2022 SPF Symposium Lisbon November 2022. Reconciling Ecological Roles and Harvest Goals: Development and Testing Management Strategies to Safeguard Marine Ecosystem Services

Baltic sprat management strategy evaluation using a Surplus Production Model as biological model

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European Union
European Maritime and Fisheries Fund

Ministry of Environment and Food of Denmark
Danish Veterinary and Food Administration

Problem

“it is a mathematical fact that you will get an underestimate of Fmsy if you ignore density dependence (DD) in any of the four factors - recruitment (or rather survival from egg to recruit), growth, maturity, and natural mortality.”

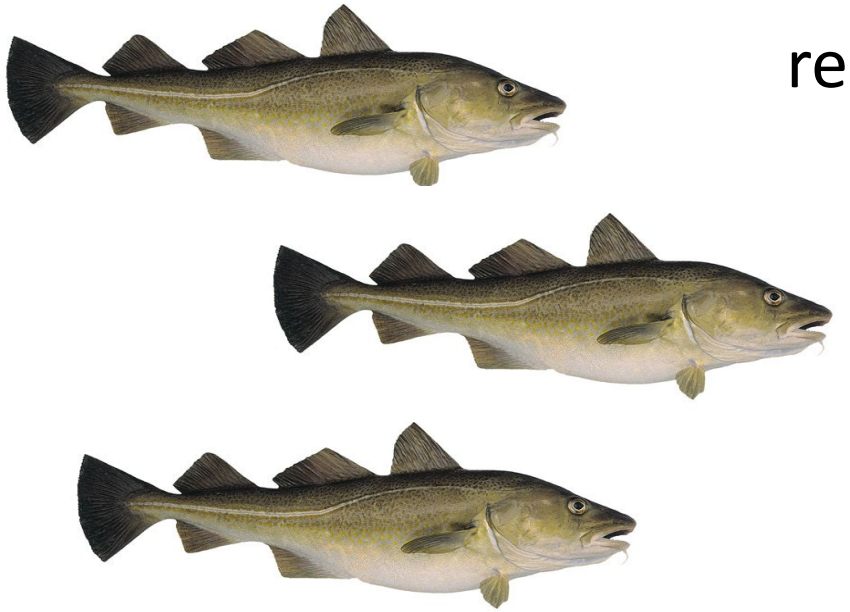
Solution

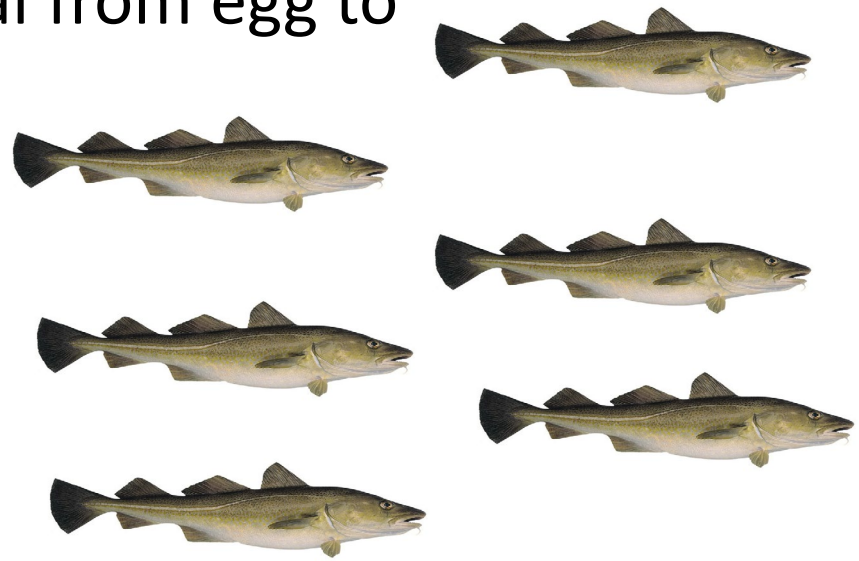
Continue using age-structed assessment models for state of the stock - but use Surplus Production Models for estimating Fmsy and Bmsy

Density dependence is how ecosystems function.

When the stock is small, individual fish:

1. Grow better
2. Have reduced natural mortality
3. Produce more eggs
4. Have better survival from egg to recruitment





Four compensatory mechanisms –

Taken into account in current management?

- Density dependent recruitment — √
- Density dependent individual fish growth — Not yet
- Density dependent natural mortality — Not yet
- Density dependent maturity — Not yet

It is a mathematical fact:
missing any of these in Fmsy calculations will give a downward bias!

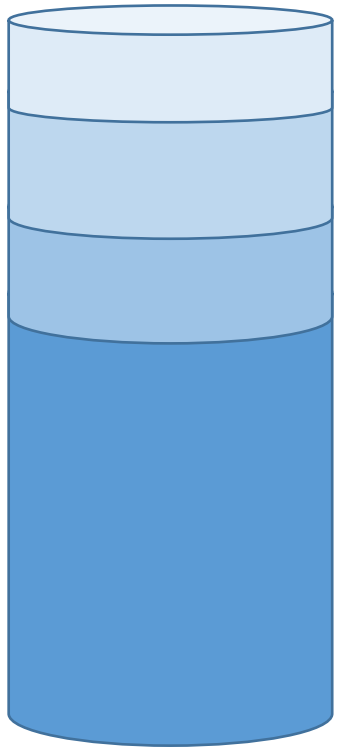
The general picture based on 53 data-rich stocks in the ICES area (FAO-area 27)

Age-structured models including DD in …	Fmsy calculated from the models	Comments
No DD	0.00	Stocks should be built to infinity
R	0.26	Average of 53 data rich stocks in the ICES area (ICES 2021)
R + growth	0.31?	"Guestimate" only a few examples
R + growth + natural mortality	0.36?	"Guestimate" only a few examples
R + growth + natural mortality + maturity	0.39	Average based on Surplus Production Models, of 53 data rich stocks in the ICES area (Sparholt *et al.* 2021)

…when you one by one, add a DD factor to the model, the Fmsy estimate increases.

Contribution to the Fmsy value – with no DD, Fmsy is zero.

	Contribution to Fmsy
DD in Maturity	0.39
DD in Growth	0.35
DD in Natural mortality	0.31
DD in Recruitment	0.26



Solution:

Produce DD sub-models for all four parameters

…as done for NEA-cod but we easily **run into the "known unknown" situation**

Therefore…

Use Biomass Dynamic Model, often called Surplus Production Models

…because they include all density dependent elements by design.

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cont…Solution

- Continue to do the historic assessments and short-term projections in age-structured models

- Do the long-term projections (MSE, Fmsy and Bmsy) using SPM (based on the historic assessment) as operating model

Ecosystem approach to fisheries management

- Everybody say they will do it
- The fact is: scientific bodies giving advice to managers still use the old fashioned single species approach with DD only in recruitment
- Including all 4 density dependent factors in single species approach get close to “an ecosystem approach”

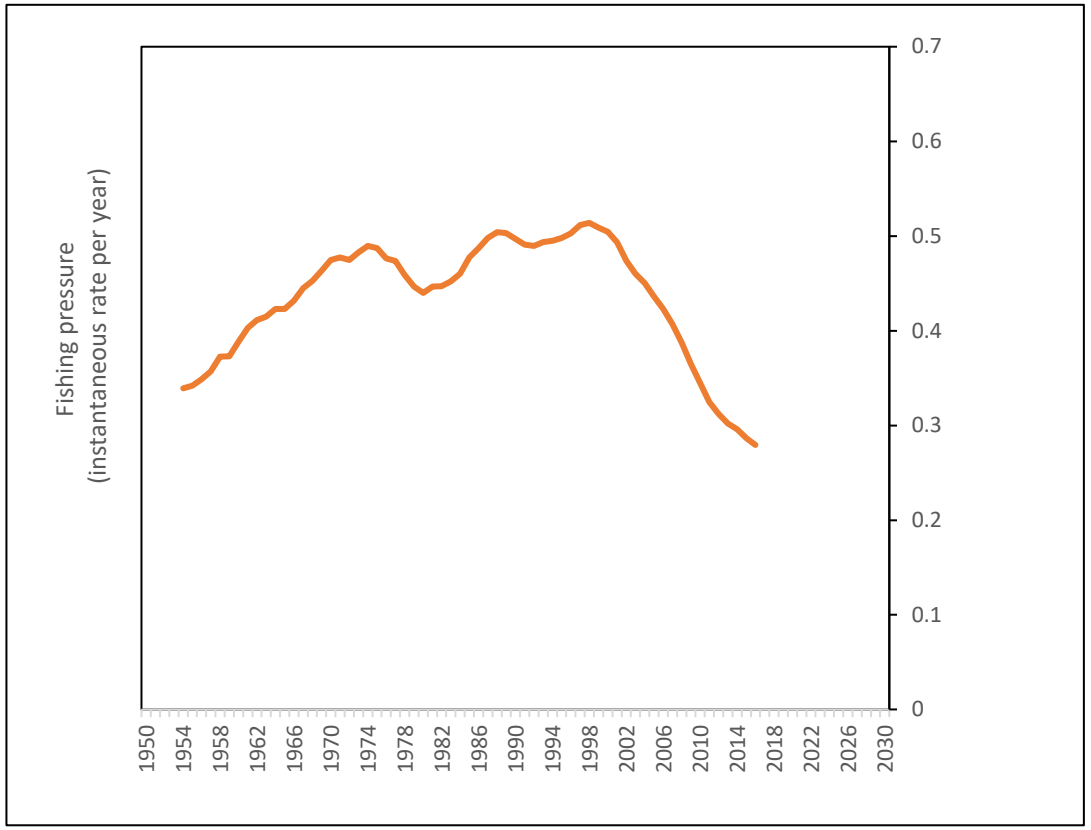
DD not a new “thing” in fisheries

- Density dependence (DD) in fish population dynamics was included from the beginning of this field of science (Baranov, 1918).
- ICES held a symposium in 1947 to consider how important DD was when fish stocks were left practically unfished during the WWII (Graham 1948).
- The seminal book by Beverton and Holt (1957) includes many concrete case studies with effects of DD on fish population dynamics.

…but maybe DD has been partly forgotten in the recent decades where overfishing made it less of a problem?

Mean fishing pressure in the Northeast Atlantic (FAO 27) – mean of 53 ICES data rich stocks.

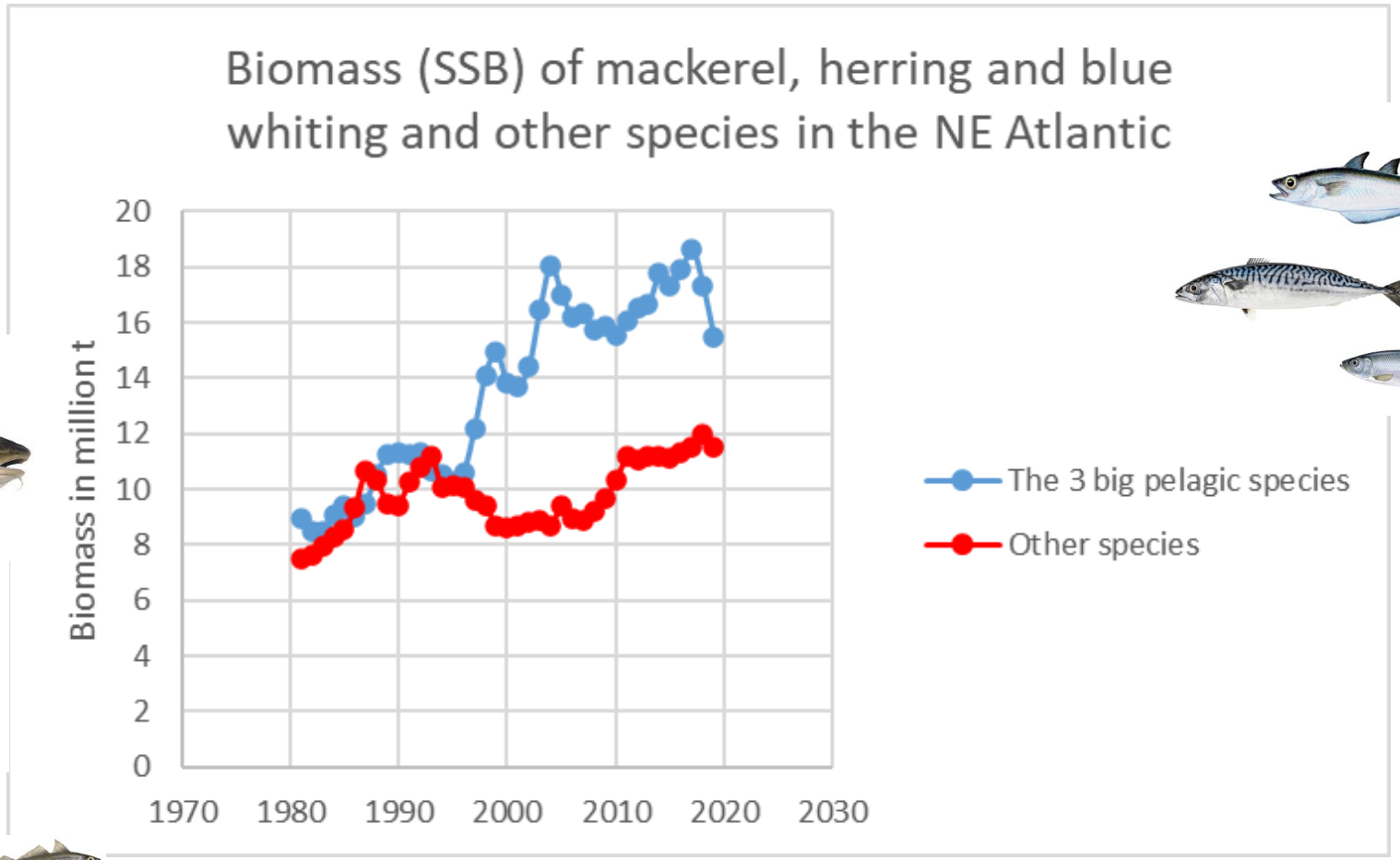
12% of Global catch

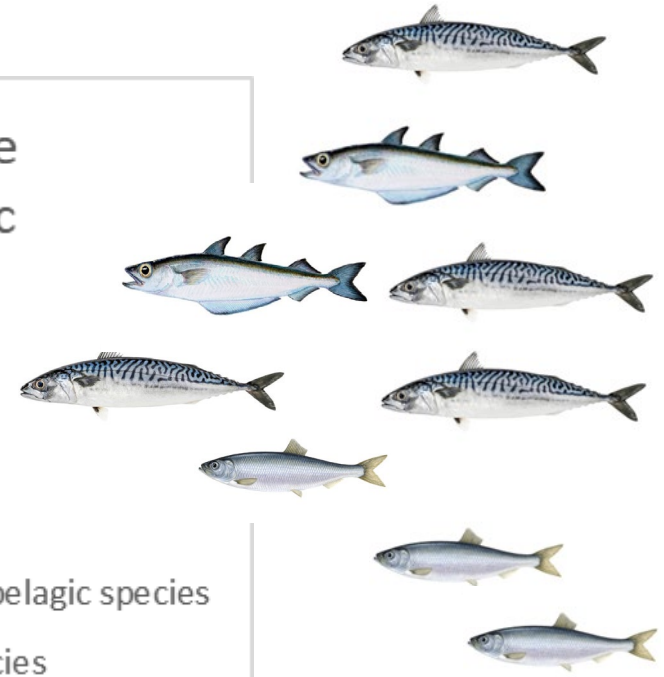


Succes story – Over-fishing has ended in the NE Atlantic!!

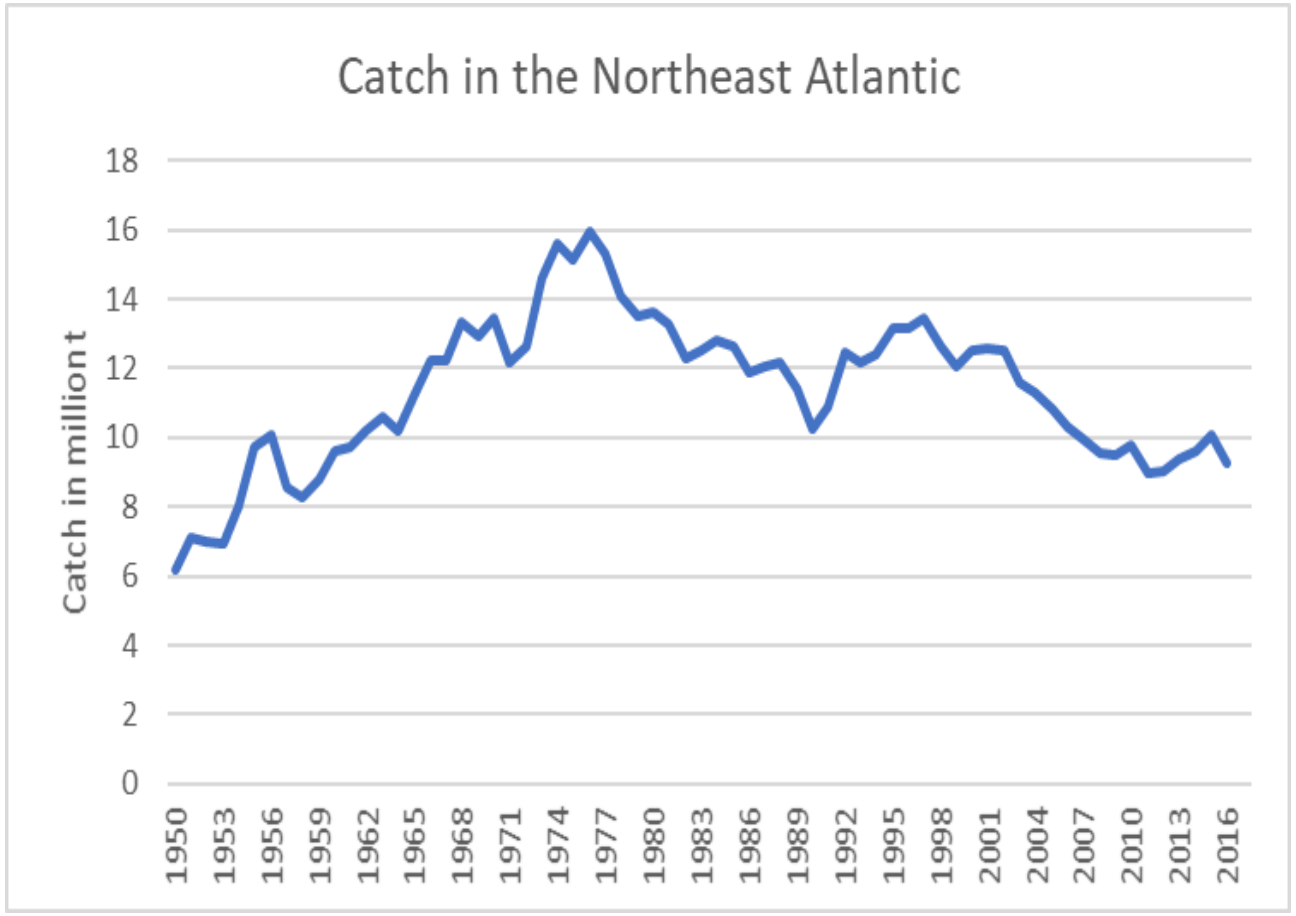
…about 10 year ago

Stocks increased – especially ”the 3-big pelagics”





Unfortunately, catches have decreased – where is the ”long-term gain for the short-term pain” scientists told managers in 1980-2000?



We suggest that part of the reason –

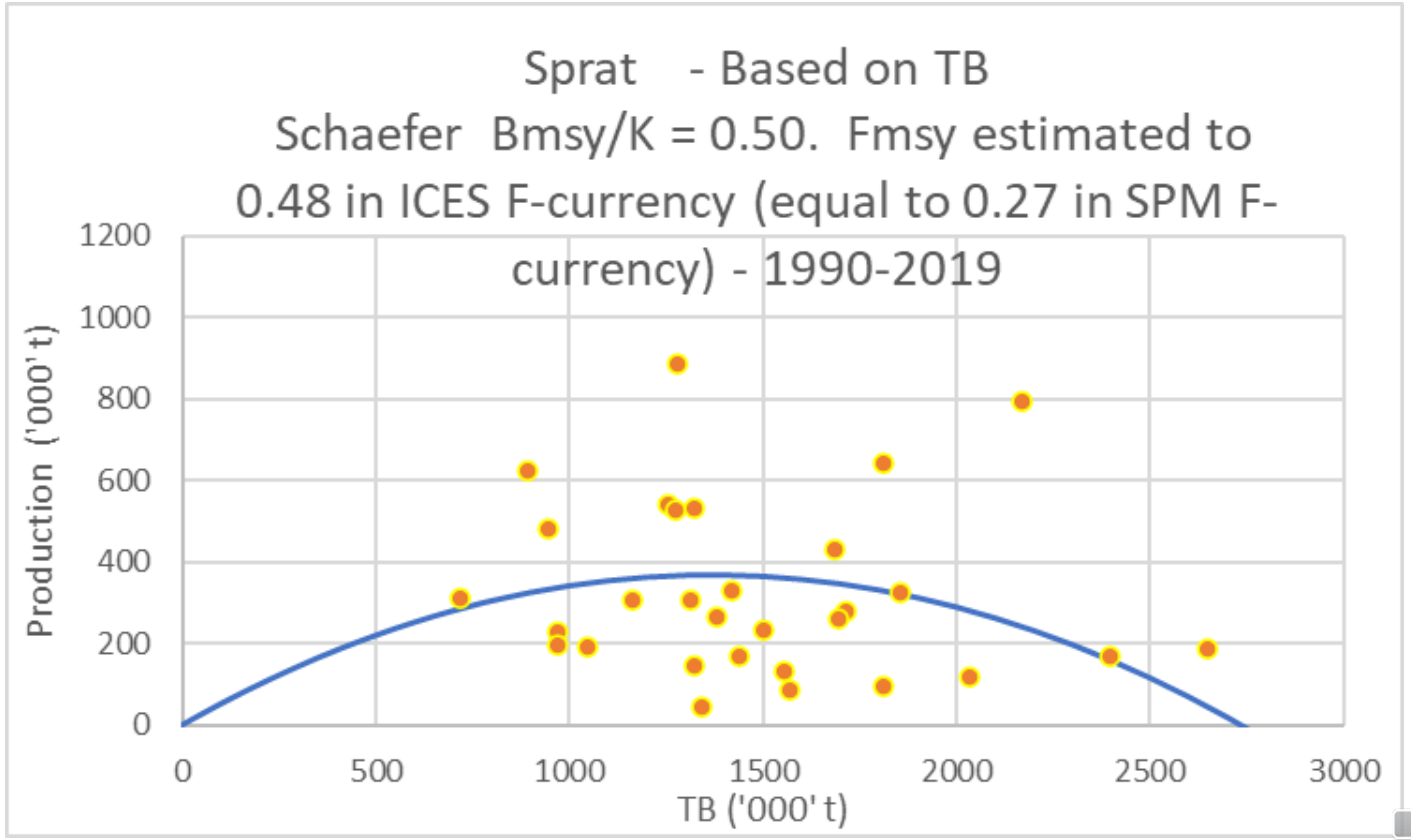
The real Fmsy (including all DD) are 50% higher than currently used values.

Steps to establish the best SPM for a given stock – here Baltic sprat

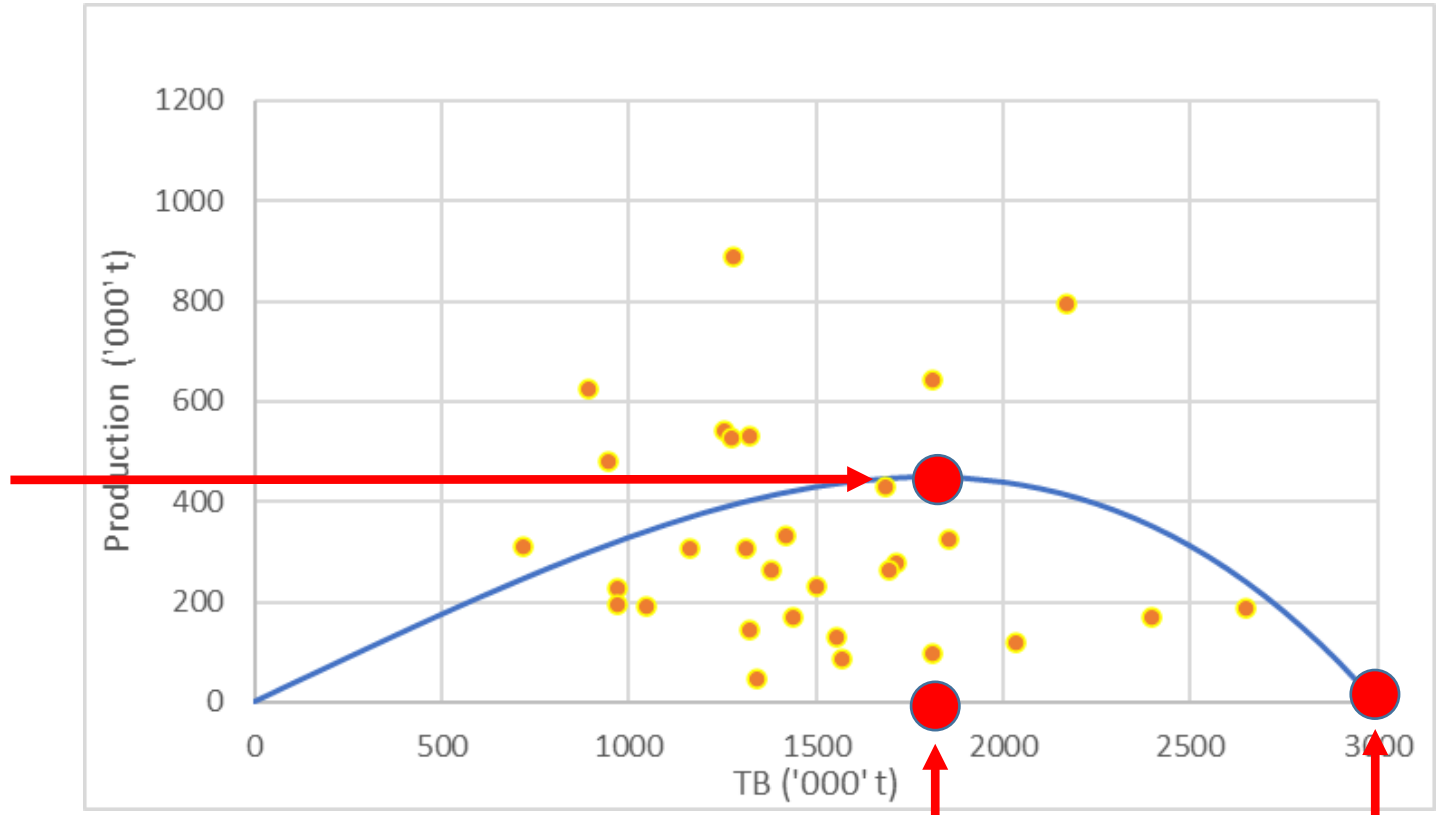
– equilibrium not needed!

Production (annual):

catch
+
increase in stock size



3 parameters needed for Surplus Production Models



Cont…Steps to establish the best SPM …

- Use stock biomass and catch from the ICES annual assessment.
- Often data are noisy and priors for the shape of the SPM-curve useful: Use a meta-analysis of 147 fish stocks from Thorson *et al*. (2012). Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information. Canadian Journal of Fisheries and Aquatic Sciences, 69: 1556–1568.
- Sometimes also the height of the SPM-curve is a problem: Use a meta-analysis by Sparholt *et al*. (2020). Estimating Fmsy from an ensemble of data sources to account for density-dependence in Northeast Atlantic fish stocks. ICES Journal of Marine Science. ICES Journal of Marine Science, doi:10.1093/icesjms/fsaa175.
- Compare to available scientific knowledge. **A big literature review**.

Compare to available scientific knowledge…

Historic assessment

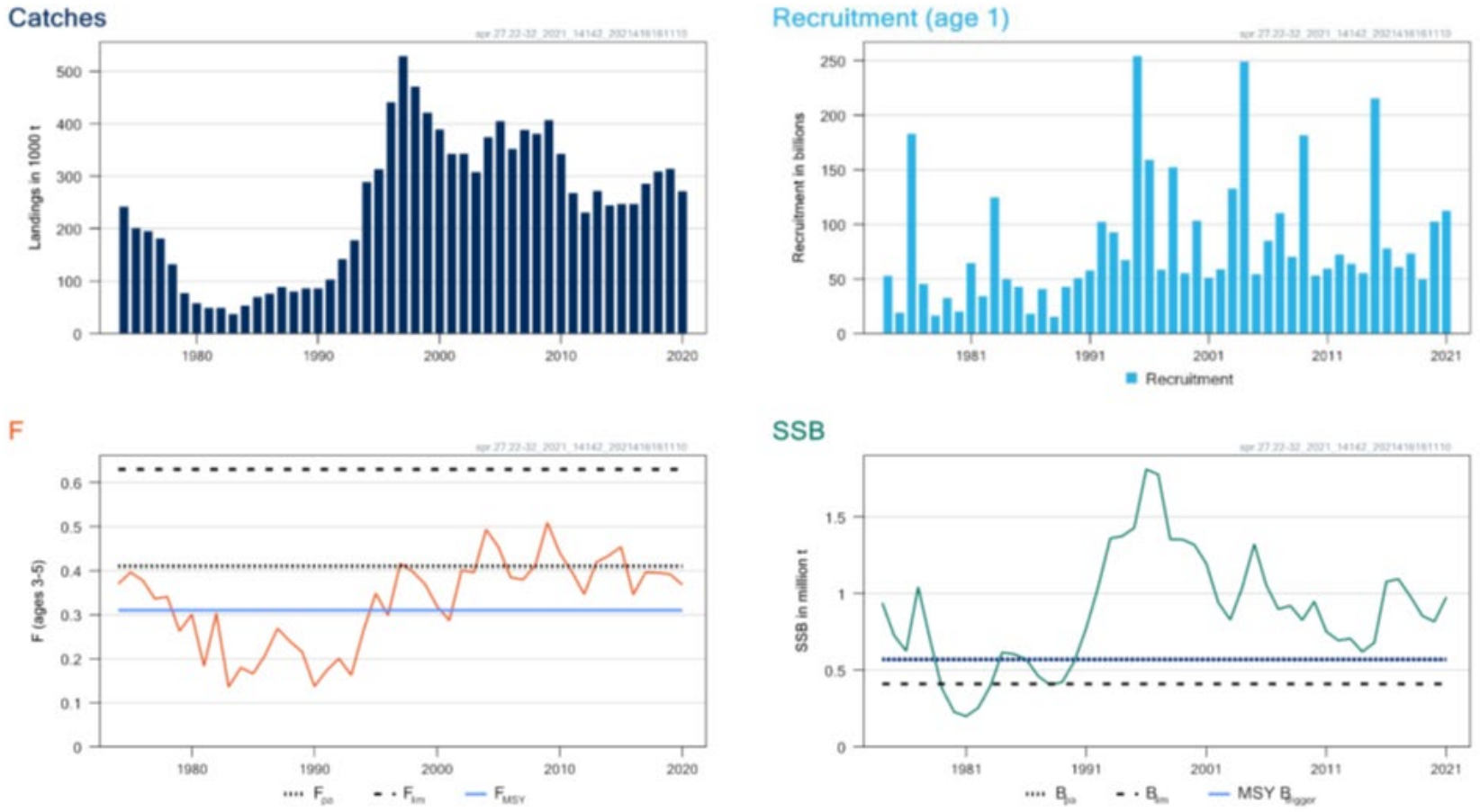


Figure 1 Sprat in subdivisions 22–32. Summary of the stock assessment. SSB at spawning time is predicted for 2021.

…available scientific knowledge

Older information

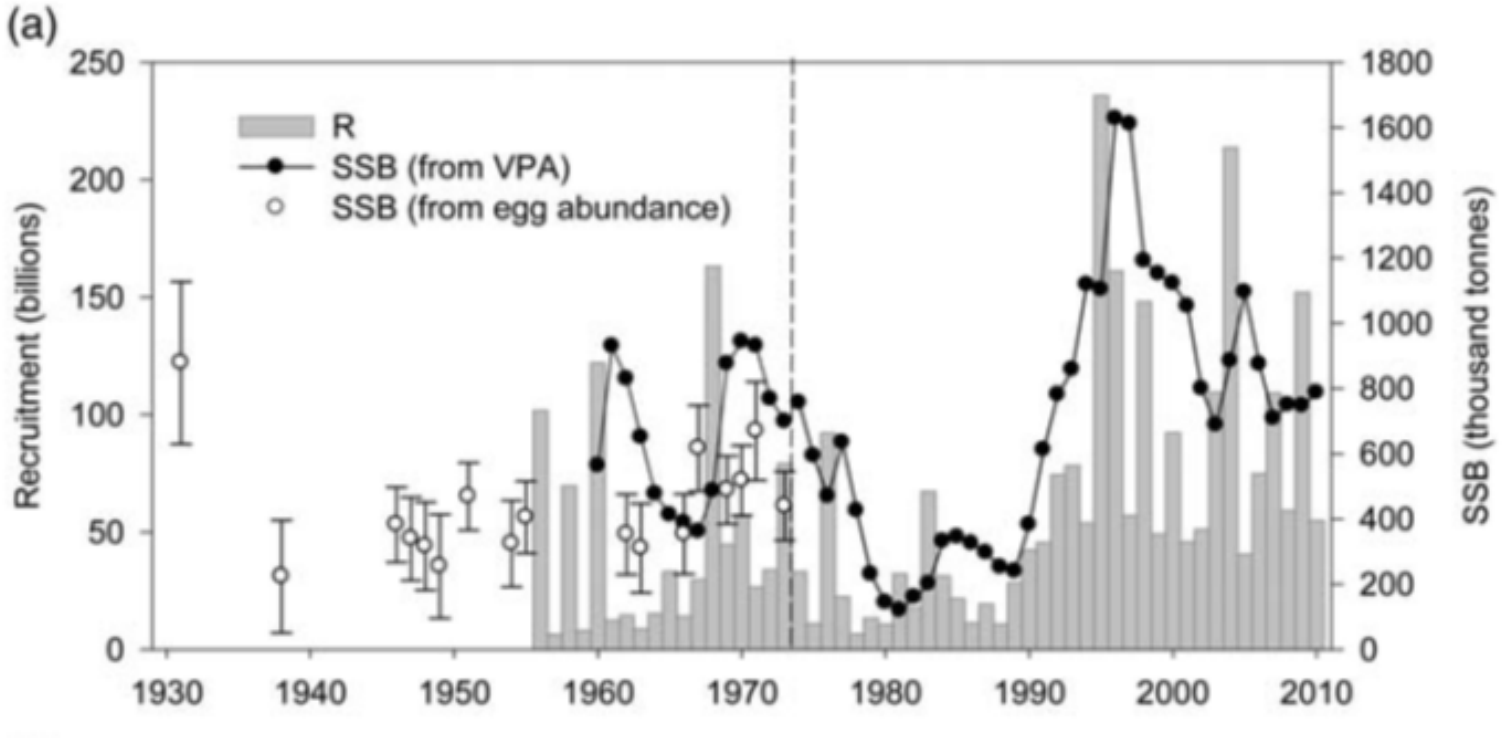


Figure 2. (a) Sprat spawning-stock biomass (SSB) and recruitment (R; numbers at age 1) in SDs 22–32 estimated from the analytical assessment (VPA); and the estimates of SSB based on egg abundance. The error bars represent 0.95 confidence intervals of the SSB, predicted from a linear regression with the average egg abundance as a predictor variable. (b) International sprat landings (L) in the Baltic Sea (Hammer *et al.*, 2008, and updates from the Baltic Assessment Working Group) together with the estimated exploitation rate (landings divided by SSB). The vertical broken lines separate the period covered by ICES assessments (from 1974 onwards) from the historical estimates produced in this study.

…available scientific knowledge

Predators

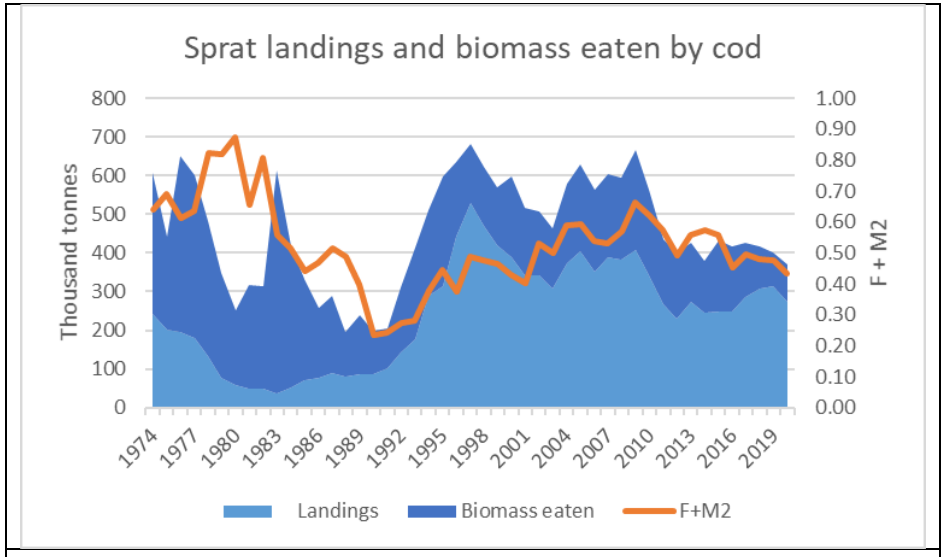


Figure 6. *Baltic sprat. Landings, biomass eaten by cod (cumulative plot) and F+M2 (fishing mortality and cod predation mortality, age 2-4). Based on data from ICES WGBFAS 2021. Biomass eaten calculated based on natural mortality minus 0.2, stock numbers and weight, by age and year.*
Note for my own sake: this figure is made in file: "K estimation Baltic sprat - - Schaefer - CV linked to SSB and n fixed Fmsy estimated but incl M2 for cod predation- 1974 - 2019 -SP includes eaten sprat.xls"

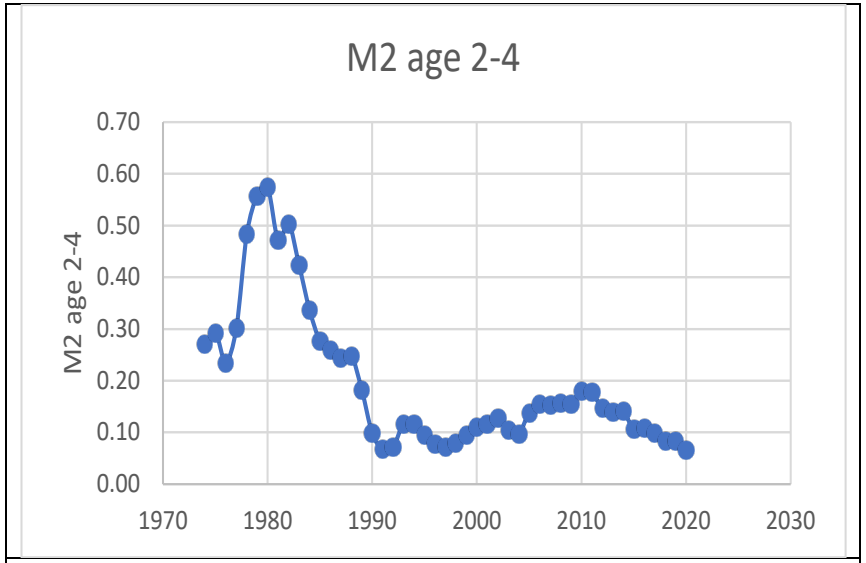


Figure 5. *Baltic sprat. M2 for age 2-4. From ICES WGBFAS 2021.* Note for my own sake: this figure is made in file: "K estimation Baltic sprat - - Schaefer - CV linked to SSB and n fixed Fmsy estimated but incl M2 for cod predation- 1974 - 2019 -SP includes eaten sprat.xls", Natmor sheet.

…available scientific knowledge

Stock-recruitment

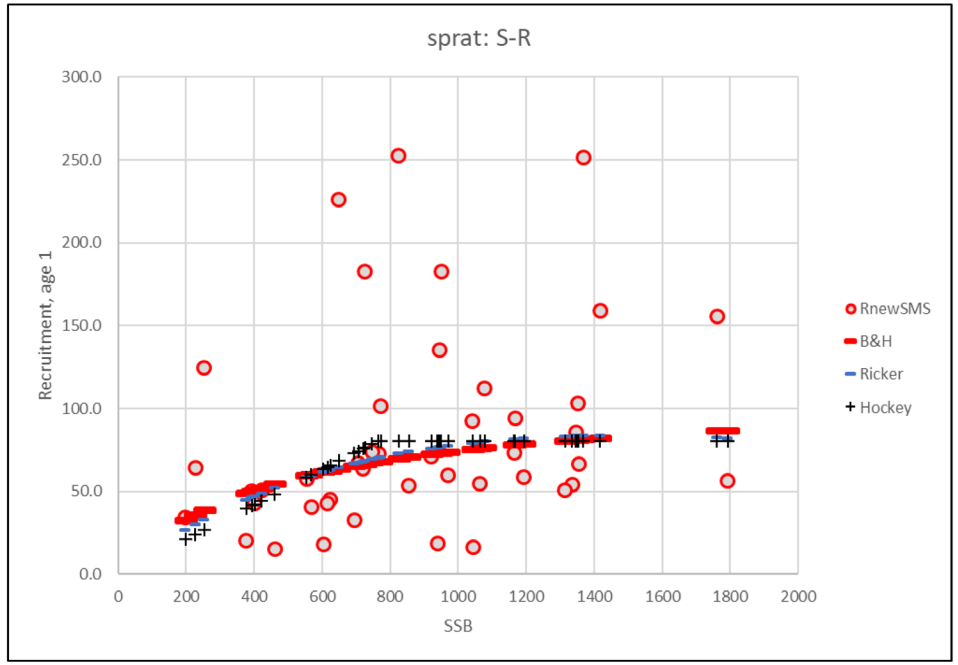


Figure 4.1. Stock–recruitment relationship for Baltic sprat; observations and fits of three models (Beverton and Holt, Ricker, and segmented regression).

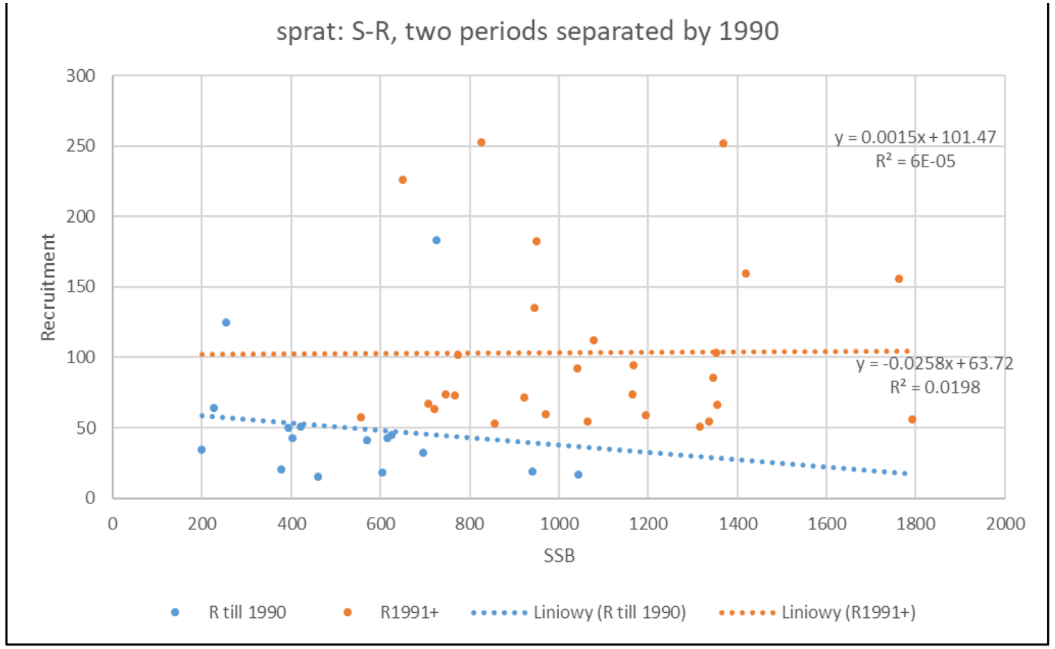


Figure 4.2. Stock–recruitment relationship for Baltic sprat separated into two periods: data before 1990 and data from 1990 onwards.

Figure 7. Baltic sprat. The S-R plots from: ICES. 2020. Inter-Benchmark Process on BAltic Sprat (*Sprattus sprattus*) and Herring (*Clupea harengus*) (IBPBash). ICES Scientific Reports. 2:34. 44 pp. http://doi.org/10.17895/ices.pub.5971.

…available scientific knowledge

Growth

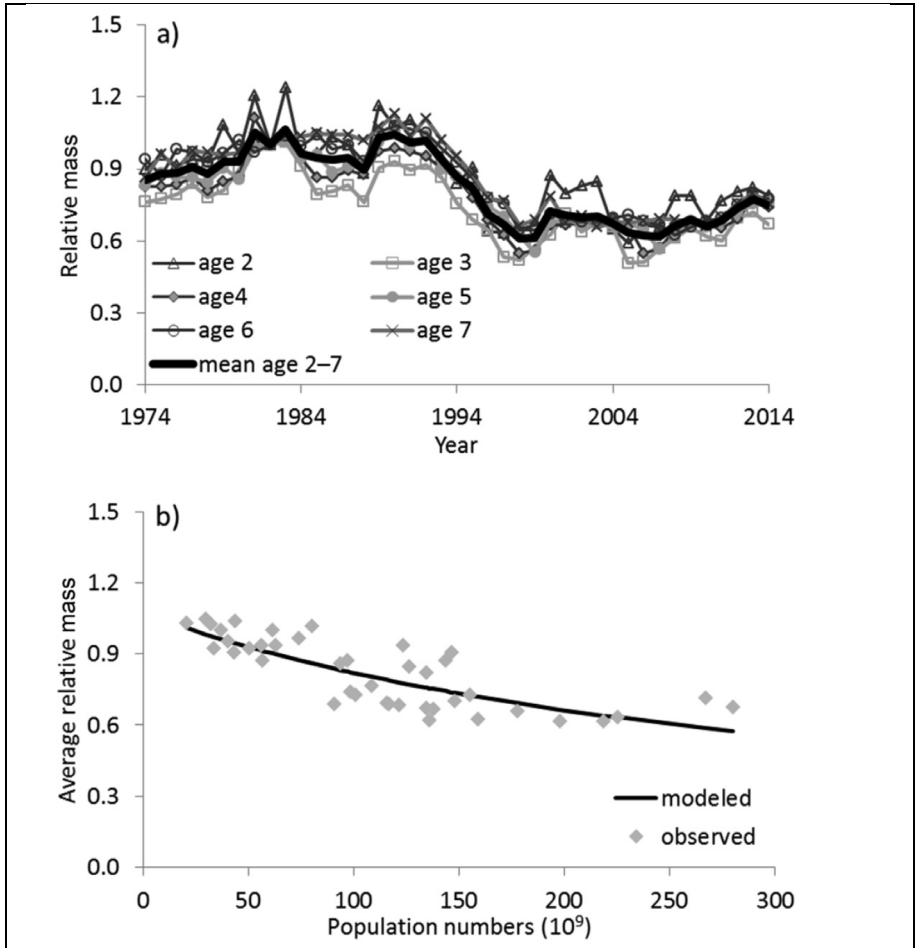


Figure 13. Baltic sprat. Relative (to the 1991 value) weight-at-age by year (a) and by stock size of sprat (b). From Horbowy and Luzenczyk (2017).

…available scientific knowledge

Carrying capacity

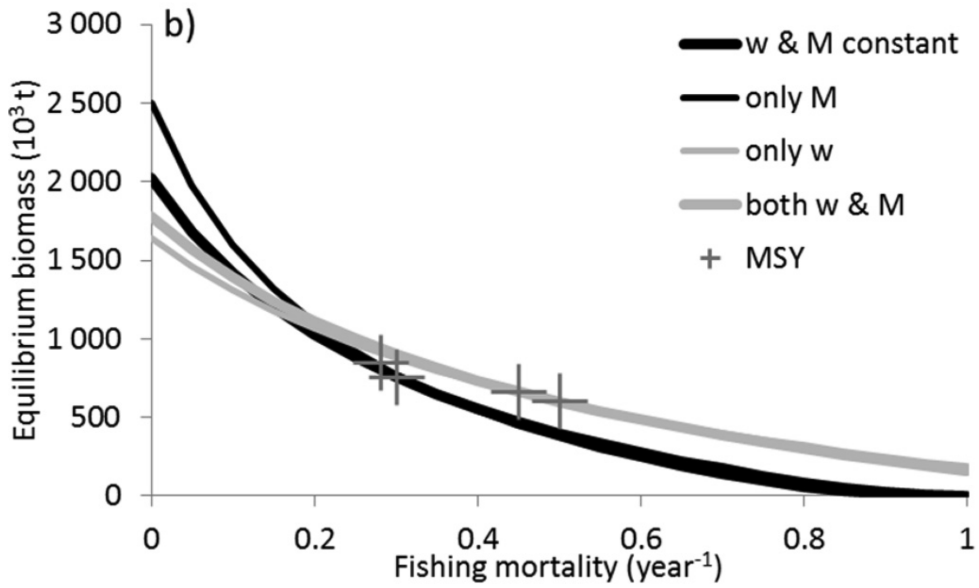


Figure 13. Baltic sprat. Equilibrium biomass of sprat relative to fishing mortality for the four combinations of density-dependent and constant growth (w) and natural mortality (M). Cod biomass is assumed at 200 × 103 t. From Horbowy and Luzenczyk (2017).

…available scientific knowledge

Food competitors
– herring

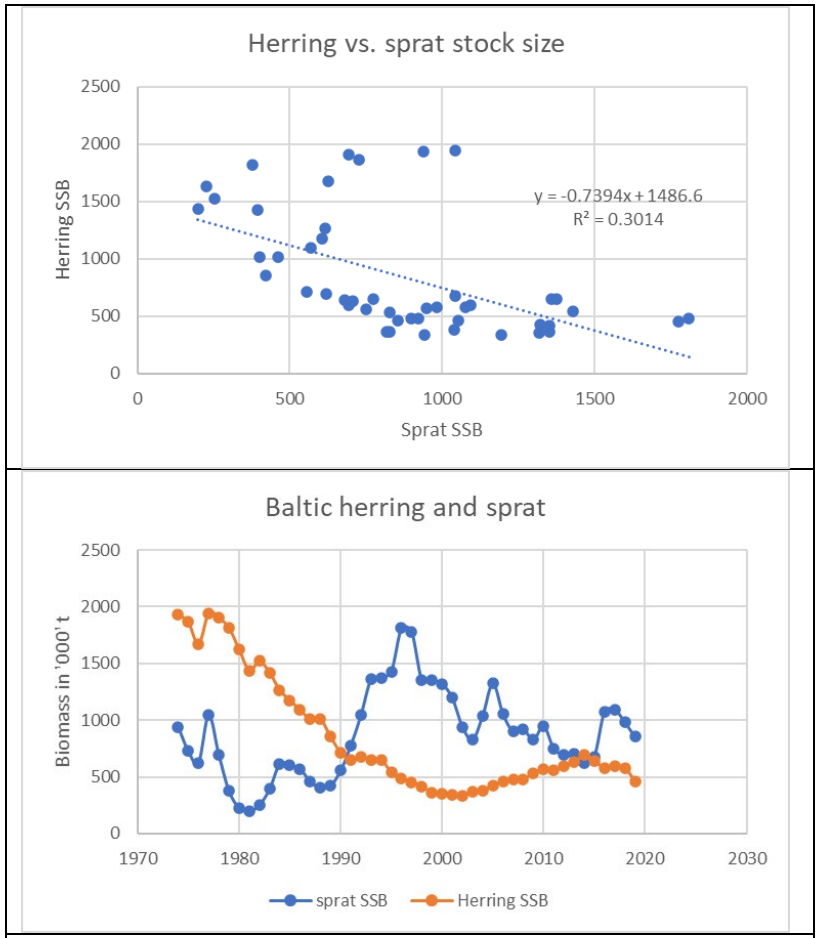


***Figure 14**. Upper panel is the correlation between the SSB of sprat (SD 22-32) and herring (SD25-29 + 32) in the Baltic. The negative relationship is highly significant. Biomass units is '000' t. Lower panel shows the SSB of each stock by year. Based on data for 1974-2019 from ICES 2021.*

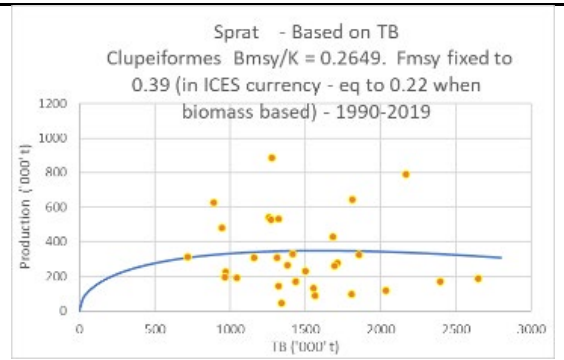
Conclusion of available science

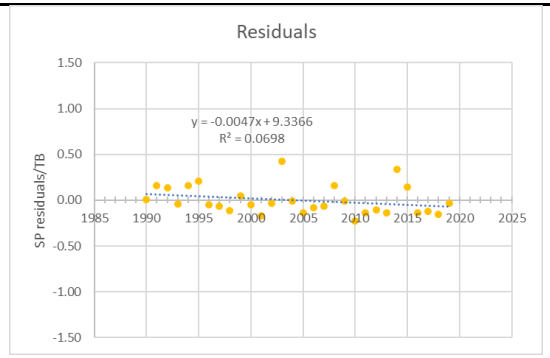
- Cod predation on sprat has varied a lot over the period 1974-2019. If cod is regarded as a part the environment for sprat two regimes can be identified, one in 1974-1989 with a high cod predation and one in 1990-2018 with a low cod predation.
- Except for cod predation no regime shifts could be identified.
- Competition for food with herring in 1990-2018 rather low and constant.
- When density dependence in growth of sprat is considered, the K should less 2300 kt.
- If cod predation is regarded as a separate “fishing fleet”, K should be less than 3500 kt.

…alternative Surplus Production Models –
informed by available science

a) Shape “Clupeiformes”
Fmsy fixed

K (TB)	6024
TBmsy	1596
SSBmsy	1205
MSY	350
R^2	0.31
AICc	16.6





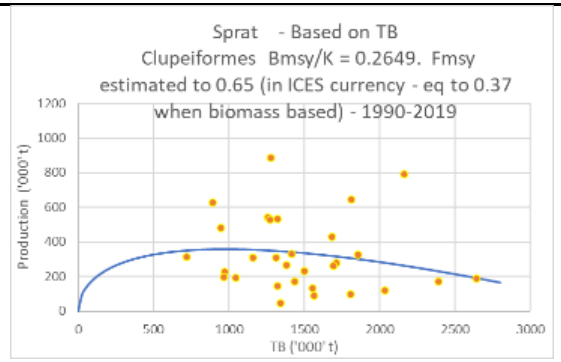
K inconsistent with available science

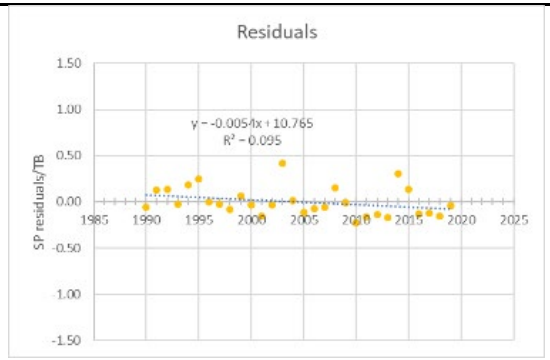
AICc low.

1 parameter estimated

b) Shape “Clupeiformes”
Fmsy estimated

K (TB)	3684
TBmsy	976
SSBmsy	668
MSY	359
R^2	0.33
AICc	19.4





K inconsistent with available science

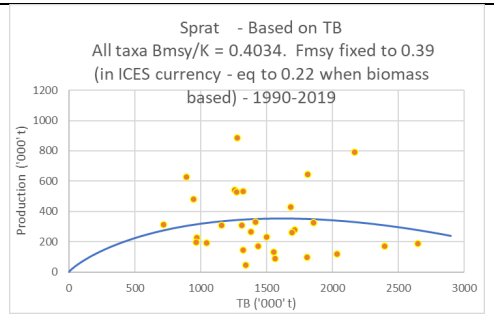
AICc high.

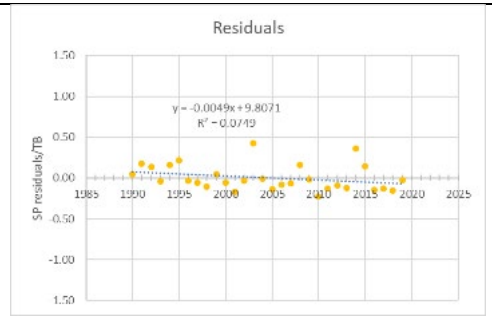
2 parameters estimated

…more alternative models

c) Shape “All taxa”
Fmsy fixed

K (TB)	3997
TBmsy	1615
SSBmsy	1220
MSY	355
R^2	0.29
AICc	16.8





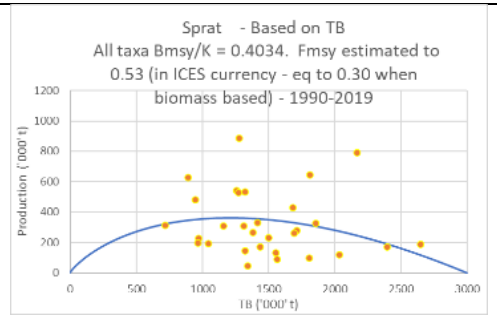
K inconsistent with available science

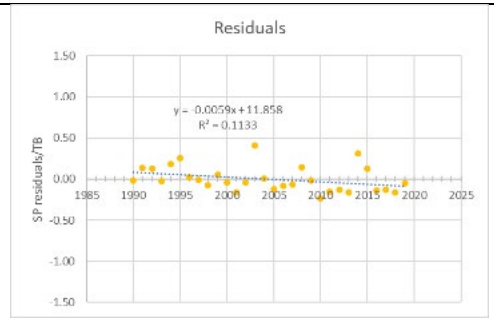
AICc low

1 parameter estimated

d) Shape “All taxa”
Fmsy estimated

K (TB)	2996
TBmsy	1208
SSBmsy	864
MSY	362
R^2	0.31
AICc	19.5





K consistent with available science altough a bit high

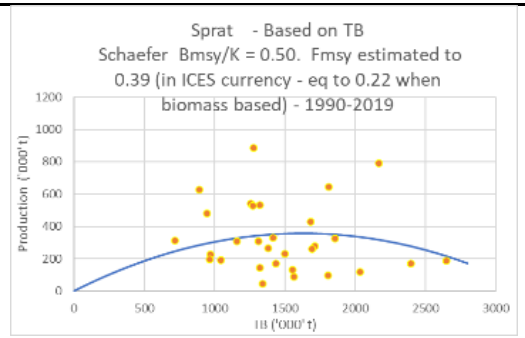
AICc high

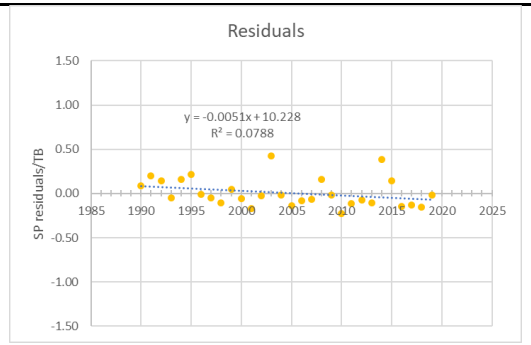
2 parameters estimated

…and more alternatives

e) Schaefer
Fmsy fixed

K (TB)	3254
TBmsy	1627
SSBmsy	1229
MSY	357
R^2	0.27
AICc	17.1





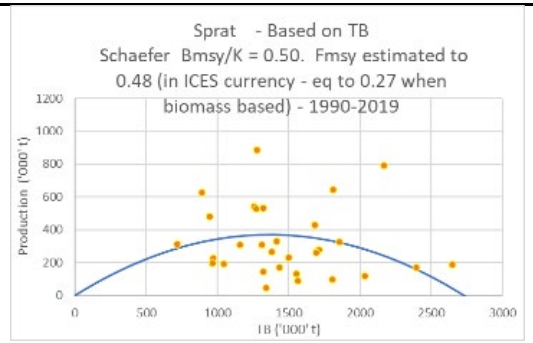
K inconsistent with available science

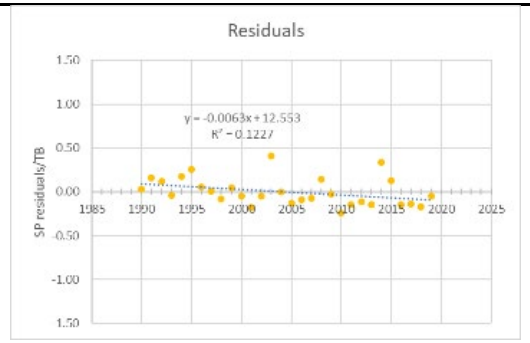
AICc low.

1 parameter estimated

f) Schaefer
Fmsy estimated

K (TB)	2733
TBmsy	1367
SSBmsy	997
MSY	369
R^2	0.29
AICc	19.8





K consistent with available science, although a bit high.

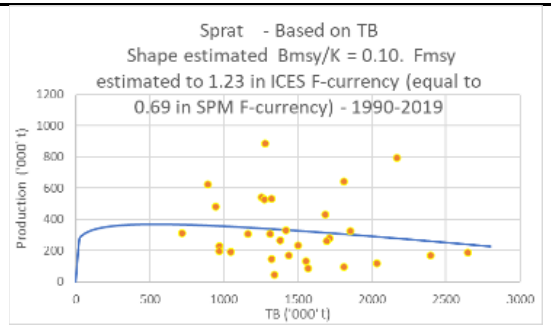
AICc high.

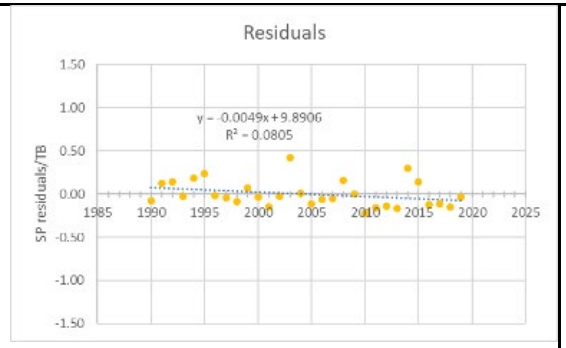
2 parameters estimated

…and more alternatives

g) Shape estimated, Fmsy estimated

K (TB)	5253
TBmsy	537
SSBmsy	256
MSY	372
R^2	0.33
AICc	23.0



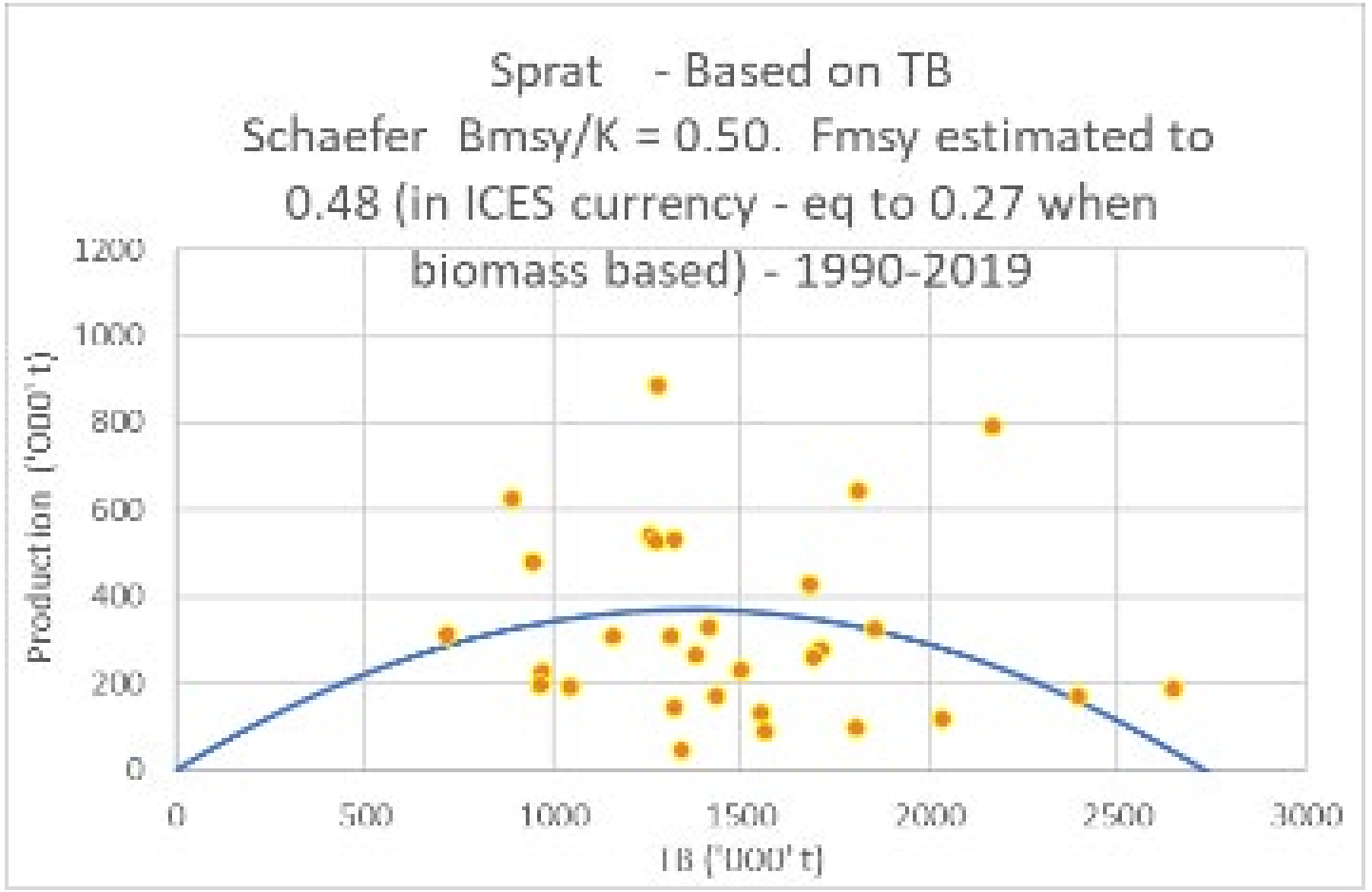


K inconsistent with available science

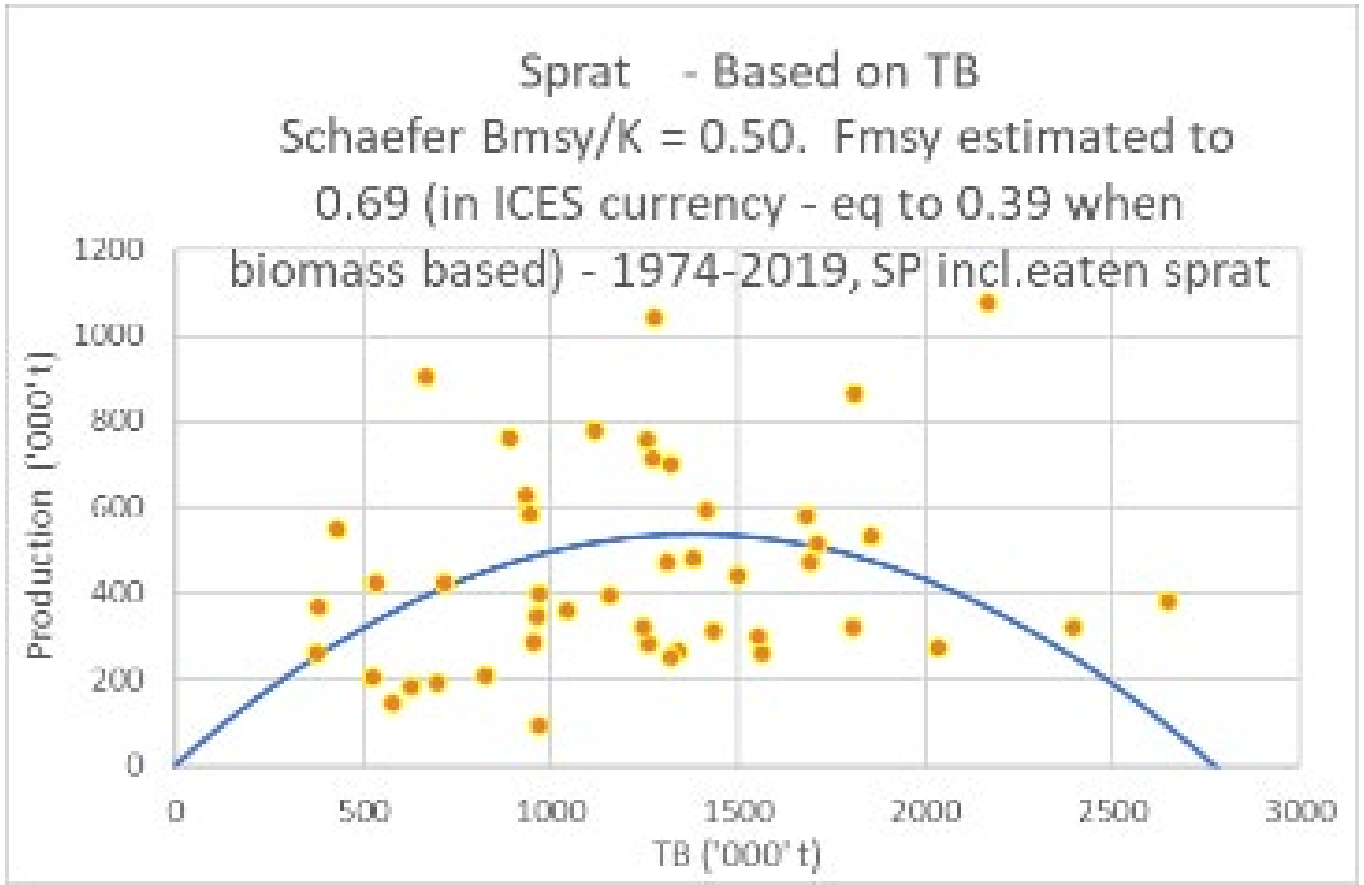
AICc high.

3 parameters estimated

Conclusion about the best SPM

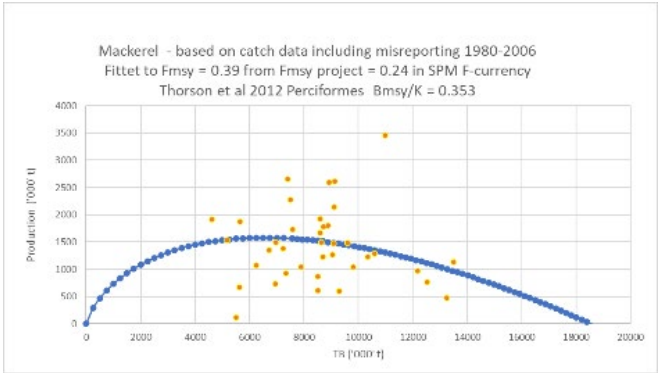


…when cod predation included as a “production” – note here that Fmsy includes predation mortality

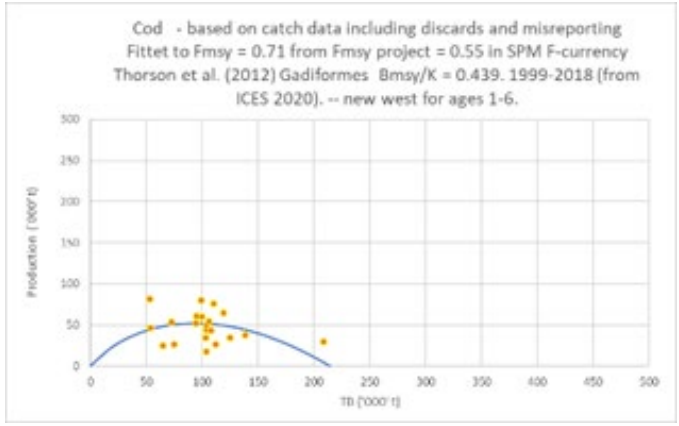


Six stock examples of final SPMs – all quite variable annual production – mainly reflecting variable recruitment

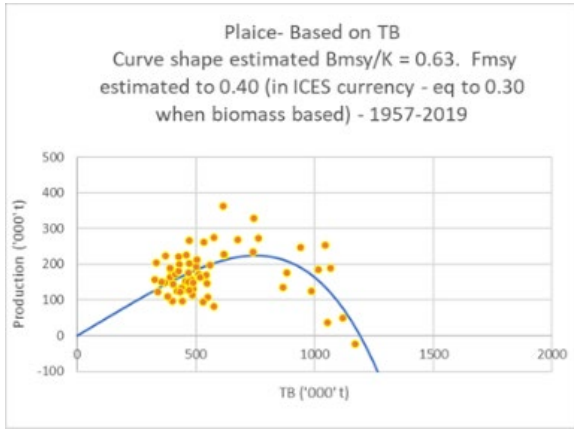
Mackerel - Northeast Atlantic



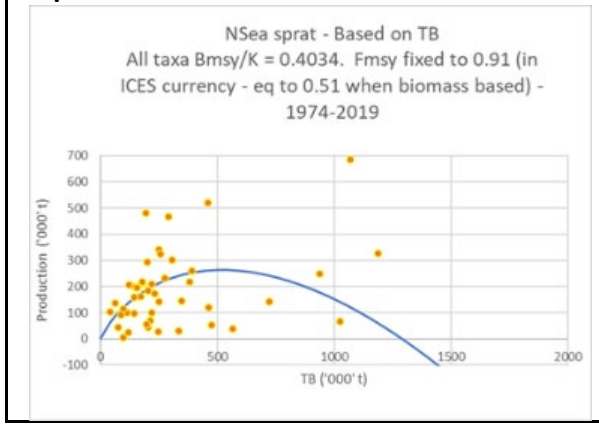
Cod - North Sea



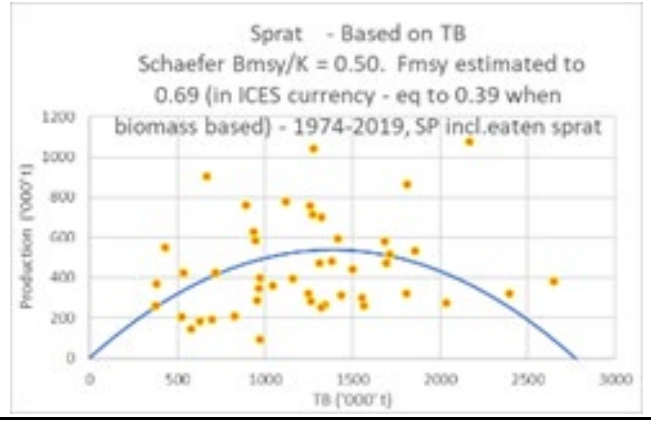
Plaice - North Sea



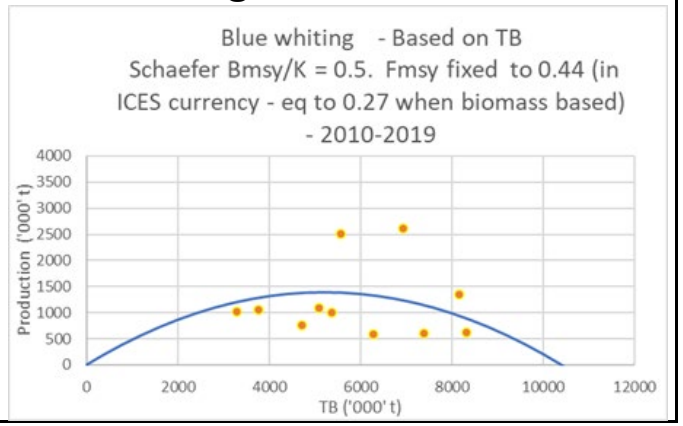
Sprat - North Sea



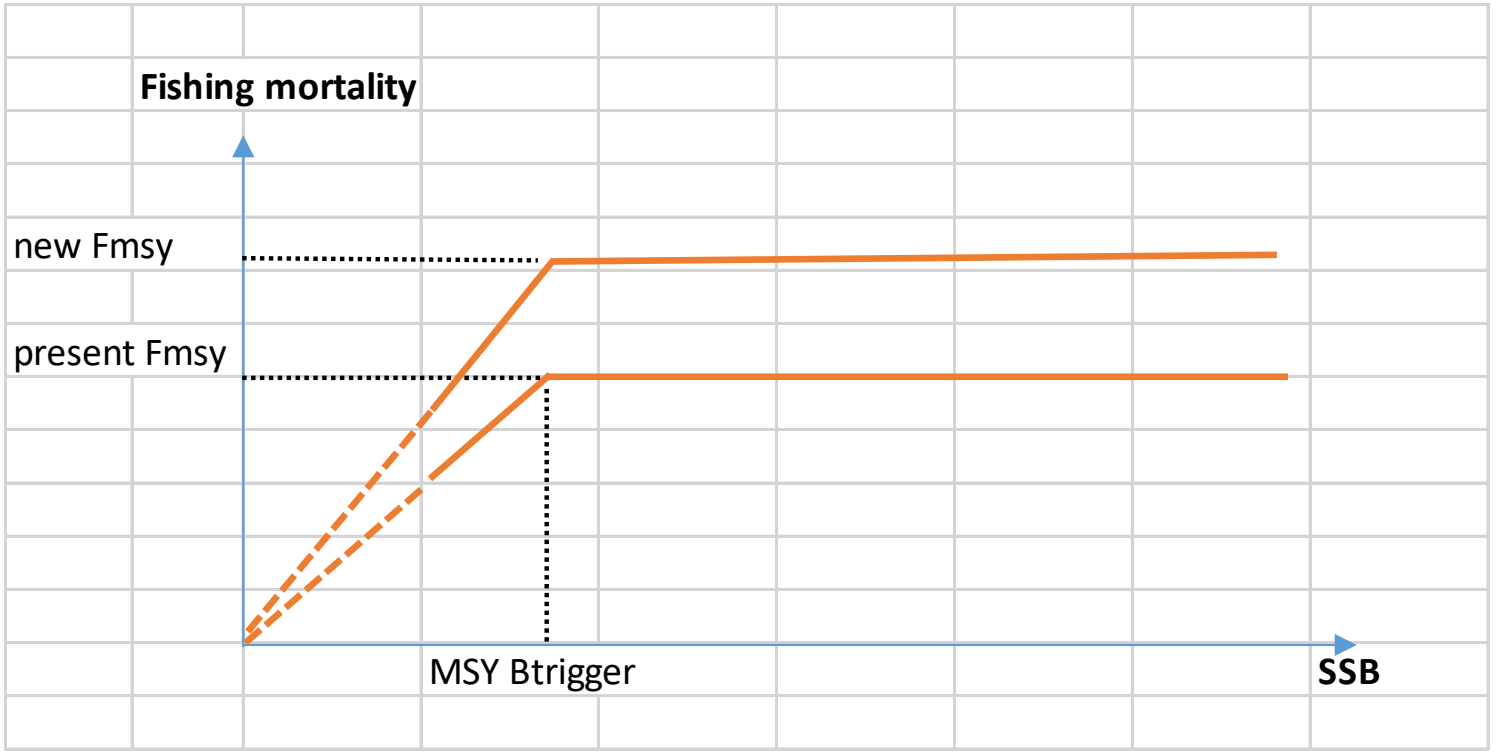
Sprat - Baltic Sea



Blue whiting - Northeast Atlantic



Harvest Control Rule still very important and will take care of the ”precautionary approach”



ICES type HCR

Using SPM as Operating Model in MSEs

To read later if you need the details. when you have the SPM model it is straight forward MSE

SPM = Surplus Production Model) MSE = Management Strategy Evaluation

The simulations are done as described below:

- 1) start with the observed TB (2020).
- 2) The real TB is obtained taking observation error into account (log normally distributed obtained from historic assessment).
- 3) Then the production, S, is obtained considering process error (assumed normally distributed and CV linearly related to TB).
- 4) The real SSB is obtained by a linear link to TB influenced by F (regression obtained from the historic assessment).
- 5) Then the observed SSB is obtained taking account of observation error.
- 6) Then intended F is obtained taking account of the HCR (linearly reduced when SSB < MSYBtrigger).
- 7) The TAC is then obtained.
- 8) The realised yield obtained taking implementation error into account.
- 9) The real TB for the following year is then obtained from the real TB the current year + real SP – realised yield.
- 10) The observed TB the following year is obtained from the real TB and observation error.

…repeat the sequence from stage 3) above for each year into the future in the simulations.

In this way it is a partial feedback MSE because the TAC in each future year is based on observed quantities rather than on OM quantities. It is based on the observed TB and SSB estimated each year from the assessment model simulated via empiric observation error. Obviously, the SPM OM cannot provide stock number by age each year in the simulations so an age-based assessment cannot be done in future years in the simulations. The approach therefore falls under the category: a “short-cut” MSE (see ICES 2020b). The observation error is based on the historical performance of the assessment.

- The approach therefore falls under the category: a “short-cut” MSE (see ICES 2020b).
- The observation error is based on the historical performance of the assessment to estimate TB (Total stock Biomass).

Results

Yield in ‘000’t

	Yield															
0.50	236	236	241	243	238	243	252	252	258	260	255	260	267	268	268	275
0.48	235	244	247	250	255	249	258	256	264	264	265	272	272	270	275	277
0.46	240	251	250	251	257	257	258	265	264	271	267	277	274	273	280	282
0.44	254	260	259	255	263	265	268	277	277	278	283	283	282	287	285	287
0.42	262	263	270	273	278	277	273	279	283	281	283	285	288	292	289	299
0.40	282	290	280	282	286	292	292	285	289	296	292	297	298	299	301	298
0.38	297	300	304	297	309	313	301	297	313	308	307	309	306	309	310	315
0.36	323	321	322	320	320	322	328	322	324	324	322	320	322	324	325	325
0.34	336	337	342	341	335	348	336	338	343	336	339	341	335	342	334	341
0.32	355	356	356	349	351	349	349	352	341	348	352	349	349	354	349	353
0.30	357	356	358	361	359	360	357	356	360	356	358	359	357	358	361	356
0.28	364	363	362	361	366	361	363	364	358	364	363	364	363	362	363	364
0.26	361	364	363	366	360	364	364	365	364	361	363	361	362	363	362	364
0.24	358	359	359	359	359	360	357	360	358	357	361	360	361	361	359	358
0.22	354	353	352	352	351	352	350	352	352	353	349	351	351	349	353	353
0.20	339	338	339	340	339	340	342	340	341	338	338	341	342	336	340	339
0.18	326	321	324	324	324	320	323	321	322	323	324	322	325	321	320	327
0.16	304	304	303	304	305	303	303	301	303	304	307	304	303	303	305	304
0.14	279	281	278	280	279	282	281	281	280	278	278	279	280	281	280	280
0.12	253	253	250	251	251	254	254	251	253	252	254	249	251	250	254	254
0.10	220	221	220	221	219	218	220	221	219	219	219	221	219	221	222	220
	450	460	470	480	490	500	510	520	530	540	550	560	570	580	590	600
								Btrigger in '000' t								

Fishing mortality

Btrigger in ‘000’t

Results - combinations of Btrigger and F that are green in all 4 plots are “good”

Yield

Annual variation in Yield

Risk to SSB to get below Blim

SSB

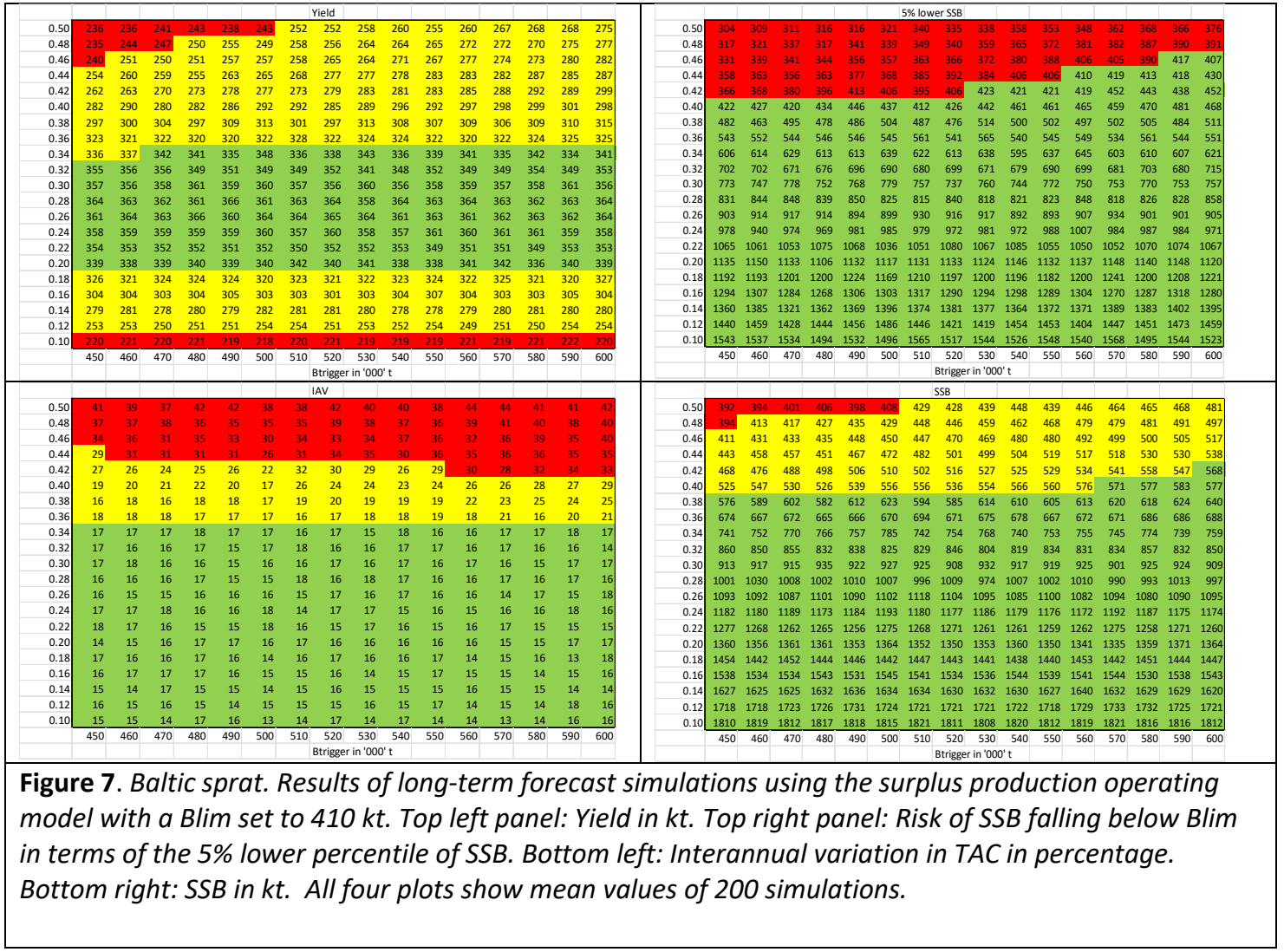


Figure 7. *Baltic sprat. Results of long-term forecast simulations using the surplus production operating model with a Blim set to 410 kt. Top left panel: Yield in kt. Top right panel: Risk of SSB falling below Blim in terms of the 5% lower percentile of SSB. Bottom left: Interannual variation in TAC in percentage. Bottom right: SSB in kt. All four plots show mean values of 200 simulations.*

Conclusion

Continue using age-structed assessment models for state of the stock and short-term forecast - but use Surplus Production Models for MSEs and for estimating Fmsy and Bmsy

Thank you !

Don’t hesitate to ask me questions on henrik.sparholt@gmail.com

European Maritime & Fisheries Fund

Ministry of Food, Agriculture and Fisheries of Denmark
Danish Veterinary and Food Administration

UNIVERSITY OF COPENHAGEN

Scientific mini-symposium
23rd of November 2022, Copenhagen

Optimizing sustainable fishing on rebuilt fish stocks in the North-East Atlantic

A group of scientists has evaluated ways of including fish interactions (density dependence) in the current single-species approach to management using Surplus Production Models.

They will discuss the issue with invited scientists, stakeholders and managers.

Check the programme and register here: https://MSE-symposium.eventbrite.com
Venue: Axeltorv 3, Copenhagen V, Denmark
For any questions, contact axelle.cordier@sund.ku.dk

Organized by the “MSE-project”: www.mseproject.org