

# The Oceanic Stage in the Life History of the Norwegian Herring.

By

**Einar Lea,**

Fisheries Department, Bergen.

## 1. Introduction.

**T**he resumption of investigations on Norwegian herring and the introduction of scale analysis in the investigations at the beginning of this century led in the course of a comparatively short time to our gaining a very much clearer conception of the biology of the Norwegian herring than had previously been possible. When we compare the contents of the works, dealing with herring, of former Norwegian investigators with the great work of our contemporary Professor JOHAN HJORT, "Fluctuations in the Great Fisheries of Northern Europe<sup>1)</sup>", this increase in our knowledge becomes very evident. Not only did our understanding of the life history of the great race of Norwegian herring become clearer, but we were also enabled to formulate and work out problems with which we should have been entirely powerless to cope without the aid of these methods. Moreover we were enabled to discover the very violent fluctuations in the numerical strength of the year-classes which have proved to be so characteristic for the Norwegian herring. Without a thorough knowledge of these fluctuations it would be very difficult, even if at all possible, to build up any really tenable and detailed theory as to the Norwegian herring.

When HJORT published the above-mentioned work it was very far from his intention to give an account of the results obtained from a finished series of investigations. On the contrary it was his intention to arouse interest for amplifying and continuing them by showing some of the results to which the new methods led. To anyone who has not himself contributed to HJORT's work, this will be clear beyond a doubt

---

<sup>1)</sup> Rapports & Procès-Verbaux, Vol. XX, 1914.

if he reads the last chapter (VI, "Review of the present situation of the Investigations," p. 202). Before resigning his position as Director of Norwegian Fisheries, HJORT endeavoured to find ways and means to realize this plan, and to some extent he was successful, although the situation in the last 12—14 years has been extremely unfavourable for any development on a scale and in a form which would be adequate in view of the problems involved. Continuity in the most important observation work has, however, been maintained; the technique has been improved; problems have been taken up and some of them solved.

I shall here deal with the work on one of these problems and its solution. The problem was recognized as such long ago, but it soon became evident that it might remain unsolved for a long time because, amongst other reasons, a set of observations required for this purpose could only be obtained when the abundant 1904 brood had ceased to predominate in the stock, whilst for another set of observations new comparatively abundant broods were necessary whose fate might be followed up with sufficient accuracy in the statistical observation material.

This group of problems can be formulated thus: what takes place between the time when the herring is still quite in its infancy and the time when it appears, capable of reproduction, on the spawning grounds?

When it is said that the answer to this question is found, this does not imply that all possible facts relating to this transition in the herring from immaturity to maturity are known, but that knowledge has been gained as to many important points, so that this phase in the herring's life history is now known about as thoroughly as other phases, whereas formerly it was practically unknown.

This problem was to prove of great practical interest even apart from the purely scientific point of view. The connexion is as follows: The fishery for the so-called "fat herring", i.e. immature but comparatively large herring, which from 1908 to 1911 had given excellent results (between 600 and 1100 thousand hectolitres according to the statistics) afforded in the following six years a less satisfactory yield (between 250 and 420 thousand hectolitres). As this fishery for "fat herring" has always fluctuated very greatly, there would be no reason to regard this decrease in itself as anything particularly unusual but for two contributory circumstances. Firstly the fishery for "small herring" improved at the same time as the fishery for "fat herring" was of doubtful value, and secondly the employment of the purse-seine in these fisheries became more and more common, whereas previously the fishery had been carried on with shore seines or nets. Amongst many people therefore the opinion began to gain ground that all these circumstances were

interconnected. It was maintained that when so many "small herring" (prospective "fat herring") were captured, partly with the aid of the new implement, the purse-seine, this must result in a reduction in the number of "fat herring". It was further maintained that the use in itself of this implement diminished the chances of the "fat herring" fishery, partly because the influx of herring into the fiords was disturbed by the purse-seine fishery, which might commence before the herring had entered the fiord, and partly because the sea became polluted, and therefore avoided by herring, owing to all the bright scales being torn from the herring during the hauling in of the purse-seine catches.

The result of such views was an agitation and a demand for the prohibition of the use of the purse-seine and of the capture of "small herring". The State authorities decided that these demands should be subjected to a close scrutiny from various points of view and referred the purse-seine question to a committee which was to issue a proposal for a revision of the law relating to the "fat herring" fishery. The question as to the prohibition of the capture of "small herring" was referred to the Director of Fisheries on the grounds that a further study of the natural history of the herring was one of the tasks necessary for a satisfactory solution of this question.

In this manner the problem as to the details connected with the transition from the immature "fat herring" to the mature "spring herring" began to interest the administrative authorities in addition to those who were concerned with it from a purely scientific point of view. It seemed very likely that fluctuations in this group of phenomena might be a very important contributory factor in distributing the herring in the sea in such a way as to account for the yields of the separate fisheries for immature herring, i.e. the "small herring" and the "fat herring" fisheries, being as they were. There was all the more reason to attach importance to this possibility, as previous scientific observations had shown that that portion of the abundant 1904 brood, which in 1908 and 1909 were still immature "fat herring" and were present in large numbers on the usual grounds, were remarkable for their unusually slow growth. It seemed a reasonable hypothesis that this slow growth had delayed the transition of the herring to sexual maturity and caused them to remain for a longer period in the inshore waters of northern Norway where the greater part of the "fat herring" are caught.

When the problem was taken up for investigation it was decided that an attempt should be made to attack it from two sides, with the aid of observations on age and growth in conjunction with observations on the condition of the sexual organs.

First of all it was found necessary to make an attempt to single out and describe as well as possible the characteristic features of the herring which without any doubt come each year, but in greatly varying numbers, to the spawning grounds in order to propagate for the first time, i.e. young herring after passing through the transition stage to maturity (the recruit-spawners). By characteristic features are here meant age, age-distribution if any, size, growth-history, and sexual development. We can imagine such a description of these recruit-spawners being made theoretically in two ways, a more direct way by obtaining samples from what we may call pure shoals of them, shoals which have not already mingled with shoals of older spawners which in previous years have passed through the transition stage from immaturity to maturity, and a more indirect way by dividing in some manner or other samples of spawning herring, in which both recruit-spawners and older spawners are found mixed.

Both ways have been tried and it can now be stated that the direct method is the simplest and most reliable, but that it is to a very high degree dependent on favourable circumstances both during fishing and whilst material is being collected for scientific investigation. Successful attempts have several times been made to obtain such pure samples, either at the beginning of the fishery, i.e. before intermingling with the older spawners has begun, or at the end of the fishing season during the so-called "after fishery". In the following the indirect method will be described in detail. It should only be mentioned in passing that in order to lead to anything this method requires representative material which has been properly collected.

Secondly an attempt had to be made by collecting samples to gain the fullest information possible concerning the characteristic features of the immature "fat herring". This task proved to present very great difficulties, which were connected with the fact that these immature herring occur in nature in varying combinations as regards age-distribution, size-distribution etc.<sup>1)</sup> A large staff of trained observers would for instance be required just to collect a material which would merely afford data concerning the fishery yield. Nevertheless, the comparatively modest investigations which have been set on foot in this manner have proved necessary and useful.

By comparing and combining these two sets of observations, the one relating to the adult spawning herring and the other to the immature

<sup>1)</sup> Some information concerning this is published in the author's paper: "Report on Age and Growth of the Herring in Canadian Waters", *Canad. Fisheries Exp.* 1914—15, Ottawa 1918, p. 110.

"fat herring", it was to be hoped that conclusions would be arrived at which would play an important part in the solution of the problem under consideration.

In the following an attempt will be made to describe the results of these investigations and to indicate the consequences as regards fishery technique and the building up of a consistent theory on the Norwegian herring.

As it is not feasible to produce here the entire material on which the conclusions are based, an attempt will be made to present the description according to the following plan. Firstly as an example there will be discussed the observations for the first period, comprising two spring seasons and the intervening summer season, of which a discussion is possible. The conclusions to which this discussion give rise will be put forward, and in their presentment it will be stated what later observations of the same kind have shown, as regards the justification of these conclusions. Some investigations will then be described which were carried out in 1927, the results of which in my judgment verify the conclusions previously arrived at. Finally there will be briefly mentioned the consequences of the investigations as regards fishery technique and as regards the presentation of the natural history of the Norwegian herring.

## 2. Investigations during the years 1915—16.

As mentioned previously, it was an unfavourable circumstance for these investigations that the abundant 1904 brood predominated to so great an extent in the stock of adult Norwegian herring. The more individuals there are in a single brood the more difficult it will be to procure observational material for age-distribution where the relative figures for the other year-classes are sufficiently accurate; and in order to obtain greater and greater accuracy it will be necessary to increase the quantity of observations to an amount which is out of all proportion. Accuracy increases, as we know, merely as the square root of the number of observations.

Since the extent of the work was perforce confined within limits which were dictated by economic considerations and by the possibilities of procuring trained observers, the investigators had to be prepared to postpone setting about the task until conditions in nature had become favourable to them.

When the investigations on age-distribution amongst the adult Norwegian herring were reorganised in 1914 and extended, symptoms

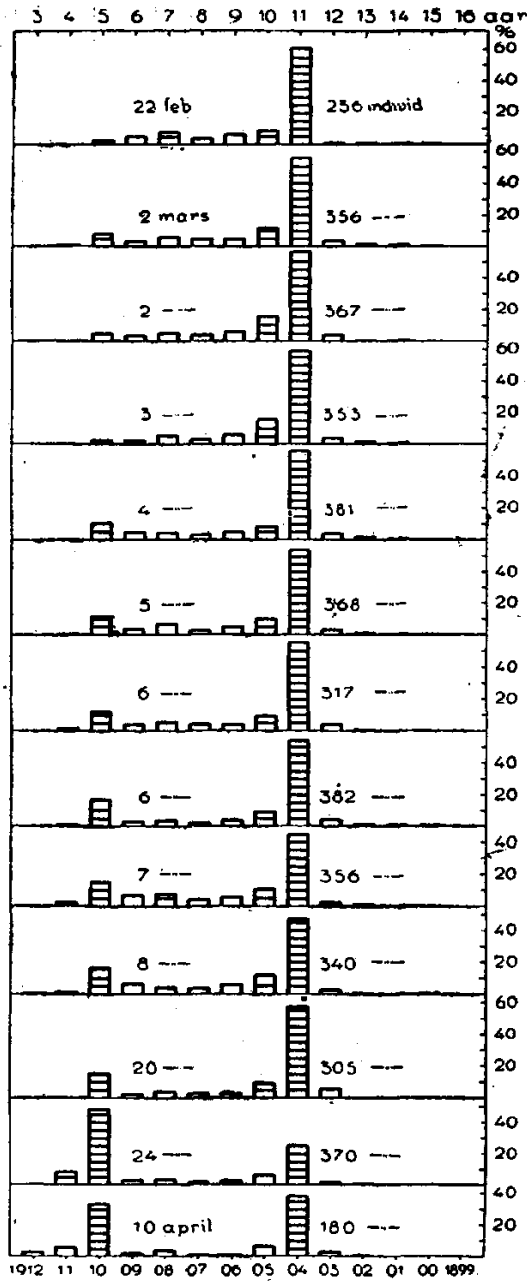


Fig. 1. Age-distribution in samples of spawning herring in 1915.

were luckily in evidence that this unfortunate circumstance would be mitigated in a short time if the observations were continued on about the same scale as in that year. It is true that the individuals of the 1904 brood still constituted more than half the stock, although they were now 10 years old, but it was certainly to be expected that the relative abundance of the brood would steadily decrease, and that natural conditions would thereby become more favourable for this investigation.

In the spring of 1915 the symptoms became considerably more pronounced, and it was even possible to gain some definite information as to the addition of recruit-spawners to the stock of spawning herring. In Fig. 1 there is given in graphic form the age-distribution in all the samples examined of herring caught with the seine during this season which were either ready to spawn or were actually spawning. All the samples caught in nets and subjected to examination are omitted, although they do not manifest any particular difference from those caught with the seine as regards age-distribution. Each horizontal section in the figure shows the age-distribution for a sample by the height of the "ladders" (where each "rung" represents 5 per cent.), and the distributions are presented in chronological order from the top downwards. The row of figures at the top of the diagram gives the age-group and the lowest row gives the year of birth (year-class).

Interesting details in the figure are as follows: 1) The first four samples show an age-distribution which is very similar to the age-distribution calculated for the previous year, when all the samples then examined are taken together and when we take into account the increase in age of one year, from 1914 till 1915. The third sample from the top especially resembles in this respect the distribution calculated for 1914 and may be here considered as an illustration of the latter. 2) In the following seven samples a change, which on the whole is progressive, appears in the age-distribution as the relative number of young, especially 5 year old, fish increases, and to such an extent that one can hardly ascribe this change to chance. These samples show great similarity with the age-distribution calculated for the same year, when all the samples are used for a basis. The sample from March 8th can in this case serve as an illustration. 3) In the two last samples there are proportionately very many of the five year old herring, and it is at the same time evident that four and three year old herring also are involved in the change, although with a considerably smaller number of fish.

The interpretation of these facts seems to be quite simple:—

- 1) The first four samples represent the remains in 1915 of the stock of older spawners which appeared the previous year.

- 2) The intermediate seven samples represent the stock during the change caused by the addition of young recruit-spawners to the congregation of older spawners already present.
- 3) In the last two samples these young fish are over-represented, as they appear in relative numbers which by far exceed their proportionate numerical strength when the age-distribution calculated for 1915 mentioned above is regarded as an approximately correct picture of the conditions in nature. That this is the case will be clear when the age-distribution for 1916 is discussed in the following.

If this interpretation of the data is correct, we are justified in the following preliminary assumption as to what happened in nature during the first months of 1915: the older spawners arrived first at the spawning grounds, the recruit-spawners not arriving until a later date. This hypothesis explains the peculiar features of the first 11 samples. These recruit-spawners continued to pour into the spawning grounds after a considerable portion of the older spawners had finished spawning and had disappeared from the grounds. This assumption explains why the last two samples contain, so to speak, too many of the recruit-spawners.

The assumptions may perhaps be formulated equally well by saying that the older spawners and the recruit-spawners entered the spawning ground in two contingents, which up till then had been separate, the former arriving earlier than the latter.

Finally, the two last samples indicate that at least three age-classes were present in the contingent of recruit-spawners, one of them, however, (the five year old herring) vastly predominating.

This assumption as to the two separate contingents of herring on their way to the spawning ground also explains (and is supported by) the conditions during the so-called "large herring fishery". This latter is carried on by drift-nets, takes place farther to the north and begins earlier than the fishery in the spawning area proper. All the samples investigated from this fishery show that the shoals of "large herring" are adult herring which are not yet quite ready to spawn and whose age-distribution recalls the distribution in the samples from the spawning ground which contain the group of older spawners.

In accordance with this assumption the two contingents of fish intermingle during the actual spawning season, and we should consequently be justified in expecting that also the other group, the recruit-spawners, were to be found in a similar condition (not fully ripe) during the time prior to their appearing in a condition ready for spawning.

It was to happen that all these preliminary assumptions were, if not completely verified, yet very substantially supported by the obser-



vations made during the fishery in the next season (spring, 1916). In Fig. 2 the age observations are given in a corresponding manner to those in Fig. 1, with the reservation that the individuals of the top-

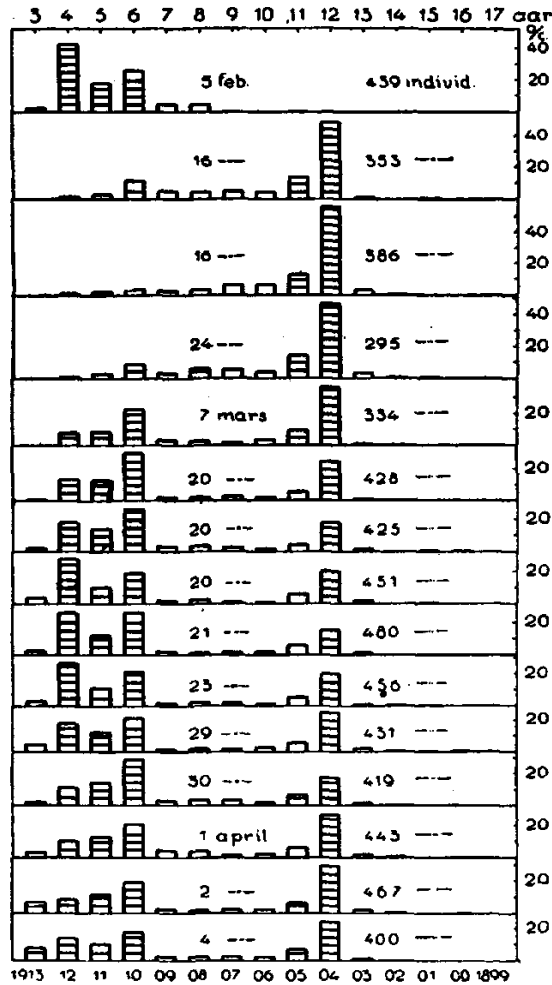


Fig. 2. Age-distribution in samples of spawning herring in 1916.

most sample were not fully ripe and were not captured in the area where the fishery for spawning herring is usually commenced, but a little to the north of it. The sample is thus to a certain extent out of place in this figure, but on the other hand it could not be placed amongst the samples of "large herring" caught at the same time. It represents some-

thing new which has hitherto not been observed and the reason for its being included in Fig. 2 is that its characteristic features explain very simply those of the real samples of spawning herring and vice versa.

For if we compare all the distributions in Fig. 2, and bear in mind what the conditions were in the previous year, we can scarcely help interpreting this first sample as representative of the group of recruit-spawners. If we disregard this first sample, the rest of the figure presents clear analogies with the figure for the previous year. There are samples from the first catches on the spawning ground proper, with an age-distribution which agrees in the main with the age-distribution calculated for the previous year. It is the older spawners which arrive first. Later in the season there occurs another change which this time is of more consequence. The younger recruit-spawners arrive later.

The last samples it is true do not present a picture corresponding to what was found in 1915. As against this fact, however, it must be pointed out that it is not to be expected that conditions will develop identically from year to year, and that the number of observations is not so great as to be looked upon as completely representing conditions in nature.

What is of importance is the fact that by suitably combining the age-distribution for the first "anomalous" sample with the age-distribution for the next samples (the older spawners), or with the age-distribution (calculated) for the previous year, or finally with single samples from the previous year, we can synthesize age-distributions, which according to wish can be given a striking resemblance with both the age-distribution for 1916 (when all the samples are taken together) and with the age-distribution for many of the later single samples from this year. As examples of such syntheses the following may be adduced. If we add six tenths of the first (anomalous) sample to four tenths of the next sample (of older spawners) we obtain a distribution which has its close counterpart in the distributions for the 8th and the 10th sample in Fig. 2. If we take four tenths of the first sample and six tenths of the next, we obtain a distribution which is very similar to the 11th sample in the figure; three tenths of the first sample and seven tenths of the next give us something which greatly resembles both the last sample in Fig. 2 and the age-distribution calculated for the season (when all the samples are taken together). If we combine the first sample in 1916 with one or other of the middle samples from the previous year (March 6th—20th) or with the age-distribution calculated for the whole of this season we obtain completely similar results.

That this must be approximately the case will be clear from a rather

closer study of the details in Figs. 1 and 2 and I shall consequently content myself here with presenting in Fig. 3 such a synthesis in graphic form, and in such a manner that the accuracy of the result can be read directly from the figure. It ought perhaps to be added that no attempt has been made to obtain the best possible numerical result. The errors in the observational material render the value of such an optimum result fictitious.

The essential point is to prove that there is an unmistakeable resem-

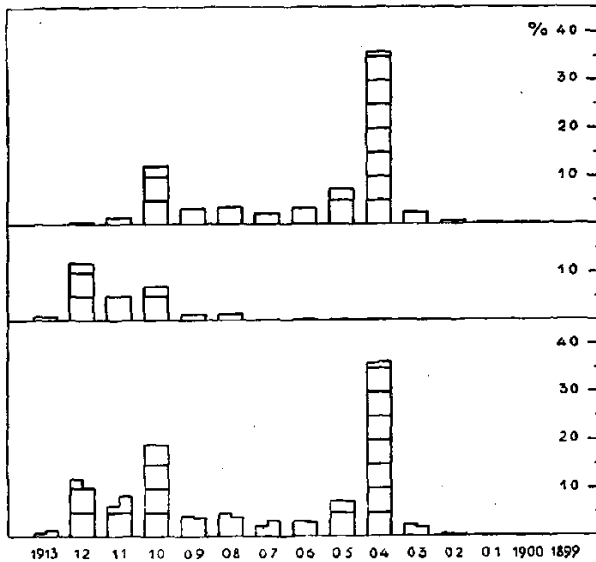


Fig. 3. Synthesis of age-distribution in the spring herring stock in 1916, combining 72.5 units of age-distribution for 1915 (above) with 27.5 units of distribution for the first (anomalous) sample in 1916 (middle figure). The result is given in the left hand column in the lowest figure. In order that the result may be tested, the distribution for 1916 arrived at by another method is given in the right hand column.

blance between the age-distributions synthesized in such a varied manner and the empirical results, whether these refer to single samples in the 1916 season or the calculated age-distribution for the whole season, when all the samples are taken together. I do not think that anyone will question the existence of this resemblance. It is, however, possible that with regard to this description of the results in 1915 and 1916 the quite justified remark will be made that they show nothing which has any validity except in so far as these two seasons are concerned. A corresponding sequence of events has, however, proved to appear time after time during the years which have elapsed between then and

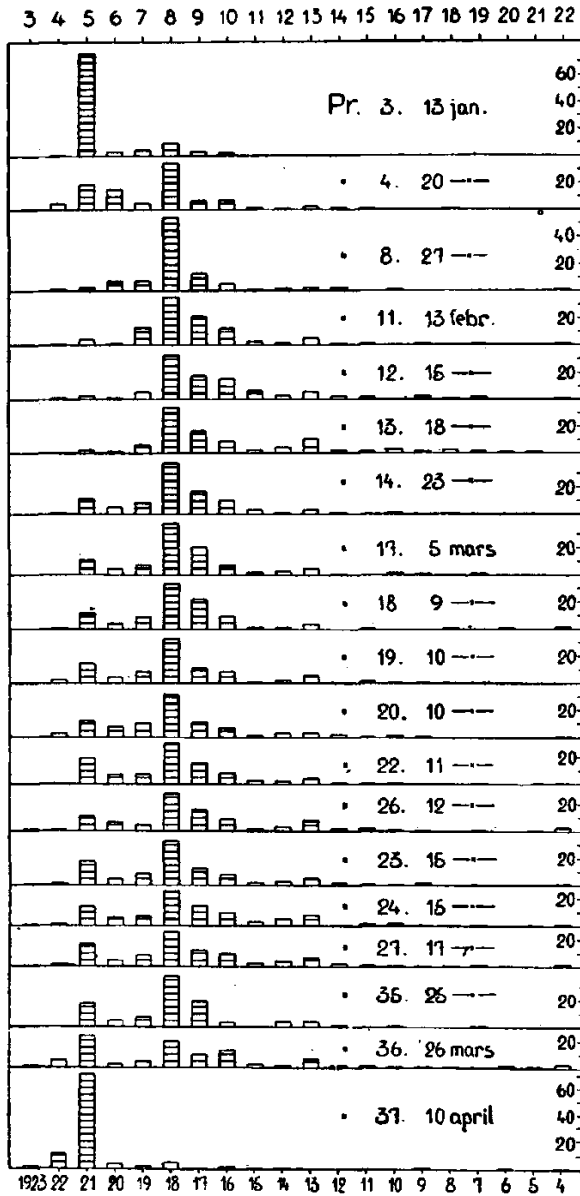


Fig. 4. Age-distribution in samples of spawning herring in 1926.

now, so that Figs. 1 and 2 may be regarded as prototypes to some extent of corresponding figures for the later years when it has been possible to state that any renewal of the stock of spawners has taken place. The best example of this is afforded by the samples from the 1926 season, whose age-distribution is given in Fig. 4. In that year a sample (probably a little impure) of recruit-spawners was obtained before the commencement of the spawning season and also a sample (similarly a little impure) at the end of the season. I regard it now as fairly certain that much the same takes place every year as in 1915, 1916, and 1926. It is another matter that the contingent of recruit-spawners can vary greatly in numbers and in some years be so small in relation to the stock of older spawners that their occurrence cannot be demonstrated in rather scanty observational material.

Regarding as verified the working hypotheses formulated above, we may proceed to pursue our problem further. It is necessary to learn what characteristic features the contingent of recruit-spawners possesses. So far as 1916 is concerned, we are in the fortunate position that direct observations are available, since the first sample in Fig. 2 may be regarded, in any case with close approximation, as a pure sample of this category. Whether the few specimens, 7 and 8 years of age, are to be regarded as an impurity or not (this being certainly the case with 4 specimens between 9 and 12 years old), is in this connexion a matter of indifference. It is certain that fish between 3 and 6 years old have come into this group, there being few of the 3 year old herring but many from the other groups.

Such direct observations are wanting for other years, but we can proceed indirectly and in several ways calculate the age-distribution, but it is more difficult to find out anything as to the size of the recruit-spawners, and the result will be less certain. The calculation of the age-distribution can be made by a subtraction, in each age-group, of the distribution found in the first samples of the season (older spawners) from the distribution as it appears in later samples, when these consist of a mixture of the two groups, or from the age-distribution calculated for the season when all the samples are taken together. Prior to this subtraction we must reduce the percentile distribution for the first samples to the extent that the differences above the category 7—8 years up to the greatest age fluctuate round about nil. Quite corresponding calculations can be made by operating with the calculated age-distributions for two consecutive years.

For 1915 we find, as mentioned previously, that the five year old herring have constituted the majority, although accompanied by some

four or three year old fish. In 1916 three age-groups were abundantly represented and in 1917 the four year old fish are found to be in a great majority, although accompanied by some five year old fish. The age-distribution amongst the recruit-spawners thus fluctuates considerably, as do also their numbers.

We can here in the sample investigation keep to direct observation by operating with the first sample in 1916 and considering it as representative of the recruit-spawners. This sample affords data relating to age-distribution and size, and the syntheses which have been made show that the contingent of recruit-spawners constituted in that year something in the neighbourhood of 30—40 per cent. in numbers of the contingent of older spawners, i.e. a very considerable renewal of the stock.

Date of this kind can then be compared with the data obtained from the material collected from the "fat herring" fishery in the summer and autumn of 1915. Upon closer investigation it proved possible to sort this material into two, apparently, natural, groups, and a third group of samples which originated partly from large fiords which to some extent had narrow inlets. The two more natural groups of samples can be characterized thus. The first group contains samples in which quite young "small herring",  $1\frac{1}{2}$  years old, constitute a considerable proportion of the stock and are found in association with smaller herring,  $2\frac{1}{2}$  years old. The samples in the second group contained larger herring,  $2\frac{1}{2}$  years old, in association with comparatively numerous herring,  $3\frac{1}{2}$  years old, a very few younger herring and solitary examples of older herring.

Even if this grouping of the samples may be regarded as more or less arbitrary, this is immaterial as regards the following line of argument. For it is clear that if we abide by this grouping (even if arbitrary) of the larger and older herring found, and contrast it with the samples from the spawning ground, we thus diminish the existing differences and make thereby an assumption which is unfavourable for the result. We shall arrive at quite the same general conclusions if we include the entire material, but the differences found then become still greater numerically. This grouping is maintained because it seems natural and correct and not arbitrary, which incidentally is confirmed by the fact that the frequency curve for length distribution becomes thereby more normal, whilst that for the entire material becomes distinctly complicated.

At the top of Fig. 5 is shown the age-distribution of the recruit-spawners (the uppermost sample in Fig. 2) and at the bottom the age-distribution in the group of larger "fat herring" from the summer and

autumn of 1915. This last distribution is obtained by the simple addition of the distributions for all the samples, since these present such great similarity that this simple method is practicable.

The two distributions show perceptible and large differences, and it is very difficult to understand how from a "fat herring" stock with an age-distribution as found there can appear by the breaking away of individuals of advanced sexual development a group of recruit-spawners with such a characteristic and varied age-distribution. The "fat herring" samples practically lack individuals of the 1911 and 1910 year-classes, which in the sample of recruit-spawners constitute not far from half the total number.

The 1912 brood constitutes the one common group of importance



Fig. 5. Age-distribution of recruit-spawners, spring 1916, (above) and of "fat herring", autumn 1915 (below).

in the two distributions. As regards this year-class, a comparison of the age-distributions gives an indefinite result, in as much as it is likely that individuals of this year-class were "fat herring" in the autumn of 1915 and spawning herring in the spring of 1916. As regards the other two year-classes (1911 and 1910) we must on the contrary conclude that they had disappeared before the fishery for "fat herring" (and collection of samples) had commenced in the summer of 1915.

The possible assumption as to the 1912 year-class does not, however, tally very well with the conclusion drawn as to the 1911 and 1910 year-classes. A dilemma arises which nevertheless might be tolerated if other observations were decidedly in favour of the assumption. But this is not the case. There are three sets of independent observations, of which the last two in any case can scarcely be reconciled with the assumption mentioned.

For if we consider Fig. 2 and bear in mind the result of the previously mentioned syntheses, there are at least strong reasons for the presumption that the age-distribution in the group of recruit-spawners has been fairly stable i.e. that the numerical relation between the year-classes has fluctuated in approximately the same way as it would fluctuate if we arranged a comparable chance experiment. This stability indicates

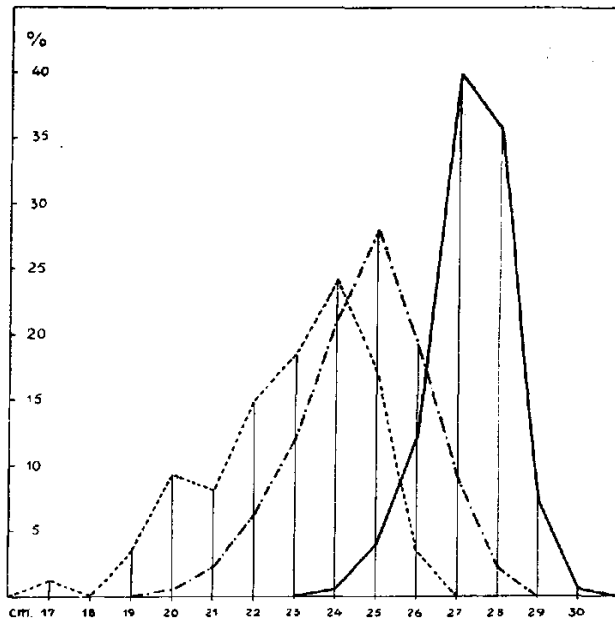


Fig. 6. Curves of length distribution of herring of the 1912 year-class:—

in samples of small "fat herring", autumn 1915, (left),  
in samples of larger "fat herring", autumn 1915 (middle),  
in the sample of recruit-spawners, spring 1916 (right).

quite definitely that the various year-classes amongst the recruit-spawners have been together in the sea for some time. If the 1912 year-class were so to speak derived from the stock of "fat herring", whilst the 1911 and 1910 year-classes were derived from other shoals, the age-distribution amongst the recruit-spawners could, it seems to me, scarcely be so little variable as is expressed by Fig. 2. One would expect there to be two sets of recruit-spawners and not, as it seems, only one.

We obtain the second set of observations by comparing the length of the individuals belonging to the 1912 year-class amongst the recruit-spawners and amongst the "fat herring". Fig. 6 enables us to make such



a comparison. The great difference in size is striking and unfavourable to the assumption. If the length distribution for the recruit-spawners were to be made by removing the larger individuals in the distribution for "fat herring" it would involve an assumption as to the size of the "fat herring" stock which appears improbable and in addition does not agree with later observations as to the numerical strength of the 1912 year-class, after all (surviving) individuals had become adult spawning herring.

The third set of investigations are concerned with the degree of development of the sexual organs of the "fat herring" of the 1912 year-class. These may briefly be mentioned, as showing that the sexual organs were in stages I and II (according to HJØRR's scale) and had no demonstrable development in the autumn. It seems improbable that herring in stage I—II are able to develop their sexual organs to stages IV and V between October and the beginning of February, although from lack of adequate observations we cannot say that this is impossible.

Considered altogether the observations for 1915—1916 afforded good reasons for regarding as unsatisfactory the conception that there was a direct connexion, and a transition of short duration, between the "fat herring" as found in the autumn of 1915 and the spawning herring as found in the spring of 1916. It was difficult to unite the observations in a consistent theory on this basis.

It is on the other hand certain that there is a connexion, i.e. that the young immature herring along the western and northern coast of Norway become in the course of years spawning herring, which congregate along the west coast during the first months of the year. Observations from 1908—1913 afford material which forces this conception upon us, and they are not so incompatible as are the later observations with the assumption of a more direct connexion, although even in these there are points which, with the aid of information gained later, can now be seen to complicate the apparently simple picture of the connexion between the young "fat herring" and the older spawning herring which these observations seemed to give.

Observations made subsequent to 1916 have confirmed the suspicion that the assumption of a simple and close connexion between these two groups of Norwegian herring was not an accurate description of the events taking place in nature, and that it was consequently necessary to alter our views in order to bring them into logical accordance with the observations.

When the necessity for such a change of view became apparent there was no difficulty in grasping which direction it must take. The fact

that the individuals composing the shoals of young herring present along the coast are too young, too small, and too little sexually developed for the recruit-spawners to be derived directly therefrom, cannot be properly understood save by assuming that the recruit-spawners come from a group of the Norwegian race of herring, which is neither usually observed nor gives rise to a coastal fishery. The conception that the herring during their development to sexual maturity pass through an oceanic intermediate stage arose as a natural consequence of the observations.

It was not difficult to verify this assumption more completely, but only indirectly, by further proofs of the sharp distinction between the immature young herring in the coastal waters and the herring ready to spawn. It is not too much to say that all the observations in our possession relating to these two groups of the same race are in agreement, and afford such indirect confirmation.

Further it was not impracticable to form indirectly some fairly definite idea as to what were the characteristic features of the herring when they were in this presumed oceanic intermediate stage. This was done by finding out what was lacking in the accessible portions of the stock (adult herring and young herring along the coast).

The difficulty, however, lay in procuring direct proof by capturing and examining the herring in the intermediate stage. No regular fishery is carried on in those areas of the sea where it was considered probable that this group of herring was to be found. Therefore direct verification was only to be obtained by fishing experiments at sea, or if, by chance, shoals of herring in the intermediate stage were to move, for some reason or other, far enough in towards the coast to come within the reach of the fishermen. It was impossible to form any definite opinion as to whether this latter alternative was likely to occur.

### 3. Investigations during the years 1924—27.

When Professor JOHAN HJORT in 1924 was setting out on his expedition to the Norwegian Sea and Greenland it was arranged that, if occasion arose, observations should be made on herring in the open sea.

For the use of my assistant in the work, Mr. TH. RASMUSSEN, who accompanied the expedition, I drew up a description of the characteristic features of the herring in the intermediate stage, so that if herring were captured he might be able at once to ascertain whether they were the herring we were seeking for or not. HJORT's expedition, however, afforded no material of interest in connexion with this subject, so

Mr. RASMUSSEN was unable to make use of this description. Nevertheless it proved to be of interest that the description had been made, and was in existence, before a single sample of herring from the supposed oceanic group had been subjected to examination. For when at length catches were made which might possibly have been representative of this group, it was all the more satisfactory, for the purpose of verification, that a prognosis, deduced indirectly and in fairly great detail, was already in existence. A comparison could then be instituted between what we expected, in view of our claims as to a logical connexion in the observations, and what was actually found. The description (which was accompanied by diagrams, which for the sake of brevity are here omitted) ran as follows:—

“— we may therefore expect that the catches of young herring which are developing towards spawning for the first time will not include any great number of fish older than  $5\frac{1}{2}$  years. The maximum age may be put at 6 summers and the minimum age at 3 summers.

For the rest, the age-distribution will greatly depend on whether the catches include many fish from the Vestland (many fish 3 and 4 summers old) or many fish from northern Norway (many fish 4, 5, and 6 summers old). As 4 is common to both contingents we might expect fish in their fourth year to be more numerous than the older ones, but it can easily happen that fish in their third summer will be still more numerous. Also if the contingent from northern Norway is particularly large, fish in their fifth summer may be well represented. We must be prepared for age-distributions such as that in Fig. 2<sup>1</sup>).

As regards the size distribution, we are justified in expecting it to be comparatively uniformly normal, as shown in Fig. 3<sup>1</sup>).

The maturing herring form, according to the assumption, a group which is a selection of the population. The selection is determined by the sexual development, and this again by the growth (the size attained). The fish from the Vestland in their third summer are presumed to be about as large as the fish in their fourth summer from northern Norway etc.

The smallest length group can be put at 21 cm., the largest at 30 cm., and the medium size at 24—26 cm.

As regards the state of the sexual organs, the stages from development already begun (II) to stage IV should be represented.

The scales should present the following peculiar features. Practically all fish which are  $2\frac{1}{2}$  years old, (3 summer zones), should have scales

<sup>1</sup>) Omitted here.

with comparatively indistinctly defined winter rings, which to some extent are difficult to see.

Fish,  $3\frac{1}{2}$  years old, (4 summer zones), if we take the largest, should be similar to those of  $2\frac{1}{2}$  years, possessing indistinctly defined rings, "Vestland-scales". If we take the smallest fish the rings should most often be sharp lines, as if incised with a knife, "Nordland-scales".

Most of the fish of  $4\frac{1}{2}$  years and older should for the greater part have 3—4 winter rings, sharp as if incised with a knife, and amongst the oldest there should be many fish with an abnormal growth in some way or other, e.g. the second year's growth smaller than the third year's, the third year's smaller than the fourth year's, etc. (Fig. 4)<sup>1)</sup>. It is assumed that the scales are taken from the area shown in Fig. 5<sup>1)</sup>. The outer rings (4th and 5th) can be less distinctly defined than the inner (formed whilst the fish were in the X-group<sup>2)</sup> area.

Should fish older than 6 years be found in the samples, it is possible that they may be fish of about the same size belonging to other populations (Shetland), interspersed in the group. These will be distinguished by their rings being less sharply defined and by their summer growth after the third summer being very slight (see Fig. 4)<sup>1)</sup>.

Up to now it has been assumed that all the fish which are developing towards spawning for the first time are mixed together. They can, however, be looked upon as divided into two groups, of which the one comprises the fish which have not developed so far as to take part in the spawning the coming spring, whilst the other group comprises the fish which are so far developed sexually as to spawn in the spring. It may be assumed that these latter sooner or later leave the less developed fish and set out on their spawning migration. If this has occurred there will thus be two groups, the one comprising smaller fish in stages II—III, and the other comprising larger fish in stage III and possibly III—IV.

The group of more developed fish will then presumably lack fish in their fourth summer with sharply defined rings (Nordland herring) and fish in their third summer with vaguely defined rings (Vestland herring), both of which must be assumed to be present and to constitute the bulk of the group of less developed fish."

The main points in the description are the following: age from 3 to 6 summers (so many summer zones on the scales), age-distribution greatly dependent on circumstances, with the  $3\frac{1}{2}$  years' group as the central one, size between 21 and 30 cm. with the average length of 24—26 cm., sexual development from II to IV, possibly an admixture

<sup>1)</sup> Omitted here.

<sup>2)</sup> See below page 27.

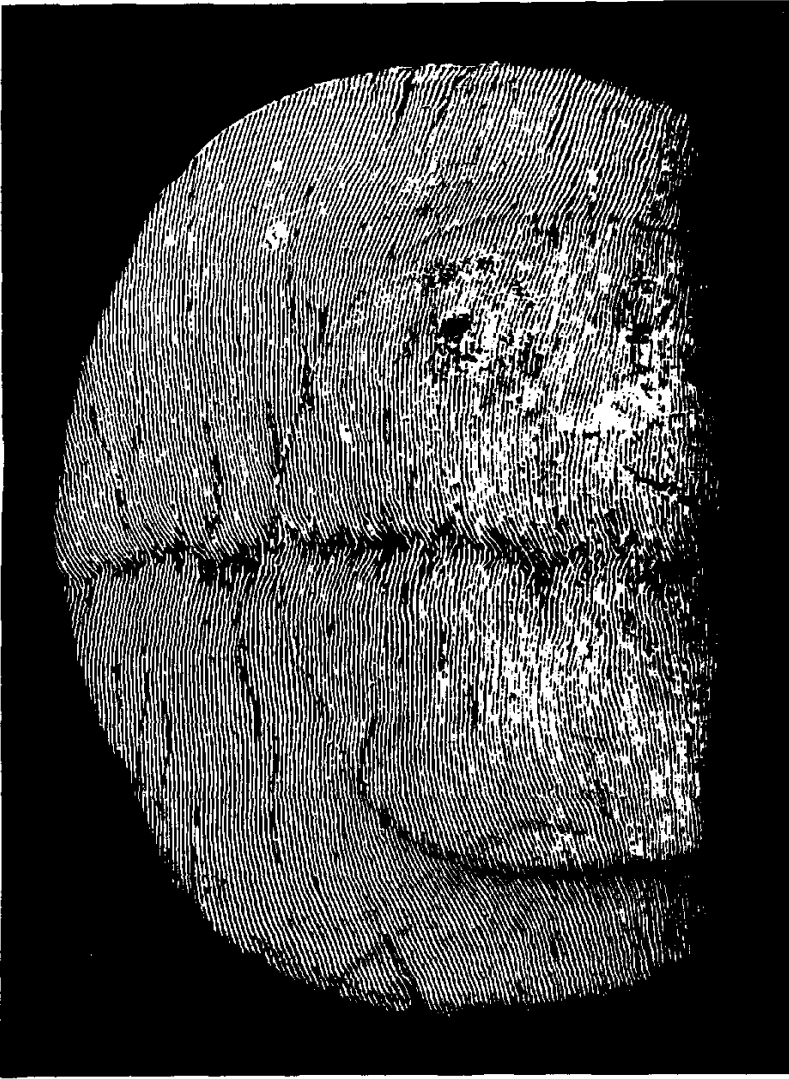


Fig. 7. Scales from a herring nearly two years old, caught in autumn 1928 in the waters of northern Norway.

of herring which do not belong to the Norwegian race, and finally certain peculiarities as to the scales of the herring which it will be necessary to describe a little more closely. -

Experience has shown that there are differences in the appearance of the winter rings on the scales from young herring which are caught



Fig. 8. Scales from a herring nearly two years old, caught in autumn 1928 off the southern part of the west coast of Norway.

in various waters along the Norwegian coast. The scales on the herring from northern Norway have rings which as a rule are sharply defined, whilst herring from the southern part of the west coast have scales with more vaguely defined rings. It is not easy to explain the differences in words; they must be seen to be realised, but they undoubtedly exist. Figs. 7 and 8 give some idea of how they appear to the investigator who carries out the scale analysis. The photographs show two scales, one from a young herring captured in the northern waters and one from a herring from the southern waters of Norway. The examples are selected so as to compensate for what is lost in the processes of photography and reproduction, and in order to illustrate the nature of the differences.

In recent years we have sought to make use of these characteristic features in the scales in analyses of the material collected in Norway, and at present it looks as if this type of analysis is at least a valuable supplementary form of observation, when it is a question of distinguishing Norwegian from other herring or of distinguishing between the various groups which together make up the Norwegian race of herring.

The first samples of herring, which could be supposed to represent the oceanic stage in the development of the herring, were derived from catches made along the west coast of Norway in May—June 1924, when a small but irregular fishery developed in that area in the neighbourhood of Kristiansund. Unfortunately it was not realised what value these samples might have had for this investigation, for which reason they were not examined as closely as they deserved. The data we possess for these samples (age, length, scale-type) indicate, however, that here were representatives of the group we were in search of.

The summer of 1925 gave better results. In that season we obtained a catch, also from the west coast, and in addition a number of drift net catches were made in the open sea during the Swedish and Norwegian fishing experiments in the entrance of the Skagerak, and these catches possessed features which are of great interest in this connexion. But these samples also were examined before their significance could be appreciated, so that the chance of a specially close examination was wasted. This set of samples, and a number of samples from 1926, together with one sample from the spring of 1927, have, however, proved to be of very great interest, and they will accordingly be discussed later.

In the summer of 1927 an occasion arose to make more complete observations. Along the coast in the neighbourhood of Bergen various herring appeared which the fishermen had difficulty in classifying amongst their "sorts" of herring. For the time and place the herring were large, and the condition of the sexual organs varied greatly from herring to

herring. According to the fishermen's statements, there were many of them off the coast but they were unwilling to enter the sounds and the fiords where they could be captured with shore seines. Many catches, although small ones, were made in the course of two or three months, and as from the very commencement it was plain that the herring probably belonged to the oceanic group we were in search of, an adequate number of herring were collected in small lots. These herring were successively examined as to the essential characteristic features, including the number of vertebrae, chiefly in view of a possible admixture of "extraneous" herring.

From the analysis of the material thus collected, it appeared that the separate small samples were greatly at variance, in as much as the number of herring with three summer zones on the scales varied greatly from sample to sample. One could not help getting the impression that in the waters where the catches were made there were two groups of herring which were in process of uniting into one group. As a consequence of this variation, we cannot expect to determine from these samples what the age-distribution is or has become after the mixing process came to an end. For the rest, there was so much agreement between the samples that it was regarded as permissible to lump them together when the observations were being worked up. That this was justified will be seen from the regularity which characterizes the frequency columns which appear upon the material being analysed.

The most important features in the material considered as a whole will be clear from Table 1, in which the length and age of the fish are the two main divisions, but where there are also made other distinctions, which require explanation.

A distinction is made between individuals, whose age entitles them to a position in the oceanic group, and young herring,  $1\frac{1}{2}$  years old, which are possibly only an admixture. Herring of this age are always to be found in summer in the waters from which the samples are taken.

A distinction is further made between herring, whose scales on the above mentioned analysis of the features of the winter rings seemed to indicate that they belonged to the Norwegian race, and herring whose scales seemed to indicate that they were not Norwegian herring. This distinction has, as will be shown later, given interesting results, both as regards methods and from a biological point of view.

Finally, each age-group in the assumed oceanic group is divided into two, according to the appearance of the winter rings on the scales. Herring whose scales had more sharply defined rings are allotted to the sub-group "northern", and herring whose scales had less sharply defined



rings to the sub-group "southern". These terms must not be understood in a too literally geographical sense. For the "northern" type probably begins, according to other investigations, at Trøndelagen, i.e. along the southern half of the Norwegian coast. The classification is made in accordance with the scale-type, independently of geographical considerations, whilst the terms "northern" and "southern" have been chosen because, taken on the whole, they are characteristic. The distinction may in fact be taken as provisional.

The group of Norwegian herring which has hitherto been characterized by the term "oceanic intermediate stage" was called, as long as its existence was hypothetical, the X-group, and this term is retained for the sake of brevity.

From the numbers in the columns farthest to the right in the table, it may be seen how the result of the analysis is affected by the exclusion of the youngest and the "extraneous" herring. Further, in the last column is given the frequency series for length distribution which is alluded to in the prognosis which was worked out beforehand in 1924.

If we now consider the bottom horizontal rows showing the age-distribution, we shall see that individuals,  $2\frac{1}{2}$ — $6\frac{1}{2}$  years of age, occur amongst those herring which have not been excluded, as constituting an admixture, either because they are too young, or because their scales seem to indicate that they belonged to races other than the Norwegian. The agreement as to this point between the prognosis and what was actually found is quite good, as the number of individuals which are outside the range of the prognosis (4 herring,  $6\frac{1}{2}$  years old and 14 herring,  $1\frac{1}{2}$  years old) constitute only 3 per cent. of the total.

Similarly the fact that the bulk of the individuals are from  $2\frac{1}{2}$ — $4\frac{1}{2}$  years old is in close conformity with the prognosis. On the other hand it may possibly be regarded as a slight error in the prognosis that the age-group,  $3\frac{1}{2}$  years, was especially pointed out as the central and typical one. It proves here to be numerically weaker than both the  $2\frac{1}{2}$  and the  $4\frac{1}{2}$  group. This disagreement is, however, more apparent than actual, since from other observations it seems probable that the 1924 year-class is bad compared with the 1923 and 1925 year-classes, and that the prognosis is correct for the ideal case, i.e. when there are no such fluctuations in the year-classes.

The herring,  $2\frac{1}{2}$  years old, belonging to the 1925 year-class, are in the majority in the material, but this fact, as mentioned previously, has no definite significance, since the number fluctuated so greatly from sample to sample. It is, however, highly probable that this 1925 year-class will prove to be very abundant. A portion of this year-class

Table 1. Analysis of the material from the autumn of 1927.

Length cm	Norwegian Herring of the X-group												Admixt.		Total		Percent				
	2½ year			3½ year			4½ year			5½ year			6½ year		Small Norweg.	3-12 Extran.	X-group	All	X-group	All	Prognosticated
	Southern	Northern	All	Southern	Northern	All	Southern	Northern	All	Southern	Northern	All									
18.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	..	4	..	0.6	..	..
19.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	..	4	..	0.6	..	..
20.....	2	1	3	..	..	..	..	..	..	..	..	..	..	..	1	..	3	4	0.5	0.6	..
21.....	7	1	8	..	1	1	..	..	..	..	..	..	..	..	3	..	9	12	1.5	1.8	2.5
22.....	26	16	45	1	..	3	..	..	..	..	..	..	..	..	2	..	48	50	7.8	7.4	9.5
23.....	87	25	115	5	6	11	..	3	3	..	..	..	..	..	..	4	130	134	21.0	19.7	14.7
24.....	76	18	99	5	11	18	..	4	4	..	..	..	..	..	..	6	122	128	19.7	18.9	18.4
25.....	39	4	45	12	12	25	1	31	32	..	2	..	..	..	..	12	106	118	17.2	17.4	15.9
26.....	3	1	5	12	9	25	4	63	70	..	8	..	..	..	..	11	108	119	17.5	17.5	15.9
27.....	..	..	..	4	1	5	8	23	34	..	26	..	..	..	..	8	67	75	10.8	11.0	9.6
28.....	..	..	..	1	1	2	4	2	6	..	11	..	..	..	..	4	20	24	3.2	3.5	5.4
29.....	..	..	..	1	..	1	..	1	1	..	..	..	..	..	..	2	2	4	0.3	0.6	2.5
30.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	2	0.3	0.3	1.4
31.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0.5
32.....	..	..	..	1	..	1	..	..	..	..	..	..	..	..	..	..	1	1	0.2	0.1	..
Total....	240	66	320	42	41	92	17	127	150	..	47	52	..	4	618	679	..	..	..	..	..
% of all..	..	..	47.1	..	..	13.5	..	..	22.1	..	7.7	..	..	0.6	2.1	6.9	..	..	..	..	..
% X-gr....	..	..	51.8	..	..	14.9	..	..	24.3	..	8.4	..	..	0.6	..	..	..	..	..	..	..
Mean length....																	24.6	24.6	24.9		

formed the basis last autumn for a fishery in the north of Norway which was unique in its abundant yield.

If we consider the classification into "southern" and "northern" types of the various age-groups, it will be seen that the "southern" type is in majority in the youngest group, there being an equal quantity of each type in the next group, whilst in the older groups the "northern" type predominates, which conforms fairly closely with what had been expected. The fish of the "southern" type tend to be slightly larger than "northern" herring of the same age. It had been expected that this difference would be more pronounced.

As regards the individuals whose scales were not of the Norwegian type, 47 were found between 3 and 12 years of age, and between 23 and 29 cm. in length. That the possibility of such an admixture had been reckoned with was due to a conjecture that the haunts of the oceanic group of young herring did not lie so far from the northern North Sea that an occurrence of mixed shoals was unlikely. Experience has shown that this hypothesis was correct. There can be no doubt whatever that at any rate the majority of the 47 individuals, which are entered as "extraneous", do not belong to the Norwegian race, but probably to one of the North Sea races. The proof of this was furnished by the counting of the vertebrae, which was a part of the investigation. The latter was carried out in the following manner. All the observation work on the actual herrings was done by my assistant Mr. RASMUSSEN who kept his own records. The scale preparations, furnished merely with serial numbers, were examined by me, each in turn as it reached me. The numbered herring were preserved and the vertebrae counted, after I had made my notes on the type ("southern" or "northern" Norwegian, or "extraneous") in a separate record. Not until these independent observations were finished were all the data brought together and analysed. The results will be described in detail on some other occasion. It will suffice here to give the most summary comparison. The mean number of vertebrae (Vert. S., HEINCKE) for the 47 "extraneous" herring was 56.6 and for the remaining herring 57.1. The standard error of the 0.5 difference was 0.1. The mean vertebral number of young fish caught during the same summer amongst the islands forming a belt along the coast ("Skjærgaard") was 57.1 (fish  $1\frac{1}{2}$  years of age) and 57.0 (fish aged 6 months). This difference is so large in proportion to its standard error that it must be genuine.

The figures in the columns farthest to the right afford a comparison between the length distribution as found (in two alternative categories for the X-group alone and for the total number of fish) and that anti-

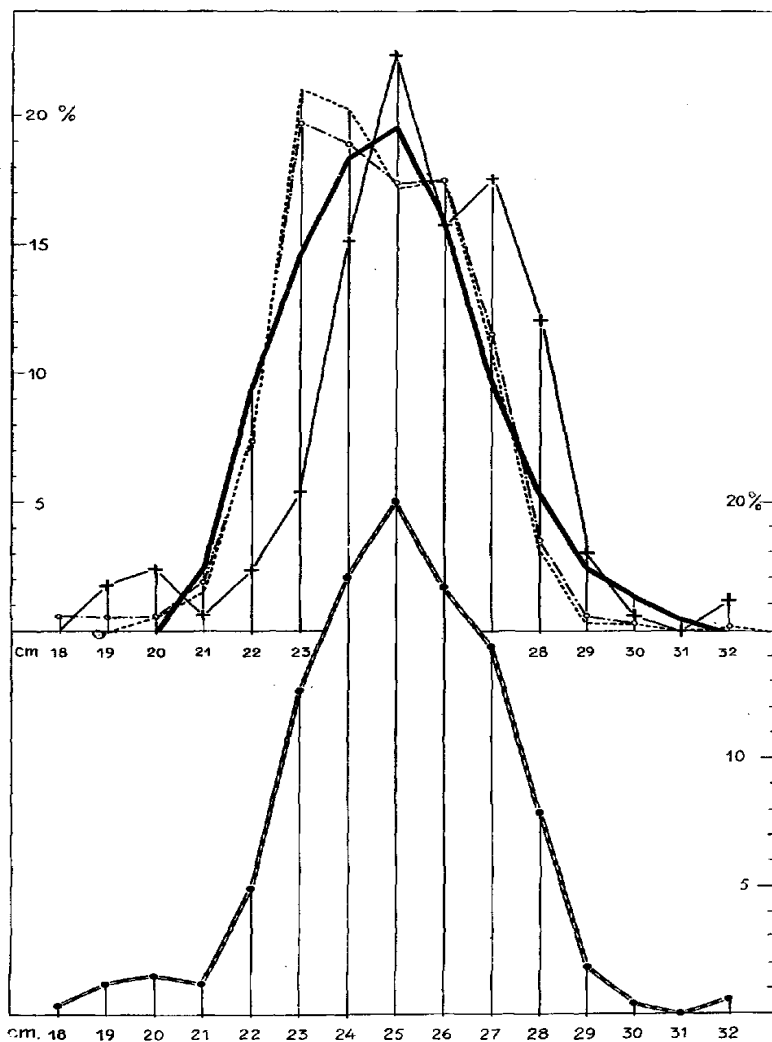


Fig. 9. Curves of length distribution for the oceanic young herring in samples from spring and autumn 1927, compared with the curve given previously.

Upper section: thin line with crosses — sample from spring 1927, dots — samples from autumn 1927, the youngest and the "extraneous" herring being excluded, dot, line, and circle — the same samples but all fish included, thick line — the curve given previously.

Lower section: the samples from spring and autumn combined, with equal parts of each.

cipated in the prognosis. The series of figures are of course not identical, but bear as strong a resemblance to each other as one may reasonably expect when one takes into account the fact that the distributions cannot be expected to be completely constant.

At the top of Fig. 9 the length frequency curve as plotted beforehand is given, together with the frequency curve in accordance with the two alternatives for Table 1. Further there is included the corresponding curve for a sample of herring which originates from a catch in the spring of 1927, and which in all probability is also a representative of the oceanic group, but from an earlier date and before the young herring of the 1925 year-class (and possibly also a number of individuals belonging to older groups) had intermingled with them.

This sample also, the characteristic features of which are shown in Table 2, contained a number of "extraneous" herring, but we have no verification from vertebral counts in this sample.

Table 2. Analysis of sample nr. 31. Kalvaag, 26th March 1927.

Length in cm	Norwegian Herring of the X-group					Extaneous	Total		Percent	
	1925 2 year-group	1924 3 year-group	1923 4 year-group	1922 5 year-group	Older Norwegian		Norwegian alone	All	Norwegian alone	All
19.....	2	..	..	..	..	..	2	2	1.5	1.3
20.....	1	2	..	..	..	1	3	4	2.3	2.5
21.....	1	..	..	..	..	..	1	1	0.8	0.6
22.....	..	1	3	..	..	..	4	4	3.0	2.5
23.....	..	3	6	..	..	..	9	9	6.8	5.6
24.....	..	7	9	3	..	..	19	19	14.3	11.9
25.....	..	10	11	15	..	5	36	41	27.1	25.6
26.....	..	3	12	7	..	2	22	24	16.5	15.0
27.....	..	..	9	7	2	10	18	28	13.5	17.5
28.....	..	..	6	6	1	7	13	20	9.8	12.5
29.....	..	..	1	3	..	1	4	5	3.0	3.1
30.....	..	..	..	..	..	1	..	1	..	0.6
31.....	..	..	..	..	..	..	..	..	..	..
32.....	..	..	..	..	2	..	2	2	1.5	1.3
	4	28	57	41	5	27	133	160	100.1	100.0
	Mean length...								25.4	26.1

As will be noticed, the herring in this sample were a little larger than those in the autumn samples, but in this sample also the resemblance with the frequency curve plotted beforehand is satisfactory.

If we consider this sample and those from the autumn as two variants within the same main group, and if we add together the two percentile frequency distributions, a distribution is obtained which is given at the bottom of Fig. 9. It is, as will be seen, fairly similar to the curve plotted beforehand.

The observations as to the state of the sexual organs of the herring examined showed that in this point there was a marked divergence from what had been expected; i.e. this divergence is not in accord with the hypothesis that the catches investigated are representative of the entire oceanic group. There were in fact only a few individuals in which the sexual products were in an advanced state of development, far fewer than one would expect if there were many herring in the catches which were to spawn in the coming spring (1928). Moreover there were many, especially of the younger individuals, which were in stage I (HJORT's scale), or were a little beyond this infantile stage.

These observations indicate quite definitely that the oceanic group of herring in the summer of 1927 was already split up into two sub-groups, the one comprising individuals with advanced sexual development (prospective spawners in the spring of 1928), whilst the other group, which is represented by our samples, contained individuals which would not be ready to spawn in the spring of 1928. Such a separation must take place once a year, and according to these observations it seems to have occurred quite early in the year.

This assumption would be supported if the herring, which actually came in as spawners for the first time in the spring of 1928, proved to be considerably larger than the herring of the same age in the samples subjected to examination. This will be shown to be the case when the detailed analysis of the observations for the spring of 1928 has been made. According to a preliminary calculation which gives approximate values, the average lengths for the year-classes 1924, 1923, and 1922 were 27.5, 28.8, and 29.6 cm. respectively, i.e. considerably more than the corresponding figures for the material from the summer of 1927.

Altogether these comparisons show so great a resemblance between what was expected and what was actually found that in my opinion we are bound to draw the conclusion that the shoals of herring, from which the observational material has been obtained, have had those very features which were to be expected if the premisses and assumptions as to the oceanic stage were correct. The existence of this phase in the life history of the herring is regarded then as proved, even though it was not possible at the same time to indicate the haunts of this group in the open sea, and although these oceanic young herring were found close in to the coast, in fact right in the fiords and sounds.

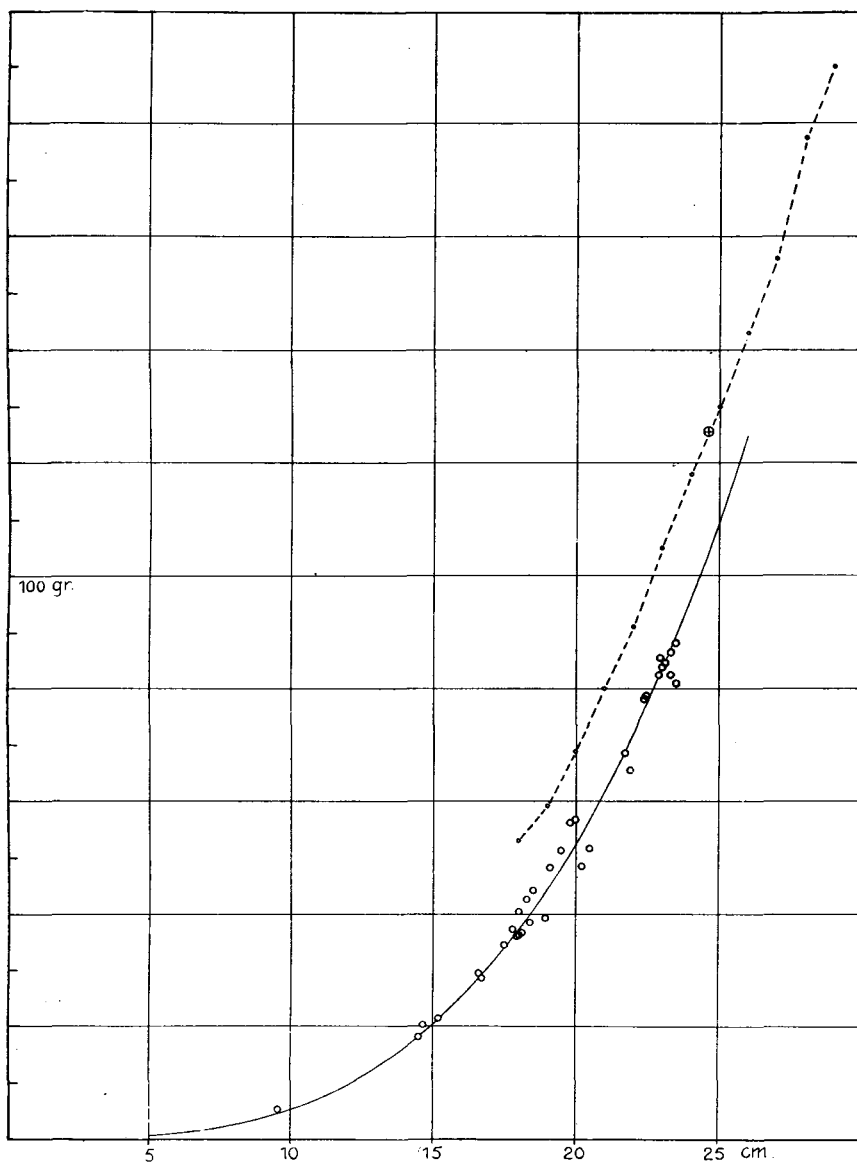


Fig. 10. The relation between length (abscissa) and weight (ordinate) for the oceanic young herring from autumn 1927 (dotted line) compared with the same relation for young herring caught off the coasts (thick line and circles).

In addition to the characteristic features of the oceanic young herring already described, the results as to weight deserve a brief discussion. In order to characterize the herring in this respect it is necessary to institute a basis for comparison; as such has been chosen a length-weight

relation which was worked out some time ago for the young herring occurring along the coast. This relation which is not a cubic parabola, but is somewhat steeper ( $W = kL^{3.3}$ ) seems to be closely applicable to young herring caught in the summer and autumn, at any rate as regards the group between  $L = 15$  and  $L = 25$  cm. This relation is given in Fig. 10, together with the central position for the samples for which it is calculated. If we examine this, we see that the function line should be regarded as a schematic expression for a position and the course of a zone within which the length-weight points find their place in a system of coordinates.

In the figure is plotted the central position for the material from the autumn of 1927, and from this a line connecting the points which give the average weight for each cm.-group in the material.

It will be seen that the position for the young oceanic herring lies far outside the zone within which are found all the samples of young coastal herring. The weight of the oceanic young herring is, when the same length group is compared, considerably greater than the weight of the young coastal herring. This difference in weight does not mean that the sexual organs of the oceanic herring were a little larger than the organs of the infantile coastal herring; the difference in weight is too great for this. Neither does it seem to be determined by any difference in the fat content. It is perhaps correct for the time being to regard the relation as an expression of the fact that the oceanic young herring have passed into another physiological state than that in which the infantile young herring are. Further investigations must show whether this length-weight relation can serve as a useful indicator for distinguishing between the two phases in the development.

That this phase in the development of the young herring should be characterized as an oceanic stage is clear, first and foremost from the fact that shoals of the group are so little in evidence along the Norwegian coast. It is very difficult to understand why the fishermen see so little of these herring unless one assumes that they regularly keep away from the coastal waters.

In addition, however, we possess some more direct observations which show that herring, which in all probability belonged to the oceanic group, were caught in the summer of 1925 in the entrance of the Skagerak, at the same time as similar herring also appeared along the west coast of Norway.

The samples sent us from the Skagerak for examination contained chiefly fish of the 1923 and 1922 year-classes. The growth history of these two year-classes proved to be so characteristic, and so different for the year-classes, that the growth calculations could be used for testing the





The Swedish sample which was very kindly placed at our disposal by Dr. K. A. ANDERSSON has proved to be of great value in these investigations. For a number of countings of vertebrae had been carried out for this sample, and with the aid of these and the growth calculations, it has been possible to coordinate all the observations in a way which might, by a metaphor, be termed biological triangulation.

As is shown in Fig. 11, the marked difference in the growth history of the two year-classes appears in all the samples. There are two definite and different courses in the path traced by the curves, the one characteristic for the 1923 year-class and the other for the 1922 year-class. Such an extraordinary coincidence affords strong evidence that all the samples have an internal connexion.

Also numerically these observations indicate that the herring in all the samples belong to the same race, since the growth figures for each year-class show a great resemblance between the samples. The greatest difference lies in the fact that the values for the adult herring from the spring of 1926 are the highest for both year-classes. This is exactly what was to be expected when we take into account the fact that the larger fish in a year-class are the first to become adult and ready to spawn. All the investigations indicate that neither the younger fish in the samples of adult herring nor the older fish in the samples of unripe herring can be regarded as representative of their year-class as a whole. They have a biological or a physiological bias, each in its own direction.

The number of vertebrae for the Swedish herring shows for Vert. S. an average of 57.2 for year-class 1923 and 57.3 for year-class 1922. The corresponding numbers from Norwegian material of unripe herring in the summer of 1927 are 57.1 and 57.2 respectively. For the material of spawning herring from the spring of 1928 the figures were 57.4 and 57.1 respectively. Even though these figures alone are no certain proof, they do lend support to the assumption that the herring in the Skagerak belonged to the Norwegian race. Apart from the Norwegian herring which have previously been encountered in the Skagerak, it is unlikely that there is any other race of herring possessing a higher number of vertebrae than 57 which could come into the question here.

Which area in the sea it is that the oceanic Norwegian herring mainly frequent, these investigations still leave uncertain, and there are altogether only a few data on which to base a hypothesis.

The slight information we possess, in the form of reports from fishing experiments and the like, points to the region to the north-east of the Faroe Islands as a possible central area for the group of young herring. But no definite theory can be built on this basis, as these fishing experiments were carried out prior to the time when it was possible to identify

the captured herring as Norwegian young herring. This question as to their distribution must therefore remain in abeyance until fresh observations can be made. Only one thing seems to be indicated by the material which up to the present is in our possession, namely that the young herring, when they abandon the coast, can enter upon extensive migrations. The samples of herring from the Skagerak, which have been examined, contained individuals on the scales of which the winter rings had an appearance which corresponded very slightly to what one sees on the scales of the coastal herring from the southernmost part of Norway, but was very similar to what one sees in the herring from the north of Norway. The same was the case to an equally marked degree in the older herring in the material from the summer of 1927.

#### **4. Some Consequences of the Theory, in Relation to the Fisheries and the Main Features in the Life History of the Norwegian Herring.**

The results described in the foregoing must, together with others, affect our judgment as to the previously mentioned demand for the protection of the young coastal herring. They must lead to the conclusion that protection is unnecessary for the stock, and that it could not be hoped that a protection of the small herring would result in a larger stock of larger "fat herring" in the coastal waters. One is forced to assume that the herring would abandon the coastal waters when it suited them, independently of whether or not they had previously been the object of fishing operations.

Further, the results tend to strengthen the impression given by the statistics of the Norwegian herring fisheries, namely that the presence of the large "fat herring" in the coastal waters and in the fiords ought not to be looked upon as something which may be expected every year. It looks more as if the so-called "large fat herring years" occur when the oceanic group of herring, or portions of them, are driven to the coast as a consequence of circumstances, which at the present moment are unknown, or when the departure from the coast in order to take up an oceanic existence is, so to speak, delayed. In the former case the captured "fat herring" would be of average size and weight at least 100 grams each when salted, whilst in the latter case the herring would be considerably smaller. It seems that both these alternatives can occur, the latter when the individuals of the year-class in question have grown up slowly. That the "fat herring" fisheries under these circumstances must undergo great fluctuations, both as regards quantity and as regards the size and quality of the captured herring, seems unavoidable, especially

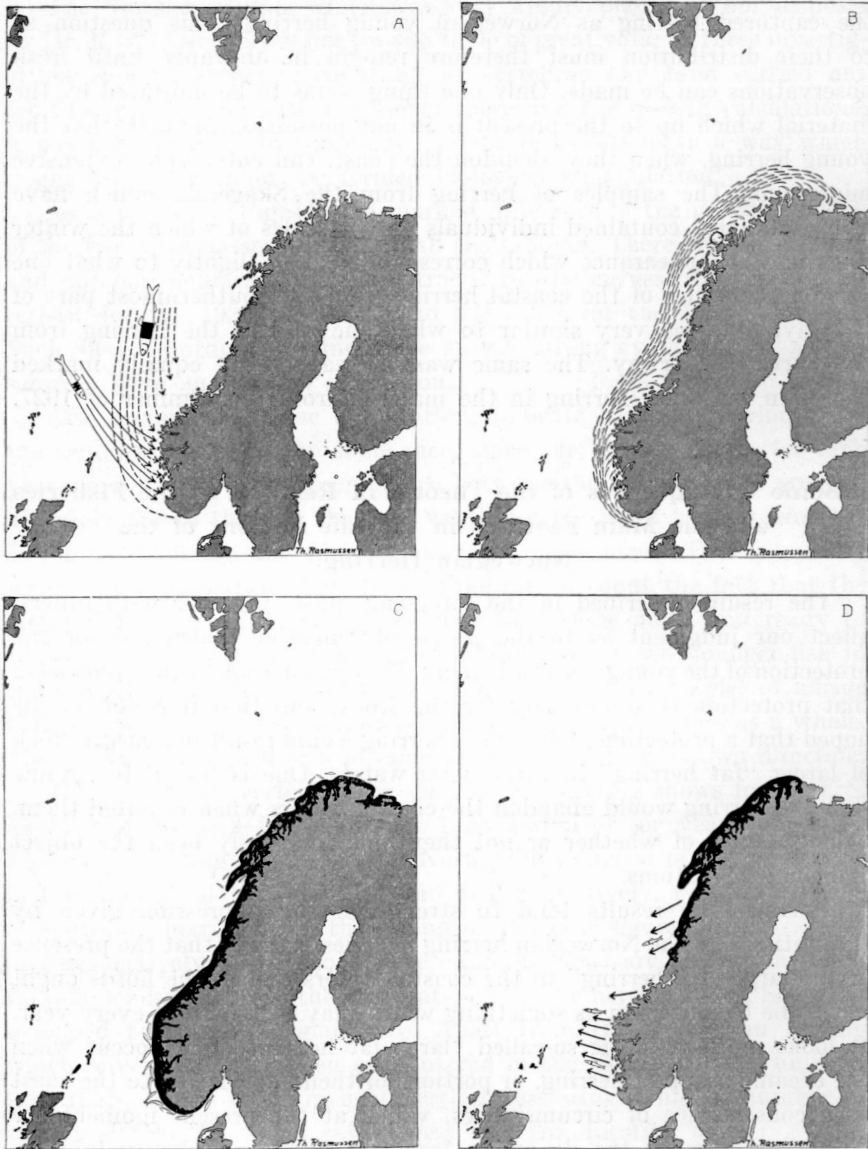


Fig. 12. Schematic presentment of the chief features in the life history of the Norwegian herring.

- A. Arrival of the spawning herring at the spawning grounds in two main groups, firstly the older spawners and then the recruit-spawners, during the season January—April.
- B. Dispersal of the year's fry along the entire coast.
- C. Sojourn off the coast in the herring's second year of life.
- D. Departure from coast, and transition to the oceanic stage, in the third year of life, of the herring which have lived along the southern part of the western coast.

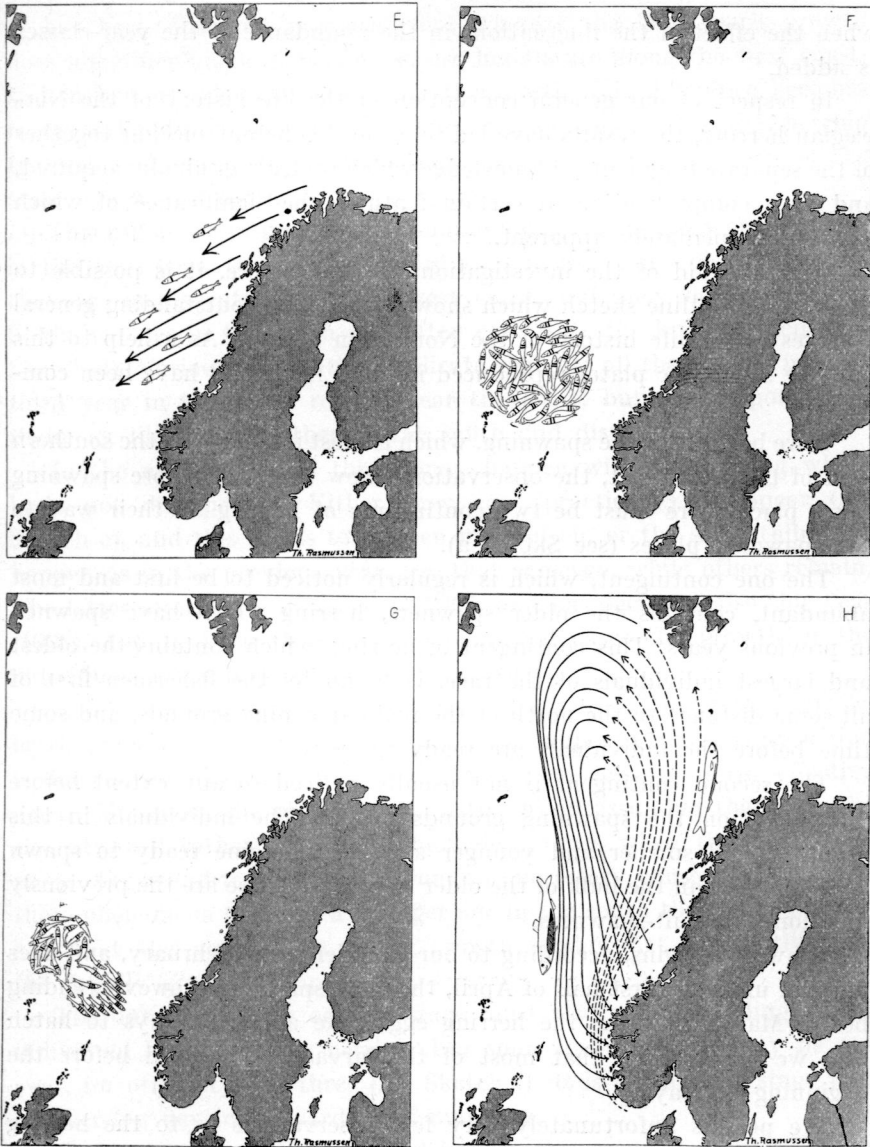


Fig. 13. Continuation of Fig. 12.

- E. Departure from coast and transition to the oceanic stage, mainly in the fourth year of life, of the herring which have lived further north along the coast.
- F. Oceanic stage. Duration according to circumstances from one to three years, age of herring between two and six, possibly seven years.
- G. Abandonment of the oceanic stage, after sexual development, by the herring which will become sexually mature at the coming spawning season.
- H. Yearly circulation of the adult herring between the spawning places and the summer haunts.

when the effect of the fluctuations in the abundance of the year-classes is added.

In respect of our general conception of the life history of the Norwegian herring, the results have led to a more coherent piecing together of the separate fragments of knowledge which we have gradually acquired, and to a comprehension of certain features the significance of which was not immediately apparent.

With the aid of the investigations discussed here, it is possible to draw up an outline sketch which shows, I hope, the outstanding general features in the life history of the Norwegian herring. As a help to this end the schematic plates reproduced in Figs. 12 and 13 have been compiled.

If we begin with the spawning, which is most intensive on the southern part of the west coast, the observations show that just before spawning takes place there must be two contingents of herring on their way to the spawning places (see Sketch a).

The one contingent, which is regularly noticed to be first and most abundant, contains the older spawners, herring which have spawned in previous years. This contingent of herring, which contains the oldest and largest individuals of the race, is found by the fishermen first of all some distance to the north of the main spawning grounds, and some time before the individuals are ready to spawn.

The second contingent is not usually noticed to any extent before it appears on the spawning grounds proper. The individuals in this group are all smaller and younger and they become ready to spawn rather later than the bulk of the older spawners. These are the previously mentioned recruit-spawners.

Spawning begins, according to our experience, in February, and does not end until the first half of April, the chief spawning, however, ending before March 20th. As the herring eggs take about 24 days to hatch out, we may reckon that most of the larvae are hatched before the beginning of May.

We possess unfortunately very few observations as to the herring fry and the fate of the smallest metamorphosed "small herring". It is supposed that their distribution is due, at any rate to a great extent, to their being transported with the currents. It is certain in any case that they are found in the course of the summer in the fiords and the "Skærgaard" on the west coast, and somewhat later more to the north, right up in the north of the Finmark (see Sketch b).

The herring appear to spend the second year of their lives in the coastal waters without making any extensive migrations (see Sketch c).

It has been observed regularly that whereas the first year's growth does not differ much in herring whose haunts are along the west coast, and in herring which have gone farther north, this difference becomes more marked in the second year of their life, and the result is that herring two years of age along the west coast become larger than those of the same age in the north.

This difference in growth is presumably responsible for what happens in the next year, the herrings' third year of life. They disappear from the fishermen's catches on the west coast, but they occur regularly in the catches in the north and often constitute the bulk of them (see Sketch d). Various observations indicate that not all the herring in their third year in the north remain near the coast, but that a portion of them act like those farther to the south and disappear.

In the next year two things may happen with the herring which have not disappeared. Either they can (practically) disappear (see Sketch e), and this seems to happen most often, or the same thing can happen as in the previous year, i.e. that some go, while others remain. The latter alternative occurred in 1907, and has occurred also this year (1928), and in both these most pronounced cases the growth of the individuals remaining behind has been slow.

It is in the third and fourth years of their lives, therefore, that the herring adopt the oceanic mode of life. It is supposed that this transition is determined physiologically, and that sexual activity is the effective agent. Moreover, the observations justify us in assuming that it is the size attained rather than age which determines when this shall take place. According to this assumption, the necessary consequence is that these phenomena occur at a younger age in the south than in the north, and that the year-classes whose growth is slow act differently from the rapidly growing year-classes.

The duration of the oceanic stage must also vary according to the individual history of the herring. For some individuals it may be one year, for others two or three (see Sketch f). It is during this stage that the herring develop towards first maturity.

Each year, at which time is not known, this group of oceanic "young herring" must be split up into two groups (see Sketch g), since the individuals which will become ready to spawn in the coming spring must separate from the individuals which will not, and which must wait perhaps one year, perhaps two, until this takes place. In the fullness of time the group which has split off arrives on the spawning grounds as recruit-spawners, and, as far as they are concerned, this cycle in their life history is completed.

It is not yet quite certain what happens to the herring in the course of the year after they have appeared upon the spawning grounds as recruit-spawners. But if they at once join the older spawners (and it is here that uncertainty prevails) they set out on a long migration which is shown (again schematically) in Sketch h (which thus for the time being holds good for older fish of the Norwegian race of herring). The migration moves northwards and is marked by the following stages: in May—June the herring are on a level with Lofoten, in July they have been observed off Bear Island, in August—September off Spitzbergen, in October again on a level with Lofoten, and in the winter months farther to the south.

During this annual and very extensive migration the herring rapidly undergo a radical process of regeneration after spawning. Already in May, less than two months after spawning has taken place, the herring are encountered to the south of Lofoten at that point where the arrow to the extreme right in Sketch h ends. They are then lean, but completely gorged with *Calanus*. During a stay I made there in 1919, I had occasion to observe how the herring in a short time were capable of consuming great quantities of food and converting it into fat. So intensely active were the digestive enzymes during this period that the herrings split along the stomach a few hours after capture, and the workmen engaged in salting them soon got the skin of their hands damaged and had to cease work. We possess information from herring oil factories to the effect that the herring literally increase their fat content day by day by nearly 1 per cent.

The further fate of the adult herring is known, partly from observations made during a stay at Bear Island in July 1914, but especially from observations and the material acquired during the expedition which in recent years, under the direction of my colleague, the consultant TH. IVERSEN, have been made in the waters in the vicinity of Spitzbergen. During these cruises on several occasions cod were caught, in whose stomachs were found herring scales and in part whole herrings. The scales bore such an unmistakeable resemblance to the scales from the samples of Norwegian spawning herring that there can scarcely be any doubt as to their belonging to the same race of herring which each year appears off the west coast of Norway. These observations may with a high degree of certainty be connected with previous observations on the occurrence of the adult herring, and indicate presumably the northern limit of the adult herring's annual migrations.

---