J. Cons. int. Explor. Mer, 35 (2): 107–120. Février 1974

Fecundity studies on North Sea herring

A. C. Burd and G. J. Howlett

Fisheries Laboratory, Lowestoft, Suffolk, England

Of the characters used for stock differentiation in the North Sea herring, fecundity studies have proved confusing to the general picture of separation into three major stocks, Bank, Downs and Buchan. By combining fecundity counts with length, a fecundity index has resulted which clearly discriminates between Bank and Downs fish. The index has been used to separate these two stocks in the mixed North Shields fishery. The proportions determined by this method compared well with those derived from other methods.

The Bank fecundity/length relationship obtained here is indistinguishable from that derived earlier by Baxter from the northwestern North Sea spawning fisheries. It is suggested that these fish were not representative of pure Buchan spawners and were probably mainly Bank herring with some Buchan spawning fish.

Introduction

Herring fecundities have been studied by many workers. Farran (1938) showed different fecundity/length relationships for the spring-spawning herring and the autumn-spawning herring off the Irish coast, and suggested that fecundity differences might be used as a stock diagnostic character. Kändler and Dutt (1958) established differences in fecundities for the central Baltic spring spawners and the western Baltic spring spawners, and suggested that the fecundity differences were related to differences in the environment of the spawning area. Baxter (1959) demonstrated that fecundity/length, fecundity/total weight, and fecundity/age relationships for the northern North Sea "Buchan" fish were significantly different from those of the Southern Bight ("Downs" stock) spawners. Central North Sea spawners, the "Bank" stock, whose spawning places lie in intermediate positions between those of the Buchan and Downs stocks (Fig. 1), have also been investigated (Kändler and Dutt, 1958; Polder and Zijlstra, 1959). The younger and smaller Bank fish have been reported as having fecundities similar to those of the Downs stock, while the older and larger fish had fecundities similar to those of the Buchan fish (Polder and Zijlstra, 1959).

In order to be able to make a fecundity estimate the fish must be sampled before the ovary has begun to shed eggs. Thus the ovary must be taken not later than in International Maturation Stage V (ICES,

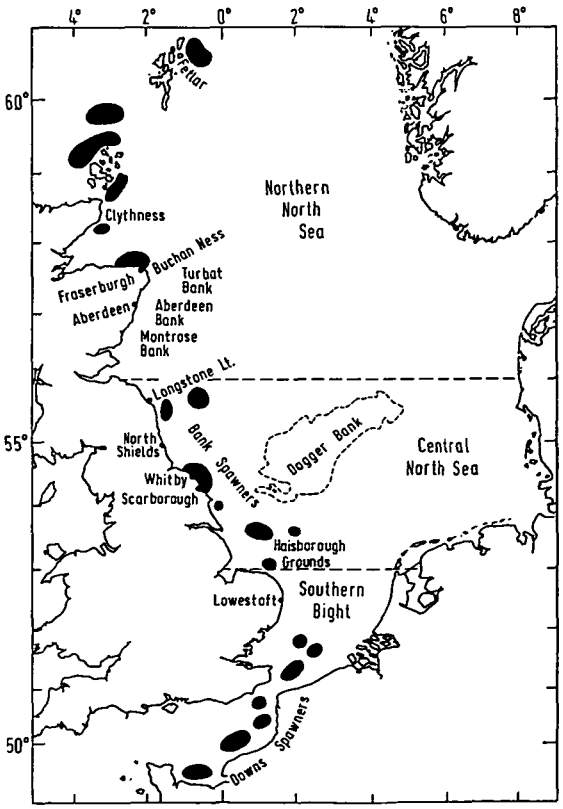

Figure 1. Map showing all place names mentioned in the text and spawning places of herring.

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Table 1. Constants for fecundity (F) and weight (W) regressions, $F = a + bW$

Year	Source	b	a	Correlation coefficient	Number of observations
1962	Lowestoft	253·32	−11·025	0·7136	106
	Aberdeen	253·46	−11·924	0·7903	120
1965	Spawning fishery	292·14	−16·679	0·9452	48
	East Anglia	282·19	−15·502	0·9321	36
1957	Southern Bight (Baxter, 1959)	277·77	−12·768	0·8911	97

Note: The correlation coefficient for Baxter's data was calculated from the data given in Baxter's Figure 2 (1959).

1965). As Iles (1964) has pointed out, both Bank and Downs fish can apparently be in this maturation stage at the same instant in time. There is thus no easy way of determining whether a Stage V fish sampled in September or October is a Bank or Downs herring, or for that matter whether Stage IV or V fish sampled in summer in the northern North Sea are Buchan or Bank spawners.

This paper discusses the fecundities of the summer-spawning fish from the Longstone and Whitby areas in relation to the observations made on the Buchan and Downs stocks. In addition, fecundities are used as a method for separating Downs and Bank stocks in the mixed North Shields and Haisborough fisheries.

Material and methods

The material was collected from routine sampling of herrings landed at the markets of North Shields, Scarborough, Whitby and Lowestoft. Each fish was subjected to the complete laboratory sampling procedure; thus all relevant data for each individual fish, length and weight, etc., were available.

Only filling fish (stages IV and V) were used in the majority of these fecundity studies. Ripe fish (stage VI) were not included because it was not possible to determine if any eggs had been shed. Both ovaries from each fish were slit open and preserved in jars containing a modified version of Gilson's fluid (Simpson, 1951). The jars were shaken at intervals to help remove the ovarian tissue from the eggs. After careful decanting, the eggs were washed in an evaporating basin and any small pieces of ovarian tissue still remaining carefully removed. The washed eggs were then poured through a funnel containing a small-meshed piece of plankton silk, and all excess water was removed by a vacuum pump connected to the funnel. All these "relatively dry" eggs, and a small random sample containing between 300 and 400, were quickly weighed. The small weighed sample was accurately counted and fecundity estimates made by raising, using the ratio total weight/weight of sample. A comparison of this method with that of Baxter (1959) who used an egg counter is presented in Table 1. This gives the regression constants for the Downs herring sampled in 1962 for both methods.

Results

The fecundity/weight relationship

Downs spawners. Material was available from collections made in 1962 and 1965. Half the 1962 material was processed by the Marine Laboratory, Aberdeen and the remainder in Lowestoft. Two series of Downs material were analysed in 1965. One series consisted of fish derived from the spawning fishery from the Hinder and Sandettié grounds. The other series consisted of fish taken in the East Anglian fishery proper. In each series sampling has covered the three most abundant age groups in the stocks in those years.

Fecundity/weight regressions were calculated for the four sets of samples. The equations of the regressions appear in Table 1. The regressions for the 1962 data processed at Lowestoft and Aberdeen are almost identical, as are those relating to the spawning fish and the East Anglian herring in 1965. None of the regressions is significantly different from the others. For comparison, Baxter's data for 1957 are shown and these parameters lie within the confidence limits of the 1962 and 1965 data.

The central North Sea samples. The summer spawners sampled at the Longstone and Whitby grounds were compared with the data of Baxter (1959) collected from the Buchan spawning grounds. It should be recalled that, since only fish in maturation stages IV and V can be used reliably for fecundity studies, there is always a possibility that some Downs herring will be included in samples from these fisheries. In 1965 and 1966 the Downs stock was so low compared with the summer-spawning fish that it is unlikely that Downs fish occurred in sufficient numbers in these samples to affect the comparison. Only a few fish were examined from the Longstone in 1965 and

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Table 2. Regression constants for Buchan, Longstone and Whitby herring (see Table 1)

Year	Source	b	a	$s_{y \cdot x}$	Number of observations
1957	Buchan (Baxter, 1959).....	481·03	−19·304	10·466	53
1965–66	Longstone.....	532·53	−32·144	11·428	42
1966	Whitby.....	559·69	−38·372	11·029	75

Note: The standard deviation about the regression for Baxter's data was calculated from the data given in Baxter's Figure 2 (1959).

these have been included in the data from this area for 1966.

Figure 2 shows the fecundity/weight regressions for the Downs and Buchan spawners and also those for the Whitby and Longstone samples. The 95% confidence limits have been fitted to the combined Downs data and also to those for the Buchan fish. The Longstone and Whitby regressions of fecundity on weight were not significantly different from those derived from the Buchan data. The regression constants are given in Table 2.

In 1965 and 1966 fecundity estimates were made on all suitable fish in the samples from North Shields and the Haisborough spawning area. In both fisheries a considerable mixture of Downs herring usually occurs with the summer-spawning Bank stock of which the Haisborough spawners are a component (Fig. 1). Again, as in the case of the Longstone and Whitby samples these data from North Shields and the Haisborough should be almost free of significant numbers of Downs spawners in 1965 and 1966. Figure 3 shows the plots of fecundity on weight for the North Shields and Haisborough data. If these fish were simply mixtures of two fecundity types – Buchan and Downs – one would expect that the points would be distributed about the two regression lines and within the 95% confidence limits. However, this is not so, the distribution of the points at low weights being mainly within the lower confidence limit of the Buchan regression and in the upper limit in the Downs regression. At high weights there is a tendency for the points to lie in the upper fiducial limit for the Buchan regression or even outside it. This might suggest that the central North Sea spawners have a somewhat different fecundity/weight rela-

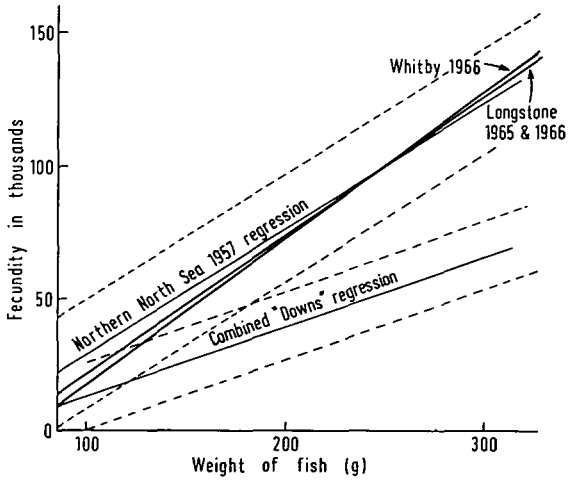

Figure 2. Regressions of fecundity/weight relationships for Whitby 1966 and Longstone 1965 and 1966 samples. The regressions with 95% confidence limits for "Buchan" and Downs stocks have been superimposed.

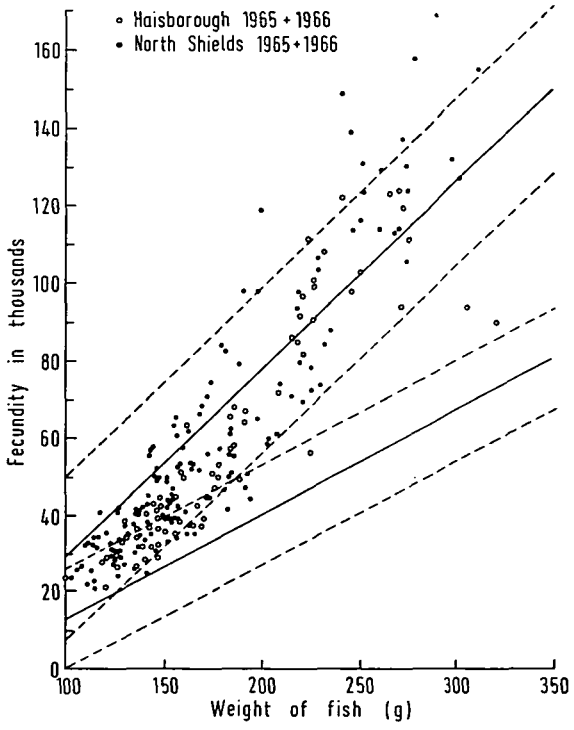

Figure 3. The fecundity/weight relation for Haisborough and North Shields samples in 1965 and 1966. The regressions with 95% confidence limits for "Buchan" and Downs stocks are superimposed.

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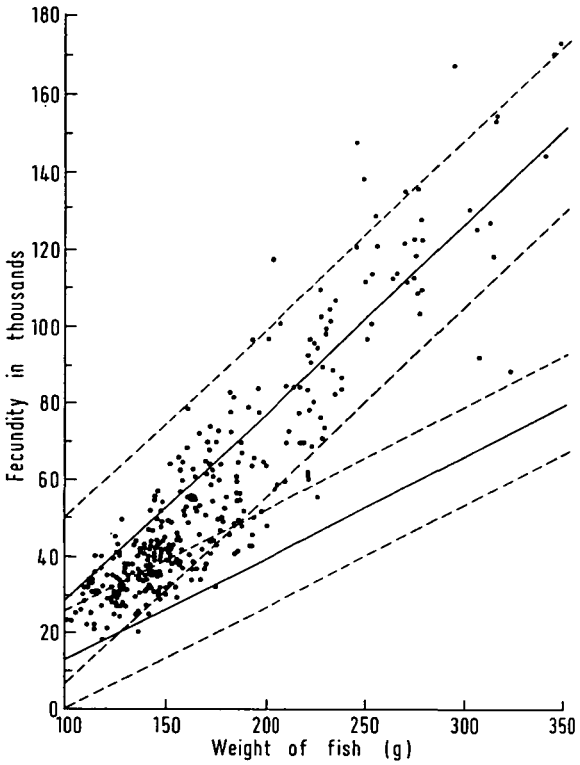

Figure 4. Fecundity/weight relation for all central North Sea data (1965 and 1966). The regressions with 95% confidence limits for "Buchan" and Downs stocks are superimposed.

tionship from that described for the fish from the Buchan area by Baxter (1959).

Figure 4 shows the plot of fecundity on weight of all the central North Sea data (Figs 2 and 3 combined). Again, for comparison, the regressions of Buchan and Downs fish with their 95% confidence limits are shown. Below 170 g almost all the observed points lie in the lower fiducial limit for the Buchan fish. However, because of the large variances about the regressions for both the Buchan and the combined central North Sea data, no significant difference (at $P = 0{\cdot}05$) can be demonstrated between the two sets of data. Table 3 gives the values of the residual standard deviation of y on x for each regression.

Table 3. Residual standard deviations $s_{y \cdot x}$

Source of sample	Year	$\times 10^{-3}$	Number of observations
Downs stock.....	1962 and 1965	6·635	310
Buchan fishery ...	1957	10·466	53
Longstone fishery.	1965–66	11·428	42
North Shields fishery.....	1965	13·164	92
	1966	12·196	67
Whitby fishery....	1966	11·029	75
Haisborough fishery.....	1965	13·773	45
	1966	8·582	23
Combined central North Sea data...		13·748	344

In the years when recruitment to the Downs stock was high, and in earlier years before the decimation of the adult stock, the central North Sea summer fisheries contained large numbers of Downs herring. These are identified from their maturation stages. For example, in July in the North Shields fishery they are defined as being those fish below maturation stage IV; in July 1962, 75% of the 3 year-old fish were below this stage. Figure 5 shows the scatter diagrams for fish examined for fecundity, taken from the 1962 central North Sea fisheries. Fish below maturation stage IV were not used for fecundity estimates and so do not contribute points to the North Shields scatter diagram in Figure 5. However, because of the imprecision of the method of staging, some Downs fish are likely to occur within maturation stage IV. Indeed it can be seen that some of the observations in each locality are distributed within the 95% confidence limits about the Downs regression line. In the Whitby material, despite the fact that the samples were taken close to the spawning places, it would seem that some fish occur with a fecundity/weight relation which could be ascribed to Downs stock.

The Haisborough fishery takes place in late September and lies in the path of the migrating Downs stock. The proportion of Downs herring in fish of maturation stages IV and V would be expected to be high. A mixture of the order of 50% might be surmised from the distribution of the Haisborough observations in relation to the Buchan and Downs regressions in Figure 5.

The above analysis has indicated that fecundity/weight plots could be used to estimate the mixture of Downs herring in the central North Sea fisheries. However, the discriminatory power of such a relationship is not very great. Although stocks of old adult herring can easily be characterized by mean fecundity per age group, the assignment of individual fish cannot be made in the most abundant young age groups. This is particularly true in fish of less than about 200 g.

The most consistent character of distinction between Bank, Downs and Buchan stocks is that of length-for-age, which naturally is reflected in differences in weight-for-age between these stocks. The mean length of Downs herring is approximately 1 cm less than that of Bank herring, and about 2 cm less

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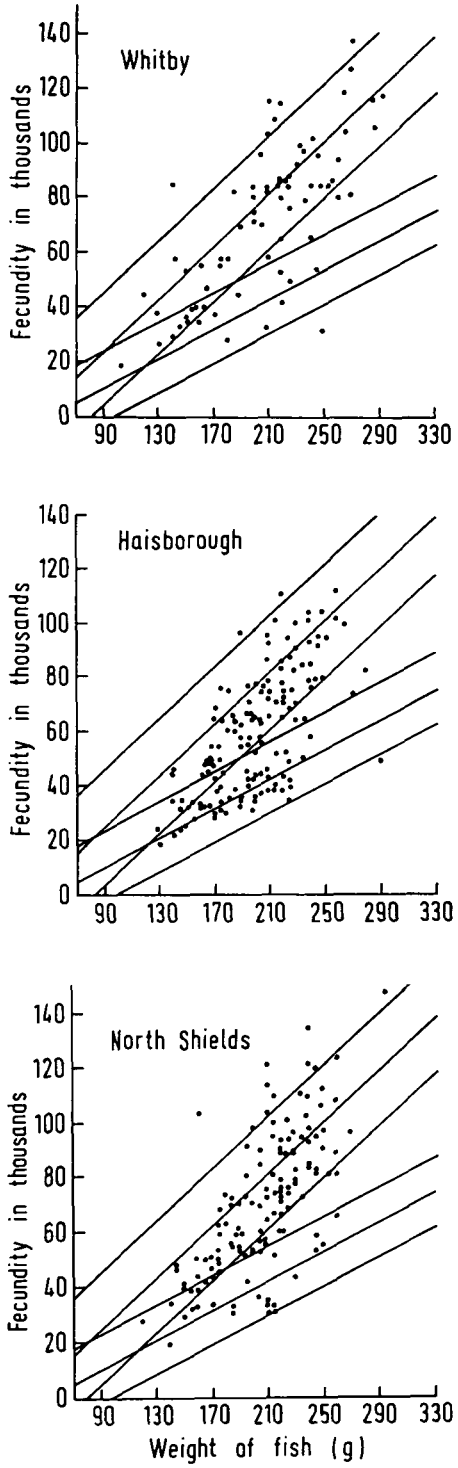

Figure 5. Fecundity/weight relations for samples from the central North Sea fisheries in 1962. The regressions with 95% confidence limits for "Buchan" and Downs stocks are superimposed.

than that of Buchan herring, at the same age (ICES, 1965). The annual growth increment between 3 and 4 years of age is about 1·5 cm (ICES, 1965). The mean monthly length increment must therefore be very small compared with the between-stock length difference. As the maturity cycles of Bank, Downs and Buchan herring are not in the same phase, the relative size of the gonads at any time will play a large part in determining the value of weight as a discriminating character between them.

The monthly percentage weight increment is, however, far greater than that in length. Table 4 shows the monthly mean weights for some age groups in the North Shields fishery. It is seen that over the 5 months there is an increase in weight per age group of the order of 28%. As mentioned above, the 1965 fishery had few Downs herring, so this change tends to reflect the temporal increase in weight for the Bank stock as the fish enter the spawning stage. For weight at age to be comparable between stocks, sampling would need to be made at exactly the same period in the spawning cycle. In plotting fecundity on weight one is correlating a potential absolute measure of a stock identity, fecundity, with a relative measure of

Table 4. Mean weight (g) per age group. North Shields fishery, 1965

Month	3 year-olds	4 year-olds	5 year-olds
May	110·3	150·6	168·4
Jun	121·6	157·4	175·9
Jul	138·2	144·9	170·3
Aug	146·2	203·4	247·2
Sep	142·5	208·8	235·0

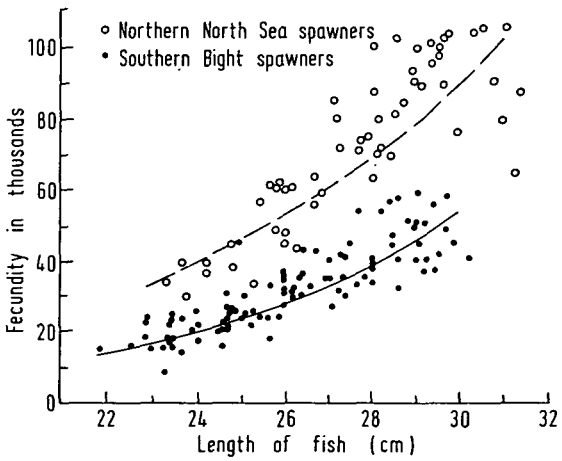

Figure 6. Fecundity/length relationships for northern North Sea spawners ("Buchan") and Southern Bight spawners (Downs). Redrawn from Baxter (1959).

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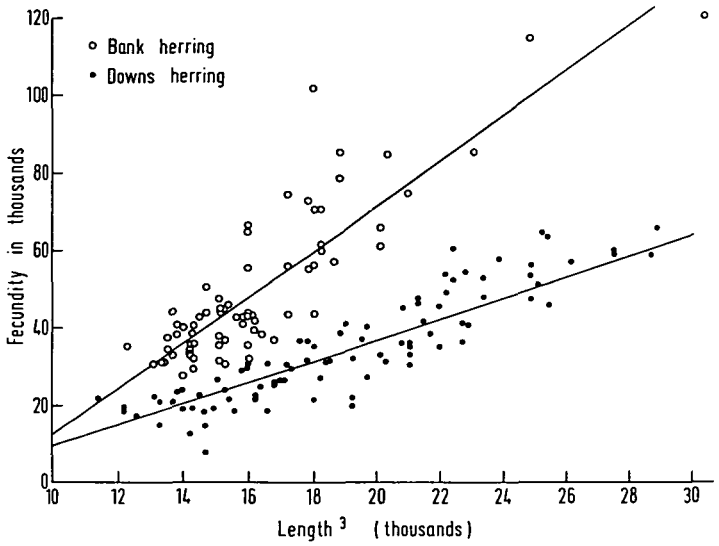

Figure 7. Regressions of fecundity on length cubed for Bank and Downs spawning stocks.

stock growth, weight. Weight is a measure of stock growth of less precision than length.

The fecundity/length relationship and the fecundity index

The form of the relationship between length and fecundity has been well established (Baxter, 1959; Bridger, 1961). The relationship is curvilinear (Figure 6) and in this form is even more difficult to adapt for discrimination than are the regressions in weight. In the following analysis of the Bank and Downs material the lengths have been raised to the third power. By this transformation linearity of the fecundity/length regression is obtained. The transformed lengths can further be interpreted as a weight function from which the effects of seasonal variations in gonad growth have been eliminated.

Figure 7 shows the regression of fecundity on length cubed for Bank and Downs herring. Although the variance about the regression remains quite high in each stock, it can be seen that there is rather a sharp demarcation between the fecundities of the two stocks even at low lengths. The regression equation parameters for the two series of data are given in Table 5.

The Downs herring were sampled as V and V–VI

Table 5. Regression equation parameters ($y = a + bx$) for data of known Bank and Downs fish

Stock	$\bar{x}$	$\bar{y}$	b	a	$s_{y \cdot x}$	d.f.
Bank.....	16 289	49 524	5·9240	– 46 969	10 259	69
Downs.....	19 185	34 321	2·9166	– 21 633	6 434	89

Table 6. Meristic characters of Bank and Downs herring used for fecundity estimates

Stock	$\bar{l}_1$ (mm)	σ	$\overline{VS}$	σ	No. of obs	Mean egg weight (mg)	σ	No. of obs
Bank.....	137·4	24·76	56·46	0·850	69	0·426	0·0037	37
Downs.....	123·5	19·22	56·56	0·675	88	0·790	0·0070	21

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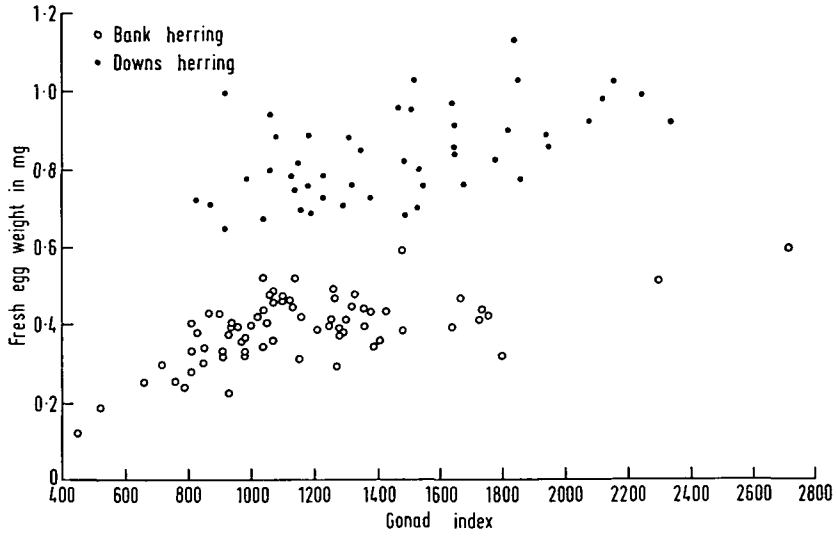

Figure 8. Relationship between fresh egg weight for Bank and Downs stock and gonad index (see text).

maturity stage fish in the 1962 East Anglian and 1965 Sandettié and Hinder fisheries. The identity of these fish as Downs herring was checked by reference to their meristic characters. The Bank herring were derived from the 1966 Whitby fishery, using fish in maturation stages IV and V. Their meristic characters are given in Table 6, together with those for the Downs herring.

The fresh egg weights of these fish were also investigated. The eggs should be measured at a comparable state of development and, since the maturation stages were considered to be too crude for this purpose, gonad weight was used as the index of maturation. A gonad index expressed as gonad weight/total fish-length cubed was calculated. The relationship between this index and fresh egg weight is shown in Figure 8. It can be seen that the egg weights of Downs herring are approximately double those of Bank herring for any given value of the gonad index. Means and variances of the egg weights, shown in Table 6, have been calculated for both stocks, using fish with comparable gonad index values. The range of gonad index chosen was 1000–1500.

The utilization of length as the second discriminant character removes the necessity for the fecundity comparisons between stocks to be made at comparable maturation stages in order to minimize differences due to gonad weight changes. Fecundities may be compared as long as the eggs are countable.

Discrimination by regression of two variables is less convenient than using a single variable. A fecundity index (fecundity/total fish-length cubed) has therefore been calculated. For Bank and Downs herring the distributions of these fecundity indices

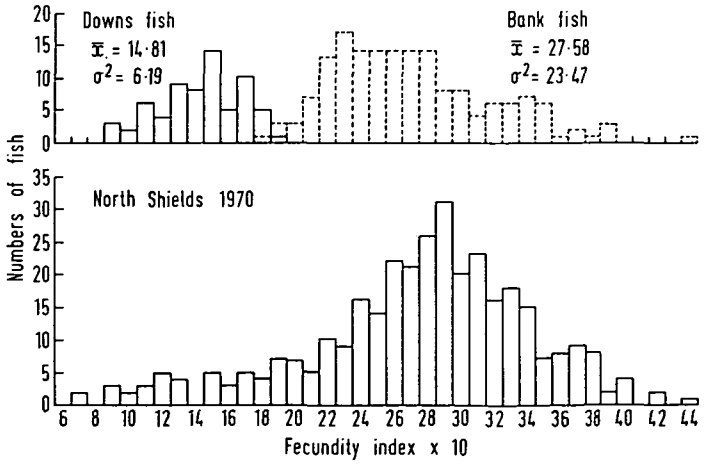

Figure 9. Fecundity index distributions for 3 year-old bank and Downs herring and the distribution of fecundity index in 1970 North Shields 3 year-old fish.

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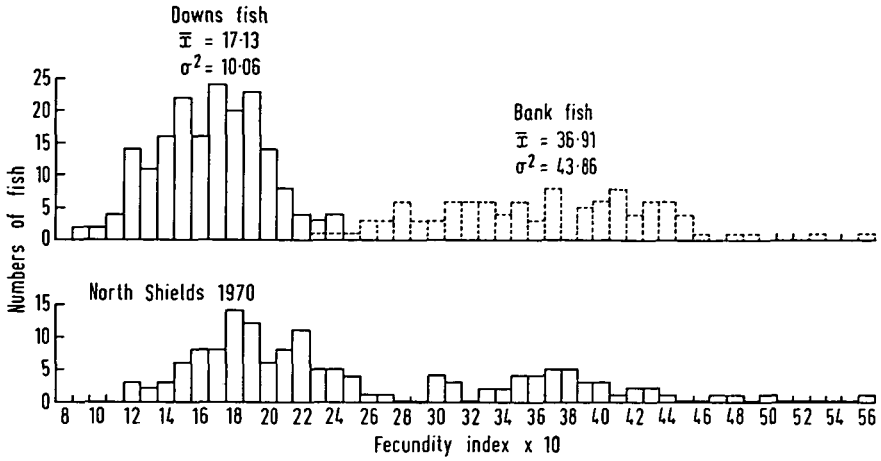

Figure 10. Fecundity index distributions for 4 year-old Bank and Downs herring and the distribution of fecundity index for 1970 North Shields 4 year-old fish.

for 3 year-old, 4 year-old and greater than 4 year-old fish are shown in Figures 9, 10 and 11. It is seen that in each case there is almost no overlap in the distributions. For each age, however, the Bank herring have variances about four times those for the Downs. The data for Figures 9, 10 and 11 have been pooled from all available material. Care has been taken to ensure that all fish were taken in high maturation stages and close to the spawning grounds of both Bank and Downs stocks.

In the North Shields fishery in 1970 all gonads in which it was possible to separate the eggs were counted for fecundity (stage III to V inclusive). Fecundity indices were calculated for all fish and the distributions for 3 and 4 year-olds, which were the most abundant age groups, are shown in Figures 9 and 10. Obviously fecundity indices cannot be calculated for fish in maturity stages II and VIII. These fish would mainly be Downs herring, and the numbers of low-fecundity index fish in the North Shields histograms in Figures 9 and 10 must therefore underestimate the proportions of Downs herring in the fishery.

Table 7 shows the proportion of Downs herring by 2 week periods for July and August in the 1970 North Shields fishery. The estimate derived from the fecundity index has been adjusted by addition of the numbers of fish in maturation stages II and VIII. The forecast method was based on fish below maturation stage IV, using both sexes (Burd and Cushing, 1962). Although there is a close similarity between the results of using the two methods for the 4 year-olds, in the 3 year-old herring the forecasting method appears to overestimate the Downs stock.

Indices of Bank and Downs recruitment as catches-

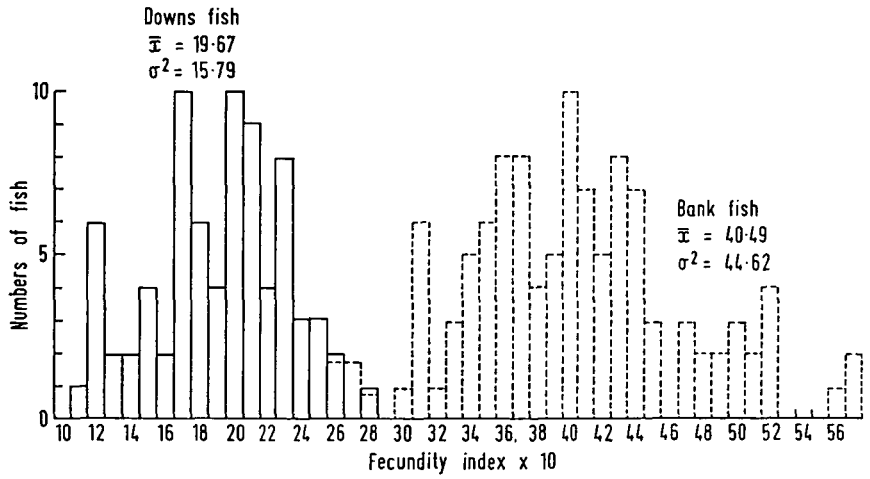

Figure 11. Fecundity index distribution for all fish older than 4 year-olds for Bank and Downs herring.

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Table 7. Estimates of the percentages of Downs herring at North Shields, 1970

Estimate	3 year-olds, %		4 year-olds, %	
	Fecundity index method	Forecasting method	Fecundity index method	Forecasting method
1st half July	27	72	79	85
2nd half July	32	64	70	77
1st half August	19	32	54	58
2nd half August	20	25	71	71
Total July	30	68	73	80
Total August	19	30	58	61
Combined July and August	26	54	68	73

Table 8. Bank and Downs recruitment indices (ICES, 1971) in catch-per-effort and standard measure

Year-class	Bank Hundreds/ fishing day	Downs Hundreds/ shot	Bank Standard measure	Downs Standard measure
1951	77	218	−0·31	0·59
2	235	109	1·13	−0·38
3	43	321	−0·62	1·51
4	63	243	−0·43	0·82
5	148	95	0·34	−0·51
6	373	180	2·39	0·25
7	20	80	−0·83	−0·64
8	126	366	0·14	1·92
9	7	30	−0·94	−1·09
1960	256[1]	180	1·32	0·25
1	74[1]	168	−0·33	0·14
2	87[1]	30	−0·22	−1·09
3	259[1]	100	1·35	−0·46
4	27[1]	68	−0·76	−0·75
5	38[1]	10	−0·66	−1.27
6	65[1]	330[2]	−0·42	1·59
7	70[1]	55[2]	−0·37	−0·87

[1] Raised by efficiency factor.
[2] Dutch catches-per-effort as equivalent to English units.

Table 9. Strength of Downs herring recruitment, relative to that of the Bank herring, in 1970 North Shields catches

Year-class	Method	Stock Bank	Stock Downs Drift data	Stock Downs Drift and trawl data	% Downs in drift and trawl data
1966	Fecundity index	1	2·33	2·13	68
	Forecast	1	2·51	2·70	
1967	Fecundity index	1	0·35	0·35	26
	Forecast	1	0·98	0·85	

per-unit-effort are given in Table 8. As these two series of estimates are derived from different fisheries and different fishing methods (Bank–Dutch trawl; Downs–English drifter), a comparison of the relative strengths of an individual year-class between the stocks is difficult. However, by converting each series to standard measure $(x - \bar{x})/\sigma$, where $\bar{x}$ is the mean index in each series and σ is the standard deviation within each series, comparability of the two series is achieved. The relative recruit strengths of the Bank and Downs year-classes may now be compared with those indicated in Table 7. In Table 9 the Downs recruitment has been expressed relative to the Bank recruitment. The Downs 1966 year-class was about twice the strength of the 1967 year-class, relative to the Bank stock and this is also evident in Table 8.

Fecundity indices were calculated from fish in the July 1971 North Shields catches. The data are derived from the length-selected samples used for the biological investigation. Fish with fecundity index values greater than 1·90 for the 3 year-old, 2·40 for the 4 year-old and 2·80 for all the older fish are taken as being Bank fish. Adjusting the numbers of Downs herring by the addition of the low maturation stage fish not included in the fecundity estimates, the relative abundances of Downs stock for the three most abundant year-classes can be calculated (Table 10). Comparing Table 10 with Table 9 it is seen that the strengths of the 1966 and 1967 Downs year-classes relative to each other are of the same order. As the Bank and Downs stocks suffer different patterns of fishing during the year, it is probably no more than fortuitous that the proportions of the 1966 and 1967 Downs year-classes have each declined by 11–12% between 1970 and 1971.

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Table 10. Strength of Downs herring recruitment, relative to that of the Bank herring, in 1971 North Shields catches

Year-class	Stock		% Downs
	Bank	Downs	
1966	1	1·305	57
1967	1	0·168	14
1968	1	0·034	3

Variation in the fecundity index with age

From Figures 9, 10 and 11 it is clear that the fecundity index increases with age within the stocks. The mean fecundity indices are summarized in Table 11. Figure 12 shows the plot of fecundity indices on length for the 3 and 4 year-old Downs herring in 1965. Within each age group there is no indication of a correlation of fecundity index with length. Figure 13 shows the plots for the 4 year-old Downs herring in 1962. Similarly, in Figure 14 the relationships between fecundity index and length for 3 and 4 year-old Bank herring are illustrated. Again it would appear that within an age group there is little correlation of the fecundity index with length and that the index is more a function of age than length.

Table 11. Mean fecundity indices of Downs and Bank stocks

Age in years	Downs		Bank	
	Mean	Variance	Mean	Variance
3	14·81	6·19	27·58	23·47
4	17·13	10·06	36·91	43·86
> 4	19·67	15·79	40·49	44·62

Because Baxter's data for the northern North Sea herring are not presented by age group, no direct comparison with this material can be made of fecundity indices derived from them. The frequency distribution of the fecundity index of Baxter's fish is given below:

Fecundity index

	21	22	23	24	25	26	27	28	29	30	31	32	33
No.	2	–	1	1	1	2	3	4	2	4	2	1	1

	34	35	36	37	38	39	40	41	42	43	44	45	46
No.	6	4	6	1	7	2	3	1	–	1	1	–	1

The range of values here is within that for Bank herring.

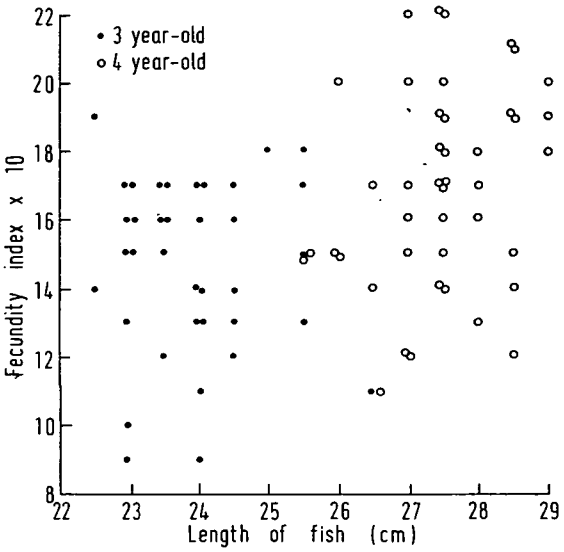

Figure 12. Relation between fecundity index and length of 3 and 4 year-old Downs herring in 1965.

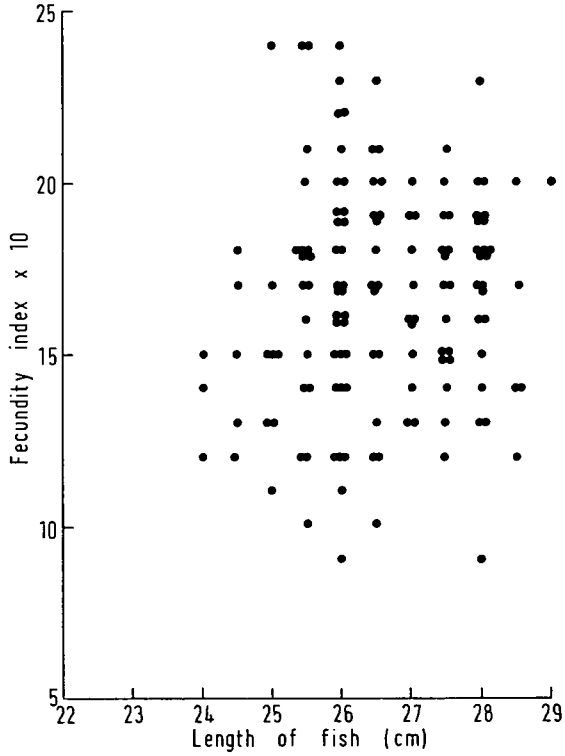

Figure 13. Relation between fecundity index and length for 4 year-old Downs fish in 1962.

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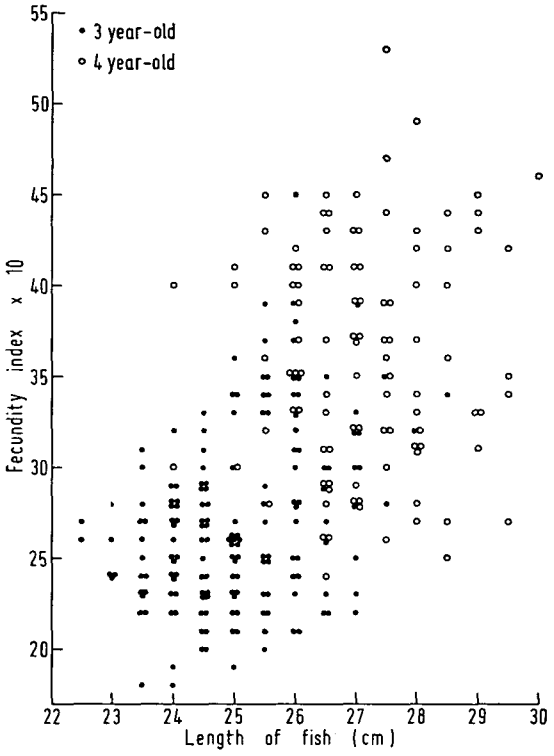

Figure 14. Relation between fecundity index and length for 3 and 4 year-old Bank herring in 1965.

Discussion

By using the fecundity index a clear separation can be made between Bank and Downs herring. Earlier, Polder and Zijlstra (1959) had gained the impression that "the Dogger herring forms a mixture ... between young Southern Bight stock and older Buchan stock. When indeed the Dogger stock forms a mixture with regards to fecundity, this peculiar point in the length/fecundity relation of the Dogger herring would be explained, when young Dogger herring were living with Southern Bight herring in the same environment, whereas the older and larger fish of the Dogger group stays with the Buchan spawners, provided the environment is responsible for the differences in fecundity."

"When genetic factors were the cause of the differences in fecundity, the aberrant length/fecundity relation of the Dogger herring would point to a gradual southwards migration during the lifetime of the North Sea herring. There are, I think, no other indications of such a migration. Besides, it is hard to see how genetic differences could be maintained in this case."

"The possibility remains, however, that the peculiar length/fecundity relation of the Dogger herring is inherent to this stock." (Polder and Zijlstra, 1959, p. 7.)

These authors were at pains to point out that in using stage V herring there was doubt as to the ground on which the fish were going to spawn. Referring especially to the young specimens which were collected in stage V on the Dogger Bank, they suggested that these might not spawn on the Dogger at all but might belong to the Southern Bight herring which migrate through the Dogger area in September to October. Iles (1964) showed that the Bank herring had a short maturation stage V, whereas that of the Downs herring was very much longer. He discussed Polder and Zijlstra's hypothesis and the extension of this by Baxter and Hall (1960), and rejected the suggestion of the mixed origin of the Bank stock. He concluded that the low fecundity fish were indeed Downs herring and that true Dogger spawners (Bank) were much more homogeneous for fecundity.

The fecundity index has been used to separate Bank and Downs herring in the mixed North Shields catches in 1970 and 1971. The relative year-class strengths thus derived have been shown to be consistent from year to year and to be in agreement with estimates derived by other methods. No difference could be shown either between the fecundity/weight regressions of Bank herring sampled on the spawning grounds at the Longstone and at Whitby, or between these regressions and the regression for the northern North Sea fish (Baxter, 1959). Similarly, no separation can be demonstrated between the Bank data of Polder and Zijlstra (1959) and that derived from Baxter's northern North Sea fish which he calls Buchan autumn spawners. Taken at face value, one might conclude that Bank and Buchan stocks were identical.

There is, however, much evidence which points to the existence of a stock or stocks separate from the central North Sea Bank spawning herring in the northern North Sea. An ICES North Sea Herring Working Group met during 1961, 1962 and 1963 to study, among other topics, the identity of the stocks of herring in the North Sea and English Channel. The Working Group concluded in its report (ICES, 1965) that the fish spawning in the Southern Bight and eastern English Channel could be regarded as a stock unit, the Downs stock. Consistent differences were observed in mean l_1 and mean length-for-age, and in otolith types, between the Downs herring and those of the spawning fish in the central and northern North Sea. Differences were also found in mean vertebral number between the different spawning groups (Buchan, Dogger and Downs).

Hempel and Blaxter (1967) comprehensively sur-

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veyed the egg weights of spawning herring from the north-east Atlantic region. They showed that the eggs of herring spawning in August on the Turbot Bank, in the Moray Firth and off Clythness, which they referred to as Buchan spawners, were lighter than those of either Bank or Downs spawners. The mean dry weights (in mg) of 100 eggs of 5 year-old herring sampled in 1961 and 1962 are calculated from Hempel and Blaxter as:

	Mean dry weight of 100 eggs	No. of fish
Buchan.....	15·397	31
Bank (Dogger).....	22·714	44
Downs.....	37·500	26

No level of significance can be given to these means, since Hempel and Blaxter calculated confidence limits on all ages of fish sampled. They reported that for the Buchan herring the 95% confidence limits were less than half the mean egg weight and that those of the other herring were between half and two-thirds of the mean egg weight. In the Buchan samples the 5 year-old fish comprised 42% of the total fish sampled, whereas in the Downs and Bank samples they amounted to only 13 and 24% respectively. It might be supposed that some of the increased variance on the mean for Bank and Downs fish is associated with the greater number of age groups sampled in these cases. It is possible that significant differences in mean egg weights between stocks could be shown with a more rigorous sampling procedure and larger numbers of specimens. Even so, the present data suggest that Downs and Buchan fish can be distinguished by egg size and both might be different from Bank herring. Bank herring sampled in 1969 at Lowestoft gave 95% confidence limits of ±27% of the mean egg weight. If this is also applicable to Hempel and Blaxter's data, then the differences between means of the stocks are real.

Table 12. Mean white fibre numbers for North Sea spawning herring

Stock	Year	Mean fibre number	Standard error
Bank.....	1969	63 842	± 702
	1970	64 976	± 1 102
Downs.....	1969	40 236	± 944
	1970	40 861	± 713
Shetland.....	1969	52 100	± 1 067
	1970	50 844	± 739
Buchan.....	1970	44 979	± 836

Recently, Greer Walker, Burd and Pull (1972) have shown that the total numbers of white skeletal muscle fibres in transverse sections taken at a point 35% of the total length from the tail differ significantly between Bank, Downs and Buchan stocks. The differences found are summarized in Table 12. The herring sampled as the Buchan stock were spawning fish caught off Fraserburgh in 1970. Samples of fish spawning off the Shetland Islands (east of Fetlar) were also analysed. These findings are in marked contrast to the fecundity observations, in which Bank herring are intermediate between Downs and Buchan. The greatest contrast lies between Bank and Downs in the case of fibre number, with the northern North Sea spawners in the intermediate position. Though this character appears to be genetically determined in mice (Luff and Goldspink, 1970), there is no evidence as yet of its genetic dependence in fish.

There is thus a considerable body of evidence that supports the view that Bank, Downs and Buchan spawning fish are separate stocks. The fecundity evidence is however contradictory. An explanation for this might be that the fish sampled in 1957 by Baxter were mainly Bank herring with relatively few true Buchan spawners. It has already been shown, for Bank herring, that, despite attempts to confine sampling to fish in maturation stages close to spawning, this cannot eliminate the inclusion of some Downs fish. This is due in part to the difference in length of maturation stage V as described by Iles (1964) and in part to the error in staging caused by the use of a subjective definition. The same doubt concerning the location of the spawning grounds of fish, unless sampled as maturation stage VI, must apply equally in the Scottish north-east coast fishery, during July and August, as on the Dogger Bank.

The regression of fecundity on length given by Baxter for the 1957 data has, in subsequent publications (Polder and Zijlstra, 1959; Baxter and Hall, 1960; ICES, 1965), been taken as being applicable to the Buchan spawning stock. However, Baxter (1963) changed his stock definition somewhat and referred to all the non-Downs fish as Bank, including the previously identified Buchan herring. The term Buchan has been used to describe those herring which spawn off the Scottish north-east coast in August and September (Wood, 1936). Spawning takes place over a wide area from Montrose Bank to east of Shetland. In the 1950s, in August and September, the main spawning fishery took place off the Aberdeenshire coast on the Turbot and Aberdeen Banks. Buchan stock originally referred to the population of fish spawning on these Banks. During the 1960s this area became less productive of both larvae and catch. Catches in August and September of spawning

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herring are now made in the coastal spawning area off Clythness and east of Shetland. The fish spawning in these areas have also been referred to as Buchan but may not be strictly comparable to the fish sampled in the 1950s.

During 1961 Baxter collected material in maturation stages II, III, IV and V from the summer fisheries in the North Sea. The samples came from grounds between the Shetland Islands and North Shields. His plots of fecundity on length for maturation stages II and III and maturation stages IV and V are shown as Figures 15 and 16. Baxter comments, "The regression lines used here refer basically to the 1957 data and although they may not represent the best fitting

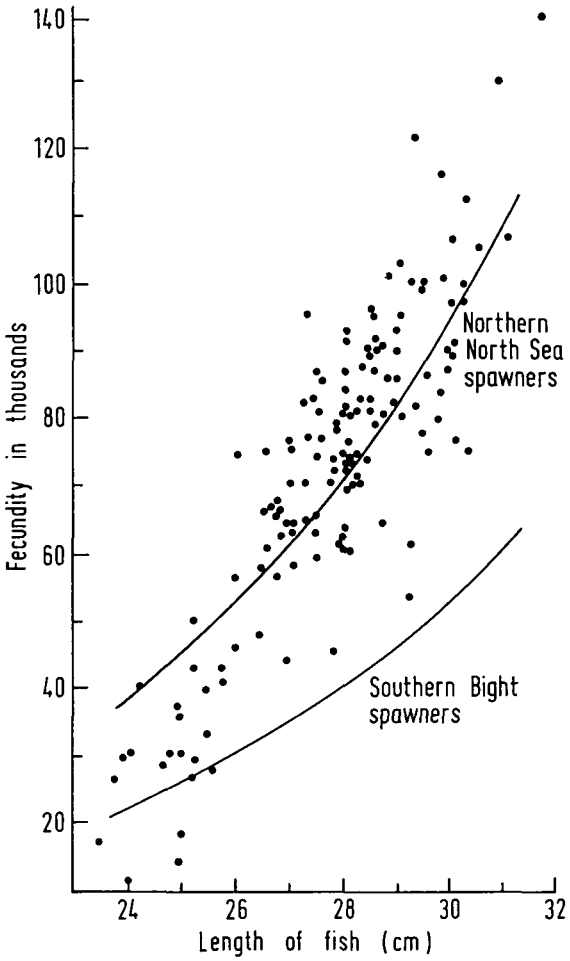

Figure 15. The fecundity/length relationship for fish sampled in maturation stages II and III from the northern North Sea in 1961. The regressions for northern North Sea ("Buchan") spawners and Southern Bight (Downs) spawners are superimposed. Redrawn from Baxter (1963).

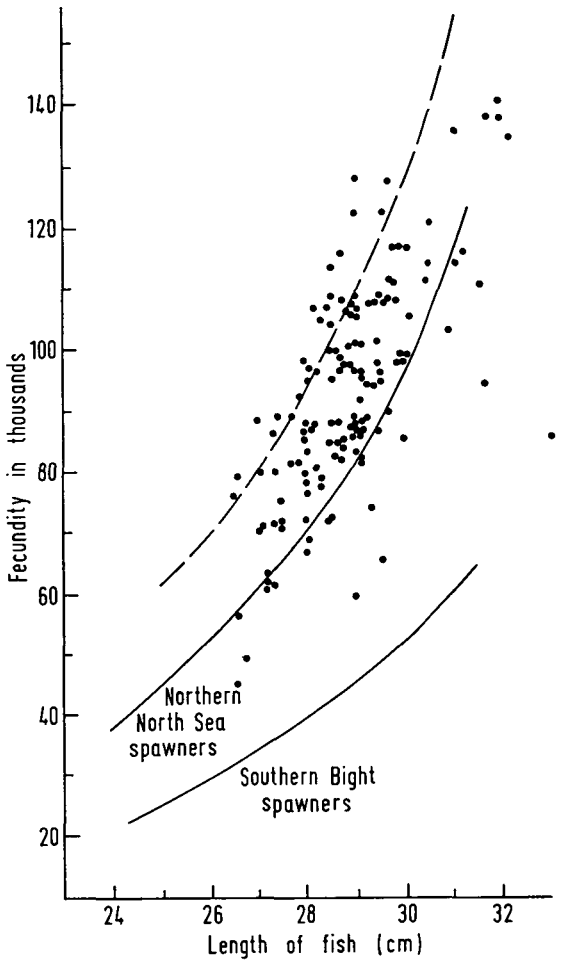

Figure 16. Fecundity/length relationship for fish sampled in maturation stages IV and V from the northern North Sea in 1961. The regression lines for northern North Sea spawners ("Buchan") and Southern Bight (Downs) spawners are superimposed. The broken line is the supposed regression for Buchan stock. Redrawn after Baxter (1963).

lines for the northern North Sea and Southern Bight spawners in 1961 they provide comparable lines of reference which may be used, with reasonable care, for distinguishing between members of the two spawning groups." (Baxter, 1963, p. 170.) If the regression for northern North Sea (Buchan) spawners was typical of this stock one might expect that the plots of fecundity on length would be distributed about the regression line. Certainly for the fish in maturation stages IV and V they diverge far from this expected distribution of points.

Supposing the ratio of gonad weight to body weight to be constant in North Sea herring, and

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as Buchan herring eggs are about one-third less in dry weight than those of the Bank herring, then the pure Buchan stock fecundity/length regression would be expected to have a mean fecundity about one-third greater than that of the Bank stock. The position of such a regression has been indicated in Figure 16, which comprises the fish in high maturation stages.

If, on the other hand, the fecundity/length relationship for the pure Buchan stock is identical with that of the Bank stock, and as the egg sizes are different, then the size of the gonad relative to fish length in the two stocks would be different. A distinction might therefore be expected in the gonadial index/egg weight relationship. Thus, in either situation one might expect to be able to demonstrate some relative difference in the reproductive capacity of Buchan and Bank fish. Unfortunately, in the absence of any spawning stock on the old Buchan spawning grounds of the Turbot and Aberdeen Banks, this hypothesis cannot at present be tested.

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