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MORTALITY RATES OF THE HERRING STOCK IN THE NORTH-WESTERN NORTH SEA

by

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Summary

Mortality rates for the Buchan herring stock, calculated from unmodified catch-per-unit-effort estimates of the Scottish drift-net fleet may have been biased in recent years by a tendency for the fleet to concentrate in a smaller and smaller area of high stock abundance. To correct for this abundance indices have been calculated for each year from 1957 to 1969 on a statistical square basis and summed over the total area of distribution of the stock. The resulting mortality rates are higher than those derived from an overall catch-per-unit-effort and show a greater increase in the period after 1963-64 when the stock is known to have been subject to much heavier exploitation. These new mortality estimates show a significant regression on estimates of the fishing effort on this stock. The intercept on the mortality axis gives an estimate of natural mortality of 0.23 for this stock.

Introduction

Mortality rates for the herring stock spawning in the north-western North Sea, based on the catch-per-unit-effort, and age compositions of the catches, of the Scottish drift net fleet are available from 1930-31 to date (Parrish and Craig 1963, Parrish 1966, Saville 1967). These have been widely used by various North Sea Herring Assessment Groups, because of the long series of data available, and because the Scottish drift net fishery has probably been subject to fewer changes in factors affecting fishing efficiency than any of the other fleets which have consistently exploited this area.

The Scottish drift-net fishery in this area however, has undergone considerable changes which must cast some doubt on the validity of using an unmodified catch-per-unit-effort as an index of stock abundance and so on the reality of mortality rates derived from these stock abundance indices. One of the more striking changes has been the reduction in the size of the area fished by the Scottish fleet over the past fifteen years. Unmodified catches-per-unit-effort are a valid estimate of stock abundance in the situation where fishing is distributed independently of the distribution of fish or when the fish are distributed evenly over the whole area. Neither of these conditions apply in the case of a herring fishery and it is possible that as a herring stock decreases in abundance the area over which it is distributed decreases rather than its density within the area of distribution. A herring fleet can aggregate onto the area of greatest density of fish so quickly that, in this situation, the catch-per-unit-effort could then remain virtually unchanged despite a major decrease in stock abundance, and the only evidence of this decrease would be the reduced area within which the fishing took place. This is the situation in the Scottish drift-net fishery where the catch-per-unit-effort has shown little change in the post-war period but there have been major changes in the distribution of fishing.

Boerema and Zijlstra (1964) and Zijlstra and Postuma (1971) have discussed an analogous situation in the Downs stock when the duration of the fishing season rather than the area of it declined as the stock decreased in size.

In this paper an attempt has been made to derive stock abundance indices which correct for changes in the distribution of fishing and to estimate from these mortality rates for the Buchan herring stock.

Material and Methods

Data are available which permit all catches of herring landed at Scottish ports to be allocated to the appropriate ICES statistical square (1^{o} longitude by $\frac{1}{2}^{o}$ latitude). From these data and information on the numbers of nets shot by each vessel the mean catch per 100 nets shot in each square fished in each month can be calculated. These have been converted to numbers of fish from data on the numbers of fish per cran for that square in that month. Regular sampling of the commercial catches for age and racial composition provided the data to convert these indices of total stock abundance to catches per 100 net shot of each age-group of autumn spawned fish. From these data the catch in numbers of each age group per 100 net shot in each statistical square fished by the Scottish drift-net fleet can be determined for each of the years 1957-1969.

It is known that the herring population fished in the north-western North Sea in the period May-July consists of a mixture of all of the major spawning stocks of the North Sea (Cushing and Bridger 1966, Anon 1965). As the objective of this paper is to obtain mortality rates for the Buchan spawning stock consideration of these data has been restricted to the month of August when this stock reaches its peak of spawning activity and when other information suggests that the Dogger and Downs components have left the area at the end of the feeding period (Cushing and Bridger 1966). A more difficult problem is to delimit the area of distribution of the Buchan stock in this month and in particular its southern boundary. It has been assumed that this stock in August occupies the area in the north-western North Sea west of 1^{o}E and north of 56^{o}N. These are also the limits which have been used to delimit the distribution of larval production of the Buchan spawning stock (Saville 1971) and are in agreement with the area from which the data for previous mortality calculations for this stock have been collected.

Averaging the statistical square abundance indices would give a better index of the total abundance of the stock than using the total catch throughout the whole area fished divided by the total effort, in that it would reduce the bias introduced by the tendency of fishing effort to concentrate in areas of high fish abundance (Gulland 1955). However, it would still tend to give a biased index if all of the fleet concentrated in areas of high abundance as may well have happened in recent years as the size of the Scottish fleet and the area fished by it has decreased. It has, therefore, been assumed that members of this stock are present in all squares, within the limits of the area defined above, where some catch has been reported in August in the international herring catch statistics published in Statistical News Letters. Catch-per-unit-effort indices, in Scottish drift-net catch per 100 nets units, have been calculated for all such squares not fished by the Scottish fleet by taking the catch-per-unit-effort of some other country fishing that square in August of that year and multiplying by a conversion factor to Scottish units. The conversion factors used are given in Table 1. These were obtained by averaging all catch-per-unit-effort ratios, between that country's effort, and Scottish effort in squares fished by both units of effort in August. This was first done on an annual basis but, as there was no trend in any of the ratios with time it was assumed that there was no major change in the efficiency of these other units of effort relative to the Scottish one over the period considered and that the overall mean provided the best measure of relative fishing powers.

These total catch-per-unit-effort indices were then converted to catches-per-unit-effort of each age-group of autumn spawners by using Scottish age and racial data for adjacent squares. The indices of abundance for each age group in each square were then summed and divided by the total number of squares in the area to give an average index for the whole area.

Results

The resulting indices of abundance are given in Table 2, and the instantaneous total mortality rates calculated from them, in Table 3. In both cases the corresponding total abundance indices and average mortality rates on an unmodified catch-per-unit-effort basis are also given for comparison. It can be seen from Table 2 that relative to the index of abundance over the whole distribution of the stock, the Scottish fleet has consistently improved its performance since 1961. This would support the suggestion that in later years the Scottish effort has been progressively concentrating more and more on the areas of greatest stock abundance. It is also apparent from the abundance indices per age group given in Table 2 that (a) since 1963 the stock has contained a higher proportion of 3 years old fish than in the preceding period and (b) that in absolute terms the abundance of 3 years old recruits has been significantly higher since 1963 than it was in the previous period.

The mortality rates given in Table 3 differ in two major respects from those calculated from unmodified catches-per-unit-effort: (a) they contain no negative values which, because of annual differences in availability to capture, are normally a feature of drift-net mortality rates and (b) they are in general higher than the unmodified catch-per-unit-effort ones. Although these estimates for mortality rates contain no negative values it would appear that they are still subject to some differences from year to year in availability to capture by drift-net. This, for example, would seem the most likely explanation of the very low mortality calculated for 1965-66 when the stock was undoubtedly subjected to very heavy fishing pressure. Despite this these new mortality rates would seem to be more realistic than those estimated previously. The unmodified ones in the periods prior to and including 1963-64, and after 1963-64, give mean mortality rates of 0.52 and 0.57 respectively. It is known that the catches of Buchan fish were much higher and the stock was much more intensively fished after 1963-64 than in the previous period yet the difference in the mean mortality rates between the two periods on these estimates is negligible. The new mortality rates on the other hand give mean mortality rates in these two periods of 0.59 and 0.87 respectively. This increase in mortality seems much more realistic.

Perhaps the best test of the reliability of mortality estimates is the relation they bear to some measure of fishing effort on the stock. The problem normally is that of estimating valid measures of fishing effort on the stock in question. The North Sea Herring Assessment Group (Anon 1970) gave two estimates of fishing effort on herring in the north-western North Sea, one based on catch-per-unit-effort of the Scottish drift-net fleet, the other on the catch-per-unit-effort of Dutch trawlers. These two sets of effort estimates do not bear a constant relationship to one another, presumably at least in part because of the differing availability from year to year to trawl and drift-net capture. As there is no basis for considering one more reliable than the other the mean of the two has been taken as the best index of effort in the north-western North Sea.

However, this stock is fished not only in the north-western North Sea during the summer feeding and spawning fisheries but also, at this time, in the southern part of its range in the central North Sea and during the winter and spring periods in the north-eastern North Sea. The total catches of herring taken in these three areas in terms of numbers of fish per age group are given in the Report of the North Sea Herring Assessment Working Group (Anon 1970). The mortality rates given in Table 3 refer only to autumn spawned fish with 2 or more winter rings. Accordingly the catches per age-group in each of these areas has been summed for fish with 2 or more rings to give a total catch in each area. A more difficult problem, and one for which currently there is no firm solution, is the proportions of the various North Sea autumn spawning stocks in the north-eastern and central areas. For the former it has been assumed that the only major components of autumn spawning fish in the area are Buchan and Dogger stocks and the total catch by numbers in each year has been partitioned between these two stocks in proportion to their larval abundance indices for that year. For the central North Sea the catches reported in Statistical News Letters from that area have been summed for statistical squares north of and south of 56°N in each year and the ratios of the total catch reported from north of 56°N to the total for area IVb has been taken as the proportion of Buchan fish in the total central North Sea catch for that year. By then summing the estimated catches of Buchan fish in the three areas total catches of Buchan fish in each year were obtained as given in Table 4. The effort estimates for the north-western North Sea were then multiplied by the ratio of the total catch of Buchan fish to the total catch in the north-western North Sea to give an index of total effort in each year on the Buchan stock. The resulting annual estimates of effort are also given in Table 4. As the mortality estimates are measured from August of one year to August of the following year the means of each year-pair have been taken as the relevant measure of effort. These have been plotted against the corresponding mortality rates in Figure 1, which also shows the fitted regression line $Z = 0.234 + .00646X$ where Z = total instantaneous mortality rate and X = fishing effort calculated as described above. This regression is significant at the 0.002 probability level if one omits the dubious value for 1965-66. It is also of interest that the intercept on the Z axis, ie at no fishing effort and so corresponding to natural mortality is 0.234 ± 0.005 close to the value widely accepted as the best approximation to the probable natural mortality rate in an adult herring population. The 1965-66 mortality is obviously under-estimated and it would seem best to omit this point from the regression. Even if it is included however, the regression is still significant at the 0.02 probability level and the intercept is not very different at 0.230.

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TABLE 1

Factors used to convert catches per unit effort by other fleets to equivalent Scottish drift-net catches per 100 nets shot.

Type of Effort	Conversion factors
German lugger trawl per 10 days fishing	0.0836
German lugger drift-net per 10 days fishing	0.0871
Netherlands herring trawl per 100 hrs fishing	0.0673
Netherlands drift-nets per 10 shots	0.1009
Polish steam trawl per 10 days fishing	0.0387

TABLE 2

Abundance indices in numbers of Autumn spawned fish per 100 net shot by Scottish drifters in the North-Western North Sea in August, 1957-1969.

Age Year	3	4	5	6	7	8	>8	Σ	Σ (C/E) ($^1/_{10}$ cran per shot)
1957	9520	4900	5017	1642	1082	743	2076	24979	206.4
1958	2160	6187	2521	2990	1167	671	1024	16721	204.5
1959	17500	1349	2665	839	1334	367	419	24473	211.6
1960	5632	12768	290	1244	372	537	513	21357	188.1
1961	825	1879	9610	519	1436	726	954	15949	209.9
1962	1781	827	897	3607	194	388	455	8150	119.0
1963	12835	496	469	569	3292	108	620	18439	278.0
1964	7809	7183	255	187	345	1415	270	17465	237.8
1965	7885	2548	4103	96	122	191	1192	16137	210.3
1966	17830	6376	2876	4825	129	74	1473	33583	311.9
1967	3081	12113	2522	1268	2096	41	524	21645	422.8
1968	10280	1518	2516	440	545	450	338	16087	238.8
1969	9830	1098	647	474	289	147	373	12857	398.5

TABLE 3

Total instantaneous mortality rates of Autumn-spawned fish in north-western North Sea 1957-69

Ages Years	3-4	4-5	5-6	6-7	7-8	8+-≥8+	Average for age-group 3 and over		Ditto for C/E	
1957-58	0.43	0.66	0.52	0.34	0.47	1.01	0.54		0.20	
1958-59	0.47	0.84	1.10	0.81	1.16	1.40	0.87		1.25	
1959-60	0.31	1.53	0.76	0.81	0.91	0.43	0.44		0.42	
1960-61	1.10	0.28	-0.58	-0.14	-0.67	0.09	0.34	0.591	-0.05	0.521
1961-62	-0.03	0.74	0.98	0.98	1.31	1.31	0.92		0.74	
1962-63	1.28	0.57	0.46	0.09	0.59	0.31	0.38		0.52	
1963-64	0.58	0.66	0.92	0.50	0.84	0.99	0.65		0.57	
1964-65	1.12	0.56	0.98	0.43	0.59	0.35	0.75		0.49	
1965-66	0.21	-0.13	-0.16	-0.29	0.50	-0.06	0.03		0.52	
1966-67	0.39	0.93	0.82	0.83	1.14	1.08	0.59	0.872	-0.13	0.566
1967-68	0.71	1.57	1.75	0.84	1.54	1.23	1.32		1.34	
1968-69	2.23	0.85	1.67	0.42	1.31	0.75	1.67		0.61	

TABLE 4

Estimates of Total fishing effort on "Buchan" stock 1957-1969 and regression of mortality on fishing effort.

Year	Total catch of Buchan fish 3 years old	Catch of fish 3 years old in N.W. North Sea	Fishing Effort in N.W. North Sea	Total Fishing Effort on "Buchan" Stock	Mean effort of year pairs (X)	Total instantaneous mortality rate of "Buchan" stock (Z)
1957	1813.9 x 10^6	1197.9 x 10^6	31.3	47.3	44.2	0.54
58	1614.6 "	911.3 "	23.2	41.0	47.4	0.87
59	3171.5 "	2060.7 "	34.9	53.7	47.8	0.44
60	1486.0 "	622.4 "	17.5	41.8	41.1	0.34
61	1561.7 "	330.1 "	8.6	40.5	37.6	0.92
62	1257.7 "	220.6 "	6.1	34.8	66.7	0.38
63	1529.4 "	171.3 "	11.1	98.7	86.1	0.65
64	2393.7 "	360.0 "	11.0	73.5	98.5	0.75
65	4229.1 "	1758.9 "	51.3	123.5	112.1	0.03
66	3781.5 "	1571.2 "	41.9	100.7	80.7	0.59
67	2076.2 "	667.9 "	19.5	60.6	170.8	1.32
68	2534.5 "	1515.5 "	168.0	280.9	192.5	1.67
69	1929.6 "	1048.6 "	56.6	104.1		

Regression equation of mortality of Buchan stock on mean effort of year pairs (omitting 1965-66).

$\hat{Z} = 0.234 + 0.0065X.$ $t = 4.49$ $P = < .002$

Regression equation of mortality of Buchan stock on mean effort of year pairs (including 1965-66):

$\hat{Z} = 0.230 + .0056X.$ $t = 2.646$ $P = < .02$

FIG.I. PLOT OF TOTAL MORTALITY AGAINST EFFORT FOR N.W. NORTH SEA HERRING