…intended for ToR c) Re-examine and update (if necessary) MSY and PA reference points according to ICES guidelines (see Technical document on reference points).

Relevant Operating Surplus Production Models for North Sea cod MSEs

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Based on analysis in WK Doc HS1-3 WKNSEA 2021, this document concludes which set of OMs based on SPMs, that it might be reasonable to consider when running MSEs for North Sea cod.

It was concluded in the above mentioned WK Docs, that it is appropriate to consider the period 1997-present as a relative stable period for the S-R relationship and with the expected time lag the period 1998-present for SPMs. At the same time, the knowledge about the stock dynamics and the environmental pressures on cod from before this period also contains information, and this is included in various ways below.

It seems to be almost a fact that the southern cod stock is depleted, and it is likely that this is mainly due to climate changes. This southern stock needs a high degree of protection, 1) not to extirpate it completely and 2) to keep the hope alive that it might miraculously recover – maybe due to genetic adaptation. Thus, the following is under the assumption that the management should only allow directed fishing on the northern stock and maybe accept unavoidable by-catch of cod in the southern North Sea.

The following OMs (Figure 1) can be regarded as plausible population dynamics for the North Sea cod for the coming decades:

1. OM1: The fact that we only have one of the two cod now in the Northern area and that this stock historically (1963-1996) has been 43% of the total stock (measured as fraction of age-1 cod in the northern area compared to total North Sea, based on IBTS quarter1 data), mean that K, MSY and Bmsy should only be 43% of the values in 1963-1996, i.e., K = 549 kt, MSY = 133 kt, Bmsy = 241 kt, and SSBmsy = 133 kt. SSQ = 5.14.
2. OM2: However, OM1 is clearly not fitting well with observations since 1998. In OM2 the curve is fitted to the observation in 1998-2018 by letting MSY vary (which is the same as Fmsy varies). K = 549 kt, MSY = 75 kt, (Fmsy= 0.40), Bmsy = 241 kt, and SSBmsy = 133 kt. SSQ = 1.48.
3. OM3: However, OM2 has unusual screwed production curve. In OM3 K is fitted instead of MSY. K = 221 kt, MSY = 54 kt, Bmsy = 97 kt, and SSBmsy = 54 kt. The fit is a little better than for OM3 as SSQ = 1.12.

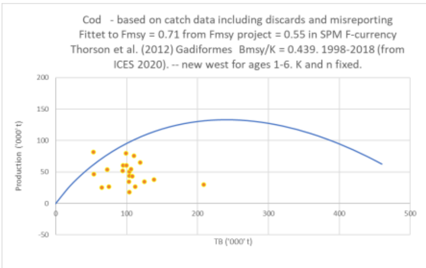
OM3 was also ran with IBTS 1q data and IBTS 3q data, instead of assessment data on stock biomass. All three runs gave very similar parameters values (see Annex 1) and therefore there is no need to consider the IBTS based ones in separate MSEs.

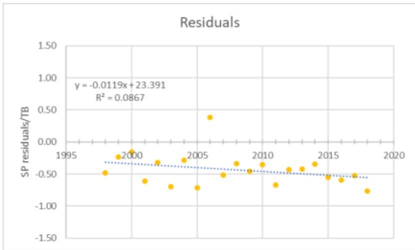
The reduced productivity of the Northern stock in the period 1998-present compared to pre-1998 period as indicated by OM2 and OM3 compared with OM1 is likely due by to the increased predation on pre-recruit cod by grey gurnards, the increased food competition from mackerel, and herring and a possibly increased predation on pre-recruit cod by mackerel and herring (see WK HS2 and WK HS3). On the post-recruit stage increased grey seal predation further reduces the cod productivity. In other words, we see this reduced productivity in the cod data and we see the reasons in the environmental data.

The weighing of OM1- OM3 when doing MSEs is a challenge. OM1 is not fitting the observation of production well in the period and should have a low weight. OM2 should have a median weight as it fits the data well but is unusually screwed (see Thorson *et al.* (2012) for 141 other data rich stocks – an extract shown in this paper in Annex 3), out of line with the value of Fmsy obtained from multispecies models, life history models and cod stocks in other areas. OM3 should have the highest weight because it fit the data well, fits the Thorson et al. (2012) production curve for Gadiformes species, and its Fmsy value is consistent with multispecies models, life history models and cod stocks in other areas. OM3 is furthermore consistent with an alternative OM3 based on IBTS data. The set of weight could be OM1 = 0.1, OM2 = 0.3, OM3 = 0.6.

OM1: 1998-2018 K fixed to 549 kt and n to the standard Gadoid value

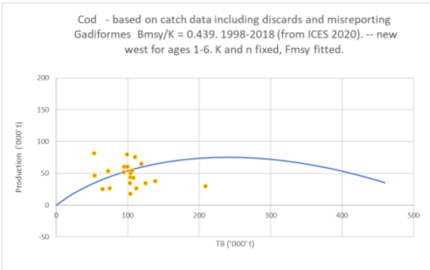
K	549
TBmsy	241
SSBmsy	105
SSBmsy in ICES- currency	133
MSY	133
SSQ	5.14

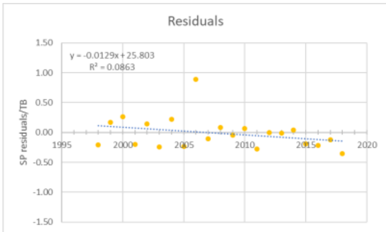




OM2: 1998-2018, Fmsy fitted to observations

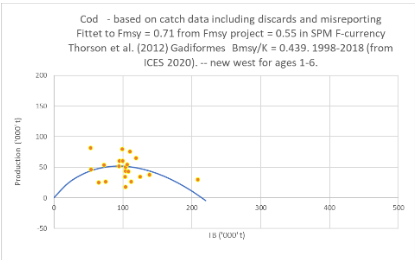
K	549
TBmsy	241
SSBmsy	105
SSBmsy in ICES-currency	133
MSY	75
SSQ	1.48





OM3: 1998-2018 K fitted to observations

K	221
TBmsy	97
SSBmsy	42
SSBmsy in ICES- currency	54
MSY	54
SSQ	1.12



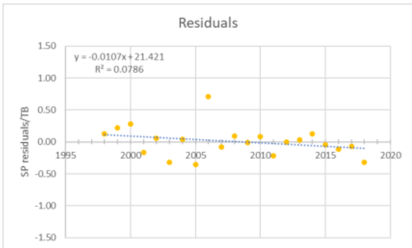


Figure 1. *North Sea cod. Alternatives OMs based on SPMs.*

Discussion

If the carrying capacity K by area is constant, the northern stock occupies an area which is 57% of the total area (depth between 20m and 200m) if RF 8 and 9 are not included (mainly a juvenile area) and 60% if RF 8 and 9 are included (see Annex 4). However, as stated above percentage of age-1 cod in quarter 1 in the northern area is only 43% of the amount so K by area seem to have been lower in the northern area than in the southern area pre-1998.

References.

Thorson, J. T., Cope, J. M., Branch, T. A., and Jensen, O. P. 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.

WK Doc HS1 WKNSEA 2021.

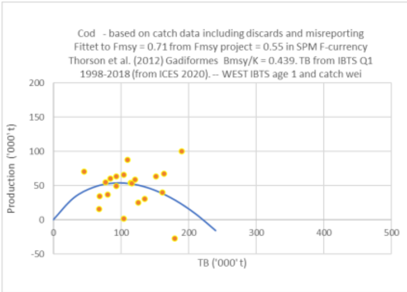
WK Doc HS2 WKNSEA 2021,

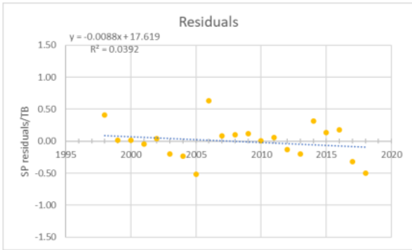
WK Doc HS3 WKNSEA 2021.

Annex 1. OMs based IBTS data instead of assessment data.

OM3.1: 1998-2018, TB based on IBTS q1

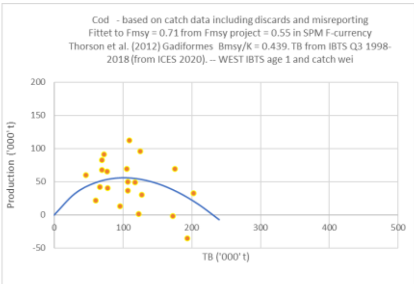
K	221
TBmsy	97
SSBmsy	42
SSBmsy in ICES-currency	54
MSY	54
SSQ	1.51

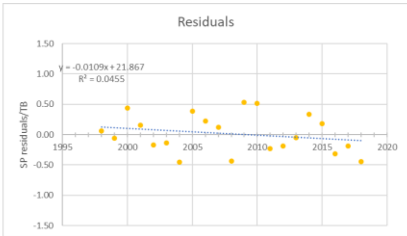




OM3.2: 1998-2018, TB based on IBTS q3

K	232
TBmsy	102
SSBmsy	44
SSBmsy in ICES-currency	56
MSY	56
SSQ	2.01





Annex 2. North Sea cod. Alternative S-R models for 1997-2019.

Figure A2.1. *North Sea cod. Recruitment vs SSB (left panels) and log residuals vs year (right panels) for the entire time series 1997-2019. Top panel is the least SSQ deviation of log values with an SSQ=3.73, the middle plot where the breakpoint is forced to be above the range of the observations SSQ=6.34, and bottom panels where the breakpoint is forced to be below the range of observations SSQ=3.76. Trendlines for the residuals shown as well as their parameters. Based on data from ICES 2020.*

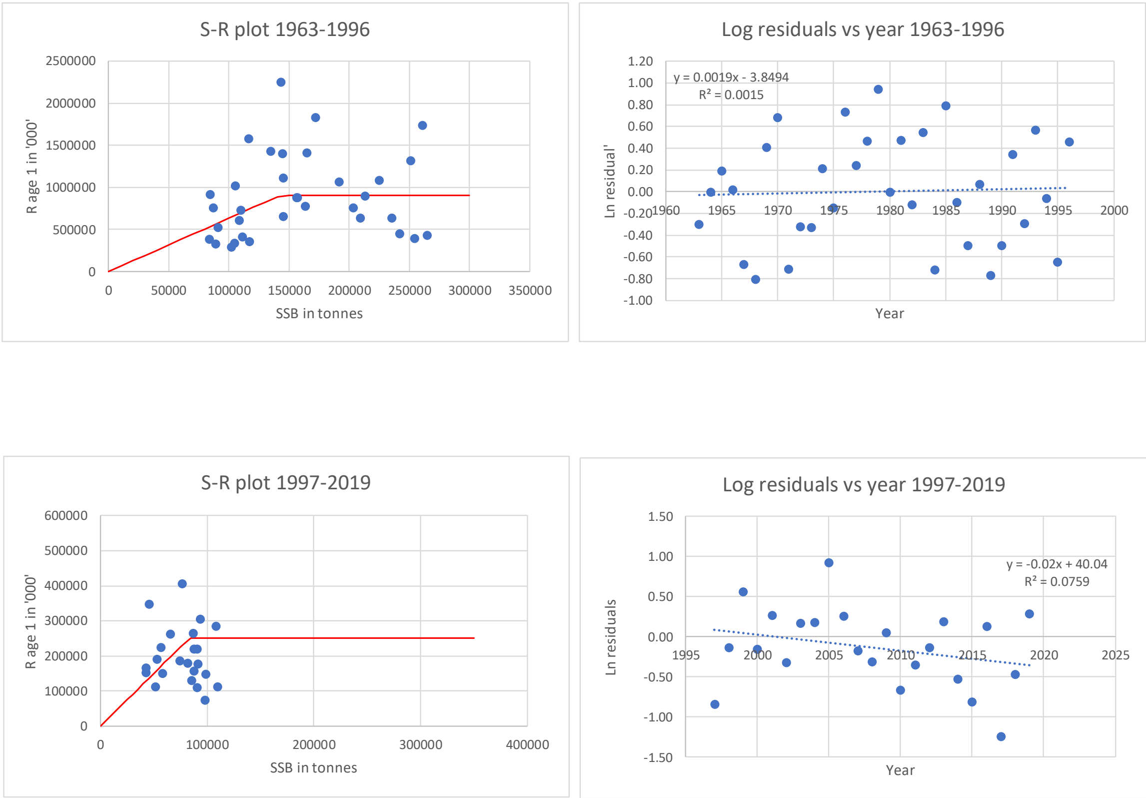
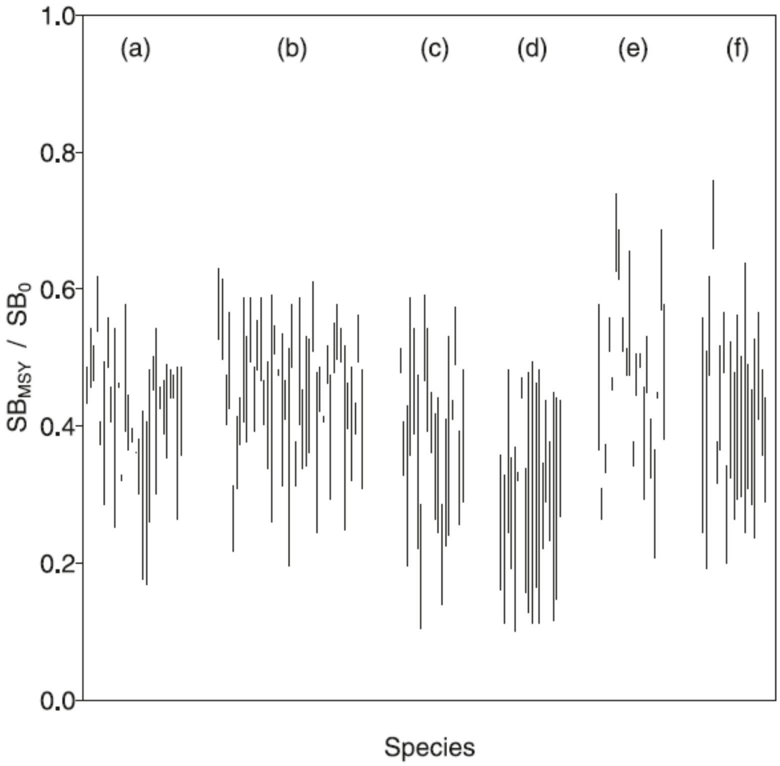


Figure A2.2. *North Sea cod. S-R model with a slope 3.0 and maximum R of 250 million. Blim then becomes around 80,000 t. SSQ=5.74*.

Annex 3. Extrcat from Thorson et al 2012.

Thorson, J. T., Cope, J. M., Branch, T. A., and Jensen, O. P. 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.

Fig. 2. Range for SB_{MSY}/SB_0 conditional on the maximum likelihood estimate of all fixed effects. The line for each species indicates values where the conditional likelihood is >5% of maximum conditional likelihood for the process-error model using spawning biomass (SB_t) as an index of abundance and including taxonomic order but not maximum length. (*a*) Pleuronectiformes; (*b*) Gadiformes; (*c*) Perciformes; (*d*) Clupeiformes; (*e*) Scorpaeoniformes; (*f*) Other.



Annex 4. Area of distribution by southern and northern cod stocks in the North Sea.

Based on IBTS Roundfish (RF) area and fraction of each rectangle with depths between 20m and 200m the table below shows the distribution area by each of the two genetic different cod stocks, a southern and a northern, in the North Sea. Unit: area of a rectangle.

RF	Southern	Northern
1		40.50
2	5.00	20.00
3		18.17
4	6.22	4.34
5	9.01	
6	31.02	
7	9.40	3.90
8		6.42
9		4.76
10	5.90	
Total	66.55	98.09

Fraction of total of sea-bed area, recruitment at age 1 from IBTS 1q survey, and SSB (RF9 excluded for SSB because this is suspected to be separate stock when sampled in 1q of the year, i.e., at spawning time) from IBTS 1q survey:

	Southern cod	*Northern cod*
Sea area 20-200m	0.40	0.60
R age 1 1974-1996	0.57	0.43
R age 1 1983-1996	0.45	0.55
SSB 1984-1997	0.28	0.72
R age 1 1997-2018	0.20	0.80
SSB 1998-2019	0.20	0.80

Just based om the cod data and the SPM approach on productivity of North Sea cod. MSY was 305 kt in 1963-1987. It decreased to 169 kt in 1988-1997 and further to 52 kt in 1998-2018 (See WK Doc HS2). The environmental analysis (WK Doc HS3) showed that:

a. Grey gurnards reduce R of cod in the North sea by a factor of exp(1.0) since the late-1990s.
b. Grey seal increased M by 0.3 for ages 1-3 combined so that is a further reduction of productivity of cod available to fishing of a factor of exp(0.3).

c. The reduction of the southern cod stock further reduced the productivity by about 20%.
d. In total this reduces the productivity since the late-1990s by factor of about exp(1.4)= 4.

Thus, the environmental data are very much in line with the SPM analyses of the current reduction of North Sea cod.