The following supplement accompanies the article

Conservation value of historical data: reconstructing stock dynamics of turbot during the last century in the Kattegat-Skagerrak

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Supplement 1. Further details of the survey database as well as standardization procedures and data analysis

Standardization of CPUE

Standardization of catch per unit effort (CPUE) to swept area per unit of time was conducted in 2 steps: trawling speed and horizontal opening of the trawls.

Trawling speed of the different research vessels

As the catch per unit effort (CPUE) was standardized to catch per hour (no. h^{-1}) per unit of swept area, swept area depended on the speed of the vessel. We set the trawling speed (S; 4 knots) of the Swedish international RV 'Argos' as 1 and estimated the relative speed (RS) of the other vessels (at the haul level). Thus, the standardized CPUE for the vessel x in the year y and haul λ was:

$$\mathrm{CPUE}\ _{xy\lambda} = \mathrm{CPUE}\ _{xy\lambda} \times \mathrm{RS}_{xy\lambda} \qquad (1)$$

where $\mathrm{RS}_{xy\lambda}$ is equal to:

$$\mathrm{RS}_{xy\lambda} = \mathrm{S}_{\mathrm{Argos}}/\mathrm{S}_x$$

When haul-specific trawling speeds were not available, the average speed of the same vessel in the same year was used (Table S1). It is worth noticing that speed does not only have

Table S1. Summary of the survey database used in the analysis with the research vessels and the number of different trawls deployed per year, number of months of sampling, relative trawl size (RTS), haul duration, vessel speed, mesh size, depth range and number of hauls. Vessel codes: Skagerrak1 (1), Skagerrak2 (2), Skagerrak3 (3), Selma (4), Eystrasalt (5), Thetis (6), LL149 (7), Argos (8) and Ancylus (9). When max value is not given min and max values are the same

Year	Vessel(s) used	Trawls used	No. months		RTS		Duration (h)		Speed (nm h^{-1})		Mesh size (mm)			Depth range (m)	No. hauls (n)
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Average		
1925	1	2	1	12	6.7	10.1	0.1	1.0	2.6	2.6	56	56	56	21–430	68
1928	1	3	2	12	5.0	10.1	0.4	2.0	2.6	2.6	56	56	56	16–325	65
1929	1	5	1	12	5.0	20.2	0.3	4.0	2.6	2.6	56	56	56	7–290	89
1930	1	3	1	12	8.6	20.2	0.3	2.0	2.6	2.6	30	56	50	11–497	102
1932	2	3	1	12	6.7	8.6	0.2	3.0	2.8	2.8	14	64	39	12–450	49
1933	2	4	1	12	6.7	10.1	0.1	1.0	2.8	2.8	12	64	29	12–584	71
1935	2	2	1	10	6.7	8.6	0.4	2.0	2.8	2.8	14	87	44	16–350	45
1936	2	4	1	11	6.1	8.6	0.2	1.0	2.8	2.8	14	64	33	11–350	66
1937	2	2	4	9	7.6	8.6	0.7	0.9	2.8	2.8	14	45	35	13–340	12
1938	2	5	2	11	5.0	20.2	0.7	1.0	2.8	2.8	14	42	37	18–425	60
1939	2, 4	5	1	11	5.0	20.2	0.2	1.3	2.7	2.8	30	42	41	10–255	142
1945	3	1	11	11	20.2	20.2	0.5	0.5	2.8	2.8	30	30	30	12–32	5
1946	3	4	3	10	2.7	8.6	0.3	1.0	2.8	2.8	14	42	25	12–324	17
1947	3	5	2	10	2.6	10.1	1.0	2.0	2.8	2.8	11	100	58	11–524	26
1950	3	3	11	12	1.2	8.6	0.6	1.0	2.8	2.8	23	23	23	11–100	3
1951	3	2	8	11	2.7	8.6	0.5	0.5	2.8	2.8	20	23	22	24–140	15
1952	3	2	1	1	8.1	8.6	0.3	0.5	2.8	2.8	20	80	28	37–67	4
1955	3, 5	3	1	12	8.1	12.1	0.3	2.0	2.7	2.8	22	80	33	14–150	102
1956	3, 5	2	2	12	8.6	12.1	0.3	1.0	1.8	4.0	11	22	19	18–176	90
1957	3, 5	1	1	12	12.1	12.1	0.3	2.0	1.4	3.0	11	80	40	18–153	49
1960	5	1	9	9	12.1	12.1	2.0		1.4		11	11	11	30	2
1961	6	1	8	12	8.6	8.6	0.4	1.7	1.5	3.9	11	80	35	11–135	23
1962	3, 6	1	1	12	8.6	8.6	0.2	1.9	1.5	4.0	11	75	27	17–118	52
1964	6	1	11	11	1.2	1.2	0.5		1.9		11	80	36	26	1
1965	6	1	3	6	8.6	8.6	0.8	1.0	1.7	3.8	11	70	19	26–482	13
1966	3, 6	2	3	12	1.3	8.6	0.6	1.0	1.5	3.2	11	30	20	22–61	57
1967	3, 6	3	1	11	1.2	8.6	0.6	1.1	2.0	3.4	18	30	19	25–109	21

Supplement 1 (continued)

Table S1 (continued)

Year	Vessel(s) used	Trawls used	No. months		RTS		Duration (h)		Speed (nm h^{-1})		Mesh size (mm)			Depth range (m)	No. hauls (n)
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Average		
1968	7	1	10	10	1.1	1.1	0.7	2.4	2.6	3.2	42	80	77	36–54	3
1969	6	1	6	6	1.3	1.3	0.5	0.5	3.2	3.2	18	18	18	33–58	3
1970	6	1	2	10	1.3	1.3	0.3	0.7	3.2	4.3	18	18	18	14–133	22
1972	3, 6	5	2	10	1.2	6.7	0.5	1.0	2.0	5.8	11	70	19	20–210	51
1973	3	1	1	2	3.3	3.3	0.5	1.0	2.8	2.8	16		16	22–110	17
1974	6	1	1	2	3.3	3.3	0.5	1.0	2.5	3.5	16		16	21–66	21
1975	8	1	2	2	3.3	3.3	0.8	1.5	1.5	4.0	16		16	21–300	14
1976	8	1	2	2	3.3	3.3	0.5	1.0	1.2	4.0	16		16	22–374	30
1977	8	1	2	2	3.3	3.3	0.6	1.0	1.9	3.2	16		16	21–235	22
1978	8	1	2	2	3.3	3.3	0.5	0.8	2.0	4.2	16		16	22–225	21
1979	8	2	3	3	1.7	3.3	0.4	1.0	2.4	4.6	16	70	21	21–104	30
1980	8	1	2	2	1.7	1.7	0.3	0.7	1.4	5.2	16		16	21–142	32
1981	8	1	2	2	1.7	1.7	0.2	0.5	2.0	4.2	16		16	22–183	32
1982	8	1	2	12	1.7	1.7	0.3	1.0	3.7	4.0	16		16	32–232	24
1983	8	1	1	3	1.7	1.7	0.3	1.3	3.1	4.8	16		16	29–210	36
1984	8	1	2	2	1.7	1.7	0.5	1.0	3.2	4.6	16		16	21–75	35
1985	8	1	2	2	1.7	1.7	0.3	1.0	3.4	7.8	16		16	21–150	33
1986	8	2	2	2	1.0	1.7	0.3	1.8	3.0	4.4	16		16	21–248	42
1987	8	2	2	2	1.0	1.7	0.3	1.0	2.8	5.0	16		16	22–300	49
1988	8	2	2	2	1.0	1.7	0.5	1.0	1.6	4.3	16		16	22–265	39
1989	8	2	2	2	1.0	1.7	0.5	1.3	3.0	4.4	16		16	18–234	43
1990	8	2	2	9	1.0	1.7	0.5	1.0	2.2	4.6	16		16	18–209	66
1991	8	2	2	10	1.0	1.7	0.3	0.5	3.0	4.6	16		16	18–265	124
1992	8	2	2	9	1.0	1.7	0.2	1.1	3.0	4.4	16		16	18–258	92
1993	8	2	2	11	1.0	1.7	0.3	1.0	2.4	4.6	16		16	18–260	144
1994	8	2	1	9	1.0	1.7	0.3	1.5	2.0	4.2	16		16	17–262	148
1995	8	2	1	9	1.0	1.7	0.5	0.5	3.2	4.2	16		16	18–265	149
1996	8	2	1	9	1.0	1.7	0.3	0.6	3.2	4.6	16		16	18–257	98
1997	8	2	1	9	1.0	1.7	0.5	0.5	3.2	4.4	16		16	19–262	89
1998	8	2	1	9	1.0	1.7	0.5	0.5	3.4	4.2	16		16	19–256	92
1999	8	2	1	9	1.0	1.7	0.5	0.5	3.4	4.2	16		16	18–257	92
2000	8, 9	3	1	12	1.0	3.3	0.3	1.7	2.6	4.4	16		16	12–218	138
2001	8, 9	3	1	11	1.0	3.3	0.3	1.0	2.6	4.2	16		16	11–261	230
2002	8, 9	3	1	11	1.0	3.3	0.3	0.5	2.5	4.2	16		16	12–255	221
2003	8, 9	3	1	11	1.0	3.3	0.3	0.6	2.5	4.2	16		16	11–262	183
2004	8, 9	3	1	11	1.0	3.3	0.4	0.6	2.5	4.0	16		16	12–263	203
2005	8, 9	3	1	11	1.0	3.3	0.3	0.5	2.5	4.0	16		16	9–280	193
2006	8, 9	3	1	11	1.0	3.3	0.3	0.5	2.5	3.8	16		16	10–260	189
2007	8, 9	3	1	11	1.0	3.3	0.3	0.5	2.5	4.0	16		16	10–254	187

implications on the swept area but also on the length-specific catchability. However, since the relationship between speed and species-specific size catchability of the different trawls used in the past was unknown, we assumed it to be constant throughout the time series.

Horizontal opening of the trawls

Horizontal opening of the trawl affects the area swept by the gear. Thus, the horizontal opening of each trawl is usually estimated as two-thirds of the length of the trawl headline (Rijnsdorp et al. 1996). However, the Vigneron Dahl system, patented in the early 1920s, introduced the concept of rope bridles between otter boards and net, usually known as sweeps (i.e. extension of the groundrope between the wing of the net and the trawl doors). This substantially increased the area of seabed swept by the gear at very little cost in terms of additional towing power, and dramatically improved trawl efficiency (Galbraith & Rice 2005). Therefore, the horizontal opening of the sweeps was added to that of the headline to estimate the total horizontal opening between the trawl doors (cf. Rijnsdorp et al. 1996; see Table S1 for details). The distance between the doors and the horizontal opening of the sweeps is regularly measured during IBTS trawl surveys (ICES 1992). This distance is dependent on the sweep length but also on the angle between the sweep/headline and the tow direction. Here, we used the average angle (49°), as measured for the Grand Ouverture Vertical (GOV) trawl on-board Argos, to estimate the horizontal opening of the sweeps for all the trawls in the database. The GOV trawl has been used on a regular basis since 1974 for all surveys performed by Argos, it is an otter trawl with a relatively high vertical net opening of 5 to 6 m, a headline of about 36 m and sweeps of 50 m. However, from 1986, the horizontal opening of the GOV was increased by an extension of the sweeps (about 100 m; ICES 1992) for hauls deeper than 70 m carried out in the 1st quarter of the year (hereafter defined as GOV1). For further details see ICES (1992).

Thus, the trawl horizontal net opening of GOV1 was set as 1 and the relative trawl size (RTS) of the other gears was expressed as relative to Argos GOV1 trawl size (TS). Thus, CPUE in the year *y*, haul λ and gear ω is:

$$\text{CPUE}_{y\lambda\omega} = \text{CPUE}_{y\lambda\omega} \cdot \text{RTS}_{y\lambda\omega} \tag{2}$$

where $\text{RTS}_{y\lambda\omega} = \text{TS}_{\text{ArgosGOV1}}/\omega$.

Finally, CPUE from the vessel *x* in the year *y*, haul λ and gear ω is:

$$\text{CPUE}_{xy\lambda\omega} = \text{CPUE}_{xy\lambda\omega} \cdot \text{RS}_{xy\lambda} \cdot \text{RTS}_{y\lambda\omega} \tag{3}$$

This value is usually defined as an area-swept abundance estimate (Harley & Myers 2001) and it corresponds here to the abundance of fish caught by trawling for 1 h a standard bottom swept area of 0.89 km^2 using a GOV1 trawl at the standard speed of 4 knots. Estimated $\text{CPUE}_{xy\lambda\omega}$ was not further standardized for different mesh sizes since the specific gear selectivity for older trawls was unknown. Instead, $\text{CPUE}_{xy\lambda\omega}$ was estimated using only individuals larger than a specific length threshold, corresponding to the first length class (in cm) that is fully selected by the largest mesh size (i.e. 80 mm in the cod end with the exception of few hauls in 1947) used during the entire time series (see Table S1). There are no specific selectivity studies in the area so we used results for plaice with the same gear where the first fully selected length class is estimated to be around 15 cm (Wileman 1988). Thus, the biomass of the stock was estimated as $\text{CPUE}_{xy\lambda\omega}$ of individuals >25 cm; this corresponds to individual around or older than 2 yr (North Sea turbot; Jones 1974). Since there are no or little data about maturity at length in the studied area (but see Jones 1974), and scarce information in adjacent areas, we preferred to use an arbitrary 25 cm in total length rather than any guess of length at maturity as the threshold for estimating historical trends in turbot biomass. This was considered as a compromise to avoid issues related to selectivity and at the same time circumvent the influence of recruitment (Age 1) on historical estimates of turbot biomass.

Calibration experiments

Several factors were used to standardize the catches of the historical trawl surveys in approximately similar units. Nevertheless, we are fully aware that a perfect standardization of CPUE coming from different trawls is not possible without ad hoc calibration experiments between different gears. Thus, to test our expected trawl productivity (based on area-swept abundance estimates) we performed an experiment to compare Argos GOV against RV 'Ancylus' *Nephrops* trawls (Svedäng 2007). Based on our estimates of the swept area, Argos GOV should produce expected CPUE values that were about 2.9 times those of Ancylus *Nephrops* trawls for demersal species (Table S1). The experiment was based on 31 parallel hauls and carried out in 2004 and 2007 in the Kattegat-Skagerrak. The outcome of the experiment showed on average CPUE values 3.3 times those of Argos GOV (data not shown), a result similar to those predicted by our swept area estimation.

GAM modelling

The effects of the predictors included in the final models are presented in Figs. S1 & S2 and discussed in the main text of the manuscript. Analysis of the residuals did not reveal any major departures from the model assumptions for all final models and the frequency distributions of the residuals did not depart from the normal distribution (data not shown).

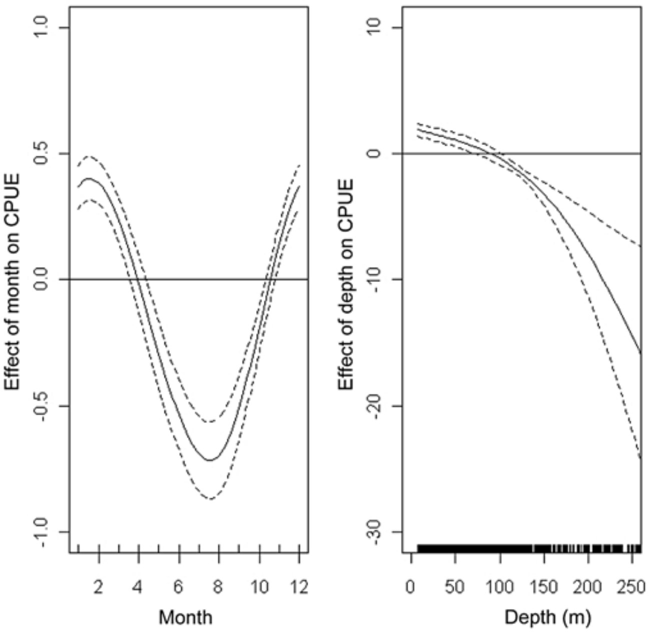

Fig. S1. Additive unidimensional predictor effects (month, depth) as estimated by the final GAM model on CPUE (kg h^{-1})

Sensitivity analysis of the CPUE model

Ecological modelling aims to understand how underlying processes interact in a system through the development of a model that cannot leave out of consideration the problem of precision and robustness. Sensitivity analysis covers several aspects related to determining how sensitive a model is to changes in its parameters, structure or, more generally, how it depends on the information presented (Saltelli et al. 2000). The degree of complexity of spatial models tends to amplify the effect of interactions between input data on the model output (Crosetto & Tarantola 2001).

Our analysis focused on testing how model predictions are affected by the size of the data set in order to evaluate the stability and robustness of the model results and understand the reliability of the model in catching the underlying process described by the data. We tested if a sample limited to a small percentage of the whole data set still captures enough variability to be able to generate a good model. If the model maintains its performance for conspicuous reductions in the sample size we are confident that our formulation is modelling an authentic signal from the data. To analyse the stability of the estimates, a correlation coefficient was calculated between the model predictions from the full and the reduced data set (Fig. S3). The sensitivity analysis was based on a randomly stratified resampling scheme, so that random samples were drawn from the data set according to the number of hauls available for each year. Due to the elevated computational costs of fitting GAM on large data sets, the number of iterations was fixed following the rule of thumb of 100 model runs

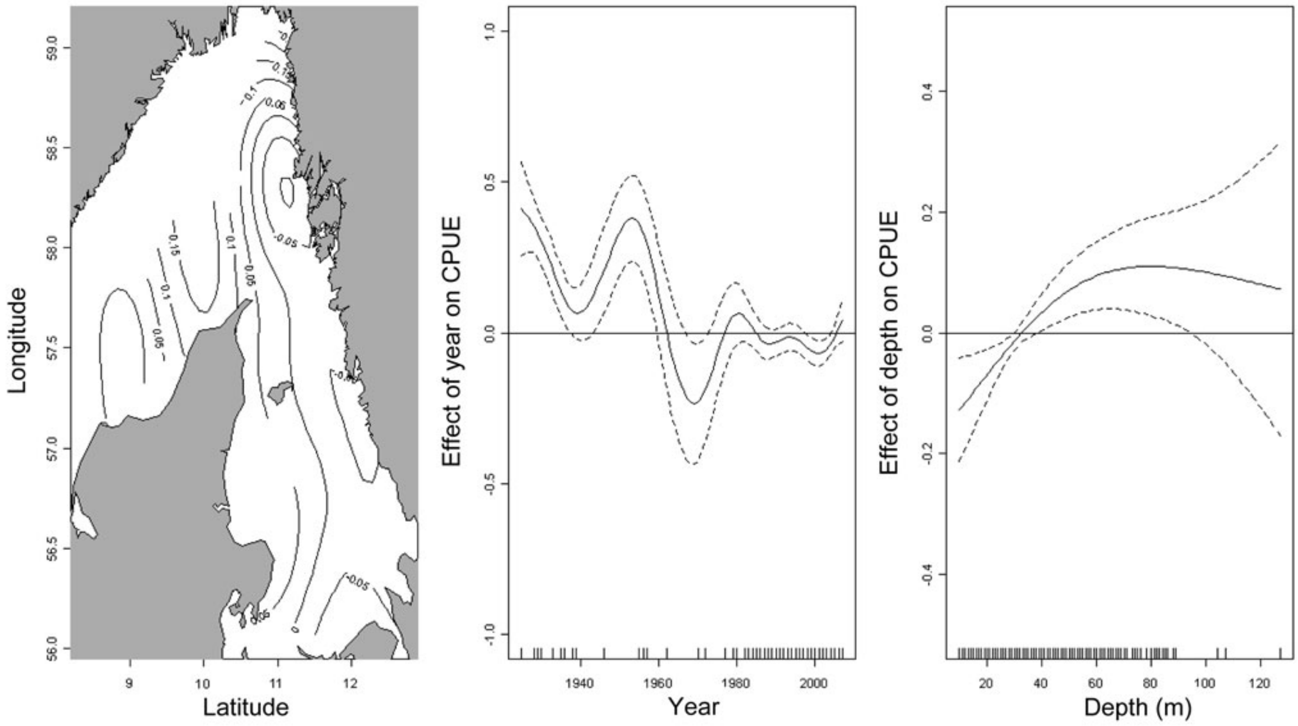

Fig. A2. Predictors as estimated by the final generalized additive model on average maximum body length (L_{max} in cm)

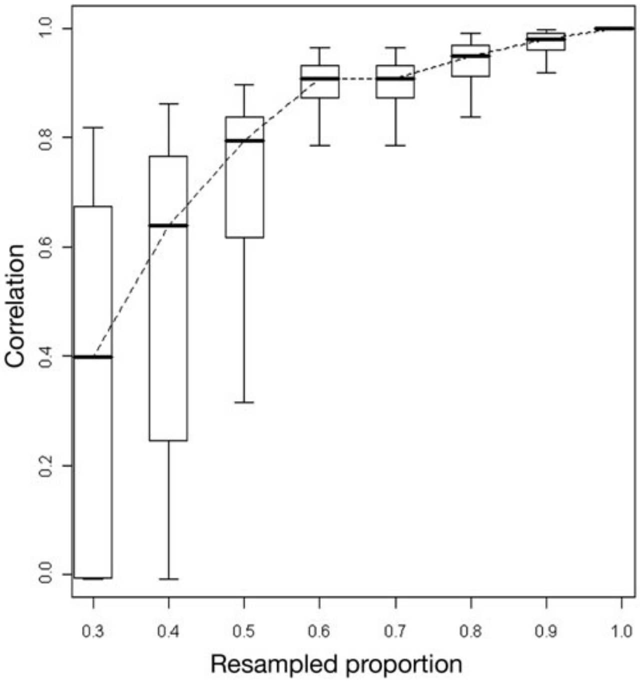

Fig. S3. Boxplot of the correlation coefficient between predictions from the full and reduced data sets (randomly sampling from 99 to 30% of the hauls). Dotted line passes through median and whiskers represent approximate 95% confidence intervals and 1st and 3rd quartiles

for each random sampling level. The ratio of sampled dataset ranged from 0.99 to 0.15 of the initial data set.

A reduction in the data set size of 50 to 70% (0.50, 0.40 and 0.30) affected the SSB estimates and their precision, and elevated median values of the correlation coefficients were observed, 0.4, 0.65 and 0.80, respectively (Fig. S3). On the contrary, the variance associated with the correlation coefficient rapidly increased passing from a resample level of 0.6 to 0.4. With this drastic reduction in the data size, only 30% of the original data set was used, the median correlation coefficient was estimated at 0.4, but the model outputs were strongly affected, considering that a significant number of runs had very low correlation coefficients (i.e. <0.2).

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