An estimate of the total biomass of fish in the North Sea

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Biomass estimates are made by combining ICES working group VPA biomass estimates of 11 commercial fish species with catch rates in the ICES International Young Fish Surveys (IYFS) in the first quarter of the year and in the English Groundfish Surveys (EGFS) in the third quarter of the year. Data from 1983, 1984, and 1985 are used.

The total biomass of fish is calculated as the mean of the three years. In the first three months of the year the mean total biomass was 8.6 million tonnes, of which the 11 commercial species constituted 5.9 million tonnes. In the third quarter it was 13.1 million tonnes, of which the 11 commercial species constituted 8.5 million tonnes. The difference between the first and third quarters was mainly caused by the migration of 0.5 million tonnes of Western stock mackerel and 1.6 million tonnes of horse mackerel into the North Sea during the third quarter. Comparisons are made between the productivity of the North Sea and other shelf regions in temperate latitudes.

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Introduction

The fish species of the North Sea can be grouped into three categories according to the regularity with which they are assessed by working groups of the International Council for the Exploration of the Sea (ICES) and the methods used for those assessments.

These are:

Category (A). The nine species of major commercial importance for which there are quantified predator/prey interactions and which are now assessed by the multispecies virtual population analysis (MSVPA) model (Anon., 1988): cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*), mackerel (*Scomber scombrus*), Norway pout (*Trisopterus esmarkii*), sandeel (*Ammodytes* sp.), herring (*Clupea harengus*), and sprat (*Sprattus sprattus*).

Category (B). A further two species, also of commercial importance, which are regularly assessed as single species by other ICES working groups: plaice (*Pleuronectes platessa*) and sole (*Solea solea*).

Category (C). All other species, mostly of minor commercial importance and not regularly assessed by ICES, but which together constitute a substantial part of the total fish biomass of the North Sea.

The aim of the present paper is to attempt to estimate the biomass of all fish species in category (C), and hence

to throw some light on related questions such as the order of magnitude of natural mortality they generated in the other species through predation, particularly in the nine MSVPA species of category (A). A comparable review of fish biomass estimates in other sea areas is also presented, so that the intrinsic productivity of the North Sea may be evaluated.

The method used is similar to the one used previously by Clark and Brown (1977) for the coastal region of the northeastern USA and by Yang (1981) for the North Sea. It consists of using the biomass estimates for the 11 commercial species from categories (A) and (B) to interpret catch rates of other species in the International Young Fish Surveys (IYFS) and the English Groundfish Surveys (EGFS) from 1983 to 1985.

The IYFS and EGFS were found suitable for this kind of estimation because they cover almost the entire North Sea. This means that changes in the distribution of a stock within the North Sea does not affect the mean catch rate of that species for the entire area.

The reliability of the estimates of biomasses obtained in this way is of course influenced by many factors, the majority of which can probably be summarized in the variable: availability. Availability is here defined as the relationship between the index of abundance obtained from the catch per unit of fishing effort and the true abundance of the stock in question. The results must therefore be interpreted with due care as the best estimates that can be made in the present circumstances.

Table 1. Specification of data available from the IYFS database per vessel for the years 1983–1985.

Vessel	1983	1984	1985
"Anton Dohrn"..	CN	CN	CN
"Cirolana"	CN+CW	CN+CW	CN+CW
"Dana"	X	X	CN+CW
"Eldjärn"	CN+CW	CN+CW	CN+CW
"Isis"	CN	CN	CN
"Scotia".........	CN	CN	CN
"Thalassa"	CN+CW	CN+CW	X
"Tridens"	CN	CN	CN

Symbols:
CN: all species recorded as catch in *number* per haul.
CW: all species recorded as catch in *weight* per haul.
X: selected species recorded.

Material and methods

Estimates using IYFS data

The IYFS has been carried out annually in February for a period of more than 20 years. It covers the whole North Sea except for the 6 % of the area which is deeper than 200 m.

The opportunities for analysing these data have been considerably enhanced since the development of a computerized database at ICES headquarters (Hansen *et al.*, 1983). For the present paper data tapes for the years 1983, 1984, and 1985 were available.

Vessels from all countries surrounding the North Sea participated in the survey. Totals of 325, 350, and 388 half-hour trawls were made in each year respectively, using a standardized bottom trawl with a mesh size of 10 mm (bar) in the codend.

Catch (in weight) per hour by species is calculated by first averaging the catches within each statistical square (approximately 30×30 nm) and afterwards taking the unweighted mean of these mean catches over the whole area.

Not all vessels participating in this survey recorded the catch per haul in exactly the same way. Table 1 specifies the data available by vessel and year. "Dana" in 1983 and 1984 and "Thalassa" in 1985 did not record all species caught. As this makes it impossible to distinguish between a zero catch and a catch not recorded, these data were excluded from the present analysis. Some vessels recorded catch in numbers per haul and not in weight. The data from these vessels were, nevertheless, included by converting number caught per hour to weight caught per hour using data from vessels which submitted catch in both weight and number. When possible this was done for each statistical square, but otherwise on the basis of means for the entire North Sea.

Mean values (1983–1985) of estimates of biomass on 1 January and 1 October for cod, haddock, whiting, saithe, mackerel, Norway pout, sandeel, herring, and sprat are taken from the MSVPA keyrun (Anon., 1987a) (Table 2). The biomass estimates of plaice and sole are taken from the relevant single-species assessment working group (Anon., 1987b). All these 11 species, i.e., categories (A) and (B), are hereafter called "standard" species, and their availabilities are calculated by dividing their catch rates in the surveys by their biomasses from Table 2. The availability of cod in the IYFS is for instance the catch rate (37.92 kg h^{-1}) divided by the biomass (261 000 tonnes), i.e., 14.5×10^{-8} h^{-1}.

Given that the biomass estimates of the "standard"

Table 2. Biomass on 1 January and 1 October of "standard" fish species in the North Sea, based on estimates from the MSVPA model (Anon., 1987a) and ICES single-species working group reports.

Fish species	Biomass in tonnes × 10^{-3} as mean values 1983–1985		Data sources
	1 Jan	1 Oct	
Cod	261	212	MSVPA (Anon., 1987a)
Haddock	473	633	MSVPA (Anon., 1987a)
Whiting	355	482	MSVPA (Anon., 1987a)
Saithe............................	477	516	MSVPA (Anon., 1987a)
Mackerel.........................	156	720[a]	MSVPA (Anon., 1987a) and (Anon., 1986d)
Herring	993	1 660	MSVPA (Anon., 1987a)
Sprat	144	252[b]	MSVPA (Anon., 1987a)
Norway pout......................	948	1 446	MSVPA (Anon., 1987a)
Sandeel	1 556	2 081	MSVPA (Anon., 1987a)
Plaice............................	475	475	Anon. (1987b)
Sole	60	60	Anon. (1987b)

[a]The biomass of 156 000 tonnes is the mean of the biomass in 1983 and 1984. The biomass of 720 000 tonnes is an estimated amount of both Western and North Sea mackerel present in the North Sea in the third quarter. The estimation is based on the assumption that 40 % of the total Western and North Sea stock is present in the North Sea in the third quarter (see Anon., 1987b).
[b]The biomass of 0-group sprat in 1985 from the MSVPA was found to be unrealistically high due to the input terminal F value that had been used. The 0-group biomass in 1985 was instead assumed to be zero in accordance with a very low IYFS index for that year class of sprat in February 1986.

Table 3. IYFS data. Mean catch rates in kg/h and N/h for the whole North Sea, and mean weight, w̄, of each species caught.

	1983			1984			1985			1983–1985	
	kg/h	N/h	w̄	kg/h	N/h	w̄	kg/h	N/h	w̄	kg/h	w̄
Galeus melastomus	0.019	0.01	3.000							0.006	3.000
Scyliorhinus canicula	0.124	0.31	0.400	0.0	0.03	–	0.388	0.57	0.675	0.129	0.538
Scyliorhinus stellaris	–	–	–	0.005	0.01	0.850				0.002	0.850
Galeorhinus galeus	–	–	–	0.004	0.02	0.200				0.001	0.200
Mustelus mustelus	–	–	–	–		–					
Squalus acanthias	1.310	0.55	2.403	0.929	0.46	2.034	4.402	1.73	2.540	2.214	2.326
Raja radiata	0.795	1.68	0.472	2.398	3.79	0.632	1.355	2.10	0.645	1.516	0.583
Raja brachyura				0.152	0.04	4.200				0.031	4.200
Raja montagui	0.059	0.11	0.541	0.189	0.20	0.956	0.346	0.31	1.133	0.198	0.877
Raja batis	1.455	0.20	7.200				0.035	0.02	1.850	0.497	4.525
Raja fullonica							0.037	0.01	3.900	0.012	3.900
Raja circularis							0.010	0.01	1.600	0.003	1.600
Raja naevus	1.590	1.84	0.864	0.237	0.22	1.100	0.516	0.55	0.933	0.251	1.016
Raja clavata				0.759	0.65	1.171	0.501	0.48	1.038	0.950	1.024
Alosa alosa				0.003	0.02	0.133				0.001	0.133
Clupea harengus +	38.574	1 285.89	0.030	37.630	1 134.49	0.033	121.652	2 775.53	0.044	65.952	0.036
Sprattus sprattus +	4.846	713.96	0.007	4.664	609.32	0.008	7.291	933.40	0.008	5.600	0.008
Argentina silus	0.001	0.01	0.100	0.004	0.42	0.009	0.001	0.04	0.021	0.002	0.013
Argentina sphyraena	0.019	1.16	0.017	0.185	6.54	0.028	0.041	1.73	0.024	0.082	0.023
Maurolicus muelleri	0.00	0.26	–	0.0	17.76	–					
Lophius piscatorius +	4.709	0.60	7.820	1.012	0.54	1.878	1.497	0.57	2.612	2.406	4.103
Gadus morhua +	38.936	26.69	1.459	40.899	51.16	0.799	33.932	30.74	1.104	37.922	1.121
Pollachius virens +	11.624	5.00	2.325	10.489	3.70	2.834	46.755	54.04	0.865	22.956	2.008
Pollachius pollachius	2.985	0.66	4.551	6.561	2.44	2.691	8.620	2.61	3.298	6.055	3.513
Brosme brosme	0.513	0.14	3.700				0.070	0.06	1.173	0.194	2.437
Melanogrammus aeglefinus +	184.851	725.93	0.255	103.750	993.52	0.104	124.937	835.99	0.149	137.864	0.169
Rhinonemus cimbrius	0.018	0.71	0.025	0.027	0.66	0.041	0.017	0.38	0.045	0.021	0.037
Trisopterus minutus	0.646	26.32	0.025	0.581	26.02	0.022	0.266	9.96	0.027	0.498	0.025
Trisopterus luscus	0.482	3.82	0.126	0.756	8.13	0.093	0.528	4.44	0.119	0.589	0.113
Trisopterus esmarkii +	23.004	1 808.84	0.013	41.571	2 816.58	0.015	31.711	2 495.15	0.013	32.095	0.014
Merlangius merlangus +	76.807	515.33	0.149	70.076	721.98	0.097	56.880	715.23	0.080	67.921	0.109
Molva molva	20.504	2.48	8.267	1.314	0.78	1.687	3.030	0.71	4.286	8.283	4.747
Molva dipterygia	0.106	0.02	5.500							0.036	5.500
Gaidropsarus vulgaris				0.002	0.09	0.020				0.001	0.020
Gadiculus argenteus				0.043	4.78	0.009				0.013	0.009
Ciliata sp.	0.001	0.10	0.013				0.003	0.07	0.036	0.001	0.025
Micromesistius poutassou				0.254	9.44	0.030	0.003	0.01	0.230	0.086	0.130
Merluccius merluccius	0.685	0.53	1.300	0.301	1.23	0.245	0.305	0.45	0.675	0.430	0.740
Gasterosteus aculeatus	0.006	0.10	–				0.0	1.84	–		
Zoarces viviparus				0.002	0.07	0.033				0.001	0.033
Syngnathus rostellatus				0.0	0.01	–					
Syngnathus acus	0.000	0.02	–								
Sebastes viviparus	0.325	2.12	0.153	0.224	1.16	0.192	0.028	0.26	0.109	0.192	0.151
Eutrigla gurnardus	6.732	53.36	0.126	14.288	122.21	0.117	3.375	25.34	0.133	8.132	0.125
Myoxocephalus scorpius	0.039	0.70	0.056				0.130	1.74	0.075	0.056	0.066
Taurulus bubalis	0.015	0.18	0.086	0.015	0.16	0.092	0.023	0.25	0.095	0.018	0.091

	1983			1984			1985			1983–1985	
	kg/h	N/h	w̄	kg/h	N/h	w̄	kg/h	N/h	w̄	kg/h	w̄
Agonus cataphractus	0.026	2.29	0.011	0.036	2.69	0.013	0.010	0.81	0.012	0.024	0.012
Liparis liparis	0.016	0.76	0.021				0.011	0.90	0.013	0.009	0.017
Cyclopterus lumpus	0.108	0.04	2.800	0.397	0.14	2.900	0.843	0.27	3.174	0.449	2.958
Trachurus trachurus	0.002	0.17	0.013				0.068	0.22	0.310	0.023	0.108
Trachinus vipera							0.004	0.27	0.016	0.004	0.014
Trachinus draco	0.001	0.01	0.100	0.007	0.64	0.012				0.003	0.150
Anarhichas lupus	1.569	0.49	3.207	0.008	0.04	0.200	0.784	0.20	4.012	1.282	3.329
Anarhichas minor	0.002	0.01	0.250	1.494	0.54	2.767				0.001	0.250
Lumpenus lampretaeformis	0.0	0.04	–								
Pholis gunnellus	0.0	0.10	–	0.003	0.26	0.012	0.0	0.01	–	0.001	0.012
Ammodytes sp. +	0.219	10.43	0.021	0.052	2.10	0.025	0.021	1.24	0.016	0.097	0.021
Callionymus lyra	0.012	1.24	0.010	0.063	1.72	0.036	0.021	0.69	0.030	0.032	0.025
Pomatoschistus iijinia minutus	0.0	0.28	–				0.0	0.05	–		
Pomatoschistus iijinia norveg.	0.0	0.27	–								
Scomber scombrus +	1.698	10.65	0.159	0.505	1.88	0.268	0.070	0.59	0.119	0.758	0.182
Scophthalmus maximus	0.111	0.07	1.621	0.051	0.05	1.081	0.053	0.04	1.436	0.072	1.379
Scophthalmus rhombus	0.095	0.06	1.600	0.030	0.05	0.550	0.041	0.05	0.863	0.055	1.004
Arnoglossus laterna	0.0	0.05	–	0.002	0.06	0.035	0.001	0.06	0.021	0.001	0.028
Phrynorhombus norvegicus				0	0	0					
Lepidorhombus whiffiagonis	0.141	0.88	0.160	0.711	1.85	0.384	0.215	0.58	0.369	0.356	0.304
Glyptocephalus cynoglossus	0.444	1.12	0.396	0.368	0.94	0.391	0.152	0.93	0.164	0.321	0.317
Hippoglossus platessoides	2.723	50.61	0.054	3.728	66.91	0.056	1.498	29.80	0.050	2.650	0.053
Limanda limanda	18.696	297.08	0.063	19.183	346.49	0.055	14.139	252.50	0.056	17.339	0.058
Microstomus kitt	2.654	8.49	0.313	2.959	9.42	0.314	1.861	5.55	0.335	2.491	0.321
Platichthys flesus	0.705	2.24	0.315	0.367	1.43	0.256	0.193	0.73	0.263	0.422	0.278
Pleuronectes platessa +	4.969	26.81	0.185	4.832	25.86	0.187	6.336	42.05	0.151	5.379	0.174
Hippoglossus hippoglossus	0.035	0.03	1.100	0.077	0.04	2.01	0.028	0.02	1.150	0.047	1.421
Solea solea +	0.030	0.17	0.174	0.040	0.45	0.088	0.014	0.25	0.056	0.028	0.106
Buglossidium luteum	0.001	0.43	0.003	0.002	0.25	0.010	0.001	0.12	0.005	0.001	0.006
All species	456.037			374.239			475.049			435.374	
All "standard" species	385.558			324.468			439.585			376.499	

+ indicates "standard" species.

203

species are correct, the availability of a given species is a measure of the ability of the fishing gear to catch the species. This is usually very variable, depending on a number of factors such as the size of the fish, mesh selectivity, time of day, depth, bottom substrate, current, and turbidity of the water.

The availabilities of the "standard" species are expected to differ substantially from each other. For instance, the sandeel will escape more easily through the meshes than the other species, mackerel are probably able to swim away from the trawl, and plaice can escape under the trawl by burying into the substrate. As a consequence the "standard" species are split into groups of species which are expected to have roughly equal availabilities:

Group 1 – cod, haddock, whiting, and saithe,
Group 2 – Norway pout,
Group 3 – herring and sprat,
Group 4 – sandeel,
Group 5 – mackerel,
Group 6 – plaice,
Group 7 – sole.

The availabilities are calculated for these seven groups of species. In Groups 1 and 3, which include more than one "standard" species, the mean availability is used. All other species caught are allocated to one of these seven groups on the basis of similarities in their behaviour and habitat. The biomass of each of the category (C) species is then calculated as the IYFS catch rate times the availability of the group.

Species not recorded in the IYFS database in 1983–1985 are necessarily ignored. This means that several small species such as gobies are excluded from the analysis. However, all species larger than about 5 cm in length are included, except the very rare ones.

Estimates using EGFS data

Data from the EGFS in the North Sea are given as mean catch in weight per hour by species in Harding *et al.* (1986). The EGFS was carried out annually in August/September from 1977 to 1986. One-hour hauls were made with a Granton bottom trawl. In the period 1983–1985, 81 stations covering the entire North Sea except the Norwegian Deep, were sampled each year. Fish larger than approximately 5 cm were caught by the gear; consequently the samples include a proportion of the 0-group fish. The MSVPA estimates of 1 October also include the 0-group of all nine category (A) species.

Catch rates in kg h⁻¹ from this survey, as mean values for 1983–1985, are used to estimate the biomass of category (C) species in the same way as for the IYFS data, except that the biomass of the "standard" species refers to 1 October.

Results

Catch rates from IYFS data

Table 3 shows the mean catch per hour of each species represented in the IYFS data in 1983, 1984, and 1985. The total catch rate as a mean value for the three years was 435 kg h⁻¹. Haddock had the highest catch rate and contributed more than 30 % to the total catch. Herring and whiting each amounted to about 15 % of the total catch and cod and Norway pout each to about 8 %.

It apears from the table that the results are rather similar in all three years, with respect to both total catch per hour and species composition.

Availabilities of the "standard" species

The catch rates, availabilities, and biomass estimates of all species represented in the IYFS or the EGFS, including the "standard" species, are shown in Table 4. Species are grouped by availability. Values are given as means for 1983–1985, together with the mean annual commercial catch in 1983–1984 from *Bulletin Statistique* (Anon., 1984; Anon., 1985). Commercial catches from 1985 are not included because data from one important country are missing for 1985 (Anon., 1986c). As can be seen from the table the mean total catch per hour from the IYFS was approximately 25 % higher than that from the EGFS.

The availabilities differ substantially between the "standard" species in both surveys. The difference between the two surveys is much smaller. For most of the "standard" species, the availabilities are a little lower in the EGFS data than in the IYFS. Exceptions are herring and sprat, which are 10 times more available in the IYFS than in the EGFS, and plaice, which are about twice as available in the EGFS as in the IYFS.

Biomass estimates

The total biomass of all fish species in the North Sea, estimated on the basis of IYFS data, is 8.6 million tonnes, of which 5.9 million tonnes is due to the 11 "standard" species. The amount of "other" species is thus 2.7 million tonnes.

The comparable estimates based on EGFS data are 13.1 million tonnes of all species and 8.5 million tonnes of the "standard" species. The amount of "other" species is thus 4.6 million tonnes.

Discussion

The analysis presented here does not fully explore the data which are available or will be available in the near future when all the IYFS data are loaded into the SIR database at ICES headquarters. Even the data now

available for the years 1983, 1984, and 1985 have not been fully examined. Data on length distribution by species would be worth while analysing in order to distinguish availability by length groups. Consequently the results presented here must be regarded as preliminary.

Catch rates of the "standard" species

The catch rate of a given species is of course a function of both its biomass and the availability. The latter is usually very variable between individual hauls, but it is greatly reduced when calculated as the mean of several hundred hauls, as in the present case. These mean catch rates are therefore a reasonably good index of the biomass of a given species.

The IYFS is intended to give indices of the year-class strength of cod, whiting, haddock, Norway pout, herring, and sprat. Trawling and survey designs are developed to cover the distribution of these particular species, and the trawl used must be assumed to be especially effective in catching them. The availabilities of these species might for this reason be expected to be higher than those of other species.

It is noteworthy that the mean availability of the above-mentioned six species is 10.9×10^{-8} h^{-1}, while it is only 1.1×10^{-8} h^{-1} for the rest of the "standard" species, i.e., sandeel, plaice, sole, saithe, and mackerel.

Availability of the "standard" species

The most striking feature of the availability estimates is the very large variation between species, as is evident from Table 4. For instance, the gadoid group has an IYFS availability 300 times that of sole. For sandeel the availability is even lower than for sole, and this is probably because a large proportion of sandeels can escape through the meshes. The differences between the other groups cannot be explained by mesh selectivity, because very small mesh sizes were used; they must be caused mainly by differences in behaviour.

Differences in distribution are not expected to contribute significantly to the differences in availabilities, because the IYFS and EGFS cover the entire North Sea and therefore also the total distribution area of North Sea stocks.

The differences in the availability of herring and sprat between the two surveys could be caused by a more pelagic behaviour of herring and sprat in the third quarter of the year than in the first quarter, making them less vulnerable to the EGFS bottom trawl.

The availability of plaice in the EGFS is about twice that in the IYFS. The more heavily rigged EGFS bottom trawl probably scours more deeply into the bottom than the trawl used in the IYFS. De Groot and Apeldoorn (1974) showed that the catch rate of plaice and

sole by a beam trawl can be increased by fitting heavy chains to the gear.

Biomass estimates

The most critical feature in estimating the biomass of species other than the "standard" species is undoubtedly found in the assumptions about availabilities; specifically, the validity of the procedure of allocating availabilities to the different groups of species.

As shown in Table 4, the biomass estimates based on the IYFS data and the EGFS data are rather similar, taking into account the large variances and probably also biases that can be expected. The biomass estimates of the availability Group 7 species, the flatfish, are particularly close. This is because the catch rate of all the flatfish species in the EGFS is about twice the catch rate in the IYFS. There are, however, a few striking differences between the two sets of biomass for other species:

a) The fact that the EGFS estimate of the biomass of horse mackerel (1.6 million tonnes) is 264 times the biomass estimate based on the IYFS. This is, however, in accordance with the marked seasonability in the migration of horse mackerel. Horse mackerel stay in the Atlantic to the west and south of the British Isles during the winter and migrate into the North Sea in summer. Kirkegaard (1986) estimated the biomass of horse mackerel off the Danish west coast in August 1985 to be 0.5 million tonnes based on acoustic survey estimates. The area covered was 25 000 km^2, which is only one twentieth of the total North Sea area. This suggests that the biomass estimate presented in this paper is an underestimate, unless horse mackerel in the North Sea are concentrated in the area surveyed by Kirkegaard.

b) The large difference between the two estimates of mackerel biomass (156 000 tonnes on 1 January and 720 000 tonnes on 1 October). This has nothing to do with the survey data, as the values for mackerel biomass for 1 October are obtained from information given in Anon. (1986d) and explained in the footnote to Table 2. However, the difference in biomass is in agreement with the very much higher catch rate found in the EGFS than in the IYFS.

c) The fact that the biomass estimates of the availability Group 2 species, i.e., the "deep sea" species, from the EGFS were generally higher than from the IYFS. The reason for this is unknown.

Since the surveys are directed towards some of the "standard" species and not the "other" species, it is possible that in general the availabilities of the "other" species are lower than those of the "standard" species. This would lead to an underestimation of the biomass of "other" species.

205

Table 4. Estimated biomass of fish species in the North Sea (as mean values for 1983–1985) based on IYFS and EGFS data, and mean annual catch in 1983–1984 from Anon. (1984) and Anon. (1985).

Fish species	IYFS			EGFS			Mean annual commercial catch in 1983–1984 $\times 10^3$ t
	kg/h A	Availability $\times 10^{-2}$ A/B	Biomass $\times 10^3$ t B	kg/h C	Availability $\times 10^{-2}$ C/D	Biomass $\times 10^3$ t D	

Availability Group 1

"Standard" species

Cod	37.92	14.5	261	23.85	11.3	212	
Haddock	137.86	29.2	473	84.88	13.4	633	
Whiting	67.92	19.1	355	50.19	10.4	482	
Saithe	22.96	4.8	477	35.28	6.8	516	

"Other" species

Galeus melanostemus	0.006	16.9	0	0	10.5	0 ⎤	
Scyliorhinus caniculus	0.129	16.9	1	0.46	10.5	4 ⎥	0.2
Galeorhinus galeus	0.002	16.9	0	0.17	10.5	2 ⎥	
Mustelus mustelus	0.001	16.9	0	0	10.5	0 ⎦	
Squalus acanthias	2.214	16.9	13	4.87	10.5	46	10
Etmopterus spinax	0	16.9	0	0.01	10.5	0	0.012
Salmo trutta	0	16.9	0	0.01	10.5	0	
Lophius piscatorius	2.406	16.9	14	1.75	10.5	17	5
Pollachius pollachius	6.055	16.9	36	2.70	10.5	26	2
Brosme brosme	0.194	16.9	1	0.30	10.5	3	6
Rhinonemus cimbrius	0.021	16.9	0	0.17	10.5	2	
Gaidropsarus vulgaris	0.001	16.9	0	0.07	10.5	1	
Molva molva	8.283	16.9	49	2.30	10.5	22	17
Molva dypterygia	0.035	16.9	0	0	10.5	0	
Ciliata sp.	0.001	16.9	0	0	10.5	0	
Merluccius merluccius	0.930	16.9	6	0.75	10.5	7	2
Eutrigla gurnardus	8.132	16.9	48	15.34	10.5	146	3
Trigla lucerna	0	16.9	0	0.24	10.5	2	
Cyclopterus lumpus	0.449	16.9	3	0.02	10.5	0	
Mullus surmuletus	0	16.9	0	0.03	10.5	0	
Anarhichas lupus	1.282	16.9	8	1.33	10.5	13	
Anarhichas minor	0.001	16.9	0	0	10.5	0	
			$\Sigma = 179$			$\Sigma = 291$	

Availability Group 2

"Standard" species

Norway pout	32.095	3.4	948	16.06	1.1	1 446	

"Other" species

Chimaera monstrosa	0	3.4	0	0.06	1.1	5	
Argentina silus	0.002	3.4	0	0.03	1.1	3	
Argentina sphyraena	0.082	3.4	2	0.33	1.1	30	
Trisopterus minutus	0.498	3.4	15	0.60	1.1	55	
Trisopterus luscus	0.589	3.4	17	0.04	1.1	4	
Gadiculus argenteus	0.013	3.4	0	0.04	1.1	4	
Micromesistius poutassou	0.086	3.4	3	1.44	1.1	131	27
Sebastes marinus	–	3.4	0	0.01	1.1	1	
Sebastes viviparus	0.192	3.4	6	0.53	1.1	48	1
			$\Sigma = 43$			$\Sigma = 280$	

Availability Group 3

"Standard" species

Herring	65.95	6.6	993	9.28	0.56	1 660	
Sprat	5.60	4.9	144	1.36	0.54	252	

"Other" species

Alosa alosa	0.001	5.8	0	0	0.55		0

206

Fish species	IYFS			EGFS			Mean annual commercial catch in 1983–1984 × 10³ t
	kg/h A	Availability × 10⁻² A/B	Biomass × 10³ t B	kg/h C	Availability × 10⁻² C/D	Biomass × 10³ t D	
Availability Group 4							
"Standard" species							
Sandeel	0.097	0.006	1 556	0.41	0.020	2 081	
"Other" species							
Gobiidae	0		0	0	0.020	0	
Availability Group 5							
"Standard" species							
Mackerel	0.758	0.4	156	7.43	1.0	720[a]	29
"Other" species							
Trachurus trachurus	0.023	0.4	6	16.33	1.0	1 585	18
Availability Group 6							
"Standard" species							
Plaice	5.379	1.1	475	10.34	2.2	475	
"Other" species							
Raja radiata	1.516	1.1	138	5.54	2.2	252 ⎫	
Raja brachyura	0.031	1.1	3	0	2.2	0 ⎪	
Raja montagui	0.198	1.1	18	0.11	2.2	5 ⎪	
Raja batis	0.497	1.1	45	0.06	2.2	3 ⎬ 5	
Raja fullonica	0.012	1.1	1	0	2.2	0 ⎪	
Raja circularis	0.003	1.1	0	0	2.2	0 ⎪	
Raja naevus	0.251	1.1	23	0.53	2.2	24 ⎪	
Raja clavata	0.950	1.1	86	0.18	2.2	8 ⎭	
Zoarces viviparus	0.001	1.1	0	0	2.2	0	
Myoxocephalus scorpius	0.056	1.1	5	0.01	2.2	0	
Taurulus bubalis	0.018	1.1	2	0	2.2	0	
Agonus cataphractus	0.024	1.1	2	0	2.2	0	
Liparis liparis	0.009	1.1	1	0	2.2	0	
Trachinus vipera	0.004	1.1	0	0.76	2.2	34	
Trachinus draco	0.003	1.1	0	0	2.2	0	
Lumpenus lampetraeformis	0	1.1	0	0.01	2.2	0	
Pholia gunnellus	0.001	1.1	0	0	2.2	0	
Callionymidae	0.032	1.1	3	0.38	2.2	17	
Scophthalmus maximus	0.072	1.1	7	0.07	2.2	3	1.5
Scophthalmus rhombus	0.055	1.1	5	0.07	2.2	3	0.3
Arnoglossus laterna	0.001	1.1	0	0.01	2.2	0	
Lepidorhombus whiffiagonis	0.356	1.1	32	0.37	2.2	17	0.9
Glyptocephalus cynoglossus	0.321	1.1	29	0.21	2.2	10	1.7
Hippoglossus platessoides	2.650	1.1	241	4.56	2.2	207	0.1
Limanda limanda	17.339	1.1	1 576	35.65	2.2	1 620	4.0
Microstomus kitt	2.491	1.1	226	3.56	2.2	162	7.1
Platichthys flesus	0.422	1.1	38	0	2.2	0	0.8
Hippoglossus hippoglossus	0.047	1.1	4	0.05	2.2	2	0.2
Buglossidium luteum	0.001	1.1	0	0.02	2.2	1	
			Σ = 2 485			Σ = 2 368	
Availability Group 7							
"Standard" species							
Sole	0.028	0.047	60	0.027	0.045	60	
Total biomass	435.374		8 611	341.27		13 061	
Biomass of "standard" species			5 898			8 537	
Biomass excl. mackerel and horse mackerel			8 449			10 756	

[a]The biomass of mackerel is assumed to be 156 000 t in the first quarter of the year and 720 000 t in the third quarter.

The species of Group 2 are distributed in the deeper part of the North Sea, and as no hauls are made in water depths greater than about 200 m in the surveys, the biomass estimates of this group are probably underestimates.

Generally, the biomasses of the commercially important 11 "standard" species are 2 to 3 times larger than the annual catch. Comparing the present biomass estimates of other fish with their commercial catches for 1983–1984 from Table 4, it appears that the catches are generally much less than one third of the biomass estimates, as would be expected for species of little or no commercial importance, the only exception being the commercial catch of ling, which is greater than the biomass estimates. Therefore, the biomass estimate of ling should probably be at least a factor 3 to 4 higher. Likewise, the biomass estimate of turbot from the EGFS seems a little low, being only twice the commercial catch.

Comparison with biomass estimates from Yang (1981)

Since the only previous attempt to estimate the total abundance of fish in the North Sea systematically is that by Yang (1981) it is important to compare the results obtained here with his findings.

First, the total biomass was estimated by Yang to be around 10.0 million tonnes (i.e., of all species, "standard" and "other"). In the present paper the comparable figure is 8.6 million tonnes based on IYFS data and 13.1 million tonnes based on EGFS data.

Secondly, the total biomass estimate of the 11 "standard" species as estimated by Yang was 4.4 million tonnes (on 1 January), while it is 5.9 million tonnes on 1 January and 8.5 million tonnes on 1 October in the present paper. The biomass estimates given by Yang were taken from single-species VPAs for the years 1977–1978 made by ICES working groups. The natural mortalities used in these VPAs were much lower than the natural mortalities from the MSVPA. Therefore, the biomass estimates based on the VPAs used by Yang would be expected to be lower than those from the MSVPA used in the present paper.

Thirdly, the total biomass estimate of "other" species obtained by Yang was 55 % of the total biomass, while in the present paper it is 32 % based on IYFS and 35 % based on EGFS. The relatively higher biomass estimate of "other" species by Yang is mainly due to the different availabilities used because of differences in allocation of species to species groups. Thus:

1) Grey gurnard (*Eutrigla gurnardus*) were grouped by Yang together with plaice and sole, which have lower availabilities than the gadoids with which grey gurnard are grouped in the present paper. This results in a much higher biomass estimate (639 000 t)

by Yang than the biomass estimates presented here (48 000 t based on IYFS data and 146 000 t based on EGFS data).

2) Argentina (*Argentina sphyraena*) and silvery pout (*Gadiculus (thori)*) were grouped by Yang together with herring and sprat, which had low catch rates in the EGFS he used. Therefore, the biomass of argentine and silvery pout was estimated to be 539 000 t, compared with 2000 t based on IYFS data and 34 000 t based on EGFS data, in the present paper.

Whether Yang's estimates are closer to the truth than mine is difficult judge. The commercial catches of all three species are very small and therefore give no answer to the question. Argentine and silvery pout are mainly distributed in deep water and are not surveyed properly in the IYFS and EGFS. Thus, both authors' biomass estimates for these two species are probably unreliable. According to unpublished data from a Dutch beam-trawl survey carried out in 1983–1986, the catch rate of grey gurnard is low in beam trawls, indicating that the behaviour of grey gurnard differs from that of plaice and sole; thus, my grouping of grey gurnard in availability Group 1 is probably preferable to Yang's.

Yang also included estimates of species not recorded in the EGFS, but their biomass was very small and is ignored in the present context.

Comparisons with other fish biomass estimates in the North Sea and elsewhere

The fish biomass density, production estimates, and other parameters for the North Sea and comparable shelf ecosystems are given in Table 5.

Jones (1982) implicitly estimated the biomass of the species in the *North Sea* other than the 11 "standard" species. By assuming production to be equal twice the annual commercial catch, he estimated their production to be 0.5 million tonnes per year in 1959–1961 and 0.4 million tonnes in 1968–1970. If it is assumed that the production/biomass ratio is 1.15,[1] the biomass of other species was 0.6 million tonnes in 1959–1961 and 0.5 million tonnes in 1968–1970. This is considerably lower than the estimates in the present paper for the period 1983–1985, i.e., 2.7 million tonnes based on IYFS data and 4.5 million tonnes based on EGFS data.

The discrepancy might be explained by Jones' assumption that the production/yield ratio is equal to 2 for the other species. This is probably an underestimate because the ratio should be smaller for the by-catch

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[1]This is the P/B ratio of the nine MSVPA species, if their biomass is taken as the mean of the biomass estimates on 1 January and 1 October from Table 2, i.e., 6.7 million tonnes, and their annual production is taken as the mean value for 1975–1985 from the MSVPA keyrun, i.e., 7.7 million tonnes (Anon., 1987a).

Table 5. Fish biomass density, production estimates and other parameters for various shelf ecosystems.

	North Sea	Georges Bank	Cape Hatteras to Nova Scotia	Eastern Bering Sea	Central Baltic Sea	Irish Sea
Area.......................... (km^2 × 10^{-3})	575	–	260	–	182	–
Primary production............. (g C × m^{-2} × yr^{-1})	200	400	300	160	–	–
Fish production .... (g fresh weight × m^{-2} × yr^{-1})	21.7 22.0	–	–	61	15.4	–
Fish biomass density............ (g fresh weight × m^{-2})	15.0 22.7	26.0 45.4	11.5 30.8	21.3 33.7	20.9	1.45[a]
Yield........................ (tonnes × 10^{-6})	2.7	–	0.4	2.1	0.5	–

[a]Demersal species only.

species than for the main target species of the fishery. The ratios for the nine MSVPA species have been between 2 and 3 for the last ten years.

Sissenwine et al. (1984) estimated the finfish biomass density (i.e., biomass per m^2) on Georges Bank as 45.4 g m^{-2} during the period 1964–1966 and 26.0 g m^{-2} during the period 1973–1975. The comparable figures based on the biomass estimates presented in this paper for the North Sea are 15.0 g m^{-2} in February and 22.7 g m^{-2} in August–September. This somewhat higher fish biomass density on Georges Bank is in line with the observed difference in the productivity between the two areas.

The primary production at Georges Bank is about 400 g C m^{-2} yr^{-1} (Sissenwine et al., 1984), while it is only approximately 200 g C m^{-2} yr^{-1} in the North Sea (Franz and Gieskes, 1983). According to Cohen and Grosslein (in press) the mean annual catch (1968–1982) was 6.7 g m^{-2} yr^{-1} on Georges Bank. According to Anon. (1988) the mean annual catch (1975–1985) was 2.7 million tonnes in the North Sea, i.e., 4.6 g m^{-2} yr^{-1}.

The continental shelf area off the northeastern USA from Cape Hatteras to Nova Scotia is approximately 260 000 km^2, and the biomass of exploitable fish and squids (larger than approximately 15 cm) has varied between 3 and 8 million tonnes from 1969 to 1972 (Sissenwine, 1986). Since 1972 the biomass has remained rather stable at around 3 million tonnes. The decline from 8 million tonnes is due primarily to heavy fishing. The primary production of the area is about 300 g C m^{-2} yr^{-1}. The biomass density of exploitable fish and squid has been about 11.5 g m^{-2} since 1972. If the weight of a 15-cm fish is assumed to be approximately 30 g the biomass density estimates of these fish can be compared with the MSVPA biomass densities of fish greater than 30 g. This MSVPA biomass density is 8.0 g m^{-2} on 1 January and 12.7 g m^{-2} on 1 October and is therefore similar to the biomass density from the shelf area after 1972. It is, however, interesting that the annual catch per unit area on the continental shelf from Cape Hatte-

ras to Nova Scotia is only about 1.5 g m^{-2} yr^{-1} (1977–1982), i.e., only about one fourth of the annual catch per unit area in the North Sea.

The eastern Bering Sea has an area about twice as large as the North Sea (Laevastu and Larkins, 1981), with a primary production of 160 g C yr^{-1} (Cohen and Grosslein, in press). The equilibrium biomass of fish and squid with the present fishery is, according to Laevastu and Larkins (1981, Table 9), between 24.5 and 38.7 million tonnes. This is about twice the biomass density of the North Sea. According to Cohen and Grosslein, the annual fish production in the eastern Bering Sea is also high, 61 kcal m^{-2} yr^{-1}. For the North Sea the production of the nine MSVPA species is 7.7 million tonnes per year (1975–1985). This is equivalent to 13.5 kcal m^{-2} yr^{-1} (assuming 1 g wet weight equals 1 kcal). If the P/B ratio for the North Sea species not included in the MSVPA is the same as for the nine MSVPA species, the annual fish production in the North Sea becomes 21.7 kcal m^{-2} yr^{-1} and 22.0 kcal m^{-2} yr^{-1} for estimates based on the IYFS data and the EGFS data respectively. In spite of the large fish production in the eastern Bering Sea the annual catch per unit area is only 2.1 g m^{-2} yr^{-1} (mean over 1965–1981) according to Cohen and Grosslein.

According to Anon. (1988), the biomass in the Central Baltic Sea (Subdivisions 25–29S), is 3.8 million tonnes on 1 January 1984. Only cod, herring, and sprat are included because these three species constitute almost the total fish biomass in the Baltic Sea. The biomass density is 39 % higher than in the North Sea in February and 8 % lower in August–September. The fish production in the Baltic is 15.4 g m^{-2} yr^{-1} compared with 21.7 g m^{-2} yr^{-1} based on IYFS data and 22.0 g m^{-2} yr^{-1} based on EGFS data in the North Sea. Thus, the Central Baltic Sea is very similar to the North Sea with respect to fish biomass and production. The annual catch in the Central Baltic is, however, only 2.9 g m^{-2} yr^{-1} (1983), while it is 4.7 g m^{-2} yr^{-1} (1974–1985) in the North Sea. However, according to Anon. (1987c), the

herring stocks and especially the sprat stocks are only lightly exploited in the Central Baltic.

Brander (1981) estimated the biomass density of demersal fish in the *Irish Sea* to be 1.45 g m^{-2}. Taking availability Groups 1, 6, and 7 as demersal species, the comparable North Sea figures become 8.29 g m^{-2} based on the IYFS data and 8.76 g m^{-2} based on the EGFS data. According to Brander, the biomass of shellfish is much larger in the Irish Sea than in the North Sea. This could be the reason for the low biomass of demersal fish in the Irish Sea, if it is assumed that the shellfish can substitute for demersal fish in marine ecosystems.

All these comparisons of the North Sea with other shelf ecosystems show that while the biomass density of fish in the North Sea is smaller than or equal to the biomass density in the other areas (except the Irish Sea), the annual catch per unit area is considerably higher. This could indicate either that the biomass of fish in the North Sea is underestimated in the present paper, or that the North Sea is more heavily fished. It is, however, certainly the case that several steps in the biomass estimation procedures used in the present paper are chosen in a way that would tend to result in an underestimate of biomass.

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