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Investigations on egg production and mortality of cod (*Gadus morhua* L.) and plaice (*Pleuronectes platessa* L.) in the southern and eastern North Sea in 1987 and 1988

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This paper presents the results of egg surveys for cod and plaice in the eastern English Channel and the southern and eastern North Sea up to 57°00′N carried out in the winter of 1987 and 1988. The spatial distribution of the total production of stage 1 + 2 eggs is given for cod and of stage 1 eggs for plaice. Total production of fertilized eggs is given for both years. In cod the total production of fertilized eggs was estimated at 9.2×10^{12} and 10.5×10^{12} in 1987 and 1988, respectively. In subarea Southern Bight total production was 1.6×10^{12} and 5.2×10^{12}, respectively, and these values were compared with data for the period 1970–1974. A substantial variability between years exists. In plaice the total production of fertilized eggs was 16.2×10^{12} and 21.2×10^{12}, respectively, in 1987 and 1988. The present values of egg production were compared with values reported in the literature and showed a close correspondence with the trend in female spawning stock biomass as estimated from VPA (Virtual Population Analysis). In 1987 and 1988 egg mortality until hatching was 95.0% and 96.7%, respectively, in cod, and 82.8% and 92.6% in plaice.

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Introduction

In recent years the enforcement of quota regulations has controlled the landings, but not the catch, of most commercial fish species and so stock assessment working groups need fishery-independent stock estimates. In the past decades several plankton surveys have been carried out in the southern North Sea to estimate the production of eggs of both cod (Daan, 1978 and 1981) and plaice (Simpson, 1959; Oray, 1968; Bannister *et al.*, 1974; Harding *et al.*, 1978a). This paper presents information on the egg production of cod (*Gadus morhua* L.) and plaice (*Pleuronectes platessa* L.) in the southern and eastern North Sea and examines whether such data provide valid estimates of the size of the spawning stock.

Methods

In 1986/1987 and 1988 plankton surveys were carried out in the beginning (December, January), the middle (February), and the end of the spawning period (March) in an area where previous surveys showed that the main egg production had occurred. Survey periods, midpoints of the survey, and the number of hauls are given in Table 1. As the timing of the spawning periods shifts from early to late in the season from south to north, the survey area was adjusted accordingly. The survey area stretched from 50°00′N to 52°00′N in December, from 50°00′N to 56°00′N in January, from 50°00′N to 57°00′N in February, and from 51°30′N to 57°00′N in March. The Flamborough area, west of 0°W, was only sampled in February 1987 and 1988. The eastern English Channel was sampled three times during the spawning season 1986/1987.

The survey grid consisted of six stations per statistical rectangle at 15′ and 45′ longitude and 5′, 15′, 25′ latitude, or at 35′, 45′ and 55′ latitude. At each station one oblique haul was taken with a modified Gulf III sampler (Zijlstra, 1970) and a mesh-size of 280 μm.

The volume of water filtered was measured with a current meter mounted in the net opening. Water depth and surface temperature were recorded at each station. Plankton samples were fixed in a 4% formaldehyde solution, buffered with borax to pH 7–8. Egg stage was determined and the developmental time calculated using the recorded surface temperature and the for-

Table 1. Numbers of eggs produced in the survey area per day and by egg stage during each of the plankton surveys in 1986/87 and 1988, together with the survey periods, midpoint of the survey (day number relative to 1 January) and the ambient temperature for stage 1 eggs.

Survey	Survey period	Mid-point	Number of hauls	Egg production ($10^9 . day^{-1}$) Plaice; egg stages 1	2	3	4	5	Ambient temp.	Egg production ($10^9 . day^{-1}$) Cod; egg stages 1 + 2	3 + 4	5	Ambient temp.
1987	North Sea total												
1	8–19/12	−18	15	1.5	2.4	2.9	0.0	0.0	10.78	0.0	0.0	0.0	–
2	19–30/1	25	193	85.1	39.1	14.5	5.9	1.2	4.91	64.7	6.1	2.0	4.61
3	9/2–4/3	51	226	196.8	146.3	70.1	63.2	22.8	3.97	242.0	45.6	26.1	4.06
4	16/3–2/4	83	208	94.3	89.4	63.6	103.1	53.6	3.26	58.0	23.0	28.5	3.41
1987	Eastern English Channel												
1	8–19/12	−18	44	7.7	3.4	2.9	0.5	0.0	11.06	0.0	0.0	0.0	–
2	28–29/1	28	15	39.1	31.1	21.2	18.8	10.4	7.74	5.2	0.3	0.0	6.99
3	24–25/2	56	15	17.0	10.1	8.1	6.8	7.1	6.27	8.1	2.3	2.2	5.74
1988	North Sea total												
1	18–29/1	24.5	134	128.6	69.9	27.8	18.7	3.9	7.31	193.0	17.7	4.0	7.26
2	15–26/2	51.2	139	210.4	183.8	102.3	94.8	22.7	6.58	164.1	47.4	22.6	6.80
3	14/3–6/4	85.8	173	25.7	26.1	19.3	25.3	9.7	5.95	10.7	4.2	1.3	5.93

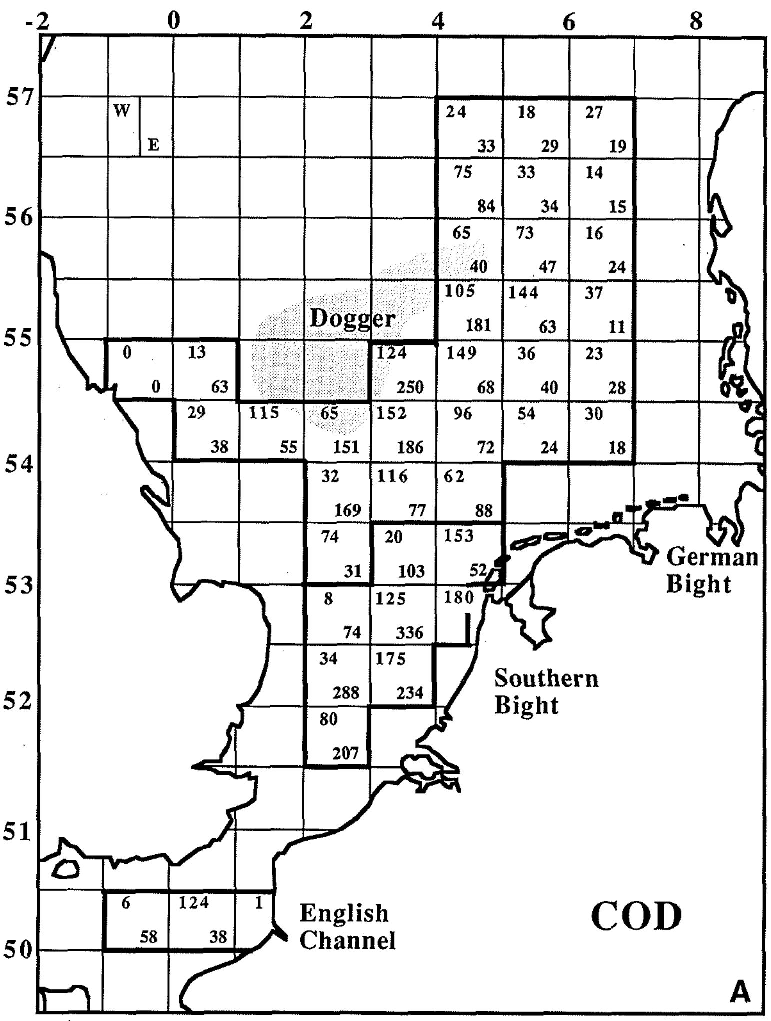

Figure 1. The spatial distribution of the total production of stage 1 + 2 eggs in cod and stage 1 eggs in plaice in 1987 and 1988. The subareas distinguished are indicated. A. Cod: eastern English Channel, Southern Bight, and rest of the survey area. B. Plaice: eastern English Channel and North Sea subareas I, II, III, IV, and V.

lankton surveys in 1986/
nuary) and the ambient

oduction ($10^9 \cdot day^{-1}$)		
gg stages		Ambient
+ 4	5	temp.
0.0	0.0	–
6.1	2.0	4.61
5.6	26.1	4.06
3.0	28.5	3.41
0.0	0.0	–
0.3	0.0	6.99
2.3	2.2	5.74
7.7	4.0	7.26
7.4	22.6	6.80
.2	1.3	5.93

distribution of the
age 1 + 2 eggs in
in plaice in 1987
as distinguished
: eastern English
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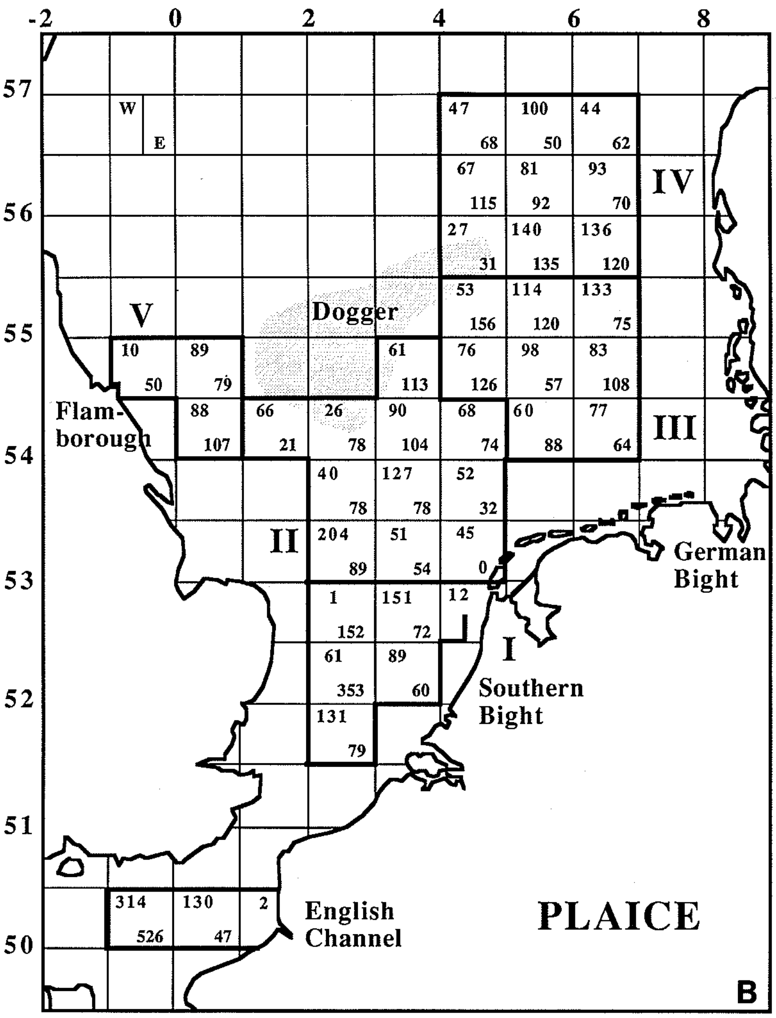
mulae given by Thompson and Riley (1981) for cod and Ryland and Nichols (1975) for plaice.

In order to yield results that are comparable with previous surveys, different methods of calculating the total production of eggs were used for cod (Daan, 1979, 1981) and plaice (Simpson, 1959). Daan's method assumes that the abundance of the three different egg stages (stage 1 + 2, 3 + 4, and 5) is normally distributed in time and estimates the corresponding production curves from the parabolic regressions of log-transformed numbers of eggs present during each survey on the week-number of the survey. Egg mortality was estimated from the integrated number of eggs in each stage present during the spawning season, after correcting for differences in development rate associated with temperature conditions. In plaice the total production was calculated by integrating the estimates of daily egg production in each survey over the time interval between the midpoints of the surveys. The start of the egg production of plaice was arbitrarily set at 14 December (day −18) and the end at 10 April (day 110). The production of fertilized eggs was estimated as the number of eggs at the age 0 days from the linear regression of log-transformed egg numbers by stage against the mean age of the egg stage. The slope of the regression gives an estimate of the instantaneous daily mortality rate (Z).

For cod, estimates of spawning stock biomass (males plus females) are given in Anon. (1988). For plaice, the female SSB (spawning stock biomass) was estimated by VPA (Virtual Population Analysis) from the total international catch in numbers (females only) from the ICES North Sea Flatfish Working Group database, taking into account the annual differences in the proportions of mature females at age (Rijnsdorp and van Leeuwen, 1985).



Results

Cod

Egg production of cod peaked in February in 1987, but in 1988 already in January (Table 1). Temperature conditions differed substantially between years, 1987 being relatively cold ($T_{febr} = 4.0°C$), but 1988 being normal ($T_{febr} = 6.5°C$). The spatial distribution of cod eggs showed a close correspondence between 1987 and 1988. The average pattern over the two years is shown in Figure 1. The main areas of egg production occur in the Southern Bight off the Dutch coast, and along the southeastern edge of the Dogger Bank. In 1988 the total production of fertilized eggs of 10.5×10^{12} in the total North Sea survey area was only slightly higher than in 1987 when 9.2×10^{12} eggs were produced. The eastern English Channel is not included in the total production because cod in the Channel are considered a separate stock. The increase in total production was due to higher production in the Southern Bight, whereas production in the rest of the North Sea was lower in 1988 (Table 2). In the Southern Bight the total mortality from fertilization to hatching was estimated at 95.0% in 1987 and 96.7% in 1988.

In Table 2 the present level of egg production in the Southern Bight is compared with the production of fertilized eggs in the period 1970 to 1974, which ranged from approximately 2.2×10^{12} to 9.0×10^{12}. The number of eggs produced in 1987 was slightly below the lowest value observed in the early 1970s, whereas production in 1988 was about three times higher than in 1987 and well within the historic range.

Plaice

In plaice the egg production peaked in February in both years but was slightly earlier in 1988 (Table 1). In Figure 1 the spatial distribution of egg production shows centres of high egg production in the eastern English Channel and in the Southern Bight. The egg production around the Dogger Bank and in the German Bight is more diffuse. The total production of stage 1 eggs in 1987 and 1988 did not differ substantially and the contribution of the subareas to the total production was also rather constant. In the North Sea the total production of fertilized eggs amounted to 14.4×10^{12} in 1987 and 18.8×10^{12} in 1988 (Table 3). Including the eastern English Channel the egg production amounted to 16.2×10^{12} in 1987 and 21.2×10^{12} in 1988. In the North Sea (subarea I–V) the total mortality of eggs from fertilization to hatching was estimated at 82.8% in 1987 and 92.6% in 1988.

Table 2. Cod production of fertilized eggs ($\times 10^9$), ambient water temperature in February (T_{febr} in °C), total development until hatching (D in days), instantaneous daily mortality rate (Z), and the spawning stock biomass (SSB in '000 t) from VPA (Anon., 1988), in comparison with data for 1970–1974 from Daan (1981).

Year	Egg-production Southern Bight	Egg-production Rest	T_{febr}	D	Z	SSB
1970	7449	–	5.2	18.4	0.027	271
1971	8989	–	5.9	17.2	0.411	269
1972	2258	–	6.1	16.8	0.277	225
1973	2201	–	7.0	15.5	0.245	197
1974	2307	–	7.4	17.9	0.297	210
1987	1632	7560	4.0	21.3	0.141	95
1988	5160	5386	6.5	15.8	0.215	96

Table 3. Plaice egg production by subarea (see Fig. 1) in 1987 and 1988 and the estimated daily mortality rate of eggs until hatching.

Area:	Surface area (km²)	1987	1988
Stage 1 eggs ($\times 10^{12}$):			
Eastern English Channel	13 818	2.02	—
I (Southern Bight)	20 720	2.63	1.80
II	40 028	2.70	2.98
III (German Bight)	28 468	2.99	2.27
IV	30 870	2.60	2.77
V (Flamborough)	10 736	0.80[a]	0.75[b]
North Sea total (I–V)		11.7	10.6
North Sea + eastern English Channel		13.7	
Fertilized eggs ($\times 10^{12}$):			
North Sea total (I–V)		14.4	18.8
North Sea + eastern English Channel		16.2	21.2[b]
Total development time until hatching (days):			
North Sea total (I–V)		25.9	15.8
Instantaneous daily mortality rate (Z):			
North Sea total (I–V)		0.068	0.165

[a] Extrapolated from one survey at peak spawning in February.
[b] Extrapolated, assuming in 1988 an equal contribution of the eastern English Channel to the total as in 1987.

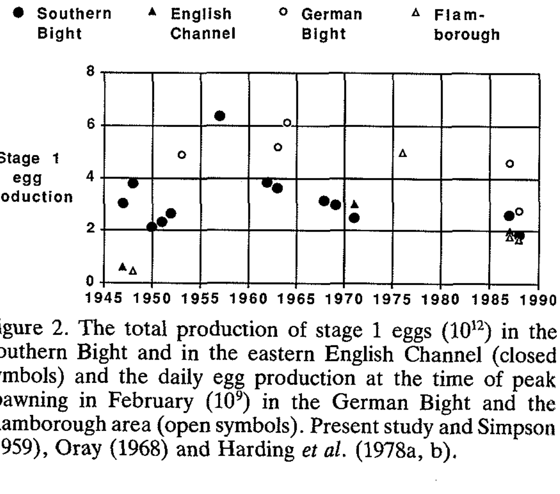


Figure 2. The total production of stage 1 eggs (10^{12}) in the Southern Bight and in the eastern English Channel (closed symbols) and the daily egg production at the time of peak spawning in February (10^9) in the German Bight and the Flamborough area (open symbols). Present study and Simpson (1959), Oray (1968) and Harding *et al.* (1978a, b).

The present egg production can be compared with historic data. The total number of fertilized eggs produced in the North Sea and the eastern English Channel in 1987 and 1988, 16.2×10^{12} and 21.2×10^{12} respectively, can be compared with an estimated production of 25×10^{12} in 1968 (Bannister *et al.*, 1974). Egg production estimates were also available for different subareas (Fig. 2): for subarea Southern Bight and eastern English Channel the total production of stage 1 eggs is shown; but for the German Bight and the Flamborough area only the daily production of stage 1 eggs at peak spawning is available for comparison. Figure 2 shows that the present egg production is in general at a lower level than in the 1960s, but at the same level as in the early 1950s. In the late 1940s egg production in subarea eastern English Channel and Flamborough was at a much lower level than at present. The time trend in female spawning stock biomass as estimated by VPA is shown in Figure 3. Both egg production and SSB show a high in the 1960s and early 1970s and a low in the early 1950s and 1980s. Egg production in the Southern Bight was weakly correlated with female SSB, when the exceptionally high egg production in 1957 was excluded ($r = 0.64$, $n = 8$, $P < 0.05$, one-sided).

Discussion

In cod the spatial distribution of eggs in 1987 and 1988 was similar to previous years, but the centre of high egg production in the eastern English Channel as seen in the early 1970s (Daan, 1978) was not observed in 1987. The number of cod eggs produced in the Southern Bight appeared to be rather variable, which is probably related to the relatively small size of the Southern Bight in relation to the total area where North Sea cod spawn (see also Macer and Parnell, 1988). Although the Southern Bight is an important spawning area for cod as far as the southern North Sea is concerned, the area is possibly too small to derive a general conclusion about changes in the total size of the spawning stock. For the total survey area (except the English Channel) the

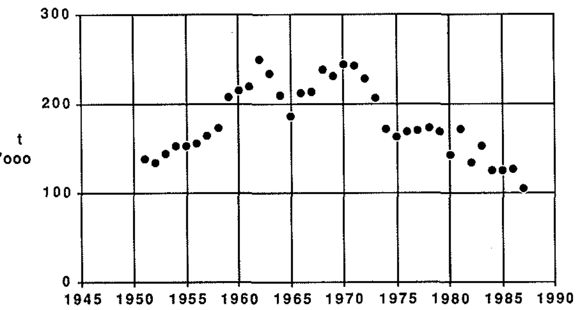


Figure 3. The spawning stock biomass ('000 t) of female North Sea plaice as indicated from the VPA and corrected for annual changes in maturity.

Table 4. Mean number of cod per hour fishing per age group for the International Young Fish Survey in 1987 and 1988, for the Southern Bight and the rest of the survey area (data from the ICES IYFS database).

	Age	1	2	3	4	5	6+
1987	Southern Bight	39.6	35.6	1.3	4.9	0.5	0.5
	rest	9.8	31.0	0.7	1.4	0.5	1.9
1988	Southern Bight	9.8	17.1	18.0	0.6	0.8	0.5
	rest	6.3	2.3	3.3	0.0	1.0	1.7

differences in egg production between the years 1987 and 1988 are much smaller, but production in 1988 is still bigger than in 1987. In the southern North Sea 3-year-old cod start to contribute to the spawning stock. An explanation for the difference between both years might be the absence of 3-year-old fish in 1987 (year class 1984 was the weakest on record), whereas in 1988 part of the strong 1985 year class recruited to the spawning stock. This year class was abundant especially in the Southern Bight (Table 4), which could explain the difference in this area between both years. It is assumed that the SSB of North Sea cod has declined considerably since the 1970s (Anon., 1988) and a much greater difference was expected between our results for cod egg production and those for the 1970s given by Daan (1981). A possible explanation might be a considerable increase in fecundity of cod in the southern North Sea (Heessen, unpublished).

In the northern North Sea cod and haddock spawn in the same period and since it is impossible to discriminate between early egg stages of these species, it is impossible to derive reliable egg production figures for the total North Sea cod stock. VPA results are only available for the total stock and no detailed data exist on the distribution of the adult component. A comparison between survey results as presented here and the trend in SSB cannot therefore be made for North Sea cod.

In plaice the spatial distribution of eggs in 1987 and 1988 was similar to previous years (Harding *et al.*, 1978a), although the relative importance of the eastern English Channel appeared to be higher in 1987. In the comparison of the trend in egg production and SSB from VPA, it should be realized that the fecundity has increased since the late 1940s (Rijnsdorp *et al.*, 1983; Horwood *et al.*, 1986). Therefore, the egg surveys may underestimate the size of the female spawning stock early in the period. The potential egg production can be estimated from an estimated SSB from VPA of 106 000 t in 1987 and a relative fecundity of 225 000 eggs per kg body weight (Rijnsdorp *et al.*, 1983). Thus the potential egg production of the total North Sea plaice population amounts to 24×10^{12} eggs and compares to an observed production in 1987 of 16×10^{12} (Table 3). A part of the discrepancy between the observed and the potential egg production can be explained by the fact that the egg surveys did not include the total area of egg production and thus give an underestimate. However, this underestimate will be rather small, as the substantial egg production in the eastern English Channel is included in the comparison because this spawning group migrates into the North Sea and stays there during the main part of the year (Houghton and Harding, 1976). Furthermore, the distribution of mature plaice in February (Rijnsdorp, 1989) makes it unlikely that other important areas of egg production occur outside the survey area. Several other possible causes for the discrepancy can be suggested: the fecundity estimate could be inaccurate, not all eggs are fertilized, some of the eggs die soon after being shed due to embryonic abnormalities, SSB estimate from VPA may be inaccurate, etc. This phenomenon deserves further study because Bannister *et al.* (1974) observed a similar discrepancy.

Despite the discrepancy in the observed and potential egg production, the trends in egg production and SSB from VPA show a good correspondence in plaice, so it may be concluded that egg surveys can yield valuable fishery-independent information. Trends in plaice SSB observed from egg surveys can therefore be used in fish stock assessment. In cod, historic data are restricted to the Southern Bight and this area is too small to be representative of the total North Sea.

Egg mortality in cod appeared to be substantially higher than in plaice. A similar observation was made by Harding *et al.* (1978b) in the Flamborough spawning area. It is generally assumed that egg mortality is mainly caused by predation (Rothschild, 1986). Since spatial and temporal distributions of cod and plaice eggs show a considerable overlap, although differences in the vertical distribution may occur, it is likely that both cod and plaice eggs encounter the same types of predators. Daan *et al.* (1985) showed that herring preferred the larger plaice eggs to cod eggs, but overall egg mortality by herring predation was less than 10% in plaice eggs and less than 1% in cod eggs. The likely predators of cod and plaice eggs are organisms, other than herring, preferring smaller prey sizes. Egg mortality in both plaice and cod was lower in 1987, when the water temperature was well below normal, although the difference in cod was less substantial than in plaice.

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