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CONTENTS

1. Introduction

During 1981, a series of ichthyoplankton surveys was conducted in the English Channel to describe the distribution and abundance of the eggs of the sole (*Solea solea* L.). MAFF research vessels CLIONE and CORELLA* were used on these surveys which happened to coincide both temporally and spatially with the spawning of the sprat (*Sprattus sprattus* L.) and could also be used for an abundance estimate of that species.

The estimatation of seasonal sprat egg production and mortality, described in this paper, has not previously been possible because no data on development rates were available. During the first survey, sprat eggs were successfully reared over a range of temperatures and their rate of development was recorded (Thompson, Milligan and Nichols, 1981).

Total seasonal sprat egg production, together with a fecundity estimate, were used to assess the spawning stock biomass in the English Channel in 1981.

2. Materials and methods

2.1 Incubation experiment

In order to obtain estimates of the numbers of eggs produced over a given time period from plankton surveys of spawning areas, it is necessary to know the rate at which the eggs develop at a range of constant temperatures.

Spawning sprats were obtained in April 1981 in the region of Lyme Bay (Figure 1a) using an Engel 800 trawl, and artificial fertilizations were carried out (Thompson, Milligan and Nichols, 1981).

Batches of approximately 50 fertilized eggs were put into 70 ml glass vials containing 60 ml of clean sea water. These vials were then transferred to an incubation block based on the design of Halldal and French (1958) and Thomas, Scotter and Bradshaw (1963). The vials were arranged with 11 in each row of 19 temperatures ranging from 4°C to 20°C, producing totals of between 450 and 900 eggs at each temperature.

The eggs were examined every 6 hours and samples of 2 to 7 eggs from each temperature were photographed and preserved in 4% neutral formalin. A record was kept of the numbers of dead eggs and the numbers of larvae which hatched, to calculate the percentage survival through to hatching and mortality rates throughout the egg stages. At the same time the temperature of each row was recorded and the eggs allocated to one of six development stages. These stages followed a modification of Simpson's (1959) classification of plaice eggs, which was based on Buchanan-Wollaston's (1923) version of Apstein's (1909) more numerous, finely divided stages.

Because of difficulty in recognizing the early development of the primitive streak in fixed specimens, Simpson's classification of Stages IB and II was modified with Stage II now beginning at Apstein's Stage VIII.

The end of each stage was calculated as the mid-point between the last occurrence of one stage and the first occurrence of the next. For observations where both stages occurred, the previous and subsequent observation times were used for the calculation.

2.2 Ichthyoplankton surveys

Three ichthyoplankton surveys from April to June 1981 were primarily designed to describe the distribution and abundance of the sole (*Solea solea* L.). The eggs of other fish species were also sorted from the samples, including those of the sprat (*S. sprattus* L.).

Samples were collected using a Lowestoft design, high-speed plankton sampler (Beverton and Tungate, 1967) 760 mm in diameter. It was fitted with a hemispherical nose cone with a 406 mm diameter aperture and a nylon, conical net of 270 µm mesh. The sampler was towed at 5 knots in a double oblique haul from the surface to within 3 m of the bottom and back to the surface. It also incorporated a temperature/depth sensor, continuously recording on a multipen analogue recorder. At each sampling position a surface seawater sample was taken for subsequent salinity analysis.

Samples were taken on a 0°15′ latitude x 0°15′ longitude station pattern, from the Dover Strait to approximately 5° west on the first two surveys (Figure 1a). Results from a third survey covering the same area but using a much coarser grid (Figure 1b) were used to supplement information gained on the previous two surveys.

Samples were fixed in 4% buffered formalin and returned to the laboratory for sorting, where they were transferred into a seawater solution of 0.5% propylene phenoxetol and 5% propan-1, 2-diol preservative (Steedman, 1976). Sprat eggs were identified, separated into one of six development stages based on a modification of Simpson's (1959) stages, and counted using a low-power stereomicroscope.

The numbers at each stage per sample were converted to numbers under a square metre of sea surface using calibrated flowmeter readings (Harding and Arnold, 1971). Numbers per square metre of each stage of egg development on each survey were plotted and contoured (Figure 2a-j). The area of each contour level was measured by planimetry and multiplied by the mid-contour value. These were summed to give total abundance of each stage of egg development on each survey.

*Since this survey, R.V. Corella has been withdrawn from service.

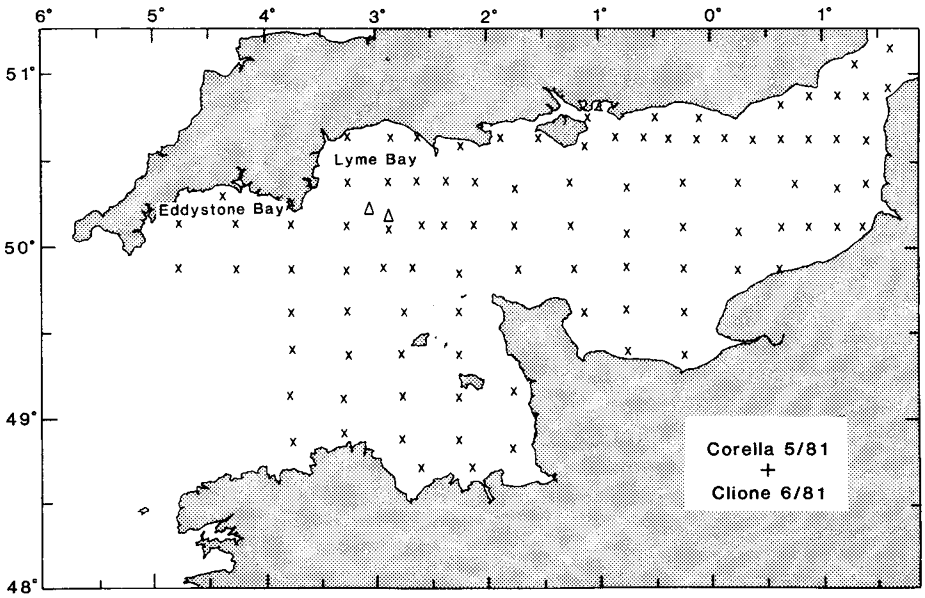


Figure 1(a) Positions of plankton stations (×) sampled on the CORELLA 5/81 and CLIONE 6/81 cruises. Positions of two trawl hauls on CORELLA 5/81 are also shown (△).

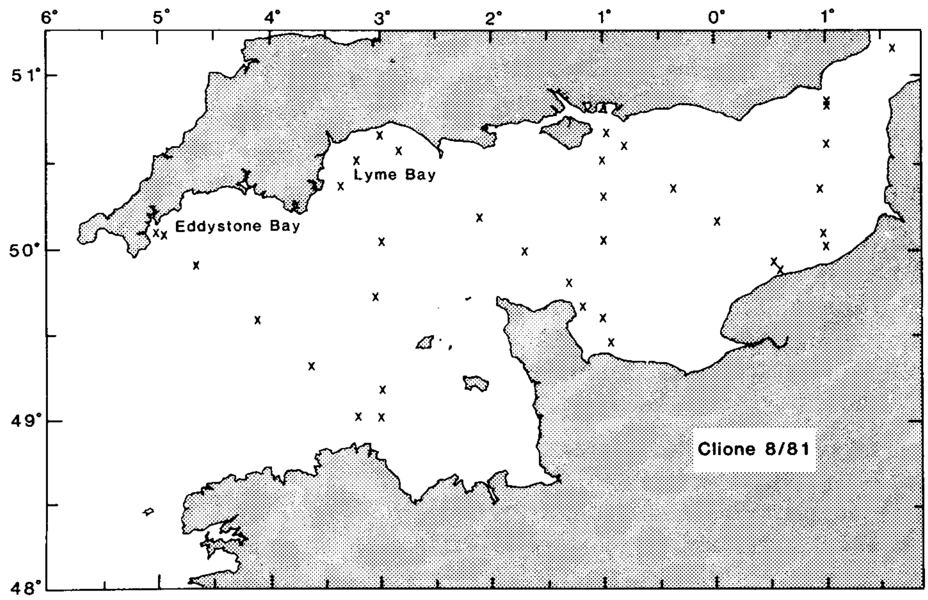
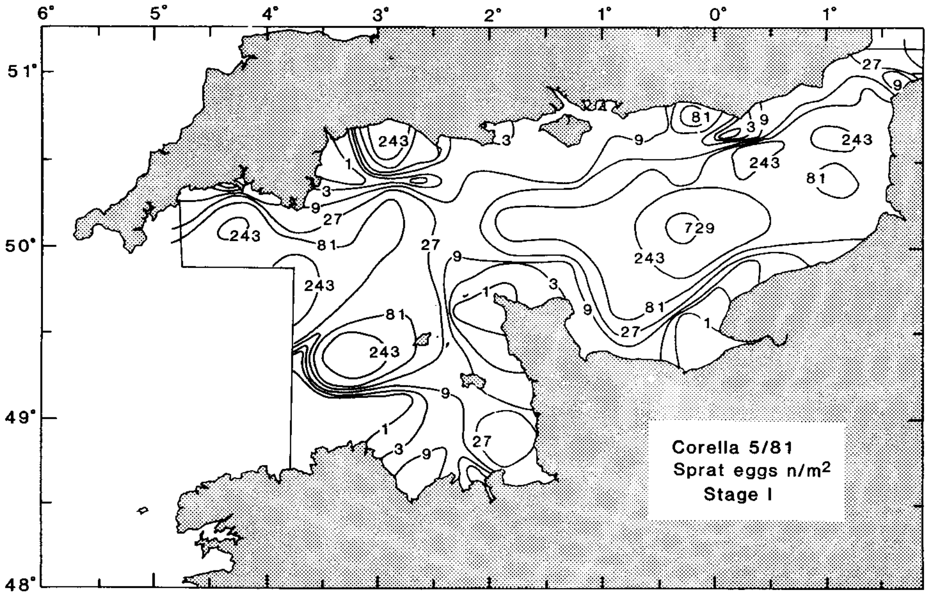


Figure 1(b) Positions of plankton stations (×) sampled on the CLIONE 8/81 cruise.

(a)



(b)

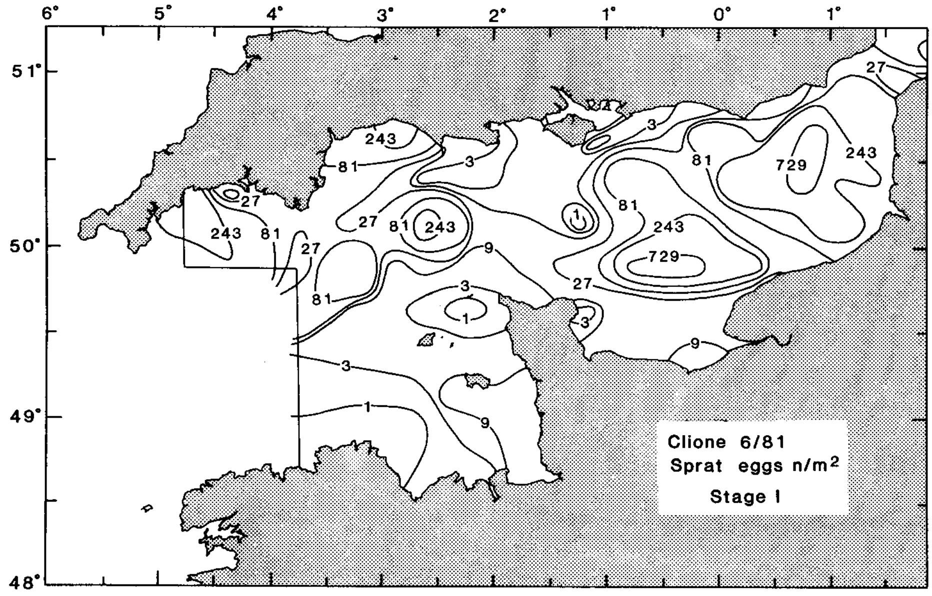
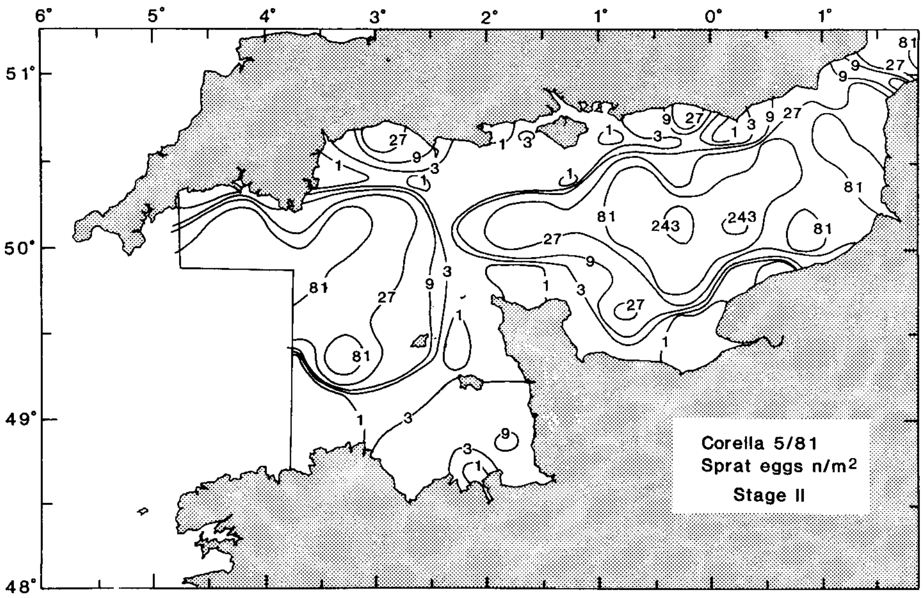


Figure 2(a-j) Distributions of five stages of sprat egg development on the CORELLA 5/81 and CLIONE 6/81 cruises.

(c)



(d)

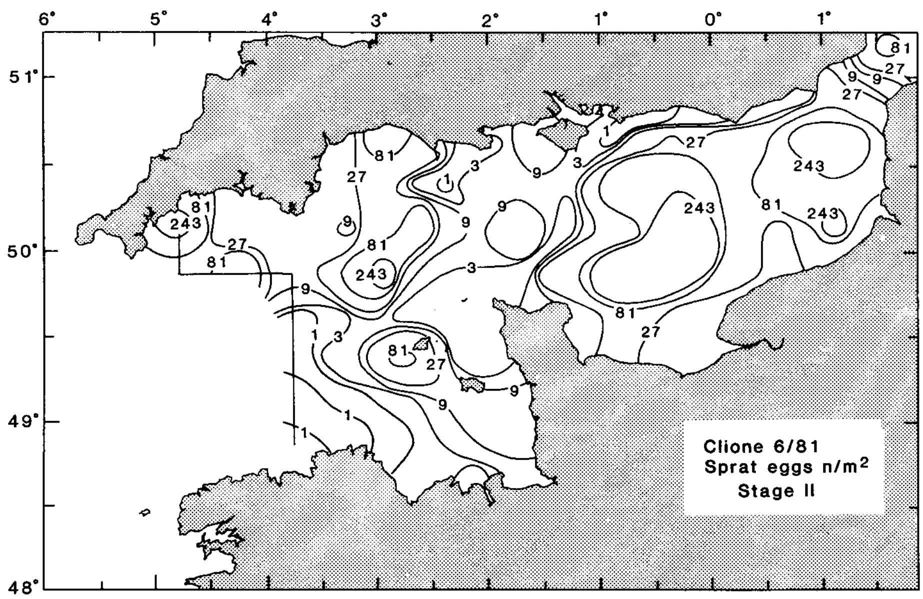


Figure 2 (continued)

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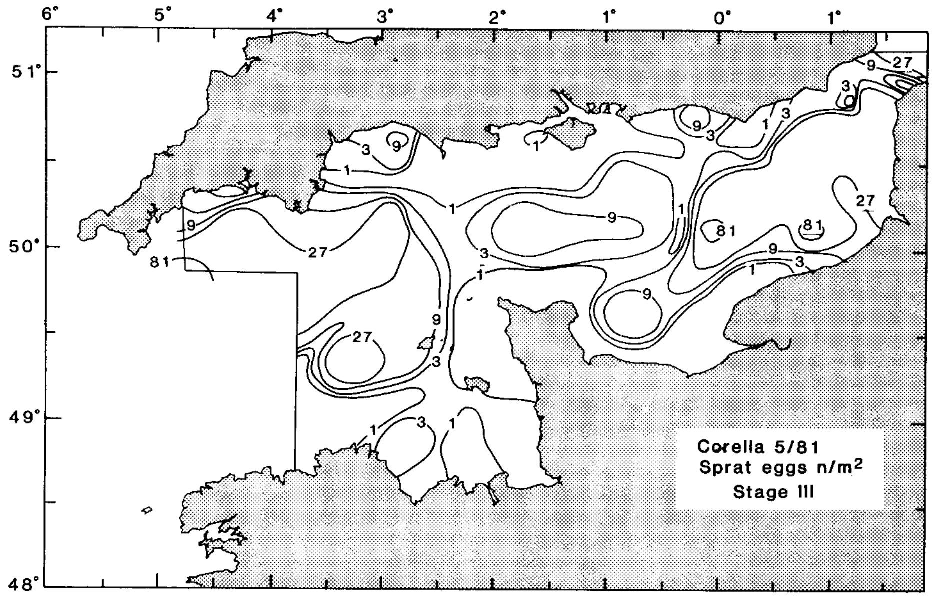

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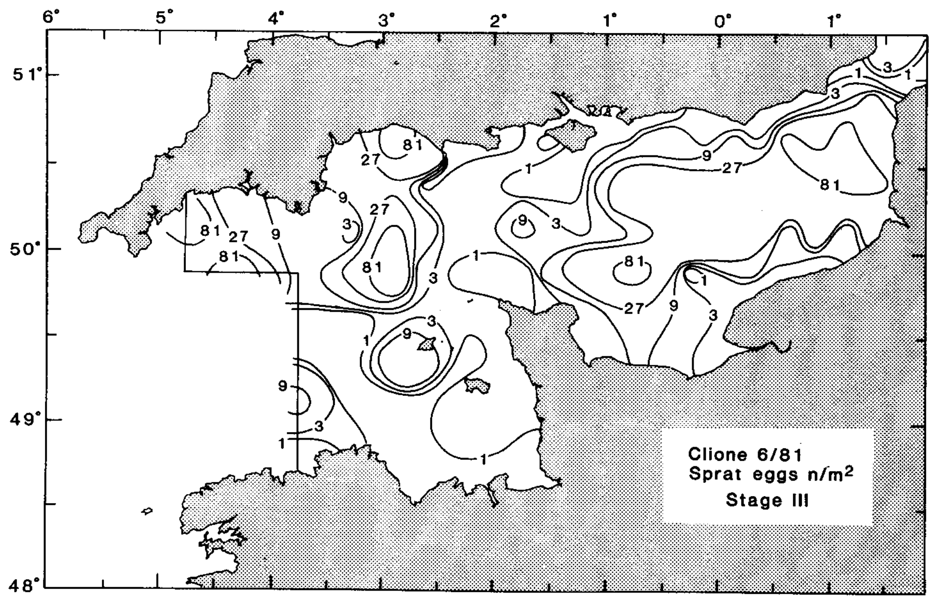


Figure 2 (continued)

(g)

(h)

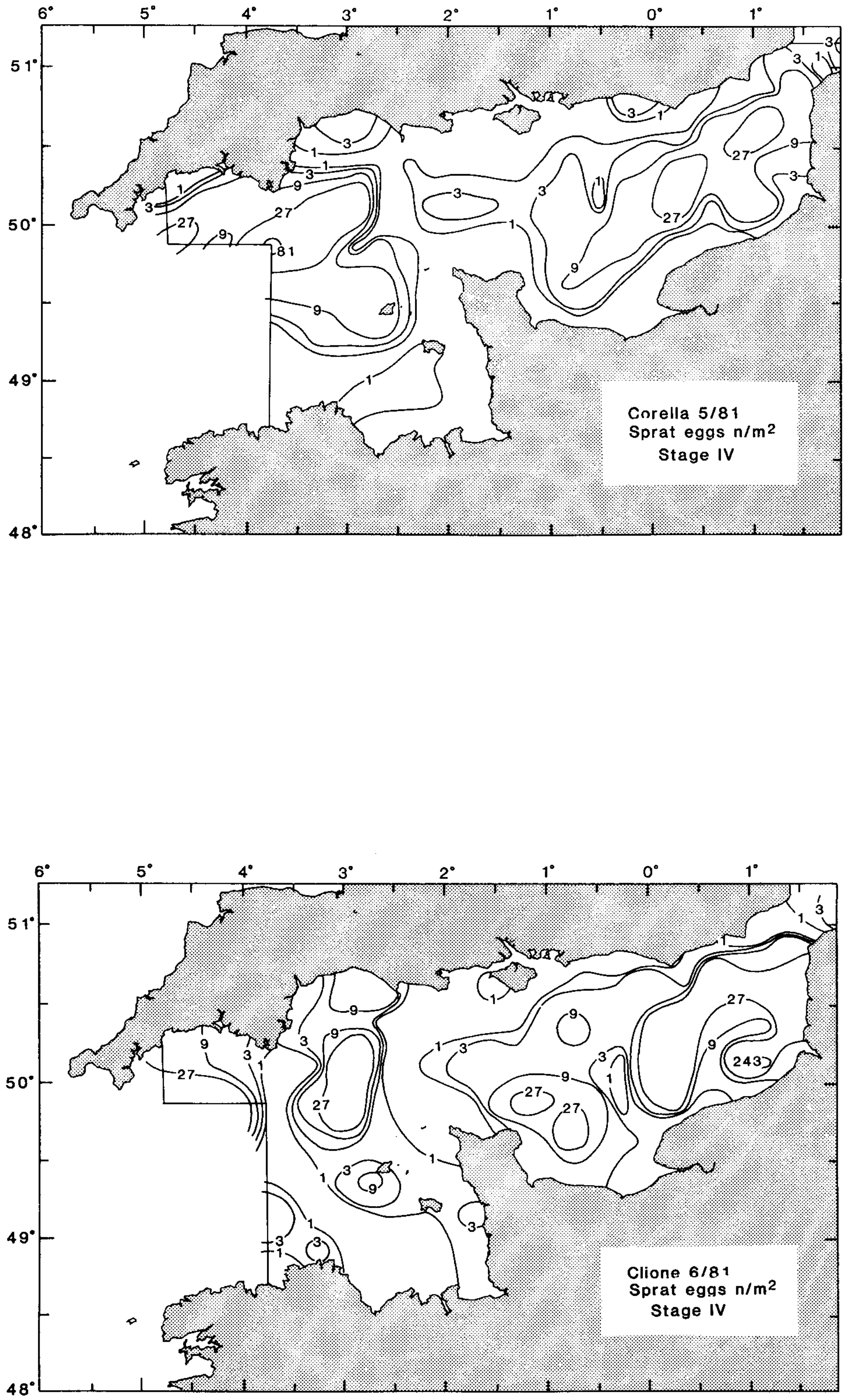
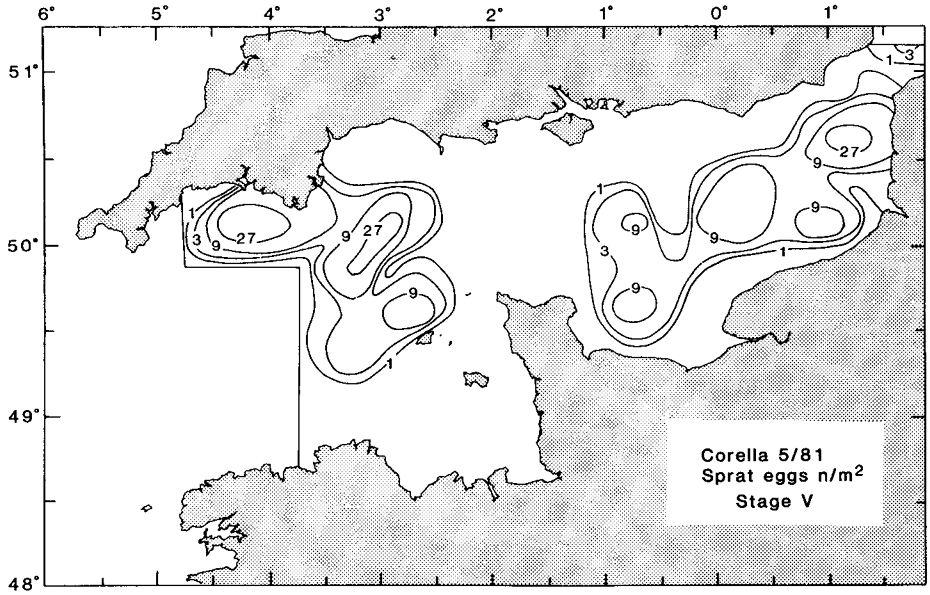


Figure 2 (continued)

(i)



(j)

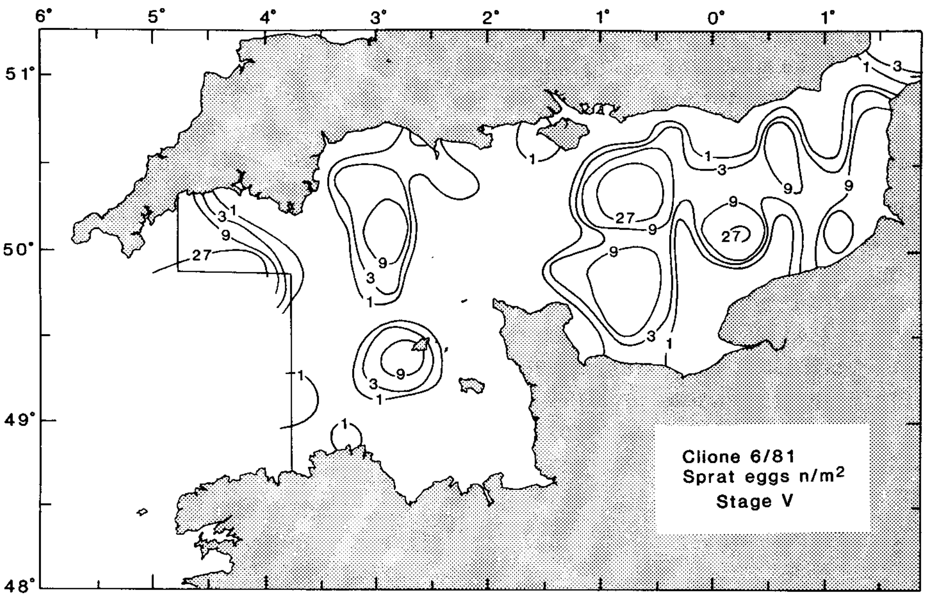


Figure 2 (continued)

2.3 Fecundity estimates

A random sample of the catch of sprats in Lyme Bay in April was returned deep-frozen to the laboratory for age, length, weight and maturity stage analysis. A basic fecundity/length relationship (De Silva, 1973) was used to produce average total fecundity per fish for each of the two trawl positions.

3. Results

3.1 Incubation experiment

The time taken in hours from fertilization to the end of each of the six development stages was calculated at each temperature. Regression coefficients are given in Table 1 for the fitted regression:

$$\ln \text{time (h)} = A \ln \text{temperature (°C)} + B,$$

with the means and standard deviations of temperature observations and percentage survival through to hatching. Curves showing development time on temperature are given in Figure 3. The lines are fitted using transformations from natural logarithms of points obtained using the regression coefficients given in Table 1.

During the incubation experiment, sprat eggs were reared through to hatching from 4.3°C to 20.0°C. Mortalities were high at the extremes of this temperature range, but survival was remarkably consistent between 6°C and 18.5°C demonstrating the inherent capability of the sprat to develop successfully over a wide range of temperatures.

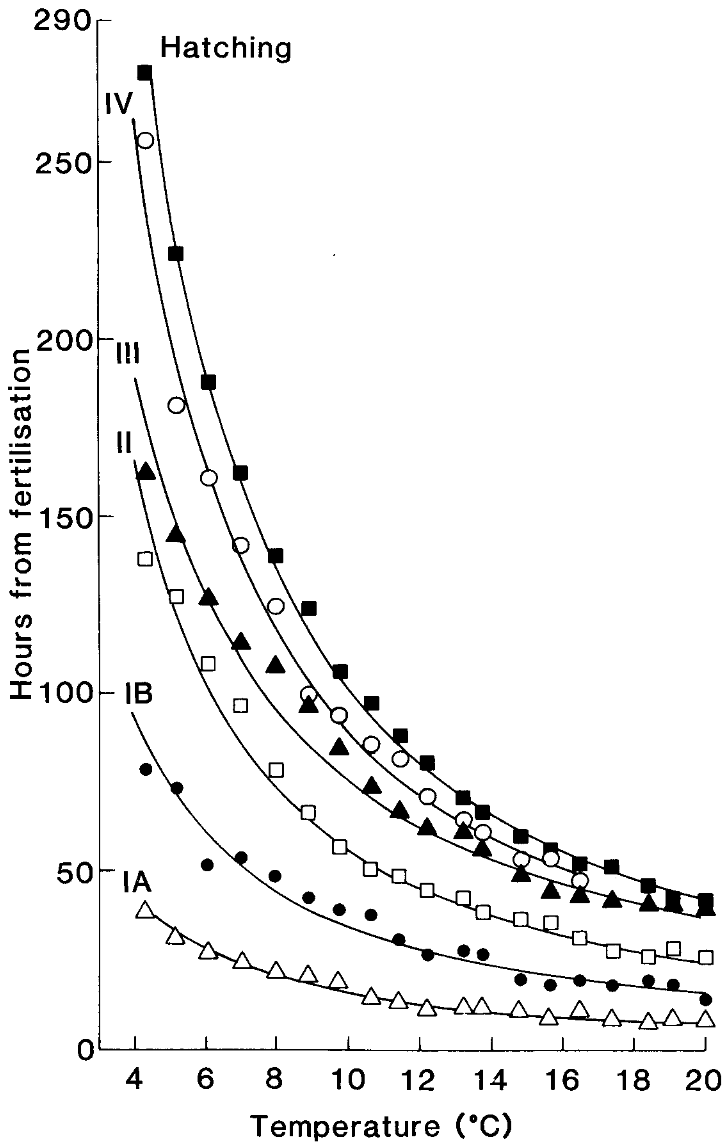


Figure 3 Sprat egg incubation stage duration: laboratory observations. The curves are fitted by the regressions given in Table 1.

3.2 Ichthyoplankton surveys

The distributions of the various stages of sprat eggs (Figure 2a-j) show that sprats are spawning throughout the Channel but that there is an area of lower production from the Cherbourg peninsula northwards, along the line of 1°45′W longitude, splitting the distributions into east and west components. The spawning in the eastern Channel in April 1981 is centred around a sampling position at 50°07.5′N and 0°15′W where Stage I egg density was greater than 1,000 m^{-2}. Egg densities were high over most of the eastern Channel being greater than 81 m^{-2} over more than half the area.

By early May the distribution in the eastern Channel has split into two, with centres at 49°55′N 0°33′W and 50°30′N 0°50′E.

In the western region the spawning pattern is quite different, characterized by three localized high spots above the 243 Stage I eggs m^{-2} contour line. These high spots occur in Eddystone Bay, Lyme Bay and over deeper water in the central western Channel.

This general distribution pattern was evident in all the egg stages on all three surveys in 1981, indicating that there was little change in spawning areas. The same pattern of spawning also occurred in a similar survey covering the same area from 18 April to 8 May 1979 (Figure 4a-b).

Temperature profiles were recorded at all sampling positions. During the first survey, in April, the surface temperature ranged from a minimum of 7.9°C in the eastern Channel to a maximum of 9.2°C in the west. There were no signs of a thermocline, with surface/bottom temperature differences up to 0.5°C.

Table 1

Sprat egg development rates. The time taken in hours from fertilization for eggs to reach the end of each development stage at each temperature. Time of first hatch and the percentage of fertilized eggs which survived to hatching is also given for each temperature. The regression coefficients are for the fitted regression ln time (h) = A, ln temperature (°C) + B

Mean temperature (°C)	SD temperature	Hours to end of stages IA	IB	II	III	IV	50% hatch (V)	First hatch	% survival to hatching
4.29	0.24	39.02	78.40	137.94	162.32	255.42	275.00	265.71	27.93
5.15	0.24	30.19	72.63	126.51	144.53	180.27	224.00	186.01	28.28
6.02	0.33	27.19	51.28	108.31	126.60	160.69	188.00	164.88	46.25
6.98	0.26	24.35	51.35	96.18	114.18	141.42	162.00	143.19	42.77
7.95	0.21	21.53	48.31	78.64	108.42	123.80	139.00	124.44	46.53
8.85	0.24	21.63	42.47	66.79	96.27	99.32	124.00	102.53	42.28
9.73	0.35	18.78	39.47	60.60	84.57	93.28	106.30	95.74	37.11
10.59	0.32	14.27	37.99	50.16	73.39	85.63	97.50	91.00	46.27
11.43	0.25	13.36	30.68	48.53	66.92	81.92	87.60	85.84	39.00
12.16	0.33	11.38	26.88	44.27	61.78	70.38	80.75	73.09	51.72
13.18	0.23	11.16	27.86	42.73	60.75	63.67	70.90	66.09	47.09
13.72	0.36	11.44	26.94	38.12	50.58	60.84	66.40	63.13	65.41
14.84	0.22	11.27	19.09	36.88	48.68	52.84	59.60	55.17	41.69
15.64	0.21	8.74	17.76	35.18	44.72	53.75	55.60	54.17	67.89
16.48	0.18	11.36	19.20	31.01	42.86	46.59	52.00	48.38	39.76
17.36	0.23	8.84	18.04	27.06	41.35		51.20	43.06	36.20
18.42	0.10	7.65	19.31	25.19	40.03		45.25	41.69	40.06
19.06	0.10	8.93	18.11	27.12	41.40		43.25	42.12	13.37
20.00	0.09	7.76	13.88	25.28	40.12		42.25	41.78	3.75
Regression coefficient A		−1.058	−1.096	−1.195	−1.020	−1.199	−1.259		
Regression coefficient B		5.217	6.061	6.794	6.684	7.254	7.509		
Correlation coefficient r		0.96	0.96	0.99	0.98	0.99	0.997		

During the second survey, at the beginning of May, the surface temperature had risen by approximately 0.5°C in the eastern Channel and by 0.7°C in the west.

Surface seawater samples were taken for salinity analysis, which ranged between 32.11‰ and 35.26‰. No relationship between either the temperature or salinity distributions and sprat spawning can be seen in these data.

The production estimates for each cruise are given in Table 2. The coarser sampling pattern on the third survey allowed only a production estimate of Stage I eggs to be made. The abundance of other stages on this survey was too low for a quantitative assessment. The production estimates were used to draw a series of spawning production curves (Figure 5) and to estimate the seasonal production of 5 egg development stages.

Using the abundances of the different egg stages, mortality estimates were calculated (Table 3) using the equation:

$$Nt/No = \exp(-Zt),$$

where No is the initial number of eggs and Nt the number surviving to the next stage in the period t, where t is the mean stage duration in hours.

By transposing the above equation, the mortality coefficient Z can be calculated. For sprat eggs in 1981 this was:

$$Nt = No \exp(-0.025t).$$

Using this expression of Nt, the numbers surviving after any given time period can be obtained.

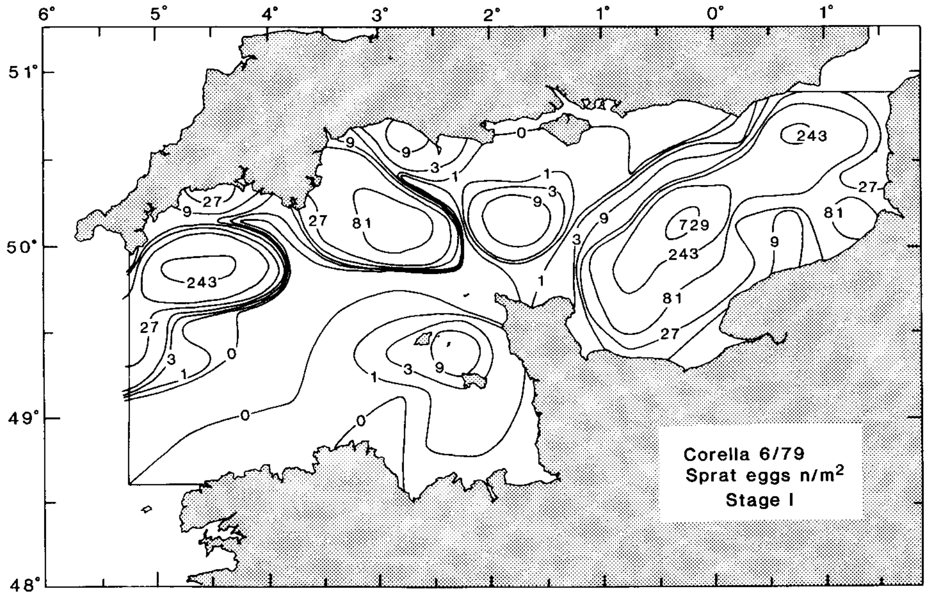


Figure 4 (a) The distribution of Stage I sprat eggs as found on the CORELLA 6/79 cruise.

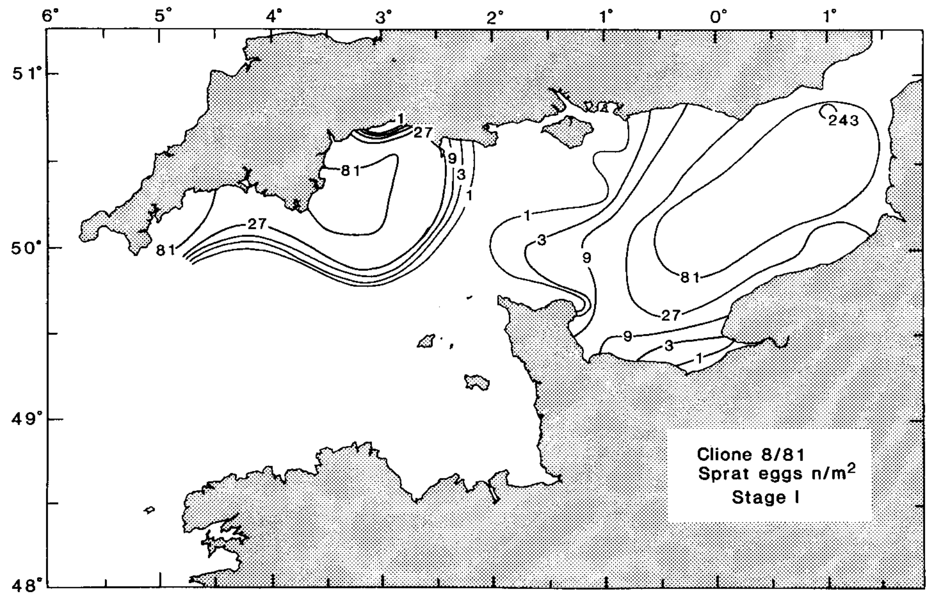


Figure 4 (b) The distribution of Stage I sprat eggs as found on the CLIONE 8/81 cruise.

Table 2 Numbers of eggs produced m^{-2} day^{-1} for each egg stage for each survey and total numbers of each egg stage produced over the whole 1981 spawning season

Egg stage	CORELLA 5/81 4-13 April	CLIONE 6/81 29 April-12 May	CLIONE 8/81 9-26 June	Area under seasonal production curves
	Numbers ($\times 10^{-9}$)	Numbers ($\times 10^{-9}$)	Numbers ($\times 10^{-9}$)	Total numbers ($\times 10^{-12}$)
I	4 229.9	4 864.3	2 521.2	475.36
II	2 941.4	5 283.7		439.14
III	1 408.8	2 065.6		183.22
IV	1 050.9	1 427.5		129.82
V	522.9	666.3		62.08

Table 3 Abundance of each stage of egg and the estimate of mortality between stages

Development stages	Abundance ($\times 10^{-12}$)	Log abundance ($\times 10^{-12}$)	Age (h)	t (h)	Mortality %	Mortality Z
I	475.36	2.677	19.68			
				32.91	7.62	0.002
II	439.14	2.643	52.59			
				23.42	58.28	0.037
III	183.22	2.263	76.01			
				18.60	29.15	0.019
IV	129.82	2.113	94.61			
				15.59	52.18	0.047
V	62.08	1.793	110.20			

Age is the number of hours from fertilization to the mid-point of each stage.
t is the time in hours between the mid-point of one stage and the mid-point of the next.
Z is the instantaneous mortality rate per hour.

Table 4 The spawning stock size estimate for the English Channel sprat for 1981

	Whole English Channel	Western Channel only
Stage 1 egg abundance	475.36×10^{12}	160.74×10^{12}
Mean fecundity from Torbay fishery	33 820	33 820
Stock estimate of mature female fish	1.405×10^{10} fish	0.4753×10^{10} fish
Male: female ratio 1:1	2.810×10^{10} fish	0.9506×10^{10} fish
Weight of mature fish (1:1 ratio)	497 932 t	168 446 t

A mortality curve was constructed (Figure 6) by plotting abundance against mean age in days, the slope of the line illustrating the rate of loss of eggs from the population throughout the spawning season.

The regression line fitted to these data gave calculated intercepts when x = 0 (fertilization) and x = 5 days (50% hatch at 8.84°C) of 984.70 and 64.78, indicating a survival through incubation of 6.58% and a mortality rate of 42% per day.

3.3 Fecundity estimates

Sprats were sampled in April with an 800 Engel trawl at two positions. On return to the laboratory, age, length, weight and maturity analysis was carried out. The number of mature female sprats taken in the trawl hauls was too small to sample for fecundity analysis. Fecundity was therefore obtained by using a relationship given by De Silva (1973):

$$F = 0.314692\, L^{4.40706}$$

where F is the fecundity of an individual and L is the length of the fish in centimetres.

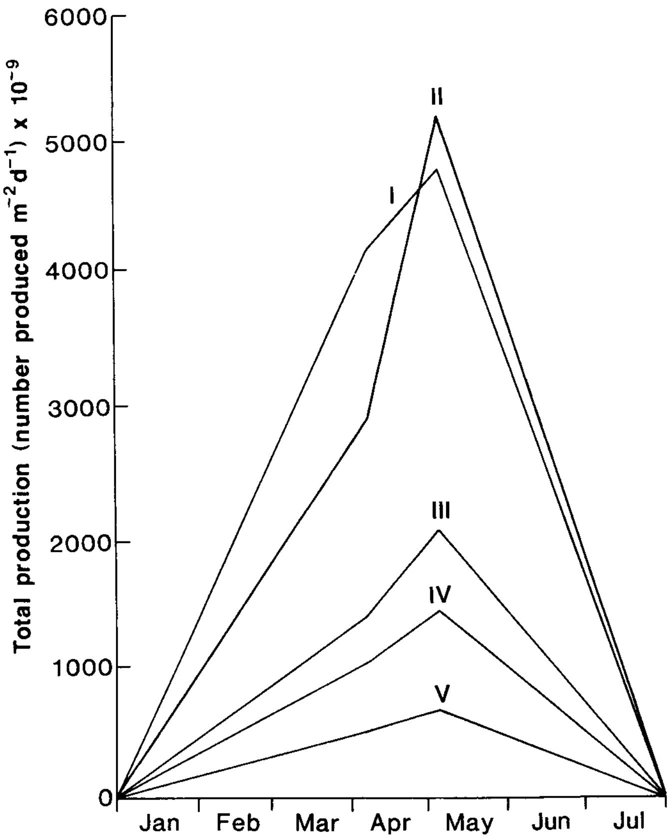


Figure 5 Seasonal production curves for sprat eggs from the CORELLA 5/81, CLIONE 6/81 and CLIONE 8/81 (English Channel) cruises.

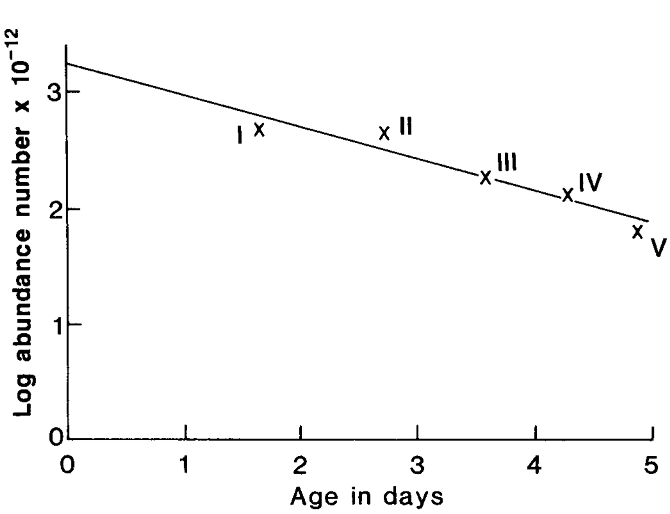


Figure 6 Mortality curve for sprat eggs during 1981. Regression: A= 2.993; B= −0.010; r= −0.945. The abundance is plotted at the mid-point of each stage.

Using this fecundity relationship and mean length from the two trawl hauls, an average total fecundity per fish was calculated at 23,685 eggs and 29,818 eggs from sampling positions 20 nautical miles and 27 nautical miles respectively off the coast. The fecundity used to produce the stock estimate given in Table 4 (33,820 eggs) was produced from data of the Torbay area commercial fishery during the 1980-81 season, which was probably more representative of the spawning stock in the western Channel.

3.4 Spawning stock biomass estimate

An average individual weight of 17.72 g was calculated from data obtained in the 1980-81 season of the Torbay area commercial sprat fishery. Using this average weight, a spawning stock biomass was calculated for the whole Channel and for the western Channel only (Table 4).

By dividing the Stage I egg abundance by the average fecundity estimate, a stock size of mature female fish was produced. Assuming a sex ratio of one male to one female, the estimated number of mature female fish is doubled to estimate the spawning stock size of 2.810×10^{10} fish with a weight of 497 932 t. Approximately a third of the Stage I egg production took place in the western Channel, giving a spawning stock size estimate of 0.9506×10^{6} fish with a weight of 168 446 t.

4. Discussion

Plankton surveys for sprat eggs in the Channel had been carried out prior to 1981. Earlier surveys were undertaken by English research vessels in May-June 1967 and July 1968, to investigate the spawning distributions of pelagic species of potential interest for industrial fishing development (Wallace and Pleasance, 1972). Later surveys, one in April 1978, covered the western Channel between Portland Bill and the Scilly Isles, up to 30 miles off the coast. Another, from April-May 1979, covered the whole Channel.

As the data on egg development had become available and estimates of egg density had been obtained from the two surveys covering the peak of spawning, it was possible to calculate total egg production and stock estimates for 1981.

Sprat eggs appear in the plankton throughout the year but, according to Russell (1976), the main spawning period off Plymouth is from January to July with eggs being most abundant in February and March. Although these surveys did not cover the whole spawning period of the sprat, the peak spawning times were adeqately sampled.

As sprat eggs are so abundant and widely distributed, it was predictable that the spawning area would not be completely enclosed by the survey. The same was true in 1979, except that there were very few eggs found in the south-western Channel, in an area not surveyed in 1981.

A third survey, in June 1981, although based on a coarse grid pattern, did confirm the spawning distribution found on the two previous surveys. A daily egg production estimate was of the same order of magnitude and also showed the decrease in spawning later in the season. The distribution patterns of eggs do not seem to be influenced by either temperature or salinity.

Comparison of sprat survival through incubation (6.58%) with that found by Riley (1974) for sole (*Solea solea* L.) eggs in the Blackwater estuary in 1969 (4.35%) shows that both species have similar survival through the egg stages. This is again indicated by the mortality rate which in the sprat in 1981 was 42% per day and in two estimates for the sole in 1969 was 49% per day and 42% per day.

There were difficulties in differentiating the early development Stages IA and IB in plankton samples, because of distortion on fixation and the problem of observation through the dense, segmented yolk. This is reflected in the poorer correlation coefficients obtained in the early stages during the incubation experiment. It was decided, therefore, to carry out all calculations of egg production and stock size estimates using total Stage I egg abundances (Apstein's Stages 0–VII). A similar problem occurs in the recognition of the first signs of the primitive streak, as described earlier.

Sprat eggs develop through to hatching at a wide range of temperatures. Fage (1920) gives the temperature range for spawning as 8–11°C, which is similar to that observed in the Channel in 1981. Harding and Nichols (in press) found developing sprat eggs off the north-east coast of England in temperatures up to 19°C in 1976. Wheeler (1969) gives a distribution ranging from the Mediterranean to the Baltic.

It is probable, therefore, that the problems encountered at the extremes of our temperature range, during the incubation experiment, are no more than a reflection of the acclimatization of the adults to a particular spawning termperature.

The estimates of fecundity could be improved in two ways. Firstly, fecundity estimates could be produced directly from fish taking part in the season's spawning. Secondly, by sampling fish throughout the spawning area and season, De Silva's (1973) fecundity/length relationship would then be more applicable.

Sprats are serial spawners, which makes an individual's seasonal fecundity difficult to estimate. The potential seasonal fecundity used assumed an average of 8.2 spawnings per season. There is a need for further work on sprat fecundity, possibly by histological examination of the gonad as carried out recently for the mackerel (*Scomber scombrus*) (Mariduena, 1984).

It is known that most of the UK and the Netherlands catches are taken in the western Channel (west of 2°W), and it is likely that most of the French landings originate from the eastern Channel (Anon., 1983). The majority of the UK catch is taken from the Lyme Bay area (02°40′W–04°00′W) within 20 miles of the coast during the months September–February. As most of the commercial catch is from this region a stock estimate was produced for the western Channel from the 1981 plankton surveys. This was estimated to be approximately one-third of the total spawning in the Channel, i.e. 168 466 t (Table 4).

No stock estimate has previously been available for the eastern Channel, but as two-thirds of the spawning was taking place there in 1981, further work is obviously required. However, little information on the stock structure of the eastern Channel fish is available since there has been limited commercial fishing in the region.

More effort is needed in producing a stock size estimate for sprat in the Channel, which would provide valuable data for management of the fishery. With the experience and knowledge gained from the 1981 plankton surveys, and a concerted effort on sprat spawning alone, it should be possible to produce a stock size estimate of those fish available to the commercial fishery.

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