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F_{MSY} estimates for constant or density dependent growth – comparison of age-structured and production models

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Objective

The objective of the analysis was to find out how well F_{msy} estimates based on production models reflect "true" values in case of:

a. constant growth

b. density dependent growth (DDG).

Methods

Analysis consisted of four steps

1. Generating the stocks with wide range of life history parameters (Operating Model)
   a) Constant growth
   b) Density-dependent growth
2. Fitting the production model (SPiCT) to generated stocks to estimate F_{msy}
3. Long-term simulations to estimate F_{msy} (ICES standard way)
4. Comparison of results

Methods, OM

Parameters of generated stocks

1. Steepness (h), natural mortality (M) & growth parameters (K)
   a) h = 0.5, 0.7, 0.9;
   b) M=0.2, 0.3;
   c) K= 0.4, 0.7, 1.2 (Linf assumed 1).
2. Ages 1-20; maturities and selectivity's were assumed 1 at all ages
3. Beverton & Holt stock-recruitment (parameters defined by h)
4. Growth: constant or DD

In total 18 stocks (36 when growth considered); for each stock and constant growth F_{msy} estimated using approach of Horbowy & Hommik (2022)* (S-R parameters with combination of YPR & SPR provide equilibrium yield and biomass curves)

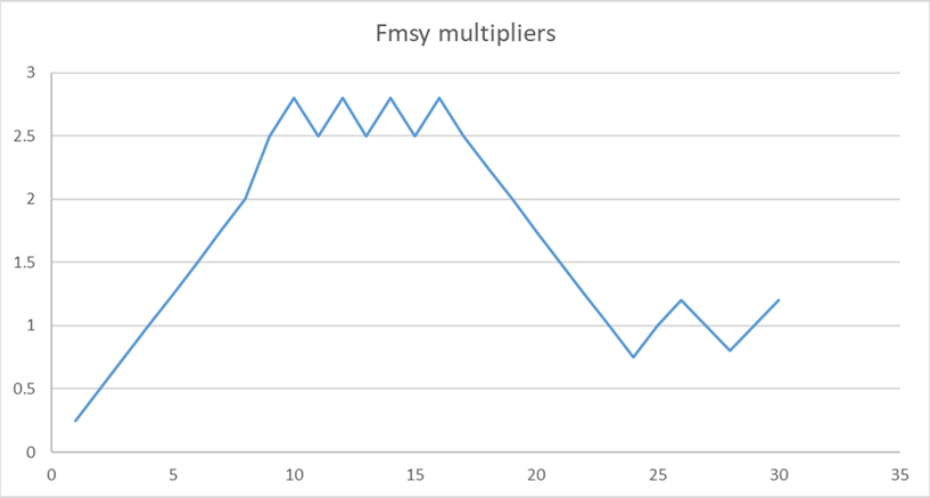
*Horbowy, J., & Hommik, K. 2022. Analysis of Fmsy in light of life-history traits—Effects on its proxies and length-based indicators. Fish and Fisheries, 00, 1–17. https://doi.org/10.1111/faf.12640

Methods, generated stocks

stock	h	k	M	estim. Fmsy
1	0.5	0.4	0.2	0.100
2	0.7	0.4	0.2	0.150
3	0.9	0.4	0.2	0.200
4	0.5	0.7	0.2	0.130
5	0.7	0.7	0.2	0.200
6	0.9	0.7	0.2	0.280
7	0.5	1.2	0.2	0.160
8	0.7	1.2	0.2	0.280
9	0.9	1.2	0.2	0.430
10	0.5	0.4	0.3	0.130
11	0.7	0.4	0.3	0.200
12	0.9	0.4	0.3	0.260
13	0.5	0.7	0.3	0.170
14	0.7	0.7	0.3	0.270
15	0.9	0.7	0.3	0.370
16	0.5	1.2	0.3	0.230
17	0.7	1.2	0.3	0.400
18	0.9	1.2	0.3	0.610

generated stocks, constant growth

Methods, fishing mortality



Fishing mortality for each stock for period of 30 years was generated as **product of estimated F_{msy}** and assumed **multipliers** (Figure). F generated in such way showed possible development of the fishery:

a) increasing in first 10 years to high level, from $0.25*F_{msy}$ to $2*F_{msy}$,

b) fluctuating at next 8 years at high levels of $2.5\text{-}2.8*F_{msy}$,

c) next declining to F close to F_{msy},

d) fluctuating at F_{msy} at final years of generated period.

Methods, DDG

Density-dependent growth as in Horbowy & Luzeńczyk (2017)*

$$w(a,y) = w(a)_{constant} \frac{\alpha}{\beta + stock}$$

where

- ✓ w(a,y) is weight at age *a* in year *y*,
- ✓ $w(a)_{constant}$ is weight constant in years,
- ✓ α, β are parameters related to DD in growth,
- ✓ *stock* is a measure of stock size used to model DD, e.g. total biomass, spawning biomass, total numbers etc.

The term $\frac{\alpha}{\beta + stock}$ is a "correction" for initial (constant) weight, when DD is included in the analysis. Parameters α and β were estimated to get the term approximately 1 for average biomass, and constrained approximately to interval 0.75 – 1.25

*Horbowy, J., Luzenczyk, A. 2017. Effects of multispecies and density-dependent factors on MSY reference points: Example of the Baltic Sea sprat. Can. J. Fish. Aquat. Sci. 74: 864–870. dx.doi.org/10.1139/cjfas-2016-0220

Methods, DDG

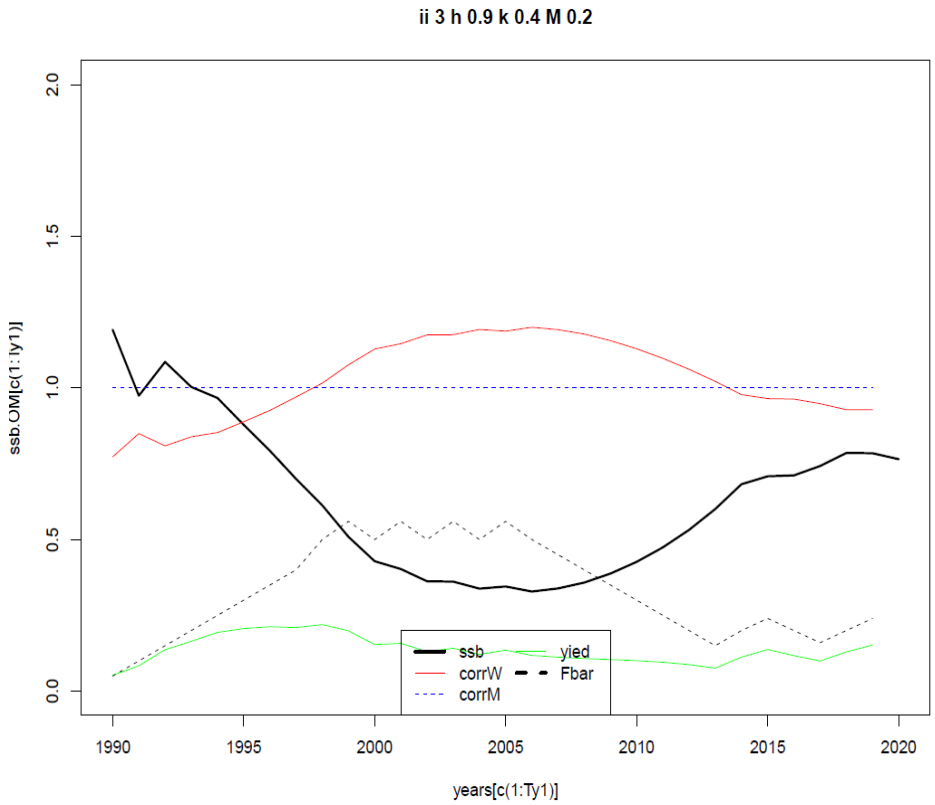


Figure. Example of a generated stock dynamics (stock 3 from Table 1). corrW & corrM are "correction" factors for constant w & M to get density dependent variable (corrM has not been used so far).

For each of such stocks (OM):

1. SPiCTs were fitted to get SPiCT based F_{msy}
2. long-term predictions (100 years) at wide range of Fs, to get F_{msy}

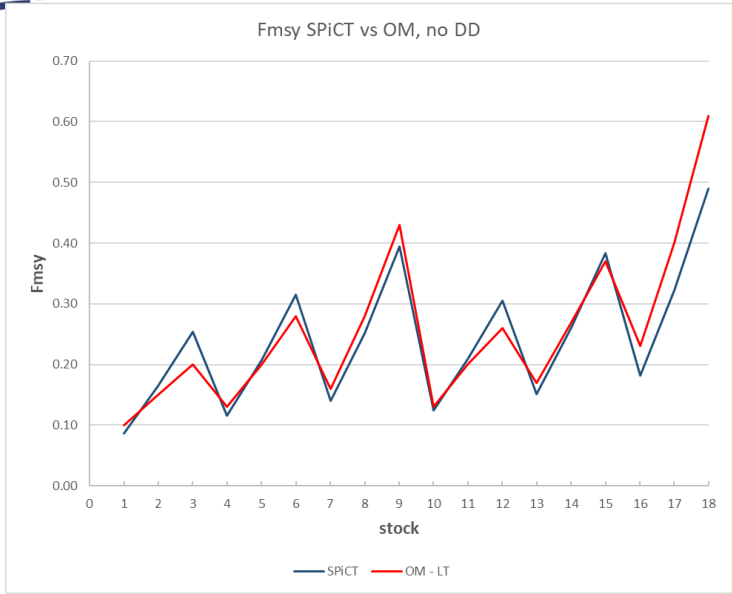
Methods, simulations

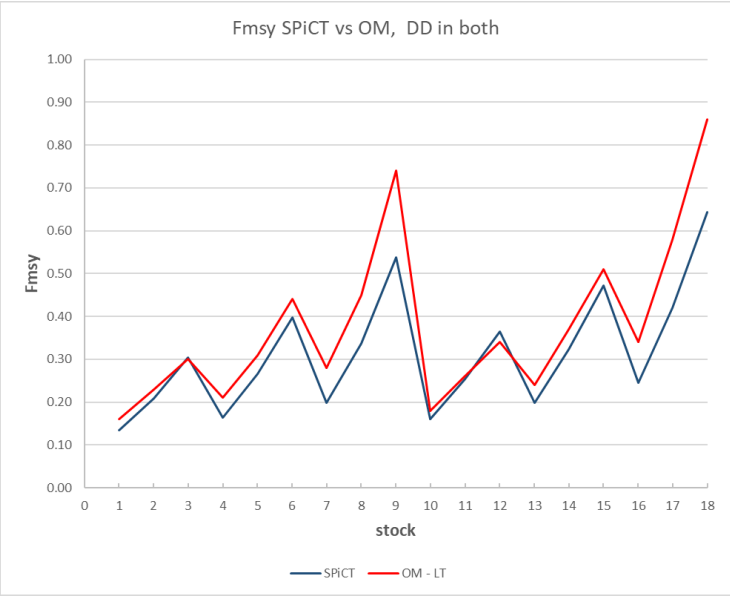
Considering DD the following options were simulated:

1. **Constant growth**, **both in generated and in prediction parts** (LT predictions based on constant weight)
2. **DD growth in both generated & prediction parts**
3. **DD in generated part but in LT predictions average of weights** from selected years simulated in generated part were used, e.g.
   a. Average weight over entire time series of the generated part
   b. Average weight over first 3 years or last 3 years of the generated part
   c. Average weight over first 10 years or last 10 years of the generated part
   d. Average weight over 5 middle years of the generated part

In total **for each stock eight LT predictions** were performed, one for each of option 1.-2. and 6 for options 3.

Results: SPiCT vs LT predictions





1. quite a similar F_{msy} estimates from SPiCT and LT predictions when DD in growth is not considered (left Figure)
2. the differences between estimates get somewhat higher when DD is included (right Figure); these higher differences are mainly for stocks with high growth rate (K=1.2), i.e. stocks 7-9 and 16-18.

Results: SPiCT vs LT predictions

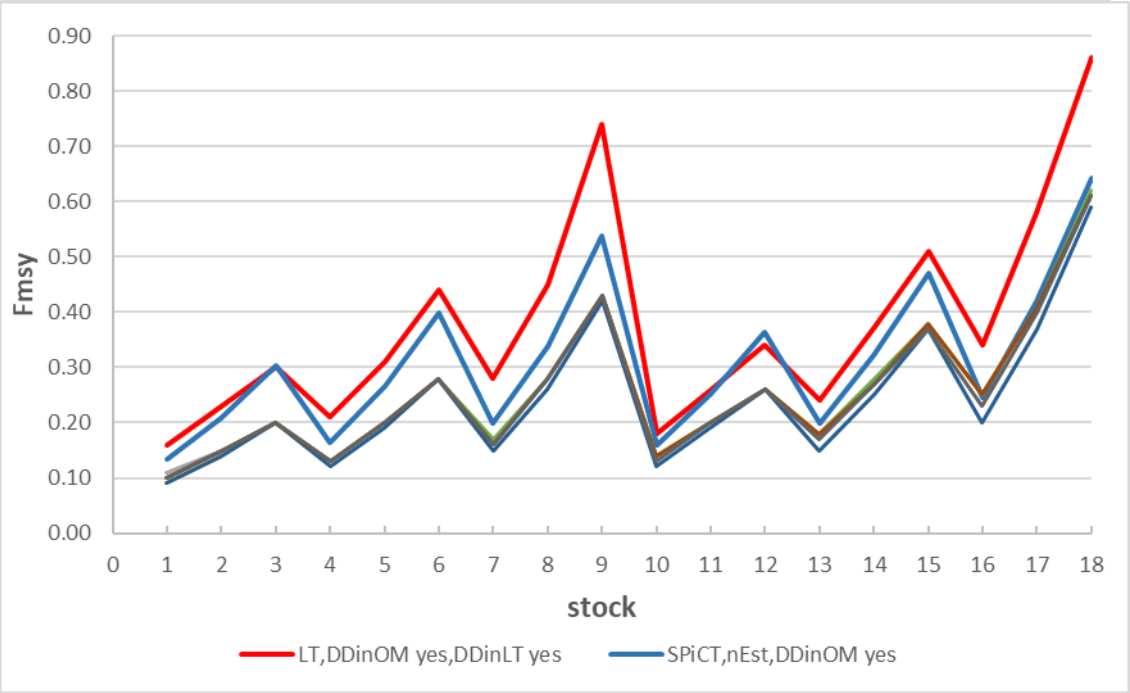


Figure. The F_{msy} obtained in different LT predictions and F_{msy} estimated by SPiCT fitted to generated stock (OM).

- thick red line = F_{msy} from LT predictions when DD is considered both in OM and LT simulations ("true" F_{msy}),
- thick blue line = estimates from SPiCT with DD in OM.
- other lines = estimates from LT predictions when DD is not considered in the predictions (but in OM is) and weights are constant basing on a mean from selected years.

Conclusions

1. F_{msy} estimates from SPiCT and LT predictions are quite similar in case of constant growth (not DD)

2. In case of DDG production model provides better estimates of F_{msy} than long-term predictions with constant weights

Thank you