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A systematic bias in Fmsy if density dependence is not fully accounted for

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Problem

“**it is a mathematical fact that you will get an underestimate of Fmsy if you ignore density dependence 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 and short-term forecast - but use Surplus Production Models for estimating Fmsy and Bmsy

Problem

My claim is:

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

- However, it is often difficult to convince those scientists, who don't know it, as I cannot point to any publication giving the proof. -- I then give them an excel sheet to do the calculations themselves but that takes time for them.

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

This is a mathematical fact!

- Those who are uncertain about this, can play around with a simple Excel case I have made. Get the file by sending me an email henrik.sparholt@gmail.com

- It is modelled over the mackerel stock (but feel free to insert your own stock data)

Results – of ”leave one out”-analysis

Equilibrium yield

Biomasses in million t	DD in all	No DD in growth	No DD in maturity	No DD in natural mortality	No DD in recruitment
	A	B	C	D	F
Stock Biomass at F=0	5.290	5.524	5.327	7.065	5.657
	Yield				
F					
0.000	0.000	0.000	0.000	0.000	0.000
0.023	0.120	0.124	0.120	0.161	0.126
0.046	0.226	0.230	0.226	0.295	0.237
0.068	0.319	0.321	0.319	0.405	0.333
0.091	0.401	0.397	0.401	0.495	0.416
0.114	0.473	0.460	0.472	0.567	0.486
0.137	0.534	0.512	0.533	0.624	0.545
0.159	0.587	0.553	0.586	0.668	0.592
0.182	0.633	0.585	0.631	0.701	0.630
0.205	0.671	0.609	0.668	0.724	0.658
0.228	0.702	0.626	0.699	0.740	0.678
0.250	0.728	0.637	0.723	0.748	0.690
0.273	0.748	0.642	0.743	0.751	0.696
0.296	0.764	0.643	0.757	0.750	0.696
0.319	0.776	0.640	0.767	0.744	0.691
0.341	0.783	0.634	0.773	0.735	0.682
0.364	0.788	0.626	0.776	0.724	0.668
0.387	0.789	0.615	0.776	0.710	0.652
0.410	0.787	0.602	0.773	0.694	0.633
0.432	0.784	0.588	0.767	0.677	0.612
0.455	0.778	0.572	0.760	0.659	0.590

The yellow markings are calculated MSY

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!

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.

.

cont…Solution

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

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

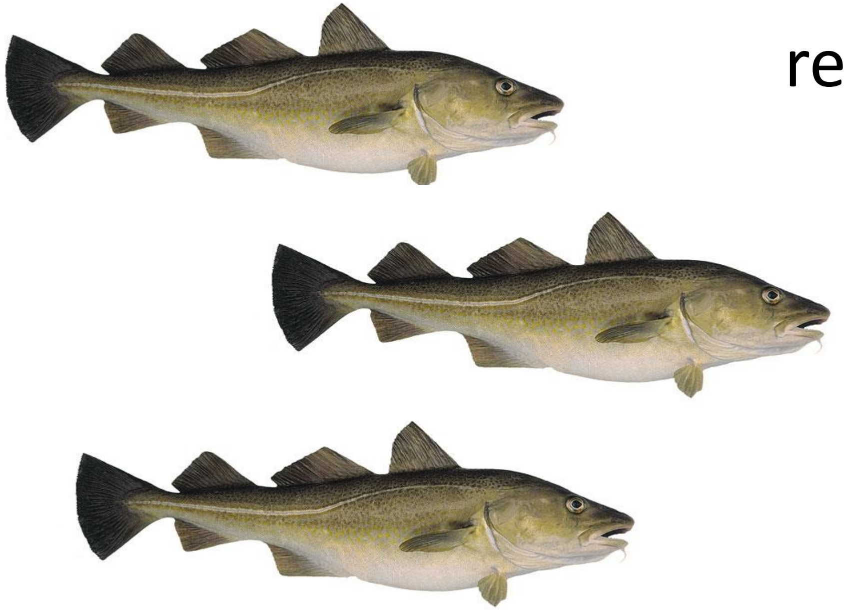
Ecosystem approach to fisheries management

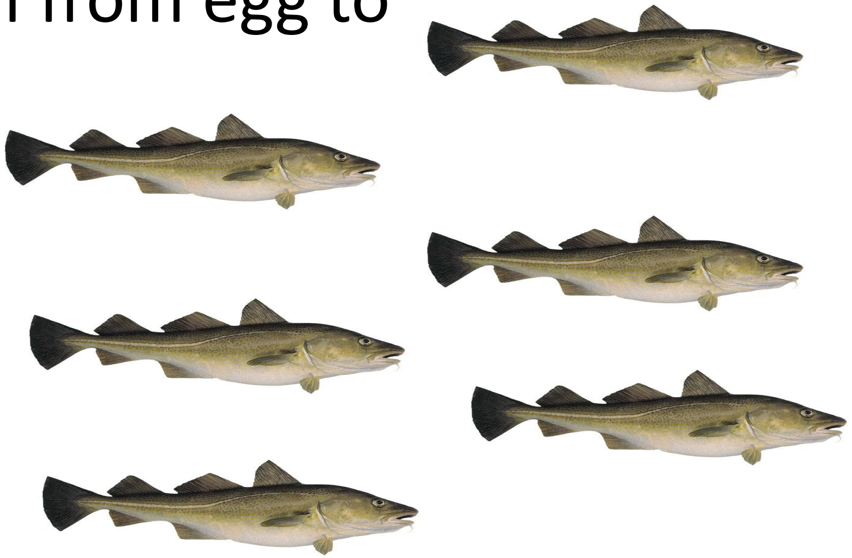
- Everybody say they will do it
- The fact is: scientific bodies giving advice to managers still use the old fashioned single species approach with DD only in recruitment
- Including all 4 density dependent factors in single species approach get closer to “an ecosystem approach”

Density dependence is how ecosystem 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



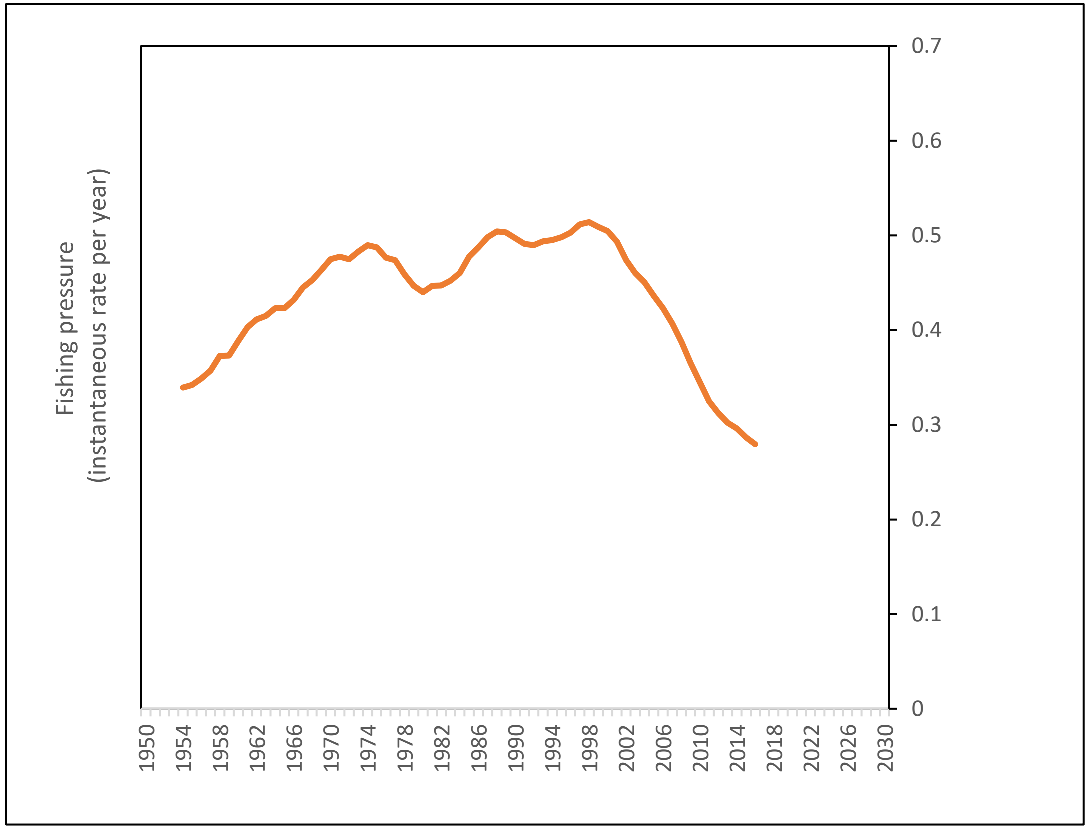


DD not a new “thing” in fisheries

- 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?

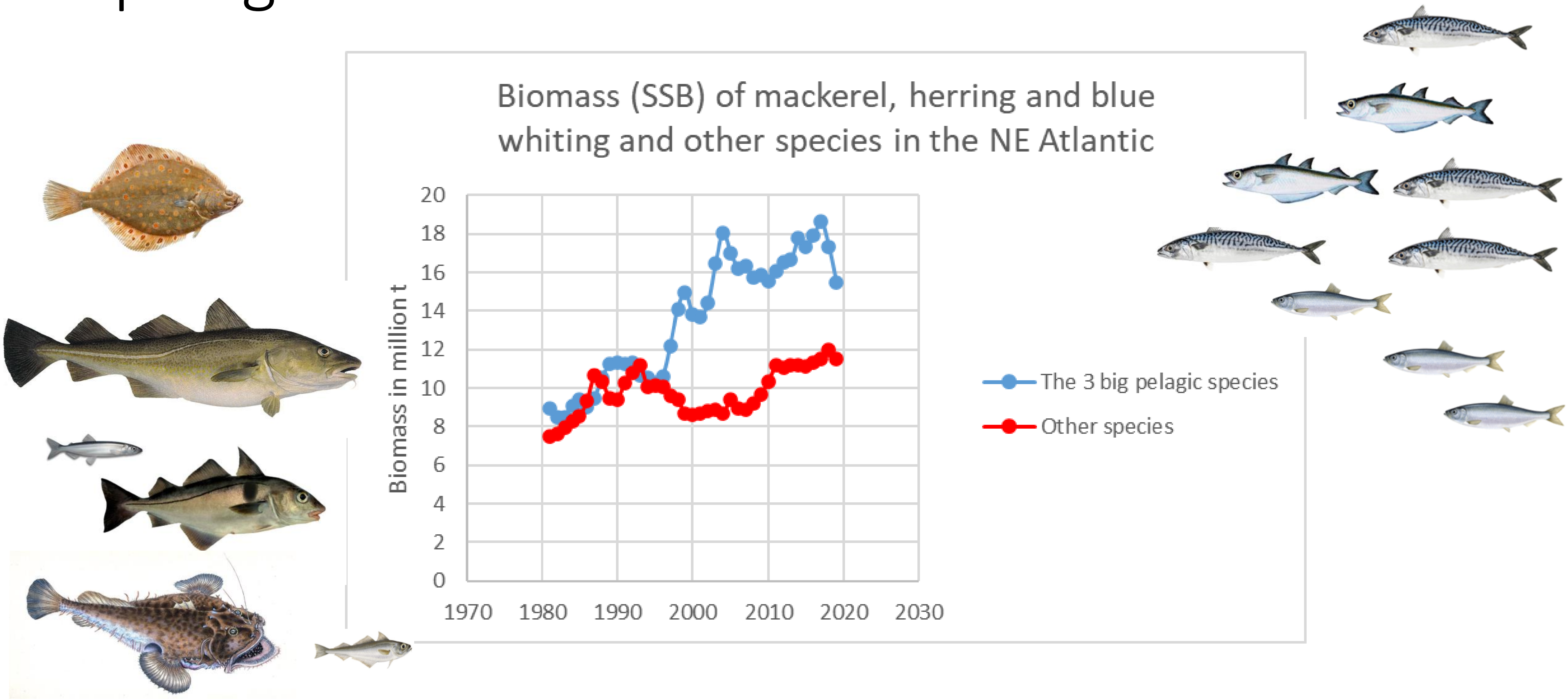
Mean fishing pressure in the Northeast Atlantic (FAO 27) – mean of 53 ICES data rich stocks.



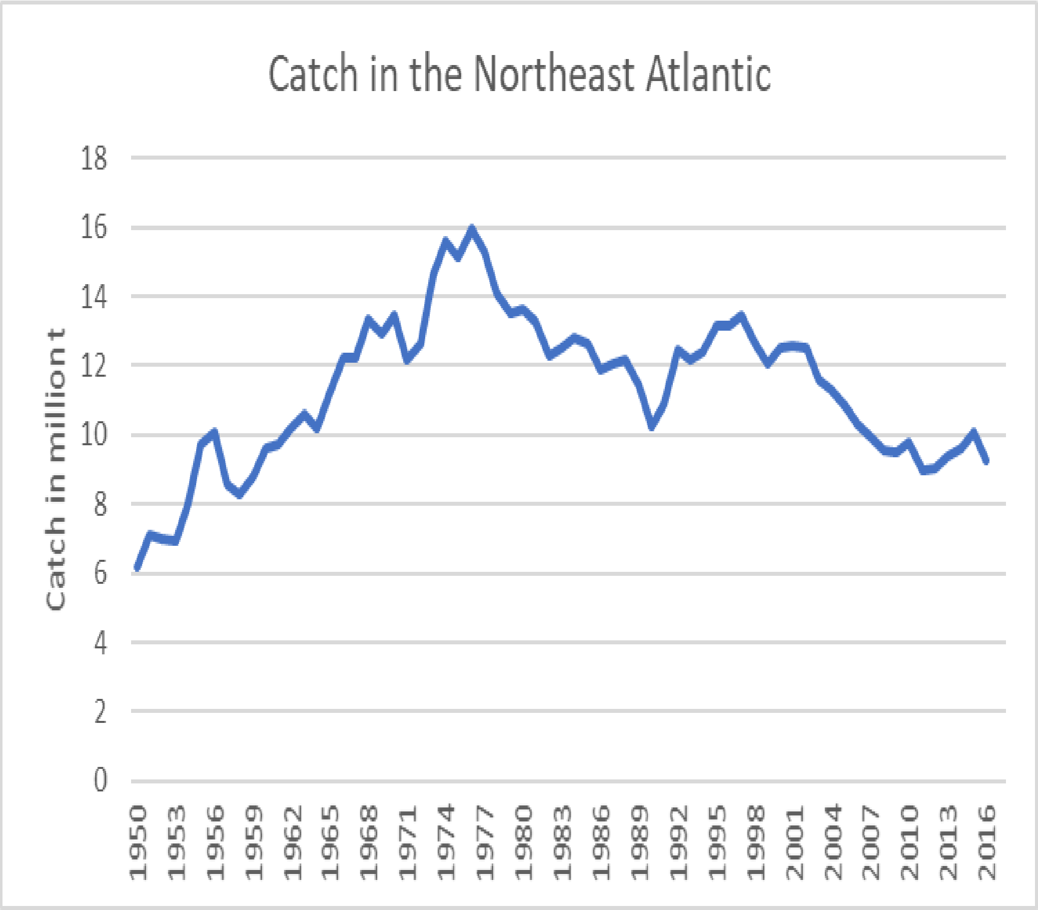
Succes story – Over-fishing has end in the NE Atlantic!!

…about 10 year ago

Stocks increased – especially ”the 3-big pelagics”

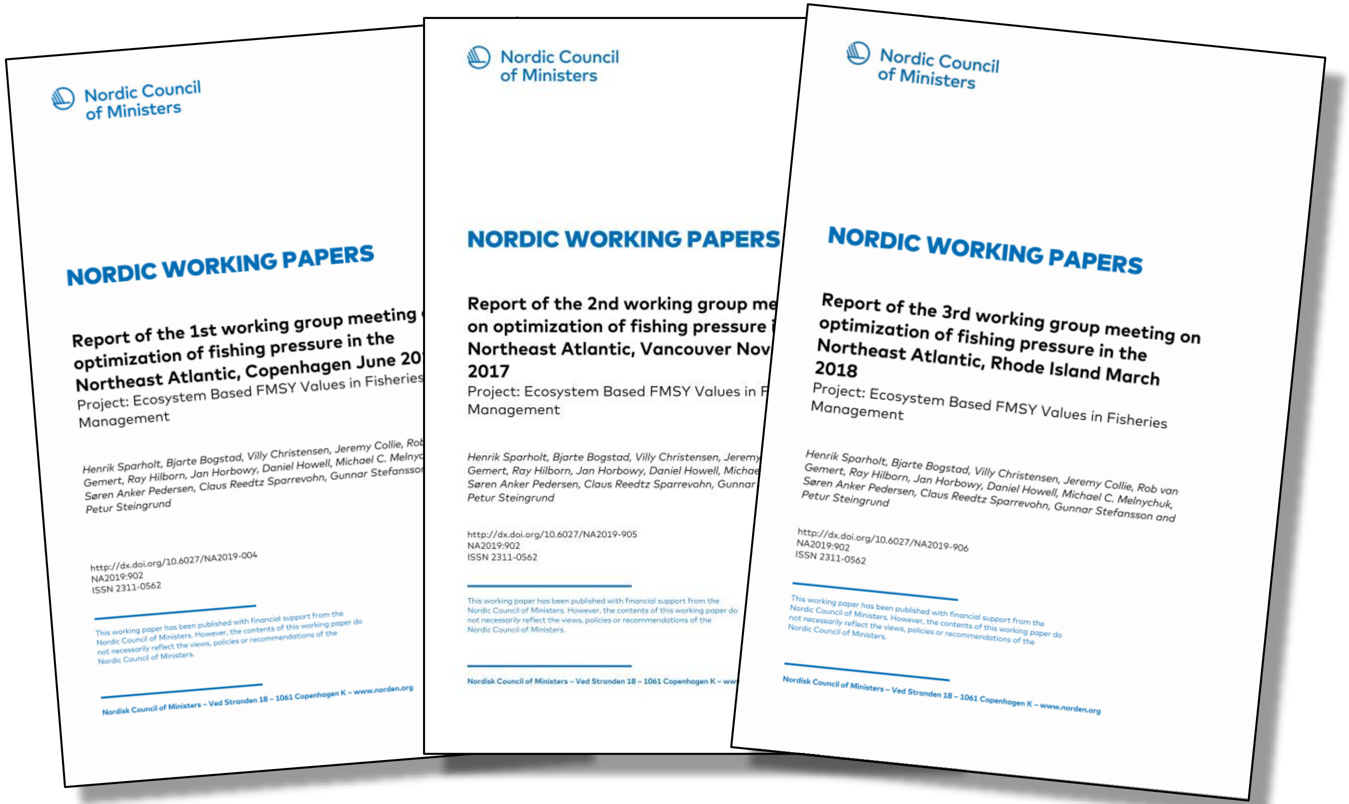


Unfortunately, catches have decreased – where is the ”long-term gain for the short-term pain” scientists told managers in 1980-2000?



Published here:

- https://www.fmsyproject.net/reports



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Original Article

Estimating F_{msy} from an ensemble of data sources to account for density dependence in Northeast Atlantic fish stocks

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A new approach for estimating the fishing mortality benchmark F_{msy} (fishing pressure that corresponds to maximum sustainable yield) is proposed. The approach includes density-dependent factors. The analysis considers 53 data-rich fish stocks in the Northeast Atlantic. The new F_{msy} values are estimated from an ensemble of data sources: (i) applying traditional surplus production models on time-series of historic stock sizes, fishing mortalities, and catches from the current annual assessments; (ii) dynamic pool model (e.g. age-structured models) estimation for stocks where data on density-dependent growth, maturity, and mortality are available; (iii) extracts from multispecies and ecosystem literature for stocks where well-tested estimates are available; (iv) the "Great Experiment" where fishing pressure on the demersal stocks in the Northeast Atlantic slowly increased for half a century; and (v) linking F_{msy} to life history parameters. The new F_{msy} values are substantially higher (average equal to 0.38 $year^{-1}$) than the current F_{msy} values (average equal to 0.26 $year^{-1}$) estimated in stock assessments and used by management, similar to the fishing pressure in the 1960s, and about 30% lower than the fishing pressure in 1970–2000.

Keywords: density dependent, ecosystem, F_{msy}, fisheries, meta-analysis, management

Introduction

Overfishing has been, and still is, a major problem worldwide. In previous decades, when many stocks in the Northeast Atlantic were overexploited and fisheries managers became increasingly pressured to reduce effort, it became clear that management approaches had to be precautionary to promote rebuilding and limit the risk of collapses under sustained fishing pressure. More recently, this precautionary approach has been supplemented by

…and here:

- https://academic.oup.com/icesjms/issue/78/1 if you have access right – alternatively by contacting henrik.sparholt@gmail.com

Extract from Sparholt *et al.* (2021) … just to give you an idea of what we did – we applied several unbiased models for each stock and took a “mean”.

	Column identifier	a	b	c	d	e	f	g	h	i	j	
#	Stock name - short	ICES 2018	Froese *et al.* SPM	RAM Legacy Data-base. Schaefer	RAM Legacy Data-base. Thorson "Taxo-nomic"	RAM Legacy Data-base. Thorson "general"	Eco-system model	Dynamic pool mo-dels, e.g. PROST	Average of b, average (c-e), f and g	GLM of h, based on life history para-meters	Final recom-mended Fmsy values - column i unless there are ecosystem or dynamic pool estimates then a mean of column h and i	Full stock name (truncated to save space)
1	reb.27.1-2		0.06	0.14	0.20	0.15			0.11	0.13	0.13	Beaked redfish in subareas 1 and 2 (Northeast Arctic)
2	bli.27.5b67	0.12	0.11						0.11	0.22	0.22	Blue ling in subareas 6-7 and Division 5.b (Celtic Seas, English …
3	whb.27.1-91214	0.32	0.37	0.31		0.28			0.33	0.44	0.44	Blue whiting in subareas 1-9, 12, and 14 (Northeast Atlantic and …
4	cod.27.5a		0.63	0.45	0.39	0.44		0.70	0.59	0.43	0.51	Cod in Division 5.a (Iceland grounds
5	cod.27.7a	0.44	0.95	0.75		0.66			0.83	0.76	0.76	Cod in Division 7.a (Irish Sea)
6	cod.27.7e-k	0.35	0.56	0.51		0.47			0.52	0.63	0.63	Cod in divisions 7.e-k (eastern English Channel and southern …
7	cod.27.47d20	0.31	0.70	0.73	0.41	0.68	0.87	0.70	0.72	0.71	0.71	Cod in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, …
8	cod.27.1-2	0.40	0.55	0.51	0.46	0.50		0.60	0.55	0.38	0.47	Cod in subareas 1 and 2 (Northeast Arctic)
9	cod.27.5b1	0.32	0.36	0.57	0.52	0.57			0.46	0.60	0.60	Cod in Subdivision 5.b.1 (Faroe Plateau)
10	cod.27.22-24	0.26	0.62						0.62	0.51	0.51	Cod in subdivisions 22-24, western Baltic stock
11	ldb.27.8c9a	0.193	0.33	0.33	0.24	0.32			0.31	0.44	0.44	Four-spot megrim in divisions 8.c and 9.a (southern Bay of Biscay …
12	reg.27.1-2	0.0525	0.10						0.10	0.14	0.14	Golden redfish in subareas 1 and 2 (Northeast Arctic)
13	reg.27.561214	0.097	0.14	0.11	0.08	0.10			0.12	0.14	0.14	Golden redfish in subareas 5, 6, 12, and 14 (Iceland and Faroes …
14	had.27.5a		0.47	0.33		0.31			0.40	0.38	0.38	Haddock in Division 5.a (Iceland grounds)
15	had.27.5b	0.165	0.28	0.39	0.36	0.39			0.33	0.46	0.46	Haddock in Division 5.b (Faroes grounds)
16	had.27.6b	0.20	0.31						0.31	0.39	0.39	Haddock in Division 6.b (Rockall)
17	had.27.7a	0.27	0.41						0.41	0.43	0.43	Haddock in Division 7.a (Irish Sea)
18	had.27.7b-k	0.40	0.87						0.87	0.67	0.67	Haddock in divisions 7.b-k (southern Celtic Seas and English …
19	had.27.46a20	0.19		0.47	0.71	0.51	0.58		0.57	0.35	0.46	Haddock in Subarea 4, Division 6.a, and Subdivision 20 (North Sea, …
20	had.27.1-2	0.35	0.43	0.30	0.24	0.29			0.35	0.26	0.26	Haddock in subareas 1 and 2 (Northeast Arctic)

Results

…on average:

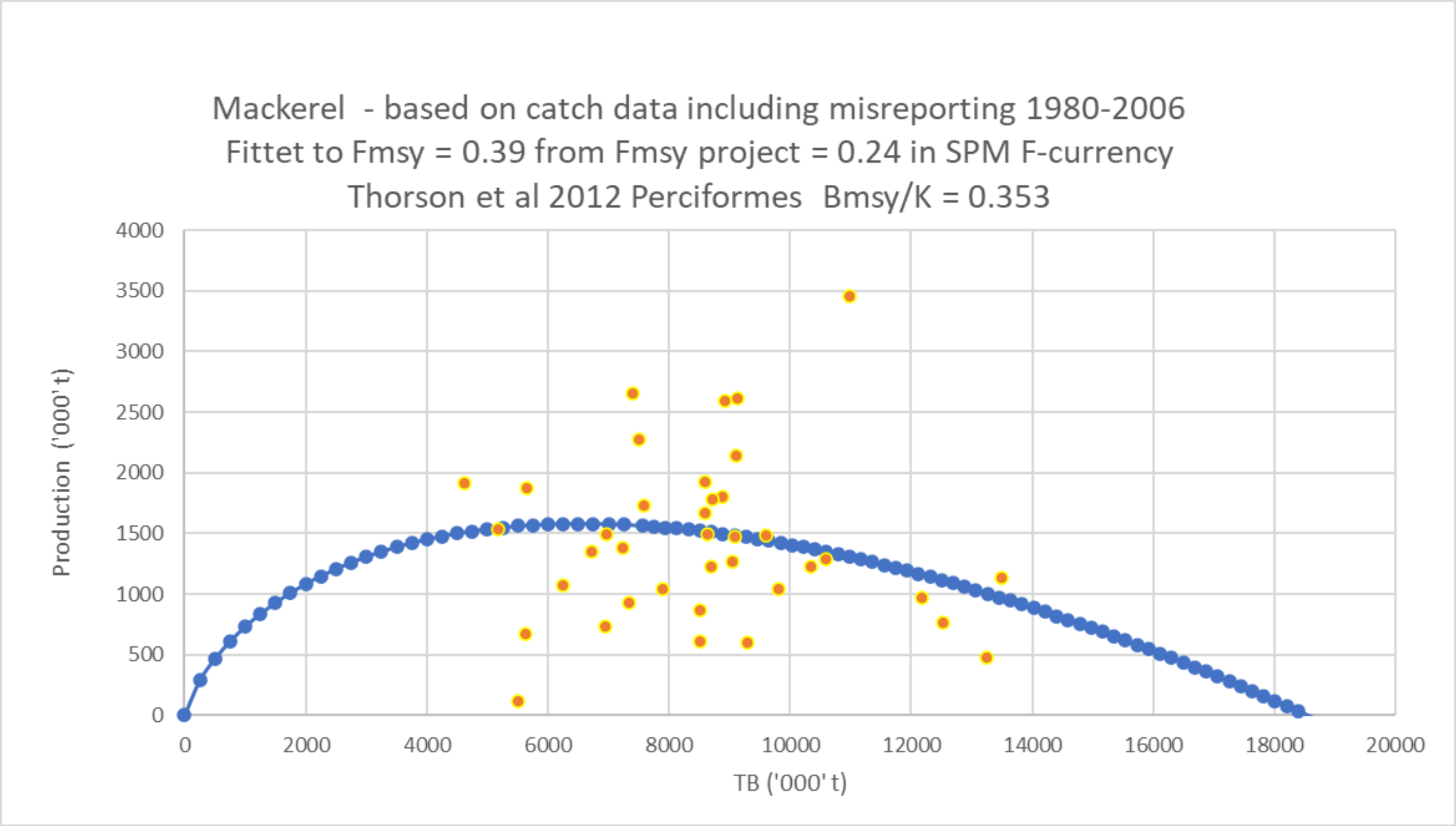
New Fmsy (including all DD) values 50% higher than current Fmsy (only including DD i recruitment) values

Steps to establish the best SPM for a given stock – here NEA mackerel

– equilibrium not needed!

Production (annual):

catch
+
increase in stock size



Cont…Steps to establish the best SPM …

- Use stock biomass and catch from the ICES annual assessment.

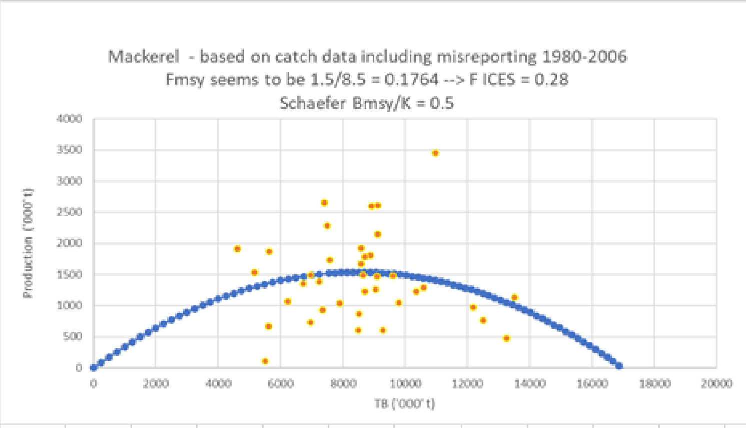
- Often data are noisy and priors for the shape of the SPM-curve useful: Use a meta-analysis of 147 fish stocks from Thorson *et al*. (2012). Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information. Canadian Journal of Fisheries and Aquatic Sciences, 69: 1556–1568.

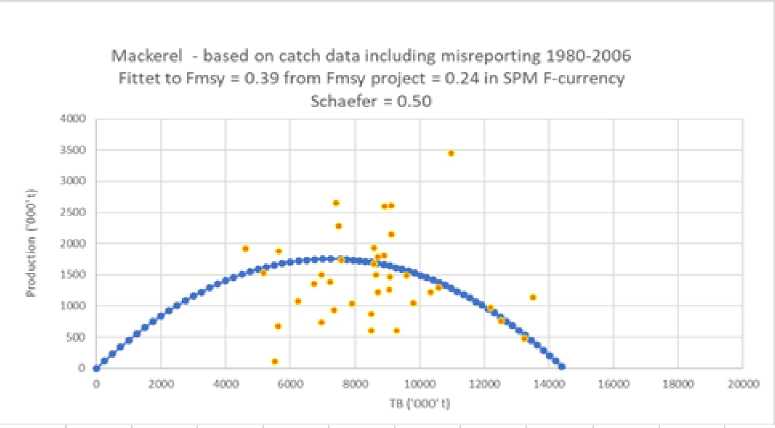
- Sometimes also the height of the SPM-curve is a problem: Use a meta-analysis by Sparholt *et al*. (2020). Estimating Fmsy from an ensemble of data sources to account for density-dependence in Northeast Atlantic fish stocks. ICES Journal of Marine Science. ICES Journal of Marine Science, doi:10.1093/icesjms/fsaa175.

- Compare to available scientific knowledge. A big literature review.

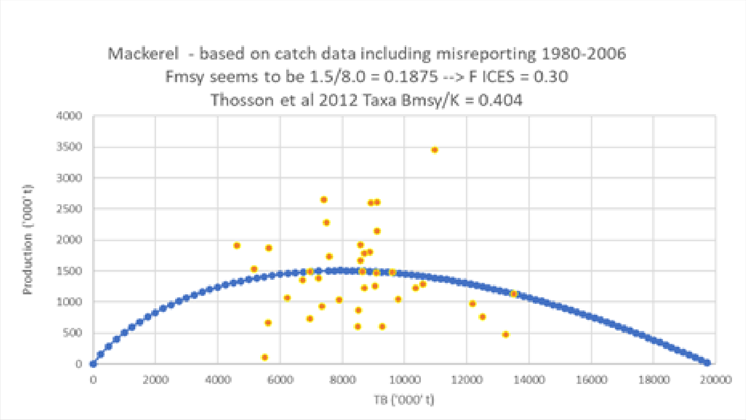
Fmsy estimated | Fmsy from Sparholt *et al.*

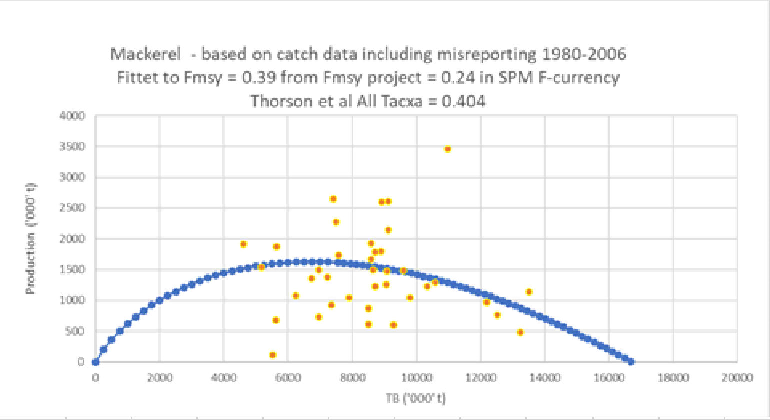
Schaefer





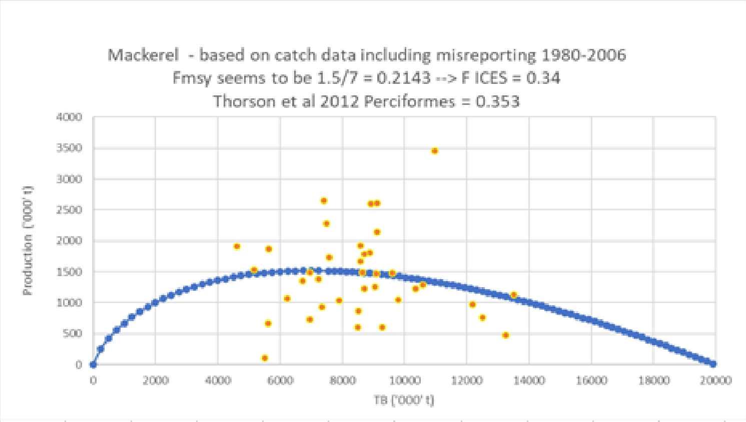
Thorson *et al.* ”all taxa”

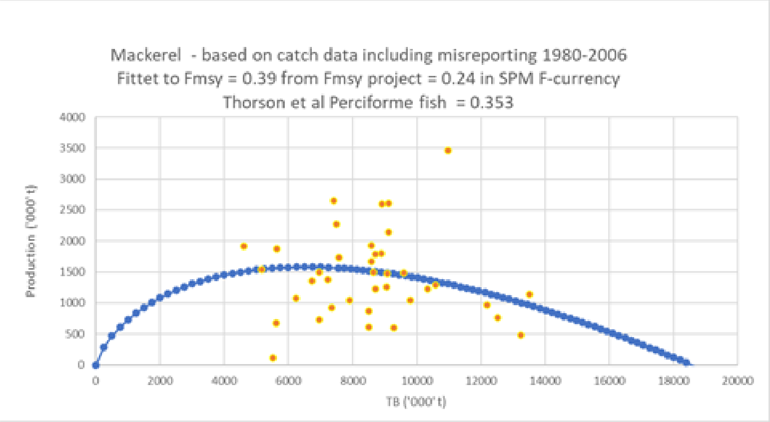




6 alternative models

Thorson *et al.* ”Perciformes”

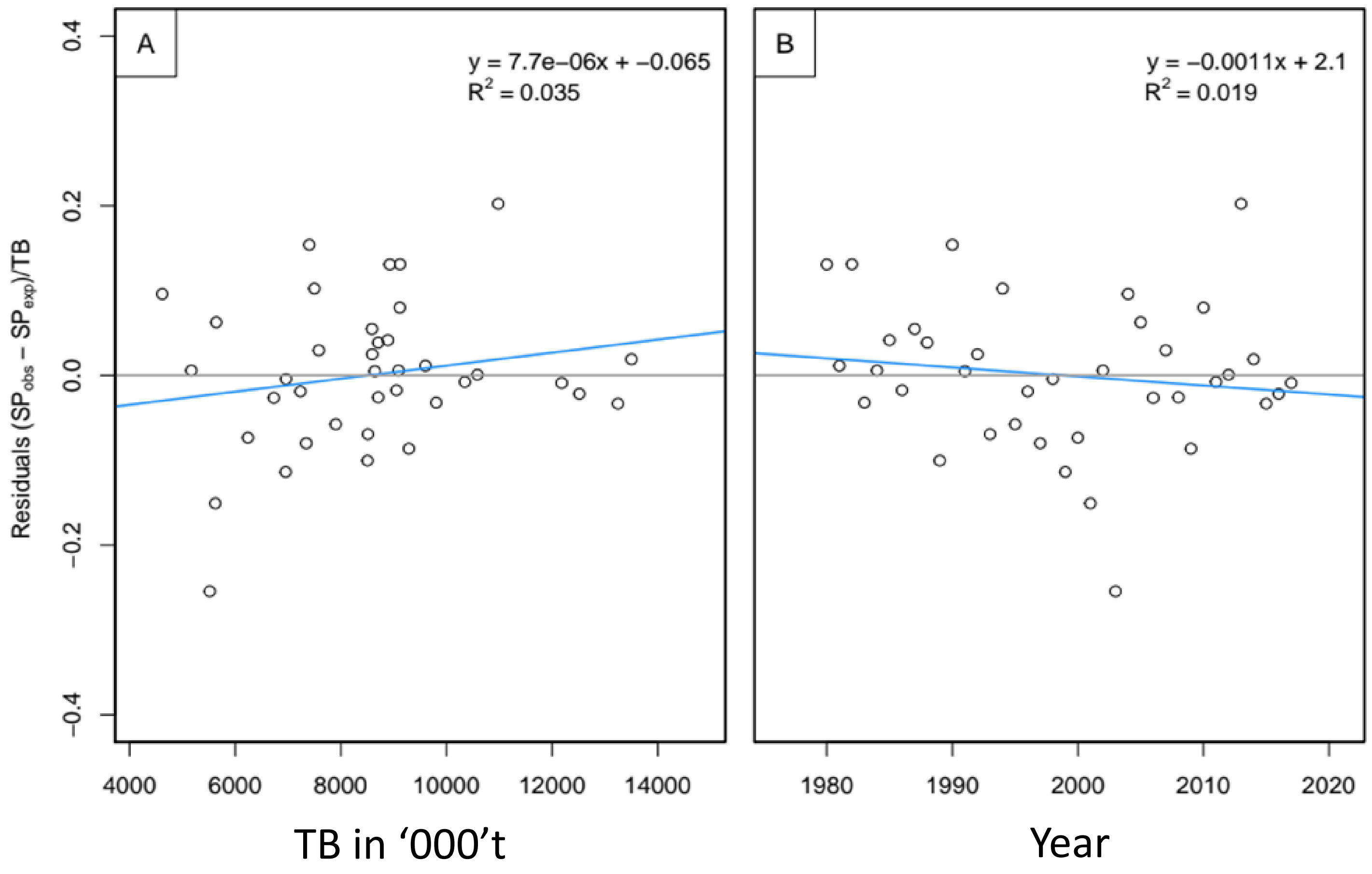




Select the best one using e.g. AICc and residual plots criteria

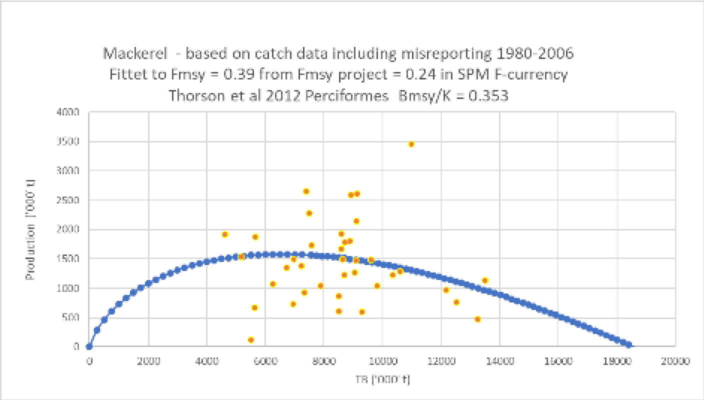
SPM model	Number of para-meters estima-ted	Bmsy/K (curve shape parameter)	R^2	AICc	SSBmsy million t	MSY in million t	K (Carrying capacity) million t	MSY/ TBmsy (Fmsy)
#0 Fmsy estimated Curve estimated	3	0.529	0.24	3.17	6.5	1.54	16.7	0.17
#1 Fmsy estimated – Schaefer	2	0.500	0.24	-0.09	6.4	1.53	17.5	0.17
#2 Fmsy estimated - Thorson et al. (2012) "all taxa"	2	0.404	0.24	-0.03	6.5	1.49	21.9	0.17
#3 Fmsy estimated - Thorson et al. (2012) "Perciformes"	2	0.353	0.25	0.01	6.7	1.48	25.6	0.16
#4 Fmsy fixed –Schaefer	1	0.500	0.11	-0.36	4.9	1.68	14.0	0.24
#5 Fmsy fixed - Thorson et al. (2012) "all taxa"	1	0.404	0.20	-1.60	4.6	1.57	16.2	0.24
#6 Fmsy fixed –Thorson et al. (2012) "Perciformes"	1	0.353	0.22	-1.94	4.5	1.53	18.1	0.24

Residual plots criteria…in this case on the borderline to be rejected – maybe the correction for misreporting in the age-based assessment not super good?

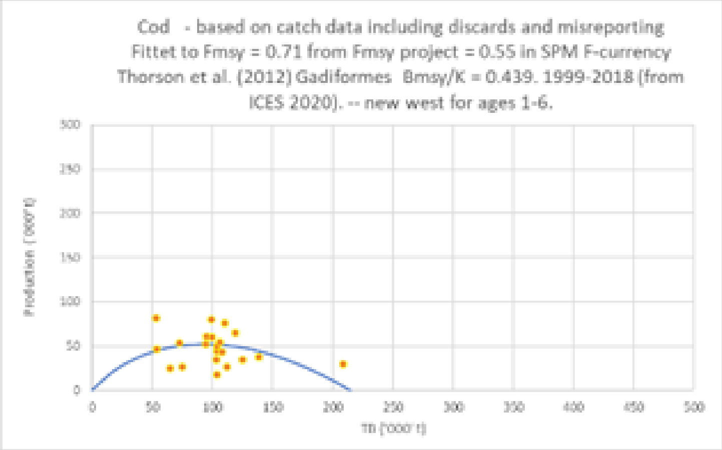


Six stock examples of final SPMs

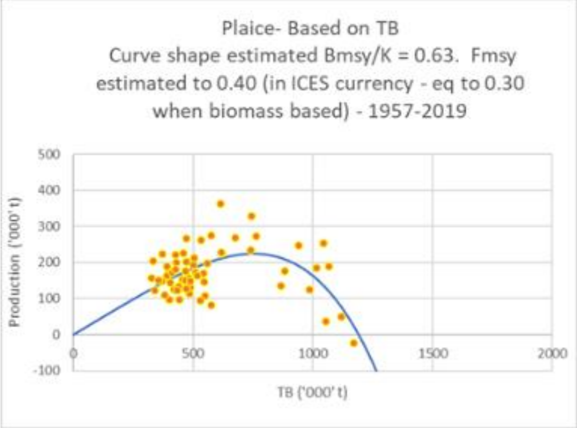
Mackerel - Northeast Atlantic



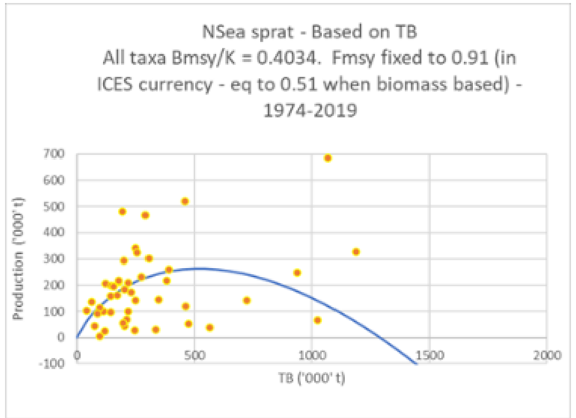
Cod - North Sea



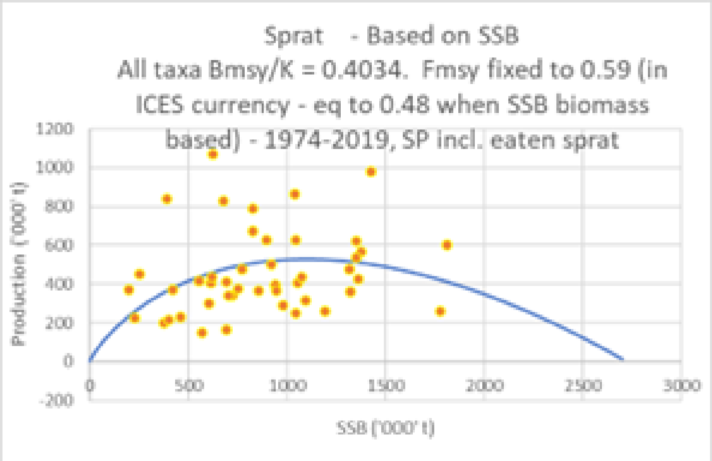
Plaice - North Sea



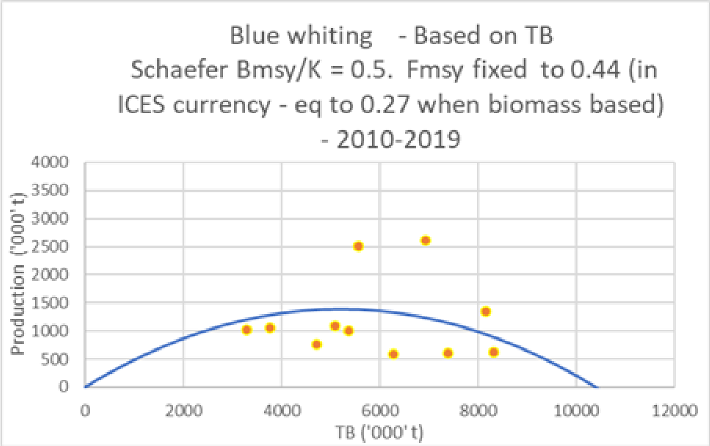
Sprat - North Sea



Sprat - Baltic Sea



Blue whiting - Northeast Atlantic



Robustness

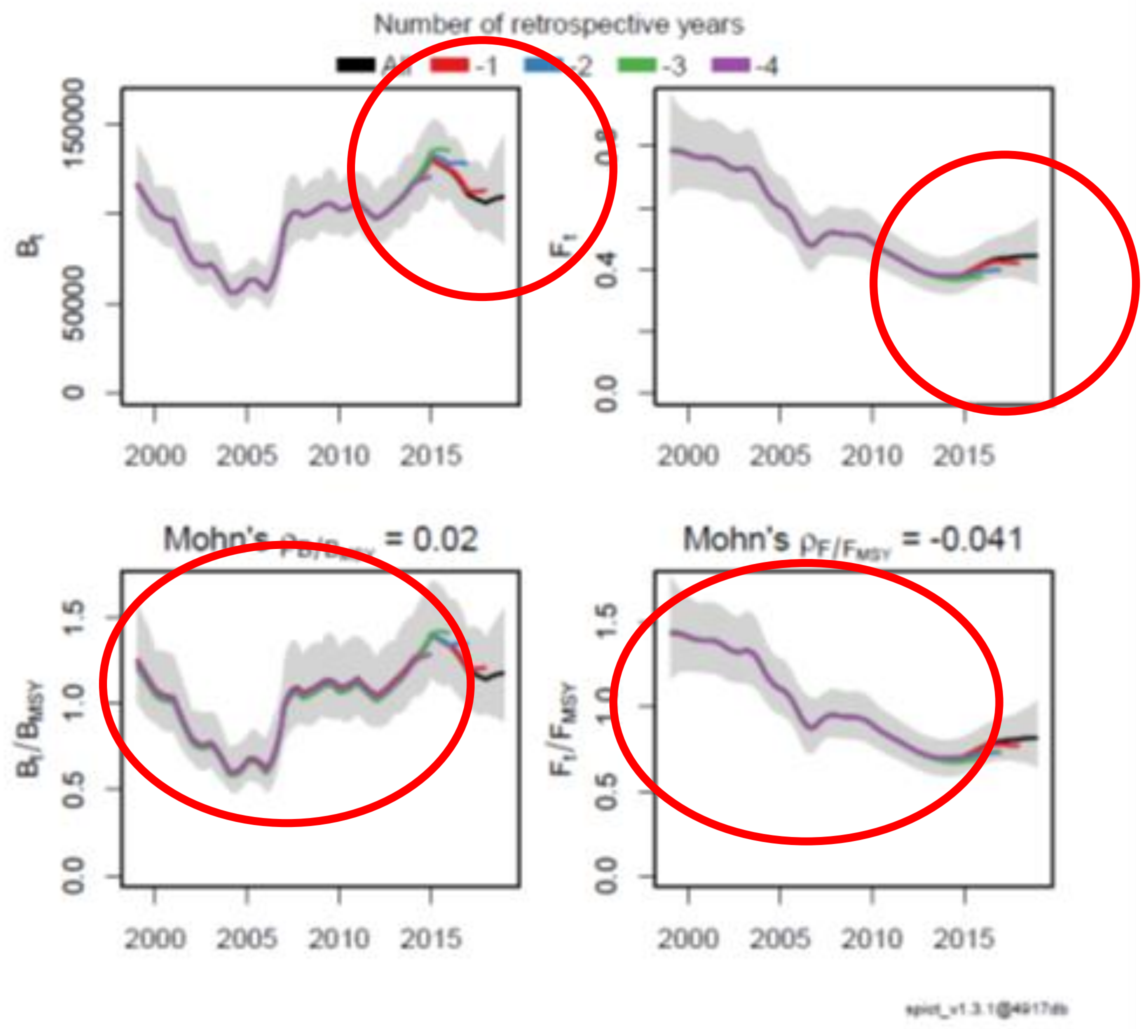
Plaice - North Sea….very robust to adding a new data year.

SPM model	Number of para-meters estima-ted	Bmsy/K (curve shape parameter)	R^2	AICc	SSBmsy '000' t	MSY in '000' t	K (Carrying capacity) '000' t	MSY/TBmsy (Fmsy)
2000-2015	3	0.5762	0.81	14.3	534	222	1253	0.31
2000-2016	3	0.5650	0.81	13.8	540	221	1288	0.30
2000-2017	3	0.5904	0.81	13.3	539	226	1235	0.31
2000-2018	3	0.5910	0.81	13.2	529	224	1214	0.31
2000-2019	3	0.5825	0.81	12.8	522	220	1215	0.31

Sprat - North Sea...very robust to adding a new data year

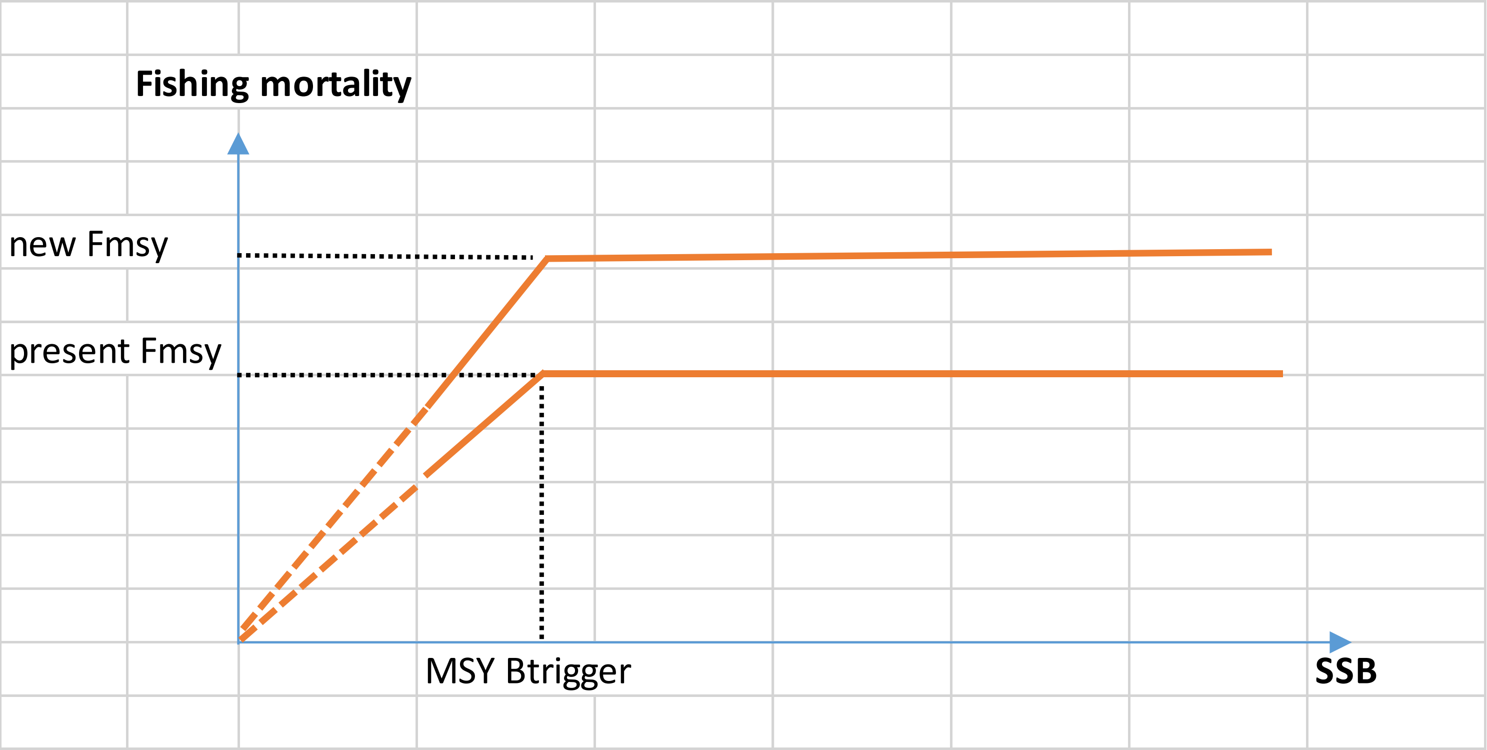
SPM model #6	Number of para-meters estima-ted	Bmsy/K (curve shape parameter)	R^2	AICc	SSBmsy '000' t	MSY in '000' t	K (Carrying capacity) '000' t	MSY/TBmsy (Fmsy)
1996-2015	1	0.265	0.70	22.5	227	186	1388	0.51
1996-2016	1	0.265	0.71	22.4	232	191	1421	0.51
1996-2017	1	0.265	0.71	23.6	233	191	1426	0.51
1996-2018	1	0.265	0.71	24.4	231	190	1416	0.51
1996-2019	1	0.265	0.71	25.1	234	192	1429	0.51

Cod - North Sea…retrospective analysis using SPiCT, quite robust



Caveat for this and the previous 2 slides – it is only the SPM which have been tested – not the annual assessment it is based on.

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



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Argument against the new Fmsy values

”ICES Fmsy includes a precautionary element, the new ones does not…”

Yes, right… …and the reasons are:

- We don’t think it is correct to include a management objective in a scientific concept like Fmsy. Science should be neutral, unbiased and non-political.
- The present Fmsy is not the fishing pressure that gives msy (maximum sustainable catch) – very confusing and non-transparent.
- Inconsistent with what is done on other parts of the World.
- Will make the management in the Northeast Atlantic look worse than it is, because fishing pressures will be compared with too low Fmsy values (See e.g. FAO The State of Worlds Fisheries, 2020).

But the management is still precautionary, because F is reduced when the stock is small (see previous slide) - only a 5% risk to get below Blim

The SPM approach often used for data-poor stocks

- Why should data rich stocks have a higher degree of precautionarity?
- It should rather be the other way around - the less data you have about a stock, the more precautionary you should be!!

Presented at several conferences

ICES Theme session Q
(co-sponsored by PICES) --

Sustainability thresholds and ecosystem functioning: the selection, calculation, and use of reference points in fisheries management

Conference 10-11 October 2018

With managers, stakeholders and scientists

CONFERENCE ON IMPROVED FISHERIES MANAGEMENT MODELS
Copenhagen 8th October 2019

Stakeholders, managers, scientists, NGOs

In ICES expert groups

We in the Fmsy-project (www.fmsyproject.net) and its follow-up MSE-project (www.mseproject.org)

have been quite active in recent years:

- ICES MIACO 2020
- WKMSEMAC 2020
- WKRPChange 2020
- WKGMSE 2020
- WKLIFE X 2020
- WKMSYSPiCT 2021
- WKNSea 2021
- WKREF1 2021
- WKREF2 2022
- WGWIDE 2022

…major changes take time

The scientific community is a “super-tanker” – it takes 10 years (my guestimate) to make a major change in the established way of doing things – you have to reach out to 1000s of scientists.

We started in 2018 and have seen some progress –

- ICES begins to include DD in its ToRs to relevant Expert Groups
- Papers are coming out with meta-analysis of DD in commercial stocks
- Papers are coming out with DD in growth for important commercial stocks
- A few MSEs have been made by ICES including DD in cannibalism and in growth

Conclusion

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


Thank you !