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Recent changes in the stock of Celtic Sea herring (*Clupea harengus* L.)

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International catches of Celtic Sea herring during the years 1966–70 averaged about 30000 tons/year. This average was considerably above previous estimates for the maximum sustainable yield of this stock. A new assessment of the Celtic Sea herring stock has been made, using information on samples from Dutch catches during the years 1958–71. High catches in the years 1966–70 were caused primarily by an increased fishing effort, resulting in an accelerated depletion of older age groups. The increase in catch due to this cause will be mainly temporarily. A second reason for high catches during this period was an increase in level of recruitment by about 50%.

Introduction

Studies on the population dynamics of Celtic Sea herring have been published by Burd and Bracken (1965), Molloy (1969) and the Assessment Group on North Sea Herring (Anon., 1970). These authors concluded that the so-called "Dunmore" herring stock was of limited size, with a maximum sustainable yield between 15000 tons (Burd and Bracken, 1965) and 22000 tons (Molloy, 1969) per year.

Catches of Celtic Sea herring in recent years have been well above these figures for the maximum sustainable yield (Fig. 1). In the years 1966–70 the annual catch has fluctuated around 30000 tons, with a maximum of 47000 tons in 1969.

The question now arises as to whether the above estimates for the maximum yield were too low, or whether the high catches in recent years were only transitional ones, due to a sudden increase in fishing effort.

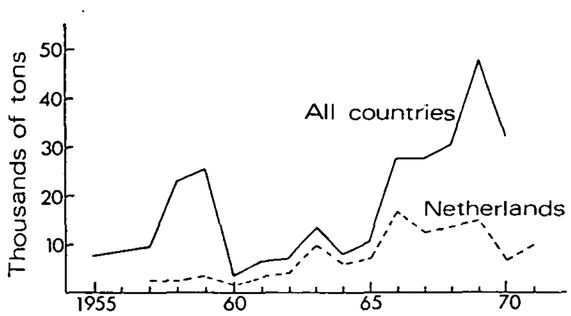

Figure 1. Annual catches of Celtic Sea herring. Total international catches from Bulletin Statistique, Dutch catches from national statistics.

Data on Celtic Sea herring have been collected by the Netherlands Fisheries Research Institute starting from 1958. Using this material, a new assessment has been made of the Celtic Sea herring stock, and the results are compared with earlier reports.

Material

Figure 2 shows monthly catches of herring by Dutch vessels in the Celtic Sea for the years 1957–71. Also indicated are the number of samples taken in each month. Samples consisted of 100–200 herring which were examined for length, sex and maturation stage. Age and racial characters were determined for 50 fish in each sample and the total age composition of the sample was calculated by means of an age-length key.

A gradual shift in the period of sampling can be seen, corresponding to changes in the fishery. During the years 1957–65 most herring was caught in December and January. Starting from the season 1966–67, fishing shifted to earlier months, partly because of an extension of Irish fishing limits which made the spawning grounds inaccessible to Dutch vessels.

In recent years samples of spawning herring have also been obtained from Irish catches, bought by Dutch vessels and shipped to Holland.

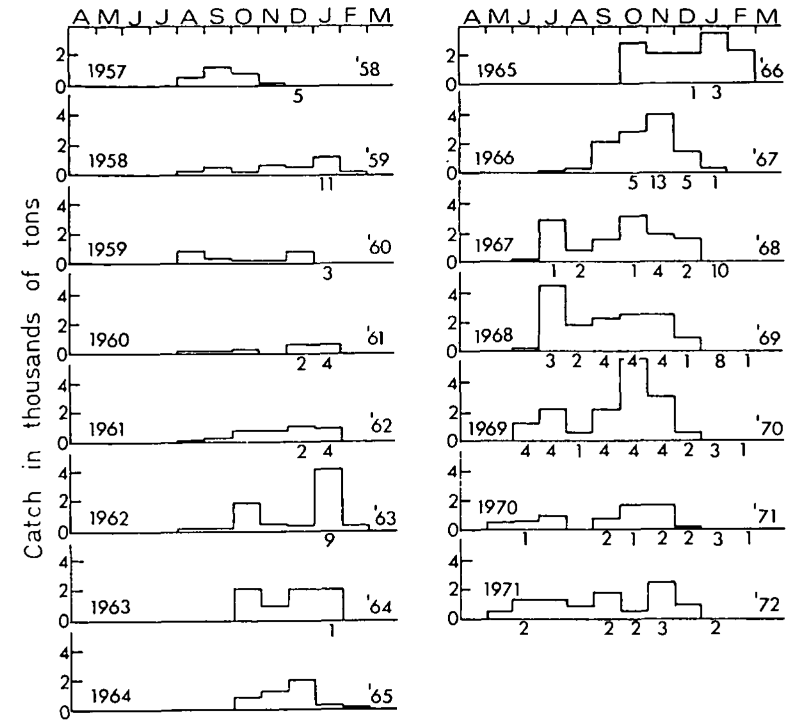

Figure 2. Dutch catches by month in thousands of tons and number of samples taken in each month (including samples from Irish catches).

Age composition

Table 1 gives percentage age compositions for three-monthly periods starting from 1957. Age is given in years of life, i.e. a three year-old fish is a fish in its third year of life. The 1st of April has been taken as the birthday of the Celtic Sea herring. Data for December–February, which constitute the longest series, have been derived mainly from samples of spawning herring. The percentage of 3 year-old fish is higher in samples from December–February than in samples from other months. Apparently, many herring do not recruit to the fishery until the spawning season in their third year of life. Age compositions in June–August are not very different from those in September–November.

Catch per unit effort and estimates of total effort

Catches per unit effort (cpe) for the Dutch trawl fishery have been calculated for the period June–August, September–November and December–February (Table 2). These three periods together cover approximately the whole fishing season for Celtic Sea herring. The division in three-monthly periods was made in order to detect whether changes in cpe would occur throughout the year, due to changes in fishing area and in availability of the herring. For the calculation of the cpe fishing effort was expressed in numbers of corrected fishing hours, i.e. fishing hours of a standard trawler of 500 hp.

Comparing the cpe values at different times of the year, it appears that differences do exist, mainly during the earlier years. Catch-per-effort data for the months June–August prior to 1966 are available only for some years. These data concern only small catches and little importance should be given to them. After 1966, the cpe in June–August fluctuated around 200 kg/h, without showing a distinct trend.

The cpe for September–November was at a minimum in 1960. It increased during the early "sixties" and reached a level of 300 kg/h in the years 1963–66. After 1966, the cpe gradually declined to a level below 200 kg/h.

The series of cpe data for December–February shows high, but also variable values for the years before 1966/67, followed by a sharp decline to a much lower level in recent years. This decline may be explained partly by changes that occurred in the fishery.

In the earlier years, the fishery in December–February took place on the spawning grounds close inshore. The cpe in this fishery was very high since the fish were easily available. This fishery, however, was strongly affected by the extension of Irish limits

Table 1. Percentage age composition of Celtic Sea herring by three-monthly periods. Samples from Dutch catches and from Irish catches bought by Dutch vessels

Season	Year	Age in years 2	3	4	5	6	7	8	9	10	10+	Number of samples	Number per kg
	1967	0	15·5	16·6	46·1	7·3	3·3	3·1	4·5	0·7	3·0	3	4·753
	1968	0	26·4	30·9	11·6	21·1	3·0	2·4	0·8	2·9	0·9	5	4·853
Jun–Aug	1969	0·4	27·3	32·1	21·3	5·8	10·0	2·2	0·4	0·4	0·3	9	5·057
	1970	0	12·7	51·4	20·3	15·6	0	0	0	0	0	1	5·283
	1971	0	11·3	34·8	31·2	17·2	4·1	0	1·4	0	0	2	4·933
	1966	5·9	12·9	49·4	7·5	9·9	4·0	3·0	4·8	1·7	0·9	18	4·925
	1967	3·6	18·2	13·3	31·9	6·2	10·0	3·1	5·8	5·4	2·5	5	4·590
Sep–Nov	1968	16·8	40·5	26·6	4·3	7·2	1·8	1·4	0·7	0·5	0·4	12	5·408
	1969	6·3	48·5	16·9	11·3	3·4	6·7	2·5	1·5	0·8	2·2	12	5·247
	1970	0·2	12·6	26·1	15·9	18·9	3·9	11·0	3·9	4·7	2·7	5	4·137
	1971	1·5	15·9	24·8	30·6	8·7	8·0	2·0	7·1	0·7	0·7	7	4·505
	1957/58	0	33·7	21·3	5·4	18·8	4·6	6·5	4·4	3·9	1·3	5	5·487
	1958/59	0	2·5	28·0	19·8	5·5	18·8	11·7	8·5	5·2	0	11	5·522
	1959/60	0·7	29·3	2·7	12·7	13·3	3·3	20·0	2·7	5·3	10·0	3	5·814
	1960/61	1·0	48·1	11·6	3·2	15·2	3·9	5·0	5·1	2·3	4·6	6	7·206
	1961/62	0	19·0	44·3	8·3	1·8	8·9	5·2	2·2	5·6	4·7	6	5·954
	1962/63	0·7	14·1	16·0	41·8	7·5	3·9	7·7	3·5	2·1	2·7	9	5·411
Dec–Feb	1963/64	–	–	–	–	–	–	–	–	–	–	1	–
	1964/65	–	–	–	–	–	–	–	–	–	–	0	–
	1965/66	0	57·4	6·5	12·5	2·5	3·7	9·7	1·0	0·5	6·2	3	6·062
	1966/67	4·9	16·3	37·2	8·0	10·4	3·8	3·3	11·4	1·9	2·8	6	4·985
	1967/68	9·3	35·3	11·2	24·2	4·6	5·9	1·6	2·1	4·3	1·5	12	5·539
	1968/69	4·2	42·5	18·1	7·1	14·8	3·9	4·8	1·0	1·2	2·4	10	5·122
	1969/70	3·8	59·5	15·5	9·9	2·5	5·7	1·1	1·0	0·3	0·7	6	6·025

to 3 miles in 1960, and again by the further extension to 6 miles after 1966. From 1966 onward, catches in the winter season consisted only of a small quantity of non-spawning herring, caught offshore in December. Thus, the sharp decline in cpe during the winter season was caused by changes in the fishery, rather than by changes in the fish stock.

It appears that cpe data for September–November form the most consistent series over the whole period of observations. In the years after 1965, the cpe in the three seasons does not differ markedly and the combined cpe for the whole year may also be taken as an index of stock density (Fig. 3).

Table 3 gives estimates of total fishing effort on Celtic Sea herring for the years 1958–70. These figures have been obtained by dividing total catch figures by the cpe of the Dutch trawl fishery in September–November.

It appears that fishing effort was high in 1959/60, then fluctuated around a lower, more or less stable level during 1960/61–1965/66 and sharply increased starting from 1966/67.

Table 2. Catch and effort data for the Dutch fishery on Celtic Sea herring (from national statistics)

Year	Nominal catch in tons				Effort in fishing hours of a 500 bhp standard trawler				Catch per unit effort in kg/h			
	Jun–Aug	Sep–Nov	Dec–Feb	Total	Jun–Aug	Sep–Nov	Dec–Feb	Total	Jun–Jun	Sep–Nov	Dec–Feb	Total
1957/58	447	2 022	?	?	33	284	?	?	13 545	7 120	–	–
1958/59	223	1 643	1 917	3 783	234	2 966	?	?	953	554	–	–
1959/60	914	655	825	2 394	1 385	3 493	2 120	6 998	660	188	389	342
1960/61	158	416	1 142	1 716	?	4 320	970	?	?	96	1 177	–
1961/62	78	1 762	1 997	3 837	170	6 250	1 160	7 580	459	282	1 722	506
1962/63	146	2 576	4 779	7 501	520	10 850	3 450	14 820	281	237	1 385	506
1963/64	0	3 281	4 008	7 289	0	9 990	4 120	14 110	–	328	973	517
1964/65	0	2 163	2 444	4 607	0	9 370	5 950	15 320	–	231	411	301
1965/66	0	4 727	7 783	12 510	0	12 880	10 930	23 810	–	367	712	525
1966/67	458	9 024	1 808	11 290	1 800	28 870	8 550	39 220	254	313	211	288
1967/68	3 693	6 745	1 502	11 940	19 940	29 050	8 300	57 290	185	232	181	208
1968/69	6 230	7 110	924	14 264	26 560	31 010	3 950	61 520	235	229	234	232
1969/70	4 082	10 721	474	15 277	26 620	45 310	2 580	74 510	153	237	184	205
1970/71	1 625	4 240	206	6 071	7 183	26 664	1 326	35 173	226	159	155	173
1971/72	3 440	4 734	970	9 144	17 246	28 091	6 818	52 155	199	169	142	175

Table 3. Celtic Sea herring. Total catches, catch per unit effort and total effort

Year	Total catch all countries in 1000 tons fresh weight (Bull. Statistique)	Dutch cpe for Sep–Nov in kg/h	Total effort all countries in 100 fishing hours of a 500 bhp standard trawler
1958	23·3	554	421
1959	25·8	188	1372
1960	3·6	96	375
1961	6·5	282	230
1962	7·1	237	300
1963	13·7	328	418
1964	8·3	231	359
1965	10·5	367	286
1966	27·6	313	882
1967	27·1	232	1 168
1968	30·6	229	1 336
1969	47·0	237	1 983
1970	(32·0*)	159	(2 013*)
1971		169	

* preliminary figures.

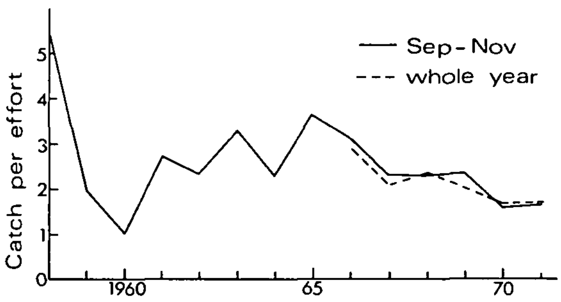

Figure 3. Catch per unit effort in 100 kg/h of Dutch herring trawlers for the months September–November and also for the whole year, starting from 1966.

Mortality rates

Total mortality

Total mortality rates (Table 4) have been calculated as

$$-Z = \ln\left(\frac{n_{t+1} > 4 \text{ years old}}{n_t \quad > 3 \text{ years old}}\right)$$

Three year-old fish have not been considered in the calculation of Z since their recruitment often is not complete at the start of the fishing season.

Because of changes in the fishery and biological sampling, data for the periods before and after 1965 had to be worked up differently. For the years

Table 4. Abundance indices and mortality rates. For the period 1958–65, age compositions for December/February have been combined with cpe data for September/November. For the years after 1965, abundance indices refer to the whole fishing season (excluding samples of spawning herring from the Irish fishery)

Fishing season	Abundance per age-group in number/fishing hour (corrected)										Z
	2	3	4	5	6	7	8	9	10	10+	
1958/59	0	65·3	731·4	517·2	143·7	491·1	305·6	222·0	135·8	0	–
1959/60	6·5	272·5	25·1	118·1	123·7	30·7	186·0	25·1	49·3	93·0	1·37
1960/61	6·9	332·9	80·3	22·1	105·2	27·0	36·4	35·3	15·9	31·8	0·88
1961/62	–	272·7	635·7	119·1	25·8	127·7	74·6	31·6	80·4	67·4	−0·41
1962/63	7·7	154·8	175·7	459·0	82·4	42·8	84·5	38·4	23·1	29·6	0·42
1963/64*	0	–	–	–	–	–	–	–	–	–	(0·28)
1964/65*	–	–	–	–	–	–	–	–	–	–	(0·28)
1965/66	0	1092·9	123·8	238·0	47·6	70·4	184·7	19·0	9·5	118·0	(0·28)
1966	85·6	191·4	675·7	104·4	152·3	58·0	46·4	89·9	26·1	20·3	0·38
1967	68·9	175·8	144·9	337·7	67·9	67·9	27·0	47·0	36·0	26·0	0·65
1968	138·7	429·6	327·4	81·5	147·3	29·2	25·6	9·7	17·0	11·0	0·85
1969	44·1	463·3	230·1	153·7	45·2	84·9	23·7	10·8	6·5	12·9	0·65
1970	2·4	195·8	293·7	90·6	91·4	26·7	56·6	19·4	20·2	12·1	0·58
1971	21·2	120·6	214·3	250·2	97·8	53·8	9·0	39·9	3·3	4·9	0·29

* not sufficient age data available.

1958–65, data on age composition were available only for the season December–February. However, cpe rates of the same season were not considered reliable estimates of stock density. In this case, cpe data of September–November have been combined with age data for December–February in order to calculate Z. These estimates of Z may have been biased by the difference in age composition between fish caught in September–November and in December–February. Insufficient age data were available for the seasons 1963/64 and 1964/65 to calculate abundance indices. An overall mortality has been calculated for this period:

$$-Z_{1963/66} = \ln\left(\frac{n > 6 \text{ years old in } 1965/66}{n > 3 \text{ years old in } 1962/63}\right) = -0{\cdot}85$$

This gives a yearly average of $Z = 0{\cdot}28$ for that period.

For the years after 1965, cpe and age data covered the whole fishing season. Differences in cpe and age composition between 3-monthly periods of the same year seemed to be caused mainly by random variation, and data for the whole year have been used to calculate total mortality rates. It appears that the mortality was high during 1958–59, then fluctuated around a lower level in 1960–65, and increased again starting from 1966.

Natural mortality

Natural mortality was estimated from a plot of Z on fishing effort, using data for the period 1959–70 (Fig. 4). The correlation between Z and fishing effort (f) is significant ($P < 0{\cdot}05$) and the regression formula is:

$$Z = 0{\cdot}3434f + 0{\cdot}21$$

(where f = fishing effort in 10^5 trawling hours). The intercept on the Y-axis gives an estimated natural mortality of 0·21. However, the following remarks should be made about this estimate of M.

a. Total mortality rates for the years 1958–65 and 1966–70 have been calculated in different ways, and the combination of these two series may have biased the estimate of M.
b. The variation in Z is very high over the whole period of observations. It can be expected therefore that the estimate of M from the regression of Z on f may contain a considerable error.
c. Mortality figures for the years prior to 1966 may have been overestimates for the total Celtic Sea stock. The winter fishery in the earlier year was based mainly on fish spawning near Dunmore. Starting from 1966 other spawning grounds along the South Irish coast were increasingly exploited as well (Molloy, 1969). Apparently, fish spawning near Dunmore were exploited to a higher degree than other components of the Celtic Sea stock before 1966. A reduction of Z in the earlier years would lower the estimate of the natural mortality.

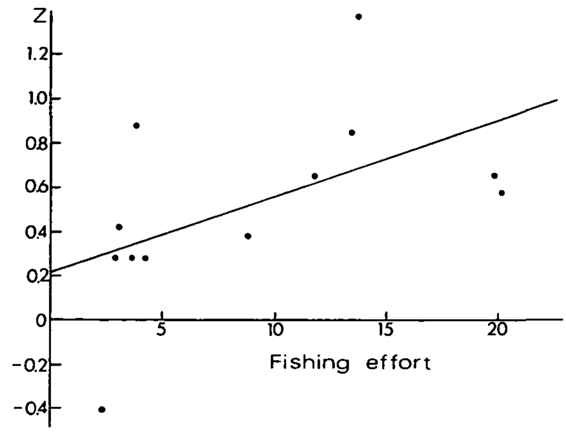

Figure 4. The relation between fishing effort (in 10 000 fishing hours) and total mortality rate Z.

The value of $M = 0{\cdot}21$ is slightly higher than estimates of M given by others. Burd and Bracken (1965) made several estimates of M. The mean value they obtained was 0·18, which they considered being perhaps too high. Molloy (1969) gives a natural mortality of 0·15 for the years 1961–68.

Recruitment

Year class strength, expressed as the abundance at 3 years of age was estimated from the abundance of the year class at higher ages, using known values of Z for the years inbetween. Abundance indices used were taken from Table 4.

Table 5 compares R_3 estimates based on age groups 4–10 with the actual cpe of the same year class at 3 years of age. On the average the cpe at 3 years of age is lower than the R_3 estimates based on higher age groups, especially in the year classes starting from 1963. This could be expected since age data used for the period 1966–71 refer mainly to summer and autumn months when some of the 3 year-old fish have not yet recruited to the fishery. Therefore, the average R_3 based on age groups 4–10 was taken as the best index of year class strength.

Strong year classes occurred more frequently in the "sixties" than in the late "fifties". The 1962, 1964 and 1966 year classes can be classified as good or very good, while the 1959 year class was notably

Table 5. Estimates of year class strength as three year olds (R_3), based on abundance as 4–10 year olds, compared with actual abundance at 3 years of age. Abundance indices in number per fishing hour (corrected)

Year class	Abundance as 3 year olds	R_3 estimates based on higher age groups R_3^4	R_3^5	R_3^6	R_3^7	R_3^8	R_3^9	R_3^{10}	Average R_3 estimate based on age groups 4–10
1955.....	65	–	248	194	–	–	–	–	221
1956.....	273	222	221	764	–	–	–	215	356
1957.....	333	498	–	–	–	496	308	236	385
1958.....	273	482	–	–	296	239	464	378	372
1959.....	155	–	–	–	196	175	147	195	178
1960.....	–	–	–	390	333	294	240	818	415
1961.....	–	–	202	252	253	394	581	134	302
1962.....	1093	988	946	965	1 065	1 258	1 195	–	1 070
1963.....	191	278	365	388	410	181	–	–	324
1964.....	176	766	689	732	575	–	–	–	691
1965.....	430	441	310	447	–	–	–	–	399
1966.....	463	525	597	–	–	–	–	–	561
1967.....	196	286	–	–	–	–	–	–	286
1968.....	121	–	–	–	–	–	–	–	

poor. From the data available so far, it is not possible to judge whether the recruitment level in the most recent years has been affected by the decline in parent stock, caused by the increased fishing effort.

Maximum sustainable yield

Growth parameters for Celtic Sea herring have been calculated from length/age data of all year classes combined in the months December–February (Table 6). The values obtained were: $L_\infty = 30{\cdot}43$ cm, $K = 0{\cdot}59$ and $t_0 = -0{\cdot}22$.

For the calculation of a yield/intensity curve, a value for the natural mortality M is required also. Comparing our estimate with those from earlier studies on Celtic Sea herring (Burd and Bracken, 1965; Molloy, 1969), a value of 0·15 seemed to be best estimate for natural mortality. Using the above values, a yield/intensity curve for Celtic Sea herring has been constructed (Fig. 5). This curve is very similar to the one published by Burd and Bracken (1965). It has no optimum for any of the fishing

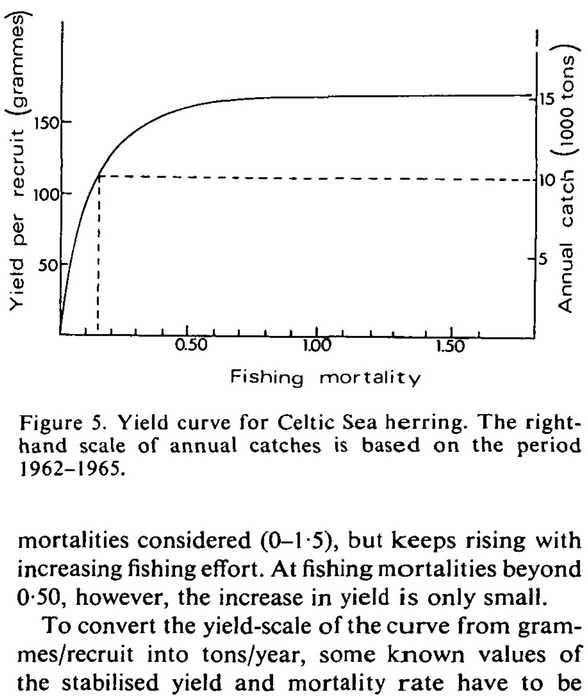

Figure 5. Yield curve for Celtic Sea herring. The right-hand scale of annual catches is based on the period 1962–1965.

mortalities considered (0–1·5), but keeps rising with increasing fishing effort. At fishing mortalities beyond 0·50, however, the increase in yield is only small.

To convert the yield-scale of the curve from grammes/recruit into tons/year, some known values of the stabilised yield and mortality rate have to be plotted in the graph. The only period in recent years with a fairly constant level of fishing effort was from 1962 until 1965 (Table 3), when the annual catch fluctuated around 10000 tons. The estimated total mortality rate during this period, based on rather poor age data, was $Z = 0{\cdot}30$. Plotting this value in Figure 5, together with the annual catch of 10000 tons, we find annual yields at other fishing intensities. The maximum yield, obtained only at fishing mortalities over 1·0, would be approximately 15000 tons, while the annual yield at $F = 0{\cdot}50$ (a more practical maximum) would be around 14·000 tons.

Table 6. Mean length-for-age in December–February. All year classes combined in the period 1966–70

Age	l	N
3.................	26·14	747
4.................	28·20	469
5.................	28·90	272
6.................	29·52	171
7.................	29·93	100
8.................	30·34	68
9.................	30·25	63
9+..............	30·48	37

Two remarks should be made here. First, as the yield curve rises steeply over the range of low fishing mortalities, small changes in F will greatly influence the yield. This implies that errors in the estimate of Z for the period 1962–65 (on which the yield-scale is based) will strongly affect the yield-scale in tons/year.

Secondly, the yield-scale in tons/year is based on the average strength of year classes caught during 1962–65. Fluctuations and especially trends in year class strength will alter the sustainable yield.

Discussion

The yield/intensity curve, calculated in the preceding section, compares well to the one given by Burd and Bracken (1965), which was based on data for earlier years. Both the shape of the curve and the yield-scale in tons/year are about the same.

However, comparing these curves with annual catches in recent years (Fig. 1), it appears that the high catches after 1965 cannot be explained only in terms of increased effort. Figure 6 shows the expected increase in catch, resulting from an increased effort, compared with the actual catches. Assuming that fishing mortality jumped from a constant level of 0·15 to a new level of 0·60 in 1966, it was calculated that catches would increase 2–3 times in the first two years after the change. After this initial period, however, catches would decline to a sustainable level, which would be only 50 % above the first level.

The discrepancy between expected catches and actual catches may be explained by two factors.

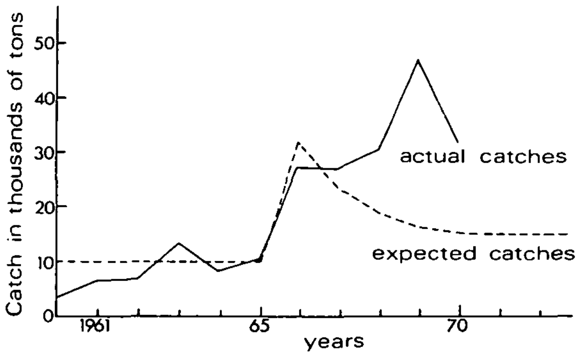

Figure 6. Comparison between expected catches after an increase in F and actual catches. F was assumed to increase from 0·15 in the pre-1966 period to a level of 0·60 starting from 1966. Stabilised yield at $F = 0{\cdot}15$ has been taken as 10000 tons/year. M was taken as 0·15.

1. Size of year classes in the catch. To calculate the average year class strength in the catch over a certain number of years, each year class (expressed in abundance at 3 years of age) has been weighted with the number of years that it was present in the catch as 3–7 years old during that period. Using data from Table 5 we find an average of 360 for the years 1962–65, and an average of 546 for the years 1966–69.

   Year classes caught during the later period were 50 % stronger than year classes caught in 1962–65, on which the yield/intensity curve was based. Therefore, the maximum sustainable yield for the period 1966–69 has been increased by 50 % to approximately 22000 tons/year.
2. Overestimate Z in the period 1962–65. As explained above, estimates of Z for the years prior to 1966 may have been too high when considering the total Celtic Sea stock. A lower Z for the years 1962–65 would increase the scale of the yield/intensity curve.

Conclusions

1. High catches in the years 1966–69 were caused in the first place by a sharp increase in fishing effort. After a transitional period, catches will decline to a lower, sustainable, level in the early "seventies".
2. Catches in the period 1966–69 were favourably influenced by the occurrence of strong year classes. This caused an increase in maximum sustainable yield of 50 %, compared to the years 1962–65.
3. Estimates of the total mortality rate for Celtic Sea herring prior to 1966 may have been too high, and estimates of maximum sustainable yield accordingly too low.
4. Taking the above factors into consideration, Molloy's (1969) figure of 22000 tons/year seems to be a realistic estimate for the maximum sustainable yield, provided year class strength remains at about the 1966–69 level.
5. Although the yield/intensity curve does not give an exact value for the maximum sustainable yield, it does show that a fishing mortality of 0·50 is about the maximum level of exploitation from a biological point of view. Increasing F beyond this point hardly increases the total yield, but introduces the risk of a stock/recruitment relationship at low stock densities. From the economic point of view, the optimum level of exploitation may be well below this fishing mortality of 0·50, considering the low catch per unit effort and yearly fluctuations in the catch, inherent to a highly exploited population.

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