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# The Otoliths of the Cod

## PRELIMINARY REPORT

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# The Otoliths of the Cod

During many years a great amount of material for the age determination of cod has been collected by the Norwegian Fishery Investigations. From 1932 the collection also comprised otoliths, the bulk of the older material being scales.

As scale preparations are a not very suitable for preservation, Sund introduced the method of photographing the scales directly on to gas-light paper. The otoliths are, on the other hand, ground and polished and only photographed in special cases.

A comparison between scales and otoliths as a mean to determine age speaks absolutely in favour of the otoliths in the case of skrei or spawning cod, while in the case of loddetorsk or younger (Finmark) fish the scales are, perhaps, just as good.

The skrei otoliths show in very many cases more zones than the scales and a careful comparison of the corresponding rings in the two classes of objects made it clear that the scale rings corresponding to the outermost otolith zones were difficult to identify on the scales. These outer otolith zones differ from the inner ones in several ways, being generally narrower and having a more conspicous clear (hyaline) band which is often wider than the opaque band, — in contrast to the inner zones where the opaque bands are the widest. The plates I and II show photos of skrei otoliths:

Plate I, fig. 1: 10 year old fish, no narrow zones near edge.<br>
„ I, „ 2: 13 year old fish, 3 narrow zones.<br>
„ II, „ 3: 14 year old fish, 3 narrow zones.<br>
„ II, „ 4: 15 year old fish, 6 narrow zones.

The narrow zones are pointed out with an x. It seem reasonable to connect this change of phase in the zone pattern with a change in the life cycle of the fish, and with the knowledge we have gained of the biology of the cod it is difficult to think of a more fundamental change than that caused by the inception of sexual maturity, the ripening of the gonads, the spawning, the fast during spawning, the spawning migration and the stay in a new habitat, — all these circumstances may well be thought to leave their imprints on the periodically growing otoliths. (In the scales these same influences may cause phenomena of wear and regeneration at the edge of the scale which may blur the picture of periodic growth as it is well known in the case of the salmon). Such narrow outer zones may be found in about 60 % of skrei otoliths while in the immature loddetorsk they are never observed. *It seems, therefore, naturally to regard the narrow zones as spawning zones.*

The material upon which the following deductions are constructed is not large, the samples consisting of about 400 ind. from Lofoten 1932 and another of about 300 ind. from the same area 1933, but even this restricted material shows so many common traits and such a regular composition that the results not very well can be considered as casual, everything pointing towards the correctness of considering the narrow zones as spawning zones and we will therefore use this term, also for the sake of shortness.

From the age analysis it appears that the majority of the samples consisted of fish from 10 to 15 years. The youngest individuals were 7 and the oldest 22 years old. Both samples show that the 1922 brood was comparatively numerous and that the 1920 brood was relatively scarce.

None of the 7 or 8-year old fish in these samples show spawning zones. Only among the 9-year old specimens do spawning zones appear although only in few cases, but in the following year group there is an increasing number of spawning zones. In the still older fish the relative number showing spawning zones increases with increasing age up to 16 years when all individuals show one or more spawning zones. Fig. 1 shows the increase in the percentage of fish showing spawning zones as the fish grows older.

If the average number of spawning zones in each year-class is computed the values shown in fig. 2 are obtained. From the age of 12 years the increase is about one spawning zone per year. *This gradual increase of about one such zone points towards the conclusion that the skrei spawn every year.*

The fish seem to have become sexually mature at very different ages. One may f. inst. find 15-year old skrei with any number of spawning zones from none to nine, i. e. *sexual maturity may develop in any year from the 6th to the 15th.*

In order to facilitate the argumentation it is necessary to define a couple of new terms, *spawning class* and *spawning group.* The older terms *age group* and *year class* (or brood) are used in their accepted sense. Thus

*Year Class* (or Brood) means the fish born in the same calendar year.

*Age Group* means fish of the same age.

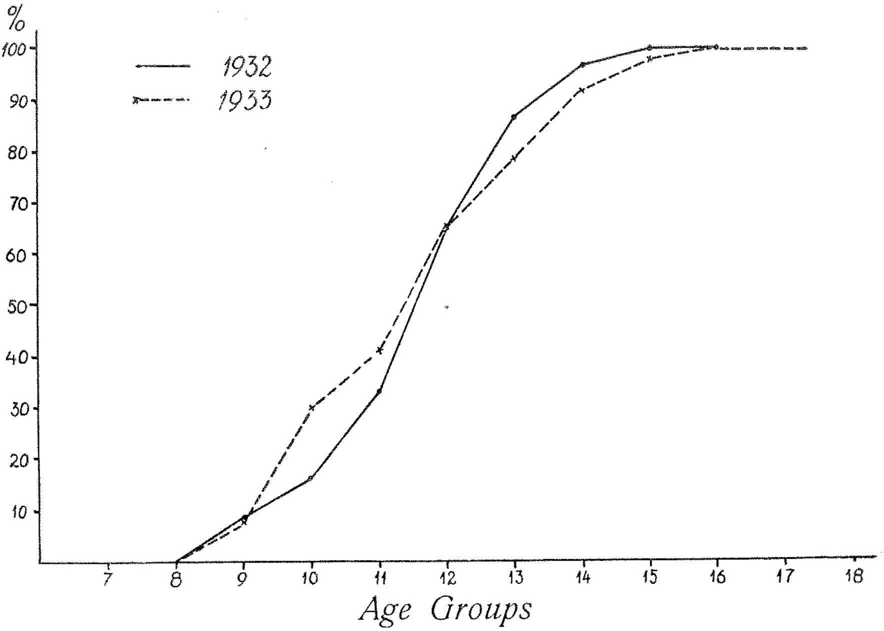


Fig. 1. Percentage of Individuals having spawned previously, within the various Age Groups.

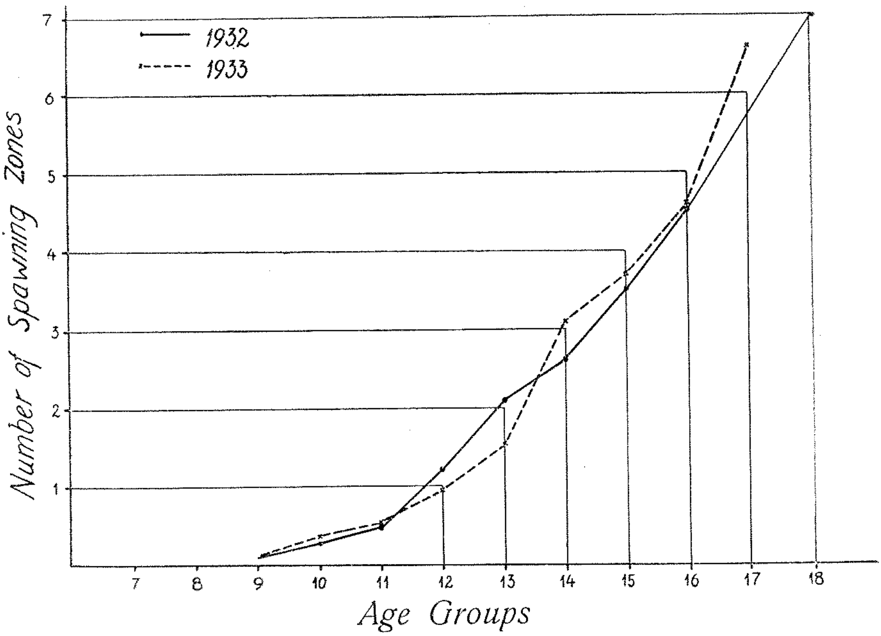


Fig. 2. The average Number of Spawning Zones, within the various Age Groups.

*Spawning Class* means the fish which have become sexually mature in the same calendar year.

*Spawning Group* means the fish which have become sexally mature at the same age.

Fig. 3 shows the observations arranged according to age and age at first spawning, the columns representing percentages of the entire sample. The most obvious fact is that such a large percentage of the material is made up of 10 and 11 years old fish and that they appear most numerous as first spawners. On the whole it is seen that also the older age groups are most mŭmerously represented in the middle spawning groups (10, 11 and 12). The apparent higher age at first spawning of the older fish may be explained by the assumption of a higher mortality of the fish who have become ripe at an early age.

At the bottom of fig. 3 the entire sample is arranged according to age at the first spawning. Individuals ripened in their 10th and 11th year appear in greatest number. Now it might be ohjected that this distribution may be caused by the predominance of the very rich brood of 1922. But even if this brood is completely disregarded, the distribution remains fundamentally the same, only that the spawning group of 11 years then appears positively the most important.

The average age at the first spawning is 10½ years in both samples. *This seems to imply that the skrei attains maturity in greatest numbers in their 10th and 11th year.*

In fig. 4 the age composition of both samples is shown at the top, below the material has been dissolved into spawning classes. In both samples the first time spawners (spawning class 1) make up the greatest number and in each higher spawning class the number of individuals decreases with increasing age.

The relative strength of the spawning classes as observed in these samples from the spawning grounds in two consecutive years shows a characteristic course, apparent from fig. 5. *It seems that the Spawning classes suffer an annual reduction of 35 to 40 %.*

If all the broods were equally numerous and if the aggregate spawning classes might be supposed to frequent the same spawning areas every year, this reduction should represent the mortality. But even if the interpretation of the narrow zones as spawning zones is accepted, it would be unjustifiable to draw conclusions as to the mortality of the skrei stock from such a restricted material as the present. The agreement between the results from the two years is, however, so close that it seems to indicate a certain regularity as to the reduction. In this connection it might be of interest to mention that during the marking experiments on skrei in 1913 and 1928 a recapture percentage

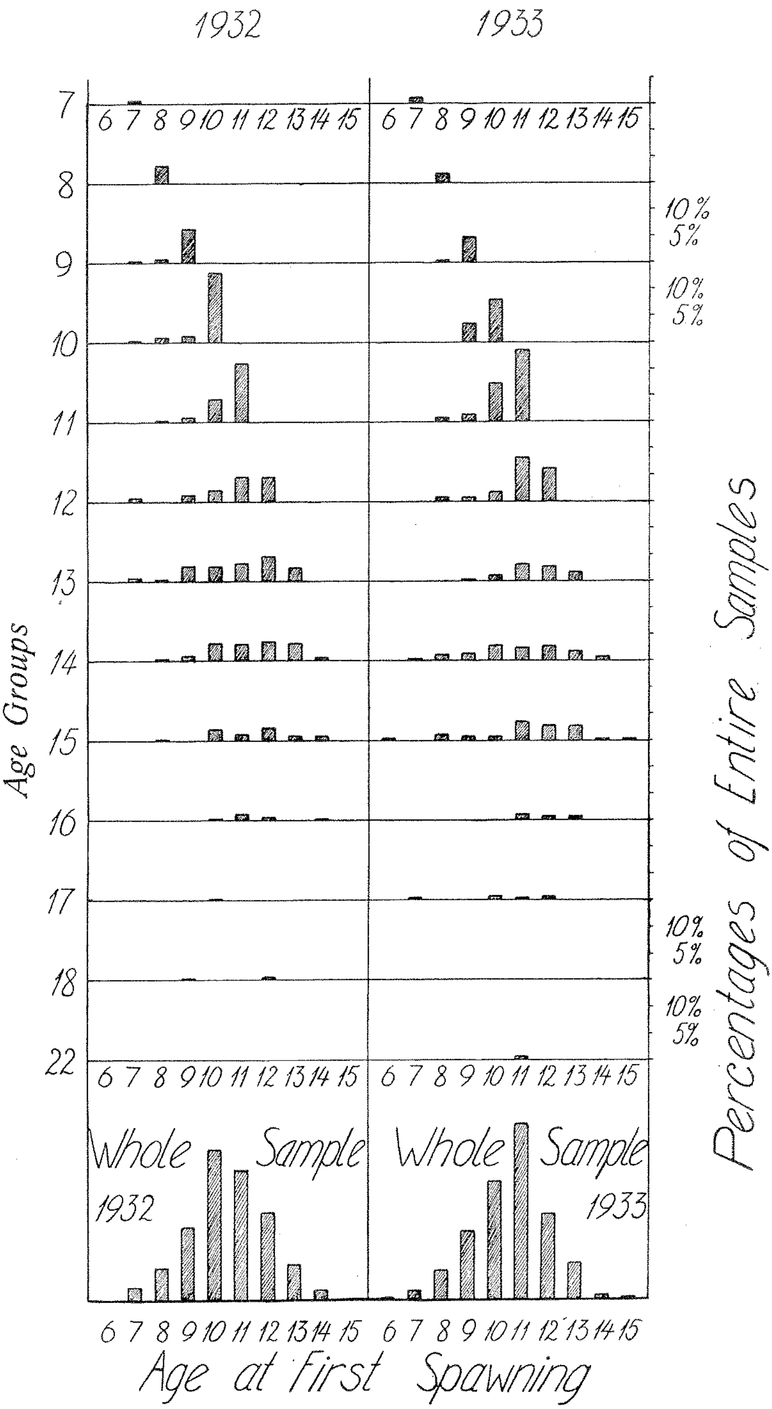
1932
1933
Age Groups
7
8
9
10
11
12
13
14
15
16
17
18
22
6 7 8 9 10 11 12 13 14 15
10%
5%
Percentages of Entire Samples
Whole Sample 1932
Whole Sample 1933
Age at First Spawning

Fig. 3.

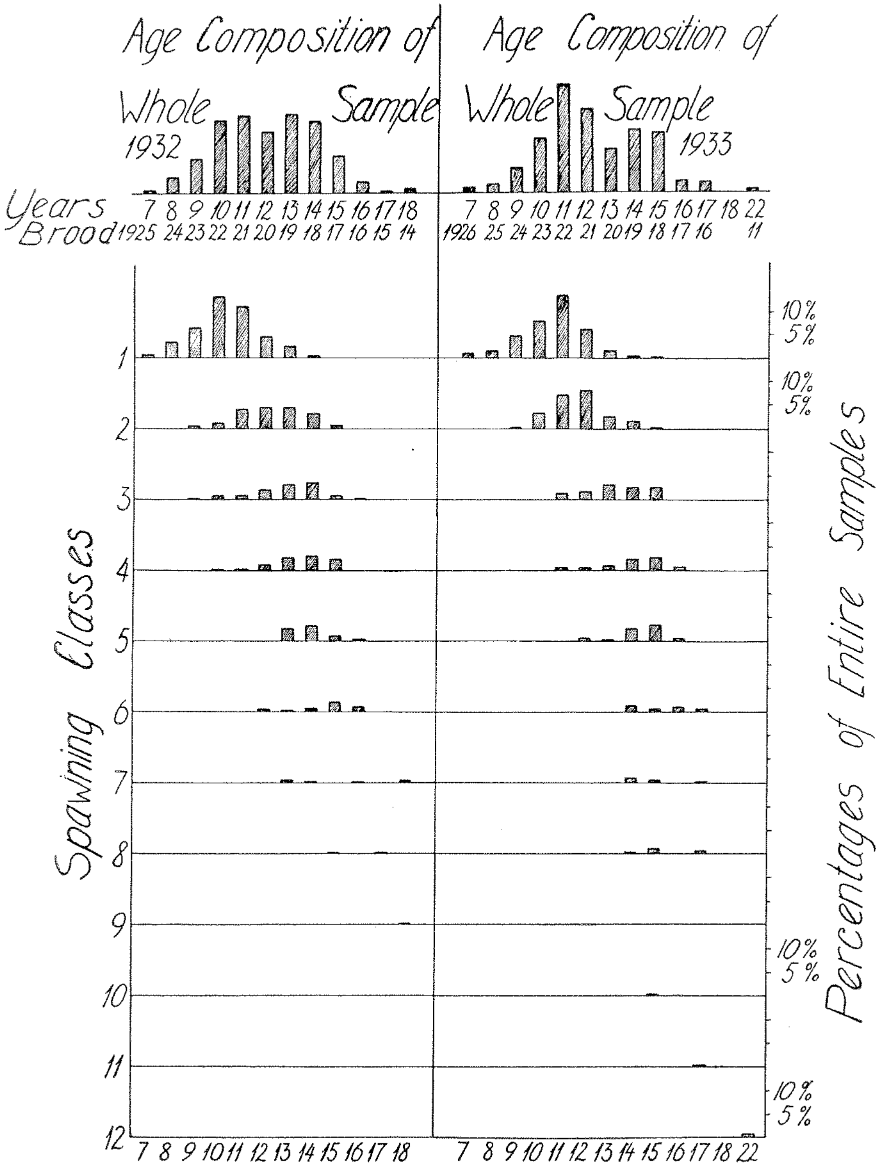
Age Composition of Whole Sample 1932
Age Composition of Whole Sample 1933
Years
Brood
7 8 9 10 11 12 13 14 15 16 17 18
1925 24 23 22 21 20 19 18 17 16 15 14
7 8 9 10 11 12 13 14 15 16 17 18 22
1926 25 24 23 22 21 20 19 18 17 16 11
Spawning Classes
1 2 3 4 5 6 7 8 9 10 11 12
Percentages of Entire Samples
10%
5%
7 8 9 10 11 12 13 14 15 16 17 18
7 8 9 10 11 12 13 14 15 16 17 18 22

Fig. 4.

of 30 % was established. This must be conjectured as a minium value of the effect of the fishery as some of the fish may have perished through the handling and some may have lost their mark and some escaped detection when caught again. This recapture percentage, therefore bears in any case witness to a very powerful taxation of the stock present on

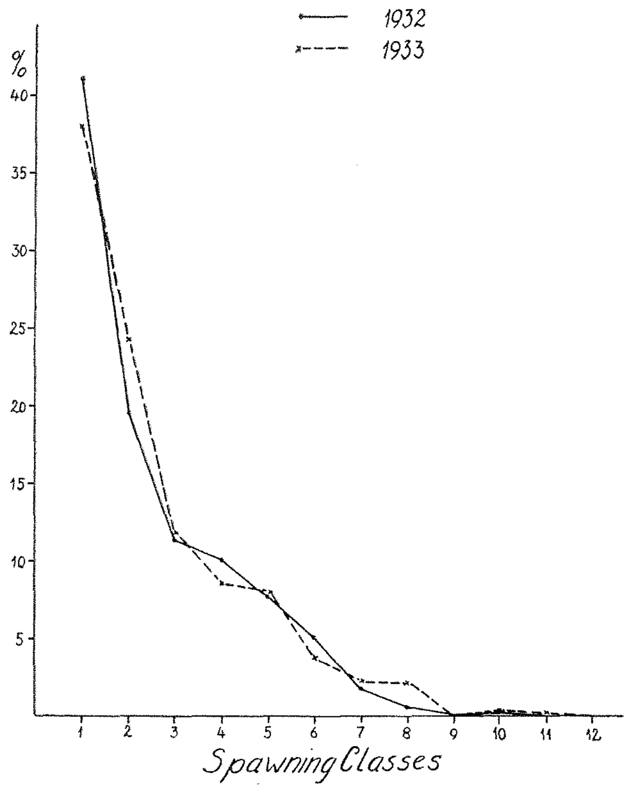


Fig. 5. The percentage Proportion of the Spawning Classes on the Spawning Area.

the spawning grounds. It is not intended to put the reduction of the numerical strength of the spawning classes in direct relation to the reduction of the stock taking place during a Lofoten fishing season. We are, on the other hand, ignorant of the proportion of the stock which comes to the spawning grounds at Lofoten and which proportion goes to other spawning grounds, also of the amount of reduction to which it is subject in those other areas. Besides, the number of skrei is certainly reduced at other seasons by natural mortality and by taxation by enemies in the sea and by fishery.

Mr. Einar Lea in his paper "Mortality in the Tribe of Norwegian Herring", (Rapp. et Proc.—Verb. Vol. LXV.) has made the mortality problem the subject of mathematical treatment. He finds that the causes of decrease (mortality) in the herring act with equal intensity on the young and the old fish and he can find no signs to be interpreted as senility even in the oldest herring. Lea has not arranged his material into spawning classes in the same way as done in the present paper, but his investigations which were based on a large material from a long series of years gave as a result a most probable annual mortality of 20 %.

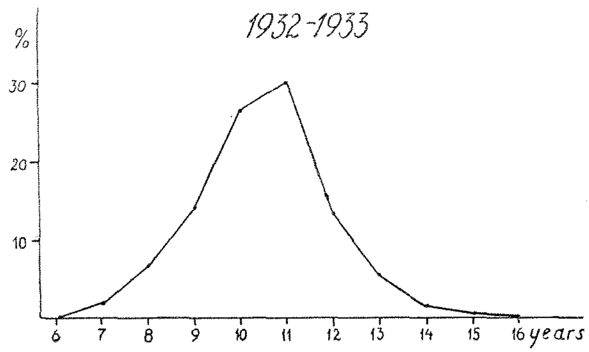


Fig. 6. The Age Composition of the First Time Spawners, 1932 and 1933 combined.

As mentioned above the skrei seem to ripen at very different ages and there is much evidence to show that the majority attain maturity in their 10th or 11th year. Also in this respect it can not be expected that this restricted material shall furnish exact evidence as to the proportion of ripening fish within the different age groups. But the general tendency of the figures seems convincing.

The different broods as well as the first-time spawners are most fully represented in the middle spawning groups. But the first time spawners (which have suffered no previous taxation as spawners) may be thought to furnish the best evidence as to the age when the cod attains maturity and as to the proportion of maturing fish in the different age classes. The unequal numerical strength of the different broods will, however, have influence on the age composition of the spawning classes and it is also possible that one brood may attain maturity at an earlier age than another. Only observations through a series of years may eliminate, resp. elucidate these conditions. Fig. 6 shows the percentual age composition of the first-time spawners for the two years 1932 and 1933 combined.

In the present material the 1922 brood is the most numerous though far from dominating. But even conceding that it bulks relatively more among the first time spawners than a brood of average intensity would do, the entire course of the curve (fig. 6) seems to correspond to a binomial curve or a curve closely akin to a binomial, and it may be considered to illustrate, in a general way the degree of sexual maturity commencing in the different year classes.

The late prof. G. O. Sars and mr. Thor Iversen have pointed out that in the shoals of "loddefisk" a great number of fish may be found which have attained skrei size but nevertheless have immature gonads in the very spawning time. Sars thought it possible that they were temporarily sterile, and Iversen introduced the term "gjelltorsk" (meaning much the same) for these fish. They differ, thus, from the ordinary loddetorsk only in size, measuring 70—100 cm.

Now, according to the investigations of dr. D. Damas, of mr. Oscar Sund and of the present author the average yearly growth of the loddetorsk amounts to about 6 cm except in the first three years when it is somewhat more. A loddetorsk of 10 years old is about 80 cm. It is very common however to find immature loddetorsk of 11—13 years and among the skrei there seems to occur first time spawners 14 and 15 years old.

It is easily conceived that these late-ripening fish attain a considerable size, but this is no reason to regard them as sterile, whether temporarily or permanently. And as no other characters have been adduced to define the "gjelltorsk" than immaturity and skrei size, *it must be considered probable that "gjelltorsk" are nothing but old immature fish.*

At the moment no special investigation has been made to show the relation between size and the ripening of the fish. But there is reason to believe that the attainment of maturity lowers the growth rate considerably. The fish which have attained maturity at an early age and have spawned many times are as a rule small for their age as the average annual growth of the skrei is only 1—3 cm. Below is a representation of the spawning groups within 3 age groups. The first-time spawners within each age group have the greatest average size and the average sizes of the succeeding spawning groups decrease with increasing number of complete spawnings.

When working up this otolith material all dubious specimens have been excluded. They amounted to about 15 %. Thereby a certain selection may possibly have taken place as the rejected otoliths may preponderately have belonged to one age group. The brood of 1922 has very easily read otoliths and this might point to the possibility

| Cm. | $10_1$ | $10_2$ | $10_3$ | $10_4$ | $11_1$ | $11_2$ | $11_3$ | $11_4$ | $12_1$ | $12_2$ | $12_3$ | $12_4$ | $12_5$ | $12_6$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | |
| 8 | | | | | | | | x | | | | | | |
| 9 | | | | | | | | | | | | | | |
| 70 | x | | | | | | | | | | | | | |
| 1 | | | | | | | | | | | | | | |
| 2 | xx | x | | | x | | | | | | | | | |
| 3 | | x | | | | | | x | | | x | | | |
| 4 | x | x | | | | | | | | | | | | |
| 5 | xxx | xx | | | x | x | | | | | | x | | |
| 6 | xxx | | | | x | xx | x | | | | | | | |
| 7 | xx | x | x | x | | x | | | | x | | | | |
| 8 | xx | | | | x | x | | | | | x | x | | |
| 9 | xxxxx | x | | | x | xxx | | | | | | x | | |
| 80 | xxxx | | | | xxxx | | | x | x | x | | | | x |
| 1 | x | x | x | | x | xxxxx | x | | x | | | | | |
| 2 | | xx | | | x | xxxx | | | | xxx | x | | | |
| 3 | xxx | | | | xxxxxx | x | x | | | x | | xx | x | x |
| 4 | xxx | x | | | xxx | xxx | x | | | xx | | | | |
| 5 | xx | x | x | | xxx | | | | | | | | | |
| 6 | xxxxxx | | | | xxxx | | | | x | x | x | | | |
| 7 | xxxxx | | | | xxxxxxxxx | xxx | | | xx | xxx | x | | | |
| 8 | xxx | | | | xxxxxxxx | xxx | | | xxxxx | xx | xxx | | | |
| 9 | | | | | xxxxx | | xx | | x | | | | | |
| 90 | xxxx | | | | xxxxx | | | | | xx | | | | |
| 1 | xx | | | | xxxx | xxx | | | | xxx | | | | |
| 2 | xxx | | | | xx | xx | | | xx | xxx | | | | |
| 3 | xxxx | | | | x | xx | | | x | xx | x | | | |
| 4 | | | | | xxxxx | | | | x | xxx | | x | | |
| 5 | xxx | | | | xx | x | | | x | x | | | | |
| 6 | x | x | | | x | | | | x | xxxxxx | x | | | |
| 7 | | | | | x | | | | x | | | | | |
| 8 | xxx | | | | xx | | | | xx | xx | x | | | |
| 9 | | | | | | x | | | xxxx | | | | | |
| 100 | | | | | x | | | | xxx | | | | | |
| 1 | | | | | | | | | x | | | | | |
| 2 | | x | | | | | | | | | | | | |
| 3 | | | | | x | | | | | | | | | |
| 4 | | | | | | | | | xx | | | | | |
| 5 | | | | | | | | | | x | | | | |
| 6 | | | | | | | | | x | | | | | |
| 7 | | | | | | | | | xx | x | | | | |
| 8 | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | |
| 110 | | | | | | | | | | | | | | |

x = One Specimen.
$10_1$ = First Time Spawners, 10 years old.
$10_2$ = Second —„— —„—

of the existence also of broods with very difficult otoliths. Many of the dubious otoliths in these two samples seem to belong to the 1920 brood.

It may be of interest to mention a character of the otoliths which, on closer examination, may furnish some clues to the biology of the loddetorsk. Fig. 2 on the plate shows a skrei otolith with 13 zones, the last 3 of which have been interpreted as spawning zones. But the other ten are also different among themselves. Starting from the centre we find a series of 6 zones resembling each other and then four mutually alike, but differing from the first six ones. More or less conspicously and in varying relative numbers these two types may be found in a great number of otoliths.

If one is permitted, in the same way as was claimed for the spawning zones, to refer certain changes in zone type to alterations in the mode of life, whether it be due to nourishment, habitat or both, one would conclude that the Arcto-Norwegian cod goes through a period which may be compared to the oceanic stage of the (young) herring. The otolith in question might thus be taken to furnish evidence of six years spent in one milieu and four in another making in all ten years when sexual maturity sets in.

The collection of otolith material has not included skrei and loddetorsk only but also, though to a smaller extent, cod native to the coast between Bergen and Finmarken. The otoliths of these coastal cod differ considerably in many ways from those of the skrei, not only in the relative width of the zones and their fine structure, but even in the external form. But also among the coastal cod several well defined types of otoliths seem to occur. Plate III, fig. 5 and 6 show two otoliths of northern coastal cod, fig. 5 from Lofoten (1933), fig. 6 from Hammerfest (1932).

The otoliths of coastal cod show also narrow zones near the edge corresponding to those interpreted as spawning zones in the skrei.

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If it is conceded that the narrow outer zones are spawning zones, the results of this investigation point to the following conclusions (the reservations arising from the small extent of the material always being borne in mind):

1) That the skrei may attain maturity from the 6th to the 15th year.
2) That the greater number attain maturity in their 10th and 11th year.
3) That it spawns every year upon having attained maturity.

4) That the first-time spawners make up about 40 % of the stock on the spawning grounds.
5) That the spawning classes are reduced in number by about 35 or 40 % for each spawning.
6) That the so-called "gjelltorsk" are the large immature, but not sterile fish of different age (8—15 years).
7) That the attainment of maturity and the spawning reduce the growth rate considerably.

Finally, that the otoliths of the skrei and the loddetorsk differ in a characteristic and definite way from those of the coastal cod, and that within the coastal stock different otolith types seem to be present, and that spawning zones are observed in the otoliths of the coastal cod also.

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Although these conclusions are drawn from a restricted material, it may be justifiable to point out their practical importance, especially because the problems of mortality and recruitment of the spawning stock present themselves here in a simplified form as resulting from direct observations.

It is apparent that if the rate can be found according to which the different spawning classes decrease in number at each spawning and the rate at which the first time spawners of a definite brood attain maturity and appear at the spawning grounds, then it would be possible on the data from a certain year to calculate the probable age composition of the stock in the ensuing year.

To get a sufficient insight into these conditions will, however necessitate a study of the cod stock along the lines followed in the present paper during a series of years. The agreement obtained between the data drawn from the material covering the two years considered gives good promise for the success of such investigations.

# PLATES

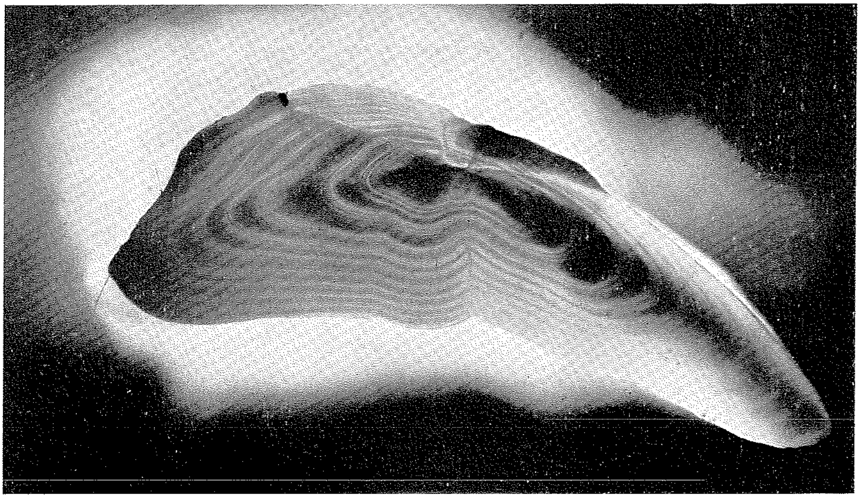

Fig. 1.

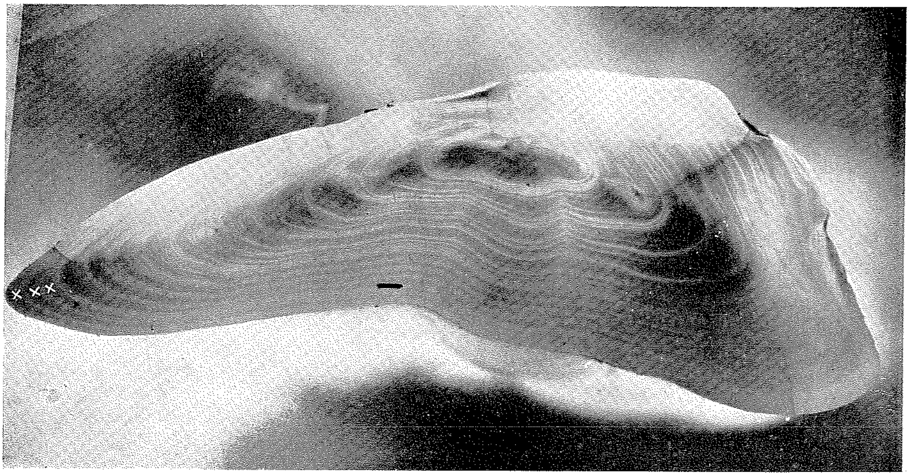

Fig. 2.

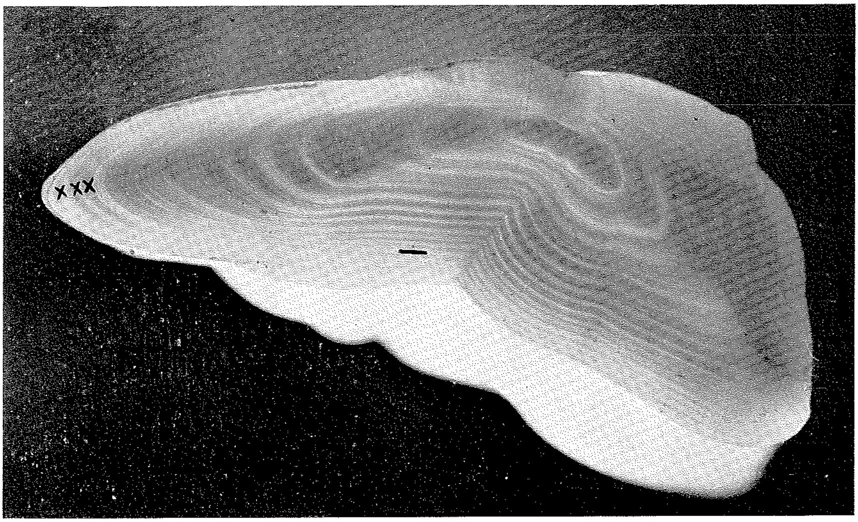

Fig. 3.

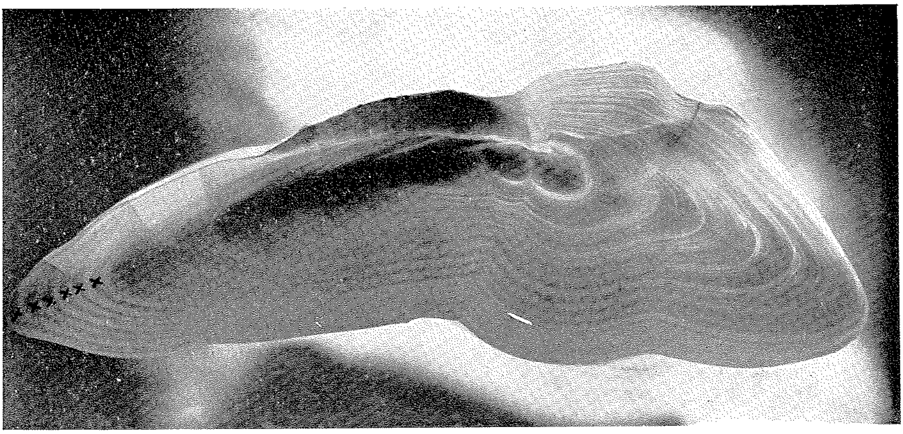

Fig. 4.

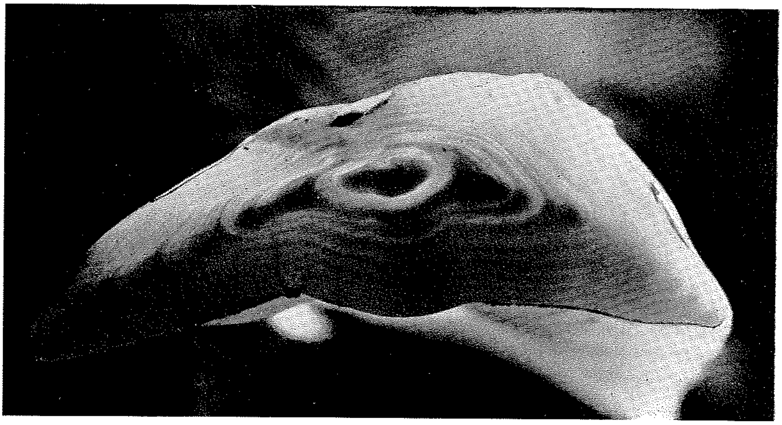

Fig. 5.

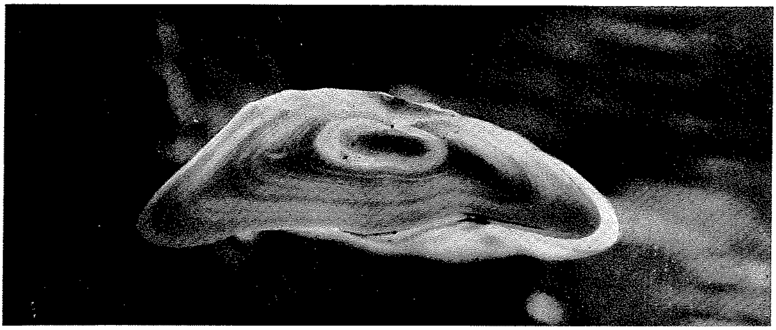

Fig. 6.