Supplement.

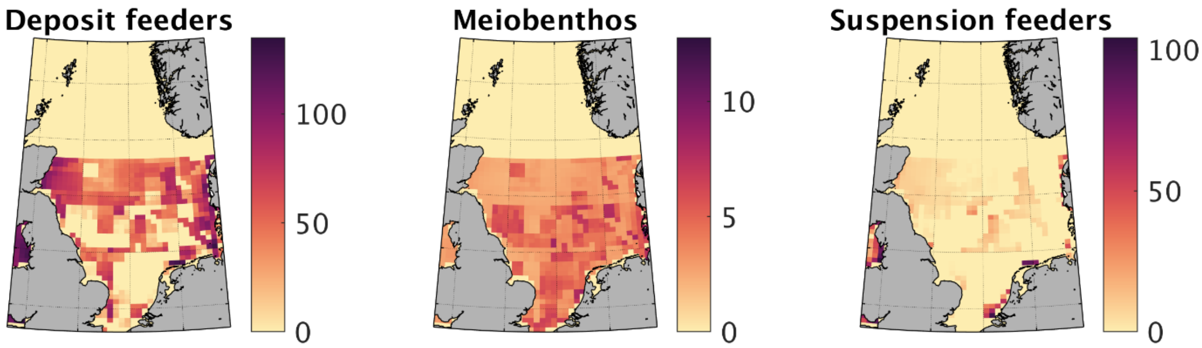

Fig. S1. Annual mean biomass (g-WW m^{-2}) of the macro-invertebrate groups; deposit feeders, meiobenthos and suspension feeders from the ERSEM model for the used HTL model domain.

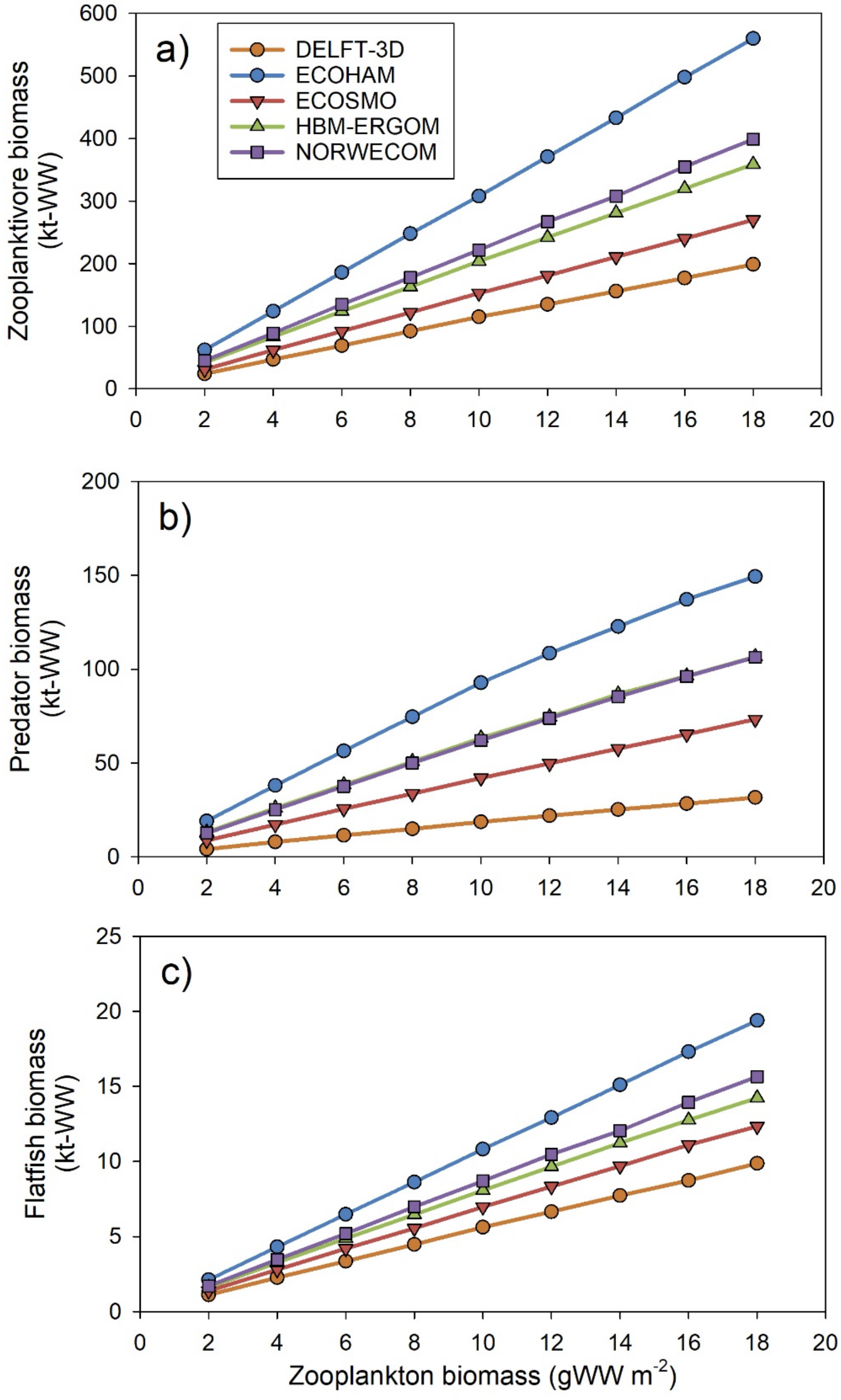

Fig. S2. Sensitivity study. Responses of zooplanktivore, predator and flatfish biomass versus increasing total zooplankton biomass, when using one bulk zooplankton size bin in all LTL models.

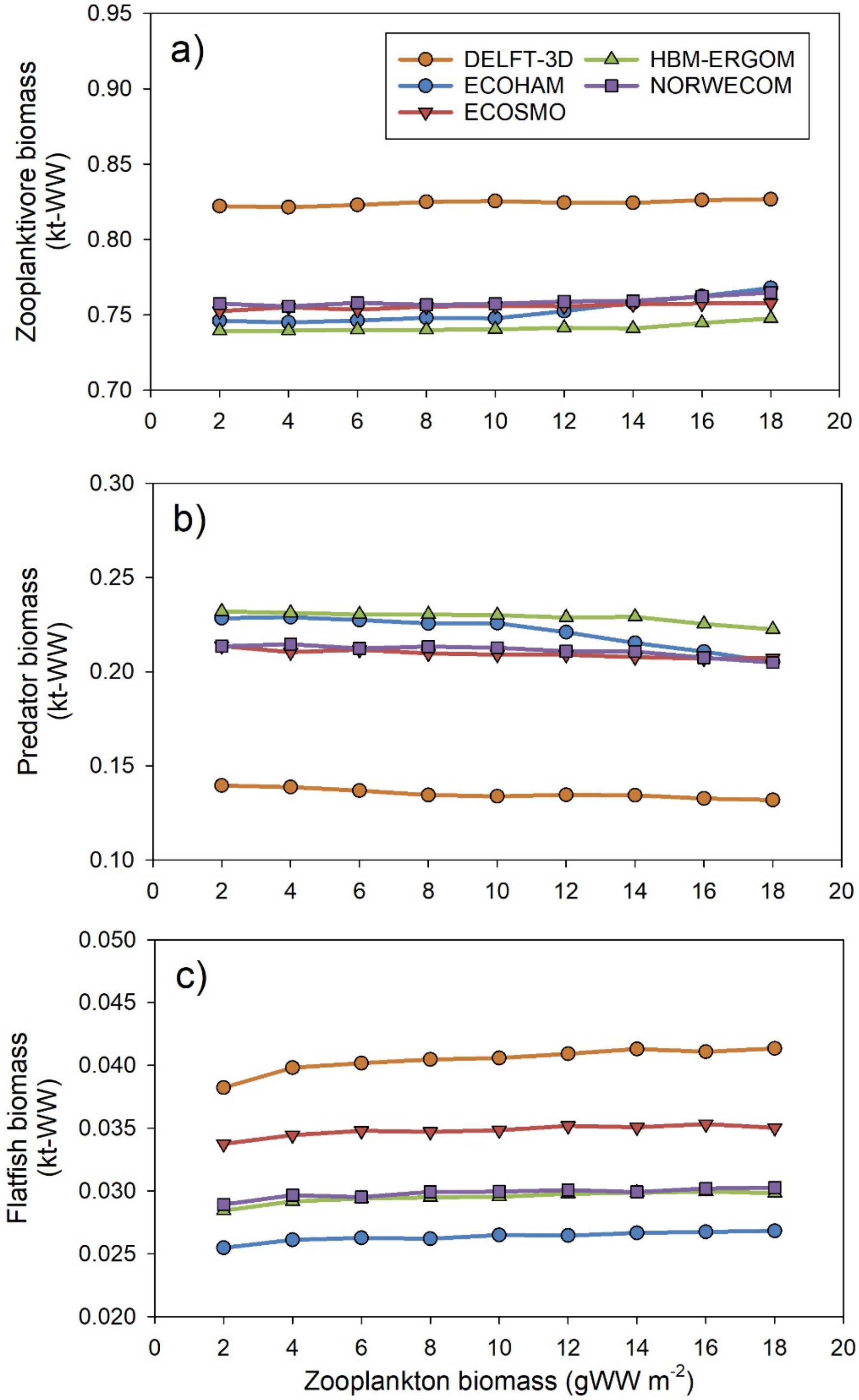

Fig. S3. Sensitivity study. Responses of zooplanktivore, predator and flatfish relative biomass contribution to total biomass versus increasing total zooplankton biomass, when using one bulk zooplankton size bin in all LTL models, see also Fig. S2.

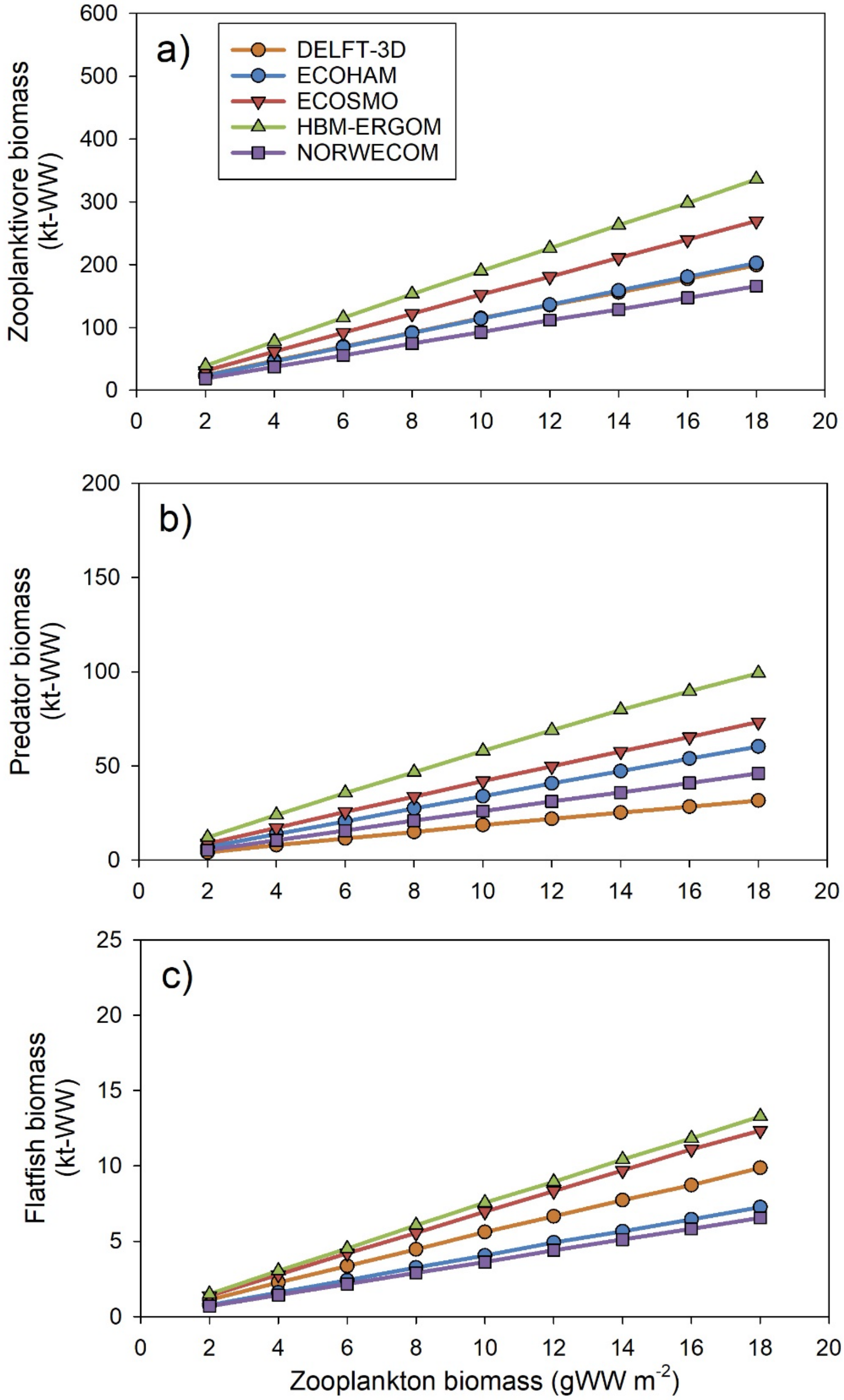

Fig. S4. Sensitivity study. Responses of zooplanktivore, predator and flatfish biomass versus increasing total zooplankton biomass, when using the original LTL model zooplankton size bins. Note that Delft3D-WAQ and ECOSMO have one size bin and ECOHAM, HBM-ERGOM and NORWECOM have two zooplankton size bins.

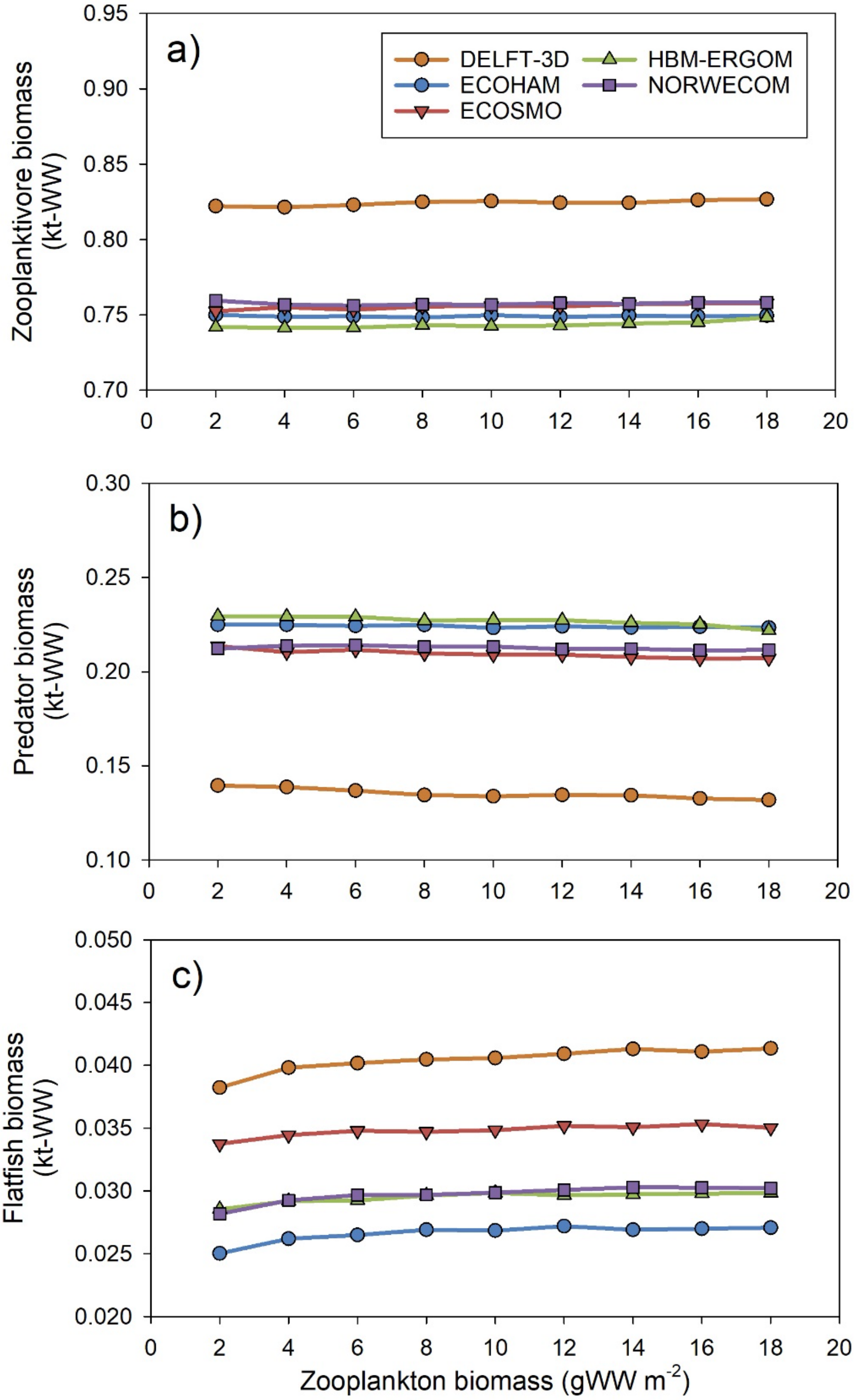

Fig. S5. Sensitivity study. Responses of zooplanktivore, predator and flatfish relative biomass contribution to total biomass versus increasing total zooplankton biomass, when using the original LTL model zooplankton size bins. Note that Delft3D-WAQ and ECOSMO have one size bin and ECOHAM, HBM-ERGOM and NORWECOM have two zooplankton size bins, see also Fig. S4.

Text S1. Fish life history

Life history parameter values on growth and maturation size were obtained from the ICES DATRAS database (accessed 24th of August 2012) for IBTS and BTS sex-maturity-age-length-weight data (SMALK). Only those 12 species present in the size spectrum model were selected (both Ammodytes and Ammodytidae for Sandeel were used) over the period 1983-2011 (1987 as starting year for BTS data). The Sex-Maturity ALK data was extracted for the North Sea IBTS and BTS data for all 4 quarters (noting that only quarters 1-3 are continued up till today for IBTS and quarter 3 is only present for BTS (in 2010 also in quarter 4 in area VIId)).

Estimating L_{inf}, K and t_0 was performed using a non-linear estimator using the Port algorithm following the equation $L = L_{inf}(1 - e^{-K(age-t_0)})$. As both the smallest as the largest fish are assumed to be underestimated in the survey due to catchability and measurement issues, additional weights are given to individual records to take this error into account. These sample weights are relative to the frequency of each length measurement. The most abundant length is assigned a weight 1, while each length measurement different from the most abundant one is given a weight equal to this difference in absolute length (in cm) and thereafter square root-transformed to not let weight scale linearly with the difference. As samples were taken from 4 different quarters, age were corrected for timing of the year by assuming that $age = age_{rings} + 0.125 + \frac{quarter-1}{4}$. The results are carefully scrutinized to ensure they are considered appropriate. Note that for some species, sexual dimorphism exists and hence L_{inf} growth is different for both sexes. In this study however, we have taken the average growth over both sexes together.

Also for the length-weight relationship a non-linear estimator, the Port algorithm, following the equation $W = \alpha L^{\beta}$ was used. As both the smallest as the largest fish are assumed to be underestimated in the survey due to catchability and measurement issues, additional weights are given to individual records to take this error into account, similar to the estimation of the growth parameters. The results are carefully scrutinized to ensure they are considered appropriate (and outlying values (input mistakes) that showed to be highly influential for the fit were removed).

Estimating size at maturity (M50) was performed again using a non-linear estimator using the Port algorithm following the equation $Mat = \frac{1}{1+e^{S1-S2\,L)}}$. To calculate proportion mature, all fish lengths were binned in centimetre classes and the ratio mature / immature was determined and treated as input value to the estimator algorithm. The results are carefully scrutinized to ensure they are considered appropriate (and outlying values (input mistakes) that showed to be highly influential for the fit were removed). The resulting estimates are presented in Table S1.

The seasonal cycle of spawning is based on literature (Table S2). Predation is based on the relative sizes of predator and prey. Based on literature and stomach content data the maximum and minimum predator-prey size ratios were estimated (Table S3). Besides size-based predation, an availability matrix was used to limit the diet of species when necessary. Limitations were based on benthic –pelagic foraging activity and a size-based scaling of the grid cell area searched per time step. This scaling of ability of searching a grid cell per time-step is based on the assumption that larger species can cover a larger area than smaller species in search of food. For this we used the length at maturity (Table S1), assuming an average speed of 5 times this length and a search window of one square meter. Given the size of a grid cell and the time step this yields a fraction of the area covered per time step, for each species. As cod and haddock have a pelagic stage and diet until reaching 7 cm in length, we used two stages in the availability matrix for these two species, as this differentiation between benthic and pelagic prey is not covered by size-dependent predation (Table S4).

Table S1. Parameter values used for growth, reproduction and survival for each species. Growth parameters and size at maturity (L_{mat}, 50% mature) were estimated based on ICES data as described above (Text S1). Other references are given when used.

Species	Growth					Reproduction			Survival	
	L∞ (cm^{-1})	K (yr^{-1})	t0 (yr)	a ($g\ cm^{-3}$)	b	φ (eggs g^{-1})	Lmat (cm)	Egg size (cm)	Amax (yr)	Madd yr^{-1})
Cod	137.95	0.183	0.519	0.005	3.173	492[g]	54.39	0.153[h]	25[c]	0.1418[d]
Dab	27.11	0.375	-0.206	0.01	2.986	3300[j]	13	0.093[h]	12[e]	0.0736[k]
Gr. gurnard	35.65	0.191	-1.261	0.004	3.198	339[a]	17.69	0.14[i]	9[c]	0.141[k]
Haddock	48.24	0.382	-0.051	0.005	3.16	480[g]	26.91	0.145[h]	20[c]	0.1541[d]
Herring	30.82	0.505	-0.193	0.002	3.429	247[g]	23.36	0.12[i]	10[c]	0.1206[d]
N. pout	21.78	0.606	-0.096	0.009	2.941	720[g]	14.35	0.11h)	4[c]	0.1877[d]
Plaice	43.45	0.255	-0.473	0.007	3.101	343[g]	22.19	0.195[h]	50[c]	0.1[f]
Saithe	152.12	0.075	-0.939	0.007	3.075	750[c]	48.62	0.112[h]	25[c]	0.179[f]
Sandeel	18.61	0.758	-0.429	0.001	3.32	640[b]	11	0.08[i]	10	0.192[d]
Sole	34.83	0.441	0.026	0.008	3.019	591[g]	20.97	0.13[i]	26[c]	0.1[f]
Sprat	16.17	0.469	-0.394	0.007	3.014	2250[c]	12.01	0.1[h)]	5[c]	0.1974[d]
Whiting	38.88	0.457	-0.012	0.006	3.08	1382[g]	21.40	0.115[h)]	20[c]	0.1551[d]

a) Boulcott P, Wright PJ, Gibb FM, Jensen H, Gibb IM (2007) Regional variation in maturation of sandeels in the North Sea. ICES J Mar Sci 64, 369-376.
b) Daan N, Bromley PJ, Hislop JRG, Nielsen NA (1990) Ecology of North Sea fish. Neth J Sea Res 26(2-4): 343-386.
c) ICES-Fishmap. Cod. Sprat. Haddock. Whiting. Sole. Plaice. Herring. Norway Pout.
d) ICES CM 2002/D:04. Report of the workshop on MSVPA in the North Sea.
e) ICES CM 2010/ACOM: 21. Report of the working group on assessment of new MoU species (WGNEW).
f) ICES CM 2011/ACOM:13. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK)
g) Jennings S, Greenstreet SPR, Reynolds JD (1999) Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. J Anim Ecol 68(3): 617-627
h) Russell FS (1976) The eggs and planktonic stages of British marine fishes. Academic Press, London, UK. 524 p.

i) Quéro J-C, Vayne JJ, Monod T (1984) Les poissons de mer de pêches francaises. Delachaux et Niestlé.
j) Calculated using method Jennings et al. 1999
k) Average of all other species

Table S2. Spawning seasonality (α) per species (Daan et al., 1990; ICES, 1993; Albert, 1994).

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cod	0.009	0.378	0.460	0.148	0.005	0	0	0	0	0	0	0
Dab	0.071	0.171	0.171	0.171	0.171	0.171	0.024	0.024	0.024	0	0	0
Grey gurnard	0.062	0.062	0.141	0.141	0.141	0.141	0.141	0.141	0.013	0.013	0	0
Haddock	0	0.055	0.332	0.332	0.221	0.055	0	0	0	0	0	0
Herring	0.077	0	0.068	0.068	0.068	0.055	0.055	0.132	0.132	0.132	0.132	0.077
Norway pout	0.074	0.145	0.257	0.222	0.151	0.038	0.038	0	0	0	0.036	0.036
Plaice	0.317	0.365	0.151	0.028	0.028	0.028	0	0	0	0	0.028	0.056
Saithe	0.224	0.224	0.224	0.224	0.100	0	0	0	0	0	0	0
Sandeel	0.042	0.042	0.113	0.113	0.042	0.042	0.042	0.042	0.077	0.077	0.113	0.255
Sole	0	0	0	0.415	0.415	0.166	0	0	0	0	0	0
Sprat	0	0	0	0.110	0.355	0.356	0.137	0.042	0	0	0	0
Whiting	0.093	0.148	0.194	0.223	0.135	0.097	0.037	0.037	0.037	0	0	0

Table S3. Maximum and minimum predator-prey size ratios and their references, either from literature or based on data available from ICES and/or WMR.

Species	Min ratio	Max ratio	References
Cod	0.022	0.44	(Scharf et al., 2000)
Dab	0.006	0.09	Based on BSIK stomach data; (Schuckel et al., 2012)
Grey gurnard	0.03	0.6	ICES stomach data 2010
Haddock	0.067	0.44	(Greenstreet et al., 1998)
Herring	0.0017	0.034	Based on minimum plankton sizes used in the model and foraging on 1 cm fish larvae at L_{inf} (ICES Fishmap report)
Norway pout	0.0018	0.087	Based on plankton sizes used in the model and 2 cm fish prey at L_{inf} (ICES Fishmap report on eating 'small' fish)
Plaice	0.008	0.06	Stomach data (Rijnsdorp and Vingerhoed, 2001)
Saithe	0.006	0.05	(Scharf et al., 2000); ICES stomach data 2010
Sandeel	0.0025	0.014	Based on minimum and maximum plankton sizes used in the model and including egg sizes of the species modelled.
Sole	0.005	0.06	Stomach data (Rijnsdorp and Vingerhoed, 2001)
Sprat	0.002	0.023	Based on minimum and maximum plankton sizes used in the model, includes eggs of all species modelled.
Whiting	0.005	0.69	(Greenstreet et al., 1998); ICES stomach data 2010

Table S4. Availability matrix for all predator (column) and prey (rows) combinations based on diet inclusion (generalist =0.01, specialist =0.5, not in diet =0) multiplied by a relative measure on the fraction of a grid cell which can be searched within a time step of 14 days in order to maximize the search area. This was based on the size at maturity and assuming a speed of 1 body length per second and a search window of 1 body length. The values presented are used as a factor to scale the availability of a resource. Note that for the spatial extent used in this study limited to the southern North Sea values for plaice feeding on macro-invertebrates were raised in order to keep the species from going extinct. The values presented here were not validated in any way. Cod1 and had1 denote the stage of individuals smaller than 7 cm which are more pelagic than demersal. Cod: cod, cod1; Grey gurnard: gur; haddock: had, had1; herring: her; Norway pout: pout; plaice: plaice; saithe: sait; sandeel: sand; sole: sole; sprat: sprat; whiting: whit; diatoms: diat; flagellates: flag; micro-zooplankton: micro; meso-zooplankton: meso; deposit feeders: dep; suspension feeders: sus; meiobenthos: mei. The latter are the resources obtained from lower trophic level models. Values are multiplied by x1000 for readability purposes.

	cod	cod1	dab	Gur	had	had1	her	pout	plaice	sait	sand	sole	sprat	whit
cod	9.14	0	2.18	2.97	4.52	0	0	24.11	3.73	8.17	1.85	3.52	0	3.6
cod1	9.14	1.18	2.18	2.97	4.52	11.76	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
dab	9.14	0	2.18	2.97	4.52	0	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
gur	9.14	0	2.18	2.97	4.52	0	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
had1	9.14	0	2.18	2.97	4.52	0	0	24.11	3.73	8.17	1.85	3.52	0	3.6
had	9.14	1.18	2.18	2.97	4.52	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
her	9.14	1.18	2.18	2.97	4.52	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
pout	9.14	1.18	2.18	2.97	4.52	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
plaice	9.14	0	2.18	2.97	4.52	0	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
sait	9.14	1.18	2.18	2.97	45.21	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
sand	9.14	0	2.18	2.97	4.52	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6

sole	9.14	1.18	2.18	2.97	4.52	0	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
sprat	9.14	1.18	2.18	2.97	4.52	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
whit	9.14	1.18	2.18	2.97	4.52	1.18	39.24	24.11	3.73	8.17	1.85	3.52	20.18	3.6
diat	1.18	1.18	1.18	1.18	1.18	1.18	196.22	4.82	1.18	1.18	92.4	1.18	100.88	1.18
flag	1.18	1.18	1.18	1.18	1.18	1.18	196.22	4.82	1.18	1.18	92.4	1.18	100.88	1.18
micro	1.18	1.18	1.18	1.18	1.18	1.18	196.22	4.82	1.18	1.18	92.4	1.18	100.88	1.18
meso	1.18	1.18	1.18	1.18	1.18	1.18	196.22	4.82	1.18	1.18	92.4	1.18	100.88	1.18
dep	9.14	0	21.84	29.72	45.21	0	0	4.82	386.4	8.17	18.48	176.15	0	3.6
susf	9.14	0	21.84	29.72	45.21	0	0	4.82	386.4	8.17	18.48	176.15	0	3.6
mei	9.14	0	21.84	29.72	45.21	0	0	4.82	386.4	8.17	18.48	176.15	0	3.6

Text S2. Fishing

Fishing effort of each fleet was back-calculated with age dependent fishing mortality estimates from ICES. The annual effort for each species in a fleet was averaged to obtain the average effort per fleet, assuming that species are caught indiscriminately and based only on the abundance and selectivity. The stock assessment results of estimated F-at-age were extracted from the 2012 stock assessment reports to estimate L25 and L50 for the selectivity curve for each species. For most stocks, time series of F start before 1983 and extend up to 2011 (except for sprat which starts in 1991 and whiting which starts in 1990, no data for sab and gurnard are available).

The selection patterns as observed in the stock assessments are age based. To estimate L25 and L50 these need to be converted to length measures and they must be described by a sigmoid curve, instead of e.g. dome shaped curves. In many stock assessments, older ages are not targeted as well as the slightly younger, but fully selected, animals. This might be due to processes as out swimming the gear or a lack of spatio-temporal overlap. Given the size of older ages however, simple gear selection equations show that they are fully selected. Hence, we have to apply a correction to our data to adhere to this 'assumption'. Therefore, per species by year, the selection pattern is rescaled to fit the interval [0,1]. Thereafter, the age at which selection equals one is determined and all older ages are assumed to have similar selection (equal 1). This results in approximations of sigmoid curves for all species-year combinations. The function fitted is described as: $Sel = \frac{1}{1+e^{S1-S2\,age)}}$. The parameters are thereafter converted to lengths given the estimated growth parameters (Table S1) and are presented in Table S5.

Table S5. Species specific L25 and L50 values for the sigmoid selectivity curve. For dab, plaice values were used, for sprat Norway pout values were used and for Grey gurnard whiting values were used as sufficient information on these species is lacking.

Species	**L25**	**L50**
Cod	13.199	22.874
Dab	11.517	17.037
Gr. gurnard	19.813	29.019
Haddock	19.093	24.345
Herring	10.129	20.790
N. pout	8.694	12.236
Plaice	11.517	17.037
Saithe	35.317	43.551
Sandeel	9.832	11.824
Sole	16.401	25.800
Sprat	8.694	12.236
Whiting	19.813	29.019

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