…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).

SSB of the southern and northern North Sea cod stock components – based on IBTS 1q.

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Based on the IBTS 1q survey the stock size of SSB was calculated for each of the cod stock components southern cod and northern cod (see annex 1) based on the definitions by ICES (2020a).

Mean CPUE in numbers by age and rectangle were multiplied with weight-at-age to get CPUE in TB (total biomass) and further with maturity-at-age to get CPUE in SSB. Weight-at-age were from ICES (2020b) moderated as stated in WK Doc HS1. Maturity ogives were taken from ICES (2020b). These mean CPUEs of SSB by rectangle were multiplied by the size of each of the southern and northern areas. Finally, a coefficient was multiplied to these values of SSB stock sizes to scale them to the SSB in '000't as used by ICES. The coefficient used was the average ratio between ICES SSB estimates and the sum of the southern and northern area SSB IBTS values for 1984-2018.

Based on DASTRAS data extracted January 15th, 2021.

SSB for the southern cod have generally been much lower than that of the northern area (Figure 1). The southern stock has furthermore decreased over time while the northern stock has increased until 2019 where it suddenly dropped.

For age 1 cod the fraction in the southern area have been larger than the fraction of SSB (Figure 1). However, already at age 2 the fraction is down to the level of the fraction of SSB. This might indicate that age 1 cod is moving back to the northern area between February one year and February the next year. This again might suggest that juvenile cod from the northern cod stock use the southern area as a juvenile foraging area to a certain extent. An alternative reason could be more heavy fishing (and probably discarding) of age 1 cod in the southern area than in the northern area.
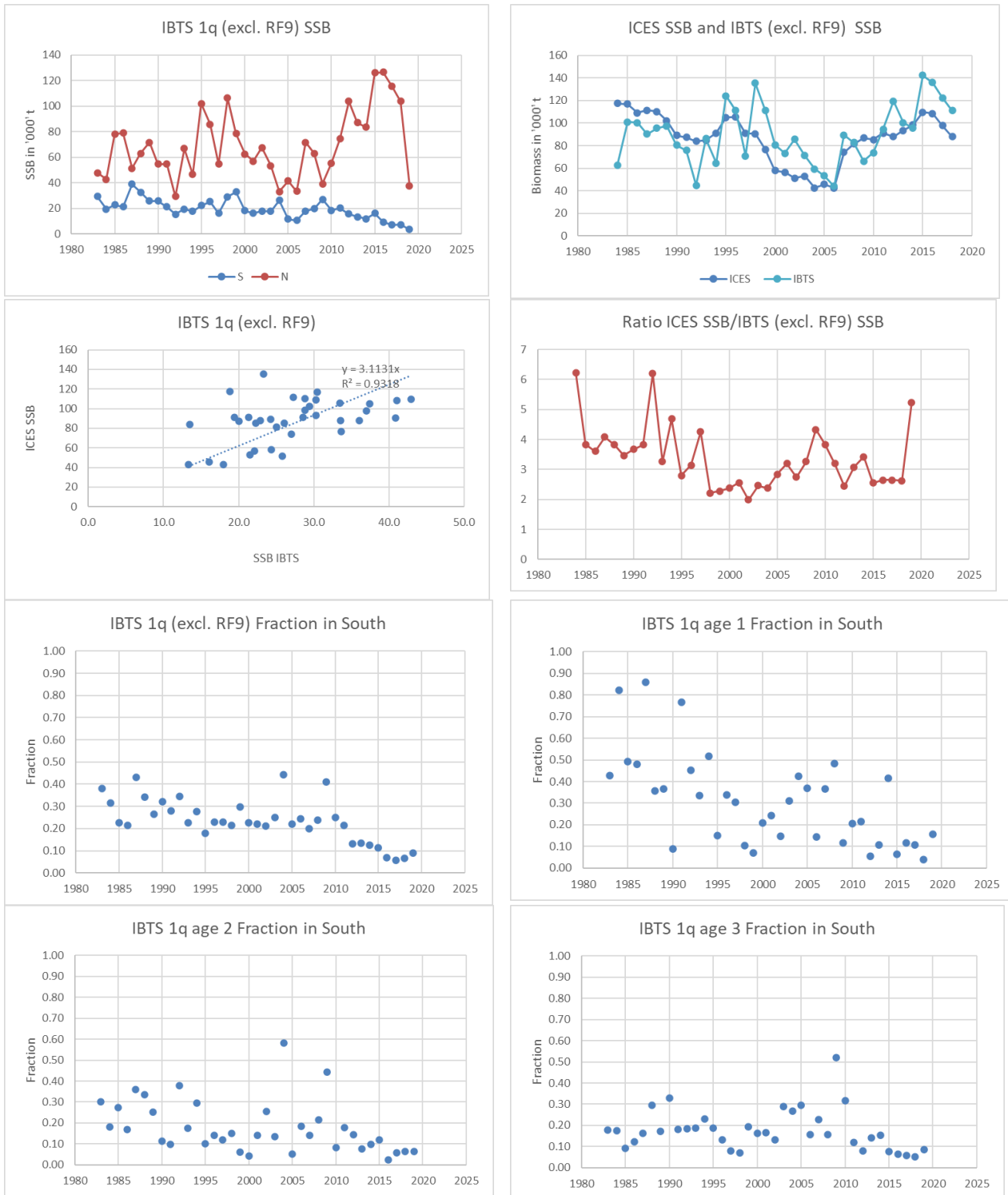
Figure 1. *North Sea cod. Top panel left: Mean SSB (spawner biomass) for the southern area (excl. RF10) (S) vs the northern area (excl. RF9) (N) (ICES 2020a). Top panel right: ICES (2020b) SSB against sum of S and N SSBs. Second row left: regression analysis between ICES (2020b) SSB against sum of S and N SSBs. Second row right: ratio between ICES (2020b) SSB and sum of S and N SSBs over time (can also be regarded as a residual plot in relation to the regression analysis). Third row left: fraction of southern SSB to total SSB (S+N). Third row right: fraction of southern TB age 1 to total TB. Bottom left: fraction of southern TB age 2 to total TB. Bottom right: fraction of southern TB age 3 to total TB.*

The fraction of total stock SSB constituted by the southern cod stock was about 0.30 pre-1998 and reduced to about 0.10 in recent years (Figures 1).

The fraction of TB was a little higher, about 0.40. The TB fraction reduced to about 10% in recent years like for the SSB (Figure 2).
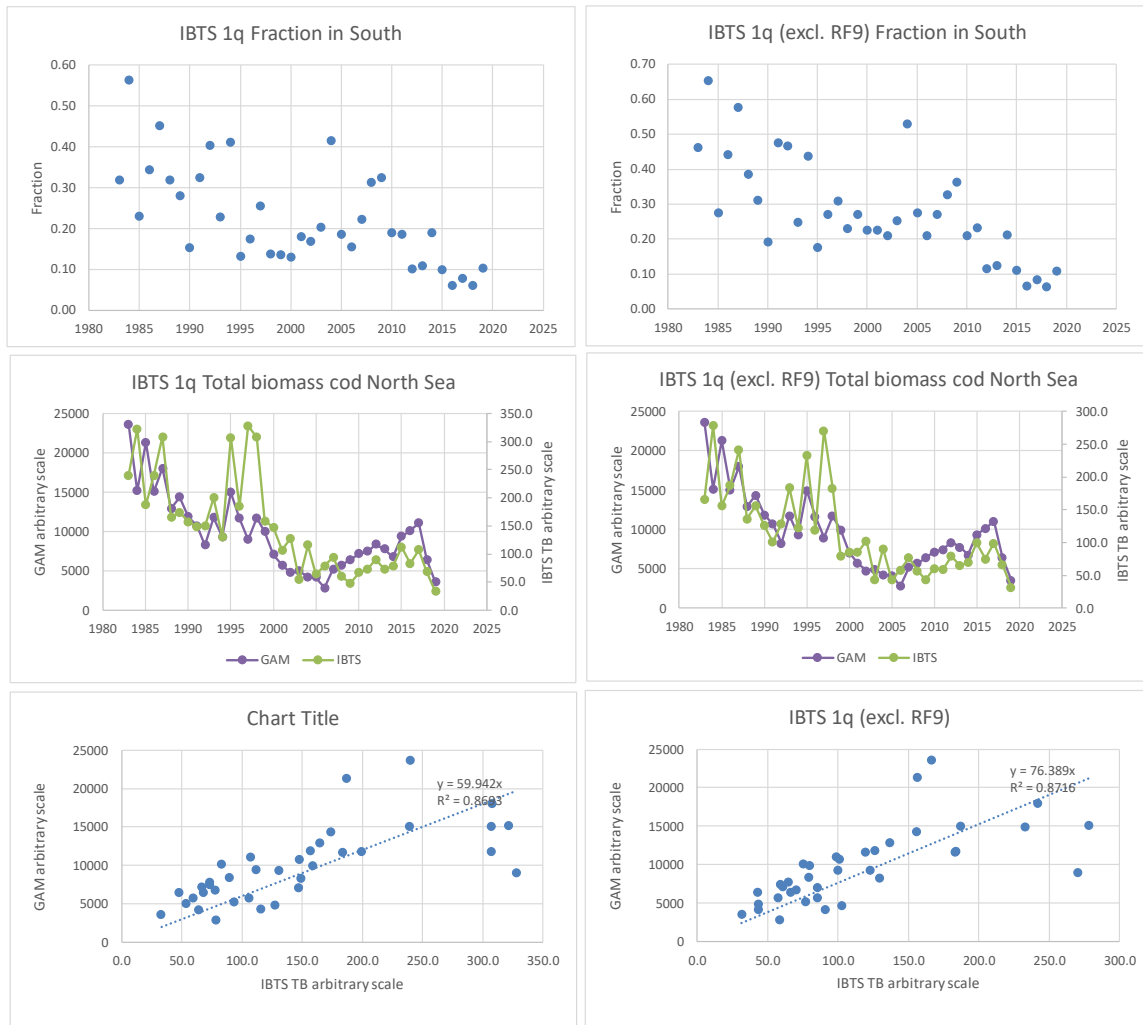

Figure 2.   *North Sea cod. IBTS 1q data. Mean TB (total biomass) for the southern area (excl. RF10) as fraction of TB of the whole North Sea cod (upper panel). TB for IBTS 1q vs the GAM indices are from ICES (2020b) in the middle panel. Bottom panel is the correlation between the two. The panels to the right are without RF9 in the IBTS calculations. The GAM indices are from ICES (2020b).*

Table 1. *North Sea cod. 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:*

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

Based on the SPM approach (See WK Doc HS2) the North Sea cod MSY was estimated to be 305 kt in 1963-1987. It decreased to 169 kt in 1988-1997 and further to 52 kt in 1998-2018.

The above analyses showed that the reduction of the southern cod stock explains about 20% of the reduced the total North Sea cod productivity. Climate changes are a likely explanation to the reduction of the southern cod stock (see e.g. WK Doc HS3).

The big picture

The environmental analysis (WK Doc HS3) and the analysis above showed that:

a. Grey gurnards reduce recruitment of cod in the North sea by increased predation by a factor of exp(1.0) since the late-1990s;
b. Grey seal increased natural mortality M, by 0.3 for ages 1-3 combined. This means a further reduction of productivity of cod available to fishing of a factor of exp(0.3);
c. Harbour porpoise increased natural mortality M by 0.40 for ages 1 and 2. This means a further reduction of productivity of cod available to fishing of a factor of exp(0.4).
d. The reduction of the southern cod stock further reduced the total North Sea cod productivity by about 20% (approximately to exp(0.2)).

In total this reduces the total North Sea cod productivity since the late-1990s by a factor of about exp(1.9)= 6.7. In addition to this but not quantified:

e. Increased food competition for cod larvae from herring and mackerel;
f. Probably (but not well documented) increased predation by herring and mackerel on cod larvae.

The environmental data and the analysis above are in line with the SPM analyses and therefore can be claimed to offer a plausible explanation of the observed reduction in productivity of North Sea cod in recent years.

References.

ICES. 2020a. Workshop on Stock Identification of North Sea Cod (WKNSCodID). ICES Scientific Reports. 2:89. 82 pp. http://doi.org/10.17895/ices.pub.7499.

ICES. 2020b. Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. 2:61. 1140 pp. http://doi.org/10.17895/ices.pub.6092.

WK Doc HS1 WKNSEA 2021.

WK Doc HS2 WKNSEA 2021,

WK Doc HS3 WKNSEA 2021.

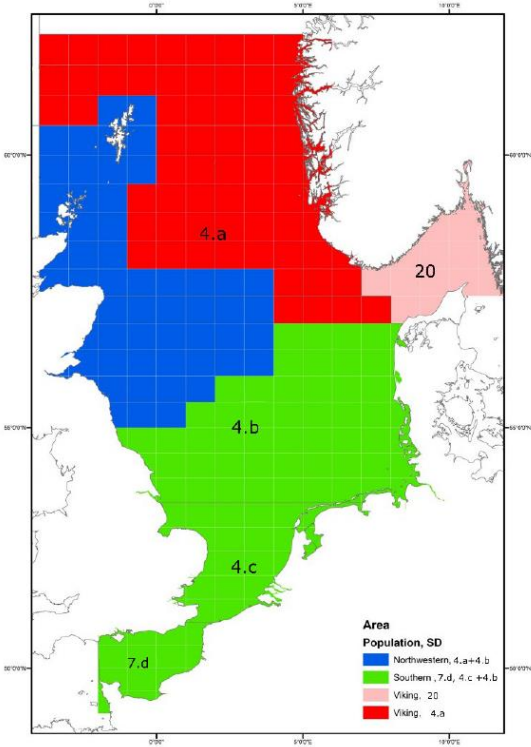**Annex 1.** Area definition.

Figure A1.   Area definition of the southern stock (green) and the northern stock (blue, red and pink).