Dissecting SAM 1: N-Processes

Anders Nielsen & Olav Nikolai Breivik
an@aqua.dtu.dk

The parts of SAM

Processes:

- The three main processes are: Recruitment ($N_{1,y}$), survival ($N_{>1,y}$), fishing ($F_{a,y}$).
- These are treated as unobserved random effects in the model
- The processes describe the development of the system we are monitoring
- Observations related to the system are used to predict these processes

Observations:

- Anything we can observe, which can help to inform about the processes
- Common options are catch-at-age $C_{a,y}$, survey index-at-age $I_{a,y}$, total catches, biomass index, tagging, lengths ...
- From the process (and a few estimated model parameters) we should be able to predict the observations

Parameters:

- Fixed effects model parameters to be estimates
- E.g. catchabilities, variance parameters, and stock-recruitment parameters.

Here we will look at the N-process part

Recruitment

- In a state-space assessment model we want to setup a recruitment process
- The simplest possible option could be a random walk, where:

$$\log R_y = \log R_{y-1} + \varepsilon_y \ , \quad \text{where } \varepsilon_y \sim \mathcal{N}(0, \sigma_R^2)$$

- Another option could be to use the spawning stock biomass (SSB) to predict the rectuitment (if recruitment is at age 1 we need to use the SSB from the year before)
- Popular options are the functions:
  - Ricker: $R = \alpha \mathrm{SSB} e^{-\beta \mathrm{SSB}}$
  - Beverton-Holt: $R = \frac{\alpha \mathrm{SSB}}{1+\beta \mathrm{SSB}}$
- To use these we can setup the process like:

$$\log R_y = \log \mathrm{SR}(\mathrm{SSB}_{y-1}) + \varepsilon_y \ , \quad \text{where } \varepsilon_y \sim \mathcal{N}(0, \sigma_R^2)$$

  where the SR() function is the stock-recruitment function assumed.
- Variance parameter σ_R^2 is objectively estimated via maximum likelihood
- Prediction is straight forward

Recruitment exercise

- The data set `Robs.RData` contains three vectors `year`, `ssb`, and `Robs`.
- Start with the empty setup code in `Robs0.R` and `Robs0.cpp`
- Implement the state-space model corresponding to the 'true' unobserved recruitment following a random walk.
- In this exercise we consider `Robs` to be observations of recruitment subject to measurement noise.
- Consider how we could implement the Ricker and Berverton-Holt state-space versions.
- With only this subset of the assessment model we cannot yet implement the Ricker and Berverton-Holt state-space versions, but we will get back to that.
- Is the model describing data well (plot)?
- Some stocks have extreme recruitment events — could we somehow adapt the model to that?

Survival

- Models use the stock equation:

$$N_{a,y} = N_{a-1,y-1} e^{-F_{a-1,y-1} - M_{a-1,y-1}}$$

- If the oldest age group contains fish age A and older (a so-called plus-group), then

$$N_{A,y} = N_{A-1,y-1} e^{-F_{A-1,y-1} - M_{A-1,y-1}} + N_{A,y-1} e^{-F_{A,y-1} - M_{A,y-1}}$$

- Even with perfect knowledge of F_{ay} and M_{ay} we should still expect some uncertainty

In state-space models:

- F_{ay} and M_{ay} are considered rates in a process, e.g. as:

$$\log N_{a,y} = \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1,y-1} + \xi_{ay} \ , \quad \text{where } \xi_{ay} \sim \mathcal{N}(0, \sigma_S^2)$$

- Can also be formulated such that $N_{a+1,y+1} < N_{ay}$ always. Here considered a 'feature'
- Very small σ_S^2 not necessarily a problem
- Large σ_S^2 or one-sided deviations from stock equation can be used to diagnose problems

Survival exercise

- The data set `Nobs.RData` contains 'observations' of N_{ay} (`Nobs`) with observation noise.
- The data set also contain a few helper variables (`F`, `M`)
- Start with the setup code in `Nobs0.R` and `Nobs0.cpp`
- Here we will implement a multivariate state-space model for $\log N$, which uses (`Nobs`) as observations.
- For the youngest age group use a random walk recruitment model.
- For the following age groups use the stock-equation and adjust for plus group for oldest age.
- The observation equation is simple, because we simply assume

$$\log N_{ay}^{(obs)} = \log N_{a,y} + \varepsilon_{ay} \quad , \quad \text{where } \varepsilon_{ay} \sim \mathcal{N}(0, \sigma^2)$$

- Estimate the three variance parameters in the model (for recruitment, survival, and observation)
- Plot the fitted versus the observed $\log N$

Configuration options for N

```
$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
 1 0 0

$keyVarLogN
# Coupling of process variance parameters for log(N)-process
 0 1 1 1 1 1

$stockRecruitmentModelCode
# Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and
# 3 piece-wise constant).
 0
$constRecBreaks
# Vector of break years between which recruitment is at constant level. The break year is
# included in the left interval. (This option is only used in combination with
# stock-recruitment code 3)

$fracMixN
# The fraction of t(3) distribution used in logN increment distribution
 0
```

Adding stock-recruitment models (extra exercise after F-part)

- The data set `Nobs2.RData` contains the same observations as the previous exercise about N, which we will be extending, but in addition data on stock mean weight, fraction maturity, fraction F applied before spawning, and fraction M applied before spawning (`SW`, `MO`, `PF`, and `PM`). All of this is needed to calculate spawning stock biomass SSB.
- For a given year y SSB is defined as:

$$\mathrm{SSB}_y = \sum_{a=0}^{A} \mathtt{MO}_{ay}\mathtt{SW}_{ay}N_{ay}e^{-\mathtt{PF}_{ay}F_{ay}-\mathtt{PM}_{ay}M_{ay}}$$

- We need to be able to calculate SSB in the c-file, because the Ricker and Beverton-Holt stock-recruitment functions depend on it. Write a function to calculate SSB in the c-file.
- Implement options to switch to Ricker or Berverton-Holt stock-recruitment (from the random walk we first did).
- Which model is the best description of the data?