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ON THE EFFECT OF FISHING ON THE HERRING OF THE SOUTHERN NORTH SEA

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
POUR L'EXPLORATION DE LA MER
VOL. XXIV. No. 2. 1959

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I. Introduction

Since the winter of 1952–53, the East Anglian fishery has declined; the fishery in November has disappeared because of the reduction in numbers of the older fish (CUSHING and BURD, 1957). By 1956, a year in which recruitment was high, the catches of all countries on the Channel and Sandettié grounds had been reduced by one-third as compared with 1955 and by half to two-thirds as compared with 1954; the Belgian spent-herring fishery did not take place.

The present paper has several aims: firstly, to define the area where fishing effort bears effectively on the Downs stock; secondly, to investigate the possibility of a change in natural mortality since 1950–51; thirdly, to estimate the effect of the industrial fishery for immature fish on recruitment to the adult fisheries; and lastly the nature of the changes in yield in recent years is described.

In the adult fisheries from 1950–55, mortality rates increased more quickly than did the estimated effort. Hence the possibility of natural changes was raised. It will be shown that in East Anglia, an increase in fishing efficiency took place; as the estimated effort in the Southern Bight was based on East Anglian effort, some true increase in effort was masked by the increase in efficiency in the East Anglian fishery. Again it will be shown that the trends of catches in the Southern Bight since before the war roughly follow the trends in apparent fishing mortality. Thus, from the estimates given, it will be confirmed that the reduction of the fisheries in the southern North Sea is due to an increase in fishing activity.

Before the question of mortality and effort is dealt with, the mortality rates themselves should be presented in full detail, as follows in Section II.

II. The Variability of Mortality Rates

Samples of fish have been examined for age in the East Anglian fishery since 1924. Since 1935 the numbers of each age-group have been estimated as number/landing (or numbers per arrival) (see HODGSON, 1939, for the detailed procedure). Table 1 shows a series of mortality rates for ten years before the war and a further series for nine years after the war; the pre-war set was calculated from the percentage age distributions raised by the average catch per effort and the post-war set was estimated by HODGSON's later sampling procedure.

Mortality rates have not been estimated from the pair of ages 4/5 because in the early years it is likely that some recruitment took place even in the fifth year of life. Since 1946, mortality rates from the age pair 4/5 may be free from error due to recruitment; since 1950–51, they are almost certainly free from that error, because of the advance in maturity which took place in that period.

Table 1

Mortality rates in the East Anglian fishery, 1928–55

	5/6	6/7	7/8	8/9	Mean 5–9
1928/29	0	0·14	0·19	0·69	0·26
1929/30	0·65	0·43	0·37	0·98	0·61
1930/31	1·07	0·62	0·63	0·49	0·70
1931/32	0·81	0·41	0·74	0·98	0·74
1932/33	0·32	0·59	0·13	0·64	0·42
1933/34	0·24	−0·08	0·47	0·34	0·24
1934/35	0·61	0·69	0·94	0·36	0·65
1935/36	−0·46	0·21	0·51	0·21	0·12
1936/37	0·52	0·75	0·92	0·59	0·70
1937/38	0·71	0·95	−0.11	0·62	0·54
Mean	0·48	0·47	0·48	0·59	

	4/5	5/6	6/7	7/8	8/9	Mean (5–9)	Mean (5–7)
1946/47	0·33	0·63	0·18	0·90	0·89	0·65	0·40
1947/48	0·38	0·13	−0·39	0·46	0·11	0·08	−0·13
1948/49	0·28	0·45	0·59	1·64	1·48	1·04	0·52
1949/50	0·60	0·48	0·50	0·69	0·33	0·50	0·49
1950/51	0·31	0·53	0·57	0·48	0·62	0·55	0·55
1951/52	0·46	0·32	0·52	0·69	0·56	0·52	0·42
1952/53	0·83	1·06	1·12	1·04	0·80	1·01	1·09
1953/54	0·39	0·36	0·07	0·45	0·18	0·27	0·21
1954/55	1·38	1·09	1·13	1·22	1·44	1·22	1·11
Mean	–	0·56	0·48	0·84	0·71		

An analysis of variance was carried out, for the ages 5–9, as presented in Table 2.

Table 2

Analysis of variance of East Anglian mortality rates 1928–38 and 1946–55

1928–38	Degrees of freedom	Mean square
Between Years	9	0·20 (p = 0·05)
Between Ages	3	0·04
Residual.................	27	0·09
1946–55		
Between Years	8	0·56 (p = 0·01)
Between Ages	3	0·24 (p = 0·05)
Residual.................	24	0·06

From the two analyses and from Table 1, the following conclusions may be drawn: —

A. Mortality appears to increase slightly with age. There are high apparent mortality rates for the 7/8 and 8/9 age pairs in 1948–49, which are possibly not reliable because they are much higher than the rates for other ages in the same years. If the mortality rates of the ages 7–9 in the years 1948–49 are ignored, the regression of mortality rate on age is slight.
B. The mean square for "Between Years" is greater than that for "Between Ages" and also greater than the residual mean square. Hence the variance due to sampling the catches, which is that estimated by the residual mean square, is less than the variances due to true changes in mortality and to other sources of variance, for example, vulnerability. Indeed, during the period 1946–55, there are significant differences "Between Ages" as well as "Between Years". This may be due to the high values in 1948–49 mentioned above.

The residual variance was further analysed in different age-groups by estimating the variance of deviations from the annual mean of age pairs. The variances for each of the four age pairs in the two periods were as follows: —

	5/6	6/7	7/8	8/9
1928–38.....	0·066	0·051	0·101	0·057
1946–55.....	0·044	0·040	0·042	0·044

The variance for each age-group is small and there is no trend of variance with age (or inversely with the size of sample). It follows that all estimates of mortality are equally precise and that they should be given equal weight. It will be noticed that the variance is less during the period 1946–55 than in the period 1928–38; as this variance is mainly one of sampling the catches, the method used in 1946–55 (HODGSON, 1939) is more efficient than that used in the earlier period.

Since 1952, it is likely that full recruitment has taken place at three years of age (CUSHING and BURD, 1957) and so the mortality rates from three to four and from four to five may be used. Since 1954, the numbers of older fish have decreased to such an extent that it is possible that they are not being sampled properly. Before this date, mortality rates did not increase much with age; since 1954, mortality rates of older fish have increased with no increase of effort, independently of the mortality rates of younger fish.

This sampling problem may be partly overcome by accepting only those estimates of numbers of an age-group which comprise more than five per cent. of the estimate of numbers of all age-groups. Using this convention, it is found that: —

(1) in 1952 and 1953, estimates of both 8 and 9 year-olds should be excluded;
(2) in 1954, 55, and 56, all estimates from six to nine are excluded;
(3) in 1957, all estimates from five to nine are excluded.

Taking into account both the recruitment change and the poor sampling of the older age-groups since 1954, Table 3 gives the mortality rates since 1952. In the sections which follow, average mortality rates are used as follows: —

1928–48...........	5–9	1950–52...........	5–9
1948–50...........	5–7	1952–57...........	as in Table 3

Table 3

Mortality rates from 1952–57

	3/4	4/5	5/6	6/7	Mean
1952/53	0·57	0·83	1·06	1·12	0·89
1953/54	0·41	0·39	–	–	0·40
1954/55	1·12	1·39	1·09	–	1·20
1955/56	0·63	0·74	–	–	0·69
1956/57	1·09	–	–	–	1·09

In the period 1948–50, the very high mortality rates for the ages seven to nine have been excluded firstly, because they are much higher than those on the younger and more abundant age-groups and secondly, because although effort was increasing at this time, the increase was not great.

III. The Relation between Mortality and Effort

A measure of effort was used in CUSHING and BURD (1957) by which the East Anglian effort as number of arrivals was raised by the ratio of the Southern Bight catch to the East Anglian catch. This measure must now be slightly corrected because the number of arrivals (or landings) is not necessarily the number of shots, because it takes no account of the number of shots made when the catches are so small that it is not considered worth while steaming back to port. Fortunately, "overdays" or "days, iced" are recorded in the collector's books, and so a factor for this effect can be estimated. Using all the post-war material and two collector's books from the pre-war period, a factor of 1·24 was obtained for converting "landings" into "shots". There was no difference between the pre-war and post-war observations and there was no trend in the very recent years. By "East Anglian effort" is now meant the number of landings recorded in CUSHING and BURD (1957), on p. 22, raised by 1·24.

The Southern Bight fisheries which work on the Downs stock (CUSHING and BURD, 1957) include the East Anglian drift-net fishery with its Dutch and German partners, the Channel trawl fishery, and the Belgian spent-herring fishery; but the northern limit of the Downs stock is not well defined. From marking experiments (particularly the Scottish ones in the northern North Sea; WOOD, PARRISH, and MCPHERSON, 1955) and from echo-surveys across the approaches to the East Anglian fishery (TUNGATE, 1958), it is probable that the Downs herring feed in the region north of the Dogger. An attempt will be made to separate the components of the Bank and Downs stocks on the Dogger.

Since 1950, the English research vessels have made nearly 100 hauls in the Dogger area in September and October. The maturity stages of the fish caught may be grouped: —

A	B	C
I–I·III	III–IV·V	V–VII and II·III

Group A are immatures from the eastern nursery ground; group B are probably Downs fish on their way south to spawn in the Straits of Dover and group C are Dogger spawners. The proportion by numbers of group B to group

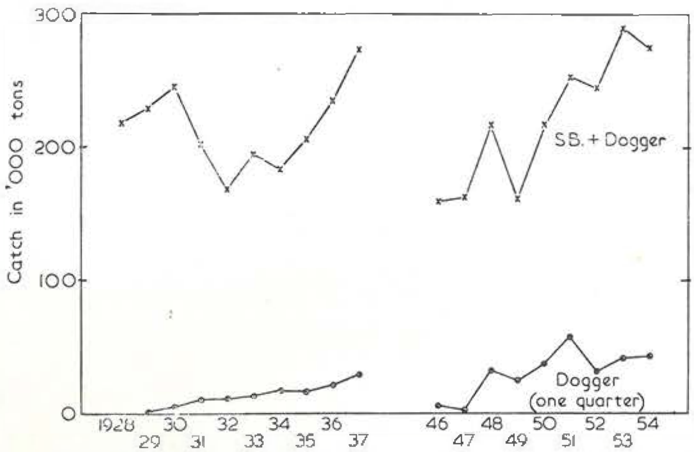

Figure 1. Catches from the Downs stock of herring in the Southern Bight and on the Dogger from 1928–55.

C was 1:3, hence it is likely that one quarter of the Dogger catches of adult fish was composed of Downs fish. Figure 1 shows the catches on the Dogger from 1928–54, reduced to one quarter, and the total catches from 1928–54 from the Southern Bight with one quarter of the Dogger catches added. High levels of catch occurred on the Dogger in 1936–37 and from 1947 onwards, and consequently the catches from the "Southern Bight and Dogger" group were higher in 1951–54 than during any four years previously. Yet this must be an underestimate because no catches north of the Dogger can yet be included.

The effort on the Downs stock in the southern North Sea may be calculated in two ways: — (1) The East Anglian effort, as the number of drifter shots, is raised by the ratio of the total catch from the Downs stock in the Southern Bight and on the Dogger, to the East Anglian catch (Col. (a) in Table 4). (2) The effort in each fishery as the number of "fishing days" is added to give an estimate of total effort; the standard "fishing day" used was that of a German trawler, which is roughly three times as effective as a drifter and the estimates of effort for each gear are corrected by factors to bring them to the standard (Col. (c) in Table 4). The two estimates are independent and the second makes use of more information, but could be biased if the gear factors are themselves biased. The quality of the first estimate depends upon the information from the fishery on which the ratio is based; for the East Anglian fishery, the evidence from echo-survey and catch distributions in area, shows that the stock is in the main adequately sampled in area.

Table 4 shows the effort as calculated from 1928–56 using the first method and from 1946–56, using the second method. It was impossible to apply the second method to the pre-war statistics because they have not been presented in a sufficiently detailed manner. The purpose of the comparison is to show that effort as calculated by the first method is reliable.

In the same table are given the catches from the Southern Bight and Dogger; it will be noticed that although the pre-war catches (1928–37) are lower than those from 1950–55, yet the effort in the latter period is on average less than

Table 4

The estimated effort exerted on the Downs stock, on the Dogger, and in the Southern Bight

	(a) By raising English effort, in drifter shots, by the ratio of the Downs catch to the English catch	(b) Column (a) corrected by the efficiency factor (efficient drifter shots)**	(c) The total number of fishing days (as made by German trawlers)	(d) Total catch in metric tons
1928	36,490	36,490		218,000
1929	39,460	39,460		229,000
1930	46,990	46,990		245,000
1931	50,530	50,530		202,000
1932	49,780	49,780		169,000
1933	48,230	48,230		195,000
1934	39,510	39,510		184,000
1935	38,940	38,940		206,000
1936	47,840	47,840		236,000
1937	49,940	49,940		274,000
1946	20,950	15,920	5,464	160,000
1947	21,770	23,080	9,630	163,000
1948	29,450	36,230	12,515	217,000
1949	22,080	31,140	9,191	162,000
1950	30,150	44,330	11,738	217,000
1951	38,210	56,180	12,726	253,000
1952	36,880	54,220	14,172	245,000
1953	47,090	69,220	15,191	290,000
1954	38,120	56,040	13,452	275,000
1955	35,289	45,880	12,925	145,000
1956	22,010*	28,610*	7,042*	82,038*

* From the *Statistical News Letters* of ICES, in which the French statistics are not included: hence the figures are underestimated by perhaps one-fifth.

** From *Bulletin Statistique*, *Jahresberichten der Deutschen Fischereien*, Rapp. Cons. Explor. Mer., **144**, and CUSHING and BURD (1957).

in the former. At the same time the average mortality rates in the East Anglian fishery taken from Table 1 were: —

1930–33	1936–38	1946–50	1951–55	1951–57
0·61	0·61	0·32	0·75	0·80

Thus, as catches increased as compared with pre-war, so did mortality, yet the effort was lower. Therefore it is possible that the efficiency of fishing increased during the period.

An attempt was made to trace a change in the relation between mortality and effort (Column (a) of Table 4) by using SILLIMAN's method (1943) for a series of short periods. Since 1928, the following periods may be distinguished: —

	Period	Z	g
I	1928–29	0·44	37,975
II	1930–37	0·51	46,470
III	1946–49	0·43	23,562
IV	1950–54	0·71	38,082

(Note: dates given cover the periods of effort.)

$$Z_A = g_A \times q + M \quad \ldots\ldots\ldots\ldots (1)$$

$$Z_B = g_B \times q + M \quad \ldots\ldots\ldots\ldots (2)$$

where M is the instantaneous coefficient of natural mortality, q is the coefficient of fishing efficiency, Z is the total instantaneous mortality coefficient, (averaged from Table 1) and g is effort averaged for the Southern Bight and the Dogger.

$$q = \frac{Z_B - Z_A}{g_B - g_A} \quad \text{(3)}$$

Substituting q in (1), from three comparisons, the estimates of M and q are: —

		M	q
II/I	1928–39	0·17	$0{\cdot}81 \times 10^{-5}$
II/III	1930–49	0·13	$0{\cdot}85 \times 10^{-5}$
III/IV	1946–54	−0·03	$1{\cdot}93 \times 10^{-5}$

Using the period 1928–49, the estimates of M and q are consistent; when the later period is employed, meaningless results are obtained. This could be due to an increase in q, the coefficient of fishing efficiency, or to an increase in M, the instantaneous coefficient of natural mortality, or both; the possibilities cannot be distinguished.

An independent method of estimating fishing efficiency was derived in the following way. Since 1935, the East Anglian statistics have been plotted in small squares (each is $\frac{1}{9}$ of a statistical square) by three-day periods; for each three-day period, it is possible to obtain the sum of catches and the sum of catches/effort. From these figures the effective overall fishing intensity may be found for each three-day period or for the season. The effective overall fishing intensity, f, is defined: —

$$f = \sum C_{ij} \Big/ \sum (C/g)_{ij}$$

where C is the catch in square i in period j, where C/g is catch/effort in square i in period j (BEVERTON and HOLT, 1957).

If the value of f for any one season is divided by the number of landings or the number of shots, a measure of the relative efficiency of fishing is obtained. Since 1935 it can be shown that this estimate of efficiency has increased by about 20%. The estimate of efficiency used in this way is defined by: —

$$f \times \frac{\text{n} \cdot \text{squares}}{\text{n} \cdot \text{shots}}$$

The number of squares comes into the estimate because fishing intensity is defined as fishing effort per unit area, or statistical square.

There is another effect to be considered: the fleet has decreased in numbers since 1935 and so the number of squares sampled has become reduced. In other words it is possible that in 1935 the stock was more extensively sampled than in 1955. To correct for this, the following method (derived by my colleague, J. A. GULLAND) was used: — 1936 was used as a standard year and comparing the fleet area in that year with any other year, there is a common area.

Let f in the common area be a;
let f in the rest of the fished area in 1936 be b;
let the stock (as the sum of catches/unit effort) in the common area be A;
let the stock in the rest of the fished area in 1936 be B.

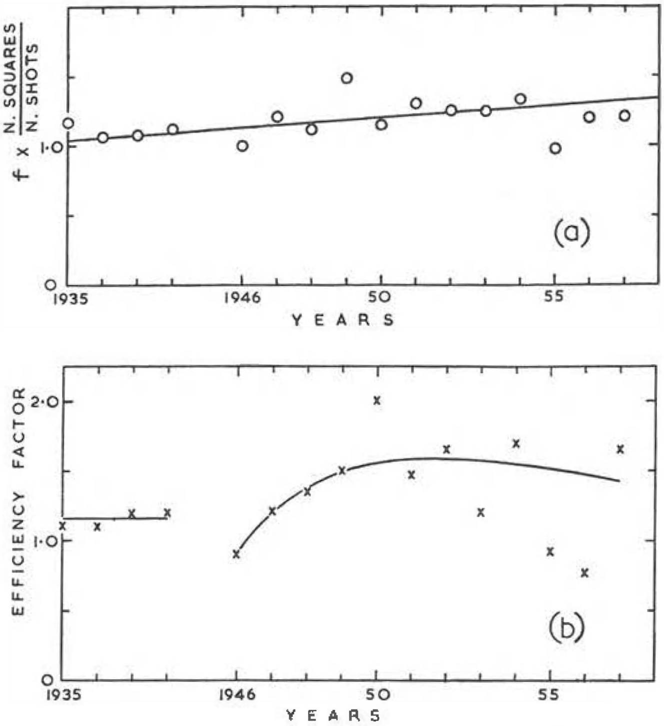

Figure 2. The increase of efficiency in the East Anglian drift-net fishery.
(a) The estimated fishing intensity dividing by the number of shots per square. – The crude efficiency factor from 1935–57.
(b) The efficiency factor corrected for the change in fleet area from 1935–57. From 1954–57 the line to the points is drawn a little too high.

Then for 1936, f is $\dfrac{(A \times a) + (B \times b)}{A + B}$

In any other year we have A', B', a' and b'; it is assumed that $\dfrac{B'}{A'} = \dfrac{B}{A}$ and so $\dfrac{(A' \times a') + (B' \times b')}{A' + B'}$ is calculable.

Such estimates based on the standard year 1936 and divided by the number of shots are corrected estimates of fishing efficiency.

Figure 2 shows the increase of efficiency from 1935–57, firstly (2a) as $f \times$ n. squares/n. shots and secondly (2b), the estimate of intensity corrected for the change in fleet area and then divided by the number of shots. It will be seen that there has been an increase in the efficiency of the drift-net as used in the East Anglian fishery since before the war. It is impossible to find the cause of this change, but it is likely to be due to one of three factors, echo-sounding, radio, or the greater sea room available to a smaller fleet; all three possible factors may be included in the more general term, searching. As the drift-net has not changed structurally during the period, an increase in efficiency must be due to improved searching, in one way or another. The line drawn to the points in Figure 2 (b) is too high in 1954–57; this means that the efficiency factor for 1954 is slightly overestimated. Consequently effort is overestimated by about

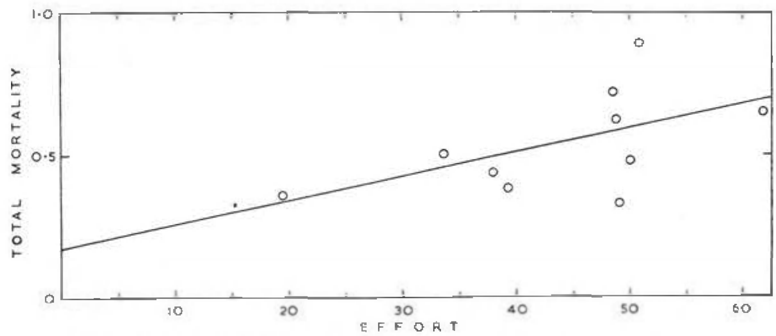

Figure 3. The regression of total mortality on effort from 1928–55.

5% in that year. This error makes no noticeable difference to the regression of Z on g from 1928–55 shown in Figure 3.

The test given by SILLIMAN's method above may now be completed with the efficiency factor taken into account: —

		M	q
II/I.............	1928–39	0·17	$0{\cdot}81 \times 10^{-5}$
II/III	1930–49	0·13	$0{\cdot}85 \times 10^{-5}$
III/IV...........	1946–54	0·18	$0{\cdot}95 \times 10^{-5}$

The estimates of M, the natural mortality, are reasonably consistent and the estimates of q, the coefficient of efficiency of fishing, show an increase over the period, of much the same order as that calculated independently. The reason for using SILLIMAN's method in short periods was to detect any change in M or q between 1928 and 1954, to find whether the regression of mortality on effort was curvilinear. The test lies in the consistency of estimates and not in the chance of their being significantly different. Thus it was the values of M and q in 1946–54 being so different from the estimates for 1928–49 that led to the discovery of a change in efficiency.

Figure 3 shows the regression of total mortality Z on effort, corrected for efficiency. The regression is not significant (the probability that the slope is different from zero is 0·1); the estimate of natural mortality is approximately 0·2. The regression includes all points from 1928–55 and they have been grouped in pairs in order to try to overcome changes in vulnerability. Vulnerability has been defined as the coefficient relating catch per unit of effort to abundance; for a given year-class, under conditions of constant mortality, an excessive catch per unit of effort in one year is countered by a reduced catch per unit of effort in the next year. In the first year, when the stock was excessively vulnerable to the gear, more fish were caught and the catch per unit of effort was high; consequently, abundance became reduced and in the next year, the catch per unit of effort was reduced. Thus, changes in vulnerability can be dealt with by pairing observations from successive years.

The period of high effort is from 1951–54: 54,220 to 69,220 drifter shots, which corresponds to a total mortality of 0·63–0·77. With a natural mortality of 0·17, we have a fishing mortality from 1951–54 of 0·46–0·60. The estimates made in this way are not of high quality because of the variability of the mortality rates. The estimate of effort is necessarily a minimal one because that exerted on the Downs stock in the feeding fisheries north of the Dogger cannot yet be

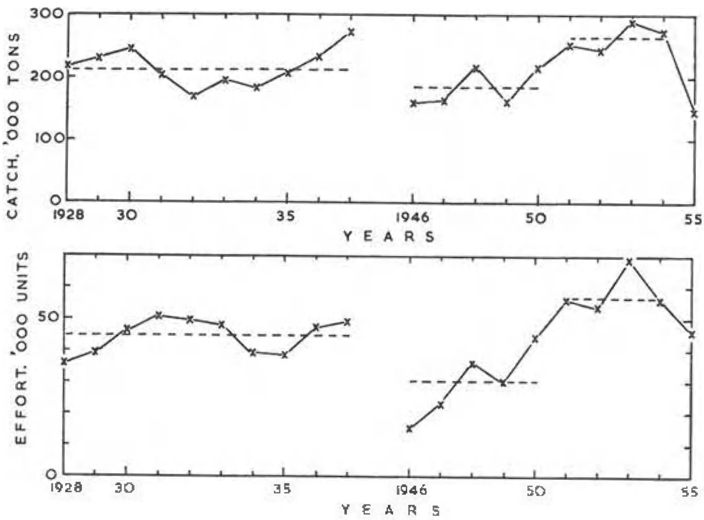

Figure 4. Catches of and effort on the Downs stock of herring in the Southern Bight and on the Dogger from 1928–55.

separated from that exerted on the Bank stock. Nevertheless, it is likely that the fishing mortality for the period 1951–54 was somewhat more than three times the natural mortality, averaged from 1928–55.

It might be possible that the older fish emigrated to the north after 1951; such an effect should be shown as a change in M or q in the use of SILLIMAN's method for short periods and should be accompanied by a drop in catches, if recruitment were constant. Recruitment was constant, catches increased and no change in M or q was detected. Hence, it is unlikely that emigration of the older fish took place.

The same point may be made in a simpler manner by comparing the catches with the effort since 1928 (Fig. 4). Three periods may be separated, 1928–37, 1946–50, and 1951–54 (the year 1938 is not used because satisfactory catch figures for that year cannot be elicited from all countries). It is clear that during the period 1951–54 both catch and effort are higher than at any other time. Hence, it is not surprising that mortality should have increased in 1951–54 and that the numbers of older fish should have been reduced.

If the period 1928–55 is divided into three sub-periods, 1928–38, 1946–50, and 1951–55, effort, catch, and fishing mortality may be compared: —

	1928–38	1946–50	1951–55
M	0·17	0·17	0·17
F	0·33	0·27	0·54
effort (efficient drifter shots)*	44,170	30,140	57,000
Catch (metric tons)	216,000	184,000	242,000

* From Col. (b) in Table 4.

Thus, the trends in catches are the same as those in F, the fishing mortality coefficient, and in effort; if the recent mortalities were due to emigration, the catches would have been reduced.

In 1955, 1956, and 1957, the numbers of older fish have become further reduced and the mortalities have remained high. The cause of the high mortalities is partly due to the poor sampling of older fish referred to above, but in 1955 the catch was nearly halved, yet the mortality on the three to four year and four to five year pairs (1955–56) remained high (0·69). It will be noticed from Figure 4 that the effort in 1955 remained as high as pre-war and so taking the regression in Figure 2 a total mortality of 0·55 would have been expected in any case.

By 1956 effort had dropped to about 20,000–25,000 drifter shots, using the method of raising the East Anglian effort by the ratio of the Southern Bight catch to the East Anglian catch; estimated as "catching days", it had fallen to about 7,000. The mortality rate at East Anglia of the three to four year pair was greater than that expected by the effort exerted. This is a single observation which may be influenced by a vulnerability effect; in the week of the full moon in November 1957, there was a strong gale which kept the fleet in port for four days and which may have dispersed the fish, giving an underestimate of four year-olds (as well as three year-olds).

With the use of rather rough methods and in the face of exceedingly variable material, we tend to conclude that the recent increases in mortality in the southern North Sea are associated with increases in fishing effort. It is thought that the peak of effort was reached in 1953 and that the true fishing effort has declined slowly till 1955 and then sharply in 1956; until 1956, it is likely that fishing mortality remained as high as 0·50. By 1957, it is likely that fishing mortality dropped below this level.

IV. The Effect of the Industrial Fisheries for Immature Herring on Recruitment to the East Anglian Fishery

In August 1957 ICES started a tagging experiment in the industrial fishery for immature herring, east of the Dogger Bank. The primary purpose of this experiment was to determine the fishing mortality by the recovery of internal tags from the fish meal factories. A secondary purpose was to give some idea of the directions of migration away from the nursery grounds into the adult fisheries by the recovery of externally tagged fish over a long period.

The processing of the data may be a little complicated and it was thought worthwhile attacking the problem from another direction, partly to give the order of result expected, as a check, and partly to make some sort of framework into which the results of this international experiment may be fitted. The method used will also give an opportunity of making a check on HODGSON's (1956) hypothesis.

The industrial fishery on the eastern nursery ground in the North Sea has yielded over 100,000 tons of immature herring in each year since 1954; as these small fish run from 1500–3500 to the cran, the number of fish caught in each year since 1954 ranges from 1,500,000,000 to 2,000,000,000. By comparison, only 100,000,000 fish were caught in the East Anglian fishery in 1955 and 1956.

There are two parts to the industrial fishery, the spring fishery practised by the Danes only and the autumn fishery exploited by the Danes and Germans. There are two main age-groups in the fishery, the I group and the II group; combining the spring and autumn fisheries, 80% of the catch by weight is composed of I-group fish and 20% of II-group fish. The autumn fishery is 5–10 times larger than the spring fishery and then the I- and II-group fish are very nearly 2 and 3 years old respectively. 0-group fish are also caught in the autumn fishery, but only in small quantities (BERTELSEN and POPP MADSEN, 1953, 1954, and 1956).

Any calculations that are made are based on the numbers of fish caught in each year-class. For this purpose, it is assumed that there are 5·5 crans/ton* and that there are 3–3500 I-group fish/cran and 1–1500 II-group fish/cran. Table 5 shows how such estimates of numbers are derived, based on the information given in the preceding paragraphs.

Table 5

The numbers of fish caught in the industrial fishery on the eastern nursery ground

	A Industrial fishery (tons)	B I group (tons)	C II group (tons)	D B × 3000 × 5·5	E C × 1000 × 5·5
1949	2,000	1,600	400	$26·4 \times 10^6$	
1950	5,000	4,000	1,000	$66·0 \times 10^6$	$5·5 \times 10^6$
1951	38,000	30,400	7,600	$501·6 \times 10^6$	$41·8 \times 10^6$
1952	49,000	39,200	9,800	$646·8 \times 10^6$	$53·9 \times 10^6$
1953	75,000	60,000	15,000	$990·0 \times 10^6$	$82·5 \times 10^6$
1954	103,000	82,400	20,600	$1359·6 \times 10^6$	$113·5 \times 10^6$

By year-classes the numbers are: –

	(a)	(b)
1948	$31·9 \times 10^6$	$39·1 \times 10^6$
1949	$107·8 \times 10^6$	$139·7 \times 10^6$
1950	$555·5 \times 10^6$	$664·1 \times 10^6$
1951	$729·3 \times 10^6$	$878·4 \times 10^6$
1952	$1103·3 \times 10^6$	$1325·2 \times 10^6$

(a) is calculated, using factors of 3000 I-group fish/cran and 1000 II-group fish/cran.
(b) is calculated, using factors of 3500 I-group fish/cran and 1500 II-group fish/cran.

A recruitment change took place in the East Anglian fishery in 1950–51, which may be considered in two ways. Firstly, HODGSON (1956) has assumed that the four year-old recruits have never reached East Anglia because they have all been caught in the industrial fishery. Secondly, CUSHING (in CUSHING and BURD, 1957) interpreted the recruitment change as an advancement in maturity, so all recruits came into the fishery at three years of age and consequently, there were no four year-old recruits after 1950–51.

The average proportion of numbers of three year-olds to numbers of four year-olds in the subsequent year, from 1946–50, is 1:1·8. So if the number/landing of three year-olds in any year-class is multiplied by 1·8 the number/landing of four year-olds is estimated for the subsequent year. Using HODGSON's hypothesis, the difference between this quantity and the observed number of four year-olds is the estimated "loss" of four year-olds, expressed as numbers/landing. In order to estimate the total loss to the fisheries in the Southern Bight, which are dependent on the Downs stock (CUSHING and BURD, 1957),

* English long ton which approximately equals the metric ton of one thousand kilogrammes.

the calculated loss must be raised by the number of landings in East Anglia in each year and by the Southern Bight factor, which is the ratio of the Southern Bight catch to the East Anglian catch.

If the industrial catch in numbers, as calculated in Table 5, is compared with the estimated loss of four year-olds in numbers, it is found that in 1951, 1952, 1953, and 1954, the estimated loss was greater than the industrial catch: —

Year-class	Years of industrial fishery	Industrial catch in numbers, by year-classes	Estimated loss of four-year-olds in Southern Bight catch	Loss/ Catch
1948	1949/50	$31{\cdot}9 \times 10^6$	$168{\cdot}0 \times 10^6$ (1951)	5·2
1949	1950/51	$107{\cdot}8 \times 10^6$	$197{\cdot}0 \times 10^6$ (1952)	1·8
1950	1951/52	$555{\cdot}5 \times 10^6$	$777{\cdot}0 \times 10^6$ (1953)	1·4
1951	1952/53	$729{\cdot}3 \times 10^6$	$811{\cdot}0 \times 10^6$ (1954)	1·1
1952	1953/54	$1103{\cdot}3 \times 10^6$	$930{\cdot}0 \times 10^6$ (1955)	0·8

The year in brackets is the year of arrival as four year-old fish in the Southern Bight.

As the estimated losses in 1951–54 were greater than the catches in 1949–53 it is likely that the apparent loss must be due to some other cause and the first interpretation referred to above must be rejected.

We now turn to the second interpretation, that an advance in maturity in 1950–51 has since then brought all the recruits into the fishery at three years of age. Since 1952, the numbers of three year-old fish reaching East Anglia have increased greatly; the actual figures are, in numbers/landing: —

1952	19,200
1953	27,700
1954	25,200
1955	12,100
1956	26,100

These figures are two to four times greater than 5,900, which was the average number of three-year-olds from 1924–50 (Table 6 in CUSHING and BURD, 1957). If the change in recruitment is accepted as being due to an advancement in maturity in 1951–52, then the high figures since 1952 are merely due to the additional recruits that used to come in as four year-olds, but now appear as three year-olds.

There is another way of calculating the probable loss of recruits to the East Anglian fishery. By this method (which follows that of GULLAND, 1955, on immature whiting) it is assumed that the change in recruitment in 1950–51 was due to an advance in maturity and so the numbers/landing of three year-old fish caught in any one year represents an index of all the recruits in that year-class.

Let N_3 and N_4 be the numbers of three and four year-old fish in the stock, respectively,

then $$N_4 = N_3 e^{-(Z)(t_1 - t_0)},$$

where (Z) is the mortality rate from t_0 to t_1, which in this case is one year. Between t_0 and t_1, the numbers of fish dying are

$$N_3 - N_4 = N_3 - N_3 e^{-(Z)(t_1 - t_0)} = N_3 \left(1 - e^{-(Z)(t_1 - t_0)}\right)$$

The fraction killed by fishing is

$$\frac{F}{Z} \times N_3 \, (1 - e^{-(Z)(t_1 - t_0)}) = C,$$

the catch of recruits (three year-old fish), assuming full recruitment at three years old.

Therefore $$N_3 = \frac{C \times Z}{F(1 - e^{-(Z)(t_1 - t_0)})}$$

the total number of fish at three years old.

If the catch of the industrial fishery has reduced N_3 the effect should be found in the following way.

If Q is the industrial catch in numbers in any year-class then

$$Q \times \varrho \times e^{-M(t_\alpha - t_\beta)} = L$$

where L is the loss to the Downs stock in numbers, ϱ is the proportion of the industrial fishery which supplied recruits to the Downs stock (necessarily less than unity), where M is the natural mortality rate of herring on the eastern nursery ground, and $t_\alpha - t_\beta$ is the time between entry to the industrial fishery, t_α, and recruitment to the East Anglian fishery, t_β.

So, without the industrial fishery, the number of fish alive at three years old would have been $N_3 + L$. Then the expression $\frac{L}{L + N_3} \times 100$ is the percentage loss to any one year-class in the Downs stock.

The calculation takes the following form for the period 1950–55 (see Figure 5).

	Z	M	Catch/landing of recruits in thousands $\times 10^3$	$N_3 \times 10^9$	$\frac{L}{\varrho} = Qe^{-M(t_\alpha - t_\beta)}$
1950	0·5	0·25	19·6	2·01	24·9
1951	0·5	0·25	13·9	1·72	84·1
1952	0·6	0·25	19·2	1·82	433·3
1953	0·6	0·25	27·7	3·36	568·9
1954	0·7	0·25	25·2	2·01	860·6
1955	0·7	0·25	10·9	1·17	1190·6

$$\frac{L}{L + N_3} \times 100$$

	$\varrho = 1$ %	$\varrho = 0·5$ %	$\varrho = 0·25$ %	$\varrho = 0·10$ %
1950	1·2	0·6	0·3	0·1
1951	4·7	2·4	1·2	0·5
1952	19·2	10·6	5·6	2·3
1953	14·5	7·8	4·1	1·7
1954	30·3	17·6	9·7	4·1
1955	50·4	33·7	20·3	9·2

The values of the percentage loss depend very much upon the value of ϱ chosen, but by 1955 all are higher than the previous estimate of 6% (CUSHING and BURD, 1957). Even if ϱ were as low as 0·10, the percentage loss in 1955

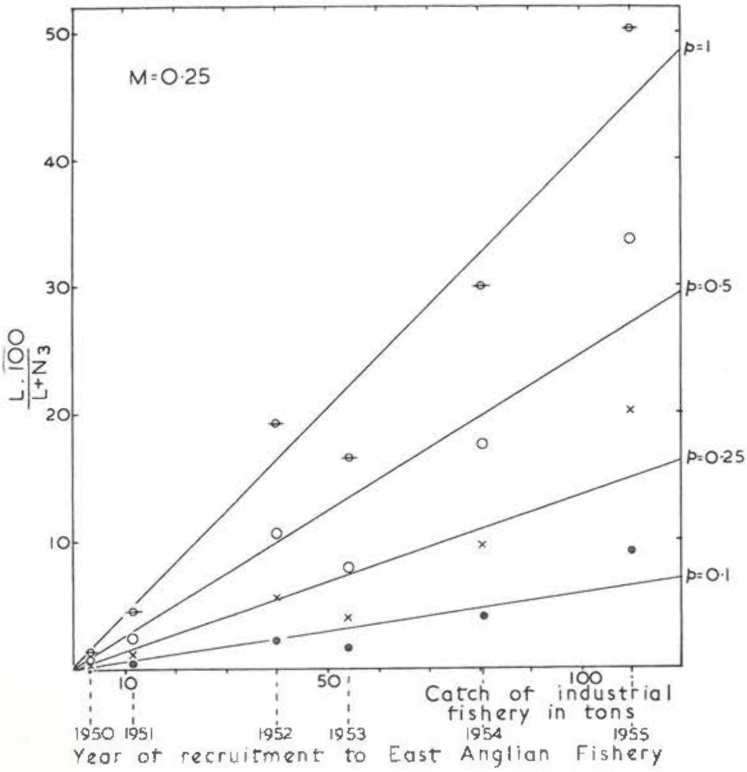

Figure 5. The estimated loss, as a percentage, to the Downs stock, due to the industrial fishery for immatures since 1950. L is the loss in numbers, N_3 is the number of recruits to the Downs stock, ϱ is the proportion of a year-class in the industrial fishery which reaches the Downs stock.

would have been nearly 10%; if ϱ were as high as 0·5, which is not improbable, the percentage loss in 1955 would have been 34%. These calculations are shown graphically in Figure 5.

The calculations given above were based on a value of $M = 0{\cdot}25$; it is possible that the value for the immature fish is higher. The percentage losses were recalculated at different levels of M, as shown in Figure 6. If M is taken to be 0·3–0·5 and ϱ as 0·25–0·5, the percentage loss in 1955 lay between 15–33%, say 25%.

Since 1952, the total loss in numbers is calculable on the following assumptions: —

	Z	F	$N_3 \times 10^9$	$\frac{L}{L+N_3} \times 100$ %	$N_3^1 \times 10^9$
1952..........	0·6	0·35	1·82	5	1·91
1953..........	0·6	0·35	3·36	10	3·70
1954..........	0·7	0·45	2·01	20	2·41
1955..........	0·7	0·45	1·17	20	1·40

where N_3^1 is the number of recruits (as stock) increased by the percentage loss

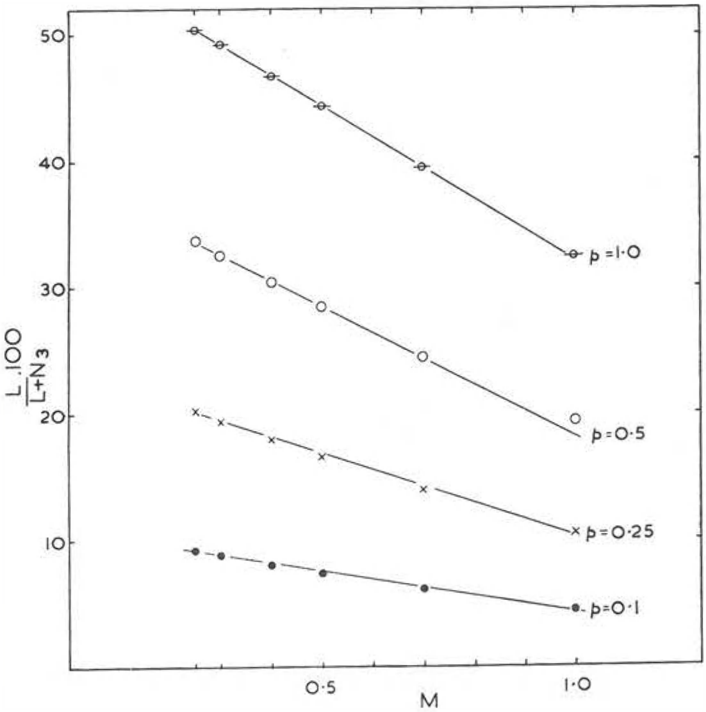

Figure 6. The relation between loss to the Downs stock and natural mortality in the industrial fishery.

estimated. So the total loss for the period 1952–55 in the Southern Bight is given by the difference between $N_3e^{-(Z)}$ and $N_3{}^1e^{-(Z)}$, etc. The loss as numbers of fish (as catch of different ages) is given in the following table: —

	3	4	5	6	
1952	0·03	–	–	–	0·03 $\times 10^9$
1953	0·09	0·01	–	–	0·10 $\times 10^9$
1954	0·13	0·05	0·01	–	0·19 $\times 10^9$
1955	0·08	0·07	0·03	0·006	0·186 $\times 10^9$

The estimated loss to the Southern Bight fisheries from 1954 onwards was $0{\cdot}2 \times 10^9$ fish, which is 4×10^7 fish in the East Anglian fishery or 20% of the East Anglian catch in 1954. In 1952, the year which HODGSON regarded as crucial, the estimated loss was only 2–3%.

V. The Yield of Herring in the Southern North Sea

The yield in weight is calculated from the following equation (after BEVERTON and HOLT, 1957): —

$$\frac{Y_W}{R} = F \times W_\infty \times e^{-M^1(t_\varrho' - t_\varrho)} \sum_{n=0}^{3} \frac{\Omega_n e^{-nk(t_\varrho' - t_0)}}{Z + nk} (1 - e^{-(Z+nk)(t_\lambda - t_\varrho')})$$

where M^1 is the instantaneous coefficient of natural mortality in the immature phase,

M is the instantaneous coefficient of natural mortality in the adult phase,

W_∞ is the asymptotic weight of the herring,

t_0 is the age of zero weight calculated from the growth equation (it may be positive or negative),

k is the "coefficient of katabolism" or the rate at which the annual increments decrease,

t_ϱ is the age of recruitment,

t_ϱ' is the age at which the fish enter the exploited phase,

t_λ is the age at the end of the lifespan,

$\Omega_0 = +1, \Omega_1 = -3, \Omega_2 = +3, \Omega_3 = -1.$

Before the yield curves are shown, the questions of selection and growth must be considered in a little more detail. All parameters used are based on samples of drift-net caught fish and it is well known that selection by a drift-net can be sharp (HODGSON, 1933). However, the effects of selection have been ignored for the moment for the following reasons: —

A. The variation in mesh size within the East Anglian fleet is probably great enough to allow the range of sizes of the abundant age-groups to be adequately sampled. RICHARDSON (1956) has shown that there are probably three points of selection at, for example, 23, 25, and 29 cm for 36 rows/yard (his Fig. 3). This range clearly covers a number of age-groups.

B. Although the gears used in the fisheries sampled from Lowestoft, Boulogne, and Ostend are as diverse as drift-nets, bottom trawls, and pelagic trawls, there is little difference between the age distribution as sampled in the three fisheries (CUSHING and BURD, 1957). Thus, it is likely that the samples of drift-net caught fish give adequate values of the vital parameters for present purposes. Also the effect of selection on the growth pattern has been minimized by back calculating the lengths from scale measurements by proportioning. The lengths-for-age obtained in this way are sometimes well fitted by the Bertalanffy equation, for example, those of the 1947–48 brood. Those of earlier broods do not fit the equation very well; there may be two reasons. The first is that there is a wide range in spawning time, which leads to variation in L_∞, the asymptotic length in the growth equation and in W_∞ and t_0 in the yield equation. Secondly, there appears to be a real difference in k in the immature and adult phases in some broods. In this paper, the best fit to the Bertalanffy equation by least squares has been used and the parameters so obtained have been used in the yield equation.

It has been shown that since 1924, the herring in the North Sea has increased in size (ANCELLIN, 1953; ANDERSSON, 1954; CUSHING and BURD, 1957); consequently, the growth parameters have also changed. In order to illustrate the changes in yield since 1928, three broods have been selected; the 1927–28 brood as a sample of the pre-war stock, the 1944–45 brood as a sample of the stock immediately after the war, and the 1947–48 brood as a sample of the stock after the recruitment change of 1950–51. The parameters are as follows: —

	1927–28	1944–45	1947–48
W_∞	177·5 g	201·5 g	226·3 g
t_0	−1·008	−1·43	−0·60
k	0·368	0·355	0·387
M^1	0·25	0·25	0·25
M	0·20	0·20	0·20
t_λ	10·0	10·0	10·0
t_ρ	1·0	1·0	1·0
t_ρ'	3·5	3·5	3·0

The yield curves are illustrated in Figure 7. They are characterized by a very flat plateau, which is far beyond the range of present fishing activity. There are marked differences between the yields of different broods; in fact, that for the 1947–48 brood has a maximum at $F = 1{\cdot}2$, which is absent from the other two. The present state is shown by the curve for the 1947–48 brood, for which the Bertalanffy equation provides a good fit to the data.

The catch/unit of fishing mortality as estimated from the yield curve for the 1947–48 brood is shown in Figure 8. Comparing this with Figure 7, it will be seen that if F were reduced from 0·6 to 0·45, the yield per recruit would be reduced from 60 to 57, a reduction of 5%; from Figure 8, a reduction from $F = 0{\cdot}6$ to $F = 0{\cdot}45$ would bring about an increase in catch/unit of fishing mortality (which is proportional to catch/unit effort) of 26%.

In the herring fishery the catch per effort is very important. Most herring fisheries in the North Sea are seasonal and mixed. The East Anglian fishery in October depends largely upon Scots fishermen who spend much of the year before October seining for white fish; French and German trawlers in November and December disperse if the herring disappear, and when they return the trawlers will gather in the Sandettié Channel from as far as the Norwegian coast. The measure on which the fishermen act is the catch/effort. If this becomes reduced too far, fishing stops. Thus, in 1955 with a poor recruit class in East Anglia, the total catch there was about 20,000 tons; in 1956, with a good recruit class, the total catch was again 20,000 tons, probably because fifty fewer boats came from Scotland, the catch/effort expected by them being too low. The Belgian spent-herring fishery did not take place in 1956–57, for the same sort of reason. The Sandettié trawl fishery in strength was reduced in 1956 to a period of ten days for the same type of reason, although some sporadic fishing continued for a longer period.

The fact that the fleets tend to stop fishing for herring rather readily means that there is a limiting catch/effort. The short history of the fishery in the autumn of 1956 shows that the value of the limiting catch/effort is roughly the same for a number of European countries, despite differences in economic and social structure. From the study of mortality rates, it is possible that in 1954–55, $F = 0{\cdot}55 - 0{\cdot}60$; let us suppose that in 1955–56, F reached 0·60, to which corresponded limiting catches/effort in the fleets of many European countries.

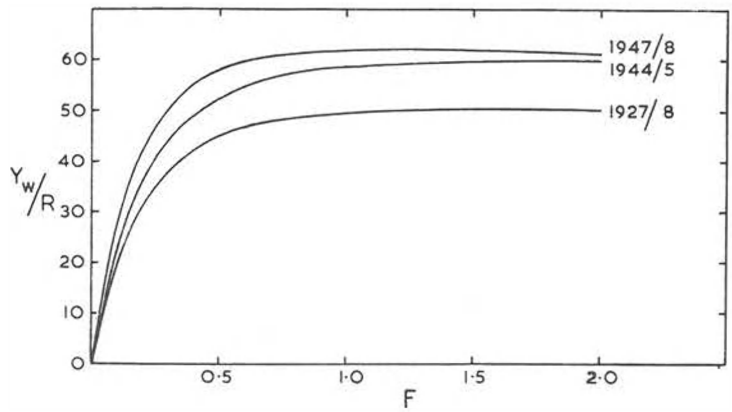

Figure 7. The yield of herring; Y/R is yield per recruit and F is fishing mortality. The yield for three broods is shown, as shown by year of birth.

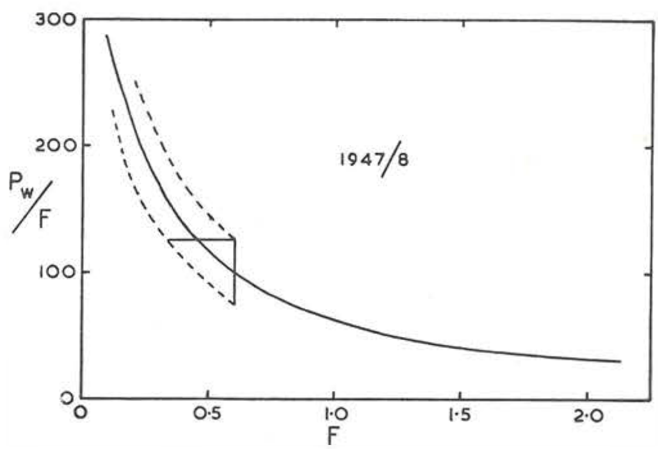

Figure 8. The catch per unit of fishing mortality (P_w/F) at different levels of F for the 1947–48 brood. The dotted lines show the coefficient of variation of catch per unit of fishing mortality due to variations in recruitment.

Just as there appears to be a limiting catch/effort at which effort decreases, so there must be a corresponding value at which effort increases. Hence, there will be an oscillation in yield and in catch/effort in place of the steady state which fishermen and their markets would prefer. Such an oscillation in yield can be described with the use of equation (8·19) in BEVERTON and HOLT (1957).

Two types of oscillation are shown in Figure 9. The first 9 (i) is a regular and sharp one. In three years fishing mortality, F, was reduced from 0·6 to 0·45 and then it was raised again to 0·6 in the subsequent three years (Figure 9 (i) a). The yield decreased as fishing mortality decreased in the first three years; this is because fishing mortality is proportional to fishing effort. When the effort, and consequently the mortality, increased from the fourth year to the sixth year,

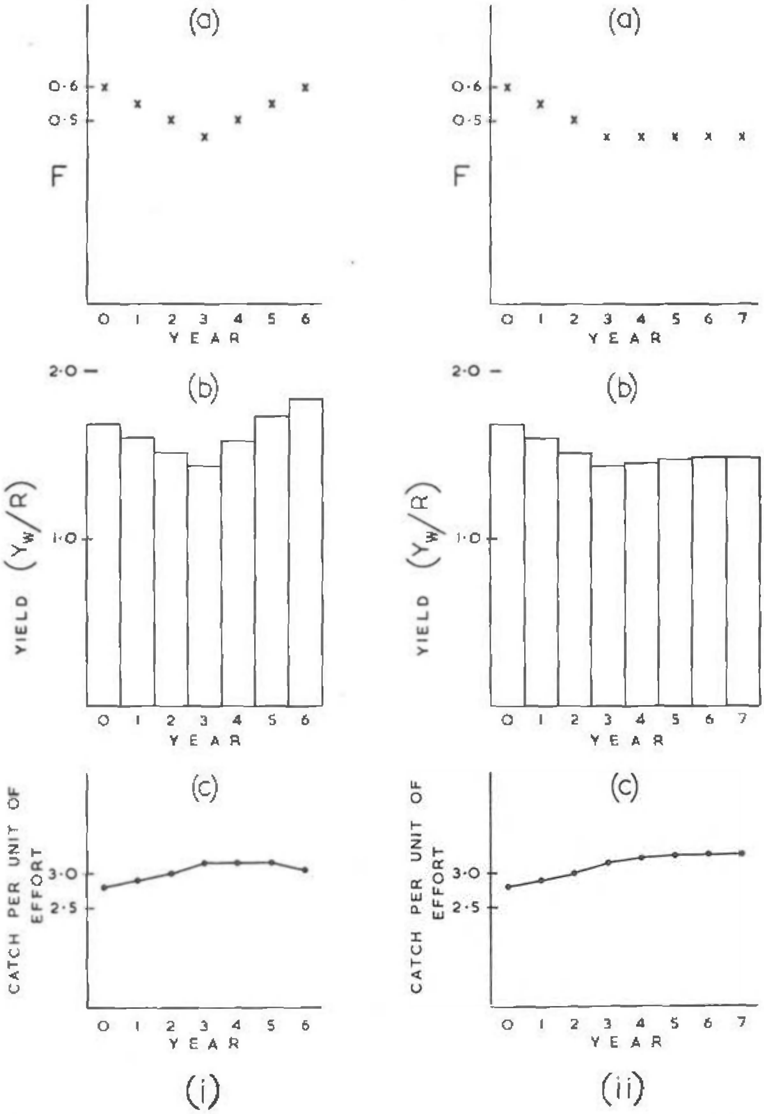

Figure 9. Yields of herring under oscillatory systems. Full explanation in text.

the yield increased above its previous level, because during the three years of relaxed fishing effort, the stock increased (Figure 9 (i) b). The changes in abundance are shown in Figure 9 (i) c: the catch per unit effort increases up till the third year after which it decreases, at first slowly and then in the sixth year, sharply. Thus, the oscillation in effort is very quickly reflected in an oscillation in stock.

The second type of oscillation is merely a reduction in fishing mortality from 0·6 to 0·45 in three years, after which it remains constant for four years

(Figure 9 (ii) a). The yield decreases as fishing mortality decreases and subsequently it rises slightly (Figure 9 (ii) b). The effect on the stock is shown in the change in catch per unit effort (Figure 9 (ii) c), changing in the opposite direction to that in fishing mortality, or effort.

We may compare the average values from the two types of oscillation as follows, in arbitrary units: —

		Yield/recruit	Catch/effort	Average fishing mortality
Fig. 9 (i)	Steady state	1·64	3·15	0·525
	Oscillatory state......	1·625	3·05	0·525
Fig. 9 (ii)	Steady state	1·61	3·30	0·49
	Oscillatory state......	1·57	3·24	0·49

The most important point is that for both types of oscillation, with the same average fishing mortality, the yield is less under the oscillatory state than it is under the steady state. More important, the catch/unit effort is greater under the steady state. This is because a greater proportion of the stock is lost by natural mortality in the oscillatory system. The result is that for a given catch/effort, a greater yield can be obtained under the steady state. In fact for a yield of 1·625, at a steady state catch per unit effort of 3·25, we would only need a fishing mortality of 0·50. Under the oscillatory system, more fishing effort would be needed (about 5%), working at a catch/unit effort of 3·05, which was 6% less.

Both systems illustrated show small changes in yield and in catch/effort of about 12% in catch and up to 20% in catch/effort. It is possible that such an oscillation did take place from 1930–37 (see Figure 1). In this case the variation in catch was nearly 30%. It is interesting that the same trend can be discerned in the average mortality rates (see Table 1). The recovery of effort could well be due to the 1929 year-class (see Table 6 in CUSHING and BURD, 1957).

The treatment so far has been that of a fishery with no variations in recruitment or in vulnerability. For the moment the effects of vulnerability must be ignored because they are not understood; the greatest source of variation in annual yield, however, is that due to recruitment, which may be of the order of five to six times.

An estimate of the variability of the annual yield due to recruitment changes has been made using the equation for yield in numbers (BEVERTON and HOLT, 1957).

$$\frac{Y_n}{R} = \frac{F_e^{-M^1}}{Z}(1 - e^{-(Z)\lambda})$$

where M^1 is the instantaneous coefficient of natural mortality in the pre-exploited phase.

A model yield from successive year-classes was calculated for twenty years, with recruitment varying randomly at the levels of 5, 10, 20, and 30; the annual yield was summed for each of the year-classes represented. The calculations were made at a number of values of F, with M constant at 0·25, and were made in two forms, firstly with partial recruitment at three years of age and secondly with full recruitment at three years of age. For the partial recruitment, it was assumed that the number of three year-old recruits was 55% of the total

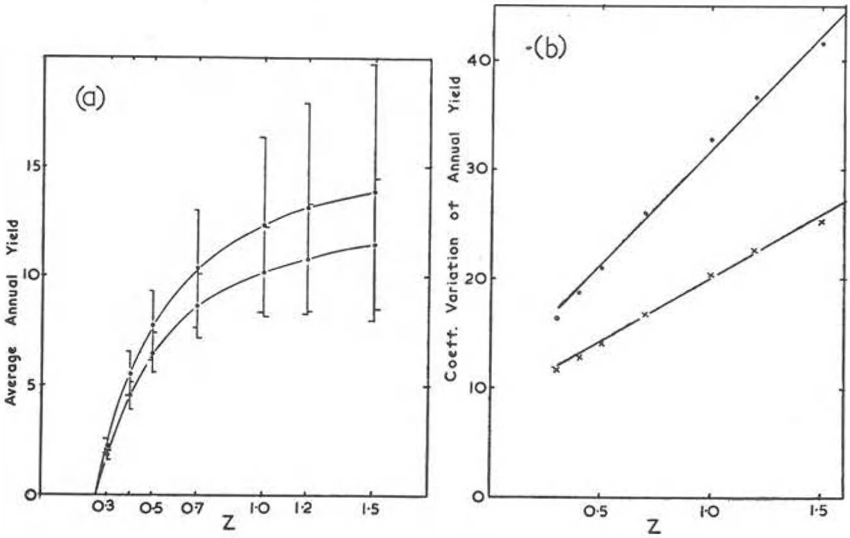

Figure 10. Variability of the yield of herring.

(a) Variability of the annual yield in numbers with increasing mortality. The upper curve is the yield when recruitment takes place at three years of age and the lower when it takes place partly at three and partly at four.

(b) Coefficient of variation of annual yield with increasing mortality. Upper and lower curves as in Figure 10 (a).

number of recruits reaching the fishery (CUSHING and BURD, 1957) at three and at four years of age. Thus the first method represents the form of recruitment before 1950–51 and the second represents that after that date.

Figure 10 (a) shows the yield in numbers as before and as after tqe change in recruitment. This corresponds to the differences in $\frac{Yw}{R}$ shown in Figure 7 between the 1944–45 brood which lived before the 1950–51 recruitment change and the 1947–48 brood which lived after the recruitment change. The main difference due to the recruitment change is an increase in yield because fishing started somewhat earlier in the life of the fish.

Figure 10 (b) also shows the coefficient of variation of the annual yield calculated from the model. From the fourteen values of annual yield with varying recruitment, variances for each level of mortality were calculated; then a coefficient of variation $\frac{(100 \text{ var})}{\text{mean}}$ was calculated. From the model as shown in Figure 10 (b), it may be shown that under conditions of partial recruitment at three years old, with $(Z) = 0{\cdot}4 - 0{\cdot}5$, the coefficient of variation would be about 12%. Similarly under conditions of full recruitment at three years old, with $(Z) = 0{\cdot}75 - 0{\cdot}90$, the coefficient of variation would be 25%–30%. It is reasonable to assume that variability due to recruitment in recent years has more than doubled.

Returning to Figure 8, which shows the catch in weight/effort at different levels of fishing mortality for the 1947–48 brood, the error due to variability in recruitment is shown as dotted lines; this error is the coefficient of variation of the yield in numbers applied to the catch per effort in weight. This is the coefficient of variation due to changes in recruitment and the differences due to calculating in numbers will only be small ones.

It is assumed that when $F = 0{\cdot}60$, the corresponding catch/effort is a limiting one and that when effort reaches this level an oscillatory system is set up. The "confidence limits" to the line of catch per effort (which are described by the coefficient of variation of the yield) show that if F was reduced to 0·40–0·45, there would only be one chance in 20 of the catch/effort reaching the limiting value at which fishing stops due to changes in recruitment. This is very important in the herring fishery because there are many small boats owned by single families, which under this treatment are equivalent to the large companies. Each stops fishing at the limiting value of catch/effort.

We may now consider the effect of the industrial fishery for immature fish on the yield of adult fish. The reduction in the adult yield due to the industrial fishery would be given by

$$1 - \frac{e^{-(t_{\rho}' - t_{\rho})(F^1 + M^1)}}{e^{-(t_{\rho}' - t_{\rho})M^1}},$$

where F^1 is the fishing mortality in the industrial fishery. It is to be hoped that this will be found adequately from the ICES tagging experiment and then it can be fitted directly in the yield curves described here.

VI. Discussion

This paper is concerned with the present state of the herring stocks in the Southern North Sea. That they have been reduced has not been questioned. The cause of reduction has been attributed to three factors: —

(1) the industrial fishery on the nursery ground (HODGSON, 1956);

(2) natural changes, in particular, emigration from the East Anglian area (PARRISH and CRAIG, 1957);

(3) fishing (CUSHING and BURD, 1957).

It has been shown in this paper that the reduction is probably not due to the industrial fishery in the manner of HODGSON's hypothesis, because for three successive years the best estimates of the numbers of four year-olds "lost" under his hypothesis are greater than the catches on the nursery ground.

On evidence available in 1956, mortality had risen recently more quickly than had the effort and so it was reasonable to postulate that the "surplus" mortality was really an effect of the emigration of older fish. However, the fact that catches had increased in step with mortality suggested that the drifters' shots had become more efficient.

Such an increase in efficiency was shown independently by dividing the fishing intensity (effort per unit area or statistical square in this case) by the number of shots. When the East Anglian effort was corrected by this efficiency factor, it was found that the total effort on the Downs stock obtained by raising the East Anglian effort by the ratio of the Southern Bight catch to the East Anglian catch, had increased since 1950 to much the same degree as mortality and catch. Hence the reduction in catches has probably been due to fishing.

If this description is accepted, the means of stabilizing the fishery are available.

The choice lies between a stable annual yield and an oscillatory annual yield. The deciding factor lies in the catch per unit of effort. If oscillation takes place, too much time is spent at or near the lower limit of the limiting value of catch per unit of effort. At the stable level, there will of course be variations in the catch/effort, but they will not reach the dangerous limiting level. The herring fishery includes a large proportion of small owners in all countries, who would survive on a stable system, but would leave the herring fishery when the system oscillates.

VII. Summary

1. From an analysis of variance of East Anglian mortality rates, it was shown that each estimate of mortality, by age or by year, was equally precise. Consequently, average mortality rates were used in subsequent work.

2. From maturity studies, it was shown that one quarter of the trawl catches on the Dogger area were composed of Downs fish.

3. A comparison of mortality changes with effort changes since 1928, showed that, since 1950, mortality had increased more rapidly than had the effort. As catch had increased as rapidly as mortality, it seemed likely that the efficiency of fishing had increased.

4. An estimate of increased efficiency was obtained independently by dividing the fishing intensity in each season by the number of shots made.

5. When the efficient effort at East Anglia was raised by the ratio of Downs catch to East Anglian catch, it was shown that effort had increased as rapidly as catch and mortality since 1950. A regression of mortality on effort was constructed: there was one chance in ten that its slope was different from zero. Using this regression, the best estimate of natural mortality from 1928–55 was 0·17.

6. An estimate of the loss to the Southern Bight fisheries due to the Bløden Ground industrial fishery was made by comparing the catch of a year-class on the Bløden Ground with the numbers in the stock in the Southern Bight of the same year-class. Taking into account hypothetical variations in natural mortality rate on the Bløden Ground and the proportions of Bløden Ground fish reaching the Southern Bight, an estimate of the loss to the Southern Bight fisheries was made — 20% in 1954.

HODGSON's hypothesis was tested by comparing his estimated loss of four year-old fish to the Southern Bight fisheries with the catch. It was shown that the estimated loss was 2–5 times as great as the catch in 1951 and 1952; hence it is likely that HODGSON's hypothesis was faulty.

7. Using the estimates of natural mortality and fishing mortality given above, the yield/recruit of herring was calculated. It was shown that a steady state yield was more efficient than that from an oscillatory system.

In the herring fisheries, there is a low limiting level of catch per unit effort, at which fishing stops. Variations in stock and yield are mainly due to variation in recruitment. From the observed variations in recruitment, the variability of yield and catch/unit effort is calculable. Thus if the limiting catch/effort corresponds to a fishing mortality of 0·6, that corresponding to a fishing mortality of 0·45 will never vary sufficiently due to recruitment to reach the dangerous limiting value.

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