Introduction: Stock assessment modeling

Olav N.R. Breivik

Thanks to Anders Nielsen for borrowing course material

Norsk Regnesentral
ANVENDT DATAFORSKNING

Overview

- Introduce assessment modeling
- Introduce statistical assessment modeling
- Introduce statistical state-space assessment modeling
    - SAM is a state-space assessment model
    - We will implement the official NEA cod model during the day!

Fish stock assessment

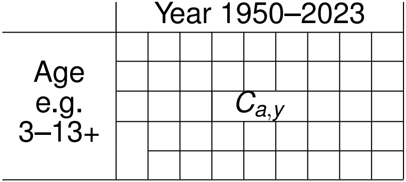
Want to know:

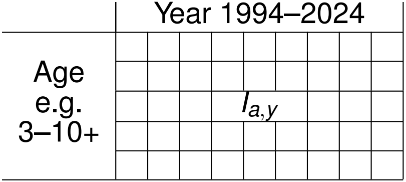
- How many fish are in the ocean?

Data:

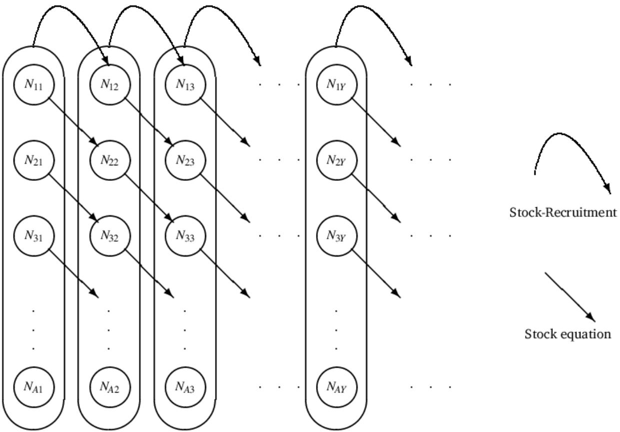
- $C_{a,y}$: Yearly catch-at-age (Typically calculated with ECA in Norway)
- $I_{a,y}$: Abundance indices-at-age

NEA haddock case study:

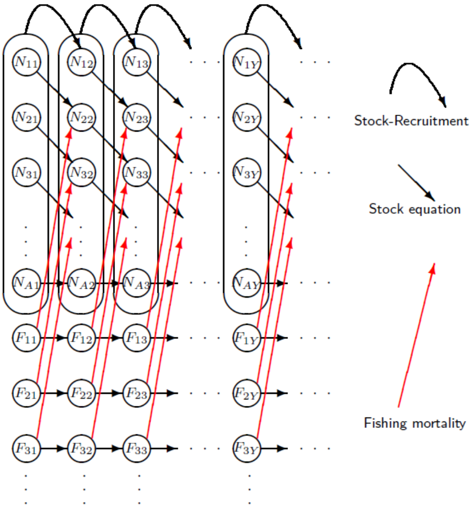




Population dynamic model



Population dynamic model



Population dynamic model

Stock equation: The number of fish in a cohort is expected to follow:

$$\frac{dN_t}{dt} = -(F_t + M_t)N_t$$

If F and M are assumed constant within each year we get:

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

- Typically included a plus age group

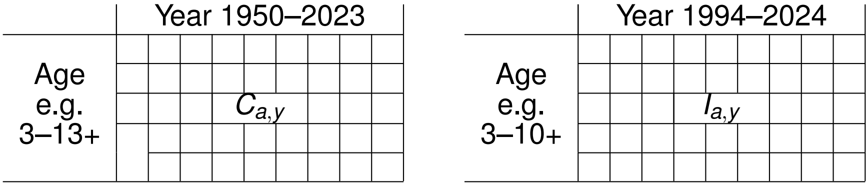
Stock–recruitment: Obviously connected — Difficult to estimate

- Often assumed random walk
- Several option we will elaborate tomorrow

Data:

- $C_{a,y}$: Yearly catch-at-age (Typically calculated with ECA in Norway)
- $I_{a,y}$: Abundance indices-at-age

NEA haddock case study:



Observation equations

Catch equation: The number of fish in a cohort after one year can be separated into:

$$N_{a,y} = \underbrace{N_{a+1,y+1}}_{\text{survived}} + \underbrace{C_{a,y} + D_{a,y}}_{\text{died}}$$

The part of the cohort that was caught during the year is:

$$C_{a,y} = \frac{F_{a,y}}{F_{a,y} + M_{a,y}} \left(1 - e^{-(F_{a,y}+M_{a,y})}\right) N_{a,y}$$

Index equation: The number of fish-at-age expected in index:

$$I_{a,y} = Q_a \underbrace{e^{-(F_{a,y}+M_{a,y})\tau}}_{\text{survived in year}} N_{a,y}$$

where $\tau \in (0, 1)$ is time of survey

Deterministic example

Imagine that a cohort consists of $N_0 = 1000$ fish in year 0. We know that $M = 0.2$ and $F = 0.4$.

```
N0 <- 1000; F <- 0.4; M <- 0.2
```

- We can calculate catch in year 0 and abundance in start of year 1:

```
C0 <- F/(F+M)*(1-exp(-F-M))*N0
N1 <- N0*exp(-F-M)
```

- We can calculate catch in year 1 and abundance in start of year 2:

```
C1 <- F/(F+M)*(1-exp(-F-M))*N1
N2 <- N1*exp(-F-M)
```

- Exercise 1a: Calculate catch and abundance the 10 first years
- Exercise 1b: How many percentage dies because of fishery each year?

See `exampleDeterministic.R` to get you started

Deterministic model

- A deterministic model ignores observation noise
- Examples:
  - Virtual population analysis (VPA)
  - The XSA-model
- These models works roughly speaking by

0: Guess the number of survivors $N_{A+1,y}$ and $N_{a,Y+1}$
1: Back calculate all $N_{a,y}$ by subtracting catch and natural mortality
2: Use surveys to adjust all $N_{a,y}$ and update survivors accordingly
3: Repeat 1-3 until survivors converge

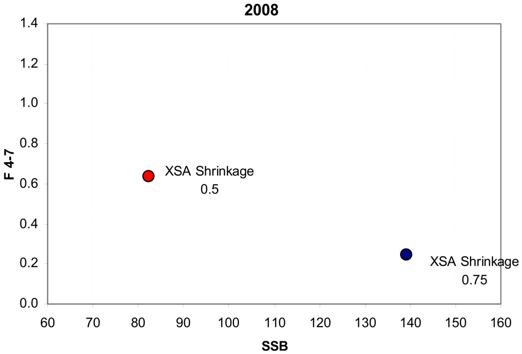
We will not do this deterministic approach! But that's how it was done before statistical models took over.

Pros and cons with deterministic model

+ Very fast to compute
+ Fairly simple to explain the path from data to stock numbers

– Difficult to explain why it converges, and what a solution mean
– These algorithms contain many ad-hoc settings (shrinkage, tapered time weights, ...) that makes them less objective
– No framework for comparing models (different settings)
– No quantification of uncertainties within model
– The assumptions are difficult to identify and verify
– With no clearly defined model more ad-hoc methods are needed to make predictions

Example: F-shrinkage for Eastern Baltic Cod



- These differences are not small and theoretical
- There are no objective way to choose between these two deterministic approaches
- Things would be simpler if we had a statistical model

Full parametric statistical assessment model

Stock equation: The number of fish in a cohort is expected to follow:

$$N_{a+1,y+1} = N_{a,y} e^{-Z_{a,y}}$$

where $Z_{a,y} = F_{a,y} + M_{a,y}$.

Need to make some simplifications to not have a too flexible model:

- Lets assume: $F_{a,y} = F_a F_y$

Observations equations:

$$\log(C_{a,y}) \sim \mathcal{N}\left(\log\left(\frac{F_{a,y}}{Z_{a,y}}(1 - e^{-Z_{a,y}})N_{a,y}\right), \sigma_c^2\right)$$

$$\log(I_{a,y}) \sim \mathcal{N}\left(\log\left(Q_a e^{-Z_{a,y}T} N_{a,y}\right), \sigma_s^2\right)$$

A full parametric statistical model

- A RTMB example is given `basicfsa.R`
- Data in `fsa.RData`
- The code is very short, so lets go trough it together.

Pros and cons with full parametric model

+ Very fast to compute
+ Fairly simple to explain the path from data to stock numbers
+ Have framework for comparing models (different settings)
+ Have quantification of uncertainties within model
+ Can verify assumptions

– Difficult to include time-varying fishing selectivity without over fitting
– Ad-hoc methods are needed to make predictions

State-space assessment model

- We studied a RTMB example is given `basicfsa.R`
- Q1: What is needed when modifying this implementation to a state-space assessment model?
- We will now introduce state-space models
  - Let's switch to presentation: `randomEffects.pdf`
  - We will be back soon

State-space assessment model

Stock equation: The number of fish in a cohort is expected to follow:

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

We log-transform and get:

$$\log N_{a,y} = \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1,y-1}$$

- Let $\log N_{a,y}$ be a latent variable
- Let $\log F_{a,y}$ be a latent variable

State-space assessment model

In SAM we assume that:

$$\log N_{a,y} = \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1,y-1} + \eta_{a,y}$$

Where $\eta_a \sim \mathcal{N}(0, \sigma_a)$

- $M_{a,y}$ is given as data
- $F_{a,y}$ is estimated as a random walk

State-space assessment model

In SAM we assume that:

$$\log N_{a,y} = \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1,y-1} + \eta_{a,y}$$
$$\log N_{A,y} = \log(N_{A-1,y-1} e^{-F_{A-1,y-1} - M_{A-1,y-1}} + N_{A,y-1} e^{-F_{A,y-1} - M_{A,y-1}}) + \eta_{A,y}$$

Where $\eta_a \sim \mathcal{N}(0, \sigma_a)$

- $M_{a,y}$ is given as data
- $F_{a,y}$ is estimated as a random walk

State-space assessment model

In SAM we assume that:

$$
\begin{aligned}
\log N_{1,y} &= \log R(\mathbf{N}_{y-1}) + \eta_{1,y} \\
\log N_{a,y} &= \log N_{a-1,y-1} - F_{a-1,y-1} - M_{a-1,y-1} + \eta_{a,y} \\
\log N_{A,y} &= \log(N_{A-1,y-1} e^{-F_{A-1,y-1} - M_{A-1,y-1}} + N_{A,y-1} e^{-F_{A,y-1} - M_{A,y-1}}) + \eta_{A,y}
\end{aligned}
$$

Where $\eta_a \sim \mathcal{N}(0, \sigma_a)$

- $M_{a,y}$ is given as data
- $F_{a,y}$ is estimated as a random walk

Exercise

- We introduced a full parametric assessment model, see `basicfsa.R`
- We can modify it into a state space assessment model by
  - Letting $\log F$ and $\log N$ be latent processes
- Exercise 3: Modify `basicfsa.R` into a state space assessment model

Hints:

- Need to include $\log N$ and $\log F$ as parameters
- Need to include process parameters in $\log N$ and $\log F$
- Need to calculate the likelihood contribution by the latent process
- Need to inform RTMB that we should marginalize over $\log N$ and $\log F$

```
obj <- MakeADFun(nll, par, random = c("logF","logN"))
```

- See `basicfsaStateSpace.R` to get you started

- That is SAM in a nut shell. Not very difficult!
- There are many model extension in SAM:
  - Correlated observations
  - Densitydependent catchability
  - Prediction-variance relation
  - Use of external data on uncertainty
  - Much more ...
    - we will go trough everything in detail the next two days
- Validation is done simple in SAM:
  - Residuals
  - Retro respective analysis
  - Leave-out runs
  - AIC comparison

Pros and cons with state space model

- \+ Very fast to compute
- \+ Fairly simple to explain the path from data to stock numbers
- \+ Have framework for comparing models (different settings)
- \+ Have quantification of uncertainties within model
- \+ Can verify assumptions
- \+ Easy to include time-varying fishing selectivity
- \+ No ad-hoc methods are needed to make predictions

- – Difficult to understand?
  - Easy to implement with RTMB

NEA cod assessment model

- Now we have implemented a state-space assessment model
- Only one small modification needed to make the NEA cod assessment model!
  - Correlated observation
  - See `SAM-NEAcod.R` for an implementation