Studies on the Dunmore Herring Stock
1. A Population Assessment

By

A. C. Burd

Fisheries Laboratory, Lowestoft

and

J. Bracken

Department of Lands, Fisheries Division, Dublin

I. Introduction

It has been recorded (WENT, 1946) that coastal herring fisheries off the south coast of Ireland have been in existence from at least the seventeenth century. Since the early nineteen hundreds the size of the catch taken from the Celtic Sea has fluctuated considerably. In part, it would seem that the amount of fishing which takes place is dependent upon the profitability of other herring fisheries, particularly those of the North Sea. It was only the decline in the East Anglian herring fishery in recent years that induced the English drifters to exploit the Dunmore fishery again. HICKLING (1946) also records that the winter drift net fishery was expanded in 1933 by English drifters, following the failure of the Plymouth herring voyage.

Sampling of the English drifter catches landed at Milford Haven was commenced in 1957. In addition hydrographic and herring larval surveys have since been made by English and Irish research vessels to delineate spawning grounds and to study larval drift. Investigations on the distribution of 0-group herring have also been made in recent years on the south and east Irish coasts.

BURD (1959) showed, from the first two season's data, that with the big increase in effort the mortality rates had risen sharply. As a result of the anxiety felt, a Working Group at the Dunmore East herring fishery was set up by the International Council for the Exploration of the Sea, to assess the results of this early work and to recommend a research programme for the area. With the addition of more recent material (BRACKEN, 1959, 1961, 1962; BRACKEN and FOSTER, 1963), this paper comprises, in fuller detail, the stock assessment presented to the Working Group (BURD, 1960).

II. Yield of the Fisheries in the Celtic Sea

The histories of the pre-war fisheries in the Celtic Sea have been described by WATKIN (1933a, b), HICKLING (1946) and BURD (1961). The areas in which the different fisheries operated are illustrated in Figure 1. The total catches

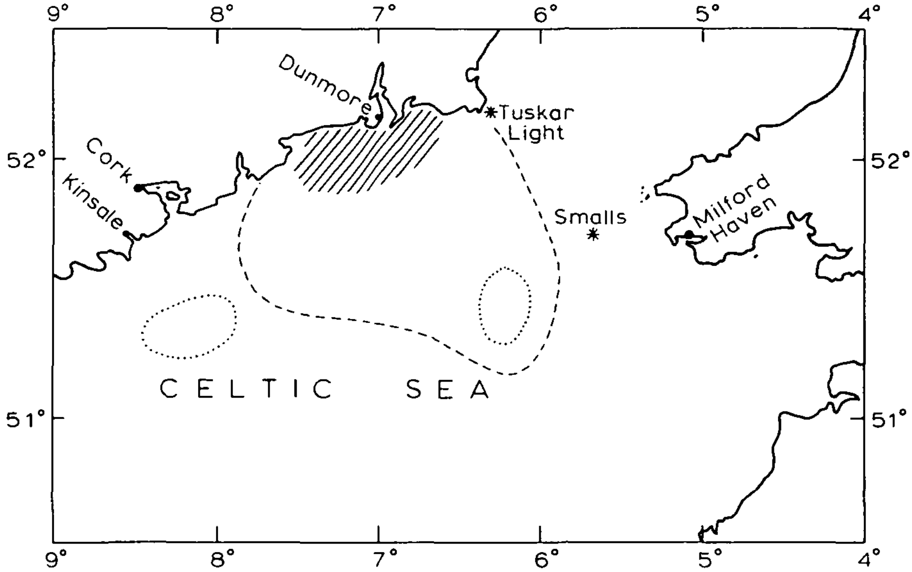

Figure 1. The herring fisheries in the Celtic Sea (after HICKLING, 1946).
Cross hatched: Area of winter spawning fishery,
Dotted line: Area of trawl fishery from Milford Haven,
Pecked line: Area of drift net fishery from Milford Haven.

for the period 1905–1961 are shown in Figure 2. Up to 1932 the major parts of the annual catches were made in the early summer drift net fishery and by trawlers at the Smalls in the summer. In some years, 1909, 1910 and 1911 particularly, a fishery took place in winter off the Irish coast close to Dunmore. In 1933 the English vessels which had fished unsuccessfully at Plymouth tried the Dunmore grounds and from that time this winter fishery became the most important. The effort in the early summer drift fishery gradually declined and it has not been prosecuted since the war.

In the immediate post-war years little effort was made to exploit the herring stock in the Celtic Sea. Prior to 1953 some catches were made by Irish vessels off Dunmore in winter and there were occasional trawl fisheries at the Smalls by French, Belgian and Dutch herring trawlers. In 1953 some English drifters returned to Dunmore for the winter fishery and subsequently a greatly increased effort was directed on the spawning concentrations. In the 1957/58 season some 26,000 metric tons of herring were taken. With the adoption of new base lines by the Irish Government in 1961 the spawning areas were closed to foreign vessels and the effort quickly declined.

During the period between 1930 and the outbreak of war the English catches amounted to between 50% and 75% of the total from the area. The changes in the main areas of fishing of ships landing at Milford Haven during the period 1930–36 are summarized in Figure 3. The data have been grouped in two-monthly periods. The ordinate in the histograms is the frequency of the taking of monthly total catches of five tons or more from each statistical area. A regular pattern of movement emerges. In January and February, the majority of the catches came from the area close to the Irish coast between Dunmore

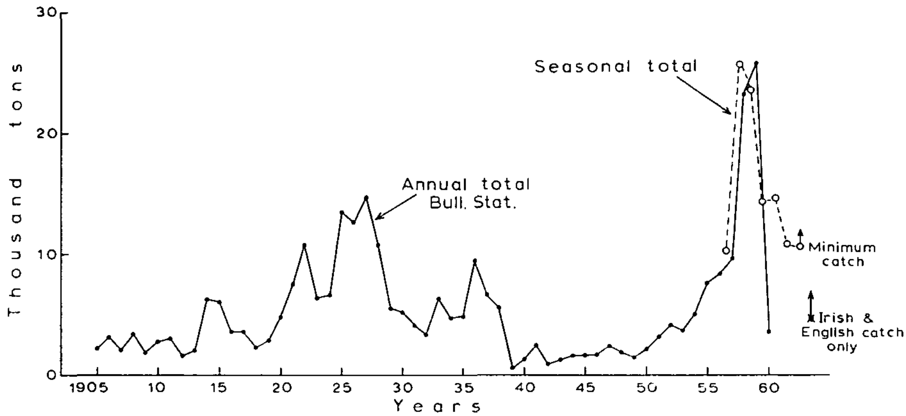

Figure 2. Total catch of herring from the Celtic Sea. Annual totals from *Bulletin Statistique*, Area VIIg; seasonal totals from national statistics.

and Kinsale. The catches consisted of full and spawning fish (FARRAN, 1944). By March and April the area of greatest catch had shifted to seaward and to the south-west, and during May and June good catches were taken over a wide area in the central Celtic Sea. WATKIN (1933a, b) showed that in April the fish were mainly recently spent, and FARRAN (1944) commented that the catches made at this time off Waterford and East Cork consisted of fish in poor condition having recently spawned. He also recorded that "owing to rich feeding on the south coast, they rapidly improve and by the middle or end of May almost all are matties in first-class condition". These observations are confirmed in WATKIN'S (1933b) more detailed maturity data. He used a modification of the Hjort maturation stages to separate maturing virgins from recovering spents. In July and August the main area of capture was some twenty miles south and west of the Smalls, while in some years large catches were made off Kinsale. This was also the case in September and October. The maturation stages present at the Smalls at this period were predominantly stages IV and V with, in August, some stage III (WATKIN, 1933a). WATKIN stated that there was no evidence of spawning taking place at the Smalls and he considered that the fish in this area were a pre-spawning concentration, prior to migrating to the spawning places.

One feature of note was the virtual absence of immature stage I fish in the Smalls samples and this was also true of the summer drift net fishery, though in June some 2% occurred in WATKIN'S samples (1933b). This would imply that the pre-recruit area lies elsewhere than in the central Celtic Sea. The distribution of fish, as described from Figure 3, might possibly be confined to the feeding migration of the recovering spent herring from the Dunmore spawning grounds. The changes in position of the fisheries and the changes in maturation stage would suggest that the Smalls trawl fishery and the winter and spring drift net fisheries are all exploiting the same stock.

Further evidence for considering the fisheries in the Celtic Sea as exploiting one population is given by HICKLING (1946). A significant correlation was obtained of catches per effort from the summer trawl fishery on the preceding winter drift net catches, for the period 1933–38 (Figure 4). However, no

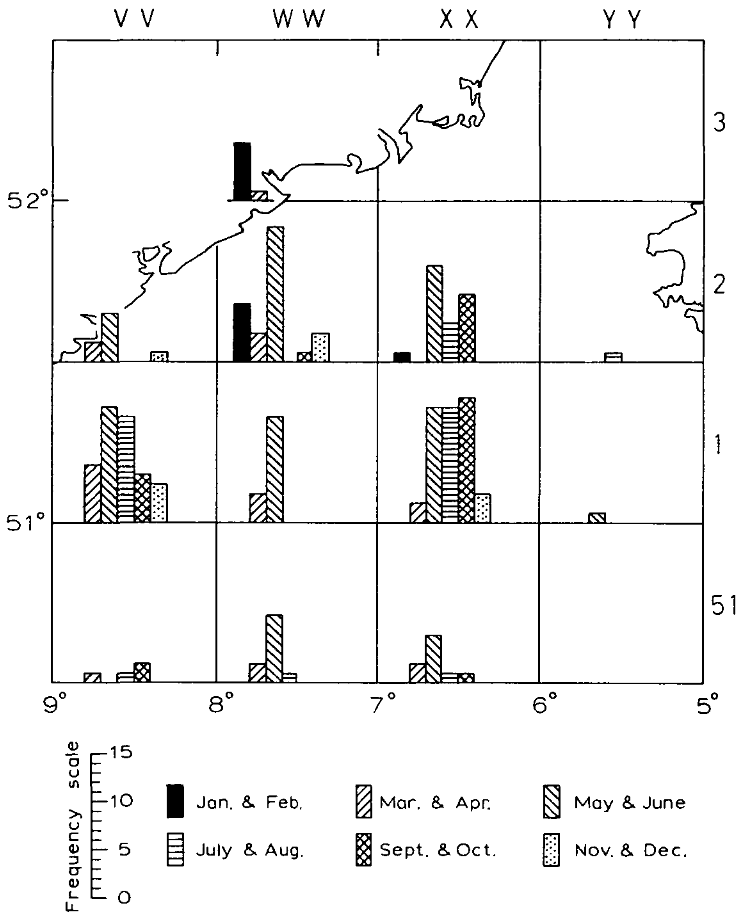

Figure 3. Frequency of the taking of a monthly total catch of herring of five tons or more in the period 1930–1936 by vessels landing at Milford Haven.

significant regression was obtained when these catches per effort were correlated with the spring fishery.

The use of the statistics 'voyage' or 'landing', which is unavoidable, will result in an underestimate of the true effort involved. In recent years it was not considered economic to return to Milford Haven with a catch of much less than forty crans. Under good fishing conditions and successful location of the shoals, a catch of this size or larger could be taken in one shot by the drift nets, but in other circumstances it might represent three nights' fishing. This effect is further enhanced by the long steaming distances to and from the fishing grounds. Thus the estimate of abundance based on catch per voyage is likely to underestimate the effort involved. The extent of the underestimate probably varies between the different fisheries, and depends upon the availability to capture. The winter fishery exploits the concentrated shoals of spawning fish, whose availability to capture is likely to be much higher than that in the dispersed feeding fisheries.

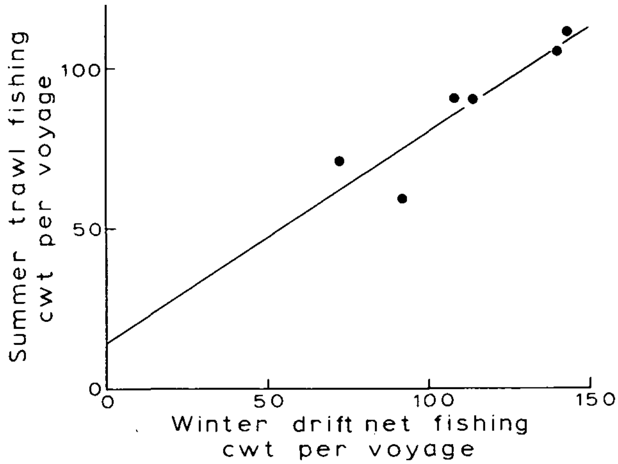

Figure 4. Celtic Sea herring; regression of catches per effort of the summer trawl fishery on the preceding winter drift net fishery, 1933–1938. (Data from HICKLING, 1946.)

The period 1930–35 was notoriously a time of low catches per shot in the spring drift net fishery. In many cases boats were at sea for up to seven days for a catch of fifteen crans (personal communication, Skipper R. K. V. PYE, M.B.E.). In fact the average number of voyages (or landings) per season declined from 601·9 for the period 1925–32 to 176·1 for the years 1933–39. In such circumstances the low catches per voyage in the spring fishery in the nineteen thirties are probably gross underestimates of the true fishing effort involved.

No correlation was obtained in HICKLING's data between the catches per effort of the trawl fishery and the subsequent winter fishery. This lack of correlation may be related to the relative lower abundances of young fish in the Smalls catches.

In the post-war period it has not been possible to compare the catches per effort in the winter drift net fishery with any abundance indices from the Smalls. The Milford Haven trawlers no longer make purely herring voyages. Occasional catches are made by Dutch, Belgian and German trawlers but no systematic fishery takes place in this region.

It may be concluded from the evidence of timing, area and stage of maturation that the three pre-war fisheries could be considered as exploiting the same stock. This view is further supported by the relative changes in annual catch per effort of these fisheries.

III. Age, Mortality and Effort

1906–1936

There are comparatively few data available on the age composition of the herring from the Celtic Sea fisheries for this period. The only systematic sampling was that of WATKIN (1933a, b) who published age data for the herrings landed by Milford Haven trawlers and drifters during the period 1923–30.

Table 1

Mean catch per voyage for July–November by Milford Haven trawlers

Year	Metric tons/ voyage	Year	Metric tons/ voyage	Year	Metric tons/ voyage
1906	5·99	1917	3·51	1927	4·39
1907	6·05	1918	1·18	1928	5·15
1908	4·59	1919	0·79	1929	4·36
1909	2·63	1920	6·05	1930	2·57
1910	1·95	1921	7·79	1931	2·37
1911	2·77	1922	7·11	1932	1·28
1912	2·57	1923	5·65	1933	5·18
1913	4·66	1924	6·23	1934	3·11
1914	3·69	1925	4·50	1935	3·82
1915	4·95	1926	3·10	1936	5·93
1916	4·93				

The total annual catch fluctuated between 1,700 and about 15,000 metric tons in the thirty years under review. Of these catches at least 50% were landed at English ports and again at least 50% came from trawlers. Monthly data for catch and number of voyages for the vessels working out of Milford Haven are available for the whole of this period. The trawl fishery tended to concentrate into the period July to November inclusive. However, minor catches were also made in all the other months. For this reason the mean catch per effort for July to November was taken as the best estimate of annual stock density. These data are presented in Table 1.

In attempting to make any assessment of the effects of fishing on a stock an estimate of the total effort involved is necessary. Using the Milford trawler catch per voyage as the best estimate of stock density, then the ratio of total catch to the Milford catch per effort gives an equivalent total trawler effort. These data are shown in Figure 5, where it is seen that a slow build-up in effort occurred during this period. Between 1925 and 1932 a maximum effort was exerted. It is only for this period that age data are available.

Using this long series of catch and effort data it is possible to examine the relation between the stock and the effort expended, despite the scarcity of age data. The relationship between catch per effort and effort is hyperbolic, for

$$S_N = \frac{R}{F + M}$$

where S_N is the number of fish in the stock, R is the number recruited annually, and F and M are the instantaneous coefficients of fishing and natural mortality. F is however, proportional to total fishing effort and can be replaced by qf, where f is the total effort and q a coefficient of proportionality, the equation then becoming

$$S_N = \frac{R}{qf + M}.$$

Taking reciprocals of both sides, the reciprocal of stock number increases linearly with respect to effort, i.e.

$$\frac{1}{S_N/R} = qf + M.$$

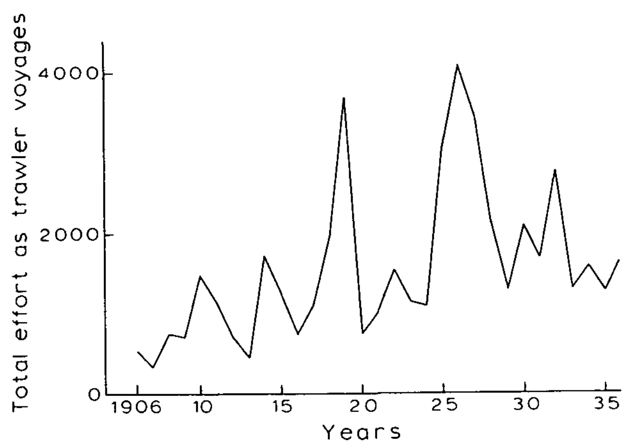

Figure 5. Celtic Sea herring fishery; total effort as equivalent Milford Haven trawler voyages.

In this particular case our index of stock number is the annual trawler catch per effort. However, in applying this equation it is necessary for three conditions to be satisfied: firstly, that recruitment throughout the period is constant; secondly, that there is an equilibrium state between the stock and the fishing rate; and thirdly that the catch is known, in numbers of fish.

Over the long period under review it has been assumed, for lack of any evidence either way, that recruitment has varied randomly about a mean level and that no trend, either with time or effort, has been present. In the years during which WATKIN's trawl samples were taken, the age-groups 5–9 comprised about 80% of the stock each year and among these age-groups there was only slight evidence of any major fluctuation in year-class strength.

Further, examining the changes in effort in Figure 5, the data could be considered to show two periods of fairly steady effort, the first from 1908 to 1924 with a mean of about 1,200 voyages, and the second from 1925 to 1936 with a mean of about 2,200 voyages. These two periods will be considered as being in equilibrial state.

In Figure 6 the reciprocal of the catch per voyage in metric tons has been plotted on total effort. It is seen that though there is a wide scatter of points at the high levels of effort a significant regression is obtained ($p < 0{\cdot}01$). If it were possible to measure the true number of fish in the stock per recruit, then the intercept on the Y-axis would be a measure of the coefficient of natural mortality, M. Since, however, we have only a proportional index of stock, i.e. catch per effort, and not per recruit, then the intercept is itself only proportional to the natural mortality, M.

The effect of using weight per effort in place of numbers will cause the intercept on the Y-axis to be underestimated. The magnitude of this underestimate is dependent on the change in average weight, i.e. the growth rate of the fish, and also on the degree to which the mean age has been reduced under the range of fishing effort. Comparing a period of low effort and a relatively high mean age with a period of high effort and low mean age, it is obvious that the number of fish per ton in the latter case will be higher than in the former, the magnitude of the difference being a function of the growth rate. In the present case some assessment can be made of the magnitude of the error involved. In 1923 the mean length of the herring sampled by Watkin was 28·4 cm, and in 1930 the mean length was 27·4 cm. The age and, hence, length distribution for 1923 is dependent on the total mortality experienced in the preceding four or five years. Similarly that for 1930 is a result of the effort expended from 1925 onward. In terms of number, these length differences represent an increase of 10% per ton in 1930 over the 1923 mean lengths. Le Danois and Heldt (1924) published some length and age data for the French trawl fisheries at the Smalls during the period 1921–1923. The mean length for their samples was 27 cm. This gives, in terms of number, an increase of some 3% per ton for 1930. These differences are insignificant compared with the variance about the regression line in Figure 6. However, some bias must remain in the estimates of the relative magnitudes of the natural and fishing mortality.

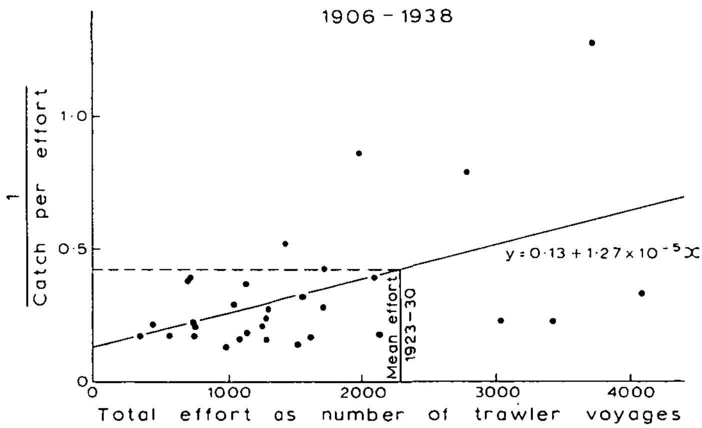

Figure 6. Celtic Sea herrring fishery; regression of reciprocal of catch per effort on total annual trawler effort.

Taking the period 1923–30 there was a mean annual effort of 2,253 voyages. The ratio of the value of the ordinate at this effort to the intercept on the Y-axis is proportionate to the ratio of total mortality to natural mortality. This ratio of total mortality to natural mortality is 3·24 : 1, or a ratio of fishing to natural mortality of 2·2 : 1. For this period it is possible to calculate instantaneous mortality rates. Table 2 gives the percentage age distributions for all samples taken each year by Watkin, whether by trawl or drift net. For the reasons stated previously, the July to November mean trawler catch per effort has been taken as a raising factor for calculating mortality rates from these data. Figure 7 shows the annual age composition as tons per voyage for the period. Total mortalities have been calculated as:

$$\frac{\text{c.p.e. of 7 years and older fish in year } n}{\text{c.p.e. of 8 years and older fish in year } n+1}.$$

For the whole period a mean total mortality of 0·65 was obtained. Applying the ratio between natural and total mortality deduced from Figure 6 an estimate of natural mortality of 0·20 is obtained.

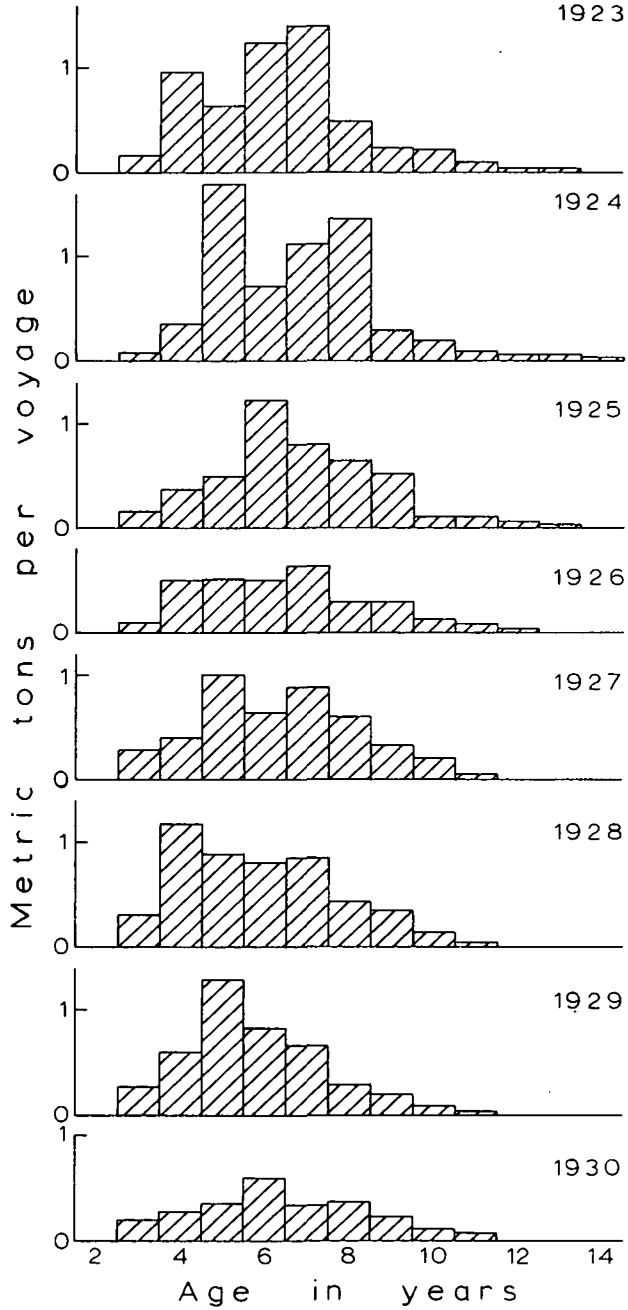

Figure 7. Celtic Sea herring; annual percentage age distributions from WATKIN's data (1933a, b) raised by July-November Milford trawler catch per effort.

Table 2

Percentage age distributions of Celtic Sea herring samples 1923–30
(from WATKIN, 1933a, b)

Year	2	3	4	5	6	7	8	9	10	>10
					Age in Years					
1923	0·10	3·10	17·30	11·50	22·60	25·30	8·90	4·30	3·90	3·00
1924	–	1·50	5·80	27·80	11·80	18·30	22·00	5·00	3·10	4·70
1925	0·50	3·30	8·40	11·00	27·60	18·00	13·90	11·60	2·20	3·50
1926	0·20	3·35	16·35	15·75	15·55	20·50	10·00	9·80	4·60	3·75
1927	–	6·60	9·05	22·75	14·60	20·00	13·65	7·85	4·35	1·15
1928	–	6·15	23.65	17·80	16·30	16·65	8·30	7·00	3·35	0·80
1929	–	6·35	14·30	29·90	19·10	15·55	6·85	4·70	2·40	0·85
1930	0·55	7·70	10·55	14·55	23·15	13·45	15·20	9·05	3·55	2·25

1946–64

In post-war years no age data are available for the Celtic Sea fisheries before 1952. Age data have been published from the Belgian Smalls catches for 1952, 1955 and 1957 (GILIS, 1953, 1956, 1958). Sampling the winter fishery commenced in England in 1957 and continued to 1960 when, with the adoption of new base lines by the Irish Government, English drifters ceased to participate in the Dunmore fishery. Age data are also available for this period from Dutch and German sources (ZIJLSTRA, personal communication; SCHUBERT, 1960, 1961, 1963, 1964). Irish sampling commenced in 1958. While there has been continuous sampling for age from 1957, the quality and quantity of material are variable. This, in part, reflects the variability in effort from season

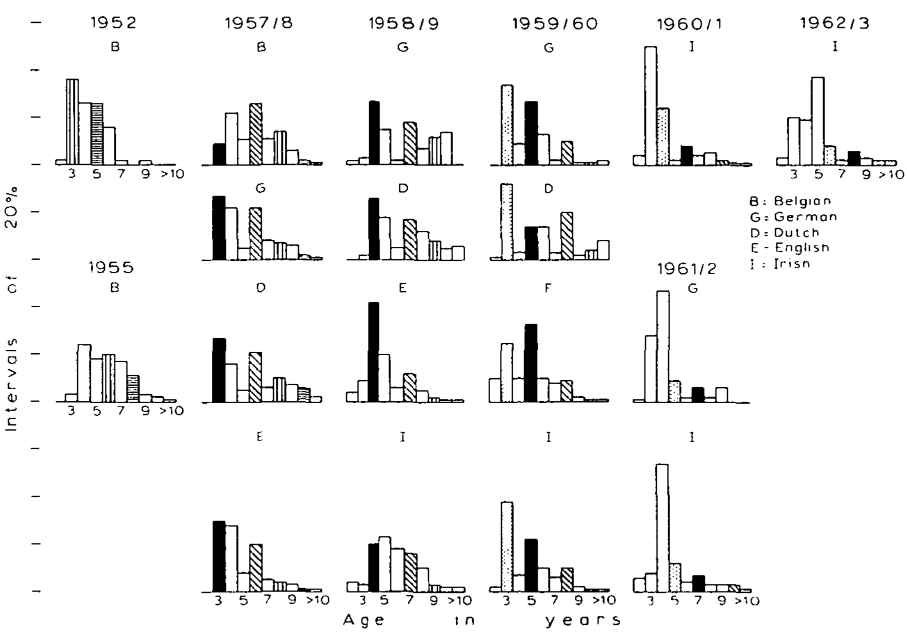

Figure 8. Celtic Sea herring; percentage age distributions for 1952–1962/63, from various sources.

to season. The percentage age distributions from the different sources are shown in Figure 8. The Dutch, Belgian and German data are derived in the main from commercial catches and comprise a sample of between 50 and 640 fish per season. The English and Irish data are based on extensive market measurements raised through an age/length key. However, the Irish observations of 1958 are an exception; these are based only on biological samples taken during the fishery from November to February. The Belgian, Dutch and German age data are derived from trawl-caught fish, the English from drifter-caught fish, while the Irish data are derived from a mixture of ring net and vinge trawl catches.

To facilitate comparison of the age compositions certain year-classes in the histograms have been distinguished by various forms of hatching. It is seen that in all the data there is good agreement on the relative abundances of the year-classes in each year. The 1956 year-class as 3 year-olds in 1959 is not so strong in the English data as in other age compositions. Perhaps this was due to the curtailment of the 1959/60 season fishery by the English vessels. The 1952 year-class in the Irish samples of 1958/59 appears to be overestimated in comparison with the other age data. Despite these minor differences the general agreement is good.

Details of total catch, effort and catch per effort are available for all the above countries, and in Table 3 the percentage age distributions multiplied by catch per effort are given for the Belgian, German and Dutch age compositions. The annual age distributions of the English drifter catches were derived by raising the weekly measurements by the catches per effort. A mean for the whole season was taken of the periodical raised age distributions. These data are also given in Table 3.

The Irish-based fleet has varied considerably in composition and efficiency since 1958. In that year, 74 vessels fished out of Dunmore East, comprising 37 ring net vessels, 19 vinge trawlers and the remainder various seiners and drifters. Before Christmas, ringers landed 80% of the total catch but in January many had ceased fishing and were replaced by vinge trawlers, which landed 70% of the catch from mid-January until the season finished in March. The same pattern, of ring-netting before Christmas and trawling after Christmas, has been maintained in subsequent years. In the 1960/61 season the fleet had increased to 96 vessels; 50% of the total seasonal catch was made by ringers operating before Christmas. In the 1961/62 season, for the first time, the number of vessels using trawls and purse seines exceeded those using ring nets. The latter took 41% of the total catch, again in the pre-Christmas period. By the 1962/63 season the main effort was trawling; ring-netters took only some 8% of the total catch. Thus in the past six years there has been a change in effort, as vessels have converted from ring-netting to trawling. In recent years the expert North of Ireland vinge trawlers have not taken part, with the result that the fishing effort of the fleet has declined. These rapid changes in the types of gear used by Irish-based boats have complicated the calculation of mortality estimates. The problem of using the Irish age data to provide adequate mortality estimates for stock abundance studies is dependent upon the derivation of a reliable estimate of catch per effort.

Since 1958 complete market statistics have been obtained of each catch landed and the effort expended by each boat. Both ring-netters and trawlers have worked simultaneously during the whole fishery. The ringers work more

Table 3

Stock abundance estimates

Belgian trawlers

Percentage age composition by kg/100 hrs fishing/h. p.

Season	2	3	4	5	6	7	8	9	10	10+	Total
					Age in years						
1952	2·3	34·7	32·4	32·4	20·7	2·3	–	2·3	–	–	127·1
1955	–	4·4	34·1	26·4	28·7	24·8	16·5	4·4	3·9	1·9	145·1
1957	–	6·9	16·4	7·9	18·4	8·1	9·5	4·4	1·2	1·1	74·0

German trawlers

Percentage age composition by tons per fishing day

Season	2	3	4	5	6	7	8	9	>9	Total
					Age in years					
1957/58	–	4·28	3·54	0·77	3·44	1·26	1·22	0·92	0·36	15·79
1958/59	0·16	0·23	1·91	1·04	0·13	1·33	0·49	0·84	1·01	7·14
1959/60	0·03	1·67	0·46	1·30	0·63	0·09	0·49	0·06	0·18	4·91
1960/61					No data					
1961/62	0·08	2·42	4·10	0·78	0·17	0·53	0·04	0·56		8·68

Dutch trawlers

Percentage age composition by tons/100 hrs fishing

Season	2	3	4	5	6	7	8	9	10	>10	Total
					Age in years						
1957/58	–	61·3	36·7	11·2	47·9	13·7	21·9	16·0	14·1	5·2	228·0
1958/59	0·3	2·3	25·9	18·4	5·0	17·2	10·7	7·7	4·7	5·7	97·9
1959/60	0·9	32·4	3·5	13·9	13·2	3·5	20·4	2·3	4·1	8·2	102·4

English drifters

Numbers of fish per net per shot

Season	2	3	4	5	6	7	8	9	10	10+	Total
					Age in years						
1957/58	0·0	170·0	155·7	44·3	102·9	27·1	24·3	18·6	4·3	7·1	554·3
1958/59	19·0	41·5	189·3	91·5	24·9	53·6	22·0	8·3	2·1	3·6	436·8
1959/60	2·3	64·7	26·8	83·6	24·6	19·1	23·6	6·0	3·4	0·7	252·5

efficiently in the pre-Christmas period when the shoals and weather are more suitable for them, and the trawlers take their main catch when the fish are spawning in January and February. In Figure 9 the regression of ring net catch per landing on trawl catch per landing is shown. The individual points represent, in the main, weekly estimates, though during some periods of low catches two or three weeks have been combined. Each season's data have been given a different symbol. The regression is significant ($p = 0{\cdot}001$). It might be expected that such a regression would pass close to the origin and not give such a high intercept. However, it must be remembered that the ring net technique of fishing, being an active method of attacking a shoal, is likely to yield a high degree of success under suitable circumstances. It was not possible to collect information on blank shots, so an overestimate of abundance in the area is bound to arise. For neither ringers nor trawlers was it possible to get full cover of a blank night's fishing, because while all boats with catches returned to Dunmore East, some vessels without fish, or with only small amounts, might go to some other harbour on returning from their unsuccessful trip.

The regression has been calculated through all years' data in order that

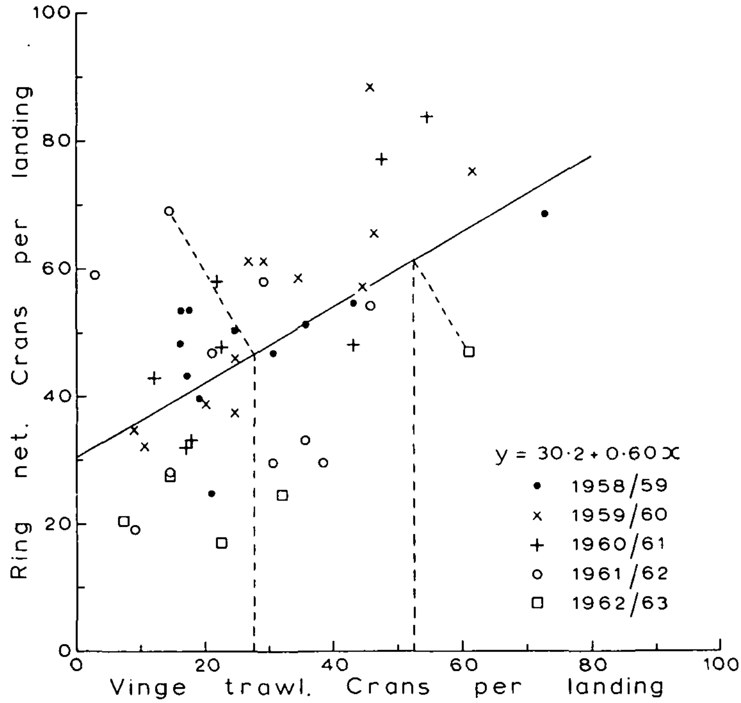

Figure 9. Regression of ring net catch per landing on trawler catch per landing of vessels based at Dunmore East. The catches per effort have been smoothed for each value by taking the value of trawler catch per effort on the regression at the minimum deviation of the observed point.

some smoothing of the effects of learning and increase in efficiency with time might be obtained. Smoothed catches per effort as trawler landings have been calculated for each point on the regression. These have been derived by taking the value on the regression line in the manner shown. These smoothed trawler catches per effort have been used to raise the corresponding market measurements to give, via an age/length key, the annual abundance indices shown in Table 4.

The catch per effort data for 1962/63 are particularly suspect, as during this season the fishery was conducted with considerable industrial disorders which resulted in disruption of the fishery. Without any doubt the catch per effort does not truly represent the state of the stock.

Table 4

Age composition of herring catches landed at Dunmore East (in crans per trawler landing, smoothed)

Season	Age in years										
	2	3	4	5	6	7	8	9	10	10+	Σ
1958/59	1·3	1·0	5·9	6·8	5·2	4·7	3·2	0·7	0·2	0·2	29·2
1959/60	0·6	12·8	2·5	7·8	3·9	2·3	3·0	0·6	0·2	0·1	33·9
1960/61	1·4	14·8	5·9	0·9	2·2	0·9	1·9	0·7	0·3	0·4	29·2
1961/62	1·1	5·3	10·5	2·2	0·8	1·4	0·6	0·5	0·5	0·2	23·2
1962/63	0·7	5·0	4·8	9·8	1·8	0·5	1·7	0·9	0·5	0·6	26·2

Table 5

Instantaneous total mortality rates, Dunmore herring

Period	Source	Age-groups							Mean ages > 3
		3/6	4/7	5/8	6/9	7/10			
1952/55	Belgian	0·06	0·09	0·22	0·52	−0·18			0·16
		3/5	4/6	5/7	6/8	7/9			
1955/57	Belgian	−0·29	0·31	0·59	0·55	0·87			0·58
1959/60 1961/62	German	0·38	0·50	0·45	1·38	–			0·78
		3/4	4/5	5/6	6/7	7/8	8/9	9/10	Ages > 3
1957/58 1958/59	German	0·81	1·22	1·78	0·95	0·94	0·37	–	1·05
	Dutch	0·86	0·69	0·81	1·02	0·25	1·04	1·22	0·84
	English	−0·12	0·53	0·58	0·65	0·21	1·08	2·18	0·87
1958/59 1959/60	German	−0·69	0·39	0·50	0·36	1·00	2·10	–	0·87
	Dutch	−0·42	0·62	0·33	0·36	−0·17	1·54	0·63	0·55
	English	0·44	0·82	1·31	0·26	0·82	1·30	0·89	0·90
	Irish	−0·92	−0·27	0·55	0·82	0·45	1·67	1·25	0·75
1959/60 1960/61	Irish	0·77	1·02	1·27	1·47	0·19	1·45	0·69	1·03
1960/61 1961/62	Irish	0·34	0·99	0·11	0·45	0·41	1·34	0·34	0·61
1961/62 1962/63	Irish	0·10	0·07	0·20	0·47	−0·20	−0·40	–	0·02

Instantaneous mortality rates have been calculated for each set of abundance data in Tables 3 and 4. The values obtained are given in Table 5. The mean instantaneous annual mortality has increased from 0·16 in the period 1952–55 to a mean of 0·75 in the period 1957–1961. During this period there has been a rapid increase in effort.

In a paper on the Dunmore herring stock presented to the Dunmore Working Group, BURD (1960) showed a clear relation between total mortality and effort. At that time the only data on the spawning fishery covering more than three years consecutively were the English drifter catch per effort data. Though there was a similar range of data from the Belgian Smalls trawl catches, these were not used, as there was some evidence to suggest that the recruit herring were not fully represented in these catches.

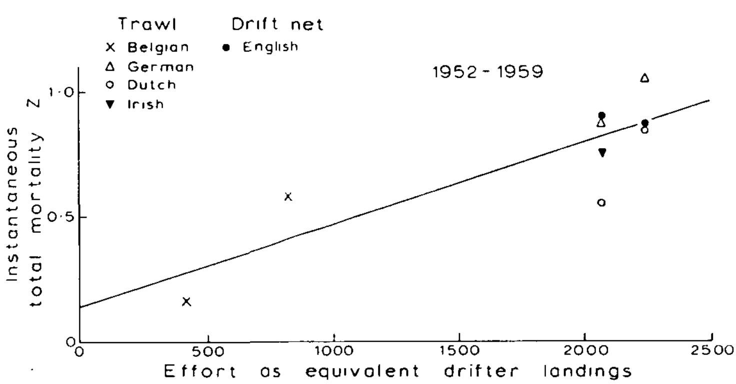

Figure 10. Dunmore herring; regression of instantaneous total mortality on drifter effort.

Table 6 gives the values of the annual total herring catch for the south coast of Ireland, the values of the annual drifter catch per landing, and the equivalent total effort as drifter landings. In Figure 10 the regression of total mortality on effort, based on these data, is shown. The annual instantaneous mortality has been plotted on the mean effort of the two seasons. In the case of the Belgian data for the periods 1952/55 and 1955/57 the effort in the last year of each series has not been included. This was because the age data were taken from the summer Smalls fishery, before the main effort in the winter had taken effect. A clear and significant regression ($p < 0{\cdot}02$) is seen, giving an estimate of natural mortality of 0·14.

Table 6

Celtic Sea herring; annual estimates of total catch, drifter catch per effort, and equivalent total effort

Year	Total catch in 1000 metric tons	Drifter metric tons/ landing	Total effort as drifter landings
1951	3·0	14·50	206·9
1952	4·1	7·95	515·7
1953	3·8	8·85	429·4
1954	4·9	15·70	312·1
1955	7·7	13·80	558·0
1956/57	10·3	9·35	1,101·6
1957/58	25·8	11·80	2,186·4
1958/59	23·5	10·25	2,292·7
1959/60	14·1	7·60	1,855·3
1960/61	14·4	–	–
1961/62	10·9	–	–
1962/63	10·7*	–	–

Owing to the adoption of new base lines by the Irish Government in 1961, no English drifters have taken part in the Dunmore winter fishery in recent years. The amount of trawling by Dutch and German vessels has also been affected to some extent. The effort has varied widely, so that some of the variation in mortality rates in Table 5 may be ascribed to poor sampling and the variable effort. As a means of smoothing out some of the variability in catch per effort the annual value for each country has been expressed as a ratio from each national series mean, and the ratios for similar periods of time have been compared between different countries. The method of calculation of the smoothed catches per effort is set out below:–

Year	Catches/effort		Ratio of annual c.p.e. to period mean			Smoothed c.p.e.	
	Dutch	German	Dutch	German	Mean	Dutch	German
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1957/58	228	16	1·65	1·25	1·45	201	19
1958/59	98	7	0·71	0·55	0·63	87	8
1959/60	103	5	0·74	0·39	0·57	79	7
1960/61	110	21	0·79	0·64	1·22	169	16
1961/62	154	15	1·11	1·17	1·14	158	15
Mean	138·6	12·8					

* Excludes Russian catch (not available).

Taking the annual catches per effort from Dutch and German sources for the period 1957–61 a mean for each series of data has been calculated and these means are shown at the bottom of columns 2 and 3. For each series the annual catches per effort have been expressed as a ratio of these period means (columns 4 and 5). If both Dutch and German vessels were fully exploiting the available stock in a similar manner then the variations in the abundance index should be the same. There is no reason to suppose that this is not so. Variations between years or countries in the ratios in columns 4 and 5 are probably due to minor variations in effort or availability, or such similar causes. Smoothing out such variation may be obtained by taking means of the ratios (column 6). When these means are multiplied by the mean catches per effort for the period (from columns 2 and 3), smoothed annual catches per effort are obtained (columns 7 and 8).

For the period 1957/58 to 1959/60 Dutch, German and English catches per effort are available. Some of the stages in the calculation of the smoothed catches per effort are shown below:–

	Ratio				Smoothed c.p.e.		
Year (1)	Dutch (2)	German (3)	English (4)	Mean (5)	Dutch (6)	German (7)	English (8)
1957/58	1·59	1·72	1·20	1·51	214	14·0	15
1958/59	0·69	0·75	1·00	0·81	116	7·5	8
1959/60	0·72	0·54	0·80	0·69	99	6·4	7

Using the same technique as described above, the ratios of each serial annual mean to the grand mean for the period have been calculated (columns 2, 3 and 4). These values have been meaned (column 5) and by multiplication with the appropriate periodical catch per effort the smoothed catches per effort have been derived (columns 6, 7 and 8).

Taking each period of overlapping national catches per effort, smoothed catches per effort have been calculated. In the case of the 1957/58 season the Dutch data have been smoothed in two ways: firstly, using the Dutch and German data for the period 1957/61 and secondly, using the Dutch, German and English data for 1957/58. The values of catch per effort so obtained were 201 and 214 tons/100 hours fishing respectively. Finally, these were meaned to give the values shown in Table 7. Similar smoothed values were derived for each season and for each national catch (Table 7).

Table 7

Dunmore herring fishery; smoothed catches per effort

Year	Dutch (tons/100 hrs)	German (tons/fishing day)	Irish (crans/trawler landing)	English (crans/drifter shot)
1957/58	207	16	–	15
1958/59	107	9	24	8
1959/60	103	8	26	7
1960/61	146	16	34	–
1961/62	144	14	28	–
1962/63	156	–	34	–

Owing to the cessation of fishing by English drifters in 1959 it is necessary to convert one of the other national series of catches per effort for the period 1960/63 to equivalent drifter catches per effort. The Dutch smoothed catch per effort for 1957/58 has been taken as standard and each subsequent annual catch per effort has been expressed as a ratio of this value. These have then been used to calculate equivalent drifter catches per effort. The calculations are set out below:–

Season	Smoothed Dutch catch/effort	Ratio	Smoothed English catch/effort	Equivalent smoothed English c.p.e.
1957/58	207	1·00	15	15·0
1958/59	107	0·52	8	7·8
1959/60	103	0·50	7	7·5
1960/61	146	0·71	–	10·7
1961/62	144	0·70	–	10·5
1962/63	156	0·75	–	11·3

From the total catch data of Table 6 estimates of the effort as drifter landings (smoothed) have been derived. These estimates, together with the unsmoothed drifter landings, are given in Table 8.

Table 8

Estimates of total effort as equivalent drifter landings, and values of *F*

Years	Unsmoothed	Smoothed	F
1951	206·9	–	0·06
1952	515·7	–	0·15
1953	429·4	–	0·12
1954	312·1	–	0·09
1955	558·0	–	0·16
1956/57	1,101·6	1,722·9	0·50
1957/58	2,186·4	1,722·9	0·50
1958/59	2,292·7	3,006·9	0·87
1959/60	1,855·3	1,880·1	0·54
1960/61	–	1,342·0	0·39
1961/62	–	1,041·8	0·30
1962/63	–	944·2	0·27

In Figure 11 the regression of total mortality on equivalent drifter effort is shown. The effort figures are the smoothed values of Table 8, and the total mortality estimates used are those of Table 5, based on the national catches per effort. The instantaneous mortality coefficient has been plotted on the

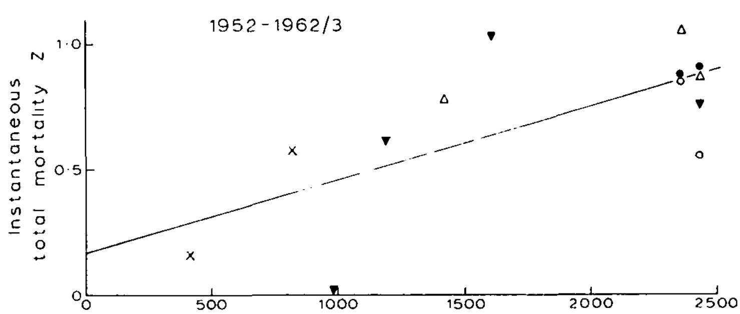

Figure 11. Dunmore herring; regression of instantaneous total mortality on smoothed drifter effort.

Table 9

Mean percentage age composition × English smoothed catch/effort in metric tons/landing

Year	Age 2	3	4	5	6	7	8	9	10	>10
1952	0·16	2·96	2·00	2·00	1·28	0·16	–	0·16	–	–
1955	–	0·42	3·36	2·52	2·80	2·38	1·54	0·42	0·28	0·14
1957	–	3·45	3·30	1·05	3·30	1·20	1·35	0·90	0·45	0·15
1958	0·23	0·31	2·26	1·48	0·62	1·25	0·70	0·47	0·47	0·16
1959	0·08	2·40	0·53	1·80	0·90	0·38	0·90	0·15	0·15	0·23
1960	0·43	5·24	2·57	0·21	0·86	0·43	0·54	0·21	0·11	0·11
1961	0·37	1·89	5·30	1·10	0·32	0·68	0·16	——	0·68	——
1962	0·34	2·26	2·15	4·18	0·79	0·23	0·68	0·34	0·23	0·23

mean effort for the years of the corresponding age data. Again a highly significant regression results, with an estimated value of M of 0·17. Using this regression, values of F equivalent to the annual effort have been calculated and are given in Table 8.

Some of the variability in the mortality rates of Table 5 may be due to poor sampling for age. In order to reduce this effect somewhat, all the percentage age compositions for each year have been combined and have been raised by the equivalent drifter catch per landing derived from the effort data of Table 8, and are shown in Table 9.

Instantaneous mortality coefficients have been calculated from these data. When the regression of total mortality (ages four to eight) on mean effort was calculated the regression was not significant, though an estimate of M of 0·13 was obtained. Cushing (in press) has shown that in a seasonal fishery, like that in East Anglia, the best relation between mortality and effort is obtained when the mortality is referred to the effort in the second year of the pair. The previous sets of regressions have been re-calculated in this manner. All estimates of M are shown in Table 10. The mean of these estimates is 0·18; this value of M is perhaps too high, being weighted by the high value of 0·27 and the less reliable pre-war estimate of 0·20.

Table 10

Dunmore herring stock; estimates of M

Year	Source of Z	Value of M: Mean effort	Effort in last year	Summed effort
1952–59	National estimates	0·14	0·13	–
1952–63	National estimates	0·17	0·27	–
1952–63	Smoothed drifter (from Table 9)	Non significant	0·13	–
1906–38	Milford trawl catches (Fig. 6)	–	–	0·20
	Mean M	0·155	0·177	0·20

IV. Discussion

It has been demonstrated in both the pre- and post-war periods that with increased fishing effort in the Celtic Sea there was a significant increase in total mortality in the Dunmore stock. With the increase in mortality from 0·19 to 1·02 we have seen an increase in total catch from some 3,000 tons to 24,000 metric tons. Zijlstra and Postuma (1963) have derived a significant regression

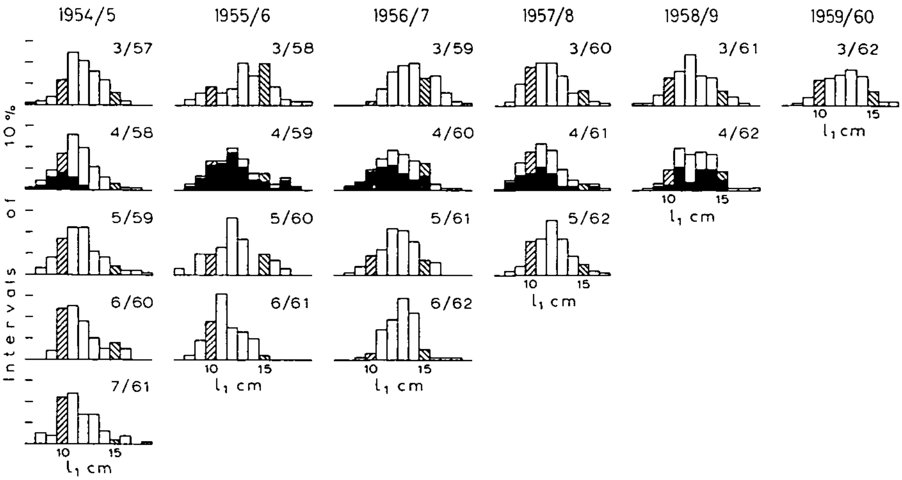

Figure 12. Dunmore herring; L_1 distributions for recent year-classes. The black histograms are the calculated L_1 distributions of the recruiting four year-old fish.

of total mortality on effort for the total North Sea catches. From 1946–50 the mean annual catch was of the order of 540,000 metric tons, with a mean Z of 0·44; during the period 1955–60 the mean annual catch rose to 780,000 metric tons and the mean Z to 0·76. Thus the lowest mean North Sea total catch was some twenty times greater than the maximum yield from Dunmore, yet the observed total mortality was some two to three times higher.

Compared with the North Sea stocks and considering the differences in sustained effort involved, the Dunmore stock must be relatively small. Comparatively small changes in effort have produced rapid variations in total mortality. The ability of the stock to sustain a high total mortality is further affected by the fluctuations in year-class strength from year to year; as can be seen in Table 9 changes in year-class strength of five and ten times have been recorded. The problem of recruitment is discussed in the next section.

V. Recruitment, Growth and Stock Assessment

By inspection of Table 9 it can be seen that recruitment to the fishery takes place over at least three age-groups, viz. two, three and four. In Figure 12 are shown the L_1 distributions of recent year-classes, derived from a combination of English and Irish data. It is seen that an increase in the proportion of low L_1 fish occurs in the four year-olds. In order to estimate the extent and manner of the recruitment in the four year-olds, the percentage L_1 distributions of the three and four year-olds have been raised by the respective catches per effort for each year-class. Using the mortality estimates in Table 8 the L_1 distribution of the survivors from three to four years of age has been calculated, and by subtraction the L_1 distribution of the recruiting four year-old fish has been derived; these are indicated in Figure 12. On average 35% of the stock are recruited as four year-olds. This is in marked contrast to the recent situation in the North Sea Downs stock where almost all, if not all, recruitment has been completed at three years of age.

It is not possible to determine whether the present Dunmore stock has experienced a growth change similar to that found in the North Sea. Critical data for before1957 are not available. However, some hint may be derived from examination of the L_1 data of GILIS (1953, 1956) and the more extensive length-for-age data from the pre-war period. The data of GILIS, being from the Smalls fishery, are unlikely to provide fully representative numbers of three year-old fish as recruit spawners. The mean L_1s of the older, fully recruited fish should be fairly representative of the spawning stock. An increase in growth rate might be more easily detected in L_1 than in total length-for-age in the adult fish. The mean L_1 values of the four year-olds in the recent year-classes are given in Table 11, together with the earlier data from GILIS (1953, 1956).

Table 11

Mean L_1 (cm) for fully recruited year-classes of Celtic Sea herring

Year-class	Mean L_1 values of four year-olds	Year-class	Sampling year 1952 Mean L_1	Sampling year 1955 Mean L_1
1954	11·8	1946	11·0 (21)	12·1 (13)
1955	12·8	1947	12·6 (32)	12·5 (50)
1956	13·1	1948	11·4 (32)	12·3 (75)
1957	11·7			
1958	13·0			
1959	12·5			

Note: Numbers in parentheses are the numbers of fish in the age samples and are not necessarily the same as those from which the mean L_1s are derived.

No striking difference in mean L_1 between the two sets of data is seen. Such differences as do exist, e.g. in relation to the 1946 year-class, might be considered as due to the low sampling level.

The mean lengths-for-age derived from various sources are given in Table 12. No trend in mean length with time can be observed in these data. It would seem that no growth change similar to that seen in the North Sea stocks has taken place in the herring of the Celtic Sea.

Table 12

Mean length-for-age of Dunmore herring (in cm)

Years	Age 3	4	5	6	7	8	9	10	Source
1921/23	24·5	26·4	28·2	29·1	29·7	29·9	–	–	LE DANOIS and HELDT (1924)
1923/30	25·5	26·8	27·6	28·7	29·3	29·7	30·1	–	WATKIN (1933b)
1926/30	26·3	27·7	28·5	28·9	29·2	29·8	29·9	–	WATKIN (1933a)
1952	24·3	25·2	27·0	27·4	28·4	–	28·4	–	GILIS (1953)
1955	24·1	26·1	27·3	28·5	29·0	29·4	30·2	30·3	GILIS (1956)
1957	25·0	26·4	27·7	28·2	28·8	29·2	29·5	29·6	GILIS (1958)
1957/58	25·0	26·9	27·9	28·3	28.6	29·4	29·3	–	BURD
1958/59	26·1	27·1	27·9	28·6	28·8	29·4	29·5	30·1	BURD
1958/59	24·1	26·7	27·8	28·7	29·2	29·6	29·8	29·4	BRACKEN
1959/60	25·9	27·7	28·0	28·7	29·4	29·4	–	–	BURD
1959/60	24·3	26·9	27·8	28·5	28·9	29·2	29·7	29·5	BRACKEN
1960/61	24·3	26·6	28·2	28·7	28·8	29·4	29·2	29·7	BRACKEN
1961/62	24·8	26·4	27·8	28·8	28·9	29·4	29·8	30·1	BRACKEN
1962/63	25·5	26·7	27·4	28·5	29·2	29·3	29·5	29·6	BRACKEN
1963/64	25·4	28·2	28·7	29·2	29·7	30·0	30·3	30·3	BRACKEN
$\bar{X}$	25·01	26·79	27·85	28·59	29·06	29·51	29·63	29·84	–

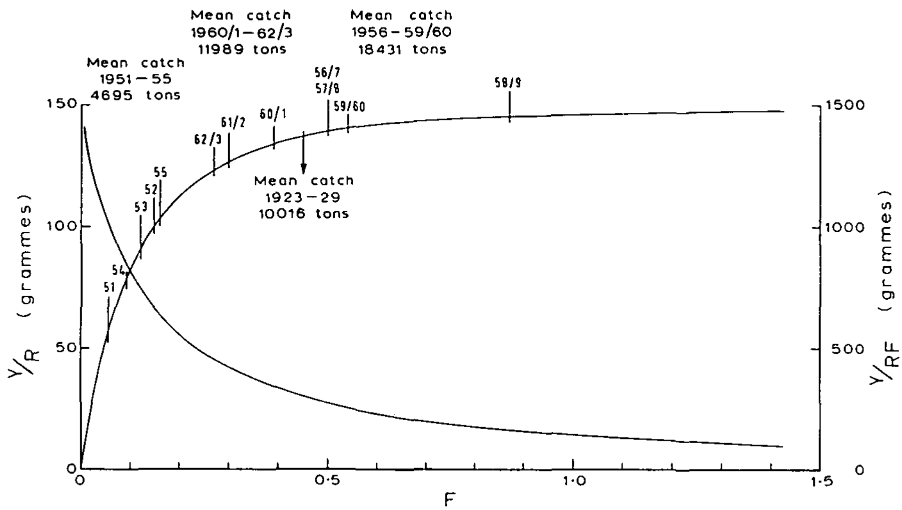

Figure 13. Yield curves for Dunmore herring. The values of F corresponding to the efforts in Table 8 have been shown on the yield per recruit curve.

In view of the similarity of the mean lengths for age in Table 12, a grand mean has been taken for each age. These data were used to obtain the growth constants of the von Bertalanffy growth equation. In fitting this curve, the mean length for three year-olds has been disregarded as being, due to partial recruitment, unrepresentative of the population of three year-old fish. The parameters of the growth curve obtained were as follows:

L_∞	W_∞	K	t_0
30·1 cm	236·0 g	0·40	−1·51 years.

In calculating the yield per recruit curve for the Dunmore stock, use has been made of the Tables of Yield Functions for Fish Stock Assessment (BEVERTON and HOLT, 1964). In these tables the original form of the yield equation has been modified by assuming that there is no upper limit to the lifespan.

The value of l_c has been taken as that of the mean length of the three year-olds, i.e. 25·0 cm. Taking $M = 0{\cdot}15$, the yield per recruit curve, as at age three, is shown in Figure 13. On this curve the values of F derived from the data of Table 8 have been indicated for each year. Also in Figure 13 is shown the theoretical yield per recruit per unit effort curve.

It is seen that the series of years fall into three groups, 1951–55 with low effort, 1956–60 with very high effort, and the period from 1961 when there was a reduction in total effort. The mean total annual catches for the three periods are also shown. From the pre-war data of WATKIN a total mortality of 0·65 was obtained for the period 1923–1930 and an estimate of natural mortality of 0·20 was made. This implies that a fishing mortality of 0·45 was generated by the fisheries of 1923–29, when a mean annual catch of 10,016 metric tons was taken. This value of F has also been indicated in Figure 13.

Table 13

Values of F, total catch, yield per recruit (Y/R), and yield/recruit/unit effort (Y/FR), for various periods

	1951/55	1956/60	1961/63	1923/29
F	0·12	0·60	0·32	0·45
Catch in metric tons	4,695	18,431	11,989	10,016
Y/R(g)	125	147	140	138
Y/FR(g)	460	180	270	300

For these four periods the theoretical yields at steady state and constant recruitment, and the actual catches, are set out in Table 13. In order to compare these data more easily they have been expressed as ratios of the values for the 1951/55 period (Table 14).

Table 14

Values of F, catch, Y/R and Y/FR expressed as ratios of 1951/55 values

	Ratio of the 1951/55 values to those for		
	1956/60	1961/63	1923/29
F	5·00	2·67	3·75
Catch	3·93	2·55	2·13
Y/R	1·18	1·12	1·10
Y/FR	0·39	0·59	0·65

The effect of increasing effort by five times between 1951/55 and 1956/60 was to increase the total catch by nearly four times, while the theoretical steady state equilibrium catch would only have increased by 1·18 times. This is understandable, in that the actual catches for the period 1956/60 are still transitional ones in which the high fishing rate is being supported by the residue of the old stock. In fact, though the mean catch for the period 1956/60 was 18,431 tons, the highest seasonal total was 25,844 tons in the season 1957/58. By 1959/60 it had dropped to 14,101 tons. Even the mean of 18,431 tons is probably too high if considered as the equilibrium catch for that period.

At the lower rate of fishing intensity of 1961/63 it is seen that the steady state yield per recruit, Y/R, is only some 5% less than that under the previous higher fishing intensity (Table 13). However, the value of catch per effort, Y/FR, is some 74% greater. The pre-war period shows a higher effort than 1961/63, yet a lower total catch. LUNDBECK (1959) has shown that the post-war German trawler fleet has increased its efficiency over the 1930 level by about 20%. For North Sea herring trawlers in particular, if the performance figure for 1930 is taken as 110, by 1951 this had risen to 167, an increase in efficiency of some 52%. For the period 1923/29 a total catch comparable with present-day efficiency would have been some 15,000 tons, i.e. 3·24 times the catch in 1951/55. This is close to the observed relative increase in F.

It would seem from the above analysis that for long-term exploitation of this stock to give a maximum economic yield in terms of catch and catch per effort, stabilization of fishing intensity at about 0·50 would result in total catches of the order of 12,000 to 15,000 tons. This, however, assumes constant recruitment.

The quantity of recruits, as three year-olds, has been calculated from the age data of Table 9. If R_3 is the stock index of recruits as at three years of age then:

$$R_3 = n_3 + (n_4 - n_3e^{-Zt})e^{mt} + (n_5 - n_4e^{-Zt})e^{2mt},$$

where n_3, n_4, n_5 are the catches per effort of the year-class in successive years, and Z is the instantaneous coefficient of total mortality.

Taking the four year-classes for which data were available up to five years of age, the mean numbers of three year-old fish recruiting as four and five year-olds were 1·09 tons/landing and 0·09 tons/landing respectively. Little recruitment was demonstrated among the five year-olds. For this reason, recruitment will be considered complete at four years of age in this material. Recruit indices for the 1949 and 1952 year-classes have been obtained by back calculation, using estimates of Z, from the regression of mortality on effort in Figure 10 for the missing years. The resulting estimates of year-class strength as three year-old recruits are given in Table 15.

Table 15

Estimates of three year-old recruits

(in metric tons/drifter landing)

Year-class	Tons/landing	Percentage recruiting at four years old
1949/50	6·23	52·5
1952/53	2·51	83·3
1954/55	4·38	21·2
1955/56	0·77	59·7
1956/57	3·91	38·6
1957/58	7·77	32·6
1958/59	3·01	37·2
Mean	4·08	46·4

Table 16

Estimates of recruitment as fully recruited three year-olds

(in metric tons per landing)

Year-class		From Table 15
1947/48	1·75	–
1948/49	1·43	–
1949/50	4·96	6·23
1950/51	3·16	–
1951/52	4·72	–
1952/53	1·16	2·51
1953/54	4·02	–
1954/55	3·46	4·38
1955/56	1·41	0·77
1956/57	6·23	3·91
Mean	3·23	3·56

It can be seen that with the exception of the 1955/56 year-class the fluctuations in year-class size are not very great. Unfortunately, the number of year-classes is rather low. By means of a technique developed by a colleague, Mr. David GARROD, a further set of recruit estimates has been made. If the $\log_e$ of the catch per effort of a year-class at each age is plotted on the cumulative effort exerted from recruitment, then the intercept on the Y-axis is a measure of the stock size at recruitment. In Figure 14 the data for the 1953 year-class are presented. The value of catch per effort for the four year-olds in 1957 is regressed on the effort in the previous year. The values of the recruit estimates

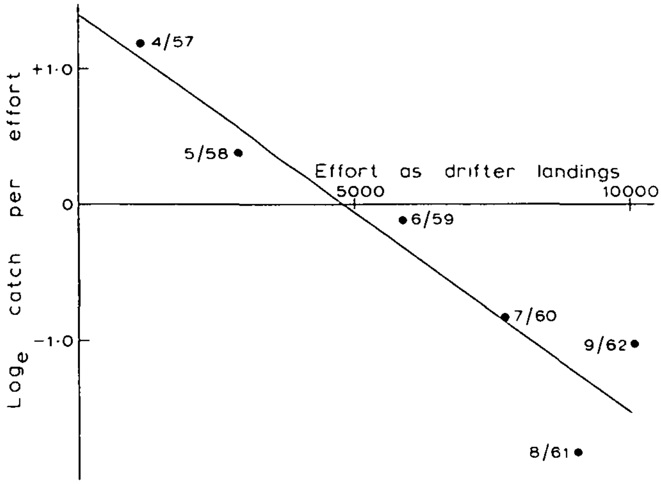

Figure 14. Dunmore herring; regression of log$_e$ catch per effort of the annual estimates of abundance of year-class on cumulative effort (drifter landings).

so obtained are catches per effort as three year-olds, as if full recruitment took place at this age. They are, then, only relative estimates and not absolute measures of recruitment. The estimates obtained by this technique are given in Table 16, with those from Table 15 for comparison. This method has some advantages over the previous one, in that it uses all the information available from the age data of the relative strength of an age-group. Poor estimates of the catches per effort of either three or four year-olds are likely to give biassed estimates of recruitment by the other technique.

Comparing the two sets of data one can conclude that the variations in annual recruitment have been relatively small in the recent period. Accepting, therefore, that the recruitment has been fairly stable, stabilization of effort to give a value of F about 0·50 would give catches oscillating about 15,000 tons. In a period in which a succession of high recruit classes entered the fishery, the fishing effort could be regulated in such a way as to raise the annual yield but still not induce too drastic a reduction in stock. In a series of years of low recruitment, curtailment of fishing would maintain the stock so that a minimum period would be required for re-stabilization. With the major spawning grounds (where the intense fishery takes place) situated within Irish exclusive fishery limits, there is considerable scope for the control of effort in such a way that, for the first time, a herring stock might be rationally exploited.

Summary

1. The annual yield of the herring fisheries based on the stock spawning off the south Irish coast has varied from some 3,000 metric tons to a maximum of about 26,000 metric tons.

2. From the catch and effort data for the period 1906–36 and age data for the period 1923–30, it was possible to demonstrate a relation between mortality and effort. From these data an estimate of natural mortality of 0·20 was made.

3. During the period 1946–64 the mean instantaneous total mortality has increased from 0·16 to 0·75 in 1957–61, when the catch was highest.

4. Significant regressions of instantaneous total mortality on effort were obtained. For the period 1952–63 a mean estimate of natural mortality of 0·166 was obtained.

5. Comparisons were made between the observed total catches and the theoretical yields per recruit at various levels of fishing mortality. Under steady recruitment, stabilization of fishing intensity to give a value of instantaneous fishing mortality of 0·5 would result in long-term yields of the order of 12,000–15,000 metric tons annually.

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