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The Abundance of Fish Stocks in the Barents Sea

by

J. A. Gulland

Fisheries Laboratory, Lowestoft

Introduction

The great increase in the landings of cod, particularly by trawlers, from the Barents Sea has often been stated to be the result of climatic amelioration (Tåning, 1953; Hill & Lee, 1957). These views, and the importance of climatic factors generally, have been criticised by Bell and Pruter (1958). They suggested that the increase in the average catch of cod per days' absence of English trawlers from 16.5 tons in 1924-28 to 72.6 tons in 1947-51, noted by Tåning, is an artefact, due effectively to using a measure of catch per unit effort which gave a poor index of stock abundance. It is the aim of the present paper to attempt to produce rather better indices of the abundance both of the size of the total stock of cod in the Barents Sea, and of the individual year-classes comprising that stock.

Statistics of Catch and Effort

It is exceedingly difficult to devise a measure of fishing effort which will remain valid over a long period of years, particularly in a developing fishery, and for an active gear like a trawl. Besides obvious improvements in the size of ship and net, and in the method of rigging the net, which are at least observable and possibly measurable, such imponderables as acquired knowledge of the grounds and improved navigational facilities are all likely to have their effect. Some corrections can be made. Vigneron-Dahl gear was introduced around 1925, and increased catch per hour on haddock by some 30% (Bowman, 1932), and assuming the increase in catches is the same for all species, this effect can therefore be eliminated by increasing early catches by a factor of 1.3 (by 1.2, 1.15 and 1.1 for the transitional years of 1925-27). In any one year the fishing power of trawlers is proportional to their tonnage and independent of their age (Gulland, 1956), so that though alterations to gear etc. may well improve the efficiency of old and new alike from one year to the next, secular changes in the catching power of the ships themselves can be determined directly by changes in the average tonnage of the fleet. Direct data on tonnage of British trawlers fishing in the Barents Sea is not available before 1946, but reasonable estimates can be made by interpolation, assuming the average tonnage in 1906 was 250. Hours fishing is a better measure of fishing time than days absence, and while not available directly before 1924, the data can be taken back to 1906 if the ratio of days absence: hours fishing in these early years is taken as the average for 1924-27.

Finally account must be taken of the kind of fish the fishermen are looking for. In the Barents Sea east of 26°E (ICES statistical region I) cod is not the only species of importance - in fact in terms of weight landed by English trawlers it ranked third behind plaice and haddock until 1923 and second, (behind haddock) until 1932. The distribution of these three species are not the same, plaice in particular being caught on grounds where other fish are not greatly abundant. These changes in species composition may reflect changes in the aims of the fishermen (and hence the grounds fished) as much as real changes. Thus in the early years English trawlers were virtually only interested in plaice, and did all their fishing on the plaice grounds, so that their catch of cod was bound to be very small, whatever the abundance of cod on the main cod grounds. All that can be said is that at that time the plaice grounds gave more rewarding catches than the cod grounds - i.e. the catches (of all fish) on the plaice grounds can be used to give an upper limit to the abundance. Even this statement should, for the early years, be treated with a little reserve - plaice stay fresh on ice slightly longer than cod, and the same value of fish takes up less space, so that even though catches of cod might be of equal of greater value than plaice catches, the small and slow trawlers of the early

19oo's might have been able to make paying voyages only on plaice. Accepting this last limitation it is possible, as suggested by Bell and Pruter, to take a figure for the total catch of all species, weighted according to value. In practice, as probably no other species have been important enough to be the primary objective of any trawler, only cod, haddock and plaice were considered. Over the period their relative values have stayed remarkably constant, and mean values of haddock 1.2 times as valuable as cod, and plaice 2.5 times cod, have been used.

The resultant figure of demersal landings (C + 1.2H + 2.5P) per 1oo ton-hours fishing (adjusted for Vigneron-Dahl) has been calculated, and is plotted for the years 19o6-196o in Figure 1. Also shown are the landings per unit effort of the individual species expressed in terms of cod value (i.e. plaice and haddock increased by 2.5 and 1.2). The basic statistics used are taken from the annual Sea Fisheries Statistical Tables; these give weights as landed, which are usually gutted fish, but from 1946-5o included a varying proportion of headless fish. All those quantities have been converted to round fresh weight. The figure for total catch then gives the value per unit effort on the most rewarding grounds. This can be regarded as the upper limit for the density of any individual species. (If the real density of, say haddock, as measured by the catch per unit effort on the main haddock grounds had been in fact higher than this, then presumably, apart from seasonal effects, fishing would have been concentrated on these more productive haddock grounds.) Conversely the estimate of density for a single species obtained by dividing its total catch by the total fishing effort in the whole region will be an underestimate, for a portion at least of the total effort may have been on grounds where that species is not very abundant. It can be argued that in some circumstances the total catch, in value, per unit effort, not only provides an upper limit, but also a reasonably close estimate. This occurs where the distribution of two (or more) species are virtually distinct, but when both (or all) make significant contributions to the landings. These conditions are not too far from being satisfied for plaice and cod. That is, if a fisherman is fishing for cod he will catch very little plaice, and vice-versa. If then say the density (in terms of value) on the plaice grounds were much below the overall catch per unit effort, then presumably few, if any, ships would have bothered to fish on them, so that very few plaice, if any, would have been landed.

The curve of total value in Figure 1 with the peaks and subsequent declines after both wars bears a striking resemblance to the corresponding plots of catch per unit effort for such heavily fished stocks as the North Sea plaice, in which the major factor controlling stock abundance is the amount of fishing. Certainly this index of stock density shows no marked tendency to increase, and the 1947-51 average (3.3) is not much more than 3o% above the 1924-28 average (2.4). Data of trawler catch per unit effort corrected as far as possible for changes in the size of ship, efficiency of the gear and fishing time have also been determined for the German trawler fleet (Lundbeck, 1959, Table 2o). His results, in terms of tons caught per adjusted days fishing are summarized in Table 1 below.

Table 1. Catches per unit effort by German and English trawlers in the Barents Sea

Period	19o4-13	1919-28	1928-38	1947-54
Total	91	83	8o	69
Cod	2o	29	36	5o
Haddock	33	47	34	4
Plaice	35	1	-	-
Weighted total	136.1	87.9	76.8	54.8
English cpe.	5.4	2.9	2.2	2.6
% of mean:				
German	153	99	86	62
English	165	88	67	79

In the last rows the landings of cod, haddock and plaice have been combined, using the same weighting factors as for the English data. These totals and corresponding English figures have been expressed as a percentage of their respective means. The two indices agree well, though in fact the German index decreases between 1928-38 and 1947-54.

Even the index used in Figure 1 must be treated with some caution. Only two of the most readily measured changes in efficiency (V-D gear and size of ship) have been taken into account. If, as is most likely, any other improvement has taken place (use of echo-sounders etc.) then the earlier values should be further increased relative to the present value. Also this index is a measure of density only over the particular grounds fished. Though the plaice declined in relative importance over these 9 years before the first war from more than 95% of the total landings in 1906 it still made up about 50% in value in 1913. Thus the figures for the years before the first war refer virtually entirely to the stock on the plaice grounds. The decline in plaice can with fair confidence be ascribed to the effect of fishing (the increase up to 1909 being probably a matter of learning the grounds etc.), and was indeed early forecast by Atkinson (1908). Some measure of the effect is given by comparing the sizes of plaice measured by him in August 1907 with the sizes of plaice landed from the Barents Sea in 1959-60 (Figure 2). The mean size has fallen 5 cm, and the larger fish (over 50 cm) have decreased from about 14% to less than 2%. Of the stocks of cod and haddock away from the plaice grounds these early data tell us little. Some information, other than that contained in the statistics themselves, is available. For instance, in 1907 some English trawlers, looking for halibut (Atkinson, personal communication), reported "Small codling have been found in quantities ..... towards Bear Island" (Atkinson, 1908). Perhaps more important the increase in cod landings in the 1930's now appears essentially as a change in composition of landings remaining in total more or less constant. While this change might be a measure of a real change in the stocks in the area as a whole, it is more likely to be due to a change in grounds fished as the plaice and probably also haddock stocks were reduced by fishing. Certainly such a real change involving an increase in cod and a decrease in species whose ranges on the east Atlantic, and also, for haddock, on the west Atlantic, extend considerably less far north than cod, would be a rather surprising accompaniment to the "warming of the Arctic" going on at that time.

The English fishery in region IIb (Bear Island - Spitsbergen) is based almost entirely on cod, so that the statistics within the region are not distorted by changes in the fishermen's preference for various species. English fishing however only started in 1929, and the best estimates of the catch per unit effort (ton per 100 ton-hours) for all years except 1929 (which was 0.27 - some 20% below the 1930 level) has been given by the Arctic Fisheries Working Group (ICES, 1959). Over this period the catch per unit effort has much the same trend as in Region I - an increase between 1932 and 1936, and high peak immediately after the war, followed by a fairly steady decline to a very low level in 1960, interrupted by a small peak in 1956 (1955 in Region I).

Much the most extensive series of data on the Arcto-Norwegian stock of cod is of course provided by the Lofoten fishery on the spawning fish (Rollefsen, 1954). Data on the average catch, in numbers of fish, per man extend back to 1860. Over the earlier years this is probably a good measure of stock, but with the more recent changes in the type of gear used - nets and purse-seines - there has probably been a gradual increase in the efficiency, so that the later figures are over-estimates of the size of stock. With this reservation in mind there do not seem to be any marked long-term trends over and above the obvious peaks or troughs of around 5 years duration (due to good or bad year-classes). The longest sustained period of below average catches was from 1896-1920, the average during this period being about 700 cod per man, compared with the average over the whole period of about 900 per man. However, the lowest catches in this period, 450 fish per man in 1918, was not much less than the figure 550 in 1935, between the two peaks of 1927 and 1946.

Changes in Population Parameters

Consideration of the density of the fish stock, as estimated from the catch per unit effort, is only of limited value in understanding what is happening to the stock, however good may be the index of effort used. Particularly when the fishing on the stock has been changing, as in the Arctic, the catch per unit effort only measures the nett effect of natural changes (if any) and changes induced by man. Thus, the density indices shown in Figure 1 are consistent with the interpretation that the stocks of plaice, haddock and cod have been successively reduced, to varying extents, by heavy fishing and that no other facta has a significant effect. They are also however equally consistent with the hypothesis that say fishing would have reduced the stock still more if there had not been parallel changes caused by changes in the environment.

When possibly both fishing and environmental factors are believed to be having an effect on a stock of fish. there are good reasons for concentrating first on the fishing, man-made, influences. On the practical side it is only these factors which by their nature can be controlled by man - i.e. if a stock has been "overfished" it may be hoped that the situation would be improved by some suitable regulation or management. More important on the scientific side is the fact that one can hope to express the direct effect of fishing in definite and quantitative terms. This can be compared with the observed changes, and the differences, if any, are due to causes other than direct fishing.

Such studies are best carried out by examining not the total density or abundance of the stock, but its vital parameters. The abundance (in weight) of a stock of fish - or indeed any other natural population - is governed solely by three factors. These are the mortality rate (which can be divided between that part due to fishing, and that due to other causes), growth of the individuals, and their reproductive rate. This last is best considered in terms of the strength of the individual year-classes, i.e. the numbers of fish born in any one year entering the exploited phase of the fishery. Also the relation between abundance of the stock and catch per unit effort may change, firstly because the density of stock on the fishing grounds for a given abundance can be altered by changes in the distribution - for instance an expansion of the area inhabited will, for a given total abundance, decrease the density. Secondly, the catch per unit effort on a given density may be changed by some changes in fish behaviour, as well as by changes in gear, though these latter should be eliminated by a proper choice of effort units.

If some factor, e.g. hydrographic condition, is affecting the stock abundance or the catch per unit effort, it must be acting through one or more of the parameters above. Such an effect is much more likely to be detected and in particular understood if it is related to changes in one particular parameter. It has been suggested that some year to year changes in trawler catches in the Bear Island area are due to the variations in the area covered by Atlantic water, and hence by the stock. Changes in growth rate have altered the average length of Lofoten cod between 8-13 years old by up to 8 cm in the period 1932-53 (Rollefsen,1954), which imply differences in the greatest and least values of the weight at age of up to 25%. In the earlier years there has been a noticeable upward trend in the average weight of individual fish at Lofoten, increasing from around 1.5 kg in 1885-1915, up to around 3.5-4 kg by 1930. The Arctic Working Group found that while changes in fishing effort accounted for the major changes in total mortality, there was considerable variation about the regression lines of the total mortality on fishing effort (ICES, 1959) (though most if not all of this variation may be ascribed to the difficulty in estimating the total mortality between a single pair of years). Any of these could be responsible for changes in stock size, both from year to year, and over a period, but since age data have been available the most striking changes have been a general increase in total mortality rate, as estimated from the catches, and which can be related to the increase in total fishing effort, and fluctuations in the strength of individual year-classes.

Year-Classes: Lofoten

The importance of year-class strength in determining the yield in any one year has long been realised (Hjort, 1914). However, in attempting to put the relation on a quantitative basis by relating the size of individual year-classes to size of stock there is a danger of producing a false relation if, as is likely, both are expressed as catch per unit effort using the same or similar effort units. Thus, if over a short period, "availability" is high, then the catch per unit effort of both stock and individual year-classes will appear large.

A fair mesure of the real abundance of individual year-classes can be obtained solely from percentage age-distributions which will be independent of any bias due to availability, provided the fishery contains several year-classes at a time. This method has been applied to Rollefsen's data from the Lofoten fishery (Rollefsen, 1954). A mean percentage age distribution can be found for the period covered by the data,and each year-class, for each age from eight to twelve, can be expressed as a proportion of the average percentage for that age. (This is essentially a modification of Rollefsen's Figure 3 to make the deviations for each age roughly the same - his deviations have their biggest value, positive or negative, for ages nine to eleven which make up the biggest percentage contribution to the catch). This proportion gives an index of the year-class strength for each age from eight to twelve. Taking the average of these five values gives a first estimate of the year-class strength, which will tend to underestimate the strength of year-classes occurring in the fishery at the same time as an outstanding good year-class.

However, these first estimates of year-classes can be used to give an estimate of the stock size, and this has been done by taking the mean of the five year-classes which in any year are between eight and twelve years old, weighted according to the average percentage of each age. A revised index for each year-class at each age can then be obtained. For instance, the 193o year-class comprised 43% of the catches in 194o, when it was ten years old. On the average ten year old fish comprise 21% of the catch, so that the first index of the 193o year-class at ten is $\frac{43}{21} = 2.05$. Similarly indices for the 1928, 1929, 1931, and 1932 year-classes were obtained, and taking their weighted mean gave a first estimate of the stock as 1.22 of average. The corrected index for the 193o year-class at ten years old is therefore 2.o5 x 1.22 = 2.5o. These second approximations of year-class strength can in turn be used to get a second approximation of stock size, and this iteration could, if wished, be repeated any number of times, though in fact the second approximation did not differ much from the first, and no further iterations were made. In Figure 3 this index of stock density has been plotted for the years 193o-52, together with Rollefsen's figure of catch per man. Agreement is very close, particularly in 193o-38, which confirms the influence of year-class strength on catch per unit effort. Viewed the other way, it shows that catch per man is a good index of density which can be used to estimate year-class strength.

Regions I and IIb

These data are, however, not the most suitable for studying year-class fluctuations. Year-class strength is believed to be determined in the first year or so of the fish's life - possibly in the first few weeks, while the data above have been taken ten or more years later. In these ten years many factors, particularly different fishing rates, may have operated to change the initial year-class strength. Earlier indices of year-class strength can be obtained from data of the trawl fisheries on the younger fish. Two separate sets of indices can be drawn, one for the Barents Sea (Region I) and the other for the Bear Island - Spitsbergen area (Region IIb). Tagging results suggest that there is little mixing of the young fish in these areas before they mature for the first time, and go to the Lofoten area to spawn. Data for these areas have been produced by the International Working Group on Arctic Fisheries (ICES, 1959), based on information from English, German and Norwegian and Russian sources. Indices of abundance, in terms of numbers caught per loo ton-hours, have been produced for each age from four to nine, for the years 1946-6o, and (for Region I), 193o-38.

Similar indices for the pre-war years in Region IIb have been estimated, using the weight caught per unit effort, as given in the Working Group report, and percentage age-composition and average weights given by Lundbeck (1954). This age-composition was based on scale readings, and therefore is not too reliable for the older fish, or for estimating mortalities, but does, when taken with the catch per unit effort estimates, give reasonable estimates for the year-class abundance.

So as to give comparable estimates for each age, the mean catch per unit effort was calculated for each age, and the abundance of each year-class expressed as a percentage of this mean. The two regions were analysed independently, and in Region IIb the mean abundance of the nine year old fish was calculated omitting the 1937 year-class, which was, in 1946, of quite exceptional abundance.

These estimates are given in the first columns of Tables 2 and 3. No correction has been made for differences in fishing mortality. In times of low fishing, e.g. the early thirties, and just after the war, the strength of the year-class appears to increase as the fish get older (e.g. the 1925 and 1939 year-classes), while in terms of high fishing (e.g. late 195o's) the year-classes appear to decline (e.g. 195o year-class). Thus these estimates of year-class strengths are influenced, particularly among the older fish, as much by the fishing during their life as by their initial abundance when entering the fishery.

Estimates of fishing mortality in the two regions are given in the Arctic Working Group report. For correcting abundance indices the best information is given by the regressions of total mortality on effort (Figures 15 and 16). Using loo million ton hours as the units of effort, the slopes of the regressions, i.e. q, the mortality caused by unit fishing effort is o.15 in Region I, and o.7 in Region IIb. (The difference probably represents the larger effective area covered by the cod stock in Region I). A factor to give the corrected index of abundance of any year-class at a given age, independent of the fishing during its life, is then

$$e^{q(f-\bar{f})}$$

where f = total fishing effort on that group of fishing during its life
$\bar{f}$ = average life-time fishing effort on that age of fish.

In both areas it has been assumed that the fishing effort acts with only half the efficiency for four year old fish but with full effect on older fish. In the observed age-compositions the maximum numbers are often taken at six years old, which suggests that five year old fish and younger are not fully recruited. However, most of the data refers to landings, and it is known that some trawlers reject appreciable quantities of fish (mostly four and five year olds), particularly before the 110 mm mesh was introduced in 1954. Even the 110 mm will allow only a proportion of four year old fish to escape, though the effective fishing on them is also reduced by geographical differences between their distribution and that of the older and bigger fish. The fishing effort undergone during their life by, say, the seven year old fish caught in 1958 is therefore taken as:-

$$\tfrac{1}{2} f_{55} + f_{56} + f_{57} + \tfrac{1}{2} f_{58}$$

where f_{55} denotes the fishing effort in 1955. (Note that only half the effort in the year of observation is taken). In the computations the deviations from the mean annual effort (309 million ton-hours in Region I, 67 million ton-hours in IIb) were used directly, so that the "effort difference" for the seven year olds in 1958 was calculated as:-

$$f' = \tfrac{1}{2}(f_{55} - \bar{f}) + (f_{56} - \bar{f}) + (f_{57} - \bar{f}) + \tfrac{1}{2}(f_{58} - \bar{f}),$$

and similarly for the four year old fish in 1958

$$f' = \tfrac{1}{4}(f_{58} - \bar{f})$$

Using these correction factors, and adjusting again to express the new abundance indices as percentages of the new mean, a set of estimates of abundance of each year-class at each age was obtained, and these are given in the right hand columns of Tables 3 and 4. The estimates of abundance at four years and nine years old are probably less reliable than for other ages, so that in calculating a mean value to give a simple index of year-class abundance they have been given less weight. The actual weights used for ages four to nine were 1,2,2,2,2,1, which have the advantage of adding up to ten and thus making computation easier.

These indices are in a convenient form for comparing year-classes, and attempting any analysis of the causes of year-class differences. If the relation between fishing effort and fishing mortality is known, they can be converted into actual numbers. Thus in Region I, 100 million ton-hours fishing causes a fishing mortality of 0.15, - i.e. the catch by 100 ton-hours fishing is 0.15×10^{-6} of the stock present. The average catch of six year old fish (the youngest age fully represented in the landings) in Region I is 13.93 fish per 100 ton-hours. The actual average numbers of six year old fish in the stock is

$$\frac{13.93}{0.15} \times 10^{6} = 92.9$$

million fish. Similarly in Region IIb, the average number of six year old fish in the stock is

$$\frac{26.68}{0.7} \times 10^{6} = 38.1$$

million fish. Multiplying by the appropriate year-class index will give the average number of six year old fish there would be in any year-class, assuming that the year-class had been subject to the average level of fishing effort. Less hypothetically the year-class strength can be expressed as the actual number of fish reaching four years old - when the fish become vulnerable to a significant level of fishing. Writing this number as N_4, the average number of six year old fish in stock =

$$e^{-Z_4 - Z_5} \frac{1 - e^{-Z_6}}{Z_6} \times N_4$$

where Z_4, etc. is the total mortality coefficient for four year old fish etc.

Assuming that the natural mortality coefficient is 0.3 and taking the fishing effort on four year old fish to be half the full effort, the values are, for Region I,

$$Z_5 = Z_6 = 0.3 + 0.45 = 0.75$$

$$Z_4 = 0.3 + 0.225 = 0.525$$

and for Region IIb, $Z_5 = Z_6 = 0.3 + 0.47 = 0.77$

$$Z_4 = 0.3 + 0.235 = 0.535$$

and the number of fish at four years old, in millions, is given by multiplying the year-class index by a factor equal to

for Region I

$$92.9 \times e^{1.275} \times \frac{.75}{1-e^{-.75}} = 92.9 \times 3.579 \frac{.75}{.5276} = 473$$

and for Region IIb

$$38.1 \times e^{1.305} \times \frac{0.77}{1-e^{-0.77}} = 38.1 \times 3.688 \frac{.77}{.537} = 201$$

Comparison of Year-Classes in Regions I and IIb, and in Region IIa

In general terms these indices of year-class strength obtained from data mainly of immature fish agree well with those obtained for the mature fish at Lofoten. The latter are, of course, determined very greatly by the extent of the fishing mortality between four and perhaps nine or ten years old, when they first enter the spawning fishery.

A more precise comparison can be made on nine year old fish, for which measures of catch per unit effort can be obtained for both the trawl fishery, and the spawning fishery. This comparison may show how good these measures are as indices of abundance of nine year old fish. The index in the trawl fishery - the feeding area - has been taken as the weighted mean of the catch per 100 ton-hours in Regions I and IIb, using weighting factors of 2:1. The index in the spawning area was obtained by multiplying the percentage of 9 year olds among the line-caught fish by the smoothed relative catch per unit effort in the English and Norwegian data (Table X of the Arctic Working Group report). (I am indebted to Mr. A. Hylen for permission to use these unpublished Norwegian data). These data are given in Table 4.

The observations are not coincident in time; the spawning data refer to a short period in the early spring, - mean date say March, whereas the trawl fishery continues for most of the year, though with a peak in summer. The mean date of the trawl data would be about July. Thus the 9 year old fish in the spring of one year may be compared with either the 9 year old fish in the following summer, or with the 8 year old fish in the previous summer.

The data from the spawning fishery will of course refer only to mature, and some allowance must be made for the proportion of 9 year old fish which are immature. This proportion is not directly available, but may be deduced from the data of the proportion of recruit spawners in each age group each year given by Rollefsen (1954). Thus denoting by ${}_{10}R_{54}$ the proportion of first time spawners among the 10 year old spawners in 1954, and similarly for other ages and years, and assuming to begin with that mortality is the same for all fish, immature and mature, the proportion P_{54} of immature fish among the 9 year olds in 1954 can be determined. Suppose 12 years old is the oldest age at which a fish may be immature, then all the immature 12 years old fish are recruit-spawners at 13

$${}_{12}P_{57} = {}_{13}R_{58}$$

or, in terms of mature fish

$$1 - {}_{12}P_{57} = 1 - {}_{13}R_{58}$$

Similarly the fish spawning for the second, or later time at 12 are the mature 11's i.e.

$$1 - {}_{11}P_{56} = (1 - {}_{12}R_{57})(1 - {}_{12}P_{57})$$
$$= (1 - {}_{12}R_{57})(1 - {}_{13}R_{58})$$

This can be repeated as often as necessary to get the percentage mature at 10, 9....... e.g.

$$1 - {}_{9}P_{54} = (1 - {}_{10}R_{55})(1 - {}_{11}R_{56})(1 - {}_{12}R_{57})(1 - {}_{13}R_{58})$$

Thus the percentage of nine year old fish which are mature may be estimated for the years up to 1953, when Rollefsen's data ends, and these are given in Table 4, column 4. (For the last two years it has been assumed that the percentage of first time spawners in each age group in 1954 and 1955 was the same as in 1953). The proportion of mature 9 year old fish rises from 11% in 1932 to 62% in 1937, drops sharply in 1938 and 1939, and thereafter remains fairly steady around 2o-25%. The proportion after 1953 may be estimated from samples taken by R.V. "Ernest Holt" off Lofoten in February and March 1958. These showed that of the fish lo years and older 62% in February, and 58% in March had not spawned when 9 years old. There are not sufficient data to estimate the proportion of 9's that were mature with any precision, but 4o% can be taken as a conservative upper limit, (i.e. ignoring the fact that some of the immature 9's will not be mature at lo). This figure has therefore been used for the years 1954-58.

There is some bias in these figures. The estimates are based on data at lo years old or older, by which time the 9 year old mature fish will have undergone fishing on the spawning grounds and the approaches thereto, which does not affect the immature fish, so that the proportion of this group of fish (the second time and later spawners) among the lo year fish will be less than it should be. That is, the figures above will be under-estimates of the proportion of 9 years old fish that are mature. However, this bias will occur, though perhaps not to precisely the same account, throughout the period, and the figures given should provide a good measure of trends in the percentage mature.

Using these figures, therefore, the catch per unit effort of 9 year old fish in the feeding areas can be converted into indices of abundance of the numbers of mature 9 year old fish in the stock (Table 4, column 5), This index may be then compared directly with that obtained from the spawning fishery. If both sets are satisfactory indices then their ratio should remain constant.

However, the ratio is certainly not constant; before the war it had an average value of rather less than 14o, possibly increasing slightly during this period. After the war it was very low, less than loo, and increased steadily to an average value of 34o in 1955-58 - a range of rather more than 3-fold. A slight change in this direction would be expected because of the higher mortality during the 195o's, which would reduce the numbers between the time the abundance was estimated at Lofoten, and the time it was estimated in the feeding areas. However, this is only a fraction of a year, approximately 4 months, and so can only cause a difference equal to a fraction of the increase in the total mortality - i.e. probably not more than a difference of 5o%. Thus the observed 3-fold increase in the spawning index relative to the feeding index must be due to a progressive over-estimate of the abundance in the data from the spawning fishery, or a progressive under-estimate of nine year old fish in the summer trawl fishery.

This is perhaps not surprising, particularly for the trawl fisheries. Though a single trawl haul may catch fish of all ages, there is a definite difference in the sizes of fish taken on different grounds; in particular there is the well known fact that the bigger (and older) fish are generally deeper. Some measure of the possible differences in the same area is given by the catches taken by R.V. 'Ernest Holt' in April 1955 on the Bear Island grounds. Fish were measured from 24 hauls, and these may be divided into three groups - those taken in less than loo fms, between loo and 13o fms, and over 13o fms. This division is not absolutely precise, as in most hauls the depth fished was not kept constant, and three hauls in which the depth varied by more than 35 fathoms could not be placed in a definite depth zone. Despite variations in depth fished, there were consistant differences between depth zones in the size of fish caught, while hauls at the same depth caught much the same size of fish. The weight caused was much more variable, ranging in the shallowest zone from 4-2oo baskets per haul, and in the other depth zones from lo-6o baskets and from 2-3o baskets. It is therefore not possible with the small number of hauls to express the catches in terms of actual abundance of each size of fish at each depth, at least not with any real precision, and in Table 5 below the data have been expressed as percentages at each depth.

The bottom two lines show the ratios of the percentages that a given size of fish forms at different depths. Thus compared with their abundance in the shallowest depth zone, the smallest fish are half as frequent in the deepest zone, while the biggest fish are seven times as frequent. Viewed another way, for hauls deeper than 13o fathoms, fish over 7o cm were more numerous than fish under 5o cm; for hauls in less than loo fms fish over 7o cm were less than 1o% of those under 5o cm.

Table 5 Percentage length distributions of cod caught at various depths near Bear Island in April 1955

Depth (fms)	Length													
	-39	40-	45-	50-	55-	60-	65-	70-	75-	80-	85-	90-	95-	100-
< 100 (A)	1.9	6.5	18.9	35.7	27.1	6.3	1.3	0.9	0.6	0.3	0.4	0.2	-	0.1
100-130 (B)	0.6	4.2	14.8	26.4	31.5	9.9	3.6	3.4	2.7	1.0	0.6	0.4	0.6	0.1
> 130 (C)	0.3	3.1	10.1	18.1	27.1	15.9	8.7	4.9	4.9	2.6	1.6	1.0	0.7	1.1
Ratio B:A	0.3	0.6	0.8	0.7	1.2	1.5	2.8	3.8	4.2	←		2.7	→	
Ratio C:A	0.2	0.5	0.5	0.5	1.0	2.5	6.7	5.4	8.1	←		7.0	→	

Trawlers do not fish at random, but where fish are abundant. If there is no big change in the size structure of the population the distribution of fishing may be unchanged and the commercial catches, or landings, may give a biassed picture of the population, but this bias will be consistent from year to year, i.e. though the catches per unit effort may not give a correct estimate of the relative abundance of, say, four and ten year old fish in the same year, they will give the relative abundances of four year old fish in different years. In 1946, in Region I, and even more in Region IIb, the most abundant age by numbers, and still more by weight in the landings, was nine years, while other old fish were also abundant. With this predominance of old fish it is likely that trawlers would concentrate on grounds where older fish are predominant. Conversely in 1960, the vast majority (80% in I, 90% in IIb), of fish in the landings were four, five and six years old, so that the trawlers might concentrate where the small fish were. Such changes in fishing pattern would exaggerate the changes in the relative size composition.

These presumed changes can be expressed more precisely in terms of the concentration as defined by Gulland (1955), that is, the ratio of the average density in the area fished to the average density of the whole accessible stock. Separate values of the concentration, k_4, k_5 .... k_9, etc. can be assigned to each separate age for each year. The density of that age in the accessible stock is then proportional to $1/k$ times the catch per unit effort. The aim of a good fisherman is to get the greatest concentration on the stock as a whole; in Region I in 1946 this would be done by maximising k_9, but in 1960 it would be done by maximising k_4, k_5 and k_6. Thus we may conclude, using an obvious notation:

$$k_9 \; 1946 > k_9 \; 1960$$

$$\text{and} \quad k_4 \; 1946 < k_4 \; 1960$$

Similar changes in concentration from older to younger fish may have happened in the spawning fishery, where nine year old fish are the younger fish. Even if it did not, a change in k_9 in the feeding fisheries by a factor of two to three would be sufficient to eliminate the trends shown in Table 4, except for some trend due to true mortality, and to make indices of catch per unit effort in the feeding and spawning fisheries consistent. For Region I this would mean that while the catch per unit of nine year old fish declined from 17.8 to 0.4 between 1946 and 1960 - a factor of 44, the actual decline is by a half to a third of this - i.e. a factor of between 15 and 22, which is still a very significant decline. A difference in k_9 of this magnitude seems quite possible, being less than that observed in the catches shown in Table 5.

If we conclude that such changes in concentration have in fact taken place, then some earlier conclusions may have to be revised. The most important concerns mortality. When this is estimated from the ratio of the catch per unit effort of a year-class in successive years, it will contain a factor equal to the ratio $k_{x+1.n+1}/k_{xn}$. If the values of the concentration do not change from year to year the estimated mortality may be biassed, but the extent of bias will be the same each year, i.e. changes in mortality will be correctly recorded. If it is supposed that k_9 has decreased by a factor of 3, and k_4 is unchanged then the changes between 1946 and 1960 in the mortality between four and nine years is over-estimated by a factor of

$$3, \simeq e^{1.1}$$

This means that the changes in the average annual mortality coefficient over these five years is over-estimated by about 0.22. A further degree of over-estimation is possible to the extent that k_4 has increased between 1946 and 1960. The changes in estimated mortality between 1946 and 196o have been used to relate total mortality to fishing effort. The errors in the estimates of mortality which have been suggested would have the effect of rotating the regression of mortality on effort, making it appear steeper than it really is. Thus the intercept, which gives an estimate of the natural mortality, would be too low. This regression will also have been distorted because the fishing effort is not the same for all ages, so that the effort index which is relevant - the effective effort on the ages from which mortality has been calculated - may not be that obtained directly from the catch and effort statistics. The extent and direction of this possible error in the regression caused by this error in effort is not easy to deduce directly without better data on the distributions of fishing and of fish of each age.

So far as changes in fishing mortality have been used in this paper, some of these errors do not matter. Thus in so far as the correction factors used to bring all estimates of the strength of a particular year-class into accord, rather than decrease with age in heavy fishing, the factors are right, for it does not matter whether the fish are disappearing from the landings because of real mortality, or because they are where the trawlers are less concentrated. However, the correction factors bring all the indices of year-class strength onto the scale of the four year old fish of that year-class. That is, the index of the 195o year-class is related to its actual abundance by a factor equal to k_4 1954. The index of year-class strengths used is therefore only consistent if k_4 is constant; if, as is likely, k_4 has increased between 1946 and 196o, the index increasingly overestimates the year-class strength. This seems reasonable in view of the fact that the average year-class index, taken over five years, increases from 46 for 1938-43 to 128 for 195o-54 in Region I, and from 58 to 235 in Region IIb.

The exact interpretation of the recent history of the cod stocks therefore depends on the degree of this possible bias in the mortality estimates. Taking them at their face value it appears that fishing accounts for three-quarters or more of the total mortality (i.e. at the present high effort $Z \simeq 1.2$, $F > o.9$, $M < o.3$) and that the serious decline in the stocks that this would have caused has been in part lessened by an increase in the average strength of year-classes. Alternatively, if the abundance of old fish has been progressively underestimated, and that of young fish overestimated, then the mortality rate in recent years has been overestimated, and that in particular the regression of total mortality on fishing effort should be rotated, suggesting mortality coefficients, at the present level of effort of around $Z = 1.o$, $F = o.6$, $M = o.4$. At the same time under this hypothesis the average year-class strength has not changed appreciably, so that the changes in the cod stock are due wholly to a moderately heavy amount of fishing.

Summary

The data from the English trawl fishery in the Barents Sea was examined to obtain the best index of the abundance of the stocks in this area. The simplest index (catch per day at sea) shows a big increase (over four-fold) in cod from 1925 to 195o. This index is unreliable for several reasons, - days at sea being a poor measure of fishing time, increasing efficiency of ships and gear, and changes in the preferred species sought by the fishermen. An index of abundance corrected for these factors shows no increase in the 193o's, though in the early years it is only possible to give an upper limit to the abundance of cod.

Indices of abundance of individual year-classes were also examined, and it was shown that under some circumstances an index of abundance of a stock can be obtained solely from percentage age composition data. Such an index was obtained for the Lofoten cod stock, and shown to agree well with the catch per unit effort (catch per man per season). A comparison of age composition data at Lofoten and in the Barents Sea suggested that there is a bias in the age data from the commercial trawlers, due possibly to a change in fishing positions, and that this had lead to a progressive overestimation of the mortality in recent years.

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Table 2. Region I (Barents Sea)
Catch per unit effort of each year class at each age, expressed as a percentage of the average catch per unit effort of that age.

Age / Year Class	Uncorrected						Corrected for fishing mortality						Weighted Mean
	4	5	6	7	8	9	4	5	6	7	8	9	
1921	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	40	-	-	-	-	-	19	(19)
4	-	-	-	-	33	43	-	-	-	-	12	20	15
5	-	-	-	33	51	66	-	-	-	17	20	23	22
6	-	-	29	40	112	52	-	-	17	23	48	28	29
7	-	39	34	55	66	55	-	30	22	33	30	33	29
8	44	51	72	69	107	110	41	40	46	41	52	81	48
9	53	114	106	111	157	159	49	88	67	70	90	135	81
1930	119	195	182	142	182	-	110	151	122	107	124	-	124
1	75	47	52	79	-	-	69	39	42	71	-	-	53
2	48	23	30	-	-	-	46	21	26	-	-	-	28
3	48	45	-	-	-	-	47	42	-	-	-	-	44
4	22	-	-	-	-	-	21	-	-	-	-	-	(21)
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	514	-	-	-	-	-	96	(96)
8	-	-	-	-	125	185	-	-	-	-	24	40	29
9	-	-	-	70	79	176	-	-	-	22	17	44	24
1940	-	-	67	141	140	159	-	-	28	49	36	50	39
1	-	35	126	277	208	124	-	23	59	111	63	50	62
2	35	108	139	283	153	118	31	73	71	136	59	65	77
3	70	56	195	108	109	61	62	41	112	62	57	53	66
4	4	57	39	97	68	46	4	43	25	70	50	61	44
5	9	20	98	110	91	46	9	16	76	108	95	87	69
6	4	112	117	65	66	55	4	102	115	85	93	155	95
7	61	155	118	85	91	35	59	158	140	135	178	159	144
8	202	179	156	131	92	38	204	194	199	252	250	225	222
9	88	247	192	113	109	46	88	271	276	285	368	298	279
1950	233	142	163	81	91	61	235	176	306	249	333	396	276
1	31	82	70	48	50	12	33	118	144	144	162	71	124
2	22	44	60	38	15	-	24	59	101	87	39	-	65
3	88	130	89	23	-	-	90	155	123	45	-	-	105
4	198	192	65	-	-	-	204	211	86	-	-	-	160
5	233	130	-	-	-	-	231	148	-	-	-	-	176
6	514	-	-	-	-	-	539	-	-	-	-	-	(539)
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3. Region II b (Bear Island-Spitsbergen)

Catch per unit effort of each year class at each age, expressed as a percentage of the average catch per unit effort of that age.

Age / Year Class	Uncorrected						Corrected for fishing mortality						Weighted Mean
	4	5	6	7	8	9	4	5	6	7	8	9	
1921	-	-	-	-	-	206	-	-	-	-	-	67	(67)
2	-	-	-	-	201	268	-	-	-	-	76	89	80
3	-	-	-	241	219	116	-	-	-	103	84	39	83
4	-	-	73	82	56	139	-	-	39	34	22	47	34
5	-	26	24	50	104	51	-	19	13	22	41	19	23
6	99	93	82	105	70	67	89	67	44	47	29	25	49
7	153	57	90	82	145	338	138	42	50	40	62	139	68
8	62	73	99	154	450	99	57	53	55	73	204	47	87
9	46	60	236	251	194	-	41	45	136	127	101	-	95
1930	7	261	115	212	-	-	7	186	70	121	-	-	111
1	71	58	124	-	-	-	65	46	83	-	-	-	65
2	0	59	-	-	-	-	0	49	-	-	-	-	33
3	0	-	-	-	-	-	0	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	1681						581	(581)
8	-	-	-	-	176	380	-	-	-	-	70	145	95
9	-	-	-	64	26	110	-	-	-	29	11	44	25
1940	-	-	75	12	77	29	-	-	40	5	36	14	25
1	-	111	79	160	39	42	-	80	45	83	21	22	53
2	125	217	127	154	76	61	113	165	81	89	46	44	92
3	125	107	259	126	151	121	117	87	173	82	122	114	116
4	38	164	99	120	46	49	35	130	70	95	45	53	77
5	96	47	76	55	43	14	88	41	68	52	47	19	52
6	25	42	29	25	17	7	25	42	29	25	20	8	26
7	87	91	58	31	16	14	86	88	53	28	18	25	48
8	347	148	132	91	71	31	333	135	112	81	100	97	129
9	103	97	99	76	44	14	99	88	88	93	130	125	102
1950	189	230	226	119	44	38	181	216	274	306	331	806	324
1	104	84	60	53	31	5	102	105	146	339	598	206	268
2	11	18	22	14	3	-	12	35	101	172	80	-	87
3	26	54	24	22	-	-	31	125	139	250	-	-	151
4	242	136	90	-	-	-	292	329	392	-	-	-	347
5	138	67	-	-	-	-	171	118	-	-	-	-	136
6	207	-	-	-	-	-	213	-	-	-	-	-	(213)
7	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4. Indices of abundance of nine-year old cod in the Arctic from data in the spawning and feeding areas

Year	IIa Catch/man A	I and IIb Catch/100 ton hrs B	% Mature C	Est. mature stock B x C = D	Ratio of indices A/D
1932	57	3.1	11	0.34	168.9
1933	42	3.6	38	1.37	30.9
1934	85	2.5	26	0.65	132.6
1935	205	2.4	59	1.42	142.8
1936	332	7.5	62	4.65	71.4
1937	419	4.4	62	2.73	154.8
1938	446	5.5	32	1.76	252.9
1946	1,352	42.9	23	17.60	136.8
1947	234	11.3	24	2.71	86.1
1948	95	6.1	21	2.18	77.1
1949	94	4.2	26	1.09	86.4
1950	243	3.5	32	1.12	215.7
1951	300	3.9	44	1.72	195.0
1952	295	3.6	40	1.44	199.5
1953	157	2.0	40	0.80	226.5
1954	121	1.3	40	0.52	215.1
1955	120	1.4	40	0.56	333.0
1956	142	1.1	40	0.44	390.6
1957	224	1.4	40	0.56	268.5
1958	143	1.3	40	0.52	382.5

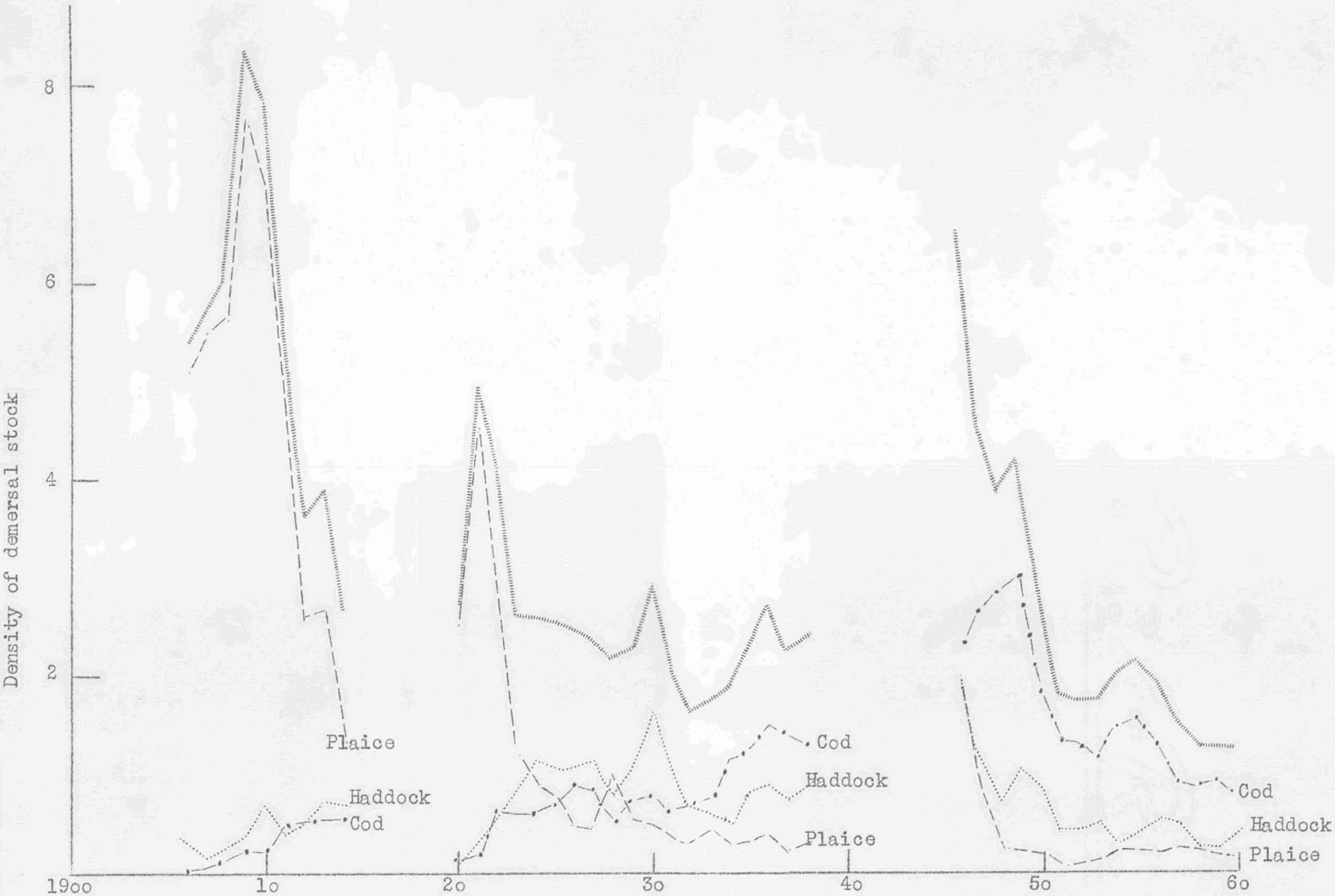

Figure 1. Density of demersal stocks in the Barents Sea, from data of British trawler catches.

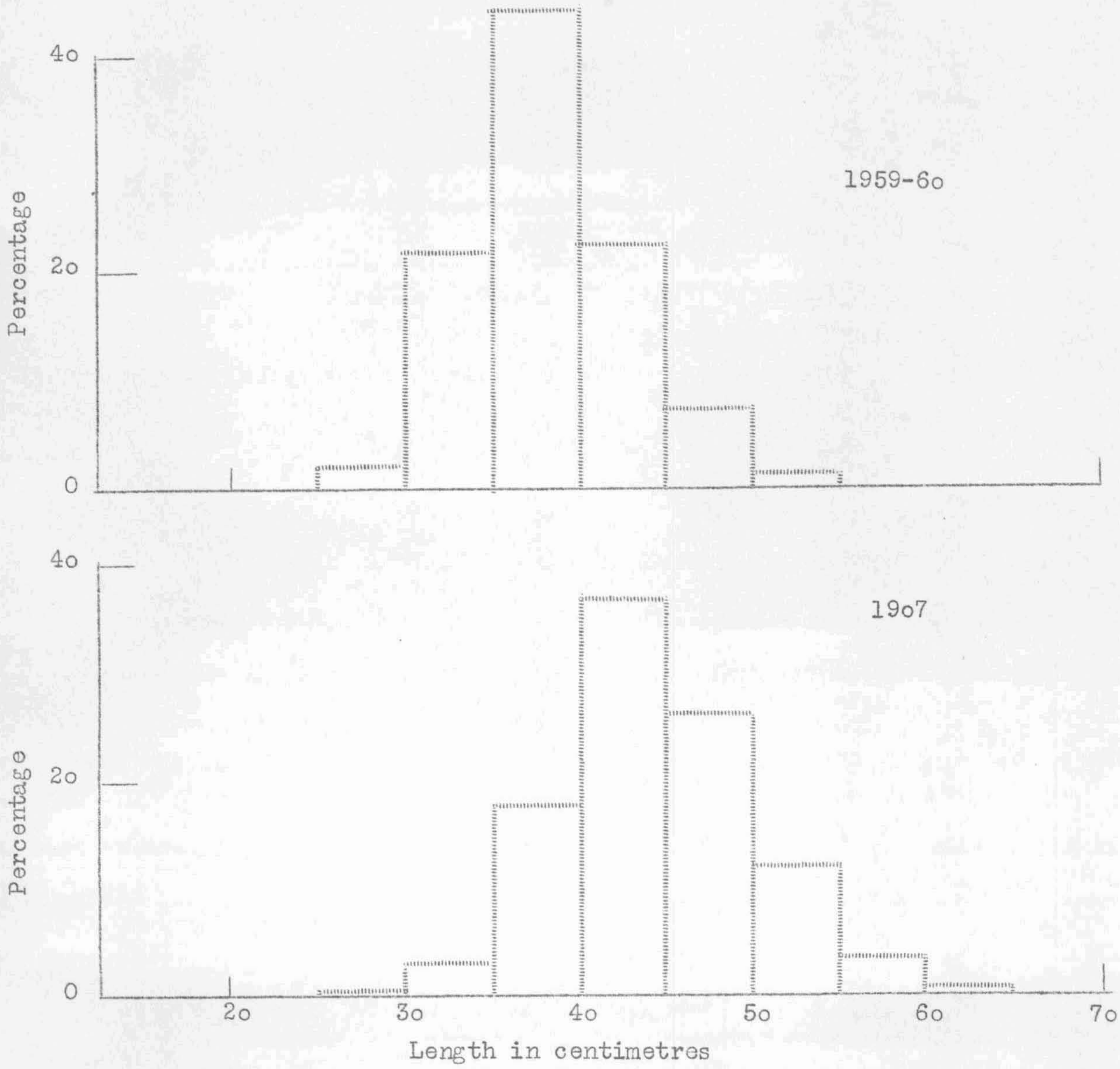

Figure 2. Size composition of plaice caught by English trawlers in the Barents Sea.

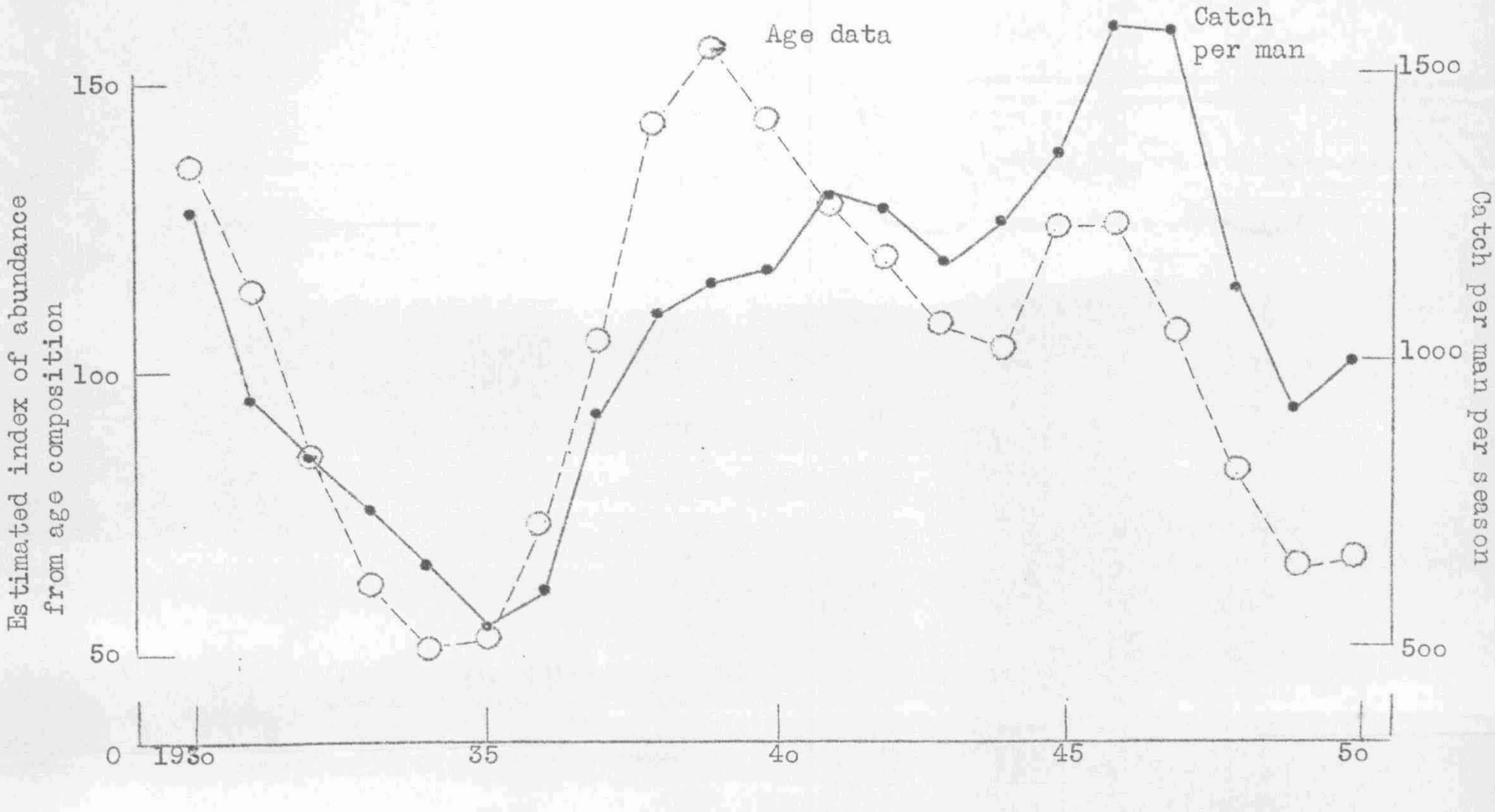

Figure 3. Indices of abundance of Lofoten cod.