY (sprMSY), and spawning potential ratio at MSY (SPRMSY) which is virgin spawners per recruit divided by sprMSY. The fishing rate, along with equilibrium landings at fishing rate and equilibrium SSB at fishing rate are also saved as output data. The Fratio (F/FMSY) and SSBratio (SSB/SSBMSY) are also saved as output data.

The output data from the observation model include observed landings (1000 fish or mt) per year, observed proportion-at-age for landings per year, observed survey index (scaled) per year, and observed proportion-at-age for survey per year.

Table 1. Description and current values for index variables, structure parameters, state variables, derived variables, and stochastic deviation used in the operating model. The phase of estimated means the parameter is not fixed but estimable in the estimation process.

|  |  |  |  |
| --- | --- | --- | --- |
| **Symbols** | **Description** | **Current Value** | **R output** |
| **Index variables** | | | |
|  | Years | and | sim1$yr |
|  | Ages | and | par.sim1$ages |
| **Structural parameters** | | | |
|  | Asymptotic average length (mm) | 800 | par.sim1$Linf |
|  | Growth coefficient (year-1) | 0.18 | par.sim1$K |
|  | Mean length-at-age at zero age (year) | -1.36 | par.sim1$a0 |
|  | Length-weight coefficient | 2.5e-8 | par.sim1$a.lw |
|  | Length-weight exponent | 3 | par.sim1$b.lw |
|  | Slope of maturity ogive | 3 | par.sim1$slope.mat |
|  | Age at 50% maturity | 2.25 | par.sim1$A50.mat |
|  | Natural mortality rate-at-age (year-1)a | 0.2 | par.sim1$M.age |
|  | Proportion of female-at-age | 0.5 | par.sim1$proportion.female |
|  | Virgin recruitment | 1,000,000 | par.sim1$R0 |
|  | Steepness | 0.75 | par.sim1$h |
|  | Slope of selectivity for landings | 1 | par.sim1$slope.sel |
|  | Age-at-50% selection for landings | 2 | par.sim1$A50.sel |
|  | Slope of selectivity for survey | 2 | par.sim1$slope.sel.survey |
|  | Age-at-50% selection for survey | 1.5 | par.sim1$A50.sel.survey |
|  | Shape of the fully selected fishing mortality rate in year | Linear increase with and |  |
|  | Annual sample size for age composition of landings | 200 | par.sim1$n.L |
|  | Annual sample size for age composition of survey | 200 | par.sim1$n.survey |
| **State variables** | | | |
|  | Annual recruitment in year |  | sim1$N.age[,1] |
|  | Spawning biomass in year (mt) |  | sim1$SSB |
|  | Abundance-at-age in year |  | sim1$N.age |
| Table 1. Continued. | | | |
| **Symbols** | **Description** | **Current Value** | **R output** |
|  | Abundance in year |  | sim1$abundance |
|  | Biomass in year |  | sim1$biomass.mt |
|  | Landings-at-age in year in numbers |  | sim1$L.age |
|  | Landings in year y (mt) |  | sim1$L.mt |
|  | Survey abundance-at-age *a* in year *y* |  | survey.sim1.age |
|  | Survey abundance (sum across ages) in year *y* |  | survey.sim1 |
|  | Observed landings in year (mt) with noise |  | dat.input$L.obs |
|  | Proportion-at-age in year for landings |  |  |
|  | Observed proportion-at-age in year for landings |  | dat.input$L.age.obs |
|  | Observed survey abundance in year y with noise |  | dat.input$survey.obs |
|  | Proportion-at-age in year for survey |  |  |
|  | Observed proportion-at-age in year for survey |  | dat.input$survey.age.obs |
| **Derived variables** | | | |
|  | Length-at-age (mm) |  | par.sim1$len |
|  | Weight-at-age (mt) |  | par.sim1$W.mt |
|  | Maturity-at-age |  | par.sim1$mat.age |
|  | Unfished spawning biomass per recruit |  | par.sim1$phi.0 |
|  | Total mortality rate-at-age in year |  |  |
|  | Fully selected fishing mortality rate in year (year-1) |  | sim1$F |
|  | Selectivity-at-age for landings |  | par.sim1$selex |
|  | Selectivity-at-age for survey |  | par.sim1$selex.survey |
|  | Spawning biomass per recruit given |  |  |
|  | Equilibrium recruitment |  |  |
|  | Catchability coefficient for survey |  | dat.sim1$q |
|  |  |  |  |
|  | | | |
| Table 1. Continued. | | | |
| **Symbols** | **Description** | **Current Value** | **R output** |
| **Stochastic deviation** | | | |
| **Process error** | | | |
|  | Standard deviation of log recruitment | 0.2 | par.sim1$logR.sd |
|  | Recruitment deviates in year |  | par.sim1$logR.resid |
|  | Standard deviation of log Fmult | 0.2 |  |
|  | Fully selected fishing mortality deviates in year |  |  |
| **Observation error** | | | |
|  | CV of landings | 0.005 | par.sim1$cv.L |
|  | Landings deviates in year |  |  |
|  | CV of survey | 0.1 | par.sim1$cv.survey |
|  | Survey abundance deviates in year |  |  |

a Currently assumed constant across years.

b Input CV of landings for estimation model: dat.input$cv.L. Input CV of survey for estimation model: dat.input$cv.survey.

Table 2. The operating model for generating age-structured population dynamics, indices of relative abundance, and age composition data.

|  |  |
| --- | --- |
| **1. Life history schedules** |  |
| E1.1 |  |
| E1.2 |  |
| E1.3 |  |
|  |  |
| **2. Stock-recruitment relationships** |  |
| E2.1 |  |
| E2.2 |  |
|  |  |
| **3. Initial condition** |  |
| E3.1 |  |
| E3.2 |  |
| E3.3 |  |
| E3.4 |  |
| E3.5 |  |
| E3.6 |  |
|  |  |
| **4. Basic abundance dynamics** |  |
| E4.1 |  |
| E4.2 |  |
| E4.3 |  |
| E4.4 |  |
| Table 2. Continued. |  |
| E4.5 |  |
| E4.6 |  |
| E4.7 |  |
|  |  |
| **5. One fleet** |  |
| E5.1 |  |
| E5.2 |  |
| E5.3 |  |
|  |  |
| **6. One Survey** |  |
| E6.1 |  |
| E6.2 |  |
| E6.3 |  |
| E6.4 |  |
|  |  |
| **7. Time series of F** |  |
| E7.1 |  |
|  |  |
| **8. Observed data** |  |
| E8.1 |  |
| E8.2 |  |
| E8.3 |  |
| E8.4 |  |
| E8.5 |  |
| E8.6 |  |

Figure 1. The general flow of operations in the simple age-structured operating model.

