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Diurnal Changes in Trawl Catches of Fishes

by

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Introduction

In attempting to measure the abundance of fish stocks the data most frequently used are the statistics of commercial fish landings, expressed in some form of catch per unit of fishing effort. It is generally accepted that such data are distorted in many ways, providing a measure of relative abundance only. One factor which may be of considerable importance in causing distortion is the diurnal variation in size and composition of trawl catches. In fisheries for some species, such as the haddock at Faroe, the diurnal changes in size of the trawl catches may be so great that some vessels may stop fishing for part of each 24 hour period. Provided that the commercial landing data are consistent, this type of variability may have little effect upon measures of relative abundance, but it can cause variance in estimates of abundance from limited data, as, for example, when only one or two vessels are involved in exploratory fishing, or in young fish surveys by research vessels.

Although it is very widely known that diurnal changes occur in trawl catches, there are surprisingly few published data available to make even preliminary estimates of the magnitude of such changes. It is the purpose of this paper to present results for some of the more common demersal species and to consider ways in which variations may occur with size and with season. The paper will not attempt to review all reports of diurnal changes, but will use results to try to illustrate different features or types of changes. It is intended first to discuss some simple cases of diurnal variations in the numbers of fish caught, and then to describe examples of changes in the size composition of catches: the behaviour of fish by day and night, seasonal variations in the diurnal pattern, and effects of tides upon catches will be considered more briefly.

Changes in Numbers of Fish Caught

Numbers Caught by Day and Night

Diurnal variations in the numbers of fish caught occur in many species sought by trawlers; thus catches of hake, herring, coalfish and redfish have all been reported as being generally smaller during the night than during the day (Hickling, 1927, 1933; Lucas, 1936; Schmidt, 1955; von Seydlitz, 1962). However, these figures represented only approximations, since they were all derived from commercial trawler catches, in which shifts of fishing ground occurred during the cruises.

North Sea plaice

During the months of April and May in 1959 and 1960, a series of cruises was made with the R.V. "Sir Lancelot" to the southern North Sea, to fish a ground at the southern end of the Haddock Bank (between 53°17'N 1°38'E and 53°12'N 1°45'E); the catches on this small ground, made at the same depth throughout the day and night, showed a well-marked diurnal rhythm in the number of plaice caught. The analysis of these catches, covering 148 trawl hauls, gave particularly clear and consistent results, which will be dealt with in some detail here to provide an example for comparison with other species. The plaice were a mixture of immature and spent fish, mainly between 25 cm and 35 cm in length.

The fishing gear used was a Lowestoft otter trawl, without bridles, with a 65 mm cotton cod-end. The trawl was towed for periods of 1 hour or 1½ hours, throughout the day and night. Although the trawl hauls were all made on the same ground, the average level of catch was less at the end of a period of trawling than at the beginning, and the level of the catch also varied between cruises. To facilitate the comparison of catches this variation was removed by expressing the results for each day's trawling in terms of percentages of the mean catch during daylight of that day. For comparison of day and night catches 'day' was defined as the period between sunrise and sunset as given for that day in "The Nautical Almanac".

Comparing twelve periods of day and night, the mean night-time catches were in all cases less than the day-time means (Table 1), the average for all twelve night means being only 69% of the day-time mean.

Table 1. Mean night catch per hour expressed as a percentage of the mean daylight catch per hour

43	68	50	68
82	99	55	65
68	79	99	54
Average of all night means = 69% of day-time mean			

Arctic cod, haddock and coalfish

Since January 1958 the R.V. "Ernest Holt" has made nine winter cruises to the northern coasts of Norway, principally trawling on the North-West and Malangen Banks for adult cod and haddock prior to spawning; these catches provide suitable material for comparison with the North Sea plaice.

The fishing gear used was a distant-water Granton trawl; the hauls were of one to two hours duration, but for the purposes of comparison, all catches have been converted to catch per hour. At this latitude the sun does not rise above the horizon in January, and even in February and March its angle is low; however, there is a period of several hours of twilight and for the purposes of analysis 'day-time' was defined as the period between morning and afternoon twilight, the time of twilight being taken as the mean of the times given for civil and nautical twilights at 71°N in "The Nautical Almanac".

The catches on these cruises were rather variable, and frequently a full day's trawling could not be completed due to bad weather; (indeed on one cruise it proved impossible to complete a single day's fishing). Nevertheless a comparison between night and day catches could be made on any cruise by taking only those days when some trawling was done during both daylight and at night, and then combining all such daylight hauls to obtain the average daylight catch per hour for that cruise, and similarly treating the night hauls. These comparisons, based on 145 daylight hauls, and 77 night hauls, are shown in Table 2.

Table 2. Ratios of day to night catches by weight, on Malangen and North-West Banks during the period January to March, 1958-63

	Mean night catch as a percentage of mean daylight catch, for each cruise				Mean night catch for all cruises combined, as a percentage of mean daylight catch
Cod	52 54	31 19	29 82	74 31	47
Haddock	31 47	26 51	4o 13	35	35
Coalfish x)	11 37	11 8o	36 156	25	51

x) The coalfish data are probably much less reliable than those for cod and haddock since they were frequently based on small catches, which were also more irregular than those of cod and haddock.

North Sea soles

It is well known that the best trawl catches of soles are usually made at night; this occurs so commonly in the North Sea than even when hauls are made over a number of grounds during a cruise the average catch at night normally exceeds that of the day. Results for ten research vessel cruises in the North Sea are given in Table 3; on each cruise the ship fished mainly on one ground.

Table 3. Soles in North Sea. Mean night catches expressed as a percentage of mean day catch

19o	383	177	194	246
17o	337	232	216	418

Average for all cruises = 256% of day-time mean

Sunrise and Sunset Catches

It is frequently claimed by fishermen that their largest catches of fish are made at sunrise, or less frequently at sunset, but although this is often accepted by fisheries scientists, there is very little confirmatory evidence available in the published literature.

North Sea plaice

During the cruises of R.V. "Sir Lancelot" in April and May, 1959 and 196o, when trawling for plaice on the Haddock Bank, it was noticed that in each 24 hour period of fishing, in addition to the differences between day and night catches, the number of fish in the first trawl haul after sunrise was usually higher than the mean daylight catch. Comparison of ten dawn trawl hauls, with the mean daylight catch for the same days, showed that the first daylight haul was 18% larger (Table 4).

Table 4. Catch of first trawl haul after sunrise expressed as a percentage of the mean daylight catch per hour

119	111	138	97
11o	143	1o6	
1o5	1o5	147	
Average of all sunrise trawl hauls, 118% of day-time mean			

A similar comparison of the sunset haul of plaice with that of the rest of the day failed to show a high catch; indeed the catch immediately before sunset was usually below the daylight average (Table 5), and the catch immediately after sunset was also usually small.

Table 5. Catch of last trawl haul before sunset expressed as a percentage of the mean daylight catch per hour

76	83	86	59
79	68	89	
1o7	76	58	
Average of all sunset trawl hauls, 78% of day-time mean			

High catches at sunrise certainly occur in other species; for example, on a cruise of R.V. "Sir Lancelot" trawling for two days on a small North Sea ground (part of the Off Ground, position 54°55'N 0°4o'E), greater numbers of dabs and whiting, as well as plaice, tended to be caught during the first haul after sunrise.

Table 6. Catch per hour at sunrise expressed as a percentage of the mean day-time catch per hour

Day	Plaice	Dab	Whiting
1	185	27o	237
2	223	189	172

Arctic cod and haddock

On the winter cruises of the R.V. "Ernest Holt" to the Malangen and North-West Banks, relatively few trawls were made immediately after sunrise or before sunset, accompanied by a sufficient number of day-time hauls to give an adequate day-time mean; only eighteen such dawn hauls are available and twenty-three sunset hauls. These dawn and dusk hauls are considered in Table 7.

Table 7. Dawn and dusk catches of cod, expressed as percentages of day-time means, Malangen and North-West Banks; for period January to March, 1958-63

Dawn catches				Dusk catches			
15o	211	7o	96	143	258	39	133
291	39	111	115	19o	43	22o	135
199	77	122	75	96	96	111	187
183	14o	71	12o	17o	384	96	112
63	122			17o	217	36	17o
				1oo	4o	1o2	
Mean value = 125%				Mean value = 141%			

Although the mean value for all dawn catches was 25% higher than the day-time mean, the figures were variable and one third fell below 95%. This does not provide conclusive evidence for the dawn haul being larger, although it is commonly held by British trawlermen, fishing these banks, that the best catches are made in the first daylight haul. The larger sample of dusk hauls gave an average value that was 41% greater than the day-time mean, and the figures fell below 95% in only four cases. The results for haddock catches were more variable than for cod, and although it appeared that the dawn hauls were probably higher than the day-time mean, there was no evidence of larger catches of haddock at dusk. The numbers of coalfish were too variable for analysis.

Konstantinov (1958) described diurnal changes in the size of catches of cod and haddock for a number of banks in the Barents Sea at different times of the year, but by contrast to the cod and haddock caught on Malangen Bank just prior to spawning, his figures show little evidence for larger catches being made at either dusk or dawn. The dawn catch of cod was larger in only one case amongst Konstantinov's results (on Goose Bank in November), and only the April and October figures for Murmansk Bank show some suggestion that the dusk haul was high; in nine other examples given this was not the case; catches of small haddock on Kanin Bank were also high at dusk, but not in two other examples. For most of his results, the largest cod and haddock catches were generally made during the middle of the day. Similarly most of the data presented by Schmidt (1955) for coalfish show that the highest catches were made in the middle of the day. On the other hand, Trout (1957) reported that cod-fishing at Bear Island in April/May was best during the period of surface twilight (there was no true night at that latitude in late spring).

Changes in the Size of Fish Caught

In the three investigations reporting diurnal changes in trawl catches of hake, herring and coalfish (Hickling, 1933; Lucas, 1936, and Schmidt, 1955), the authors also found differences in the length distribution of the fish caught by day and night. Such length changes must fundamentally affect estimates of the abundance of different size or age groups within a population, and some further examples are considered below.

Size of Fish Caught by Day and Night

North Sea plaice

Length measurements made on samples of plaice caught during the 24-hourly periods of trawling on the Haddock Bank (referred to above) failed to show a diurnal change in the size composition of the fish; however, the samples were not large. Extensive numbers of plaice were measured during five days' trawling in August 1948 by the R.V. "Sir Lancelot" and the R.V. "Platessa". The two ships fished for the same periods of day and night, with Lowestoft trawls similar to that used on the Haddock Bank survey, except that both had a single tickler chain added and the "Sir Lancelot" used 3o fathom bridles; the fishing was on the Off Ground. A total of 3,o24 fish was measured, and from these large samples it was apparent that the plaice in the day-time catches were bigger than those caught at night. The difference in the length distributions was not large, being a shift of about one centimetre, the same changes were observed on both vessels and their data has been combined (Figure 1). From these observations, and from the failure to observe a difference in length distributions on the Haddock Bank, it appears that diurnal changes in the mean size of plaice in catches may be small, at least during the spring-summer feeding period.

Arctic haddock

During a cruise of the R.V. "Ernest Holt" to the SE Barents Sea in 1959, large diurnal changes in the length distributions of the haddock catches were observed. The fish were extensively sampled and more than three thousand fish were measured; it was therefore possible to analyse the changes in some detail.

The data were collected over four successive periods of day and night trawling at the north end of Skolpen Bank (about 71°21'N, 35°o'E) at the end of November, 1959, at depths of 11o to 125 fathoms (mainly between 115 and 12o fathoms). At this latitude the sun does not rise above the horizon in mid-winter and for the purposes of analysis 'day-time' was defined as the period between morning and afternoon twilight, as for Malangen Bank.

The fishing gear used was a standard distant-water trawl, but the cod-end was covered with a bag of small-meshed netting in order to retain the fish which passed through the meshes of the cod-end. The trawl hauls were of $1\frac{1}{2}$ hours' duration, and all the haddock caught, both in the trawl and in the cod-end cover, were combined for the present analysis.

Comparing the four periods of day and night fishing, the mean number of haddock caught per night-time haul (mean of 12 hauls) was 63 fish, only 28% of the mean day-time number (219 fish - mean of 11 hauls). The length distributions of the haddock catches were examined in an attempt to determine whether the diurnal changes were due to movements of the whole population or only of a certain group within the population, and it was found that the mean length of the haddock was markedly smaller during the day than during the night. The percentage length distributions for the day and night catches are shown in Figure 2. By expressing the mean night catch as a percentage of the mean day catch, for each 5 cm length group (Table 8), it was apparent that the greatest diurnal changes occurred in the smallest fish (the higher value for 20 cm fish than for 30 cm may be false, since the samples were small); little change occurred in the catches of the largest haddock. Intermediate sizes of fish showed intermediate changes (Table 8).

Table 8. Diurnal changes in composition of haddock catches

Length (cm)	Mean day catch (11 hauls)	Mean night catch (12 hauls)	$\frac{\text{Mean night catch}}{\text{Mean day catch}} \times 100$
20-24	4	1	25
25-29	8	1	12
30-34	31	2	7
35-39	41	6	15
40-44	39	9	23
45-49	22	7	32
50-54	16	6	37
55-59	20	10	50
60-64	17	9	53
65-69	10	7	70
70-74	6	4	67
75+	2	2	100

Since the intensity of surface illumination was very low during day-time at latitude 71°N, the visible range at 100 fm would be small, so that catching efficiency due to changes in the visible properties of the trawling gear would not be expected to vary much between day and night; this was supported by the fact that the largest haddock, which should have been best able to avoid the trawl, were caught in similar numbers in both day and night hauls. It was possible that smaller fish might escape through the "square" of the net, but the ratio of night to day catches continued to change in a regular manner for the larger fish which would have been retained by the netting in the "square". It was therefore concluded that the main cause of the diurnal variations in the catches was a change in availability due to large numbers of the smaller haddock leaving the sea-bed at night.

Two days after the completion of work on North Skolpen Bank, trawling was begun in an area of similar size on the north-eastern edge of the North Deeps (about 70°50'N, 40°10'E), some 100 miles to the ESE. The haddock on this bank were mainly in the 30-50 cm range, and since these small fish had shown the greatest diurnal variations in numbers at Skolpen Bank, it was expected that the day-time catches would form an even greater percentage of the total catch. However, on this new ground, over the three day and night periods studied, the night catch was consistently higher than that of the day, being 132, 270, and 197%. The trawl hauls were made at the same depth (110 to 130 fathoms), the haddock were feeding in the same manner, and at present no explanation can be offered to account for the apparently different behaviour of the haddock on these two banks in the Barents Sea.

Hake and herring

Considering diurnal changes in the length distributions of hake caught off Ireland by three commercial trawlers, Hickling (1933) found that the smaller fish tended to leave the sea-bed at night to a greater extent than did the large hake. The catch and length data for hake caught on one of these cruises covering seventeen night hauls and twenty-three day hauls, have been analysed further, and, as in the case of the Barents Sea haddock, it was apparent that the greatest diurnal fluctuations occurred in the catches of the smallest hake of less than 29 cm, and the least changes in the catch of the largest fish (although these still showed a twofold change); changes in catches of mediumsized hake fell between (Table 9).

Table 9. Diurnal changes in catch composition of hake, from catches of "Trawler Prince", December 193o (Hickling, 1933)

Length (cm)	$\frac{\text{Mean Night Catch}}{\text{Mean Day Catch}} \times 1oo$
Below 29	16
3o-39	36
4o-49	47
5o-59	53
6o-69	44
7o +	55

A very similar pattern of diurnal change has also been reported for trawl-caught herring in the North Sea. By a re-examination of Fulton's data on trawled herring (Fulton, 1922), Lucas (1936) was able to show that whilst diurnal changes were evident in the size of the catches, these were largely due to the migration of "small" herring from the bottom at night, the numbers of "large" herring remained relatively constant throughout the day and night (although there was some tendency for the quantity of "large" fish caught to be a little greater during the day).

More recently Richardson (196o) also reported that the mean length of North Sea herring in trawl catches was greatest at night; this was due to an increase in the numbers of large herring caught at night, together with a decrease in the number of small immature herring. However, by separating the large fish into maturing or "full" adults, and "spent" adults, Richardson was able to show that the changes were complex. The catch of "full" herring decreased at night in the same way as the catch of small immature fish; at the same time the catch of "spent" fish increased. During the day, catches of "spent" herring fell to a minimum, whilst both immature and "full" fish were caught in greatest numbers. Thus the full and spent adult herring of the same length apparently had opposed behaviour.

Although the herring is considered to be essentially a 'pelagic' fish and the haddock a 'demersal' fish, it is interesting that both Lucas' analysis of the day and night catches of a Hull herring trawler over three years, and Richardson's results showed less diurnal variation in size of catch than occurred in the catches of haddock on Malangen Bank in winter.

Coalfish

Schmidt (1955) has reported that the mean length of coalfish in trawl catches made at S.Iceland and off the Norwegian coast in the winter was greater during the day than during the night. Unfortunately, the results were presented as percentage deviations from the mean size, so that it was not possible to determine whether the changes were due to the movement of a group of fish or to a gradual change throughout the population. However, Schmidt stated that at night the small coalfish, of less than 85 cm, descended to the sea-bed, whilst the larger fish swam up into midwater; during the day-time the large fish went back to the sea-bed and the small fish returned to midwater. The behaviour of the coalfish seems to be complicated, since Wagner (1959), also working off S.Iceland in winter, reported rather different changes in mean size over periods of 24 hours. He found that the coalfish caught during the middle of the day were only a little larger than at night, but, more noticeably, the mean size fell both at dawn and at dusk. In the northern North Sea the mean lengths of Wagner's coalfish samples reached both their maximum and minimum during the night. However, the samples measured were not extensive, and fishing was carried out at a number of different depths; this alone would be expected to affect the length distribution.

Size Changes at Sunrise and Sunset

Since changes occur in the numbers of fish caught at sunrise and sunset, at least in some species, it is appropriate to consider whether there are differences in the length distributions of the catch at these times. Apart from Wagner's observation that the mean size of coalfish caught at Iceland decreased both at dusk and at dawn, there appears to be a few other data for such changes. However, some evidence was provided by a cruise of R.V. "Sir Lancelot" in August, fishing from dawn until dusk over three days, at a position just north of the Cleaver Bank (approx. 54°05'N, 3°25'E).

The length distributions of the catches of whiting and haddock tended to increase during the course of each day's trawling, the smaller fish being caught in greatest numbers in the first haul after sunrise. The figures for the three days' catches were combined to give mean length distributions, at dawn, during the day, and at dusk, for both whiting and haddock; these are shown in Figures 3 and 4.

Fish Behaviour by Day and Night

It is the purpose of this paper to present some examples of ways in which the composition of trawl catches may change diurnally, but not to attempt detailed analyses of the reported changes in terms of the behaviour of the fish (in fact we have insufficient information to do so). Nevertheless, in discussing the ways in which catch composition may change, it is obvious that the behaviour of the fish cannot be completely ignored; indeed this aspect has already received some mention in the presentation of the results.

Reactions to fishing gear

From the results of day and night trawl catches it is seldom possible to differentiate completely between changes in the catching efficiency of the gear at night, when it cannot be seen by the fish, and the effects of darkness on the behaviour of the fish, such that the numbers of fish available for capture by the gear may be altered. Changes in the efficiency of the gear at night are probably best illustrated by the seine net, in which the warps stir up a cloud of sand and mud which in daylight probably helps to drive fish inwards, so that fish from a large area are herded into the path of a relatively small net; at night seine net catches are usually low, probably because the fish are not driven inwards as efficiently by warps which they do not see. Diurnal variations in trawl catches are frequently not as great as those of the seine net, but the trawl-doors and bridles probably have a similar herding effect to the warps of the seine net and the catching efficiency may likewise fall in darkness. These suggestions are supported by the results of laboratory experiments recently described by Blaxter, Parrish, and Dickson (1963), in which it was apparent that vision was the most important factor governing the behaviour of fish in relation to fishing gear, the type and magnitude of the fish's reaction to gear depending principally on the light intensity, water transparency, and the visible properties of the gear itself.

The material available for analysis in this paper has tended to emphasize examples of decreased catches at night. But there are, of course, many other trawl fisheries in which the largest catches are made at night, indeed night seining for flatfish is sometimes carried out on certain grounds.

Innate behaviour changes affecting availability

Well defined diurnal cycles of swimming activity have been described in a number of fish (for example, the plaice, Harder & Hempel, 1954; and the minnow, Harden Jones, 1956), and probably occur to some extent in most species. Such activity would probably be reflected in changes in the composition of the trawl catches, particularly when associated with feeding or with vertical migrations. Thus plaice are visual feeders and when caught just before dawn have empty stomachs (Jones, 1952). The high catch after sunrise is probably associated with the onset of the daylight feeding cycle; at this time it would be expected that the fish are actively searching over the sea-bed for food and therefore might be more readily disturbed by the trawl footrope than after the initial feeding period.

It is generally assumed that diurnal changes in the vertical distribution of fish play a major role in causing changes in the catch, and may be sufficiently large in such fisheries as for hake, that fishing operations are suspended for part of the 24 hours. The most familiar example is, of course, the herring, but in recent years it has become evident that many species previously considered to be essentially bottom-living also carry out extensive vertical movements, at least for some part of the year. Parrish & Blaxter (1963) have reviewed the vertical distribution of some of the main commercial Atlantic fishes. They point out that the general features of the vertical distribution of fish are closely associated with their feeding habits; however, they appear to have been unduly influenced in their review by this point -

they seem to have ignored many published reports and their figures are misleading. For instance, Parrish & Blaxter state that the vertical range of coalfish mostly extends 7 to 1o metres from the sea bottom, and although the fish may have a pelagic distribution over deep waters, they believe that there is "no evidence of marked diurnal variations in vertical distribution". But coalfish have been regularly caught near the surface with purse seines in Norwegian fjords and off Iceland; Schmidt (1955) has clearly shown diurnal vertical migrations of 1oo m for coalfish off Iceland, and I have observed similar migrations by large ripe fish off the western coast of Norway. Similarly, these authors' contention that there are only small diurnal variations in the vertical distribution of cod, haddock and hake is not supported by many of the observations of other workers. Further quantitative information on the vertical distribution of such 'demersal' species is required at present; valuable new results are likely to come from the development of midwater trawling techniques, which will contribute to the understanding of changes in the catches on the sea-bed.

Seasonal Variations

The condition of the fish

Changes in the condition of fish are quite likely to be accompanied by modifications of the pattern of diurnal appearance of that fish in the trawl catches, particularly during gonadal maturation and the spawning migration, which is frequently also accompanied by a decrease in feeding activity. Thus Lucas (1936) suggested that the 'large' herring, which showed relatively small numerical differences in the day and night trawl catches, might well have been maturing, or sexually mature fish, whereas the 'small' herring, showing large diurnal changes, were probably immature. My own observations on North Sea herring (to be published later) also indicated that ripe fish, prior to spawning, left the sea-bed at night later, and at lower light intensities, than feeding herring at an early stage of maturation; the ripe fish also returned to the sea-bed earlier in the day. On the other hand, Richardson (196o) reported little or no difference in the diurnal patterns of appearance in trawl catches of small immature and large ripe herring, but after spawning he found a complete reversal of the diurnal pattern in the spent fish.

In the Lofoten cod there appear to be similarly large changes in behaviour after spawning; although the ripe cod are caught in extensive trawl fisheries along the Norwegian coast, few spent fish are caught. From the duration of the trawl fisheries it was expected that spent cod would be caught if near the sea-bed and Trout (1957) has suggested that the cod become pelagic after spawning.

Submarine light

In discussing seasonal changes in the diurnal pattern of catch composition it is important to distinguish between changes in the behaviour of the fish, and changes in the period of daylight. Seasonal changes in submarine illumination may be marked; during winter the duration and intensity of illumination are low, and in shallow seas turbidity may be at a maximum, whilst in summer both the duration and intensity of daylight are at a maximum, whereas turbidity is usually low (except in areas of phytoplankton production). Since either directly or indirectly light is without doubt the most important external factor governing diurnal changes, many seasonal variations follow the annual light cycle. In this respect the Arctic seas are extreme, since there is little light in midwinter and no night in midsummer. It is therefore particularly interesting that the results of Konstantinov (1958) show little or no diurnal change in the catches of cod on Murmansk Bank, in continuous daylight in July, or in the catches during almost continuous night of January; similarly, no change occurred in cod catches at Bear Island in December and January. But during the spring and autumn, diurnal changes in cod and haddock catches were quite marked on all the Barents Sea banks investigated.

Tidal Effects

Tides can be expected to exert marked effects on trawl catches, both mechanically, by directly affecting the speed of tow and the working of the net so that it may fish with greater or less efficiency for some species or sizes of fish, and also by causing changes in the behaviour of the fish themselves. In regions where tidal currents are strong, as in the Southern Bight of the North Sea, flatfish may bury more deeply, or lie more closely to the sea-bed about the time of tidal maximum. For parts of the tidal cycle it would not be unusual for lighter materials from the sea-bed to be swept up, increasing turbidity near the bottom; fish may temporarily avoid this turbid layer, or the decrease in visibility may change the catching efficiency of the trawl.

Conclusion

It has been the aim of this paper to consider some of the ways in which the size and composition of trawl catches may vary diurnally and to present some data to illustrate such changes. It has been shown that there may be almost continuous variations in the interaction between the trawling gear and the behaviour of the fish of different size-groups over each period of 24 hours, and that differences in the diurnal pattern may occur with time of year or from place to place. In some cases these diurnal changes are small, but in others they are pronounced.

These findings may have considerable effects upon attempts to estimate abundance. They are particularly important when only small quantities of data are available; they are likely to be of much less importance to estimates of relative abundance from market data, even so their effects may be appreciable in some instances. For example, Hickling (1933) showed that larger hake were caught at night rather than during the day, and it was noted (Hickling, 1927) that only a few of the trawlers fished throughout the day and night, most ships omitting the night hauls. In such a fishery a change in economics could make it worthwhile for a greater number of boats to fish by night, and this could affect figures for catch per unit effort and abundance by size. Similarly, it follows from Lucas' analysis of diurnal changes in the composition of the catches of North Sea herring trawlers that it would be inappropriate to attempt a direct comparison, or combination, of size-composition data derived from trawl and drift-net landings in this type of fishery.

Diurnal variations in catch offer considerable difficulties to attempts to make quantitative assessments of the distribution and abundance of fish by trawl surveys with research vessels. In particular, since catches of small fish may show the greatest diurnal changes, which may well also vary with other environmental parameters such as depth and feeding, it could be difficult to predict with accuracy the future size of a stock from the limited catches obtainable from single vessel surveys for O-group fish.

Graham (1956) offered some guidance on the problem of day and night variation between catches, stating that it was inefficient to spend time on every occasion to check this effect. He continued, "When the phenomenon under investigation - such as graduation in fish density with depth - shows clearly in the data collected, in spite of uncontrolled variations, it is even more significant .... unless the magnitude and direction of one of the sources of error happen to be associated with that of the independent variable, in this instance depth. Such an association need not be assumed, in the absence of evidence of it". An example of this kind of error occurring was provided on a cruise of the R.V. "Ernest Holt" fishing in the SE. Gullies area near Bear Island in 1954. Two series of trawl hauls were made, beginning at the top of the bank in the morning and progressing deeper to 2oo fm during the day. The density of the cod caught appeared to decrease with depth, although their mean size increased. However, the shallower hauls were made during daylight and the deeper at night. In Figure 5 the length distributions of the catches from 5o to 9o fm (day-time) and from 9o to 2oo fm (night) are shown; the figure bears some resemblance to Figure 2 for catches of Barents Sea haddock by day and night (but at the same depth). At the time of the cruise it appeared that the change in size and density of the cod with depth was real, and this might have been accepted on the basis of Graham's statement, but on the grounds of the results discussed in this paper it could equally have been due to diurnal net avoidance, or vertical migration by the smaller fish. Fortunately, in this case a third series of trawl hauls was made from deep water in the morning up to the top of the bank and at night, and this confirmed that the apparent change in size and density with depth was real. Some indication of the type of diurnal pattern to be expected in the catches of cod would obviously have been valuable in this example.

Although it is an essential part of the experimental method to examine the variability of results, frequently there is insufficient time on research vessel cruises to make such detailed checks, as Graham observed. In this respect the present author feels that in view of the scarcity of quantitative data on diurnal changes in catch composition, it would be most valuable if well-established examples which may be in the possession of other laboratories could be published, especially in those cases when a small ground has been fished for several days and a consistent pattern has emerged (as for the plaice on the Haddock Bank) or when a larger area has been fished during the same season over a number of years (as for cod and haddock off the northern coasts of Norway). In such cases it would be of importance that the catch data be presented with some indication of variance and the significance of the results. (This has not been done in the present paper for the purposes of this Symposium, but the final version will have the tables appended). This information would provide estimates of both the direction and magnitude of such changes for that region, and might further be used with other reports to build up a composite picture of the annual changes in diurnal pattern occurring within a particular species.

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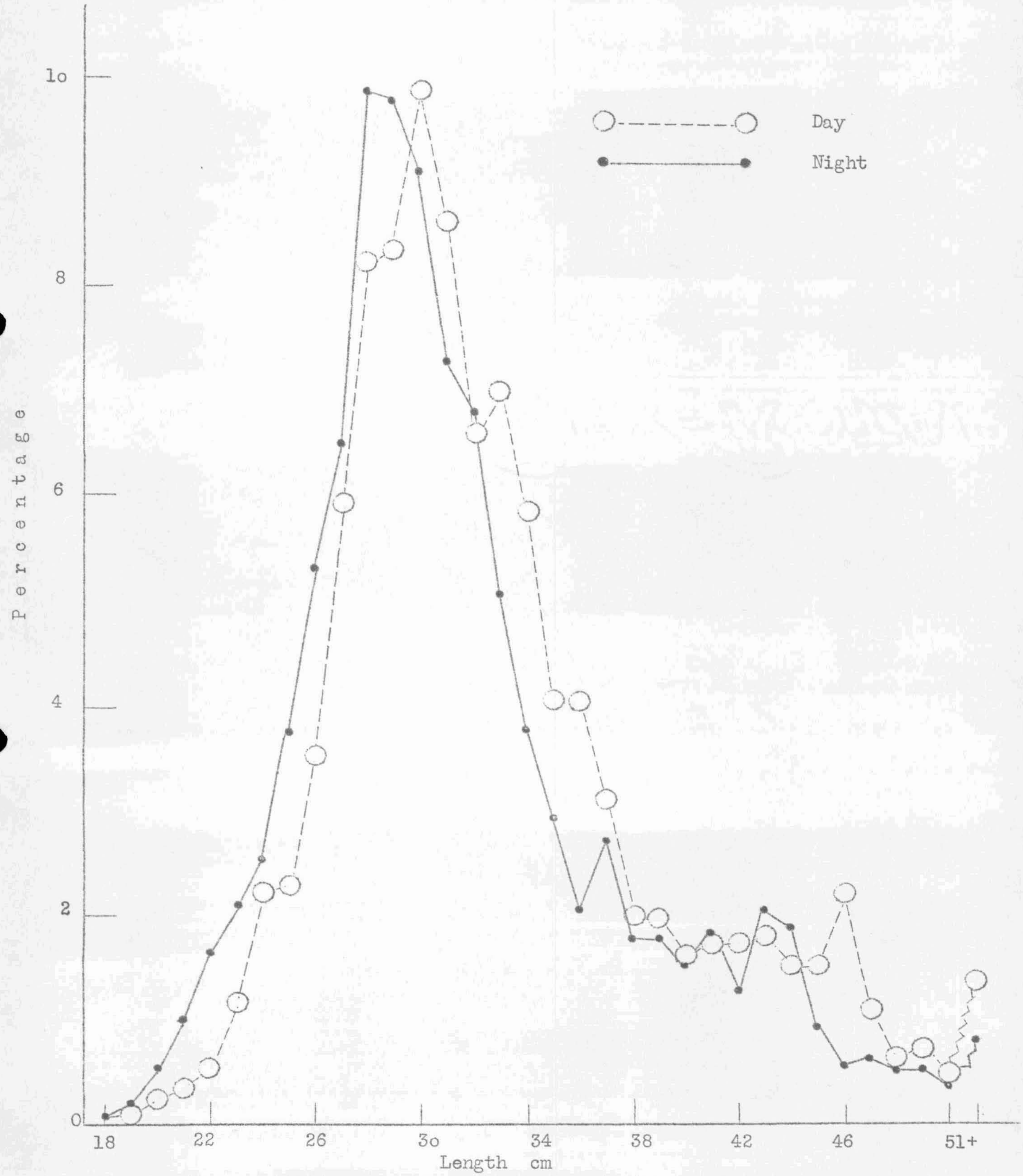

Figure 1. Length distributions of North Sea plaice caught by day and by night (for 1,457 day, and 1,567 night fish).

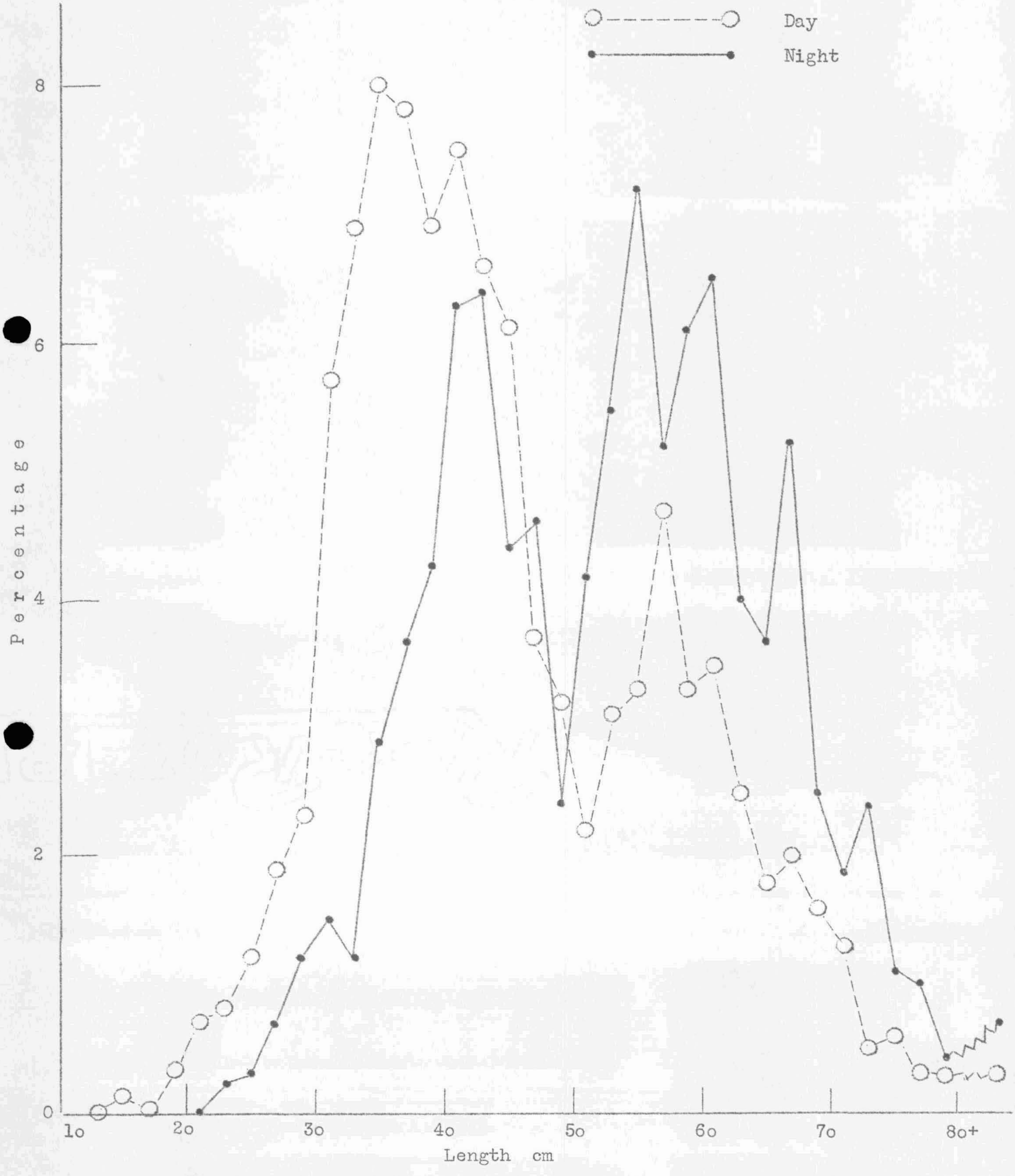

Figure 2. Length distributions of Skolpen Bank haddock caught by day and by night (for 2,4o9 day, and 76o night fish).

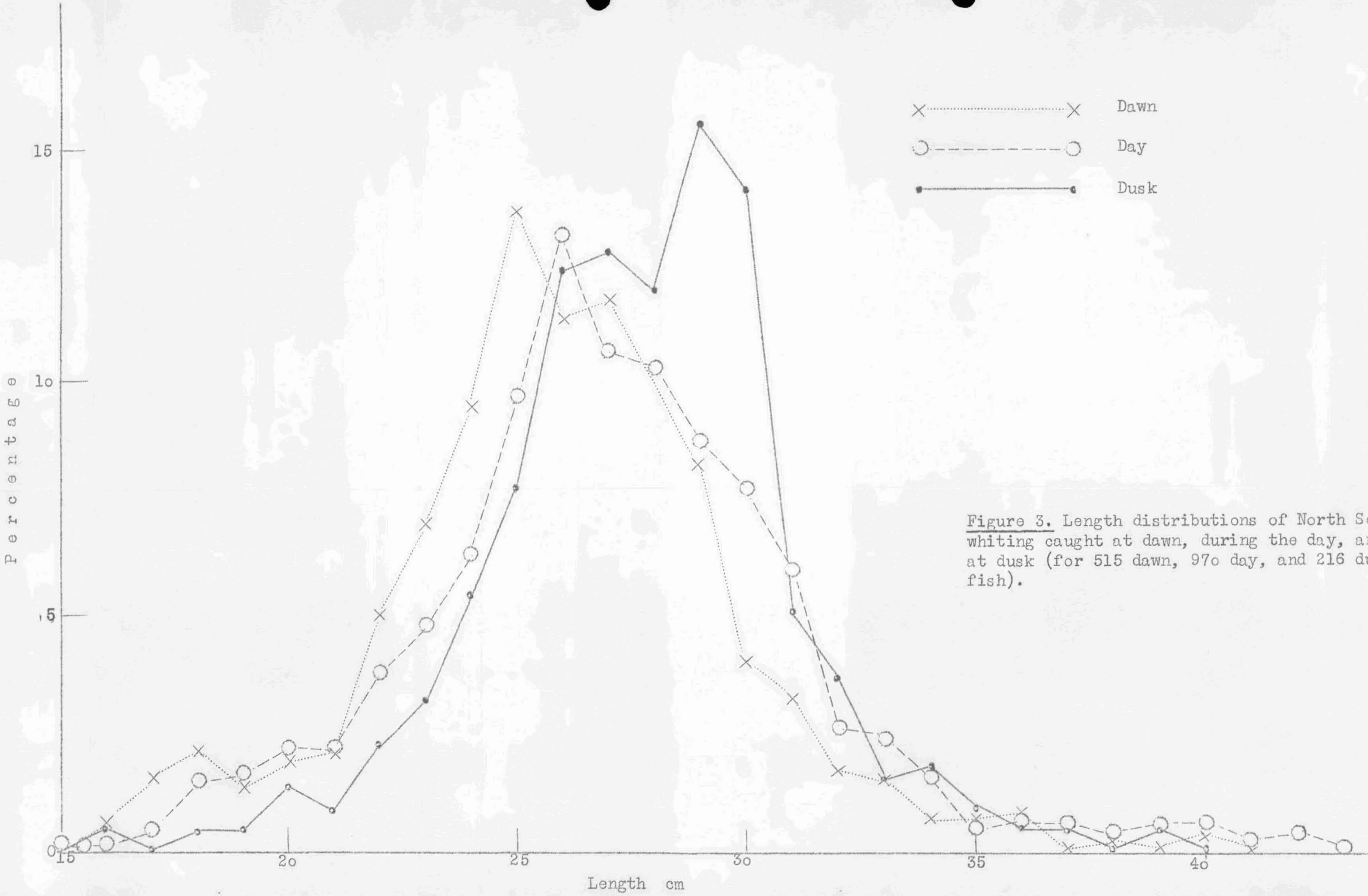

Figure 3. Length distributions of North Sea whiting caught at dawn, during the day, and at dusk (for 515 dawn, 970 day, and 216 dusk fish).

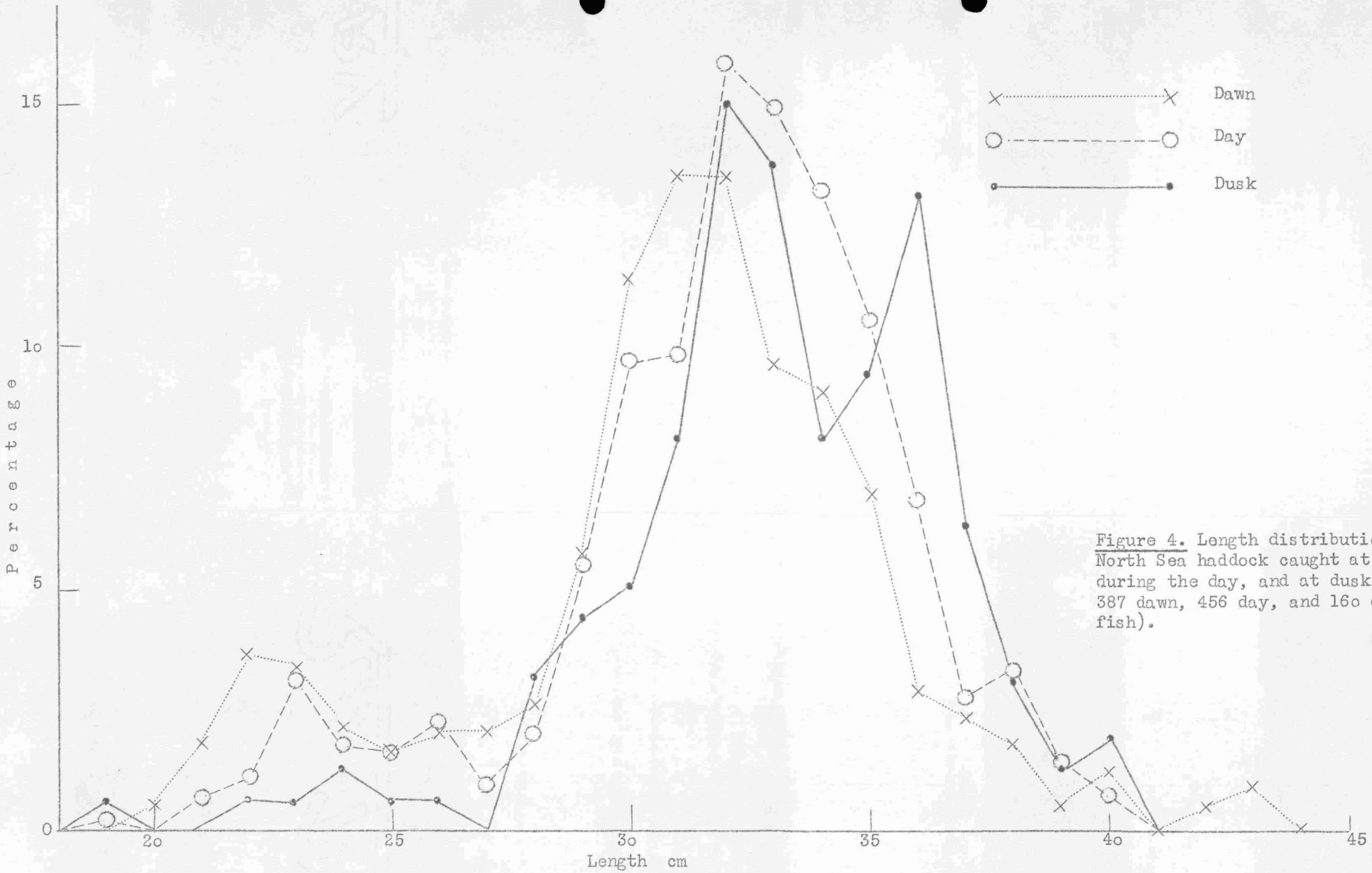

Figure 4. Length distributions of North Sea haddock caught at dawn, during the day, and at dusk (for 387 dawn, 456 day, and 16o dusk fish).

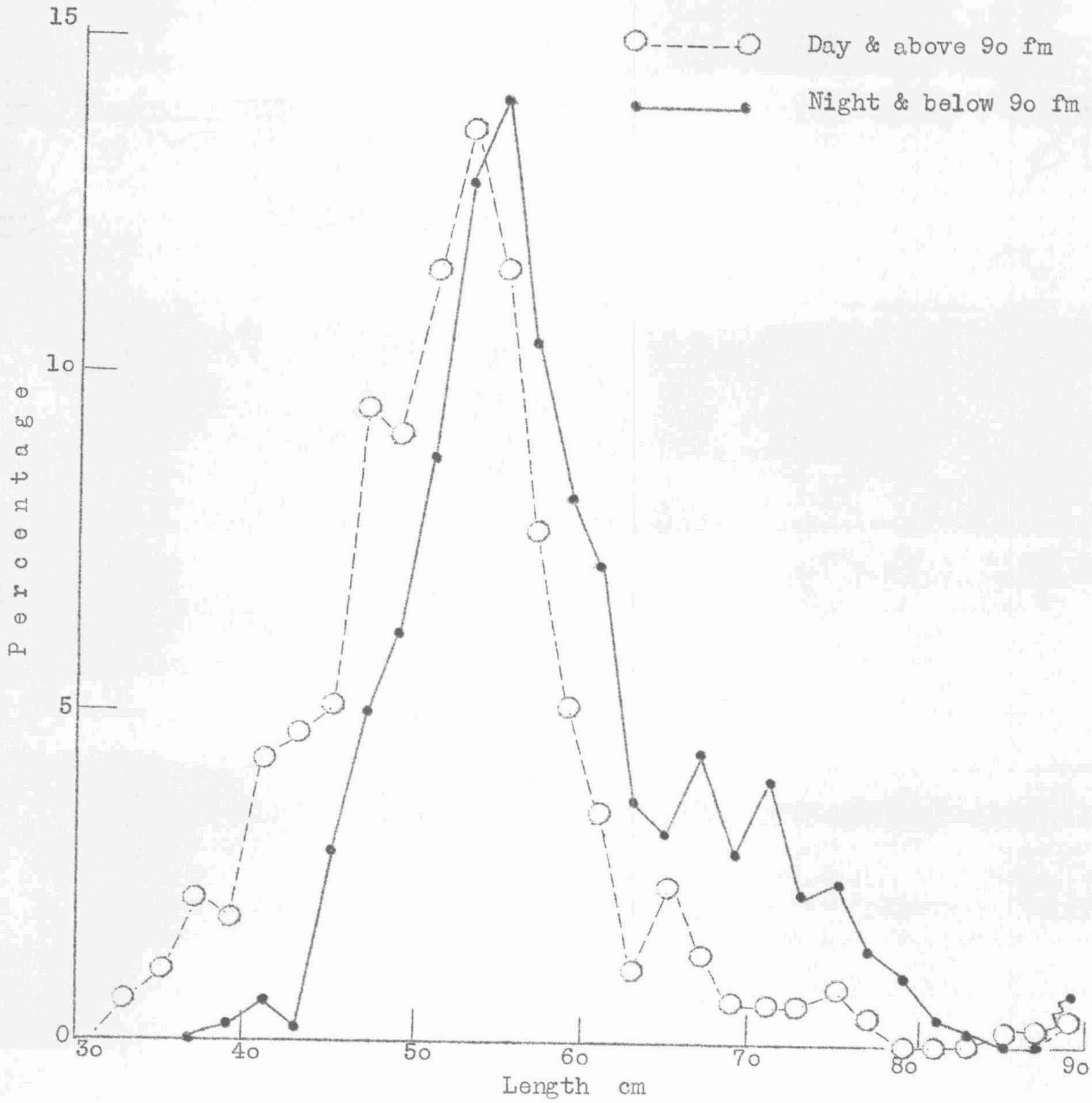

Figure 5. Length distributions of Bear Island cod caught by day (between 5o and 9o fm) and by night (between 9o and 2oo fm) derived from 476 day, and 5o7 night fish.