327

HERRING OF THE NORTH EUROPEAN BASIN AND ADJACENT SEAS

Translations from the Russian

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SEL'DI SEVERO-EVROPEYSKOGO BASSEYNA I SMEZHNYKH MOREY
THE HERRING OF THE NORTH EUROPEAN BASIN AND ADJACENT SEAS

Translations from the Russian

Polyarnyy nauchno-issledovatel'skiy institut morskogo rybnogo khozyaystva i okeanografii., Murmansk, 1956, Vypusk 9.

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CONTENTS

EDITOR'S PREFACE TO TRANSLATIONS

Russian herring research has been greatly expanded since World War II and in the past decade a number of biological reports on Clupea harengus have been published. One of Russia's most comprehensive accounts of the biology of this species has been published as Trudy No. 9 of PINRO (Polyarnyy Nauchno-issledovatel'skiy Institut Morskogo Rybnogo Khozyaystva i Okeanografii).

Four of the English-speaking fishery laboratories have collaborated in translating Trudy No. 9. The Lowestoft laboratory of the Ministry of Agriculture, Fisheries, and Food provided translations for articles 2, 3, and 5. The Aberdeen laboratory of the Scottish Home Department was responsible for articles 6 and 7. The St. Andrews, New Brunswick laboratory of the Fisheries Research Board of Canada had translated articles 1, 4, and 8. The U. S. Bureau of Commercial Fisheries laboratory at Boothbay Harbor, Maine provided a translation of article 9.

Librarians Eileen C. Howard of Lowestoft, H. McCall of Aberdeen, and Lewis R. Day of St. Andrews were active collaborators with the general editor Leslie W. Scattergood of Boothbay Harbor.

In the Literature

In all instances, literature citations have been abbreviated. Following is a list of some Russian abbreviations:

ANII Arkticheskiy Nauchno-issledovatel'skiy Institut (Arctic Scientific Research Institute).

AN SSSR Akademiya Nauk, SSSR (Academy of Science of the U.S.S.R.).

AzcherNIRO Azovo-Chernomorskiy Nauchnyy Institut Rybnogo Khozyaystva (Azov-Black Sea Fisheries).

DAN Doklady Akademii Nauk SSSR (Reports of the Academy of Sciences of the U.S.S.R.).

Gidrometizdat Gidrometeorologicheskoye Izdatel'stvo (Hydrometeorology Publishing House).

GIOA Gosudarstvennyy Institut Opytnoy Agronomii (State Institute of Experimental Agriculture).

GOIN Gosudarstvennyy Okeanograficheskiy Institut (State Oceanographic Institute).

GUSMP Glavnoye Upravleniye Severnogo Morskogo Puti (Main Administration of the Northern Sea Route).

Izd. Izdaniye (edition); izdatel' (publisher); izdatel'stvo (publishing house).

Kn. Kniga (book).

LGU Leningradskiy Gosudarstvennyy Universitet (Leningrad State University).

Medgiz Gozudarstvennoye Izdatel'stvo Meditsinskoy Literatury (State Publishing House of Medical Literature).

MGU Moskovskiy Gosudarstvennyy Universitet (Moscow State University).

MOIP Moskovskoye Obshchestvo Ispytateley Prirody (Moscow Society of Naturalists).

Mosrybvtuz Moskovskiy Tekhnicheskiy Institut Rybnoy Promyshlennosti i Khozyaystva (Moscow Technical Institute of the Fish Industry and Fisheries).

MRP Ministerstvo Rybnoy Promyshlennosti (Ministry of the Fish Industry).

PINRO Polyarnyy Nauchno-issledovatel'skiy Institut Morskogo Rybnogo Khozyaystva i Okeanografii (Polar Scientific Research Institute of Sea Fisheries and Oceanography).

Pishchepromizdat Sosudarstvennoye Nauchno-tekhnicheskoye Izdatel'stvo Ministerstva Promyshlennosti Prodovol'stvennykh Tovarov (State Scientific and Technical Publishing House of the Ministry of the Food Products Industry).

t. tom (volume).

TINRO Tikhookeanskiy Institut Rybnogo Khozyaystva (Pacific Ocean Fisheries Institute).

VNIRO Vsesoyuznyy Nauchnyy Institut Morskogo Rybnogo Khozyaystva i Okeanografii (All-Union Scientific Institute of Maritime Fisheries and Oceanography).

VNIORKh Vsesoyuznyy Nauchno-issledovatel'skiy Institut Ozernogo i Rechnogo Rybnogo Khozyaystva (All-Union Scientific Research Institute of the Fish Industry of Lakes and Rivers).

vyp. vypusk (issue, number, publication).

ZRIS Za Rybnuyu Industriyu Severa (For the Fishing Industry of the North).

The deficiencies in the literature citations in the translated articles are inherent in the original papers. We have not attempted to correct or complete them.

THE HERRING OF THE NORTH EUROPEAN BASIN AND ADJACENT SEAS

PREFACE

In order to realize the decree of the Party and the Government concerning the development of the Soviet fisheries, the Polar Institute in 1937 began a large scale investigation of the biology of the Barents Sea herrings. The principal results of these investigations are published in Volumes IV, VI and VII of the Trudy PINRO. It was found that the Atlantic-Scandinavian herring which originate from the northernmost spawning places, near the Lofoten Islands, spend the first year of their lives in the Barents Sea. There they grow and live until the onset of maturity. The immature herring are in large schools which from the year 1938 onwards were exploited by drifters.

It was found that the tribe of immature Atlantic-Scandinavian herring in the Barents Sea was composed of a small number of age groups. Until the third year of age, the herring is of little commercial importance, and at an age of 4-5 years the greater part leaves the Barents Sea. Thus only three, sometimes four, age groups may be the object of fishery along the Murman coast.

With a limited number of age groups, great fluctuations in the strength of the year classes will be largely reflected in the size of the stock and accordingly will also affect the fishery. This was the practical conclusion of the PINRO investigations on the natural basis for the relative size of the herring fishery in the Barents Sea. During the following period, the experience of the fishery confirmed this hypothesis. By the presence of only one rich year class in the stock, the catch was very good; but when all the year classes were poor, the output of the fishery was quite different.

This main conclusion determined the direction of the following investigations of the Polar Institute.

It was necessary to find the habitat of the mature herring which had grown up in the Barents Sea and find out if these fish could be exploited in any way. The long life of the Atlantic-Scandinavian herring gives rise to the assumption that the mature part of the stock might be of great practical importance for the Soviet fishery.

The first investigations in this direction were carried out in 1939. Large schools of mature herring were discovered west of the Spitzbergen Archipelago.

After the conclusion of the Second World War, the Polar Institute resumed the study of the migrations of the mature herring in the area of the Spitzbergen current. A small experimental fishery expedition in 1947 may be taken as the beginning of the development of the Soviet herring fishery outside the borders of the Barents Sea.

During the following period, Soviet seamen, in close collaboration with the scientific workers of the Polar Institute, extended the area of the fishery and begun to catch herring throughout the year, exploiting the schools of the herring on their way to the feeding or spawning areas.

During this period, the main attention of the Soviet scientists was directed to the migrations of the mature Atlantic-Scandinavian herring which had contributed to the great fishery of the USSR in the North European basin. During these years, a large amount of material was also collected on the distribution of the immature herring. New spawning areas were disclosed by the Soviet investigators of the Atlantic-Scandinavian races of herring on the edge of the continental shelf of the North Sea and around the Faroes.

In order to study the migrations of the Atlantic-Scandinavian herring, it was necessary to organize extensive hydrographic investigations. Such investigations were carried out by the Institute during the following years, adding essential corrections to the scheme of the currents of the Norwegian Sea, presented at the beginning of this century by Nansen and Helland-Hansen.

The investigations threw light upon the biology of the Atlantic-Scandinavian herring, the areas and conditions of their reproduction, the drift of the larvae and young, the migrations of the mature individuals, the structure of the spawning population, and the biological premises of a rational fishery. These questions are treated in a paper by Yu. Yu. Marti in the present volume.

The feeding conditions of the Atlantic-Scandinavian herrings are described in the papers by E. A. Pavshtiks, V. A. Rudakova, and V. D. Abramova. A study of the ripening of the gonads is given by V. A. Naumov.

The results of the Soviet investigations on the summer-spawning herring in the region of Iceland and the Faroes are given by K. A. Liamin. The author submits well-founded data on the existence of this race, stating its difference from the spring-spawning Atlantic-Scandinavian herring, and demonstrates the scheme of its life cycle.

Also published in the present collection of papers are the latest works of the Institute on the biology of the herring of the White Sea by B. M. Tambovtsev and A. P. Vilson.

THE FUNDAMENTAL STAGES OF THE LIFE CYCLE OF ATLANTIC-SCANDINAVIAN HERRING [1/]

Yu. Yu. Marti

Brief Account of Explorations, Materials, and Methods

Atlantic-Scandinavian herring were, for many years, the subject of extensive investigations conducted by a number of North European research workers.

Works by Boek (35), Runnström (65, 67) and Sund (72, 76) contain detailed information on the locations and conditions of herring-spawning along the Norwegian coast. Investigations of Schmidt, Jespersen (51), Tåning (78-80) completed the data available on herring reproduction in the waters of the Iceland region. As a result of research by Sars (68), Runnström (66), Hjort (50) and Lea (56), we have at our disposal detailed information on the existence of young Atlantic-Scandinavian herring in the littoral waters of Norway.

We possess data on the age composition of the spawning schools of Norwegian herring for a period of over fifty years.

A number of publications have appeared on the study of growth, sexual maturity, and fertility of Scandinavian herring.

The systematic position of this race has been determined on the basis of the research carried out by Heincke (48), Johansen (52, 53) and LeGall (57). Research on Atlantic-Scandinavian herring has been invariably carried out in coastal waters.

After several herring specimens were caught at the beginning of this century in the middle of the Norwegian Sea by the exploration vessel "Mira" (54), Iversen, a Norwegian captain, found large herring in the guts of cod caught in the vicinity of Western Spitsbergen and Jan-Mayen Island.

On the basis of these observations, Lea (56) drew a scheme for the migrations of Norwegian herring, published in 1929, and of some current interest. The limited data available on migrations of Atlantic-Scandinavian herring prevented us from thoroughly studying their biological peculiarities and differences from other races of the Atlantic herring.

Soviet research has been directed from the very beginning towards exploration of new herring-fishing grounds. Therefore, the study of herring distribution in the sea, their migrations, and concentrations became the main task in our investigations. The remaining problems of herring biology were of secondary importance. As a result of this singleness of purpose, within a relatively short period of time, the Soviet scientists attained considerable knowledge of the Atlantic-Scandinavian herring.

The main patterns of distribution of young, sexually immature herring in the Barents Sea were established prior to the outbreak of the war.

During recent years, Polar Institute investigations have been conducted on a still larger scale. Scientists concentrated on the main problem - i.e., study of migrations of adult Atlantic-

1/ Fisheries Research Board of Canada Translation Series, No. 167.

Scandinavian herring within the borders of the entire area inhabited by these fish, from the southwestern coast of Norway and Iceland to Western Spitsbergen and Novaya Zemlya.

These investigations enabled us to solve the problem of seasonal distribution of commercially important concentrations of herring in North Atlantic waters. On the basis of these data, the fishing industry of the Soviet Union organized an extensive herring fishery in this particular zone of the ocean.

The present article presents data and observations collected by the Polar Scientific Research Institute of Fisheries and Oceanography over the course of almost two decades.

It is quite obvious that methods of investigation were bound to change during such a long period of time. Nevertheless, aside from the technical means employed, or of the tasks faced by the investigators - be it a study of the drift of herring larvae or solution of some practical problems connected with the fishing fleet - the research conducted by the Polar Scientific Research Institute of Fisheries and Oceanography was based on the thorough and complex study of organism and environment in their indissoluble interrelation and interaction.

During the study of different phases of the development of herring, we always considered the interrelation of different cycles with the preceding phenomena and the degree to which these latter determined the subsequent stages of biological development. Captains of exploratory and fishing ships participated in the research set up by the Polar Institute. At all stages of research the conclusions were verified through practical fishing, since all these investigations were practical in character and set up to solve practical problems.

Throughout the entire period of research, the task of establishing migration paths and conducting observations on the movement of herring, proved to be the most difficult. This always has been one of the most difficult problems in fishery investigations. Particular difficulties arose when the scientists attempted to determine the migratory habits of marine fishes, which are known to be extremely active and migrate over great distances.

F. Heincke (48) made the first attempt to solve the problem of migrations of fishes. He believed that a more thorough study of the morphological structure of herring from different regions would enable us to follow their distribution in the oceans during migrations. F. Heincke was able to solve the problem of migrations along the most general lines only. He succeeded in proving that there exist in European coastal waters different races of herring populating limited areas and differing from each other in structural characteristics, and the seasons and conditions for spawning.

The method employed by F. Heincke did not provide detailed information on the migrations of the different races of herring isolated by this investigator, because the number of herring samples at his disposal, obtained outside the customary fishing grounds, proved insufficient, and because the characteristics of different herring races, as defined by Heincke, did not apply to young, sexually immature specimens, due to the fact that morphological characteristics strongly vary with age.

Later on, the method suggested by F. Heincke was somewhat modified. Researchers disposed of the analysis of numerous plastic characteristics and concentrated on meristic indices. Determination of the number of vertebrae was considered particularly important and, in the opinion of a number of scientists, including Lissner (58), Schnakenbeck (69) and LeGall (57), it furthered the knowledge of migrations of herring of different races. However, the study of the varying number of vertebrae showed that this characteristic is also subject to considerable fluctuations. Initially, it was believed that estimation of the number of vertebrae in 100-200 specimens of herring was sufficient to establish the race of the herring thus examined. Later on, however, it was found that the mean index of the number of vertebrae in herring from different regions varies from one year to another. Thus, observations conducted by Prof. M. P. Somov on herring from the Barents Sea over the course of almost twenty years showed that the mean number of vertebrae changes considerably from one generation to another. The Norwegian scientist Rasmussen (62) arrived at analogous conclusions. Thus, it became obvious that when considering the number of vertebrae as a criterion for determining the race, it must be taken into account that this characteristic varies from one generation to another.

Morphological investigations yielded certain results only in the initial stages of the study of distribution and migrations of herring. For present scientific demands and practical requirements this method is entirely unsuitable.

In the first decade of our century, an attempt was made to follow the movement of schools of Norwegian herring hatched in 1904, the scales of which bore a mark due to poor feeding conditions in 1906. Meek (59) drew a map of the migrations of young Norwegian herring on the basis of the distribution of the herring bearing these marks. This map is presented in his work, as well as in the work by P. Yu. Shmidt (32) entitled "Migrations of Fishes" and in a number of textbooks on ichthyology.

More recent investigations on the rate of growth of young Norwegian herring carried out by Ottestad (60), led him to conclude that a sharp drop in the increment in the third year of growth is a relatively frequent phenomenon and can be attributed to herring lingering in the littoral zone. Thus, Ottestad questioned the observations and map of Meek. At present it is difficult to give an opinion on this subject without a more thorough analysis of all factual material. It is almost impossible to assume that the unfavourable feeding conditions of 1906 only affected the extensive Norwegian herring region. If this is the case, it is only logical to assume that these "marked" specimens might also have been found among other races of herring, among herring from the North Sea in particular. Personally, we consider the map of migrations suggested by Meek as rather open to question and it will be discussed further.

As a result of the work of Norwegian scientists a method of "reading" the scales of herring has been developed, and this permits determining the origin of herring (Northern and Southern type), the season during which they move into the open sea, as well as the age at which sexual maturity occurs. The Barents Sea herring investigations of P. A. Murashkintseva (18) showed that the criterion on which the Southern and Northern types of rings on the herring scales are distinguished is subjective. In a great number of specimens, we observed rings of transitory type. Moreover, the Northern and Southern types of rings may form not only due to the physical and geographic conditions characteristic of the latitude inhabited by the given herring, but due to local conditions as well (such as littoral and open sea zones, where the feeding conditions vary from one year to another, etc.).

It is extremely difficult to solve the problem of migrations by examining the structure of scale rings. This index is important only in the study of dynamics of the populations, in forecasting the sexual maturation and spawning of adult fish schools.

The differences in the rate of growth are also of little importance in the solution of the problem of migrations. The reason for the latter is that there are considerable individual fluctuations in the annual rate of growth, and in the peculiar circumstances of the formation of schools even within one and the same region. Therefore, the presence in a region of herring bearing some definite indices of growth may complicate the problem instead of solving it.

Indices representative of the age composition should be used with great caution, since the drift net, which is the principal gear for herring fishing, is a selective device. Moreover, we wish to point out that the size composition of a drift net catch is also conditioned by the net selectivity and natural selection of fishes during the formation of a school.

For a long time, the tagging of herring was not considered advisable because of the harmful effects this rather drastic operation has on the fish. In Alaska, the first experimental tagging of herring was done by Rounsefell and Dahlgren (64). They used a tag inserted into the body cavity of the fish. The tags were subsequently detected by special magnetic instruments installed in the conveyer through which the herring travelled from the boats to the processing factories. This method proved to be quite effective, but its application is limited because the herring must be delivered by a conveyer system. During recent years, this method has been widely used in Norway and Iceland.

After the end of the war, Wood (81), a Scottish biologist began using small external tags, which were attached to the body of fish by means of a wire near the dorsal fin.

The number of tagged herring subsequently found in catches was relatively high. This proved that the use of external tags is effective.

The Polar Institute undertook experimental herring tagging early in 1952. White Sea herring moving towards the shores for spawning were observed. We used red celluloid tags fastened with a nickel wire anterior to the dorsal fin. The high percentage of tagged fish found in catches showed that this marking method can yield good results. As an experiment in 1953-1955, the Polar Institute released approximately 12, 500 herring bearing such tags.

Studying fish migrations by tags is quite effective. However, the movement of the tagged fish can only be followed within the regular fishing grounds. When tagging fish to study their migrations and at the same time to determine the fishing intensity, the important factors are the number of fish that survive the test and the maximum possible tag returns. If, however, the only purpose is to establish migration paths, it is important that the mortality rate of tagged fishes should not be excessively high.

Effective detection of tagged fishes in catches depends primarily on the tag's conspicuousness and the methods of processing the fish. Internal tags and the tag-detection methods, therefore offer considerable advantages in places where great quantities of fresh herring are landed directly from the fishing boat. This method could not be used at all, however, where the herring are processed directly on board the fishing boat, since the magnetic instruments would have to be installed on board each herring-fishing vessel, and this would considerably complicate processing operations. We, therefore, believe that in our fishing industry, external tags should be used. Herring bore satisfactorily Polar Institute tags. The tag labels are readily noticeable ensuring that a great number of tagged fish can be subsequently detected in catches.

Herring fishing as developed by the Soviet Union during the last few years leads us to expect favorable results from mass tagging. However, this should not be the only method used. The modern organization of fisheries, the extensive application of detecting instruments used to reveal concentrations of herring, and the large-scale fishing all suggest that the new method for the study of migrations consists briefly of the following: Modern underwater detection instruments built on the principle of supersonic wave reflection enable scientists quickly and accurately to locate and follow movements of herring concentrations. At present, we are able to estimate the schools of herring, their distribution and density only on the basis of test catches. Detailed study of abiotic and biotic conditions in which the movement and concentration of herring schools occur is a highly important aspect of this method. This task presents no difficulties, since instruments registering the temperature and salinity while the ship is in motion are already available. Ensuring continuity of observations on biomass and composition of plankton is somewhat more difficult.

The suggested method of observations on the interrelations between organism and environment is an element of the new methodology employed in studying the migrations of fish and can be considered a great achievement. In the past, studying the environmental conditions of fish consisted of taking observations at "stations", whereas the method suggested is based on the quantitative characterization of the elements of environment and distribution of the species over a large area almost simultaneously. When a large number of fishing boats are fishing herring concentrations, it is relatively easy to determine the biological characteristics of the schools, since even now all the captains endeavor to determine the size of the herring concentration on which they fish, while the exploratory ships analyze the catches from the biological viewpoint to establish the size of herring, stomach content, fat content, and stage of sexual maturity. Under these conditions, one or two detailed biological analyses of the herring schools made on board the exploratory boat complete the characterization of the concentration. These analyses become particularly important when the laboratory analyses, including the age determination of the fish, are carried out directly on shipboard. The technique of drift net fishing enables the fishermen to determine the directional movements of schools, a factor which plays an important role in systematizing the observations. Mass tagging of herring from the school on which the fishing is conducted enables the scientist to verify experimentally the movements of schools.

The work of the commercial fisherman coincides perfectly with that of the scientist endeavoring to study the migration of fish. This method has great possibilities, as it enables the fleet to remain within the region where the herring concentrate, and this naturally increases the productivity of its operations. Using this method, we succeeded in following the movement of herring concentrations in a number of regions, though over rather short distances. The method, based on direct observations on the biological grouping of herring, a method Heincke said could not be applied at the beginning of our century, has now become the technique promising optimum practical possibilities.

The samples characterizing the biological composition of herring catches were collected throughout the entire period of research by the same methods. Samples of herring consisting of 100-200 specimens, depending on variations in size, were taken from the catches of exploratory, reconnaissance or, though less frequently, fishing boats. In the case of samples obtained from the drift net catches, we always recorded the dimensions of the mesh of the nets in the drifting order, estimated the mean catch per net, the depth of submersion, direction from which the herring entered the net, etc.

Samples of herring were delivered in slightly salted state to the laboratory, where they were subjected to the following thorough biological analysis: Length from the tip of the snout to the end of the median rays of the caudal fin, sex and degree of maturity of the gonads determined by the seven-point system, age, fattiness, etc. In certain samples, we counted the number of vertebrae in all the specimens. Total weight and weight of gonads were determined from fresh material only. During recent investigations, the complete biological analysis of herring samples, including the determination of the age of herring from the scales, was made on board the exploratory ships.

In the present article we used a relatively small portion of the data collected by the Polar Institute, which we believed indispensable for solving the problems involved in this research - i.e., the study of biological peculiarities, spawning regions and environment, migrations of young and adult specimens, specific structural details of the spawning stocks and reproductive capacity of the Atlantic-Scandinavian herring.

REPRODUCTION AND BIOLOGY OF

MATURE ATLANTIC-SCANDINAVIAN HERRING

Regions and Conditions of Reproduction[1/]

The fact that herring spawn off the south-western coast of Norway was probably well-known long before the investigations of Boek (35). Boek established that herring spawn in this particular region on the slopes of the banks situated near the underwater "valleys" along which they approach the shore. Spawning occurs at a depth of 70 meters. Most frequently the herring deposit eggs in those areas where the floor is covered with large and small gravel. Boek succeeded in gathering compact lumps of fertilized eggs mixed with bottom material from these areas.

Runnström (65, 67), Sund (72, 76) and other Norwegian researchers have shown that spawning in these regions begins in the middle of February, continues throughout March and ends in early April. The spawning grounds are located along the entire south-western coast of Norway, from Cape Lindesnes in the south to Ålesund in the north.

The most important spawning grounds are south of Bergen, near Karmøy and Boknfjord. North from Ålesund, we found herring larvae in early stages of development on Traena Bank, located around 64° north latitude. Observations by Runnström (67) show that herring reproduce at depths of 5-10 to 140 meters. It has been established that spawning is particularly intensive at the depth of 40-80 meters.

According to the same author, percentages of herring eggs found on different kinds of bottom in the region of the south-western coast of Norway were as follows: On rocky soil - 45.5% (of the total amount of roe encountered), on seaweeds overgrowing the rocks - 7.7%, on stony ground - 11.7%, on gravel - 7.7%, on sand - 1.8%, on shell rock - 24.9%, on soft bottom - 0.7%.

LeGall (57) showed that herring spawn off the south-western coast of Norway at a water temperature of 4-7°C and a salinity of 33-35. Runnström pointed out that the greatest egg deposition was found along demarcation lines between the slightly less saline and relatively cold waters of the surface layer (where the water temperature is usually below 4-4.5°C and salinity less than 32-33) and the warm, highly saline Atlantic waters which usually lie at a depth of 40-50 meters and more.

1/ The study of the spawning grounds of the Atlantic sub-species of herring, Atlantic-Scandinavian race in particular, involves certain difficulties in view of the fact that these spawning grounds are located at considerable depths. Scientists have not always, nor everywhere, succeeded in gathering roe from the bottom by means of trawls or bottom-scrapers. The easiest and the most reliable method of locating the herring spawning grounds consists of gathering early larval stages with nets made of silk or some other fine mesh. The presence of a great number of these larvae in the water considerably facilitates the task. Spawning grounds in the region of Iceland, Faeroes and on the Lofoten shelf have been located with the help of the above-mentioned method. Freshly swallowed roe that may be found in the guts of haddock is a reliable index of spawning grounds.

Establishment of spawning grounds on the basis of catches of mature fish, males with liquid sexual products in particular, is a far less reliable method, since these fish may be found at considerable distances from spawning grounds.

In the Viking Bank region and north from it, along the slope of the continental shelf, Clark (38) found herring eggs in the guts of haddock. During the spring, we also found freshly-hatched herring larvae in this region.

In February - early March, 1952-1955, Soviet boats fished the pre-spawning herring concentrations on the Viking Bank with drift-nets. A great number of specimens with running sexual products were found in these catches. On February 27-28, 1953, the author of the present article succeeded in observing a rather interesting spawning on the south-eastern slope of the bank, at a water temperature of approximately 7°C. In 1952 and 1953, German trawlers (71) fished herring with herring trawls on the Otter Bank. The average catch per boat per day was 13-16 tons in February-March; this is confirmation that large concentrations of the pre-spawning herring of this region are present in the deep layers. As a result of special investigations established under the supervision of I. G. Yudanov and carried out by the Polar Institute in February-March, 1955, on board the exploratory boats "Professor Mesyatsev" and "Academician Berg", our knowledge of reproduction of Atlantic-Scandinavian herring became considerably enriched.

A great number of herring larvae in early stages of development were found on the Otter Bank, to the west of the Shetland Islands, in the region of the continental slope where the depths reach approximately 200 meters, at a temperature of approximately 7° and a salinity of 35.3.

Herring spawning in the region of the Faeroes was established by Tåning (77) and Clark (39). The larvae of spring-spawning herring were found here in March, April and May. The largest catches of larvae were obtained near the eastern shores of Sudero Island within the limits of the 50-meter isobath at a temperature of 5-7°C and salinity of 35.1-35.3.

Concentrations of herring with running sexual products were found on bank "192" to the north-east of the Faeroes, at the end of March, 1952, by B. V. Istoshin, scientific member of the Polar Institute, during exploratory operations on board the "Musson".

In the latter half of March, 1955, exploratory boats found a considerable quantity of herring with running sexual products to the north-east and east from the Faeroes, in the region of the 200-meter isobath.

In mid-April in that region, A. P. Vilson, a scientific member of the Polar Institute, while on board the expedition boat "Academician Berg", found herring larvae present at early stages of development.

The study of herring reproduction in the Icelandic region was begun at the beginning of our century by I. Schmidt, who conducted scientific-commercial explorations on board the expedition boat "Tor" in that area between 1903 and 1908. Data collected in the course of this research were analyzed at a much later date by Espersen (51) and published in 1920.

From 1924 until most recently, herring-spawning near the shores of Iceland was periodically studied by Tåning (78, 80). Brief reports on herring reproduction in this region were also written by Fridriksson (42, 44).

The reproduction in the region of Iceland of the Atlantic-Scandinavian spring-spawning herring was experimentally proved on several occasions. In April 1904, Schmidt caught more than 2,850 larvae, 7-8 to 15 mm. in length. In April 1925, the boat "Fiila" caught at three stations 142 larvae, 6 to 14 mm. in length in surface tows. Between March 27 and April 3, 1950, Fridriksson found developing eggs at a depth of 6 to 70 meters to the west of Vestman Island (63°20.9'-63°27.7' of northern latitude and 20°19'-20°30.5' of western longitude). The eggs were gathered with a scoop-net.

The larvae caught in the region of Iceland in May and June, during the research conducted by Schmidt and Tåning, must also be attributed to the spring hatching.

In 1903, we caught in three stations 25 larvae, 15 to 25 mm. in length; in 1904, we caught in 9 stations 53 larvae 15 to 25 mm. in length; in 1905, in 5 stations - 56 larvae, 15 to 25 mm.; in 1924, in 5 stations - 8 larvae, 10 to 15 mm.; in 1934, in 6 stations - 13 larvae, 10 to 25 mm.

In 1904, the research was conducted most thoroughly, and Schmidt found larvae less than 10 mm. in length along the entire extension of the southern and south-western coast of Iceland, within the borders of the continental shelf, at the depth of 35 to 102 meters. A particularly great number of larvae were found at the stations No. 17 (63°25' of northern latitude and 18°00' of western longitude), and No. 18 (63°26' of northern latitude and 20°11' of western longitude), at the depth of 102 and 50 meters. The boat "Filla" found herring larvae in approximately the same region between April 18 and 20, 1925. In May and June the larvae of herring 10 to 25 mm. in length (of spring origin) were found along the southern and western shores of Iceland.

Thus, the theory that herring spawn in the spring off the southern coast of Iceland has been recently confirmed by the discovery of eggs developing in this area on the bottom and found in the stomachs of haddock, as well as in the catches of the earliest stages of recently hatched herring larvae.

Soviet research was developed in this region by the Polar Institute in 1934, i.e., prior to the publication of the work by Runnström. Unfortunately, the results of these investigations appeared in print only in 1938 (22, 23). More detailed study of herring reproduction in this area was carried out by the Polar Institute in 1938 (14, 15). Investigations continued after World War II.

In 1949, the expedition on board the "Persey-II" thoroughly explored the outer slopes of Lofoten shelf from Sørøy to Røst. Freshly hatched larvae were found along the slope between Røst and Andøy.

At present, as a result of the investigations carried out by the Polar Institute in 1938 and 1939 (14), and on the basis of observations set up at the end of the Second World War, we may consider it as an established fact that herring reproduce in the region of Lofoten shelf to the south of Andøy. North-east from this island, herring spawning was observed in 1939 on Malangen Bank and in the region of Svengrund, though on a rather small scale. Herring eggs were frequently found in the region of Lofoten Islands in the stomachs of haddock.

The most intensive spawning in this region occurs at depths over 150 meters, within the limits of the 172 to 225-meter depths. We found no larvae in the early stages of development eastward from Sørøy.

Marti (15) and Tikhonov (30) believed at the beginning of their research that herring may reproduce in the North Cape and Nordkyn Banks, while Professor Rass (21) thought it probable that herring reproduce in the gulfs and bays of Kola Peninsula. These suppositions were subsequently refuted. Throughout the entire period of research (i.e., the years 1938, 1939, 1947 and 1949), the Barents Sea remained at its highest temperature level in 50 years; and, consequently, the spawning regions as established for these particular years must be considered as correct.

There is no herring spawning either in the Barents Sea nor in the region of Bear Island and adjacent banks. At first, it seemed plausible that in the Lofoten Islands region the herring should spawn somewhat later than off the south-western shores of Norway. This impression was formed because the spawning period is somewhat later for the herring that recently attained sexual maturity (the first-time spawners), and which had spawned in the Malangen Bank in early April, 1939. Investigations of the past few years have proved that spawning is mainly completed by early March, and the mass hatching of larvae is observed in early April.

The entire slope of the Lofoten shelf is washed by Atlantic waters and consists almost entirely of hard bottom in the form of large-grained sand, gravel, shells and, occasionally, stones. The bottom temperature on Lofoten shelf during the spawning period is 4.5 - 7.5^{o}C. The salinity fluctuates between 32 and 35.1.

The main data on the environmental conditions for reproduction of Atlantic-Scandinavian herring are presented in Table 1.

A comparison between the spawning conditions in different regions shows a great similarity between them. In all the regions, the spawning takes place within relatively short periods of time: from the middle of February or beginning of March to the middle or end of April at a temperature of 4-5^{o}C to 6-7.5^{o}C and salinity of 32 to 35.3. The spawning regions are located at a considerable depth -- from 40-50 to 100-120 meters and, in the region of Lofoten, spawning occurs at a depth of more than 150 meters along the slope of the continental shelf, near great ocean depths. The spawning regions along Iceland's southern coast are situated in the Irminger current, which is a warm water branch of the North Atlantic current.

Spawning grounds along the south-western coast of Norway and on Viking Bank are washed by waters reaching the shores of Norway through the deep water channel oriented towards the Danish Straits. The spawning grounds located in the vicinity of Faeroes are also markedly affected by the warm Atlantic waters. Finally, the Lofoten spawning grounds are situated near the slope of Norway's north-western shore, washed by the warm Norwegian current waters proceeding towards the western shores of Spitsbergen, and into the Barents Sea.

DRIFT OF FRY AND CONDITIONS FOR ITS EXISTENCE DURING THE FIRST FEW YEARS OF DEVELOPMENT

The drift of the fry plays a very important role in the life of the Atlantic-Scandinavian herring. The importance of these movements can hardly be overestimated. From the very first day following the hatching of larvae and over the course of the next several months, the fry are indissolubly bound to the waters in which they were hatched.

According to the data of our scientists, the drift of young fish discontinues when they are either carried away into the littoral zone, or sink to the bottom. The movement of water masses determines the region of future development of young herring. Thus, the larvae hatched in the region of Lofoten Islands may be found under most diverse conditions of existence: they may be carried to the shores of western Spitsbergen, Murman, Novaya Zemlya, or into the White Sea. The differences in the rate of development, age at which sexual maturity is attained, and the distance covered during return migration of the herring larvae are determined by the living conditions for fry in each of these regions. In other words, drift affects the entire life cycle of young herring.

The pattern of drift of the fry of Norwegian herring was drawn for the first time by Meek (59), who illustrated their drift from the south-western shores of Norway to the northern shores of Norway. The existence of this drift had been assumed earlier by Sars (68), who proved at the end of the past century that the fry from the northern provinces of Norway, fat herring from more

TABLE 1. ENVIRONMENTAL CONDITIONS FOR ATLANTIC-SCANDINAVIAN HERRING SPAWNING.

Spawning grounds	Factors on the basis of which spawning has been confirmed				Spawning season	Temperature °C	Salinity ‰	Depth in m.	Investigators
	Spawning Specimens	Eggs on the bottom	Eggs in the guts of haddocks	Early stages of larvae					
South-western coast of Norway	X	X	X	X	Mid-February to mid-April	4.0-7.0	33-35	5-10 to 140, more often 40-80	Boek, Runnström, Sund
Viking Bank	X	--	X	X	End of February -March	4.0-7.0	34.3-35.3	50-70	Clark, Yudanov, Marti
Northern slopes of the North Sea	X	--	X	X	End of February -March	6.0-7.0	35.0-35.2	About 200	Clark, Vilson, Yudanov
West of Shetland Islands	X	--	X	X	February-March	7.0-7.5	35.2-35.3	" "	Clark, Yudanov
Faeroes	X	--	X	X	March-April	5.0-7.0	35.1-35.3	50-200	Tåning Istoshin, Vilson
Icelandic Region	X	X	X	X	March-early April	6.5-6.8	About 35	50-102	Schmidt, Espersen, Fridriksson
Lofoten shelf	X	--	X	X	End of February, March, April	4.5-7.5	32.0-35.1	50-225	Ryzhenko, Runnström, Manteyfel', Marti

southerly areas, and large winter herring found near the southwestern coast are in reality fish of different ages from the same shoal of Norwegian herring. Hjort clearly outlined the importance of young herring migrations in his report devoted to the phenomenon of fluctuations (50).

Later on, the pattern of drift of the Norwegian herring fry was exposed in detail by Lea (56). At the time of the publication of this map, the Lofoten spawning grounds for herring were still unknown and the young herring found in the Barents Sea were considered by Norwegian investigators as "imported" from the south-western shores of Norway. Averintsev (1), Ryzhenko (23), Yudkin (33) and recently Prof. Rass (21), as well as our own research, showed that the hypotheses concerning so extensive migration of herring larvae are groundless.

Now, after the drift of herring fry from Lofoten spawning grounds was studied in detail, the conditions for drift of larvae and fry from the south Norwegian spawning grounds became more clearly outlined. The conditions governing this drift are rather specific and lie in the fact that south Norwegian spawning grounds are located close to the shores and the current runs close to the shores along the entire extent of the Scandinavian coast; the entire coast of Norway consists of fjords cutting deeply into the continent and having a free water exchange with the open sea; the group of south Lofoten Islands with the large offshore slopes protrudes far into the open sea forming a large natural trap in the form of Vestfjord, which is on the larvae's migration path. The above peculiarities compel the herring fry drifting from the south-western shores of Norway to settle down along the entire extent of the coast, from Bergen to Finnmark. The majority of fry reach the provinces of Nordland and Troms; further to the east, past North Cape, they form but relatively small concentrations.

The conditions for drift of herring fry observed in the Barents Sea are quite different. The spawning grounds along the north-western shore of Norway are, as we mentioned above, located along the very slope, at a considerable distance from Lofoten Islands, at the depth of 150 to 225 meters. The North Atlantic current passes here at a certain distance from the shores and, before reaching the Barents Sea, divides into several branches. Near Andøy, due to the topography of the ocean floor, part of the waters proceed towards the north forming the so-called Spitsbergen current. Near Sørøy, where a large shelf is located, the waters divide into two streams. The first current proceeds along Sørøy, bends around northern Norway and forms the source of the main branch of the North Cape current. The second current bends around the shelf from the north and proceeds into the northern zone of the Barents Sea.

The Barents Sea is relatively shallow being located entirely within the borders of the continental shelf. The coast, along which the drift proceeds, is rich in fjords only in Norway, whereas the Murman shores have but two large fjords: Motovka and Kola gulfs, and several small gulfs farther to the east.

Studies of larval drift carried out by the Polar Institute as far back as 1938 (14), showed that the distribution of these larvae westwards from North Cape is in the direction of the North Cape current. Judging by the number of larvae that were hatched during the year and were found in the stomachs of cod, the current of the drifting fry branches anew in the Barents Sea. The fry proceed via the northern branch of North Cape current towards the western slopes of the Central plateau and farther to the north, to Persey Bank.

The fry drift in the main branch of North Cape current to Goose Bank, dividing into two branches that proceed along the northern and southern slopes at the bank. A portion of fry undoubtedly settle down in the region of Murman shelf penetrating with the Kanin current to Kanin Nos Peninsula and Kolguyev Island. The southernmost course of the migration of fry to the Barents Sea passes near the Murman shores. The fry drifting along the coast of Murman settle down in Motovka and Kola Gulfs, Teriberka Bay, Drozdovka Gulf and Iokanga. Great numbers of young fish penetrate into the White Sea with the littoral Murman current. The extreme points of the dissemination of the herring hatched during the current year in Barents Sea are by the beginning of winter as follows: western shore of Spitsbergen (near Horn Sound), south-western zone of the Central elevation, the shelf of Novaya Zemlya, southern slope of Goose Bank, Kanin Nos and Inlet of the White Sea. During the season of movement, i.e. from spring to the beginning of winter, the herring fry are carried by the current a distance of 450-750 miles from the spawning grounds, at a mean velocity of 2-3 miles a day.

Figure 1 shows the average lengths of herring larvae in different regions and their rate of growth during the drifting period. During the entire period of observations, the smallest sizes (8-10 mm.) have been observed in the region of the shelf of south Lofoten Islands and adjacent sections of sea.

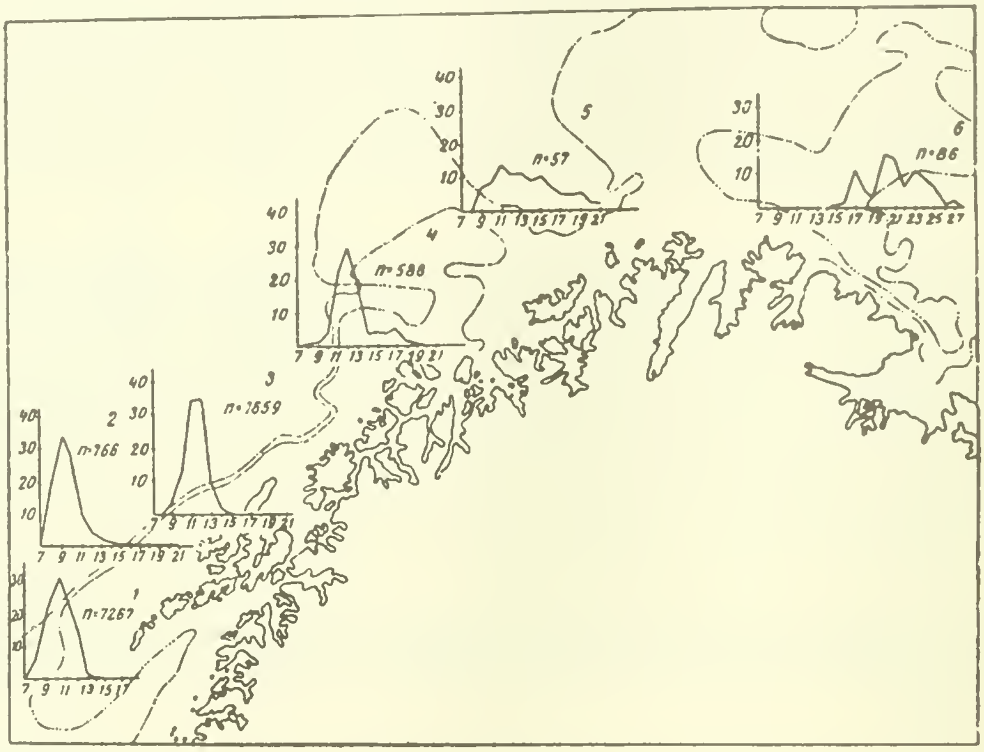

Figure 1. Sizes of herring fry in different zones of the north-western coast of Norway (according to the summarized data of observations conducted by the Polar Institute).

To the north-east in the region of Vesterålen Islands, larvae 10-14 mm. in length prevail. To the north-east, from Ringvassøy, we found accompanying 11-13 mm. larvae a relatively great number of specimens 14-18 mm. The size of larvae found farther to the north, within the 200-meter isobath, is approximately the same as described above. Beyond North Cape the length of larvae varies from 15-27 mm. Near the shores of Murman, herring fry are 40-50 mm. in length. In the autumn, the young herring hatched during that year reach 70-90 mm. in length.

When studying the life cycle of Murman herring, Prof. Rass (21) concluded that all its fry pass through, near the shores of Murman, the so-called littoral stage which occurs, in his opinion, in Motovka and Kola Gulfs, and in bays near the rivers Teriberka, Voronya, Iokanya; it is while in this stage that fry actively migrate from these areas and settle down in the Barents Sea.

We refuted the aforementioned findings in the work of 1941. Data collected during recent years show that the littoral phase is not characteristic of all the Murman herring fry, but of a very small portion of these fish, drifting in the proximity of the shore. This probably is the main difference between the migration of herring fry from the South-Norwegian and Lofoten spawning grounds.

The Polar Institute's annual observations on the distribution of herring fry and study of the content of the stomachs of trawl-caught cod enable us to assume that the importance of different migration paths of the fry varies from one year to another. During certain years, a great number of young herring are carried along the main branch of the North Cape current to settle down on the ocean floor, at a certain distance from the shores, in the region of Murman shelf and Goose Bank; during other years, however, the drift along the Murman shores is more intensive, and, as a result, a great number of fry settle down near the shores and enter the White Sea. Only a relatively small number of fry are carried into the northern zones of the sea. The drift of herring fry, hatched in the course of a year, to the western shores of Spitsbergen, was studied in both 1939 and 1950.

Herring fry may penetrate the Barents Sea from the spawning grounds located along the south-western shore of Norway only at the age of 1-2 years and it seems rather improbable that they could reach the eastern zones of the Barents Sea.

The highest catches of small herring are obtained in the north-western sections of the Norwegian coast, in the provinces of Nordland and Troms; a relatively limited fishing for small herring is conducted west of North Cape; easterly from Kola Meridian small herring are found en masse. All this rather clearly outlines the limits of the herring fry dissemination from the southern and northern spawning grounds. The main bulk of fry from the southern spawning grounds settles down south of Lofoten Islands: the fry of Lofoten origin are carried away into the eastern half of the Barents Sea. The intermixing of fry from the southern and northern spawning grounds probably occurs in the region of eastern Finnmark, where we may find the rapidly drifting fry from the southern spawning grounds and the delayed young herring of Lofoten origin.

Thus far the drift of herring larvae from Viking Bank and Faeroes has not been studied at all.

The drift of fry undoubtedly takes place in the region of Iceland, where the spawning grounds are located along the southern part of the south-western coast of the island, in the zone of the Irminger current. This important phase in the life cycle of Iceland herring remains obscure as yet. Thus far there is hardly any small herring industry in the Icelandic region.

In 1936, Fridriksson (42) carried out explorations for spawning herring and discovered near the south-western shores of Iceland a great number of one-year-old herring, 8-10 cm. in length. Moreover, in the aforenamed work Fridriksson mentioned large concentrations of small herring found in 1907 along Iceland's western coast.

Investigations conducted by Tåning in 1939 and 1946 (80, 81) showed that herring larvae found along the western coast are larger than those from the southern coast. This confirms the theory that herring fry drift along the shores of Iceland, from the south towards north-west. There are two rather large shallow bays on the western shore of Iceland - i.e. Faxa Bay and Breidafjord, with numerous islands and banks, which undoubtedly have the most suitable environment for the fry of herring and other fishes. At the same time, the herring larvae may drift to the south-west, in the direction of Greenland.

The origin of larvae hatched in spring, 15 to 25 mm. in length, which were caught in early summer 40-60 miles south-easterly from Iceland, is rather obscure. Tåning assumes that these larvae were carried off the shelf by a current. This is quite possible, however, it is equally logical to suppose that these fry were brought from shallow waters situated between Iceland and the Faeroes.

The living conditions for herring fry during the first few years of their existence, particularly during the first winter, when the small fish are still unable to undertake prolonged migrations and spend the winter in the area to which the current has carried them, are of great interest from the viewpoint of the study of drift. These conditions are most interesting in the Barents Sea, where year-old fish frequently penetrate into the most northern and eastern regions.

We assumed that herring fry may be found at temperatures close to zero or even at subzero temperatures (15). More recent observations have confirmed this supposition. In all the remote regions of the northern half of the Barents Sea, in its shallow south-eastern zone, the fry spend the winter at temperatures either close to zero, or even several tenths of a degree below zero.

It has been proved now beyond doubt that Murman herring at the age of 8 - 11 months spend the winter in the White Sea under the ice, since during the early spring we find them deep in the Kandalaksha Bay. During the cruise of the exploratory vessel "Saratov" between Kanin Nos and Shoina at the end of December, 1948, and in early January, 1949, we discovered a considerable number of herring hatched during that year.

During the drift, the herring fry find themselves under most diverse temperature conditions depending upon the direction of the current. The fry drifting towards the north and into the northern zone of Barents Sea are under identical temperature conditions throughout the course of the entire migration, whereas the fry proceeding to Barents Sea, find themselves in the littoral zone where the waters have a somewhat higher temperature. Over the vast territory of the Barents Sea the fry encounter most diverse conditions of external environment. In the littoral zones of Murman, in Kola and Motovka Bays, the young herring populate less saline waters having during the summer a high temperature level, which abruptly drops in the winter. The White Sea is characterized by extremely sharp fluctuations in temperature.

Finally, in the northern regions, the fry of herring are subjected to very low temperatures during both winter and summer seasons.

In each region, there exist specific conditions governing feeding, season of growth, and wintering.

The majority of herring fry are found during their first year of development in salinities of 33-34, although in some cases we may find the fry in almost fresh water, such as found near the rivers Teriberka, Voronya and Titovka.

The drift of larvae and fry of herring occurs in the upper sea levels, where they also remain during the fall. In collections of the Polar Institute there are numerous samples of fry gathered from the decks of exploratory and fishing boats, where during rough weather they were washed aboard. After the winter homotherm, the fry change to the benthipelagic mode of existence.

In the eastern and northern regions of the sea the phenomenon of homotherm occurs earlier, as a result of which the fry descend to the benthipelagic levels at an earlier date. As a rule, by the end of January the herring fry hatched during the current year remain in benthic levels in all the zones of the Barents Sea. This period of life of young herring has been studied in detail by Prof. V. R. Aleev (3) and V. N. Tikhonov (27, 28, 29).

The exceptionally great eurythermal ability of herring fry should be regarded as adaptability that has been developed as a result of natural selection. Without this adaptation, the drift of herring larvae into the northern peripheries of the Atlantic Ocean could not have been accomplished as it would inevitably result in the death of the majority of young hatched that year, which probably did occur in the past, while the migration was in process of formation.

The great eurythermal ability of young herring determines first of all the duration of the growing period, which has been described by G. V. Boldovskiy (8) and confirmed by the data obtained through the study of scale growth carried out by N. Solovyeva (25) and Murashkintseva (18). In connection with the lengthy feeding period of young herring the need to accumulate fat reserves is excluded (34). The organism utilized all resources for growth purposes.

The living conditions for young herring in the Norwegian coastal zone are more uniform, although temperature conditions in fjords of the northern provinces are, of course, more severe.

When studying factors responsible for fluctuations in number of different generations of Norwegian herring, Hjort (50) voiced the supposition that too extensive migrations of fry are unfavorable and may result in young fish eventually finding themselves under conditions unsuitable for their existence. Hjort wrote that it would be desirable to find out over what distance the fry migrate and the possibility of reaching areas where the living conditions are favorable.

The exceptional adaptibility of fry to life under diverse conditions of external environment, first of all low temperature, led us to believe that even in Barents Sea, which is the most severe region of the northern Atlantic, there are no zones where living conditions are lethal for young herring. Whatever the distance which the fry migrate, the ultimate point of passive drift is always close to Atlantic waters. A year earlier or a year later, depending upon the feeding conditions and the growth rate, the herring fry return to the places where they were hatched.

Of course, the survival rate of fry in different sections of their area of dissemination is unequal, however, the main reason for the death of fry is not in abiotic factors, but in the activity of numerous and diverse predators, first of all the cod.

GROWTH OF YOUNG HERRING AND BEGINNING OF RETURN MIGRATION.

The second year of existence is characterized by active settlement of young herring. In the Barents Sea, two-year-old herring penetrate particularly far to the south-east, into Chesha Bay, shallow Pechora regions, including the Pechora River estuary, and drift into the Kara Sea via Kara Strait and Yugorski Shar.

Occasionally they enter the bays and gulfs of the Murman coast in great numbers.

In the White Sea, two-year-old specimens of Murman herring are found with the White Sea herring fry. Young herring enter particularly willingly the relatively warm zones, where the waters have a low salinity. The winter dissemination of the two-year-old fish is as extensive as summer dissemination. We also encounter the herring of that age at Persey Bank, beyond 77° of northern latitude, along the shores of Novaya Zemlya and in the White Sea.

The third summer marks a transitory period in the existence of young herring. By the end of the summer, they reach 15-18 cm. in length. Fat reserves accumulate in tissues and body cavities, gonads begin developing. With the advent of the cooler autumn season, the area of dispersal of three-year-old fish decreases in size as the fish concentrate in the regions affected by warm waters of the North Cape current. The movement of herring takes on a directed character, in view of which we regard this particular moment as the beginning of their return migration.

Our observations (15) showed that the character of young herring growth under diverse conditions over its vast range in the Barents Sea varies greatly and determines the behavior of herring to a considerable degree.

The highest rate of growth was observed in herring from the western zone of the sea; the rate decreases as we proceed towards east and north. The herring population of the White Sea shows the lowest growth rate. The sizes of herring specimens hatched during the current year in different regions were as follows. The mean length of 1-year-old fish of the generation hatched in 1932 off the Murman coast fluctuated in different samples between 7.8 and 10.5 cm., whereas in the White Sea it was 6.2 cm. The length of herring hatched during the year of the generation hatched in 1933 in the coastal zone of Murman fluctuated within the limits of 9.3 - 10.6 cm. In the White Sea the length of 1-year-old specimens (at the beginning of the second year of their life) did not exceed 9.3 cm.

Young herring of the generation hatched in 1937 in the region of Finnmark measured an average length of 9.0 - 9.1 cm., in the region of Kanin - 8.7 cm., in the region of Kolguyev - 7.8 cm., from the White Sea - 7.0 cm. The 1943 herring year class along the coast of Murman reached 9.5 - 10 cm. in length at the age of 9-10 months, and in the White Sea were a maximum of 8 cm. at the age of 1 year.

In 1950, the fry hatched during that year measured the following lengths in different zones of the sea: in the south-eastern slope of Bear Bank - 10.5 cm., on western Spitsbergen - 10.2 cm., south-western slope of the Central elevation - 9.9 cm., northern and central zones - 9.3, Pechenga Gulf - 9.3, northern slope of Goose Bank, 8.8 cm.

The reason for such wide fluctuations in the rate of growth of herring fry from the Barents Sea lies in factors of external environment: first of all the temperature conditions, amount of food available, and duration of growing period. When studying young herring growth, we found that the correlation factor between the increment of the first year and increments of the following few years is extremely high. Thus, the correlation factor between l_1 and l_2 fluctuated for certain samples between $+0.60 \pm 0.50$ and $+0.70 \pm 0.05$. We attribute the high correlation between the increment of the first year and increments of the subsequent years of growth to the individual peculiarities of growth proper (strong specimens grow faster, whereas weak fish lag behind in their development) as well as to the fact that the living conditions and rate of growth of young fish remain unchanged in the course of the first 2-3 years of their existence, since we observed no significant migrations during that period of time.

Herring fry that find themselves in the northern zone of the sea remain within that zone until the beginning of the return migration, similarly the fry brought to the shores of Murman remain in littoral zones until the return movement to the west begins.

Differences in the growth rate of young herring in different regions determine the differences in the dates at which the return migration begins. Return migration of adult three-year-old fish developed in the western zone of the Barents Sea is more clearly pronounced than that of three-year-old, slowly developing, specimens that originated in the northern or eastern peripheries of the sea. The latter fish may remain within the borders of their initial range for one, two or three years longer.

Norwegian fisheries statistics separate sexually immature herring into a separate class, the so-called "fetsild", i.e. fat herring. The latter differ from the small herring (the "smaasild") in size and greater fattiness; from adult herring ("storsild" and "vaarsild") - in the condition of the gonads. Thus, "fat herring" form a definite biological group of fish 16-18 cm. to 24-25 cm. in length, between the age of three years and the age at which they become sexually mature. These fish are characterized by high fat content of muscular tissues and a great quantity of oil in the body cavity. Gonads of fat herring are at the II-IV stage of development according to the seven-point system. In the Norwegian Sea, the herring at this stage of development change to the marine mode of life, leaving the littoral waters. In Barents Sea, fat herring migrate to the western region, approaching the spawning grounds.

In Norwegian waters, the fishery for fat herring is particularly intensive between Ålesund and Lofoten Islands and has a coastal character; great quantities of fat herring are caught in fjords.

Fishing for fat herring is conducted along almost the entire Norwegian coast, excluding its most northerly provinces. The main regions of intensive fishing for fat herring are situated to the south from the region where small herring are caught in great quantities, which is undoubtedly related to the southward movement of fat herring.

The migration scheme for young Norwegian herring suggested by Meek (59) shows that the general direction of the movement is towards the south. According to this scheme, herring proceed into the open sea in winter, approaching the shores in summer. Distances covered during these periodic migrations increase with age. In their fourth or fifth year, herring appear in the spawning grounds off the south-western shores of Norway. Migration of young Norwegian herring into the North Sea is rather improbable, according to the scheme of Meek.

According to the scheme suggested by Lea (56), fat herring leave the littoral waters a year or two before they attain sexual maturity and proceed into the open sea, where, northerly from the Faeroes, they undergo the so-called oceanic stage. Having matured sexually, they proceed from the above region to the south-western shores of Norway. The fact that fat herring move into the open sea and not along the shores has been further confirmed by the experience of the Norwegian fishing industry.

The course of fat herring movement off the shores of Norway and into the open sea has been shown by a marked herring (No. 1656), released on September 7, in the region of Lofoten Islands (68°25' north latitude) and caught again in the vicinity of Helgoland Ridge (16°55' north latitude, 3°08' east longitude).

Lea's scheme introduced an additional factor that has been omitted by Meek. Lea pointed out that, because of a faster growth rate and early sexual maturation, the fat herring leave the southern regions of Norway earlier than the herring from northern regions. The specimens that developed in the southern regions of Norway attain sexual maturity as a rule at the age of 4 and 5 years, occasionally even at the age of 3 years; in the northern zone, however, the majority of herring mature at the age of 5-6 years. Runnström (66) expressed the supposition that Norwegian herring undergo the oceanic stage mainly in the zones of vortices formed by the Norwegian current. No special observations on the distribution of fat herring beyond the borders of the Barents Sea have been set up thus far. The data on this group were obtained as a result of experimental fishing with drift nets with a mesh of 30-32 mm. Experience has shown that the herring 22-24 cm. in length become entangled in the nets with 32-34 mm. mesh size. We frequently observed 23-24 cm. fat herring caught with large-meshed nets in commercial quantities. In certain cases, the catches of fat herring reached 5 and even 8 tons per vessel per day.

Figure 2 shows the results of observations on the distribution of fat herring during the period of 1939 to 1953. Fat herring were found in a greater or lesser number in almost all the zones of the Norwegian Sea, as well as in Spitsbergen current, approximately up to 75-76^{0} north latitude. The maximum incidental catch of fat herring was in commercial catches from the western branch of the Norwegian current, near Mohn's Threshold, southerly and southeasterly from Jan Mayen.

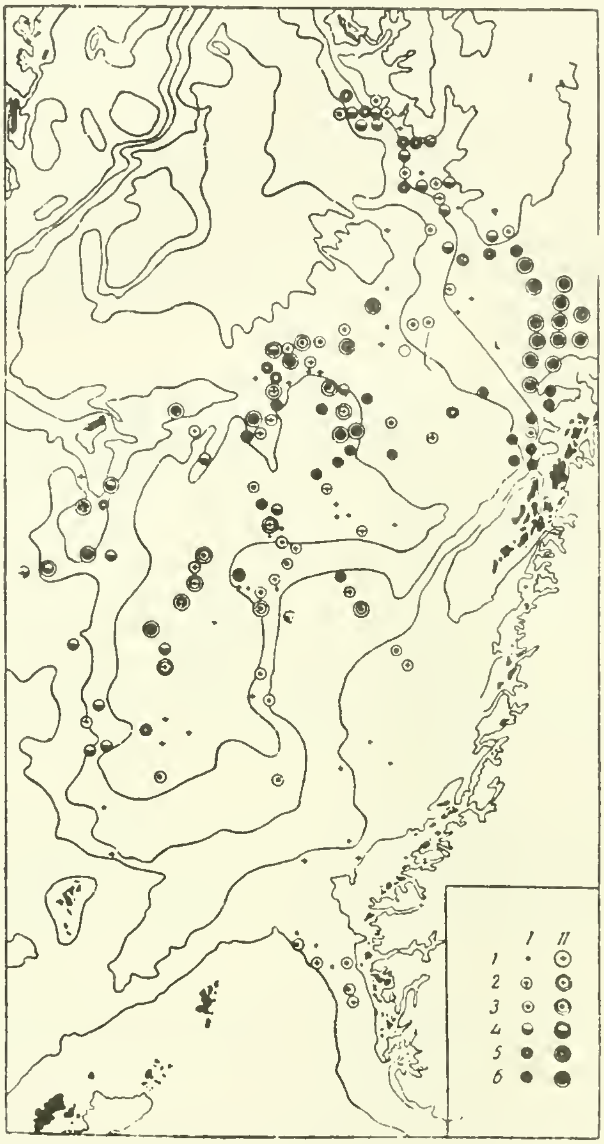

Figure 2. Distribution of fat herring (24 cm. and less in length) in Norwegian and Greenland seas as observed by the Polar Institute in 1939-1953. I. In samples obtained from catches of less than 1 ton. 1 - one to two specimens; 2 - up to 5 specimens; 3 - up to 10 specimens; 4 - up to 25 specimens; 5 - up to 50 specimens; 6 - more. II. For the samples obtained from catches of more than 1 ton the indices are encircled.

In the southern half of the Norwegian Sea, we carried out but a few control driftings, so the amount of fat herring existing in this region cannot be estimated on the basis of our observations. The relatively large incidental catch of fat herring obtained in 1952 and 1953 may be due to the abundance of the 1947 and 1948 year classes. We also wish to point out the high growth rate of fat herring from the open zones of the Norwegian Sea. In certain samples, the three-year-old herring were approximately 25 cm. in length.

The distribution and migration of fat herring in the Barents Sea were subject to extensive investigations conducted by the Polar Institute during the pre-war epoch in connection with the organization of the marine herring fishery in the Murman region. Recognition for finding commercial concentrations of fat herring in the Barents Sea should be given to S. V. Averintsev, who in the summer of 1933, on board the exploratory drifter-trawler "Kuzhma", explored the Murman shelf and obtained commercial catches at several stations (1).

Information on the fat herring distribution was considerably extended in 1937 as a result of the investigations set up by the Polar Institute on board the exploratory boat "Avangard" (15).

In 1938 and 1939, the fishery on the fat herring concentrations in the southern zone of Barents Sea was conducted by a fishing fleet. Investigations of the Polar Institute showed that fat herring remain in the zone of the North Cape current and its ramifications over a considerably smaller area than small herring. As a rule, the area of concentration extends towards the east as far as 40-45° of eastern longitude. During the summer, the fat herring drift in an eastern direction via the North Cape current, migrating in the winter to the western zones of the sea in order to avoid the low temperature.

Fat herring enter the littoral zone of the Murman region at the beginning of the hydrological summer. As a rule, their concentrations arrive in the second half of July - at the beginning of August. Fat herring leave this region in September-October.

Lengthy observations made by the Polar Institute on the biological composition of herring in the coastal zone of Murman showed a definite regularity in the fluctuations in age composition occurring in this region. Four- and five-year-old herring usually prevail in August near the shores of Murman, whereas in September their number considerably decreases, and the three-year-old fish take their place. Still later, the two-year-old fish increase in number.

When studying the biological composition of catches obtained in the coast regions, scientists encountered a highly interesting phenomenon which was at first incomprehensible, namely the decrease in mean length of herring in certain age groups during the course of the fishing season. Initially, attempts were made to explain this phenomenon by the presence among the Murman herring of races having different growth rates. Such theories have been refuted, however, by our work of 1941. The decrease in size of fish was explained by the earlier movement of adult specimens from the littoral zone. The study of a fat herring school from the western regions of the sea and of the pre-spawning concentrations of the first-time spawners, confirmed our suppositions: we observed that larger specimens disappeared from the Murman coast. At the same time, we observed the opposite phenomenon in the western zones of the sea, i.e. accumulation of large specimens.

The decrease in size of the four- and five-year-old fish is greater than that of younger specimens, a result of their earlier movement to the western regions of the sea. This theory may be illustrated by the mean lengths of different age groups during different months which have been estimated for the periods of time between 1937 and 1939 and 1946 to 1950. The length of five-year-old fish from August to September decreases by almost 1 cm., i.e. drops from 22.6 to 21.68 cm.; in October, there are but a few five-year-old specimens in the littoral zone, so their length cannot be estimated. In August, the class (3+) of the four-year-old herring are on an average 19.08 cm. long, whereas in October the mean length drops to 18.2 cm. The mean length of three-year-old fish in August is 16.57 cm. and increases in September to 16.83 cm., which is probably due to the fact that the three-year-old fish have grown in the meantime; in October, the mean length decreases to 16.15 cm.

Our observations have shown that the drop in the length of herring accompanies the return migration and the changes occurring in the average size of fish may serve to a certain extent as a criterion for estimating the rate of migration. It is interesting to note that during the autumn of 1934, when the five-year-old herring were delayed for a prolonged period of time in the littoral waters of Murman and entered the gulfs, their mean lengths remained almost unchanged: in September, they were 22.33 cm. in length; in October - 22.40 cm.; in November - 22.24 cm.; and in December - 22.12 cm. In 1935, however, when the herring began moving from Zapadnaya Litsa Gulf in April, the mean length of the remaining herring dropped to 21.90 cm.

Investigation of the biological composition of herring yielded the principle on which the herring schools are formed; the principle is based on individual divergencies in the growth rate and development. Only at the age of one or two years are the herring schools uniform with regard to the age of the specimens forming the schools. Subsequently, the principle of age, as the factor determining the composition of the schools, is replaced by the size principle. Large fishes of younger ages join older specimens, while the herring of retarded development remain with younger fish. From that moment on, the herring schools are multi-age groups.

Fat herring observations revealed a number of interesting facts with regard to the interdependence between the growth rate of different generations and the duration of their stay in the Barents Sea. In view of the continuous emigration of large specimens (from the fat herring schools), the determination of their growth rate involves considerable difficulties. We may speak with certainty only with regard to the size of the three younger groups.

Indices of the rate of growth of four- and five-year-old herring estimated from samples collected in the central regions of the sea, will be always lower than in reality. Therefore, when determining the indices of the rate of growth for individual generations, we utilized data on the length of three-year-old fish at the time of interruption in their growth during the preceding year (i.e. in the autumn).

To draw a comparison between different indices, we used only the materials gathered in the Murman coast regions (the littoral branch of the North Cape current between 33° and 40° east longitude)[1/]. The mean lengths of the three-year-old fish during different years are shown in column 4 of Table 2. During the observation period the mean length of three-year-old fish was approximately equal to 16.7 cm. Three-year-old specimens of the 1931 and 1936 year classes reached the largest size, whereas the 1931, 1933, 1938 and 1948 year classes were the smallest.

Juxtaposition of the mean dimensions of fish of different year classes with the age at which they became sexually mature and duration of their stay in the southern zone of Barents Sea showed a most definite interdependence: the fish of all year classes that develop at a high rate and attained sexual maturity early left the Murman coast zone and migrated beyond the borders of the Barents Sea earlier. Year classes delayed in their development and maturing later remained both near the

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1/ In order to avoid the effect of selection of fish according to their size, which occurs during the formation of schools, we experimented only with the samples consisting at more than 50% of three-year-old specimens.

shores and in the open zones of the Barents Sea for a longer period of time. Thus the rate of return migration of the growing herring is undoubtedly conditioned by the growth rate and age at which they become sexually mature. These same factors account for the fact that Norwegian herring in the southern Norwegian provinces migrate away from the shores earlier than schools populating the northern fjords.

The varying increment observed in different herring year classes is a result of a very complex sum of factors, to provide an analysis of which would be an almost impossible task at this time. The connection between the growth rate of different year classes and the number of specimens forming these year classes can be revealed with great precision. All the abundant year classes are characterized by high growth indices.

Table 2. RELATIVE NUMBERS OF SPECIMENS FORMING DIFFERENT YEAR CLASSES OF MURMAN HERRING, AREA OF THEIR PROPAGATION, AGE AT WHICH THEY BECOME SEXUALLY MATURE, AND DURATION OF THEIR STAY IN BARENTS SEA.

Year classes	Their relative abundance	Characteristics of the area of propagation.	Mean length of three-year-old herring (2+)	Age of sexual maturity	Duration of their stay in Barents Sea (number of years).	
					Littoral zone	Open sea
1930	Very abundant	Large, eastern	16.0	Late	5	6
1931	Poor	Western	17.4	Early	3	4
1932	Above average	Central zones	16.0	Late	3	5
1933	Average	" "	15.6	Late	3	4
1934	Abundant	Large, eastern	16.6	Medium	4	6
1935	Above average	Central zones	16.7	Medium	3	4
1936	Poor	Western	18.3	Early	2	4
1937	Above average	Large, eastern	16.6	Medium	3	No data
1938	Abundant	" "	15.8	Late	4	" "
1939	Above average	Central zones	No data	No data	3	" "
1940	Below average	" "	" "	" "	2	" "
1941	Poor	No data	" "	" "	No data	" "
1942	Average	" "	" "	" "	" "	" "
1943	Abundant	Large, eastern	17.0	Late	3	6
1944	Above average	Western	17.2	Early	2	4
1945	Below average	Central zones	17.0	"	3	4
1946	Below average	Central zones	16.5	Medium	3	4
1947	Above average	Large, eastern	16.7	"	4-5	5
1948	Abundant	Large, eastern	15.0	Late	4-5	5-6
1949	Poor	Western		Early	3	4
1950	Abundant	Central zones		Late	4-5	5-6

Similar regularity has been established for the herring from other regions and a number of other fish species. Moreover, the reason for the decrease in the growth rate of the herring of abundant year classes is attributed as a rule to the intraspecies relations, which are a result of the excessive population density.

We believe, however, that in the given case such an explanation is not sufficiently substantiated. In the case of overpopulation of a water basin by fish, the deterioration in living conditions also affects the immediately preceding and the following year classes existing at the same time in the given basin. In the Barents Sea, we observe an altogether different phenomenon. The several successive generations simultaneously populating the basin differ considerably from each other in the growth rate. Thus, the abundant 1930 year class was characterized by a low rate of growth, whereas the subsequent generation, i.e. the herring hatched in 1931, was not numerous and developed at a high rate. We believe that if the intraspecies relations were indeed the determining factor, the 1931 year class should also have been characterized by poor growth, since it too developed in conditions of "overpopulation" of the sea by fishes of the 1930 year class. We may quote a few more examples of the simultaneous existence in the Barents Sea of year classes 1936 and 1937, generations hatched in 1947 and 1948, etc.

We are inclined to attribute the differences in the growth rate of different year classes to the environment of the first few years of the life of fish, the "selection" of which is determined by the drift of fry. Such an explanation is apparently closer to the truth, since there exist irrefutable facts showing that the fry of abundant year classes spread mainly in the eastern and northern directions, whereas young herring belonging to poor year classes spreads mainly westwards.

The importance of abundant herring year classes for the coast and littoral fishing industry increases in view of these fishes' long stay near the shores. Fat herring play a particularly important role in commercial fishing during the years when they remain in the littoral zone and enter the fjords. The factors accounting for the mass movement of fat herring into fjords have not been sufficiently studied as yet.

Intensive movements of herring into the gulfs of the Murman shore in the fall of 1933 and 1934 have been explained differently by different authors. Manteyfel' and Boldovskiy (13) believed that these movements are a regular phenomenon, inbred over many years as a result of the search for optimum conditions of existence during the winter (low temperatures contributing to the drop in metabolism).

Glebov (9) shared the above viewpoint to a certain degree. However, he observed correctly that neither the summer, nor the winter movements of herring into the gulfs are an inevitable phase in the life cycle of these fish. Finally, Mironov (17) endeavored to prove the connection existing between the herring movements and changes in the earth's magnetism in the region of Barents Sea. These latter hypotheses were erroneous in view of the fact that the authors attempted to find an explanation for the movements of herring in conditions of external environment only, either ignoring (17) the organism proper, its distribution, abundance, and physiological condition or considering it of secondary importance (9).

The general level of modern knowledge of herring biology enables us to discuss factors responsible for these movements. Mass movements of fat herring into the gulfs are always preceded a year or two years by summer movements of small herring. The study of age composition of the herring catches obtained over a period of several years in the coast zone of our country, along the coast of Murman and Norway, convinced us that the year classes making such movements en masse are very abundant. Thus, the high catches of fat herring obtained in Norway in 1909 were due to the exceptionally abundant year class of 1904, which determined the success of the Norwegian fishing industry for over 15 years.

Movements of fat herring observed in 1928 were due to the abundant year class of 1925, those observed in the Murman region, as well as in Norway, in 1933 and 1934 - to the 1930 year class, which was extremely abundant for both the Murman and Norwegian schools.

Movements of fat herring observed in the Murman region are conditioned by strong year classes abundantly represented in the littoral branch of the North Cape current. Fat herring appear in the gulfs in the course of their western migration along the Murman shores.

In Norway as well as Murman, the herring enter fjords where there is a continuous exchange of water with the adjacent section of the sea. This usually occurs during the syzygial phases of the low and high tides, when the exchange of waters between fjords and adjacent sections of the sea reaches its maximum. The latter factor shows that the herring enter fjords not in search of some specific environment, but when conditions in the fjords become similar to the conditions in the open sea. The movements of herring into the gulfs occur as a result of the general delay of herring in littoral waters due to some peculiarities of their physiological condition determined by the preceding conditions of their development.

The presence of great numbers of fat herring in the region of Iceland has been discovered only recently. In Koll Bay (western coast of Iceland) during the winter of 1946/47, we caught about 140 thousand centners of fat herring, and in the winter of 1947/48 the catches amounted to 1,800 thousand centners. Prior to that, fat herring were caught in the region of Iceland in very small quantities. In Koll Bay, we found herring belonging to older age groups together with the fat immature herring. According to the observations of Fridriksson during the first year, the three-year-old fish of the 1944 year class (43) dominated in catches; during the following season - the four-year-old herring of the same year class were caught in greatest numbers.

A small number of fat immature herring is observed every year north of the island, amidst the schools of older herring. The data available on fat herring from the waters around Iceland are limited to the above discussed observations.

We now wish to draw a preliminary though undoubtedly correct conclusion concerning the habits of fat herring. The Murman school of fat herring concentrates in the western zone of the Barents Sea. Only a small number of these fish approach the shores of Kola Peninsula during the summer. Fat herring of the Norwegian school leave the coast zones and move into the open sea. Undoubtedly, in the waters of Iceland, this type of herring also live at a certain distance from the shores. Only isolated year classes having a low growth rate and late maturation remain in the school of fat herring populating the waters off the shores.

ISOLATION OF MATURING HERRING AND SPAWNING

MIGRATION OF FIRST-TIME SPAWNERS.

As mentioned above, the Norwegian scientists found no concentrations of maturing first-time spawners near the shores of Norway. One or two years before the fat herring become sexually mature, they leave the Norwegian fjords and arrive on the spawning grounds at a maturity stage close to ripeness. Maturation of young herring (the oceanic stage) takes place, according to Lea's scheme (56), north of the Faeroes.

The school of fat herring is as if divided into two groups. The first group remains near the shores and is formed of younger specimens, the second group lives in the open sea. It is composed of older herring and of herring having a high rate of growth.

Herring in the oceanic stage are continually in the process of attaining maturity.

The isolation of maturing herring from the Barents Sea was already observed in pre-war research in the case of the abundant 1934 year class, observations of which have been conducted over a period of several years (15).

In the pre-spawning concentrations of Murman herring spawning for the first time, we found the young specimens having the highest rate of growth, which, as we established, arrived from the schools of fat herring of the littoral zone.

Only single specimens of Murman herring, having an exceptionally high rate of growth, mature at the age of 4 years. Mass maturation begins at the age of 5 years. Only the fish with the highest rate of growth (having the mean length of at least 22.5-23 cm.) become sexually mature at that age while the specimens developing more slowly mature 1 or 2 years later.

This theory has been confirmed by data on the growth rate of herring, which attained sexual maturity at varying ages (see table 3).

The specimens becoming sexually mature at the age of 5 years have the highest rate of growth; the growth indices of the herring maturing at the age of 6 years are somewhat lower and of those becoming mature at the age of 7 - still lower.

TABLE 3. GROWTH RATE OF THE HERRING THAT REACHED SEXUAL MATURITY AT THE AGE OF 5, 6 and 7 YEARS (PRE-SPAWNING CONCENTRATIONS -January, 1939).

Age at sexual maturity	Year class	Rate of growth (cm.) for the following years of development						
		1	2	3	4	5	6	7
5	1934	8.6	12.5	16.0	20.2	22.5	-	-
6	1933	8.5	12.9	15.8	18.4	21.2	23.1	-
7	1932	6.4	11.5	15.3	17.7	20.0	21.9	23.7

In early April, 1939, the exploratory fishing trawler "Beluga" discovered on Malangen Bank these schools of herring of the 1934, 1933 and 1932 year classes spawning for the first time. This information, as well as observations conducted on board the exploration boat "Persey-II" in 1949, showed that the spawning of first-time spawners takes place in the north-eastern half of the Lofoten spawning region 30-40 days following the spawning of older herring.

The process first-time maturation of Norwegian herring has not been studied thus far. It doubtless occurs in a manner similar to that of the Barents Sea herring namely: large specimens become mature changing from the fat fish stage to the maturing stage, earlier. They arrive in the spawning grounds after the spawners of older age groups and reproduce at the end of March, even beginning of April.

Iceland herring first-time spawners probably populate the waters to the south-west from the Island.

FEEDING MIGRATIONS OF ADULT HERRING.

The study of migrations of Atlantic-Scandinavian herring of older age groups was initiated by the Polar Institute of Fisheries and Oceanography in 1939, when, in summarizing data collected, it became evident that the Barents Sea is populated only by young, sexually immature herring and that the complete life cycle of herring might be studied only through extensive and thorough investigations of the adjacent regions of the Norwegian and Greenland seas.

Using the boats "Knipovich" and "Avangard", in 1939, we explored the eastern edge of the Spitsbergen current from Bear Island to South Cape (south tip of Spitsbergen). Many herring concentrations were found over the entire territory covered by the investigations. Several drift net catches amounted to over 50 centners.

After World War II, the migrations of the older age groups of herring were again investigated. A cruise on board the exploratory boat "Rynda" took place in 1946; and, in 1947, by the decision of the Council of Ministers of the USSR, a small scientific research expedition on board two exploratory and four fishing boats was organized, and this gave rise to the development of the Soviet commercial herring fishery outside the Barents Sea.

At the end of June, at the latitude of Bear Island, the expedition boats met herring schools moving from the south towards the north. In July, the migration of herring was followed to 77-78^{o} north latitude. The return movement of herring in the southern direction was followed along the slope to 73-72^{o} north latitude.

During subsequent years, the fishing grounds were expanded considerably in a southern direction. In 1952, upon the initiative of I. G. Yudanov and with his personal participation, an experimental fishing expedition went to the Viking Bank region, where large pre-spawning concentrations were spotted. Thus, from 1952 on, the fishing grounds began expanding in both directions - to the north as well as to the south. Since 1953, Soviet fishermen have fished for herring in the Norwegian and Greenland seas during the entire year.

The recently organized large-scale Russian commercial herring fishing in the North-European basin contributed to the rapid development of exploratory work and research conducted by the Polar Institute along the entire extent of the migration grounds of the Atlantic-Scandinavian herring.

COMPOSITION OF MIGRATING SCHOOLS AND MAIN DISTRIBUTION PATTERN OF ADULT HERRING

The main conclusions drawn on the basis of the data collected in the process of the 1939 research (15) are as follows:

In July-August, 1939, in the zone of the Spitsbergen current, we discovered large concentrations of herring 28 to 35 cm. in length with gonads at the stage of redevelopment. In July, the specimens in the VII-II, II-III development stages prevailed; whereas, in August, we encountered most frequently herring in the II and III-IV development stages.

Sexually immature herring 22 to 25 cm. in length were found in considerably smaller numbers. Only single specimens of herring 26-27 cm. in length were caught.

The age of large herring ranged from 6 to 16 years. The majority of sexually immature specimens belonged to the 1934 year class. When determining the age of herring caught in that region, we encountered the following phenomena: the six- and seven-year-old herring (5+ and 6+) were represented in the catches by fish of two dimensions - i.e. either 24-25 cm. or 28-30 cm. in length. The growth rate of the former was low, the increment of the preceding year was considerable and only slightly below the increment of the year before that; the stages of sexual maturity were not above the II and II-III stages. Herring of the latter group were of the same age, however, and showed an incomparably higher growth rate; the increment for the previous year was insignificant; the sexual maturity was at the III stage and higher. Herring of the former group had not spawned yet, whereas the latter fish had already spawned.

The average length of six- and seven-year-old herring from the group of the herring that have already spawned proved to be very high: the length of six-year-old fish (5+) was 27.5 cm., that of seven-year-old herring, 28.7 cm. The percentage of six-year-old herring in the catches from the Spitsbergen region that had already spawned was very low: six-year-old herring of the 1934 year class formed only 1.2 per cent of the specimens that had already spawned, the seven-year-old fish of the 1933 year class, 10.9 per cent.

The above investigations enabled us to demonstrate the following: in the explored zone of the Spitsbergen current, i. e. in its northern half, there exist but few herring 26-27 cm. in length; specimens 6-7 years of age that have already spawned once or twice are extremely rare among adult fish; the growth rate of the six- and seven-year-old fish that have already spawned is very high.

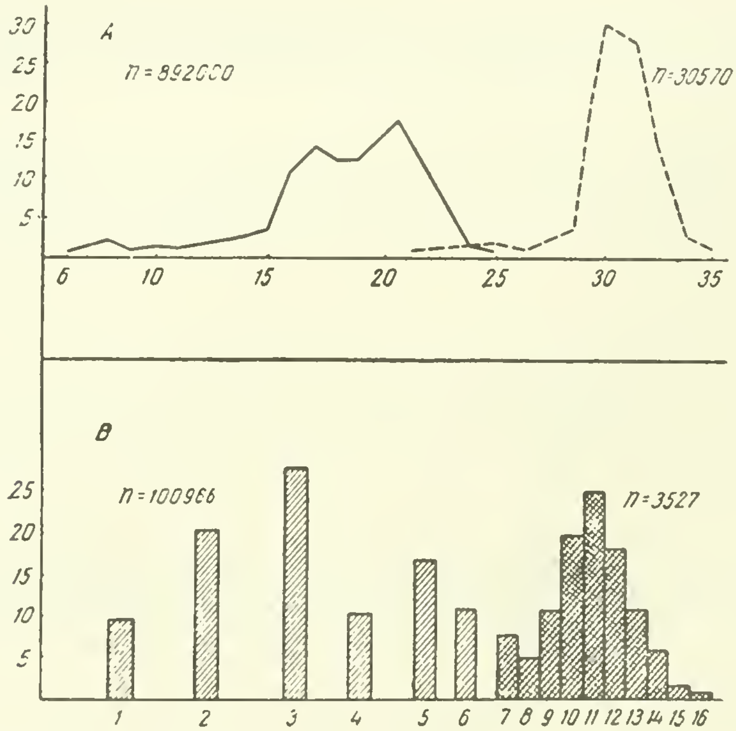

Figure 3. Length and age of herring from the Barents Sea and northern zone of the Spitsbergen current (after L. A. Bakunenko and M. M. Vykhristyuk; A-length; B-age).

At that time, we expressed the theory that extensive migrations to the north are only made by herring over 8-9 years of age and over 29-30 cm. in length; the young fish, having a high rate of growth and measuring at the age of five years 28-29 cm. in length, migrate with the older fish. The main bulk of the six- and seven-year-old herring does not participate in these particular migrations, remaining isolated from both the younger herring that populate the Barents Sea, and older herring migrating considerable distances northwards. We voiced the supposition that herring belonging to these age groups might be found during the summer on the border of the Barents and Norwegian seas, in the region of the western channel, between the North Cape and Spitsbergen branches of the Norwegian current and in the southern zone of the Spitsbergen branch, south from 73° north latitude.

While studying the biological composition of herring caught in the Spitsbergen current in 1946 and 1947, we found identical regularities: there were very few fish 26-28 cm. in length in the catches, the specimens over 8 years of age prevailed, whereas single specimens of relatively young herring that had already spawned were characterized by a high growth rate.

These observations convinced us that the aforementioned hypothesis concerning the less extensive migrations of herring at the age of 6-8 years was correct. In order to solve ultimately this problem, in 1948, L. A. Bakunenko and M. M. Vykhrystiuk set up under our supervision a research on the biological composition of the herring schools caught in the Spitsbergen current. They analyzed the age composition of the catches, studied the growth rate of different year classes using back calculations of lengths at each year of life, and examined the spawning marks to establish the age at which these fish became sexually mature. Simultaneously, they analyzed the herring data from the southern zone of the Barents Sea.

The main results of the investigations thus carried out may be outlined as follows: herring up to 25 cm. in length are found in the Barents Sea, whereas specimens 29-32 cm. in length populate mainly the region of the Spitsbergen current.

The main bulk of catches obtained in the southern zone of the Barents Sea consists of young, sexually immature fishes at the age of 4-5 years; 6-7-year-old herring were rarely found; in the Bear-Spitsbergen zone the majority of catches consisted of specimens over 8-9 years of age (Fig. 3). The differences in the respective growth rates of young and older specimens proved to be considerable. Thus, using back calculations of lengths at each year of life, it was found that the length of 6-8-year-old herring that were caught in the Spitsbergen current was in the fourth year of life 22.3 cm., in the fifth year 26.1 cm., and in the sixth year 28.1 cm.

Herring of older age groups reach such lengths 1 or 2 years later. L. A. Bakunenko and M. M. Vykhrystiuk, having examined the spawning marks, established that younger specimens have a relatively greater number of such marks as compared with the older fish. Thus, the 5-6-year-old specimens found in Spitsbergen current had one to three marks, averaging 1.5 to 1.8. Sexual maturity occurred in these fish at the age of 4-5 years, in certain specimens even at the age of 3 years. In fish 10-12 years of age we observed 5-6 spawning marks, i.e. they became sexually mature at the age of 5 years and later (Table 4).

Thus, the investigations by L. A. Bakunenko and M. M. Vykhrystiuk showed that only herring of the older age groups migrate far into the north, via the Spitsbergen current. The main bulk of 6-7-year-old herring, having a medium or low growth rate and which have already spawned once or twice, remains outside the Barents Sea, but, undertake no feeding migrations into northern latitudes.

TABLE 4. NUMBER OF SPAWNING MARKS AND AGE AT WHICH SEXUAL MATURITY OCCURRED IN HERRING OF DIFFERENT AGES. (After L. A. Bakunenko and M. M. Vykhrystiuk).

Year class	Age	Mean number of spawning marks	Age at sexual maturity	Number of fish
1942	5	1.5	3-4	4
1941	6	1.8	4-5	6
1940	7	3.0	4-6	45
1939	8	3.6	4-6	88
1938	9	3.1	5-7	179
1937	10	5.0	5-8	236
1936	11	4.6	5-8	140
1935	12	6.3	6-8	115
1934	13	7.3	6-8	68
1933	14	8.1	6-9	21
1932	15	8.3	6-9	6

Herring 26-28 cm. in length, though rarely found in the Bear-Spitsbergen region, were often caught in commercial quantities during the exploration of southern regions.

The largest concentrations of herring feeding after the first spawning, were found near Mohn's Threshold and in the eastern half of the Norwegian Sea.

After the numerous investigations had been completed, the distribution pattern of herring of different lengths in the Norwegian and Greenland seas became evident. The pattern is shown in Figure 4 for July, when all the age groups of adult herring are particularly far away from the spawning grounds.

Mass measurements of herring that were carried out from 1939 to 1954 served as a basis for the clarification of the above patterns. The overall number of measured fish amount to 72,000 specimens.

In Figure 4, we presented for each of ten large regions the herring length frequencies compared to the total length frequencies for all the regions 1/.

We observed the greatest number of young fish and lack of adult herring in the eastern half of the Norwegian Sea - i.e. in region 5. Regions 4 and 8, in the vicinity of Mohn's Threshold, are characterized by a scarcity of large herring and excess of young specimens. In region 9 near the Jan Mayen, we observed a certain surplus of the largest herring 32 cm. and more in length, and a certain shortage of fish 29-31 cm. in length.

1/ The total length frequencies for all the regions and individual length frequencies for different regions have been reduced to a thousand.

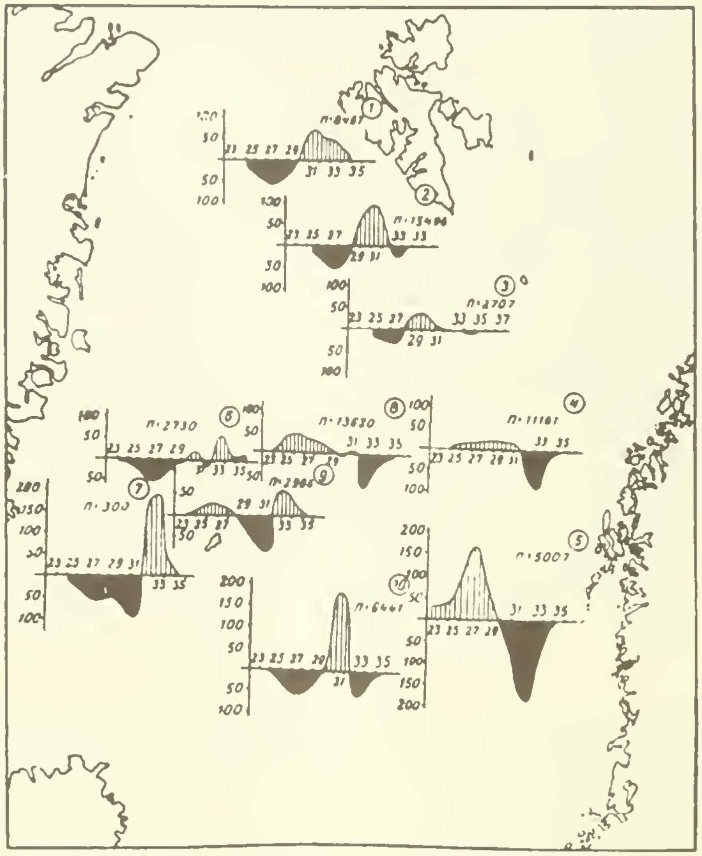

Figure 4. Distribution of herring of different lengths in the Norwegian and Greenland seas in July. Variations for different regions are presented in deviations from the total length frequencies for the period of time between 1939 and 1954. (The overall number of the measured fishes - 72,000 specimens). 1. - north from the 77th parallel; 2. - between 74°30' and 77° of north latitude; 3. - between 73°00' and 74°30' of north latitude, east from 4° of east longitude; 4. - between 71° and 73° of north latitude, east from 4° of east longitude; 5. - south from 71° of north latitude; east from 4° of east longitude; 6. - polar waters, to the north-west from the polar front, between the Bank "600" and Jan Mayen Island; 7. - west from the meridian of Jan Mayen Island; 8. - the region adjacent from the south-east to the Bank "600"; 9. - the zone of Bank "774" and eastern slope of Iceland's shelf; 10. - western half of Norwegian Sea between Helgoland Ridge and the polar front.

In the western half of the Norwegian Sea in region 10, the herring 29-31 cm. in length prevail. Large herring are particularly abundant beyond 76° north latitude.

Analysis of the age composition of herring catches showed a similar picture. We observed the greatest number of herring of older age groups north of 74° north latitude. In 1950, in the northern zone of Spitsbergen current, there prevailed the herring 12-14 years of age, in 1951 - the 13-year-old herring. In 1952 and 1953, we obtained no samples characterizing the age composition of the herring catch north of 74° north latitude. In 1954, the 10-12-year-old herring prevailed in the Spitsbergen region.

South of 74° north latitude, in the vicinity of Mohn's Threshold, we encountered in the course of the entire period of observations, i.e. from 1950 to 1954, younger herring at the age of 6 to 10 years.

Farther to the west, beyond the zero meridian, in the region adjacent to Jan Mayen, the age composition of catches is characterized by a great admixture of fishes of the older age groups.

Thus, the theory maintaining that young sexually mature herring accomplish but limited feeding migrations may be now considered as an established fact. The Bear-Spitsbergen region and polar waters beyond Mohn's Threshold are not visited by the first-time spawners. They feed south of 73-72°, north latitude within the limits of the Norwegian Sea.

Our theories concerning the possibilities of fishing on such herring may be reduced to the following: when the middle-aged fish are represented by few year classes, the older fish groups determine the maximum success of fishing. When, however, 6-7-year-old herring are represented by abundant year classes, they may be of a greater impor nce than the herring of older age groups. In each individual case, this problem must be solved with the help of corresponding investigations, during which the magnitudes of remainder and recruitment are taken into account[1/].

FEEDING OF HERRING AND CHANGES OCCURRING IN THEIR PHYSIOLOGICAL CONDITION

Our investigations enabled us to clarify certain details of feeding migrations, first of all, to show the drastic changes occurring in the physiological condition of adult herring, which determine the character of such migrations.

The main spawning taking place off the south-western coast of Norway and in the vicinity of islands is completed in late March. At the beginning of April we found on the spawning grounds only a small number of first-time spawners that spawn at a later date.

Feeding migrations proceed down the current, which facilitates the movement of herring. The speed of their swimming exceeds the current's mean velocity, and the schools pass every day from the warmer to the cooler waters. All the populations of ocean herring reproduce at a temperature of 5-7°. Searching for food, the herring that have spawned during the first half of the summer may enter the waters having a temperature of 3°. In mid-June, 1941, Captain V. A. Egorov discovered herring concentrations south-west of Spitsbergen, where the temperature was 2.8°. In early June 1954, herring concentrations were observed in the zone of Bank "774" at the temperature of 2°.

According to E. A. Pavshtiks, the feeding migrations of herring are closely related to the pattern of plankton production in the Norwegian and Greenland seas.

As is well known, the annual cycle of the plankton production may be divided into four periods corresponding to different hydrological seasons: i.e. winter, spring, summer, and autumn.

During the biological winter, which corresponds to the hydrological winter, the main bulk of

1/ In 1955, these assumptions have been confirmed. The intensive replenishment of an adult school by representatives of the abundant 1950 year class ensured high herring catches at the end of the feeding season, southerly from Mohn's Threshold. The 1950 year class formed on an average 45 per cent of the 1955 catches.

planktonic organisms (of which Calanus finmarchicus forms a considerable portion) remains in the benthic layers or at considerable depth. The biological spring is marked by mass production of phytoplankton (blooming of the sea) and migration of Calanus finmarchicus from great depths to the surface layers for reproductive purposes.

Large herring of older age groups, usually spawning in March, begin feeding on the concentrations of reproducing Calanus finmarchicus and Euphausiacea. With the emergence of nauplii and early stages of young Calanus, the biomass of plankton becomes usually greatly reduced, since adult Calanus disappear from plankton after the reproduction has been completed.

During the season of biological summer, young Calanus finmarchicus become transformed into fat red Calanus, as a result of which the biomass of plankton greatly increases, reaching its maximum. The herring which have spawned for the first time feed on red Calanus.

With the approach of autumn, Calanus finmarchicus begin diurnal vertical migrations. At night, the amount of plankton in surface layers increases relatively, although its overall biomass decreases considerably. During the autumn the main bulk of plankton consists of small Copepoda, such as Pseudocalanus elongatus, Oithona atlantica, and Oithona similis.

At the beginning of the winter, surviving Calanus finmarchicus specimens sink to depths of over 300 meters.

The dates marking the beginning of the biological seasons and the duration of these seasons in the southern and northern regions of the Norwegian and Greenland seas are variable. The spring-summer period continues in the littoral waters of Norway and in the southern zone of the Norwegian sea for half a year, whereas, in the central deep water regions, it does not exceed four months and in the Greenland Sea is occasionally shorter than three months. As a result of these fluctuations in the periods of plankton production, the biological seasons seem to shift gradually from the southern coast regions to the north and north-west, to the borders of the east-Iceland and east-Greenland cold currents. The feeding herring migrate to the north and north-west following the displacement of the biological spring.

By July, the herring of older age groups arrive in polar waters at the very beginning of biological spring in that region (phytoplankton develops, Calanus hyperboreus reproduce).

Young sexually immature herring and the herring that have spawned for the first time remain for most of the feeding season in the waters of the Norwegian current, where they feed on red Calanus. Their migration paths are shorter than those of large herring. In July, they arrive in the region of mixed waters, near Mohn's Threshold, however, they do not enter the polar waters.

The dates at which the herring arrive in different regions may vary considerably during different years. Observations between 1947 and 1955 showed that one of the factors accounting for fluctuations in the dates of arrival of herring on the feeding grounds, i.e. at the border of polar waters, lies in the annual fluctuations in the period of plankton production. The development of plankton is affected in its turn by the general thermal state of waters and meteorological conditions.

The above observations led us to assume that during the early summer, as a result of the intensive feeding, the herring grow mainly in length, whereas during the latter half of the season they increase in weight as a result of the accumulation of fat deposits.

The annual increments (in length) of adult herring during the feeding migrations are on an average as follows: 6th year - about 2 cm., 7th year - 1.5 to 2 cm., 8 - 9th year - about 1 cm., and later 0.5 - 0.3 cm. a year.

Increments in weight, which reflect the development of the organism more correctly, are of greater interest to us. Following spawning, the weight of herring decreases markedly due to the discharge of eggs and sperm from the gonads and to the reduction in fat content of the body tissues. The fattiness factor becomes reduced to 1 and less. In the course of the summer feeding, the weight of herring increases by 10-12 per cent and the fattiness factor rises to 1.1 - 1.2. In Table 5, we present the minimum and average weight for herring of identical length at the end of the reproduction period, prior to the beginning of feeding migration, as well as the mean and minimum weight at the end of the summer, following the feeding season, and the fattiness factor. We believe it correct to consider the fattiness factor of herring at the beginning of spawning migration of herring as being equal to 0.95, i.e. somewhat below the mean index, since the number of herring among the fish samples on the basis of which it has been estimated undoubtedly included certain specimens that have already started feeding; for the herring, which completed the feeding, the ratio may be considered as equal to 1.1.

TABLE 5. WEIGHT AND FATTINESS FACTOR (K[1]) PRIOR TO AND AT THE END OF THE FEEDING MIGRATION.

Length in cm.	Prior to migration				After migration			
	Minimum individual		Mean		Mean		Maximum individual	
	Weight in gm.	K	Weight in gm.	K	Weight in gm.	K	Weight in gm.	K
27	210	1.06	215	1.09	--	--	--	--
28	215	0.98	225	1.02	250	1.14	284	1.29
29	225	0.95	265	1.09	280	1.15	301	1.23
30	225	0.83	280	1.04	295	1.09	350	1.30
31	243	0.81	295	1.06	315	1.06	370	1.24
32	255	0.78	300	0.91	345	1.05	380	1.16
33	302	0.77	338	0.94	368	1.01	415	1.17
34	312	0.79	345	0.88	--	--	445	1.13

1) $K = \frac{100.P}{L3}$.

Knowing the mean indices of fattiness at the beginning and end of the feeding migration and the growth rate of herring, we may draw the curve illustrating the gravimetric growth of Atlantic-Scandinavian herring (Figure 5). Although it cannot be absolutely exact, it undoubtedly provides a more correct conception of the increase of herring weight in the course of their life than the curves customarily used demonstrating the growth of fish during different years.

Young herring gain weight slowly. The drop in weight during the winter-spring season is rather negligible and consists in the main in consumption of some negligible amount of fat reserves. The maximum increments in weight occur in the 6th - 8th year of life, when herring still show a good growth rate and the absolute volume of gonads is small. During the late period of their life, the herring increase in weight considerably since the main energy is then used for restoration of the gonads.

During feeding migrations, the chemical composition of herring, fattiness in particular, changes to a considerable extent. At the beginning of June, the fattiness[1/] of herring does not ex-

1/ In all these cases, we presented the overall fattiness, i.e. the fattiness of the given herring as a whole. We used here the data provided by the Technical-chemical Laboratory of the Polar Institute of Fisheries and Oceanography.

ceed 6-7 per cent, whereas by the end of June - early July it increases considerably reaching 10-12 per cent. Maximum fattiness (18-21 per cent) is observed during the last half of July and in early August. From mid-August, when the gonads begin developing, the fat content gradually decreases.

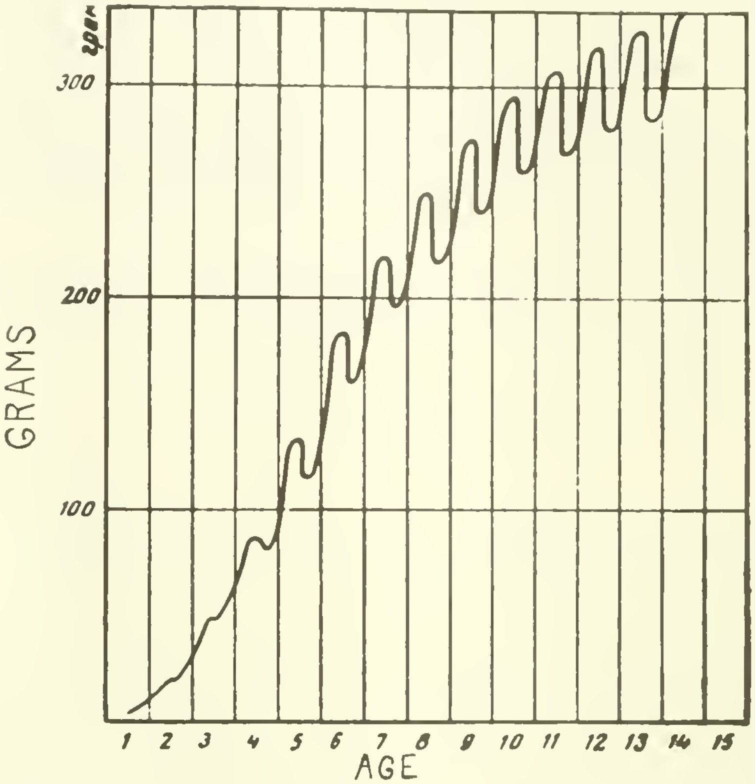

Figure 5. Curve illustrating the increase in weight of Atlantic-Scandinavian herring.

The maximum fattiness of flesh is equal to 25-27 per cent. The amount of albumins in the muscular tissues varies slightly. During the first half of the season, the albumins constitute 16.2-17.5 per cent, during the latter half 16.5 - 17.5 per cent.

Following the information provided by V. A. Rudakova, during the first half of the season the restoration of herring gonads occurs very slowly, during the second half - very rapidly. In June, the gonads in the majority of herring are at the VII-II stage and do not exceed 3 per cent of the overall weight of the body. The weight of gonads in males and females is identical, constituting 2.7 per cent of the total body weight in the former, 2.6 per cent in the latter.

In July, the II-III stage is prevalent. At that time, the testes increase in size reaching the mean weight of 3.5 per cent. The weight of ovaries remains unchanged.

Herring gonads begin developing intensely in the latter half of the summer, when their content reaches its maximum index. At that time, the herring at the III, II-III, rarely at the III-IV, stages of development prevail. Testes increase in weight particularly rapidly, reaching during that season 8 to 10 per cent of the overall weight. The weight of ovaries is equal to 5-6 per cent. In September-October, in the majority of herring, the gonads are at the III-IV and IV stage of development. Gonads constitute 14-16 per cent of body weight in males, 9-10 per cent in females.

With the changes in physiological condition, there arise in herring new reactions to the external environment -- temperature and currents in particular. As we have mentioned above, at the end of spawning the herring move along with the current and spread in relatively cold waters. From mid-July, the well fed herring with gonads in the process of restoration discontinue moving northwards (down the current) and concentrate near warm Atlantic waters.

The change in the direction of migration in the northern half of the Spitsbergen current occurs between July 10 and 20. During the early half of July, over the entire area of the Spitsbergen current, the herring begin migrating in the northern direction; however, they discontinue the movement north of 74° north latitude. South of 74° north latitude, the herring continue moving to the north until the end of July. August is marked in all the regions by the beginning of mass migration of herring in the southern direction.

The date on which the return movement of herring schools to the spawning grounds begins is determined to a considerable extent by the feeding conditions.

MIGRATION PATHS AND MAIN FEEDING GROUNDS

OF ADULT HERRING

The study of migratory habits of herring required extensive oceanographic investigations directed at defining more precisely the pattern of the constantly active currents. Such investigations were conducted during the last few years simultaneously with oceanographic observations.

A map of the currents of the Norwegian and Greenland seas was drawn at the beginning of our century by Norwegian scientists Helland-Hansen and Nansen (49). Following the said scheme, the warm waters of the Atlantic current, having passed the Faeroe-Shetland channel, proceed to the north-east, along the continental slope of the Scandinavian peninsula. Approximately at the latitude of the Lofoten Islands, a branch of that current deviates towards the west forming a large eddy in the central zone of the Norwegian Sea. The remaining waters continue flowing to the western shores of Spitsbergen and form a second eddy near Nansen Threshold, this time within the borders of the Greenland Sea. Near Andøy Island, a branch deflects from the Norwegian current and proceeds into the Barents Sea. This is the North Cape current. A part of the waters of the Spitsbergen current flow into the Arctic ocean. In the western half of the basin, there passes the cold Greenland current descending to the south along the shores of Greenland, north of Iceland a portion of these waters turns to the south-east and proceeds to the Faeroes in the form of the east-Icelandic current.

It is important to note that according to the scheme of Helland-Hansen and Nansen in the western half of the Norwegian Sea, beyond the fifth meridian of east longitude, there exists a system of vigorous vortices and no streams flowing in the northern direction. That scheme has been somewhat improved by Soviet researchers V. A. Perezkin (7) and V. T. Timofeev (26).

Investigations of the Polar Institute have shown that the scheme of Helland-Hansen and Nansen requires additional corrections. Having developed the vast oceanographic information available, B. V. Istoshin and A. P. Alekseev suggested the following pattern of currents in the studied region.1/

The Norwegian current divides in the southern half of the Norwegian Sea into two large branches - western and eastern. The former branch proceeds to the north approximately along the zero meridian and, near Mohn's Threshold, forms several branches flowing in western direction.

1/ The article appears in the present symposium.

Warm Atlantic waters penetrate as far as Jan Mayen via the latter branch.

The second--eastern (or continental)--branch proceeds to the north-east along the continental slope. Its direction corresponds to the scheme of Helland-Hansen and Nansen. In the process of investigations of the Polar Institute, the hydrological importance of the underwater relief of the Norwegian and Greenland seas, particularly to the east from Jan Mayen, where underwater elevations of volcanic origin were discovered, has been established. The chain of ancient volcanoes extends from Jan Mayen to southern Spitsbergen.

In the region of these sea mounts, the vertical waters circulation is very strong, which creates favorable conditions for plankton development. Moreover, drastic temperature fluctuations on the slopes of the elevations contribute to the concentration of herring in these regions.

The polar front zone is relatively constant, adapted to the ocean floor topography to a greater extent. The polar front extends from Jan Mayen to the south, along the underwater chain of mountains proceeding in the direction of the Faeroes and to the north-east, along Mohn's Threshold.

Thus far, the migration paths of herring have been studied only in isolated regions of the North-European basin.

In 1951, we followed the drift of herring schools which had completed spawning, along the eastern branch of the North Cape current from the south-western shore of Norway up to the latitude of the Lofoten Islands. In 1952, the migration of herring via this particular course was not as clearly pronounced. The majority of schools moved to the north via the western branch of North Cape current across the Helgoland Ridge and in the direction of Bank "600". Furthermore, we located the movement of herring along the eastern edge of the East Icelandic current. That path led the herring to Jan Mayen and Bank "774". A relatively insignificant movement of herring in the western direction was recorded in 1953 during the cruise on board the exploration boat "Professor Mesyatsev" along the southern border of the East-Icelandic current. That latter course probably leads to the eastern coast of Iceland.

The movement of herring concentrations into the region of the polar front is illustrated in Figure 6. The pointers show only relatively large concentrations, the location and direction of the movement of which have been verified by exploratory or reconnaissance boats. The majority of these concentrations were intensively fished.

During the third cruise of the scientific research boat "Professor Mesyatsev" in 1953, we succeeded in observing the arrival of herring in the zone of the polar front and the movement of schools into the polar waters, where the temperature conditions at the surface hardly differed during that season from Atlantic waters ($6-7^{0}$). In polar waters, the herring remained near the surface, since at the depth of 25-30 meters we noted that the temperature dropped drastically. Beneath that depth, the temperature was at sub-zero level.

At that time (middle of July), certain schools of herring were found at a distance of 50-60 miles from the polar front. The schools were very dense, and the fishing was very successful: certain boats obtained as much as 25 to 30 tons of fish per drift.

Herring began leaving the polar waters in the second half of July and continued moving away throughout August.

A considerable number of adult herring were feeding in 1954 west and north-west of Jan Mayen and to the north from Bank "600" (Figure 7).

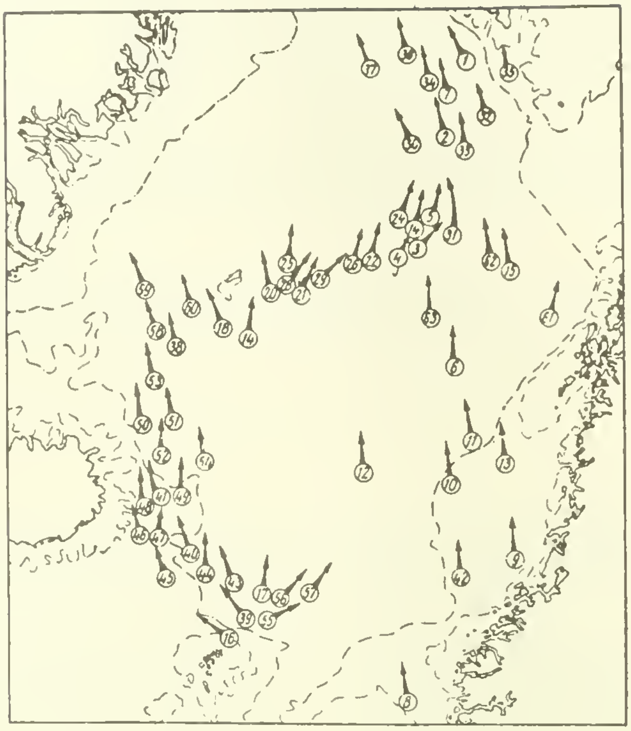

Figure 6. Migration paths of herring to feeding grounds as observed from 1949 to 1955: 1. July 10-12, 1949; 2. June 21-24, 1950; 3. June 26-28, 1950; 4. June 14-17, 1950; 5. July 17-19, 1950; 6. July 6-9, 1951; 7. July 7-21, 1951; 8. March 2-7, 1953; 9. March 6-10, 1953; 10. April 13-15, 1953; 11. April 11-15, 1953; 12. April 17-21, 1953; 13. April 21-25, 1953; 14. June 16-19, 1953; 15. June 18-19, 1953; 16. June 21-25, 1953; 17. June 22-27, 1953; 18. June 23-27, 1953; 19. June 22-23, 1953; 20. June 29-July 7, 1953; 21. July 1-7, 1953; 22. July 3-9, 1953; 23. July 7-10, 1953; 24. May 27-28, 1954; 25. June 3, 1954; 26. June 3, 1954; 27. June 1-5, 1954; 28. June 7-12, 1954; 29. June 10-15, 1954; 30. June 22, 1954; 31. June 23-25, 1954; 32. June 29-July 2, 1954; 33. July 4, 1954; 34. July 5, 1954; 35. July 6-9, 1954; 36. July 7, 1954; 37. July 7, 1954; 38. July 11, 1954; 39. July 21-31, 1954; 40. July 21-31, 1954; 41. July 21-31, 1954; 42. March 22-28, 1955; 43. May 1-22, 1955; 44. May 8-24, 1955; 45. May 21, 1955; 46. May 25, 1955; 47. June 1, 1955; 48. June 5, 1955; 49. June 10-11, 1955; 50. June 12, 1955; 51. June 12, 1955; 52. June 13, 1955; 53. June 15, 1955; 54. June 23, 1955; 55. June 8-9, 1955; 56. June 10-11, 1955; 57. June 12-14, 1955; 58. June 19, 1955; 59. June 25-28, 1955; 60. June 26-28, 1955; 61. June 22-25, 1955; 62. June 28-31, 1955; 63. July 16, 1955.

Figure 7. Feeding grounds of adult Atlantic-Scandinavian herring.

In 1955, plankton production was inhibited by unfavorable hydrometeorological conditions. Red Calanus appeared only in July, and young herring fed at first on Oikopleura labradoriensis and young Themisto abyssoirum, while herring of older age groups in the region of the polar front lived on Calanus hyperboreus, young Themisto libellule, and Oikopleura. In most regions, the red Calanus appeared in July and were found in herring guts up to September. The feeding of herring was not intensive, but remained uniform throughout the whole summer (June-September), and all the herring had some food in the guts. Due to the uniform character of feeding, the herring were quite fat by September.

It has been established that, from the viewpoint of the fishing industry, the most important path of the return migration of herring schools to the spawning grounds passes across the western zone of the Norwegian Sea (Figure 8).

In 1950, a number of herring schools proceeded from Bank "600" to the south-west. However, the presence of a large school somewhat farther to the east enabled us to concentrate the fleet in the region of 7° east longitude.

From the latter region, the herring schools moved in August and September towards the south.

In 1951, we followed the movement of very large concentrations of herring moving via the western edge of the western branch of North Cape current. In 1952 and 1953, the fleet fished herring moving to the south along the line of contact between the cool waters of the east Icelandic current and the warm waters of Atlantic origin.

In early September, 1954, we observed the movement of herring schools from Jan Mayen in the direction of Iceland. Later on, in the second half of September and during October, a great number of schools moved from Bank "774" in the north-east, along the eastern offshore slope of Jan Mayen.

Figure 8. Migration paths of herring to the spawning grounds as observed in 1949-1955. 1. July 21-22, 1949; 2. August 22-23, 1949; 3. August 1-5, 1950; 4. August 6-10, 1950; 5. August 26-31, 1950; 6. August 21-25, 1951; 7. September 6-10, 1951; 8. September 26-30, 1951; 9. August 16-20, 1952; 10. September 11-15, 1952; 11. September 11-15, 1952; 12. December 21-25, 1952; 13. July 16-20, 1953; 14. July 16-20, 1953; 15. July 21-25, 1953; 16. July 21-25, 1953; 17. August 5-6, 1953; 18. August 10-15, 1953; 19. August 10-15, 1953; 20. August 10-12, 1953; 21. August 10-20, 1953; 22. September 1-5, 1953; 23. September 1-5, 1953; 24. September 1-5, 1953; 25. September 21-25, 1953; 26. September 26-30, 1953; 27. January, 1953; 28. August 1-5, 1954; 29. August 4-8, 1954; 30. August 26-31, 1954; 31. August 31-September 9, 1954; 32. September 11-15, 1954; 33. October 21-25, 1954; 34. November 1-3, 1954; 35. November 13-15, 1954; 36. December 22-25, 1954; 37. January 1-5, 1955; 38. January 15-20, 1955; 39. August 11-15, 1955; 40. August 17, 1955; 41. August 30-September 1, 1955; 42. August 9-10, 1955; 43. August 14-16, 1955; 44. August 16-17, 1955; 45. August 17 18, 1955; 46. August 25, 1955; 47. September 15, 1955; 48. September 20-21. 1955; 49. September 21, 1955.

The period during which the observations on the distribution and migrations of herring were conducted was too brief to enable us to draw ultimate conclusions on the relative importance of migration paths and on the degree to which these courses may vary from one year to another. During our investigations, the most important course of migration of herring to feeding grounds passed across the central zones of the Norwegian Sea, along the western branch of the Norwegian current. The paths following the eastern branch and the western course passing along the edge of the East-Icelandic current, are of lesser importance.

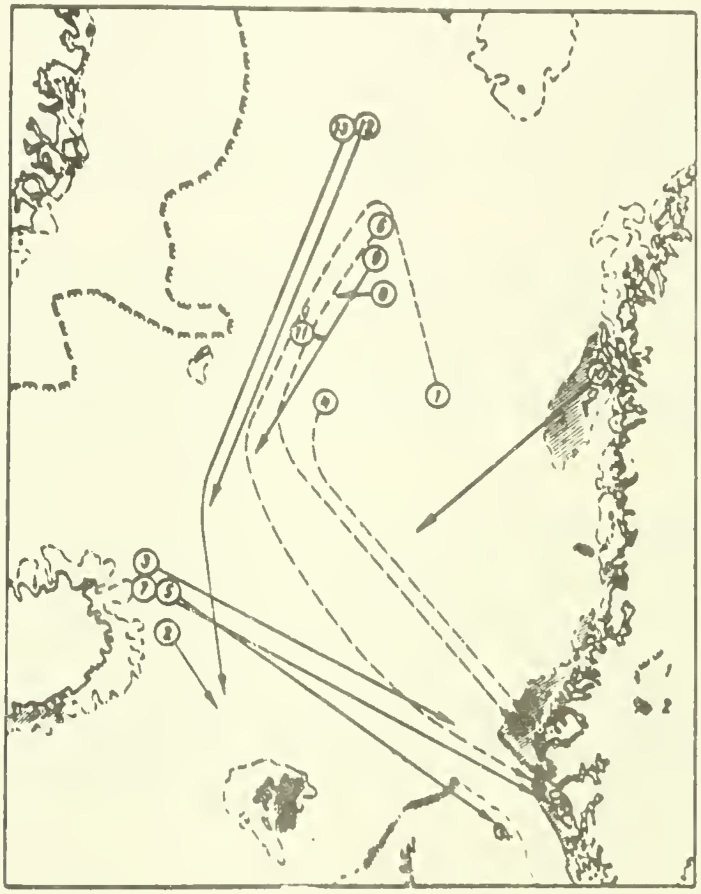

Figure 9. The paths followed by tagged herring, after A. P. Vilson: 1. Frontiers of the floating ice. 2. Spawning grounds. Index numbers of herring specimens are encircled (see Table 6).

It is still highly unrealistic to attempt a definition of the migration paths of different populations of Atlantic-Scandinavian herring. We nevertheless believe it possible to draw the following indisputable conclusion: it is probable that herring from the southernmost spawning grounds penetrate the western regions of the Norwegian Sea and vice versa, the herring from the northern spawning grounds migrate most probably to the eastern regions of the Greenland Sea.

TABLE 6. RECAPTURES OF TAGGED HERRING

Fish number	Number of the mark	Data on tagging		Data on recoveries		Number of days spent in the sea	Distance covered in miles	Mean velocity of movement, in miles
		Date	Region	Date	Region			
1	4154	12/VI/1953	69°33' N.L.- 5°22' E.L.	31/I/1954	61°34' N.L.- 5°00' E.L.	233		
2	3330	12/VIII/1954	65°34' N.L.- 11°40' W.L.	Aug. 1954	The region between Iceland and Faroes	-	-	-
3	3544	15/VIII/1954	66°49' N.L.- 11°52' W.L.	31/I/1955	62°55' N.L.- 1°55' E.L.	168	240	1.4
4	4423	22/VIII/1954	69°44' N.L.- 0°36' W.L.	19/I/1955	62°24' N.L.- 5°37' E.L.	150	400	2.6
5	3693	14/VIII/1954	66°24' N.L.- 11°31' W.L.	Feb. 1955	60°40' N.L.- 2°30' E.L.	About 170	240	1.4
6	A 147	21/VII/1954	72°55' N.L.- 5°06' E.L.	IV-V, 1955	Norway, the region of Trondheim	253	-	-
7	3492	14/VIII/1954	66°24' N.L.- 11°31' W.L.	IV-V, 1955	Off the shores of Norway	About 200	240	1.2
8	A-6308	I/VIII/1955	71°42' N.L.- 4°00' E.L.	12/VIII/1955	71°15' N.L.- 2°50' E.L.	12	30	2.5
9	A-6571	3/VIII/1955	72°20' N.L.- 3°38' E.L.	19/X/1955	68°55' N.L.- 5°30' W.L.	76	270	3.5
10	1656x)	7/IX/1952	68°25' N.L.- 16°00' E.L.	17/IV/1953	66°55' N.L.- 3°08' E.L.	220	300	1.4
11	6142	24/VII/1954	71°21' N.L.- 2°12' W.L.	22/VIII/1955	71°10' N.L.- 0°00' W.L.	28	50	1.7
12	A-6965	13/VIII/1955	75°00' N.L.- 5°42' E.L.	1/XI/1955	68°10' N.L.- 8°15' W.L.	79	540	6.9
13	A-7025	13/VIII/1955	75°00' N.L.- 5°42' E.L.	16/XII/1955	64°00' N.L.- 8°30' W.L.	125	760	6.1

x) Norwegian tag.

TRANSLATOR'S NOTE: N.L. - North Latitude; W. L. - West Longitude; E.L. - East Longitude.

The data on recoveries of tagged herring (Table 6 and Figure 9) are of great interest. The total number of tagged specimens recaptured in 1954-1955 was approximately 20. We may now state with certainty that the herring from the region situated west of Bear Island migrate into the southern zone of the Norwegian Sea; that the herring move along Mohn's Threshold to the southwest (herring 12 and 13); that herring from the Icelandic region migrate to the shores of Norway and Viking Bank (herring No. 8 and 9). The mean speed of the movement of herring to the spawning grounds varies from 1.2 to 6.9 miles a day.

Schools of feeding herring may often be observed in calm weather from the boat. We observed particularly large concentrations of herring on July 18 and 19, 1950, near Mohn's Threshold, where for more than fifty miles, hundreds of herring schools drifted towards our boat. In all directions towards the horizon, as far as the eye could see, we saw only herring schools. Some of them were easily detectable from the rippling surface of the water. The majority of the schools had clearly outlined contours resembling large triangles. The herring moving at the head of the school were particularly visible. They remained continuously near the surface, frequently leaped, and turned over in the air. Approaching the drift nets, the schools ceased their movements for a while, then moved on. That night, the catches per drift net were 1.5-2 tons.

Migration periods of herring vary considerably from one year to another. Thus, on June 18, 1941, Captain V. A. Egorov spotted herring at the latitude of Horn Sound (southern Spitsbergen). In 1951, the first schools of herring were encountered at that date only at the parallel of Bear Island, i.e. 200 km. farther to the south.

As a rule, herring schools enter the region of Mohn's Threshold along the western branch of the Norwegian current in the early half of June. In 1954, however, considerable concentrations were located near the Bank "600" on May 26.

The dates of the southern movement of herring also vary substantially. In 1939, throughout August and in early September, the herring concentrated in great numbers north of Bear Island, whereas during subsequent years, the herring vacated that region at the end of July. The factors accounting for the variations in the dates of return migrations of herring from northern regions have not been sufficiently studied as yet. We have grounds to assume that the duration of the stay of herring in the said regions depends on the feeding conditions. When the fry on which herring feed are abundant, the herring may stay in the north for a longer period of time, whereas in the case of food deficiency in northern regions during August, the herring soon migrate into the southern zones.

The direction of migration of herring to the north and the duration of their migration are determined by the preceding period of the development of herring, the age at which the herring spawn and oceanographic conditions in more southerly situated regions.

Herring of the older age groups, the schools of which form the vanguard during the movement to the north, travel farthest north.

Thus far, the order in which herring schools move in the southern direction remains obscure. Since the older age groups arrive first on the spawning grounds, we may assume that during the southern migration they overtake younger fish. On the basis of observations available, this process occurs in October-November.

We wish to point out that during the said period there occurs a drastic re-grouping of herring schools. We frequently observed the marked prevalence of either males or females in the catches. Males usually prevail in the schools moving at the head of the migrating concentration, while the females remain, as a rule, northerly from the concentration of males.

PRE-SPAWNING CONCENTRATIONS OF ADULT HERRING AND THEIR ARRIVAL ON THE SPAWNING GROUNDS

The main migration path to the spawning grounds passes across the western reaches of the Norwegian Sea. A great number of herring return via the western edge of the western branch of the Norwegian current. The exceptional importance of the latter course is due to the fact that during the feeding season the main bulk of herring approaches the polar front, partially entering the polar waters. On return migration, the herring keep close to the warm waters of the Atlantic current, which probably serves as an orientation mark during the movement of herring to the spawning grounds.

We wish to point out that the migration paths to the spawning grounds coincide with the new scheme of currents of the Norwegian Sea drawn by B. V. Istoshin and A. P. Alekseev. If a large eddy existed in the central zone of the Norwegian Sea, the migration path of herring would probably proceed towards the flow of Atlantic waters extending from Jan Mayen Island to the east towards the shores of Norway.

During the last few years, we succeeded in revealing the interrelation between the location of the autumn migration paths and of the summer feeding grounds of the herring. The farther into the Polar waters the herring schools penetrate, the more westerly are their migration paths and, vice versa; the schools, which feed southerly from the polar front, proceed southwards via the eastern zones of the sea. Thus, in 1952, a large adult herring concentration fed in the polar front zone near Bank "600". Their path in September-October passed across the central zones of the Norwegian Sea, somewhat westerly from the zero meridian. In 1954, the main bulk of herring fed in polar waters. The 1954 migration path of herring was more westerly and passed in the vicinity of the polar front.

Despite the extensive research and large-scale reconnaissance operations that have been carried out during these last few years, herring concentrations were found in the winter only in the proximity of the East-Icelandic current. Wintering herring were spotted in 1952, 1953, and 1954 over a relatively small area, where at a depth of 50-80 m., there was a cold water layer below 2.5-3.5°C. We think it probable that this is not the only wintering region for adult herring and that their presence and possibilities of fishing in that region are determined first of all by the cold water layer which lies at a relatively shallow depth and prevents the herring from sinking to excessively great depths. In regions to the east of the Norwegian Sea, the cold layer is at a depth of several hundred meters. In such conditions the herring are inaccessible to present fishing methods.

Predators and competitors of herring.

During the season of feeding migrations, large herring are pursued by predators, but are consumed by the latter in only insignificant quantities. After the large whales were exterminated in the Norwegian and Greenland seas, the existence of herring became naturally much safer. Now very few whales may be found. Bottle-noses (*Hyperoodon*) and killers (*Orca*) are also not numerous and are the object of a small-scale fishing industry conducted by Norwegian boats. More frequently, herring concentrations are attacked by schools of white-sided dolphin (*Lagenorhynchus acutus*).

Cod prey on herring only in the zone of the slope, but are rarely found at great distances from shores or in regions of great depths; this is confirmed by the fact that only single specimens of cod are found in drift nets. Cod are found in greater numbers in the Jan Mayen region (herring shark are rarely found in the Norwegian Sea).

Large herring are almost inaccessible to birds, excepting gannets, which, however, populate only the southern zone of the Norwegian Sea.

Within their entire feeding grounds, herring encounter no serious competition. Mallotus villosus Cell. live farther to the north in the cold waters of the Greenland Sea and Spitsbergen shelf. Cod, haddock, and rosefish young are found mostly in the eastern branch of the Norwegian current, in the vicinity of the slope. The biomass of these young fish is insignificant as compared with the number of herring feeding in that region. These young fish are herring food rather than competitors of the herring.

Mackerel are rarely found in the Norwegian Sea. The young of the blue whiting - Poutassou, are encountered here more often than other fish and are distributed in a manner similar to that of herring, but these fish are also scarce. In the southern half of the Spitsbergen current, as well as in the region of Jan Mayen, we frequently found young salmon in drift nets. Young lumpfish may be almost always observed in that region; these fish were carried away by the current in the zone of Norwegian coast from some place and are drifting to the north, whence they are probably not destined to return.

Over the entire territory situated north from Thomson's Threshold and affected by the warm Norwegian current, the herring are in reality the only numerous fish species utilizing the abundant food resources of that region. We may say that over that entire vast territory the herring encounter no serious competitors and predators are scarce. Large herring perish during the period of feeding migration to northern latitudes in considerably smaller numbers than during preceding phases of development, when the herring are consumed by cod, Cololabis saira, rosefish, and numerous species of sea gull.

ON THE PROBLEM OF DISTINGUISHING DIFFERENT SCHOOLS OF ATLANTIC-SCANDINAVIAN HERRING

Atlantic-Scandinavian herring accomplish the most extensive migrations of all the herring of the Atlantic and Pacific oceans. In view of this, the problem of identifying different schools of these herring is extremely complex. We are now at the initial stage of the study of the above problem and it will take a considerable time to find an ultimate solution.

Similarities in the living conditions within the limits of the range of Atlantic-Scandinavian herring represent a serious obstacle to the establishment of sufficiently well-defined morphological characteristics, which would enable the scientists to distinguish different races from each other. So far, all the attempts undertaken to that effect have failed (12, 36, 62).

The divergencies in the growth rate of different schools of the ocean herring are very insignificant, and it may well be that the errors of measurement exceed many times the actual divergencies. The differences in the age composition of a school cannot be regarded as a criterion for the study of different populations, since, on one hand, biological groupings of ocean herring lead an isolated existence and an analysis or a juxtaposition of the age composition of the school may be provided only within the limits of such groupings, and, on the other hand, the analysis of age composition cannot provide us with the desired answer to the problem in view of the synchronous character of the phenomena of fluctuations in the case of Atlantic-Scandinavian herring within the borders of their entire range.

The 1904 year class was exceptionally strong for both the Norwegian school, which spawned off the south-western shore of Norway, as well as for the herring that spawned in the region of Iceland (42, 70) and the gulf of St. Laurence, on the western shores of the Atlantic (55).

The next strong year class, hatched in 1918, was abundant along the Norwegian shore, Murman coast, and Icelandic region. During the more recent period, strong herring year classes were produced in all the three regions in 1930, 1937, 1938 and 1943.

We are firmly convinced that different schools of the ocean herring may be identified with precision only through a step-by-step study of the propagation and migration of different year classes. Moreover, that task may be facilitated if we succeed in studying in detail some exceptionally strong year class. Mass tagging of herring would also be of great assistance in our work.

The degree of isolation of different schools of Atlantic-Scandinavian herring varies in the course of their existence. We believe it possible to express the following considerations on that subject. There is no doubt that spawning grounds of ocean herring were observed between the Lofoten Islands and the south-western shore of Norway. The spawning grounds situated along Iceland's southern coast, i.e. located in a different system of Atlantic current, are isolated from each other to a still greater extent. The spawning grounds in the vicinity of the Faeroes are separated from Iceland and Norway by great depths. The spawning grounds along the south-western coast of Norway and on Viking Bank are located considerably closer to each other and characterized by similar conditions. They are situated on both sides of the Norwegian channel: the former - on the slope of the continental shelf of the Scandinavian peninsula, the latter - on the western slope of the Norwegian channel, within the borders of the continental shelf of the North Sea.

The direction of the drift of fry from the spawning grounds may be considered relatively constant. The extent of drift, however, may vary considerably, as demonstrated in the example of the Barents Sea. Thus, the isolation of younger age groups is an undoubted fact. We wish to emphasize that the isolated character of the distribution of younger age groups of herring is here understood as the relatively isolated existence of the main bulk of fry of different schools.

The recently matured herring reproduce, of course, on the spawning grounds most closely situated to their feeding grounds. After sexual maturity has been attained, the migration routes of different populations are separate to a somewhat lesser extent.

The mass tagging of cod conducted by the Polar Institute and foreign scientists for a number of years, showed that different populations, even the populations located at great distances from each other, may become intermixed. Tåning (77, 79) presented data on cod migration from the region of Iceland to Newfoundland, Faeroes, and Lofoten Islands. He also observed the migration of cod from Jan Mayen to Iceland. The migration of cod from the Barents Sea to the south-western coast of Norway was established by Idel'son (11). N. A. Maslov (16) reported that the cod tagged in an arm of Motovka gulf (where it was caught among spawning specimens) migrated to the Lofoten Islands.

There also exist data on the cod migration from the western shores of Greenland to Kanin Nos. The cod covered the above distance at the end of a migration that lasted for 7 years (47).

Cod migrations are much more closely connected with the continental shelf than herring migrations. Nevertheless, migrations of cod from one region to another have been observed for the entire North Atlantic territory. Consequently, intermixing of different populations is even more probable in the case of herring, taking into account the extensive feeding grounds and great longevity of these fish.

Apart from migrations of a comparatively small number of individual specimens from one school to another, it is possible that the migration paths of different populations of herring became displaced as a result of varying oceanographic conditions in different regions. The latter assumption may be further confirmed by the results of tagging the cod, which complete regular annual migrations between Iceland and Greenland. However, according to Tåning, the extent of these migrations fluctuates markedly. During certain years, only a small percentage of fish specimens marked in Greenland were caught in Iceland - 5.9 per cent (1927), whereas during other years more than half of them were recovered (54 per cent in 1931 and 72 per cent in 1933). In 1930-1933, several specimens of cod marked in the Barents Sea were caught off the south-western coast of Norway (11). During the last few years, despite the large-scale tagging, we observed no migration of cod from the Barents Sea to the southern shores of Norway (16). We attribute the latter circumstance to the considerable warming of the north-eastern peripheries of the Atlantic --the Barents Sea in particular-- during recent years.

We have grounds to assume that the degree of isolation of different populations of Atlantic-Scandinavian herring is less for abundant year classes, which are always propagated over larger territories.

The theory expressed by the Icelandic scientist Fridriksson (42), maintaining that the spring school of Iceland herring is insignificant in dimensions, is scarcely credible. Fridriksson assumes that, having completed several spawnings, the older herring of the Norwegian schools migrate en masse to the region of Iceland and the Lofoten Islands.

We think it more probable that herring of older age groups migrate from the region of the Lofoten Islands to the south-western shores of Norway.

There is no doubt that the migration of herring from Iceland to Norway takes place, but this migration is probably small-scale.

The insufficient information available on the subject matter prevents our discussing the drift of herring fry hatched in the region of Viking Bank. It is not unlikely that the drift of fry from the Viking Bank proceeds at a certain distance from the shores and that their further development occurs in the open zones of the Norwegian Sea. This is the most significant gap in the data on biology of Atlantic-Scandinavian herring and must be filled as soon as possible.

In Icelandic waters we encounter herring of all stages of development - from early larvae to the oldest age groups. However, the incomplete data on their biology complicate the task of drawing a precise scheme of migrations.

In the opinion of Fridriksson, the main bulk of large herring caught north of Iceland are Norwegian spring herring arriving there for feeding purposes from the south-western shores of Norway. Fridriksson regards the fact that the feeding grounds of large Norwegian herring are unknown, as the most convincing argument in favor of his hypothesis. He wrote on that problem as follows: "Norwegians do not know where their herring spend the summer, while Icelanders do not know the spawning grounds of their schools. Both problems may be solved if we admit that the two populations belong to the same school and if we assume that the herring from the northern coast (of Iceland) spawn in Norwegian waters; we may thus explain the migrations of both the Icelandic as well as the Norwegian herring".

Feeding of Atlantic-Scandinavian herring in the region of the polar front in the northern zone of the Norwegian Sea and eastern half of the Greenland Sea is now beyond doubt. It has been established through investigations, and confirmed by the experience of the intensive Soviet fishing industry, which now conducts fishing on these herring along the entire extent of their migration paths, from the spawning grounds to the polar front and back.

Simultaneously with the movement of the main bulk of Norwegian herring to the feeding grounds in northern latitudes, a portion of the schools feeds in Icelandic waters. The latter fact has been recently confirmed by the results of the tagging, as outlined in the 132nd volume of the Rapports Procès Verbaux (46).

The type of tag used by Norway and Iceland can be detected only by means of special magnetic installations and therefore, cannot contribute to the formation of a correct conception of the migration paths of herring. These tags are recovered only where there exist the magnetic installations, i.e. in Iceland and Norway. On board our ships, the internal tags cannot be detected.

We believe that only a small portion of Norwegian school feeds in Icelandic waters. The course of migration of that school to Iceland passes along the southern edge of the East-Iceland current.

Growth and sexual maturation.

A correct idea of the development of Atlantic-Scandinavian herring may be obtained only after their biological peculiarities have been studied in detail. The isolated existence of different biological groups and formation of these groups by lengths, and the drastically varying individual growth rate are the main obstacles to the solution of our problem.

When determining the sizes of herring according to the data obtained through direct observations, we knowingly arrive at erroneous conclusions, since within the borders of different regions occupied by individual biological groups the prevalent age groups alone have the length close to the mean indices. The lengths of younger and older herring deviate considerably from the mean figures.

If we endeavored to establish the average size of herring of the Lofoten-Barents school on the basis of data collected in the southern zone of Barents Sea, we would arrive at a relatively correct conclusion only concerning the length of the first three- and four-year-old groups. The lengths of fishes of the older age groups will be determined incorrectly and be much lower than the established mean length. This is easily understandable in view of the fact that the herring having a high rate of growth leave the southern zone of the Barents Sea earlier than the herring developing at a slower rate.

The mean length of herring of different ages may be established on the basis of data obtained through direct observations only according to the prevailing age groups of different biological groupings. Mean dimensions of 2- and 3-year-old herring may be determined in the regions of mass development of small herring, the length of fishes at the stage of sexual maturation - according to the data obtained from the regions of pre-spawning concentrations, and so forth.

Determination of the growth rate of herring by scales, according to the method of back calculation, involves errors identical to those committed when applying the method of direct observations. Young specimens found in the schools that are formed of older age groups are characterized by a very high growth rate and vice versa, the old herring found among younger fish have a low rate of development.

The range of variations in the growth rate among Atlantic-Scandinavian herring is very large. Five-year-old specimens from the Barents Sea usually reach 22.5-23 cm. in length. In the

Norwegian Sea, we find amidst the schools of older herring the 6- and 7-year-old fish, whose length at the age of 5 years was 27.5-28.3 cm. The number of herring having a high rate of growth is always lower among the older age groups than among young fish.

The data on the growth rate of herring most closely approaching the correct indices may be obtained by back calculation of such age groups of herring, among which the correlation between the specimens having different growth rates approaches the natural correlation between these age groups in a school. We arrived at the conclusion that the 9- to 12-year-old specimens are precisely such age groups. At that age, all the herring fall into the category of older age groups. While taking into account the aforementioned considerations, the calculated growth rate of the Atlantic-Scandinavian herring differs nonetheless insignificantly from one region to another.

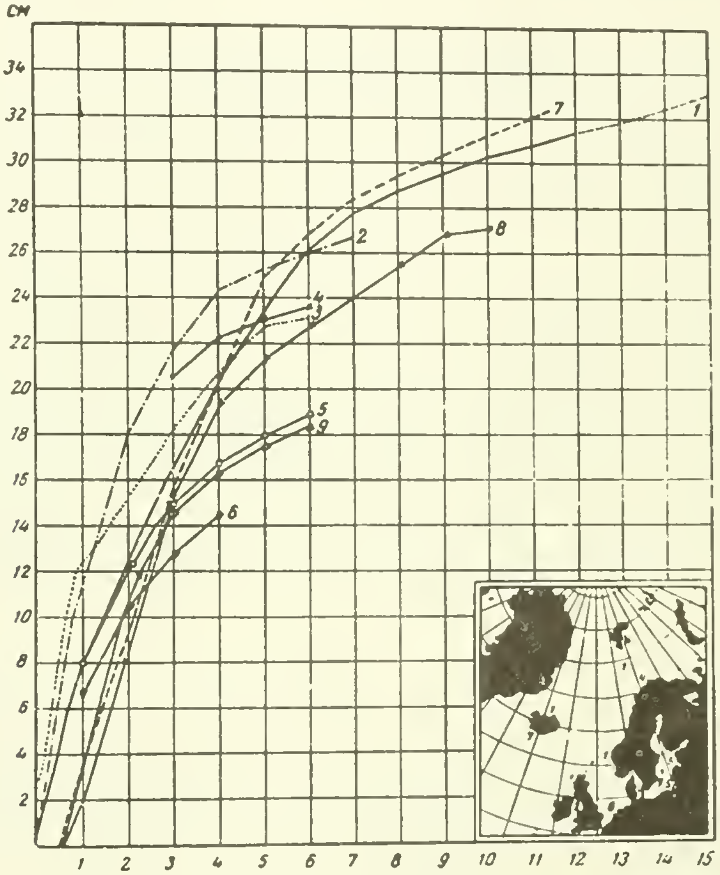

Figure 10. Rate of growth of herring from the north-eastern Atlantic.

In comparison with other herring races of the north-eastern Atlantic, the Atlantic-Scandinavian herring are characterized by a relatively low growth rate during the first two years of their development (Table 7, Figure 10). Later on, at the age of 5 years, their length is greater than that of bank herring from North Sea, Irish Sea or Baltic Sea basin.

In distinction from the majority of herring races, the Atlantic-Scandinavian herring continue growing after they become sexually mature and reach 32-33 cm. in length at the age of 12 to 15 years. The herring from the continental shelf are characterized by a drastic drop in the rate of growth following sexual maturation.

Sexual maturity in the Atlantic-Scandinavian herring occurs most frequently at the age of 4 to 6 years. Individual specimens become sexually mature at the age of 3 years. The herring that are strongly inhibited in their development mature late. Small herring from the continental shelf become sexually mature at the age of 2 to 3 years. Bank herring attain sexual maturity at the age of 4 to 5 years.

Atlantic-Scandinavian herring are characterized by a great longevity.

As a rule the 10-to 15-year-old herring form at least 30-40 per cent of commercial catches. Individual specimens found in catches are 17 to 18 years old and older. The longevity of Iceland herring, spawning in the summer, is equally great. The remaining herring races do not live longer than 8 to 10 years. Herring from the Baltic Sea have the shortest life cycle.

TABLE 7. GROWTH RATE OF HERRING FROM THE NORTHEASTERN ATLANTIC

Herring	1	2	3	4	5	6	7	8	9	10
I. Spring-spawning										
Atlantic-Scandinavian (1)[1/]	7.9	12.5	16.6	20.3	23.6	26.1	27.7	28.8	29.6	30.3
From Celtic plateau (2)	11.3	18.2	21.8	24.2	24.9	26.3	26.8	--	--	--
From south-western zone of Baltic (3)	12.5	15.4	18.3	20.9	22.6	23.0	--	--	--	--
Borge-Poll (4)			20.4	22.1	23.0	23.5	--	--	--	--
Bay of Danzig (5)	8.0	12.4	15.0	16.7	18.0	19.3	--	--	--	--
Gulf of Riga (6)	7.4	10.6	12.7	14.3	--	--	--	--	--	--
II. Summer- and autumn-spawning [2/]										
From the region of Iceland (7)	3.8	9.2	16.1	21.2	24.7	26.8	28.3	29.4	29.9	30.9
North Sea (Dogger Bank) (8)		8.0	15.0	19.2	21.6	23.0	24.0	25.6	27.0	27.1
Baltic Sea (Bay of Danzig) (9)	--	10.7	14.3	16.2	17.7	18.6	--	--	--	--

1/ Figures in brackets indicate the regions as marked in Figure 10.

2/ The age of herring spawning in the summer and autumn corresponds in the foreign literature to the number of winter rings, i.e. is 1 year younger. We present in the table the true age, i.e. we regard the increment of the first winter as the first year of development. For the herring from Dogger Bank that increment must be equal to 2-4 cm., i.e. is approximately the same as for the sprat.

On the stock and fishing of Atlantic-Scandinavian herring.

Fecundity and reproductive capacity of sea herring.

We may outline the following specific peculiarities of fecundity for all sea herring, the Atlantic-Scandinavian herring race in particular. Individual fecundity of all sea herring is rather low, considerably lower than that of many other fishes, and the eggs of herring do not mature in batches. With the increase in size and weight of the fish, the fecundity of different herring races increases markedly. All the herring are characterized by polycyclic spawning.

Sea herring deposit their eggs in considerably smaller quantities than representatives of the cod and flounder families, than the majority of carps, perches and herring from the Caspian and Azov-Black Sea basins. For the majority of populations, the individual fecundity is estimated in several tens of thousands of eggs; for some of them the fecundity does not exceed 3-5 thousand (6).

The investigations of V. M. Naumov (19) and I. G. Fridland (31), as well as the research of other authors, convincingly demonstrated that the eggs do not mature in batches neither in the case of Atlantic herring nor of herring from the Pacific Ocean. The assumption of P. A. Dryagin (10) that the eggs of Pacific Ocean herring mature in batches must be considered erroneous. Moreover, we wish to point out that the simultaneous maturation of eggs in the herring with few vertebrae, which originated in Northern seas, coincides well with the general scheme of the evolution of sexual cycles, as suggested by P. A. Dryagin.

The size of herring ova varies insignificantly in different races despite the considerable differences in the length and weight of the fish themselves. Only the ova of summer-spawning herring are considerably smaller than those of spring-spawning herring. Farran (41) proved this fact for the herring from the Irish Sea, while K. A. Liamin, a member of the Polar Institute, established this rule for the summer-spawning Icelandic herring. Thus, the diameter of ova of spring herring from the Irish Sea fluctuates between 1 and 1.3 mm., those of the summer and autumn herring - from 0.7 - 1.0 mm., and with spring herring from the Irish Sea, 25-26 cm. in length, the number of ova fluctuates between 30 and 40 thousands, for summer and autumn herring of identical length the ova are, according to Farran, almost twice as abundant, i.e. 60 to 100 thousands.

The fecundity of summer-spawning Icelandic herring is almost 21/2 times higher than that of Atlantic-Scandinavian herring spawning in spring.

The fecundity of all herring races increases greatly with age, increment in length, and weight of the fish. Thus, according to A. I. Ambroz (4), the herring from the southern Maritimes 70-80 gm. in weight, have only 17 thousand ova; at a weight of 300-350 gm., their fecundity rises to 70-80 thousand ova. The largest herring from Peter the Great Bay, weighing 500 gm., have over 100 thousand ova.

The fecundity of Atlantic-Scandinavian herring increases considerably with increment in length and weight. Thus, according to I. G. Yudanov (34), first-time spawners 23-24 cm. in length have only 15-18 thousand ova, whereas herring 30 cm. in length and about 300 gm. in weight have 60-70 thousand ova. The largest specimens of ocean herring 32-33 cm. in length have 90 to 100 thousand ova. The fecundity of small herring and sprat from the White Sea also rises considerably with an increase in weight and length. According to Antipova (5), the fecundity of Onega herring is characterized, depending upon the weight of the fish, by the following indices: 3 gm. - 5 thousand ova, 4 gm. - 7.2 thousand ova, 5 gm. - 13.2 thousand ova, 6 gm.-14.2 thousand ova.

According to the data of A. P. Vilson, the three-year-old Kandalaksha herring 15 cm. in length and 30 gm. in weight have 7 thousand ova; four-year-old herring 19.7 cm. in length and 62 gm. in weight have 14.8 thousand ova; and five-year-old herring 20.2 cm. in length and 73 gm. in weight have 16.3 thousand ova.

Seletskaya found that the number of ova in sprat spawning in Visla estuary, was as follows: 2 years - 13 thousand ova, 3 years - 18 thousand ova, 4 years - 28 thousand ova, 5 years - 37.5 thousand ova. According to the investigations of A. P. Vilson, two-year-old sprat 12.5 cm. in length from Viborg Bay have 4.2 thousand ova, and three-year-old sprat, 16 cm. in length, contain 9.1 thousand ova. A. N. Probatov and A. I. Frolov (20) presented highly interesting data on the fecundity of small herring populating Lake Tonnay (eastern coast of Sakhalin). Two-year-old herring approximately 14 cm. in length, have 11.3 thousand ova, three-year-old specimens about 17.6 cm. in length have 14.6 thousand ova and four-year-old herring 20.2 cm. in length have 21.5 thousand ova.

The fecundity of sea herring is presented graphically in Figure 11. The diagram enables us to see the fecundity of different races of herring in relation to the length and age of the fish. It would be even more interesting to establish the dependence between fecundity and weight of the list; however, the data required for such juxtaposition were not found in all the works utilized in this study.

The conclusion is self-evident - the fecundity of herring depends to a very considerable degree on the size of fish. All the races of small herring are characterized by low fecundity.

The fecundity of Atlantic-Scandinavian herring is similar to that of other races of large herring. The low fecundity of sea herring is compensated by the great number of spawnings, since these herring are characterized by great longevity. This is particularly well pronounced in Atlantic-Scandinavian herring in view of the fact that they increase considerably in size after the occurrence of sexual maturity and are notable for their great age.

A female Atlantic-Scandinavian herring releases in the course of five years approximately 350 thousand ova, i.e. the number of ova cast during 10 years may amount to 800 thousands.

Mixed composition of the spawning population of Atlantic-Scandinavian herring accounts for a certain stability in their reproductive ability. All the other races of herring that are characterized by short lives and a simpler composition of the spawning population, have a lower reproductive ability. Moreover, the quantity of eggs released by these latter may be subject to considerable fluctuations as a result of the varying number of specimens of different year classes.

Industrial exploitation of Atlantic-Scandinavian herring.

Atlantic-Scandinavian herring form the most numerous school among all the herring of the oceans of the world. The great abundance of these herring is determined by their vast feeding grounds embracing almost the entire boreal zone of the north-eastern Atlantic. Atlantic-Scandinavian herring utilize the most productive zone of this basin - the region of the polar front, where, as a result of the intensive vertical circulation of water volumes, there are formed outstandingly favorable conditions for plankton development.. The herring feed on zooplankton of both the warm Atlantic and the cold polar waters.

Good feeding conditions account for the high growth rate of Atlantic-Scandinavian herring distinguishing them from the herring of the continental shelf. The mixed composition of their spawning population enables us to assume that the dimensions of their school vary insignificantly. The reproductive capacity of Atlantic-Scandinavian herring is relatively stable, since several different age groups participate in reproduction.

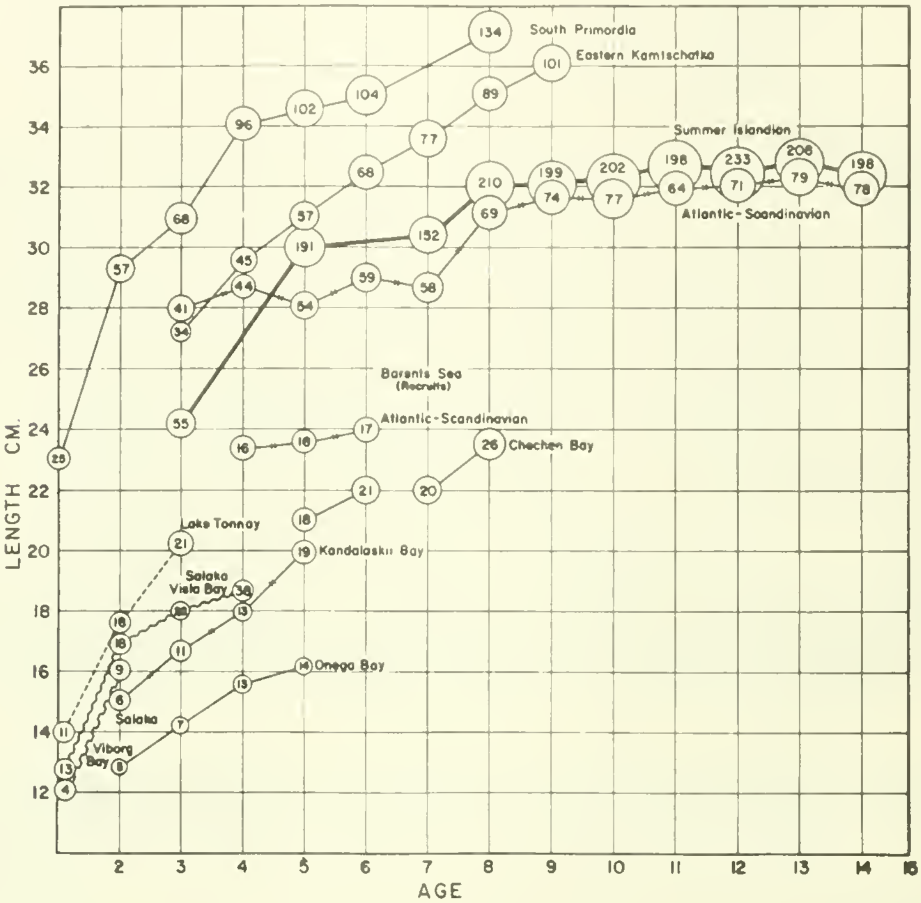

Figure 11. Fecundity of sea herring by age and size: southern Maritimes - after Ambroz (1931); eastern Kamtchatka - after Panin (1950); region of Iceland, summer race - after Lyamkin (1955); Norwegian Sea, ocean herring - on the basis of data of the Polar Institute; Chesha Bay - on the basis of data of the Polar Institute; Tonnay Lake - after Probatov and Frolov (1951). Kandalaksha Bay - after Vilson; Onega Bay - after Dmitriev (1946); Vistula Bay, spring sprat (salaka) - after Seletskaya (1952); Viborg Bay, spring sprat (salaka) - after Vilson.

It may be seen from the experience of the European fisheries that the considerable increase in the catches of herring noted during the last few decades occurred in the main as a result of the intensified fishing on Atlantic-Scandinavian herring (Figure 12).

Yearly catches of bank herring from the North Sea amounted in 1913 to 6.5 million centners. Despite the considerable improvement of the drift-fishing technique and organization of a large-scale trawl fishing in North Sea, catches increased but insignificantly during the last 40 years.

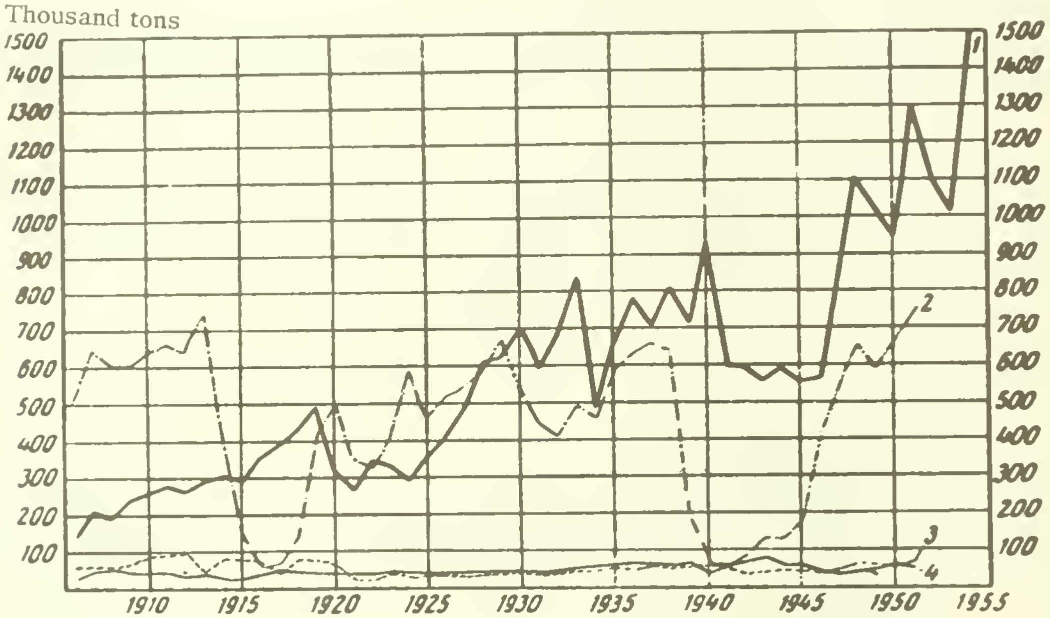

Figure 12. Catches of herring obtained in the north-eastern zone of Atlantic. 1. Atlantic-Scandinavian herring; 2. North Sea, British Channel, Irish Sea, and north-western coast of Scotland; 3. Kattegat and Skagerak; 4. Baltic Sea.

The catches obtained in the English Channel, the Kattegat & Skagerak, and the Baltic Sea also increased little during that time, whereas the catches of Atlantic-Scandinavian herring increased ten-fold during the same period.

Catches of Atlantic-Scandinavian herring increased most in Norwegian waters. Up to 1915, the annual herring catches in Norway did not exceed 3 million centners. In the thirties, they reached 5-7 million centners and during recent years they amounted to 10-12 and more million centners a year. During the last two decades, a fishing industry developed in Icelandic waters, based on the Atlantic-Scandinavian race of herring. Atlantic-Scandinavian herring became the object of large-scale fishing conducted by the Soviet Union during the season when these herring are feeding in the Norwegian and Greenland seas.

There is no doubt that, given rational exploitation, the catches of the stock of Atlantic-Scandinavian herring may be greatly increased. However, the existing system of exploitation of their reserves can by no means be considered as rational, since a considerable number of these herring are caught very young, long before they become sexually mature.

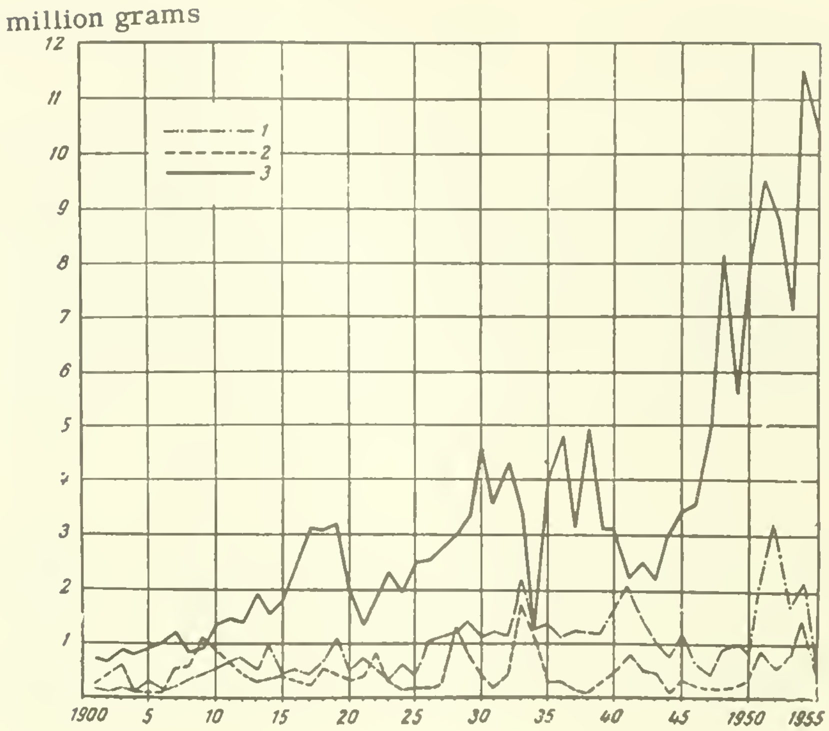

Figure 13. Catches of herring obtained in Norwegian waters. 1.- small; 2. - fat; 3. - winter herring.

As is well known, there exist in Norway three types of herring fisheries - for adult herring during the spawning season, for fat sexually immature herring 4-5 years of age, and for 1- and 2-year-old small herring. Figure 13 illustrates the respective developments of these three types of fisheries.

Adult herring during the season of migration to the spawning grounds play the most important part in the Norwegian fishing industry. Having at our disposal the data on catches, age composition (76), and mean weight of adult herring, we are now able to reproduce tentative indices of the number of specimens of individual year classes of different years that were caught in the process of fishing the given group.

The most abundant year classes provided the fishing industry with the following number of adult specimens: 1904 year class - 5.2 billion; 1918 year class - 4.2 billion; 1923 year class - 4.6 billion; 1930 year class - 4.6 billion; 1934 year class - 2.7 billion; 1937 year class - 2.7 billion[1/].

These most numerous year classes ensured the success of Norwegian winter fishing from 1910 until 1942.

Catches of large herring increased in Norway during that period from 1 to 5 million centners. We naturally assume that the fishing intensity on different year classes was unequal and increased during the more recent years of that period. Comparing the catches of the 1904, 1918, and 1930 year

1/ At this time, the 1937 year class was not yet fully exploited by fishing.

classes obtained during different years, all year classes of which provided the fishing industry with similar indices of catches that amounted to 4.2-5.2 billion specimens, we obtain the figures presented in Table 8.

The 1904 year class yielded considerable catches for 10 years. Fishing the 1918 year class continued over approximately the same period of time; however, the amount of herring caught during the first five years of commercial exploitation was considerably greater than during the subsequent period. The 1930 year class was fished heavily for 7 years; a particularly great number of herring of that year class were caught at the age of 6-8 years. The above data show that the rate of exploitation of individual year classes increased during recent years and year classes of approximately equal abundance are now thoroughly exploited by fishing within shorter periods of time. In view of the aforesaid, the number of the oldest specimens in a stock has decreased. In our opinion, herring of the 1904 year class prevailed in catches over such a protracted period of time not only because of its great abundance, but also because of the low fishing intensity during that period.

The slight drop in the number of the oldest specimens in the spawning population of Norwegian herring observed after the thirties is quite normal, since at the beginning of our century the stock of Atlantic-Scandinavian herring were actually still intact. We may state that the effect of fishing conducted over the course of several decades produced no drastic changes in the structure of the spawning population of the Norwegian stock. At the beginning of our century, as well as now, the spawning population is represented by a great number of different age groups, which contribute to the preservation of a high and stable reproductive ability of the race.

In our opinion, the development of fishing on adult herring cannot seriously affect as yet the stock of Atlantic-Scandinavian herring, since to catch an additional million of centners of large herring we need eliminate only 300-350 million specimens.

However, we think that the fishing of young herring conducted by Norway affects the stocks of herring in an altogether different manner. The main bulk of young Atlantic-Scandinavian herring of the Norwegian school populate coastal waters, directly offshore, where they are easily accessible to fishermen.

In the past, when the fishing of Atlantic-Scandinavian herring was still little developed, elimination of several hundreds of thousands of centners of young herring a year was fundamentally unimportant. In that respect, we fully share the viewpoint of Lea (40). At the present time, however, the fishing intensity has greatly increased, and the fishing industry aims at obtaining maximum catches of Atlantic-Scandinavian herring. Under such conditions, the elimination of a great number of young fish will affect in one way or another the overall potential herring catch. Therefore, the problem of fishing young herring must be subjected to very serious investigations.

Only a few years ago, it seemed that Norway decided to stop fishing for small herring, while intensively developing the fishing of large herring. The catches of young herring obtained during five years, i.e. from 1946 to 1950, amounted to 4 million centners, i.e. constituted 0.7-0.8 million centner a year. These figures amounted to approximately half the annual young herring catches recorded in the thirties. This undertaking appeared quite rational, since Norway itself, more than any other country, should be concerned about rational exploitation of the stock of Atlantic-Scandinavian herring. However, in 1951, the catches of young herring increased again and were over 2 million centners in 1951; in 1952, about 3.0 million centners; in 1953, to 1.5 million centners, and, in 1954, over 2 million centners. The overall catches for the 4 years were equal to approximately 8.5 million centners, i.e. twice the amount caught in the course of the preceding five years.

TABLE 8. CATCH OF HERRING OF THE YEAR CLASS AFTER REACHING SEXUAL MATURITY.

Year class \ Age	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Older ages	Total number millions
1904 year class, million specimens	12	173	239	590	495	375	522	325	380	411	480	442	350	188	89	94	43	5210
Per cent	0.2	3.3	4.6	11.3	9.5	7.2	10.1	6.2	7.3	7.9	9.2	8.5	6.7	3.6	1.7	1.8	0.8	100
1918 year class, million specimens	8	143	671	500	485	372	374	275	200	338	245	223	121	44	80	78	74	4230
Per cent	0.2	3.4	16.0	12.0	11.7	8.9	8.9	5.6	4.7	8.0	5.8	5.3	2.9	1.0	1.9	1.9	1.8	100
1930 year class, million specimens	13	14	791	1170	748	790	457	329	124	96	22	51	7	--	--	--	--	4610
Per cent	0.3	0.3	17.2	25.3	16.2	17.2	9.9	7.1	2.7	2.1	0.5	1.1	0.1	--	--	--	--	100

In order to find out to what extent the intensive fishing of young fish of different year classes affects the catches of adult fish of the year classes in question, we decided to estimate the correlational dependence between the catches of small and large herring of individual year classes. The dependence between the catches of small and large herring proved to be not a direct, but an inverse relation. All the abundant year classes that were subjected to intensive fishing at an early age provided the fishing industry with relatively small catches of large herring and, vice versa, the year classes which were left relatively intact until they became sexually mature provided the fishing industry with maximum catches of adult fish. Thus, the 1904, 1918, 1923, 1943 and 1944 year classes from which there were eliminated but 2 to 5 billion young specimens, provided the fishing industry with 4-6 billion adult fish, whereas the 1925, 1932, 1934, 1937, 1938 and 1939 year classes that were subjected to intensive fishing prior to the occurrence of sexual maturity, yielded subsequently but a small number of large herring - i.e. from 1 to 3 billion specimens.

Mass extermination of young herring intensifies the harmful effect of poor year classes and reduces considerably the abundance of good years.

We think that even a stock as numerous as that of the Atlantic-Scandinavian herring, cannot be subjected to fishing of its juveniles and adults without changing the structure of its spawning population. At the same time, changes in the said structure will disturb the stability of the reproductive capacity of the stock, since fluctuations in the number of specimens forming different year classes will be conditioned under such circumstances by both the survival rate of young specimens as well as by the amount of eggs deposited; on the other hand, the productivity of the fishing industry will decrease, and fluctuations in the catches will be greater as a result of the reduction of the number of age groups of herring which are fished.

Particular attention should be given to the fact that the compound structure of the spawning population of Atlantic-Scandinavian herring is an important means of adaptation, ensuring a certain stability in the number of specimens forming their stock. It protects the race against the possibility of a drastic reformation of its stock under the effect of fluctuations.

It seems to us indisputable that the maximum catches of Atlantic-Scandinavian herring may be ensured only on condition of the rational organization of fishing, the maximum preservation of young fish being its chief element.

Conclusions

1. In the light of the investigations of Soviet and foreign scientists, Atlantic-Scandinavian herring form a specific race differing from other races of Atlantic sub-species in the range and living conditions, spawning season, growth rate, age structure of the spawning population, as well as a number of other morphological characteristics (such as body proportions , number of vertebrae, etc.).

2. The life of the Atlantic-Scandinavian herring proceeds in the main north of the underwater ridges extending from Greenland to the shores of the Scandinavian peninsula.

The waters of Atlantic origin penetrating via the Faeroe-Shetland channel, between Iceland and Greenland, between Iceland and the Faeroes, as well as the regions of contact of these waters with polar water volumes and waters of continental origin, are the environment in which Atlantic-Scandinavian herring exist.

3. Reproduction of Atlantic-Scandinavian herring takes place in the southern zone of their range, off the shores of Norway, along the northern and eastern edges of the continental shelf of

the North Sea, to the west from the Shetland Islands, in the area of offshore shelf of the Faeroes and along the southern coast of Iceland. Spawning is observed at the end of the winter - in early spring at the depths ranging from several tens of meters to 200-225 m., at a temperature of 6-7.5^{o} and salinity of 33-35 per cent. The most intensive spawning occurs at the depth where waters of Atlantic origin meet the littoral waters. The main spawning grounds are now located along the south-western coast of Norway.

4. The passive drift of larvae and fry resulting in their dissemination over vast territories during the first year of their existence plays an important role in the life of Atlantic-Scandinavian herring. The drift of fry has been most thoroughly studied in the Barents Sea to which fry from Lofoten region are carried in the course of 150-200 days. The fry from southern Norwegian spawning grounds drift to the northern shores of the Scandinavian peninsula.

5. Having grown and matured, the young herring proceed to the places of their origin. The date on which return migration begins depends to a great extent on the growth rate and the size of the fish. In the Barents Sea, 5-year-old herring reach 22.5-23.0 cm. in length, in the Norwegian Sea the herring of identical age are 27.5-28.0 cm. in length. In view of the aforesaid, the herring from the Norwegian Sea become sexually mature at the age of 4-5 years, whereas herring in the Barents Sea attain sexual maturity at the age of 5-6 years. Individual specimens that were delayed in their development mature at the age of 7-8, even 9 years.

6. Sexually immature herring migrate to the open sections of the sea 1-2 years prior to the occurrence of sexual maturity. In the Barents basin they are found in greatest numbers in the western zone of the sea. A great number of young maturing herring populate the north-eastern arm of the Norwegian Sea, south from Mohn's Threshold. Spawning grounds of first-time spawners are located in the proximity of their feeding grounds.

7. Migrations of adult Atlantic-Scandinavian herring into the north latitudes are associated with feeding. The feeding takes place in the most productive zone of the North-European basin, in the region of the polar front and adjacent areas, where, as a result of the intensive vertical circulation of water volumes, there are formed outstandingly favorable conditions for plankton development.

8. The rhythm of feeding migrations of the older age groups of Atlantic-Scandinavian herring is coordinated with the vernal processes of the plankton development when the warm- and cold water Calanus reproduce in the surface layer. Migration periods of young first-time spawners coincide with the development of red Calanus. Older age groups feed also in polar waters beyond the borderline of the polar front. The frontiers of their area of dissemination extend as far as the edge of the floating ice. During the feeding season, young herring 6-7 years of age travel as far as the edge of the polar ice, but rarely beyond.

9. During a migration in search of food, the physiological state of herring drastically changes. The herring, exhausted by spawning, lose almost all their fat reserves. During that period, their fattiness ratio drops to 0.9-0.8. Over the course of 3-3.5 months during the feeding season the weight of herring rises 25-30 per cent. Their fattiness ratio increases to 1.2-1.3. Herring reach their maximum fattiness indices in late July-early August, when the proportion of fat to the overall body weight amounts to 18-20 per cent. From that moment on, the gonads begin developing intensively. By September, the maturity factor reaches, in males 11-12 per cent, in females - 6.8 per cent of the body weight. The southward migration of the herring schools to the spawning grounds coincides with the latter period.

10. Migration paths of maturing herring pass across the western zone of the Norwegian Sea,

along the edge of the polar ice. Older age groups keep closer to the polar waters, whereas the course of the drift of young herring passes more easterly, across warm waters of Atlantic origin.

Herring-tagging during the last few years has shown that the speed of return migration to the spawning grounds fluctuates within the limits of 2.0-6.9 miles a day.

11. The degree of identity of Atlantic-Scandinavian herring does not remain unchanged during the course of their existence. There can be no doubt that different spawning grounds are isolated from each other. The development of young herring prior to the onset of sexual maturity also proceeds in an isolated manner. Adult herring accomplish the most extensive migrations of all herring from the Atlantic and Pacific oceans. In the opinion of the author, the identity of different schools that have been hatched on different spawning grounds becomes difficult to determine during that particular period of the herring's life.

The tagging experiments carried out by the Polar Institute showed that herring feeding far north, around 75^{0} north latitude, as well as those feeding in the west, between Iceland and Jan Mayen, both reproduce off the south-western shores of Norway.

The study of that particular problem is at the present moment at the initial stages. The identity of herring hatched in different regions may be determined with precision through a sequential step-by-step study of the distribution and migrations of different year classes.

12. The fecundity of Atlantic-Scandinavian herring is similar to that of other races of large herring (herring from the Maritime, Kamchatka). The low fecundity of all the sea herring is compensated by the great number of annual spawnings in the course of their long existence. This is particularly pronounced among Atlantic-Scandinavian herring due to their considerable size increment after the occurrence of sexual maturity as well as their great longevity.

13. The reproductive capacity of Atlantic-Scandinavian herring is relatively stable, since a great number of different age groups participate in spawning.

All other races of herring, characterized by a short life-span and a simpler composition of their spawning population, have a lower reproductive capacity. The quantity of eggs deposited by these herring may undergo considerable fluctuations due to the drastic variations in the number of individuals of different year classes.

14. Atlantic-Scandinavian herring form the largest stock of all herring of the oceans of the world. The catches of these herring have particularly increased in the waters of Norway, where we already observed several overall annual catches exceeding 11-12 million centners. The stock of Atlantic-Scandinavian herring is affected by the fishing of young and adult specimens, which, in opinion of the author, is bound eventually to modify the age structure of the adult stock.

On condition of a rational organization of fisheries, ensuring maximum preservation of young, the catches of Atlantic-Scandinavian herring may be considerably increased.

15. Due to the decreasing importance of older age groups in the fishing industry during the last few years, further investigations of the Polar Institute must be directed towards defining more precisely the migrations of young sexually mature herring in order to intensify the exploitation of these herring by the fishing industry.

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CHART OF CONSTANT CURRENTS IN THE

NORWEGIAN AND GREENLAND SEAS

A. P. Alekseev and B. V. Istoshin

The earliest information which we possess on the constant currents of the Norwegian and Greenland Seas is found in a chart made by the German geographer Petermann in 1857. In 1887, the Norwegian physicist Mohn charted the current lines for the Norwegian, Greenland and Barents Seas on the basis of an analysis of observations made during an exploration on the vessel "Foringen". This map, which in itself is not without interest, shows the currents in the Greenland Sea in positions totally different than their true positions. Thus, Mohn represents the warm Spitsbergen stream as coming from the Barents Sea through the channel between Bear Island and Spitsbergen.

The next stage in the research, which considerably enlarged our knowledge of the currents in the Norwegian and Greenland Seas, is represented by the voyages of the Norwegian ship "M. Sars". From their observations, B. Helland-Hansen and F. Nansen were able to draw a theoretical chart of the currents in the Norwegian and Greenland Seas, and this chart is still of value today.

The Great October Socialist Revolution, which laid the foundations for an intensive study of the North by Russian expeditions and vessels, has also played a decisive role in the investigation of the Norwegian and Greenland Seas. One of the first decrees of the Soviet after gaining power was to set up a Floating Marine Institute on the "Persey", which carried out a great deal of research work in the northern seas. V. A. Berezkin (1) collated the observations of the expeditions on the "Persey", the "N. Knipovich" and the "Sadko" and drew the first dynamic current charts for the Greenland Sea.

Following the great oceanographic survey carried out in 1939 by the Arctic Institute on the "Sibiryakov", similar charts for the Norwegian and Greenland Seas were compiled by V. T. Timofeev (3).

Whereas all, or almost all, the Soviet research on currents in the Norwegian and the Greenland Seas up to World War II was concerned with the solution of general oceanographic problems, since 1945 investigations directed towards guaranteeing the expansion of the herring industry with the aid of essential information on the distribution of water masses and the velocity and direction of currents have been beginning to take first place.

What was sufficient for a general understanding of the circulation of water masses in a sea or ocean could not satisfy practical demands. It is well known that the life of the Atlantic herring is closely bound up with the system of warm currents and with the "polar front" 1/ zones. Furthermore, a knowledge of the currents is essential for the correct deployment of drifter fleets as well as for navigation. It would be difficult to overestimate the importance of this last factor in view of the enormous size of the Soviet herring fleet.

Thus, the herring industry could not be carried on effectively without detailed knowledge of the currents.

In 1946, the Polar Institute embarked upon large-scale hydrological work, in addition to re-

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1/ "Polar front" (Knipovich /2/) is the zone in which the warm and cold waters meet, i.e. the zone of convergence.

search on the herring, in the Norwegian and Greenland Seas. One of the main purposes of this work was to improve the accuracy of the chart of constant currents. The hydrological observations of earlier years - which were made at stations situated too far apart (30 or more sea miles) - did not permit individual details in the distribution of currents and eddies to be shown, and consequently in the post-war work of the Polar Institute the distance between stations has been reduced to 20-15 or even 10 miles with a view to preparing a completely detailed current chart.

This work has made it possible to compile a new chart of constant currents in the Norwegian and Greenland Seas differing fundamentally in a number of respects from the universally recognized chart of Nansen as well as from other charts.

In addition to the observations of the Polar Institute, certain data from the literature - mainly on the cold East Greenland current (1, 3) - and data provided by drifters[1/] have been used in the compilation of the current chart.

When compiling the chart, the authors worked on the principle of following the axes of the currents on the basis of the vertical and horizontal distribution of the temperature (Figure 1) and salinity of the sea water while at the same time using the data on plankton (biological data). Great attention was paid to the effects of the bottom contours.

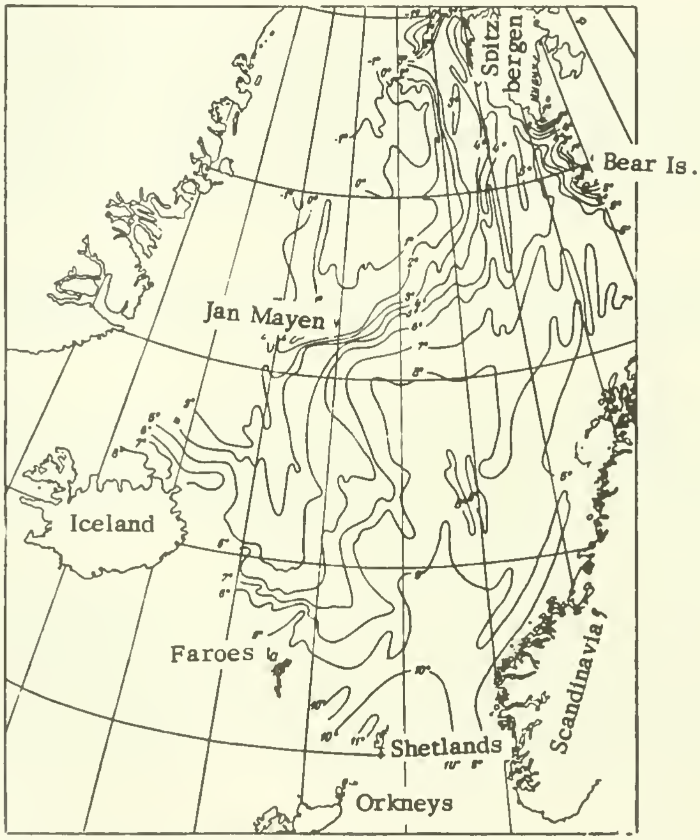

Figure 1. Distribution of temperature of surface water in the Norwegian and Greenland Seas (June 1954).

1/ These latter were based on astronomical observations made by the captains at the beginning and end of the drift, due allowance being made for the wind.

The advantage of the described method is the fact that it is possible to use the maximum quantity of existing data for the solution of the problem; the disadvantage is the difficulty of determining in a number of cases the directions of currents when they are subject to considerable eddying.

In order to eliminate a number of the defects enumerated, the authors used the "dynamic" method when analysing the data from the hydrological observations of the Polar Institute. The "dynamic" method has been repeatedly used (Berezkin, Timofeev and others) for the Norwegian and Greenland Seas and has given fairly good results. Its use for these deep seas, with their more or less fixed system of currents, has been thoroughly proved. None of the other indirect methods can replace the "dynamic" method if the problem confronting the authors is taken into consideration.

An analysis of observations for certain areas over a period of several years enabled us to conclude that certain currents and eddies are stable. The most stable currents and eddies were found to be those conditioned by irregularities of the sea bed.

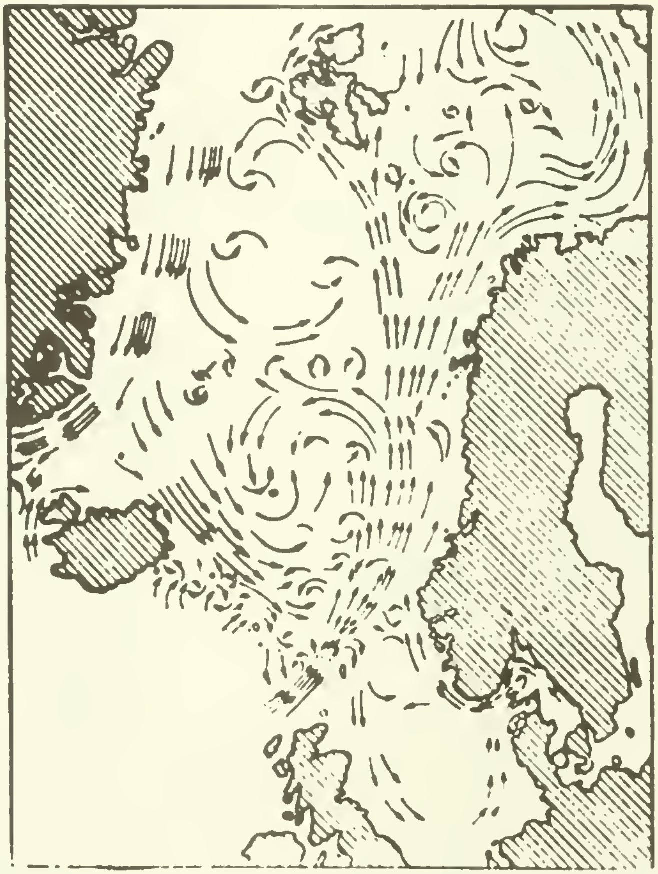

Figure 2. Nansen and Helland-Hansen's current chart of the Norwegian and Greenland Seas.

The following are the main features of Nansen and Helland-Hansen's chart: the Norwegian (Atlantic) current flows in a strong stream between the Faroes and Shetlands in a northerly direction and then along the Norwegian coast and the continental slope. In the centre of the Norwegian Sea, this current forms a vast cyclonic eddy, which is joined in the west and south-west by the cold East Icelandic current. A second huge cyclonic eddy occurs in the centre of the Greenland Sea.

This is formed by waters from the warm Spitsbergen and cold East Greenland currents. In addition to the branching towards Jan Mayen Island, a part of the Atlantic water finds its way into the Barents Sea (North Cape current, see Figure 2). As has been pointed out, the authors' chart of constant currents in the Norwegian and Greenland Seas differs basically in a number of ways from the chart of Nansen and Helland-Hansen (Figure 3). We will discuss these differences further.

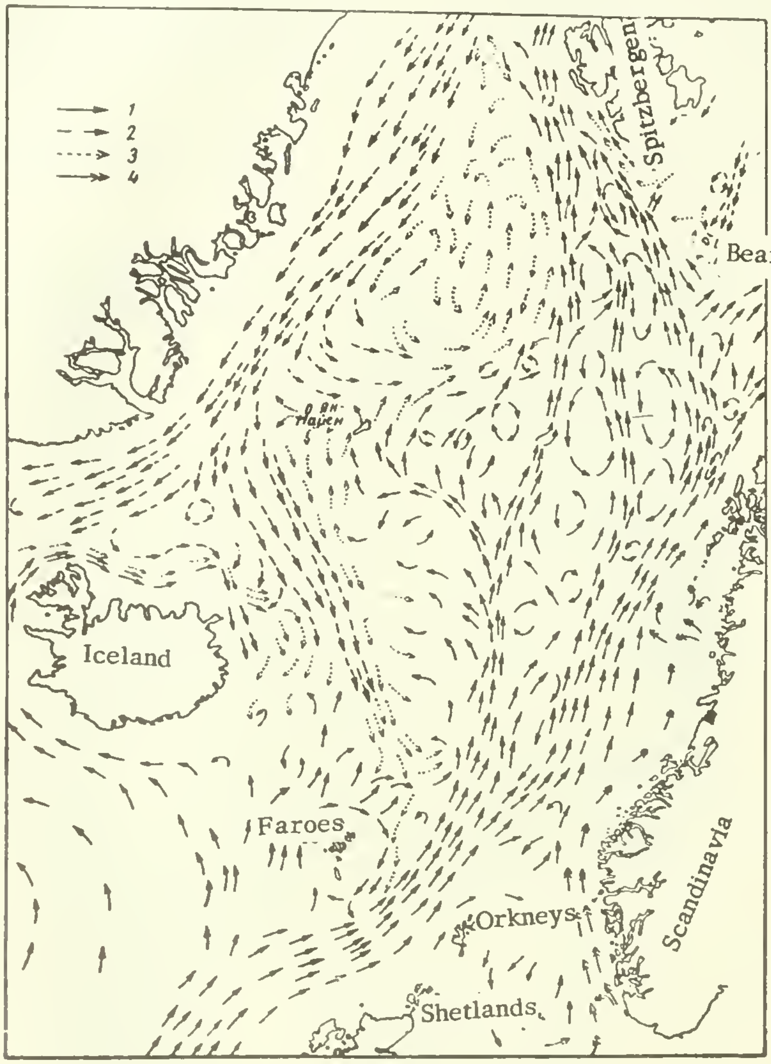

Figure 3. Chart of constant currents in the Norwegian and Greenland Seas compiled from results of research carried out by the "N. M. Knipovich" Polar Scientific Research Institute of Marine Fishery and Oceanography (PINRO). 1. Warm currents (largely unmixed Atlantic waters); 2. Cold currents (polar waters); 3. Currents of mixed waters (which have lost their original characteristics); 4. Currents of low salinity, warm in summer and cold in winter.

The principal difference - as has been explained - lies in the fact that the Norwegian (Atlantic) current does not continue in an unbroken stream but splits up into a number of more or less separate branches. This is due to the peculiarities of the contours of the bottom. The spaces between the separate branches are occupied by eddies of a (predominantly) cyclonic character.

In the central area of the Norwegian Sea, there is no cyclonic eddy but several anti-cyclonic eddies in which the Atlantic waters descend towards the sea bed. This is confirmed by charts showing distribution of water temperature at different levels, and especially by that showing temperatures at a depth of 750 m. (Figure 4). In the area of Jan Mayen, the Atlantic waters travel not from the south-east, as can be seen from Nansen and Helland-Hansen's chart, but from the south in the form of an independent branch.

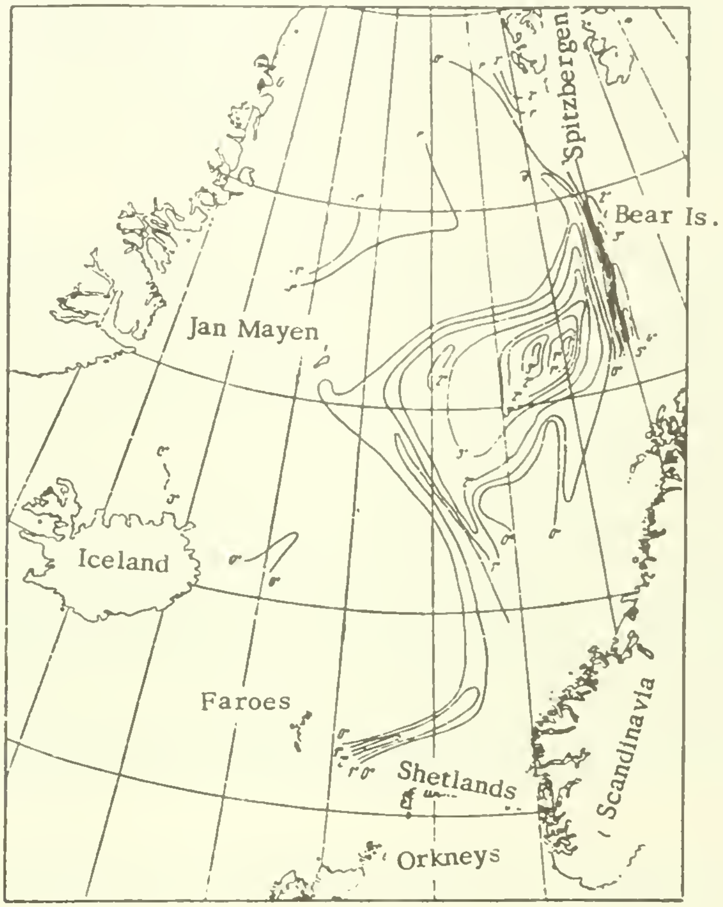

Figure 4. Distribution of temperature at a depth of 750 m. (June 1954).

Apart from the main differences already described there are a number of lesser differences which can be seen from a close examination of the authors' chart. We shall give only a brief description of this chart here.

The Norwegian (Atlantic) current, which is a continuation of the North Atlantic current and the Gulf Stream, enters the Norwegian Sea mainly through the Faroe-Shetland channel. In the eastern part of this passage the Atlantic waters travel in a northerly direction, whereas in the western part they run in a southerly direction. The space between these two currents is filled by eddies of an unstable character. The Atlantic waters also enter the Norwegian Sea between Iceland and the Faroes, but on a much smaller scale. Some of these waters help to form the return current in the Faroe-Shetland channel, but a portion of them unites with the Norwegian current. A certain proportion of the Atlantic water, rounding the Shetlands on the northern side, flows in the direction of the North Sea. In the area of the South Norwegian channel, the Atlantic waters descend below the less dense water of the Baltic current, which travels in a northerly direction along the Norwegian coast. The Norwegian current, further to the west, follows in the same direction. It begins to split up into separate branches under the influence of the peculiarities of the bottom contours in the area of the Norwegian Plateau. A part of the Atlantic water, crossing the Helgoland Ridge, forms an eastern branch of the Norwegian current, whilst the rest, rounding the Helgoland Ridge to the west, forms its western branch. The western branch travels north and in turn throws off a number of streams, some of which form an eddy upon meeting the East Icelandic current. The stream which flows to the area of Jan Mayen is an offshoot of the western branch. The extremely complex relief of Mohn's Threshold contributes towards the formation of a large number of eddies, in which intensive intermingling of the Atlantic and polar waters takes place. At the same time, the western sector of Mohn's Threshold serves to some extent as a natural barrier to the northerly movement of the Atlantic waters and to the southerly movement of the polar waters. The general movement of water in this area turns east and north-east along Mohn's Threshold and then north, reinforcing the western branch.

The eastern branch of the Norwegian current travels along the continental slope between the Norwegian shoal water and the Foringen Plateau. At approximately 68°N a stream of Atlantic water breaks away from the eastern branch and has been named the "central branch of the Norwegian current". The central branch enters the Greenland Sea between longitudes 10° and 11°E. Off the southern Lofoten Islands, the eastern branch again divides into two currents, one of which runs northward along the continental shelf, whilst the other - which is known as the North Cape current - enters the Barents Sea. At the latitude of Spitsbergen the eastern, central and western branches unite to form the Spitsbergen current.

The space between the Spitsbergen and the East Greenland currents is where the Atlantic and polar waters intermix - with intensive development of eddies, mainly of a cyclonic nature. In the area of northern Spitsbergen, some of the Atlantic water turns west and then south. Owing to its greater density, this water descends and, together with the East Greenland current, travels southwards, remaining below this current throughout its length. Most of the water of the Spitsbergen current enters the Polar Basin sinking below the less dense polar waters.

The cold currents of the Norwegian and Greenland Seas consist of the East Greenland current and its Jan Mayen branch, the East Icelandic current and the Bear Island and East Spitsbergen currents.

The Bear Island current is due to the movement of ice and cold water of low salinity from the Barents Sea into the Norwegian Sea. This current thrusts to the south and south-west of Bear Island in the form of a tongue.

The East Spitsbergen current also comes from the Barents Sea, rounding the southern extremity of West Spitsbergen Island, along which it travels in a northerly direction.

The East Icelandic current enters the Norwegian Sea between Jan Mayen and Iceland. The surface layers of this current extend to the area of the Faroes, whilst the bottom layers even enter the Faroe-Shetland channel, running into the gap between the counter-moving currents of Atlantic water.

The East Icelandic current obstructs the entry of the warm waters of the northern branch of the Irminger current into the Norwegian Sea, and its temperature and salinity are somewhat increased as a result of this intermingling with these waters.

Our chart of constant currents in the Norwegian and Greenland Seas is mainly for the surface layer. The observations on which the chart is based were for the most part made during the warm season of the year. Winter (as well as summer) observations were used only for the compilation of the current chart in the southern part of the Norwegian Sea. An analysis of the data obtained during the second oceanographic survey of the Norwegian and Greenland Seas (June 1955) confirmed the accuracy of the basic features of our current chart.

Seasonal current charts will have to be compiled since herrings are now being fished throughout the year. In the very near future, a study of the dependence of the constant currents of the Norwegian and Greenland Seas on the winds will be necessary and the processes of eddy formation will have to be examined and investigated. The method of studying currents must also be improved by adapting the regular instrument observations to the application of the latest scientific and technical advances.

Conclusions

1. The Atlantic current in the Norwegian and Greenland Seas spreads in the form of a series of more or less separate branches (the principal of these being the eastern, central and western branches), and not in a continuous stream, as is shown in the current chart of Helland-Hansen and Nansen.

2. In the central area of the Norwegian Sea, there are a small number of anti-cyclonic eddies in which the Atlantic waters sink to the lower depths.

3. The Atlantic waters enter the area of Jan Mayen not from the north-east, as is shown in Nansen's chart, but from the south and south-east in the form of an independent branch.

4. From the authors' current chart it is possible to establish the positions of the zones of the polar current - the zones of convergence of warm and cold currents. These zones are situated in the following areas: the south-western part of the Norwegian Sea, Mohn's Threshold to the north-east of Jan Mayen, the areas to the west and south-west of Bear Island and West Spitsbergen.

5. The authors' chart indicates the close link between the constant currents of the Norwegian and Greenland Seas and the contours of the sea bed.

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PLANKTON AS AN INDICATOR OF WATERS OF DIFFERENT ORIGINS IN THE NORTH ATLANTIC SEAS

V. D. Abramova

INTRODUCTION

During the last few years, the Polar Institute has been carrying out large-scale complex investigations in the North Atlantic Seas, as a result of which it has now become possible for the Soviet deep-sea herring fleet to operate throughout the year.

If the resources of fish in the North Atlantic Seas are to be exploited further, the habitats of the herring must be studied and, first and foremost, currents and plankton must be investigated.

Plankton is the basic food of the herring, and on the distribution of the plankton organisms depends the behavior of the herring at any given season and, consequently, the success of the herring-fishing industry.

In its turn, the distribution of the plankton depends on the hydrological conditions, which means that plankton organisms can serve as indicators of the hydrological conditions in any given area.

The idea of using plankton as an indicator of the hydrological conditions of the sea has long occupied the attention of research workers. It has been established that plankton organisms are the most delicate indicators, reacting to the slightest changes in the hydrological conditions of the environment.

Plankton is particularly valuable as a biological indicator in those areas of the sea where masses of water of different origins meet and intermingle and cannot be determined by hydrologica methods. Only the presence of specific forms of plankton in the waters can give any idea of their origins.

A great deal of work has been carried out by Russian investigators in the polar seas with a view to discovering whether or not it is possible to use plankton, and phytoplankton in particular, in the preparation of ice forecasts and for determining the lengths of biological seasons in different seas (3, 14, 18).

Similar investigations were begun in other countries somewhat earlier. Cleve (20) and Gran (21) did extensive work in the Norwegian Sea and in Icelandic waters, as a result of which the ecology of individual species of phytoplankton and zooplankton and their zoogeographical distribution have been described. Gran identified certain groups of plankton organisms which are characteristic of Atlantic and Arctic waters. This work is still valuable today.

The work of the British investigators Hardy (22), and Russell (23, 24, 25) in the seas round the south of Britain and in the North Sea date from a somewhat later period. However, we are still far from having a perfect knowledge of the biology of plankton organisms.

Our task was to explain the influence of the currents and temperature on the qualitative and quantitative distribution of plankton, to identify the principal forms characteristic of certain conditions and to use them as biological indicators of the hydrological conditions of the sea.

Material and Method

The present work is based on the material collected in the Norwegian and Greenland Seas during the spring and summer of 1953 on the exploration vessel "Professor Mesyatsev" (E. A. Pavshtiks) and the exploration vessel "Akademik Berg" by research workers of the Herring Laboratory. The work carried out in 1953 covers the area from the Faroes (latitude 60°N) to latitude 73°N.

The material collected during 1951 and 1952 was used for comparison. Up to 1951, the research work carried out by the "N. M. Knipovich" Polar Scientific Research Institute of Marine Fishery and Oceanography (PINRO) was in the northern areas of the Norwegian Sea and in the south of the Greenland Sea.

Investigations in the southern and central areas of the Norwegian Sea were begun in 1951. The number of stations and the number of plankton samples taken at each of them during the period 1951-3 will give an idea of the extent of the work.

	1951	1952	1953	Total
Number of stations	415	382	246	1043
Number of samples	708	741	664	2113

The plankton was collected with a Nansen closing net of No. 23 gauze at the standard levels (300-500, 200-300, 100-200, 50-100, 25-50, and 0-25 m.).

Some of the specimens consisted only of the total catch from bottom to surface, which makes it difficult to determine not only the depth at which a particular organism lives but also its relation to temperature and salinity.

The most valuable material is that collected by E. A. Pavshtiks, who 'fished' the 10-25, 5-10, and 0-5 metre levels in addition to the standard levels. This gives the fullest picture of the vertical distribution of plankton organisms.

It should be noted, however, that Nansen's net is not efficient for catching nanoplankton (the smallest forms) or actively swimming plankton organisms, especially the higher crustaceans - Euphausiacea. Consequently, no quantitative calculation of plankton caught with a Nansen net is very reliable.

The complete analysis of the collected material was made at the Laboratory. The species of the plankton organisms were identified with the aid of a Reichert binocular microscope. The quantity of organisms was determined visually according to the scale: 'occasional specimens', 'very little', 'little', 'moderate quantities' and 'large quantities' - which corresponds to the five-mark system. In order to be able to compare the material, the plankton specimens were weighed and the crude weight was converted into mg/m^3, i.e. the biomass of the plankton was calculated for the 0-50 m. layer.

Charts showing the distribution of warm-water and cold-water organisms, graphs of plankton distribution in dependence on temperature, and charts of individual plankton populations in different years were then prepared.

QUALITATIVE COMPOSITION AND DISTRIBUTION

OF PLANKTON

Before proceeding to an analysis of the data we must first sketch the geographical features of the Greenland and Norwegian Seas.

One feature of the Greenland and Norwegian Seas is the presence of very deep depressions in their central area. In the eastern area, there is a broad continental plateau with a steep shelf.

The latest work of PINRO (B. V. Istoshin and A. P. Alekseev, 1950-1) has considerably supplemented and improved the accuracy of the current chart of the Norwegian and the Greenland Seas.

It has been established that the Norwegian current entering the Norwegian Sea from the south by way of the Faroe-Shetland channel splits up into three branches, which give a series of offshoots as they travel north.

The cold Arctic waters enter the Greenland Sea from the north. The polar East Greenland current and its eastern branch, the East Icelandic current, are of great importance.

The East Greenland current brings enormous quantities of ice from the Arctic into the western areas of the Greenland and Norwegian Seas, and this results in a constant cooling of the surface waters.

This current does not pass into the central regions of the Greenland and Norwegian Seas, but under the pressure of the warm Atlantic waters passes round Jan Mayen and comes into close contact with the western branch of the Norwegian current on its way to the Faroes.

The zone of contact between the warm and cold waters is called the "polar front" (10). The optimum conditions for the development of animal and plant organisms occur here.

At the point where the warm and cold waters meet, the mass of water is enriched with organic matter as a result of the destruction of large quantities of organisms which are unable to adapt themselves to the abrupt change in temperature. In addition, owing to the fact that the water masses are well mixed at the places where the warmer and more saline waters coming from the south meet the colder and less saline northern waters, abundant quantities of mineral salts rise and all the layers of water are saturated with oxygen.

Owing to the great expanse of the Norwegian and Greenland Seas from south to north, the hydrological conditions in the individual areas of these seas have a unique character, and consequently plankton begins to develop at different times in different areas and the length of each biological season also varies.

The diagram showing the lengths [illegible] seasons for these seas at various latitudes has been prepared by Bogorov (2), and Pavsh[illegible] [illegible]) has determined the times at which the principal plankton groups develop in the Norwegian and Greenland Seas.

The development of biological processes in the Norwegian Seas begins in the south and gradually moves northward following the paths of the Norwegian current. This is due to the fact that the southern areas are more affected by the warm Atlantic waters with their high salinity (35 $^{0}/_{00}$ and more) and their surface temperature of 10-15 $^{\circ}$C. These waters carry with them the typical

Atlantic plankton fauna. However, cold-loving organisms which normally inhabit polar waters have been found in considerable quantities in the area of the Faroes.

The presence of both organisms indicates that waters of two different origins are intermingling here - and this was particularly characteristic of 1953 (Figure 1). Among the warm-water species are Collozoum groënlandicum, Physophora hydrostatica, Tomopteris helgolandica, Meganyctiphanes norvegica, Nematoscelis megalops, Limacina retroversa, and the cold-water species include Calanus hyperboreus, Metridia longa, Scolocithrix minor, Clione limacina, Themisto libellula, Limacina helicina.

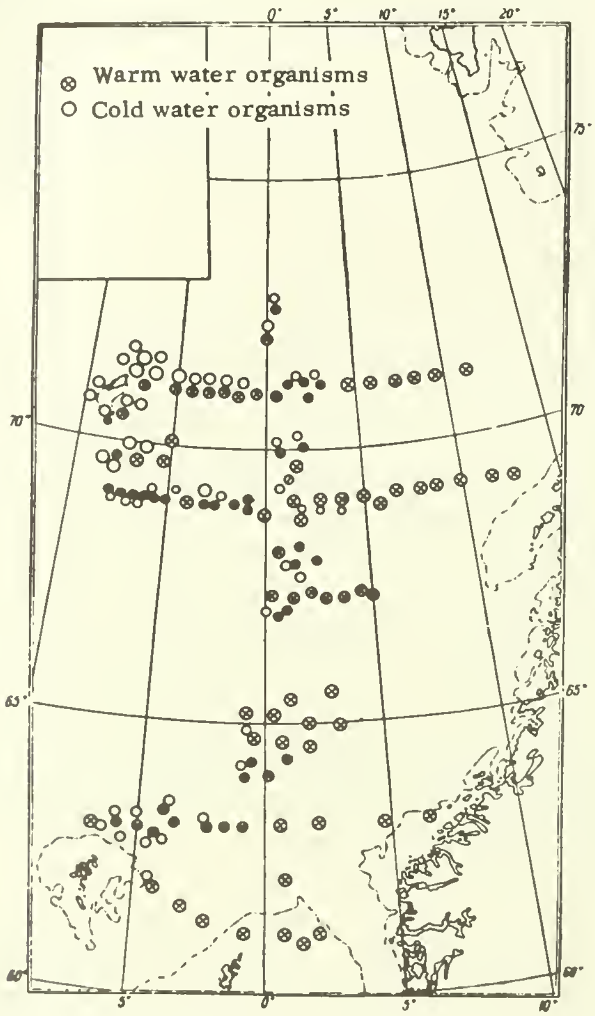

Figure 1. Distribution of warm-water and cold-water organisms in the 0-100 m. layer in 1953. ⊗ Warm-water organisms; o Cold-water organisms.

The positions of the isotherms in May and June 1953 (Figures 2 and 3) show that the cold waters of the East Icelandic current form wedges in the Atlantic waters and at isolated points come right to the surface as cold patches. The polar front is indicated most clearly here.

It should be noted that despite the presence of warm and cold currents in the Norwegian and Greenland Seas the polar front is not everywhere sufficiently clear (1).

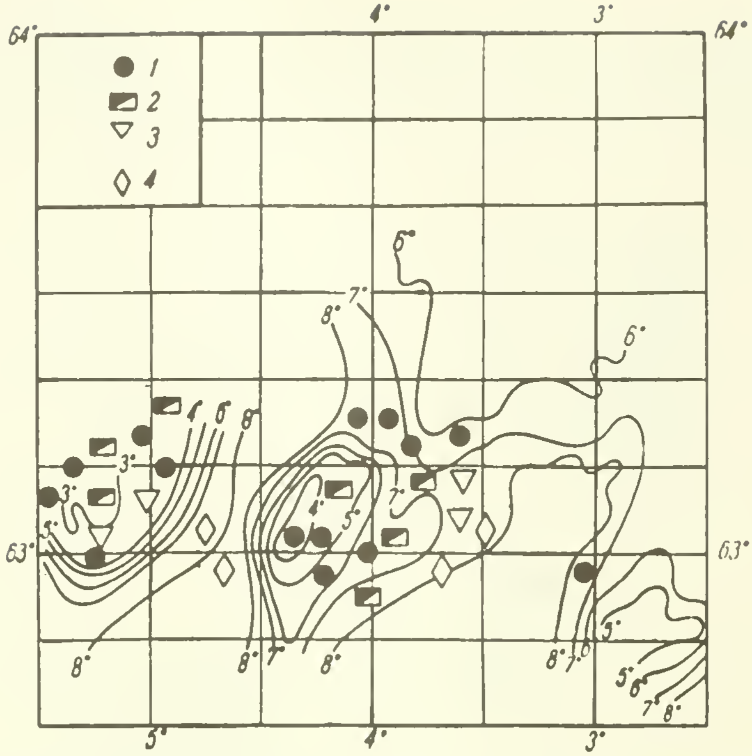

Figure 2. Surface temperature distribution in May 1953. 1. Calanus hyperboreus; 2. Metridia longa; 3. Limacina retroversa; 4. Nematoscelis megalops.

Some species of plankton organisms are widespread in the North Atlantic, and these are the species which occur in the greatest quantities. They include the following: Calanus finmarchicus, Pseudocalanus elongatus, Microcalanus pusillus, Spinocalanus abyssalis, Oithona similis, O. atlantica, Oncea borealis, Themisto sp.

Calanus finmarchicus is the most numerous species of plankton in the Norwegian Sea, but its quantitative distribution varies from place to place. C. finmarchicus is not plentiful in the southern part of the Norwegian Sea and its quantity begins to increase only as it travels northward with the current. Very large quantities of C. finmarchicus have been noted in the path of the continental current. The biomass of plankton in May 1953, during the season of mass development of C. finmarchicus, reached 4,509 mg/m^3. It should be noted that in the more northerly parts of the central areas of the Norwegian Sea, where polar and Atlantic waters are intermingled, the ratio of Calanus finmarchicus and C. hyperboreus is 1:2 in the 50-100 m. layer at less-than-zero C. temperature.

On the other hand, in the central areas of the Norwegian Sea, where the salinity is higher (35^{0}/oo and more) and where the temperat[illegible] freezing point, the quantity of C. finmarchicus increases considerably whilst that of C. hyperboreus decreases, giving the inverted ratio of 2:1 (Table 1). The no less numerous species of Copepoda - Pseudocalanus elongatus - is found together with C. finmarchicus, and the quantity of it increases in the courses of the currents. This species is also unequally distributed in the individual areas of the North Atlantic (Table 2[1]).

1/ Translator's note: Table 1, rather than Table 2, contains information on P. elongatus.

In the spring and summer of 1953 (Figure 4) the largest quantity of P. elongatus was observed in the southern part of the Norwegian Sea, to the north of the Faroes in latitude 63°N and longitude 3° W, in the north-central and central areas of the Norwegian Sea in the western current and in the area east of Jan Mayen. Above latitude 72°N, the quantity of P. elongatus diminishes.

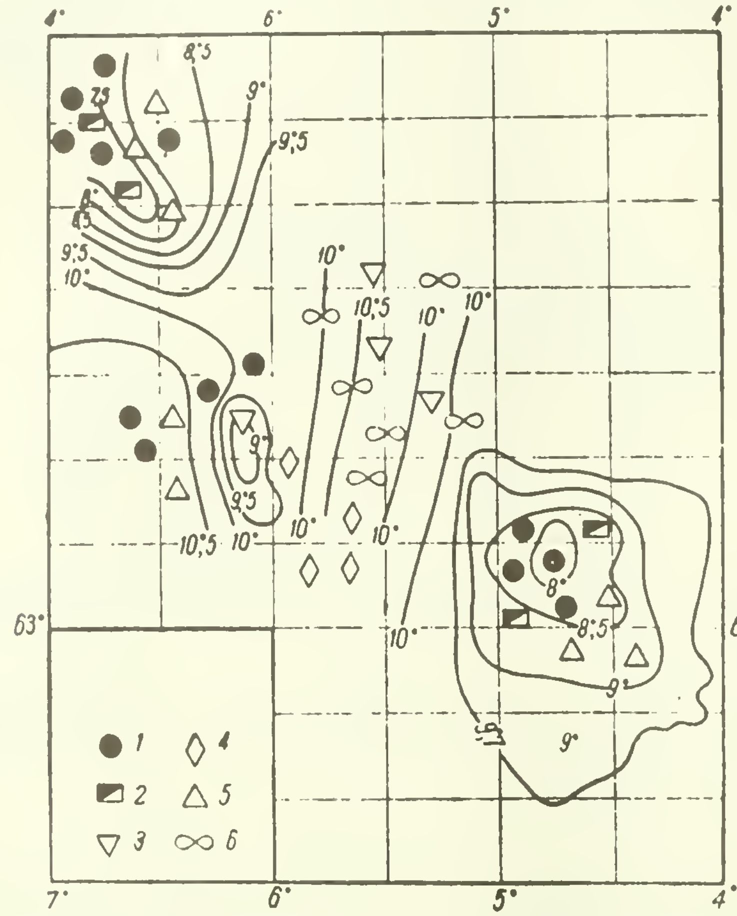

Figure 3. Surface temperature distribution in June 1953. 1. Calanus hyperboreus; 2. Metridia longa; 3. Limacina retroversa; 4. Nematoscelis megalops; 5. Themisto libellula; 6. Collozoum groënlandicum.

The Amphipoda group (Themisto abyssorum, Th. compressa f. compressa, and others) occupies second place. Themisto compressa f. compressa is a relatively warm-water form of Amphipoda and has been observed by us mainly in the southern part of the Norwegian Sea along the coasts and in the coastal current. The most numerous species of this group are Themisto abyssorum and Themisto libellula.

Themisto abyssorum is widespread in the central part of the Norwegian Sea and in the southern areas of the Greenland Sea. Themisto libellula is a cold-water species and its habitat lies to the north of that of Th. abyssorum (Figures 5 and 6) where the temperature ranges from +0.1 to -0.7°C and the salinity is 34.55°/oo.

Table 1. Vertical distribution of individual species of zooplankton[1/] in the North Atlantic in dependence on salinity and temperature. (+ = occasional specimens; ++ = very little; +++ = little; ++++ = moderate quantity; +++++ = large quantity)

Salinity S^0/oo Temperature t^0 Depth in metres	34.79 -0.82 100	34.69 -1.71 50	34.60 0.58 25	34.90 -0.90 100	34.81 -1.17 100	34.72 -1.14 50	34.63 -0.63 25	34.78 -0.55 100	34.74 -1.66 50	34.67 -0.65 25	35.16 3.47 100	34.99 3.88 50
Collozoum groënlandicum	+	-	+	+	+	+	+	+	+	+	++	+
Physophora hydrostatica	-	-	-	-	-	-	-	-	-	-	-	-
Dimophyes arctica	+	-	-	+	+	-	-	+	-	-	+	-
Aglantha digitale	-	-	-	-	-	-	-	-	-	+	+	-
Tomopteris helgolandica	-	-	-	-	-	-	-	-	-	-	+	+
Conchaecia borealis	+++	-	-	+++	+	-	-	+	-	-	+++	++
Calanus hyperboreus	++++	++++	+++	++++	+++++	++++	+++	+++	+++	+++	+	+
Calanus finmarchicus	+++	+++	+++	+++	+++	+	++	+	++	++	+++	+++
Centropages hamatus	-	-	-	-	-	-	-	-	-	-	-	+
Heterorhabdus norvegica	-	-	-	-	-	-	-	-	-	-	-	-
Pleuromamma robusta	-	-	-	-	-	-	-	-	-	-	-	-
Metridia venusta	-	-	-	-	-	-	-	-	-	-	++	++
Rhincalanus nasutus	-	-	-	-	-	-	-	-	-	-	-	-
Microcalanus pusillus	-	-	-	-	-	-	-	-	-	-	-	-
Pareuchaeta norvegica	-	-	-	+	-	-	-	+	-	-	+	-
Pareuchaeta glacialis	-	+	-	-	-	-	-	+	+	-	+	-
Euchaeta spinosa	-	-	-	-	-	-	-	-	-	-	-	-
Pseudocalanus elongatus	+	+	+	+	+	++	+	+	+	++	+++	+++
Aetidius armatus	-	-	-	-	-	-	-	-	-	-	-	-
Lucicutia flavicornis	-	-	-	-	-	-	-	-	-	-	-	-
Scolocithrix minor	-	-	-	-	-	-	-	-	-	-	-	-
Oncea borealis	+	-	-	+	-	+	-	+	-	-	+	-
Nematoscelis megalops	-	-	-	-	-	-	-	-	-	-	+	-
Meganyctiphanes norvegica	-	-	-	-	-	-	-	-	-	-	+	-
Limacina retroversa	-	-	-	-	-	-	+	+	-	+	-	+
Limacina helicina	-	-	-	-	-	+	-	-	+	-	-	-
Clione limacina	+	+	+	-	+	+	-	-	+	+	+	+
Sagitta elegans	+	+	+	+	+	-	-	+	+	+	+	-
Eukrohnia hamata	+++	+	-	-	+	-	-	+	+	-	+++	+
Oikopleura labradoriensis	-	-	-	-	-	-	-	-	-	-	+++	+++

Salinity S°/oo Temperature t° Depth in metres	35.99 3.65 25	35.17 2.71 450	35.17 5.39 100	35.17 5.57 50	35.17 5.57 25	35.05 3.35 100	34.99 3.58 50	35.10 3.68 100	35.19 7.9 75	35.37 8.5 100	35.42 9.5 50	35.50 9.7 25
Collozoum groënlandicum	++	-	++	++	++	+	+	++	++	+++	+++	++
Physophora hydrostatica	-	-	+	+	-	-	-	+	+	+	+	+
Dimophyes arctica	-	+	+	-	-	+	-	+	+	-	-	-
Aglantha digitale	-	+	+	-	-	+	-	+	-	+	-	-
Tomopteris helgolandica	-	-	+	+	-	+	-	-	+	+	+	-
Conchaecia borealis	-	+++	+	+	-	+++	+	++++	+++++	-	-	-
Calanus hyperboreus	+	+	+	+	+	+	+	+	+	+	+	+
Calanus finmarchicus	+++	+++	++	+++	+++	++++	++	+++	+++	++++	+++++	+++++
Centropages hamatus	+	-	-	+	+	-	+	-	-	-	-	-
Heterorhabdus norvegica	-	+	-	-	-	-	-	-	-	-	-	-
Pleuromamma robusta	-	+	-	-	-	-	-	-	-	-	-	-
Metridia venusta	-	-	++	+	-	+++	+	+++	-	-	-	-
Rhincalanus nasutus	-	+	-	-	-	-	-	-	-	-	-	-
Microcalanus pusillus	-	+++	+++	+	-	+	-	+	+	-	-	-
Pareuchaeta norvegica	-	+	+	-	-	+	-	-	+	-	-	-
Pareuchaeta glacialis	-	+	-	-	-	-	+	+	-	-	-	-
Euchaeta spinosa	-	+	+	-	-	-	-	+	-	+	-	-
Pseudocalanus elongatus	+	-	+	+++	+	+	+++	++	+++	+	++++	++
Aetidius armatus	-	+	-	-	-	-	-	-	-	-	-	-
Lucicutia flavicornis	-	+	-	-	-	-	-	-	-	-	-	-
Scolocithrix minor	-	+	-	-	-	-	-	-	-	-	-	-
Oncea borealis	-	+	+	-	-	+	-	-	-	-	-	-
Nematoscelis megalops	-	+	+	-	-	-	-	-	+	-	-	-
Meganyctiphanes norvegica	-	+	+	-	-	+	-	+	+	+	-	-
Limacina retroversa	+	+	+	+	+	+	+	+	+++	+++	+++	+
Limacina helicina	+	-	-	-	-	-	-	+	-	-	-	-
Clione limacina	-	-	-	+	-	+	+++	+	-	+++	-	-
Sagitta elegans	+	-	-	-	-	-	+	+	-	-	-	-
Eukrohnia hamata	-	-	+	+	-	+	+	+	-	-	-	-
Oikopleura labradoriensis	-	+++	+++	++++	+++	+++	+++	+	+	-	+	-

1/ The quantity of organisms was determined by the method adopted by PINRO (see section entitled "Material and Method").

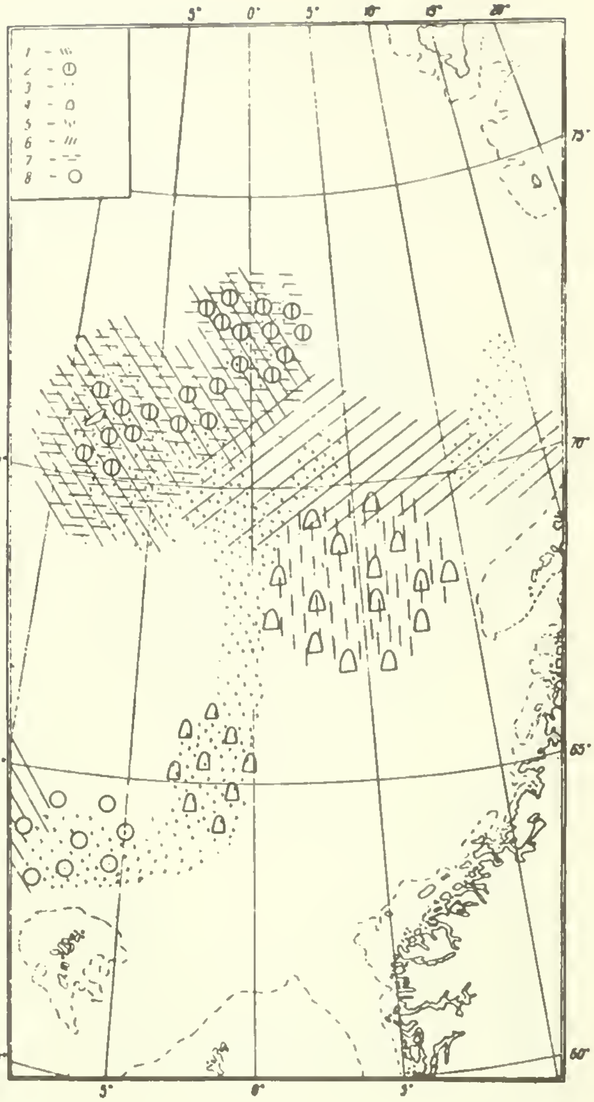

Figure 4. Population distribution of individual species of plankton during the summer of 1953. 1. Themisto libellula; 2. Oithona similis; 3. Pseudocalanus elongatus; 4. Aglantha digitale; 5. Oikopleura labradoriensis; 6. Themisto abyssorum; 7. Oncea borealis; 8. Euphausiacea.

Th. libellula is the predominant species in the Greenland Sea. In the north central area of the Norwegian Sea (in the Jan Mayen region and further north between longitudes 6°W and 0°) Themisto libellula and Th. abyssorum are found in the ratio of 3:1 at a salinity of 34.60-34.90°/oo and a temperature of +0.55 to -1.71°C.

On the other hand, in the central areas of the Norwegian Sea in the 50-100 m. layer, where the salinity is 35°/oo and more and the temperature is +3.47 to +3.86°C, the ratio of Th. libellula and Th. abyssorum is 1:3, i.e. Th. abyssorum predominates (Figure 7 and Table 2).

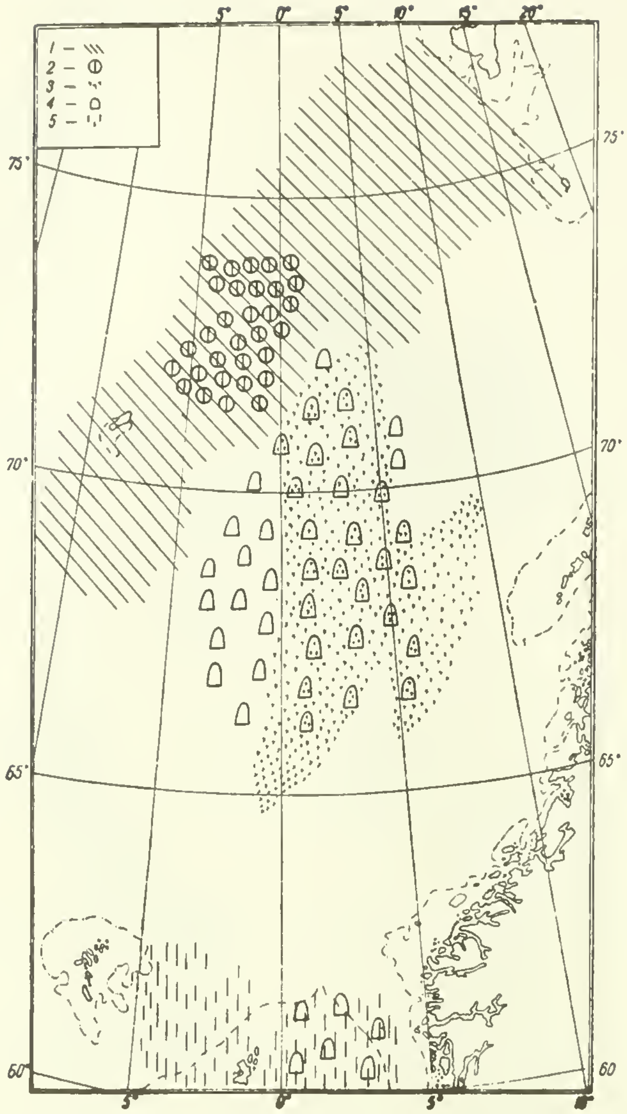

Figure 5. Population distribution of individual species of plankton during the spring-summer period of 1951. 1. Themisto libellula; 2. Oithona similis; 3. Pseudocalanus elongatus; 4. Aglantha digitale; 5. Oikopleura labradoriensis.

A small group of organisms which are found in very large quantities during the summer must be mentioned. To this group belong the marine Cladocera (Evadne nordmanni, Podon leuckarti), Cyclopidae (Oithona similis), Calanidae (Centropages hamatus, C. tipicus, Paracalanus parvus, Acartia clausi, A. longiremis) and others. In the literature these are described as neritic species (8). However, according to the data available to us, these organisms are found in large quantities in the open part of the sea (central areas of the Norwegian Sea) far from any coast, in areas with varying hydrological conditions. They therefore withstand the various fluctuations in salinity and temperature. They live exclusively in the surface water layers 0-50 m., and mainly in the 0-25 m. layer. They can therefore be regarded as surface species.

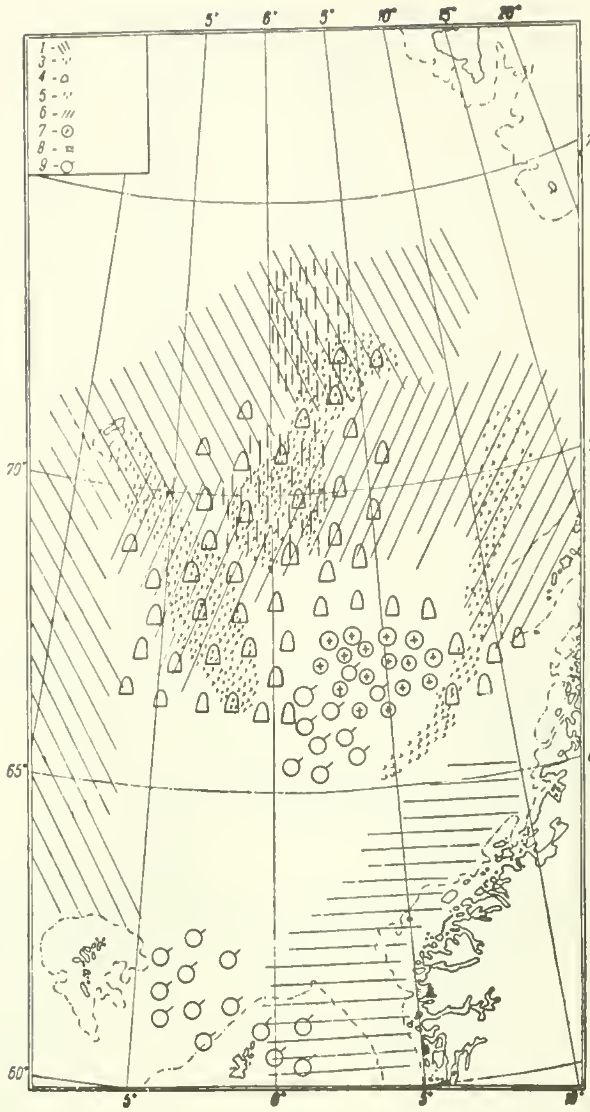

Figure 6. Population distribution of individual species of plankton during the spring-summer period of 1952. 1. *Themisto libellula*; 2. *Oithona similis*; 3. *Pseudocalanus elongatus*; 4. *Aglantha digitale*; 5. *Oikopleura labradoriensis*; 6. *Them. abyssorum*; 7. *Limacina retroversa*; 8. *Meganyctiphanes norvegica*; 9. *Physophora hydrostatica*.

The Norwegian Sea is under the constant influence of the Norwegian current, and consequently typical warm-water organisms are widespread in it. In addition to the above-mentioned usual mass species, warmth-loving species such as *Collozoum groënlandicum*, *Physophora hydrostatica*, *Tomopteris helgolandica*, *Metridia lucens*, *M. venusta*, *Rhincalanus nasutus*, *Pleuromamma robusta*, *Euchaeta spinosa*, *Meganyctiphanes norvegica*, *Nematoscelis megalops*, *Limacina retroversa* and others are found almost everywhere (see Figures 1, 8 and 9).

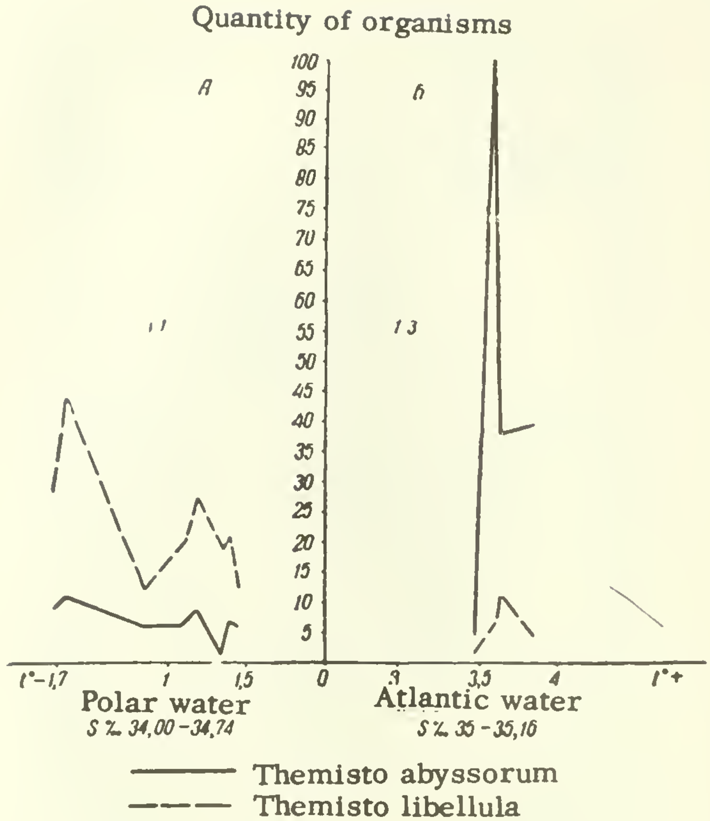

Figure 7. Variation in ratios between Themisto libellula and Themisto abyssorum in dependence on temperature in the polar waters and the Atlantic waters.
1. Quantity of organisms 2. Polar waters 3. Atlantic waters.

———— Themisto abyssorum

- - - - Themisto libellula

Some Atlantic species are extremely hardy with regard to temperature variations, and this enables them to travel far north into the Greenland Sea with the waters of the Norwegian current.

However, only those warmth-loving organisms which inhabit the surface water layers penetrate to the northern latitudes. Among these organisms are the Halosphaera viridis (flagellates), Colonial radiolaria, Collozoum groënlandicum, Limacina retroversa, (pelagic mollusc). These species are mostly concentrated in the 0-100 m. layer. In 1951, C. groënlandicum was found almost as far as latitude 77°N in the Norwegian current where the temperature was 1.7°C and the salinity 34.04°/oo. It may be assumed that this species penetrates a good deal further.

None of the warmth-loving plankton organisms which inhabit the Norwegian Sea in the deeper layers of water were found by us in the Greenland Sea.

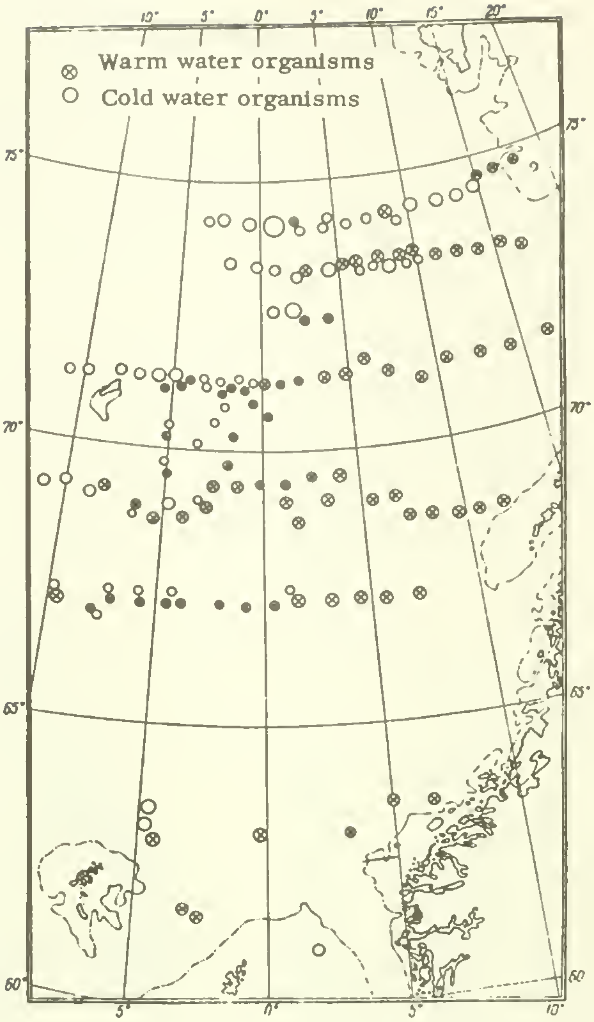

Figure 8. Distribution of warm-water and cold-water organisms in the 0-100 m. layer in 1952. ⊗ Warm-water organisms. o Cold-water organisms.

It appears that this is mainly due to the submarine ridge known as Mohn's Threshold[1/]. In some places, Mohn's Threshold has large eminences alternating with banks, above which rise caps of cold water, forming a sort of barrier which holds back the warm-water plankton fauna, hindering its northward movement.

An interesting biological feature of certain plankton organisms in the North Atlantic is the fact that individual species that inhabit the high latitudes and constitute the bulk of the zooplankton there are also found in considerable quantities in the central areas of the Norwegian Sea, normally at great depths, where the temperatures are low (0-1°C) and the salinity reduced (less than 35°/oo). Among these organisms are Dimophyes arctica, Calanus hyperboreus, Pareuchaeta norvegica, P. glacialis, Metridia longa, Scolocithrix minor, Clione limacina, Sagitta elegans, Eukrohnia hamata and Oikopleura labradoriensis.

1/ A natural frontier in the north of the Norwegian Sea running in a north-easterly direction from Jan Mayen to Bear Island.

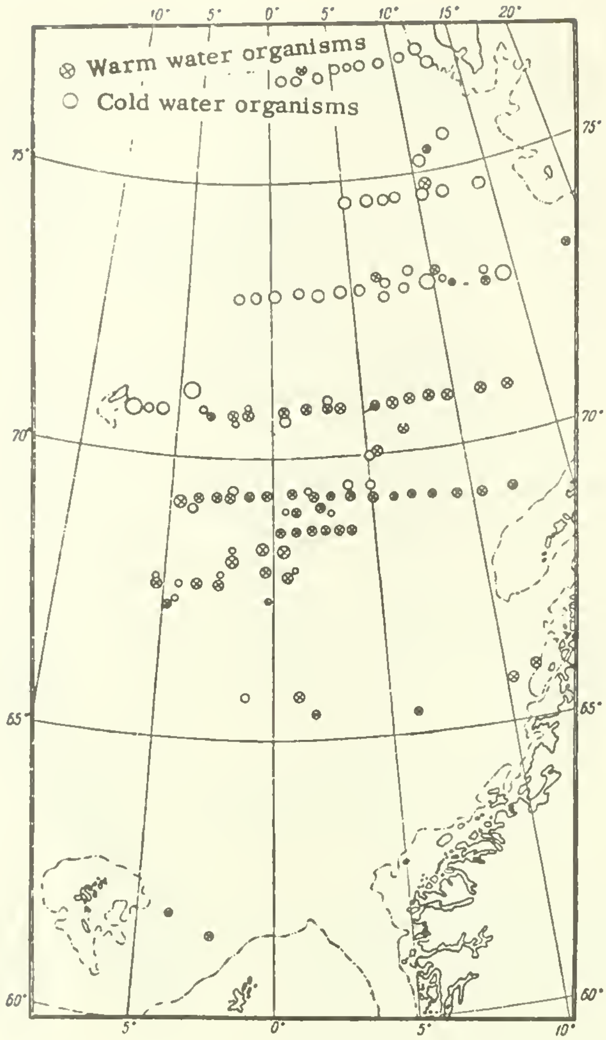

Figure 9. Distribution of warm-water and cold-water organisms in the 0-100 m. layer in 1951. ⊗ Warm-water organisms o Cold-water organisms.

In the charts (Figures 1, 8, and 9), the organisms in the central areas of the Norwegian Sea are shown as cold-water species, since the biotopic conditions here are similar to those of the Arctic.

In the light of observations made over a number of years, we are inclined to regard them as bathypelagic species as far as the Norwegian Sea is concerned. In the Norwegian Sea, these organisms are indicators of deep waters and low temperatures.

The heterogeneous composition of the plankton indicates the presence in the North Atlantic seas of waters of different origins and confirms the existence of constant currents in the Norwegian and Greenland Seas from the Atlantic Ocean and the Polar Basin.

Thus, the plankton composition also varies with the differences in origin and distribution of the water masses.

TABLE 2. QUANTITATIVE DISTRIBUTION OF SPECIES OF AMPHIPODA IN THE NORWEGIAN SEA RELATED TO THE DEPTH, SALINITY AND TEMPERATURE.

Salinity S^o/oo	34.79	34.69	34.60	34.90	34.81	34.72	34.63	34.78	34.74	34.67	35.16	34.99	34.99	35.17
Temperature t^o	-0.82	-1.71	-0.58	-0.90	-1.17	-1.14	-0.63	-0.55	-1.66	-0.65	-3.47	3.88	3.65	5.38
Depth in meters	100	50	25	100	100	50	25	100	50	25	100	50	25	100
Species														
Themisto libellula	28	20	17	20	18	42	21	20	43	18	1	4	11	6
Themisto abyssorum	9	7	6	6	6	23	7	7	11	1	4	39	37	100

TABLE 3. VERTICAL DISTRIBUTION OF INDIVIDUAL SPECIES OF COPEPODA IN THE NORTH ATLANTIC SEAS RELATED TO THE DEPTH, SALINITY AND TEMPERATURE (EXPRESSED AS PERCENTAGES).

Salinity S^o/oo	34.78	35.17	35.17	35.05	35.19	34.41	34.41	35.37	35.42	35.50
Temperature t^o	-0.55	5.57	5.57	3.35	7.9	1.0	1.0	8.5	9.5	9.7
Depth in meters	100	50	25	100	75	50	25	100	50	25
Species										
Metridia longa	52			80						
Metridia lucens							4.3	38.3	27	
Temora longicornis		35	90		25					27
Acartia clausi		30			27	70	9.5			
Oithona similis						25	35	18		
Oithona atlantica		23	10.5				5.9	27	70	70

Bogorov (4) gives the following vertical graduation for plankton: "Surface", "middle-depth" and "deep-water". These divisions, however, are very arbitrary. Although the individual species are found in masses in specific strata ("surface" species and "deep-water" species), we cannot go so far as to say that they are found only in a given layer.

The organisms change their level according to the biological season, time of day, and ontogenetic characteristics of their development.

Table 1 shows how the individual plankton species in the North Atlantic are dependent on specific depths, temperatures, and degrees of salinity.

Table 3 shows the quantitative distribution of a small number of species of Copepoda in the North Atlantic seas.

QUANTITATIVE DISTRIBUTION OF PLANKTON

Influence of Currents on the Quantitative Distribution of Plankton

An increase in the quantity of warm-water or cold-water organisms indicates increased influx of warm or cold waters.

A variation in the intensity of the influx of warm or cold water exerts a considerable influence on the development of the biological processes and on the times of the biological seasons. Mass development of plankton is characteristic of the biological spring. As a rule, however, an increase or decrease in the plankton volume during the biological spring period is due to a variation in the intensity of the influxes of warm or cold waters.

Development of plankton in 1952 and 1953 in the Norwegian Sea began at the same time, and the plankton biomass in these years in the latitude of Andøy was almost the same (Figures 11 and 12). We can conclude from this that the intensity of the influx of warm waters into the North Atlantic seas was the same during the last two years, but in 1953 an increase in the quantity of warmth-loving organisms was observed in the central and north-central areas of the Norwegian Sea and in the south of the Greenland Sea (see Figure 1); this appears to be due to a certain strengthening of the western branch of the Norwegian current.

During the summer months, there is a noticeable decline in the plankton biomass, which is mainly due to its being eaten by planktonophages, especially the herring. In Figures 10, 11 and 12, the places with the lowest plankton biomass are in the areas through which the herring have passed or remained for a considerable period (according to the figures of the Herring Laboratory). This distribution of the plankton biomass for the different years is for the same season (June) and for the same depth (0-50 m. layer).

The observations of 1952 showed that the plankton biomass is smallest in the currents (Figure 13, graphs I, II, III) and at the places where warm and cold waters intermingle (see Figures 10, 11, and 12). In order to get an idea of the times at which the biological processes develop in the current and beyond its boundaries, we used the figures for the mean biomass of plankton from stations in and outside the paths of the currents. The illustrations show how the biomass increases towards the centre of the current.

In the spaces between the currents the biological processes become later in time, and their development is slow and uniform (low biomass). This can be seen particularly clearly in graph II.

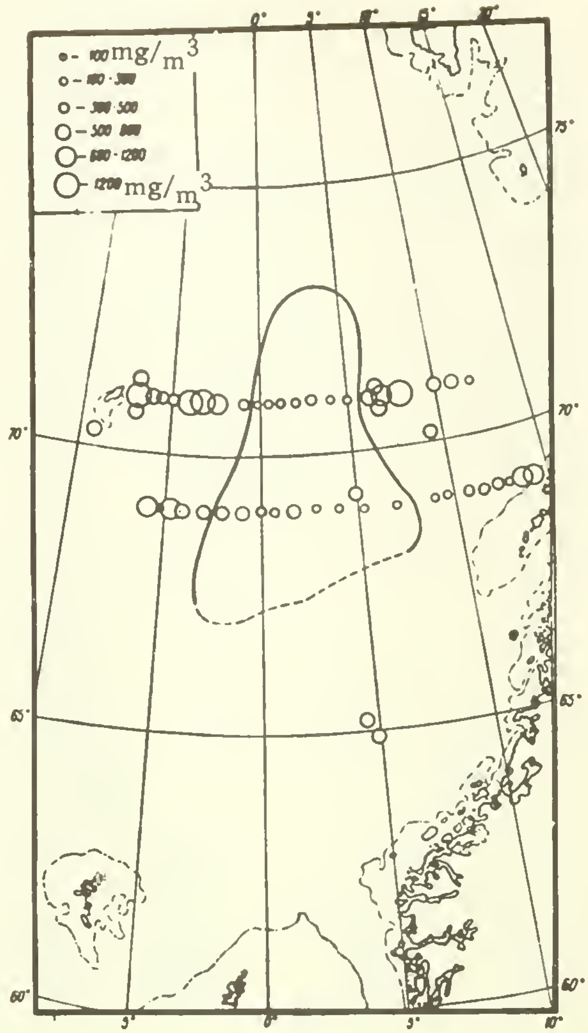

Figure 10. Biomass of plankton (in $mg/_m3$ in the 0-50 m. layer in 1953.

The boundary of the feeding area of the herring in June 1953 is indicated by the continuous and broken line.

At first sight, the 1953 chart(Figure 10)does not confirm this conclusion, as the lowest volumes were observed in June in the current (western branch). However, according to the herring fishery survey, large numbers of herrings gather in this area in June every year (see Figures 10, 11, and 12) and remain here in these concentrations for a long time and eat most of the plankton.

Influence of Temperature on Quantitative Vertical Distribution of Plankton

Variations in the quantity of plankton also vary to a large extent with the temperature of the water.

Mass development of plankton, together with a considerable increase in its biomass, begins in the spring when the upper layers of the water start to become warmer.

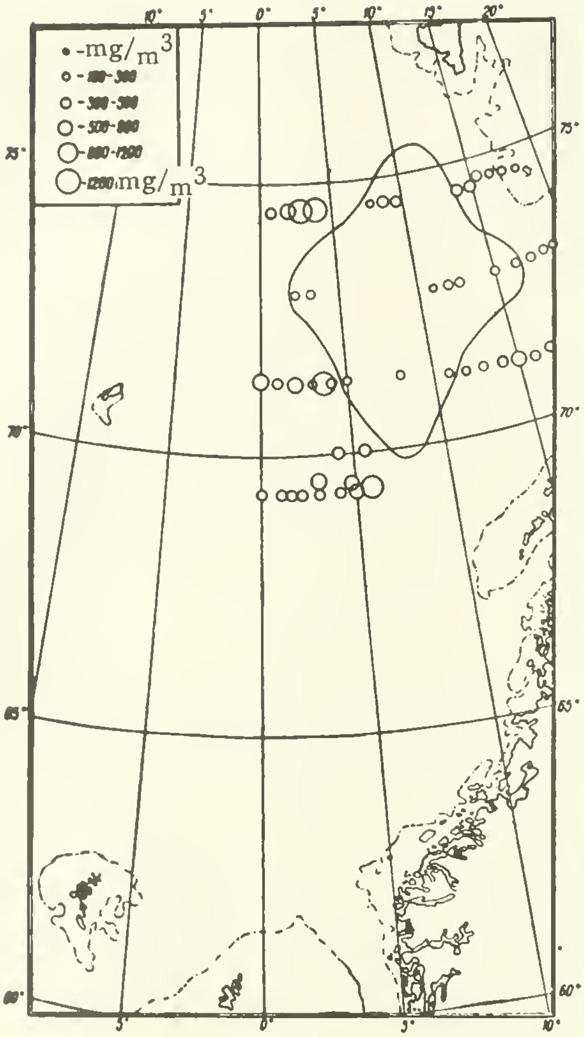

Figure 11. Biomass of plankton (in mg/$_m$3) in the 0-50 m. layer in June 1952.

The boundary of the feeding area of the herring in June 1952 is indicated by the continuous line.

When the temperature falls there is a slowing-down in the development of plankton as well as in the increase of its biomass.

Table 4 shows the biomass in the area round Jan Mayen in June 1953 at neighboring stations of one of the sections.

According to data obtained by the PINRO Oceanographic Laboratory in 1952 and 1953, there was a rise in the cold bottom waters near Jan Mayen, which explains the sharp reduction in the biomass of plankton at station 89.

The influence of temperature on the development and vertical distribution of plankton are clearly illustrated by graphs I, II, III and IV (Figure 14).

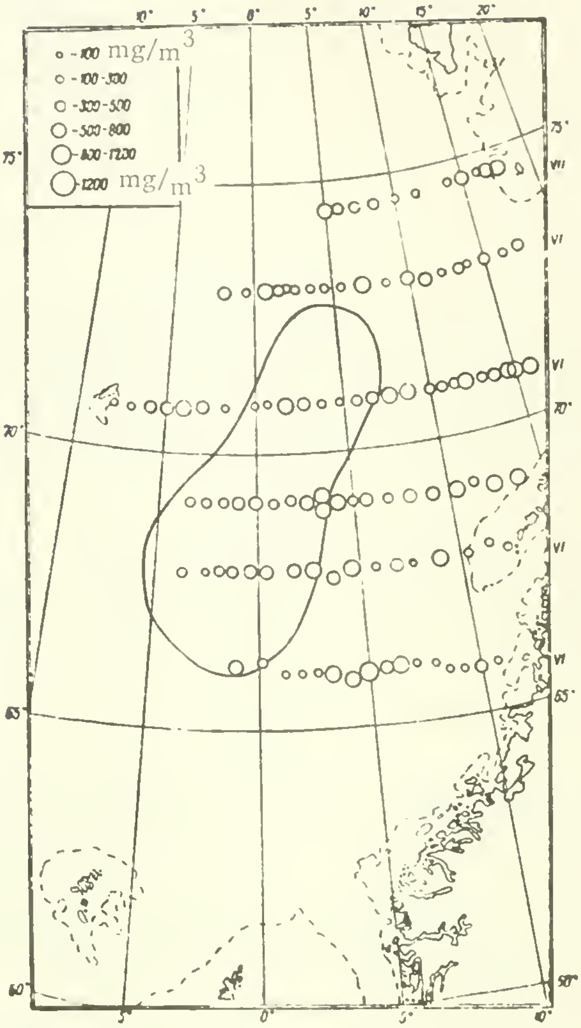

Figure 12. Biomass of plankton (in $mg/_m3$) in the 0-50 m. layer in May, June and July 1951.

The boundary of the feeding area of the herring in June 1951 is indicated by the continuous line.

During the early biological spring (April-May) the water temperature is the same throughout almost its entire depth and scarcely any warming of the upper layers can be observed. Plankton is evenly distributed. Its biomass is very low - 20-30 $mg/_m3$ (graph I). Then, from June onwards, the temperature of the upper water strata rises, and there is one layer (thermocline) where the abrupt temperature change is very marked (graph II). The mass development of plankton begins during this season. Its biomass increases noticeably and the plankton collects above the thermocline, which, as it were, creates a kind of "floor" which contains the plankton.

During the summer months, the vertical distribution's dependence on the temperature is somewhat different. This is partly due to the biology of the organisms themselves.

Table 4. Variation in biomass of plankton in dependence on temperature variation.

Number of stations	Layer	Mean temperature of water in °C	Biomass in mg/m^3
89	0-50	-0.1	331
90	0-50	1.2	1875.1

Owing to the sharp increase in the temperature of the upper layers of water, the thermocline sinks somewhat and almost ceases to act as a barrier containing the plankton. At this period, the biomass of plankton rises to 1200 mg/m^3 (graph III) in the thermocline. This phenomenon is particularly pronounced in the areas near the polar front (in the vicinity of the Faroes and Jan Mayen), where warm and cold waters meet. Here, in the layer of abrupt temperature change, cold-loving organisms - especially Calanus hyperboreus - also collect in large quantities (graphs III and IV).

In the polar-front areas, the development of the biological processes is later than in other areas, and the biological spring occurs during the summer months. The cold-water copepods multiply at low temperatures, and as the upper layers of water are well warmed by this time, the bulk of C. hyperboreus becomes concentrated in the thermocline, where the temperature is low.

SPECIAL FEATURES OF PLANKTON DISTRIBUTION IN 1951-53

It is well known that the qualitative composition of plankton varies in the course of the year and that there is a specific composition of organisms, or complex, for each biological season. This is due to variations in the physicochemical conditions of the environment (12).

However, in some years certain deviations are found during the period of mass development of the plankton; variations occur in the ratio of individual species to one another and in the area which they occupy.

Thus, in 1951, there was a very extensive spread of Aglantha digitale (see Figure 5) during the spring and the summer season in the central areas of the Norwegian Sea to a depth of 200 m. This medusa, being an oceanic deep-water species, remains in the currents. In different areas, however, it is found in association with other species. At the end of March and during April, Aglantha has been found in the south of the Norwegian Sea, on the Viking Bank, in association with Oikopleura labradoriensis.

O. labradoriensis occurs in an isolated patch in the channel between the Faroes and Shetlands.

Further north, for instance in latitude 65°N, large quantities of Aglantha (in May and June) in association with Pseudocalanus elongatus have been observed in the western branch of the Norwegian current as far north as latitude 72°N.

In 1952, at this same season, a patch of Euphausiacea (Meganyctiphanes norvegica) and Siphonophora (Physophora hydrostatica) was observed in the plankton in the southern part of the Norwegian Sea (see Figure 6). An "outburst" of the pelagic mollusc Limacina retroversa in association with Physophora hydrostatica was found on the Norwegian Plateau in the continental stream of the Norwegian current.

Figure 13. Distribution of plankton biomass in the current and in the area between currents (June, July, and August 1952). I. North central areas of the Norwegian Sea and the Bear Island-Spitsbergen area of the Greenland Sea -June; II. Jan Mayen, Central Plateau, Central Basin, (southern and western parts), Norwegian Plateau -July; III. Central areas of the Norwegian Sea and northern part of the Norwegian Plateau -August.

________ In the current
. . . . Between the currents

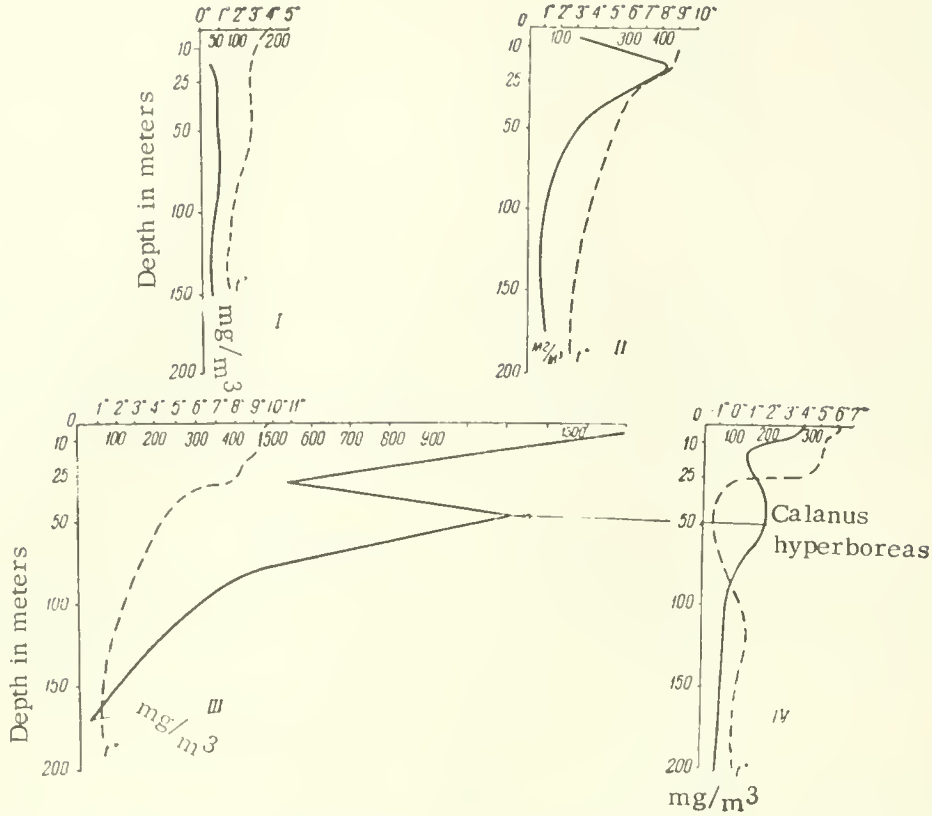

Figure 14. Variations in biomass of plankton in dependence on variations in water temperature. I. Near the southern edge of the East Icelandic current (station No. 67, 19th May 1953); II. In the southern central part of the Norwegian Sea, in mixed waters (station No. 108, 16th June 1953); III. To the north-east of the Faroes, in the waters of the East Icelandic current (station No. 110, 22nd June 1953); IV. To the north-east of Jan Mayen, in mixed waters (station 134, 13th July 1953). Vertical scale: Depth in metres.

In the Central Basin (western part), on the Central Plateau, and in the area of Jan Mayen there is a population of two species of Amphipoda: Themisto abyssorum, whose habitat includes the "patch" of Oikopleura, and Themisto libellula, whose habitat lies along the northern boundary of the Norwegian Sea and further west. The species Th. libellula predominates in the Greenland Sea (see Figure 5).

During the 1953 season, the principal species of Copepoda in the plankton was Pseudocalanus elongatus, which was found everywhere in the 0-25 metre layer. Its quantity increases in the currents. (see Figure 4). Thus, in the middle of May, P. elongatus was found in considerable quantities near the Faroes in latitude 63°N and longitude 3°W. The quantity increases towards the north, especially in the western current.

In the area of Jan Mayen, P. elongatus is usually found in the 50-metre layer in association with Oithona similis and Oncea borealis.

In 1953, O. similis was found in large quantities with On. borealis, the latter being a widespread species in the northern seas. The largest quantities of these two species were found in the 0-25 m. layer in the area of the polar front, near Jan Mayen and between latitudes 71°30' and 73°N in longitude 3°E.

Conclusions

The physico-geographical characteristics of the Greenland and Norwegian Seas and the existing system of warm and cold currents in the individual areas create peculiar hydrological conditions - the phenomenon known as the polar front - where warm-water and cold-water organisms are found simultaneously, their presence enabling us to ascertain the nature of the water masses in a given area of the sea.

2. The most numerous forms in the plankton found in the North Atlantic are Copepoda - Calanus finmarchicus and Pseudocalanus elongatus.

The quantities of these are particularly great in the currents (continental and western).

The second place is occupied by the group Amphipoda (Themisto abyssorum and Th. libellula) in the north central part of the Norwegian Sea. Themisto libellula is the predominant species in the Greenland Sea.

The marine Cladocera and individual species of Copepoda (Cyclopidae and Centropagidae) which inhabit the surface layer of water (0-25 m.) constitute a numerous group during the summer in the central areas of the Norwegian Sea.

3. Warm-water plankton organisms are widespread in the Norwegian Sea. This is due to the presence of the constant Norwegian current in this sea.

Individual warm-water plankton organisms (Collozoum groënlandicum, Limacina retroversa), the main bulk of which is concentrated in the 0-100 m. layer, travel far northwards into the Greenland Sea (reaching latitude 77°N).

Deep-water organisms do not enter the Greenland Sea, as they are checked by Mohn's Threshold.

4. Some plankton organisms which inhabit high latitudes, where they constitute the basis of the zooplankton, normally inhabit the bottom waters in the central areas of the Norwegian Sea. Among these are the species Dimophyes arctica, Calanus hyperboreus, Pareuchaeta norvegica, P. glacialis, Metridia longa, Scolocithrix minor, Clione limacina, Sagitta elegans, Eukrohnia hamata, Oikopleura labradoriensis.

5. Variations in the strength of the warm- or cold-water currents have a considerable influence on the development of the biological processes and on the times of the biological seasons.

Any strengthening of a cold- or warm-water current can be assessed from an increase in the quantity and from the distribution of warm-water or cold-water plankton organisms, such as took place in 1953 (strengthening of the western branch of the Norwegian current).

6. Plankton is considerably more abundant in currents than it is beyond their boundaries. During the summer the biomass in the 0-50 m. layer is 4,000 mg/m^3, whereas in the space between currents it scarcely reaches 300 mg/m^3.

Consequently, the quantity of individual species of plankton also serves as an indicator of currents.

7. Temperature is an important factor influencing the vertical distribution of plankton.

A thermocline arises with the warming of the upper layers of water in spring. The mass development of plankton normally begins at this time of year; its volume increases noticeably, and the plankton collects above the thermocline, which serves as a "floor".

In the summer, in the areas of the polar front, there is a large plankton biomass above and in the thermocline, cold-loving organisms - especially Calanus hyperboreus - collecting in this layer.

8. Waters of different origins differ considerably in their qualitative plankton composition. In view of this fact, charts of plankton distribution can be used for drawing the boundaries of a current more accurately when making current charts of the areas under investigation.

9. A certain deviation in the distribution and predominance of populations of different species is observed in some years during the period of mass development of plankton.

Thus, Aglantha digitale was the predominant species of plankton in the central areas of the Norwegian Sea during the spring and summer period of 1951. In the south, Aglantha was observed in association with Oikopleura labradoriensis. Further north, for instance in latitude 65°N, Aglantha is observed more and more in association with P. elongatus in the western branch of the Norwegian current, as far as latitude 73°N.

At the same season in 1952, patches of Euphausiacea and Siphonophora were observed in the plankton in the southern part of the Norwegian Sea. An outburst of the pelagic mollusc Limacina retroversa was observed in the central areas. There is a population of Amphipoda in the central plateau and in the area of Jan Mayen.

In the 1953 season, the predominant species of plankton was Pseudocalanus elongatus - one of the Copepoda. In the area of Jan Mayen, P. elongatus was observed in the 0-50 m. layer in association with Oithona similis and Oncea borealis.

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SEASONAL CHANGES IN PLANKTON AND FEEDING MIGRATIONS OF HERRING[1/]

E. A. Pavshtiks

INTRODUCTION

In recent years, the Soviet herring-fishing industry has covered almost the entire feeding area of the Atlantic-Scandinavian herring.

The biology of the herring depends on the seasonal changes in the marine plankton. At the same time, the schools of feeding fish affect the composition and quantity of plankton. Seasonal phenomena in the plankton, on the other hand, depend, to a considerable extent, on solar radiation and the hydrological conditions of the basin.

Regular observations of the dynamics of plankton production, first in the Barents Sea, and during recent years in the Norwegian and Greenland Seas, have made it possible to establish approximate periods for the plankton production and the duration of the biological seasons for the various regions of these seas.

A study of the principles governing the development of marine biological seasons, as well as a disclosure of the reasons for the migration of herring are necessary for the proper organization of a survey of the fishing industry (20).

In this work, the results of the research into the influence of annual fluctuations in the periods of the plankton production for the fattening of herring in the Norwegian and Greenland Seas have been summarized.

This research was conducted by the Polar Institute from 1948 to 1955.

History of Research

The following Soviet scientists were engaged in a study of the seasonal phenomena in the northern seas plankton: P. P. Shirshov (30), V. G. Bogorov (2, 3, 4), B. P. Manteyfel' (17, 19), V. A. Yashnov (31). These investigations were connected with the utilization of the northern sea route and the development of the fishing industry in the North.

In the Arctic or polar seas--this was established by the studies conducted by V. G. Bogorov and B. P. Manteyfel'--several plankton complexes which are characteristic of the various biological seasons, can exist simultaneously in close proximity (at times even in one and the same region). V. G. Bogorov furnished a description of the biological seasons in the plankton of various seas. He also compiled a chart of the changes in their duration.

PINRO investigations in the Barents, Norwegian and Greenland Seas confirm to a considerable extent the accuracy of the principles--disclosed by Bogorov--that govern the seasonal plankton

1/ Fisheries Research Board of Canada Translation Series No. 175.

distribution.

PINRO expeditions that carried out research in the Barents Sea from 1935 to 1941 studied the relationship of herring to the different plankton complexes. It was proven that the distribution of schools of herring and other pelagic fish in the sea and the times of their approach to certain regions depend, to a great extent, on the time of the plankton production.

Somewhat earlier, the British scientists, Hardy, Savage and Wimpenny (42), Savage (38, 39, 41), and Savage and Hardy (47), who studied the North Sea herring, had studied the relationships between plankton and herring.

When counting the number of herring caught in regions with various plankton complexes, they came to the conclusion that "blooming" has a negative or adverse effect upon herring schools; but that concentrations of Calanus finmarchicus are favorable for herring. Hardy, Lucas, Henderson and Fraser (36) also established that at certain times the positive relationship between plankton and herring is interrupted and assumes a negative nature. They furnished no explanation for this phenomenon; for they lacked the data on the seasonal changes of plankton in relation to hydrological and meteorological conditions.

In recent years, works were published in foreign countries (44, 45, 47) in which plankton was regarded as an indicator of waters of various origins.

It is a matter for regret that nothing was said in the latest works of Norwegian and English scientists about the role of plankton in the life of the herring.

Soviet scientists approached this problem in a different way: their investigations dealt with a wide range of problems (seasonal changes in phytoplankton and zooplankton, the feeding and fatness of herrings, changes in the hydrological regime or cycle, etc.).

The works of N. V. Pchelkina (28, 29), T. N. Mosentsova (25, 26), B. P. Manteyfel' (18, 19) and G. V. Boldovskiy deal in detail with the relationship of herring to the various plankton complexes in the Barents Sea.

It was established that there is not always a direct relationship between the concentrations of zooplankton and herring. For instance, in August, an inverse relationship was observed between herring concentrations and Calanus finmarchicus. But, in September and October, C. finmarchicus has no influence upon the distribution of herring; for its quantity in the upper water strata has been reduced considerably and the herring, having stored sufficient fat, almost cease to feed.

A. P. Kusmorskaya (13, 14, 15) carried out interesting work in connection with the influence of sardines upon the distribution of plankton in the Sea of Japan. She, i.e. Kusmorskaya, came to the conclusion that in those years when the sardines met with favorable feeding conditions in the open sea their approach to the shores was delayed. When feeding, the sardines tarry in one region or another. This depends on the quantity of feed they encounter and on favorable temperature conditions (15).

M. S. Kun (11, 12), I. M. Meshcheriakova (24), V. T. Bogayevskiy (1), K. I. Panin, coworkers in TINRO (Pacific Fisheries Research Institute) carried out analogous research in Far Eastern seas. These authors also noted that the feeding migrations and the feeding periods of pelagic fish were related to the seasonal plankton changes.

The plankton of the Norwegian and Greenland Seas has been studied to a considerably lesser degree than the plankton of the North and Barents Seas.

A study of the plankton of the Norwegian Sea was begun as early as the XIX century. But, at that time, the study was of a descriptive nature. The monograph by Gran (33) is the most complete summary of the investigations of the early period. He set aside groups of planktonic organisms that characterize Atlantic and Arctic waters. Gran is of the opinion that the development times of plankton during the spring-summer period can change depending on the temperature of the Atlantic current.

On the basis of oceanographic observations from 1900-1904, Helland-Hansen and Nansen wrote also on the existence of annual fluctuations in the temperature cycle of the Norwegian Sea.

These scientists came to the conclusion that in warm years cod would approach the shores at a later date than in cold years. They are of the opinion that in cold years more of the polar waters enter the Norwegian Sea. These waters abound in nutrient substances. This results in conditions that are favorable for the production of plankton and, therefore, also for the fattening of fish. Their hypothesis was confirmed also by our observations.

At first, the PINRO investigations embraced only the region of the Lofoten Islands and the south-eastern regions of the Greenland Sea (1947-1949).

Since 1950, plankton has been collected also in the open part of the Norwegian Sea. The region of the research increased each year and by 1954 it included the large water basin of the Norwegian and Greenland Seas.

Our investigations made it possible to establish a few principles that govern the production and distribution of plankton during the feeding period of herring.

Material and Methods

Material that had been gathered in the Norwegian and Greenland Seas during the past eight years (1948-1955) formed the basis for our work. During this period, 4,700 samples were collected at 2,106 stations.

Plankton was gathered with a Nansen closing net. It had a diameter of 50 cm. The material used was gauze No. 3/23. The plankton was gathered at standard depths: 0-25 m.; 25-50 m.; 50-100 m.; 100-200 m.; 200-500 m.

The depths 0-10 m. and 500-1,000 m. were fished only on some occasions. In stormy weather, as a rule, only a total catch was made (0-100 m., 0-50 m.).

All the plankton samples were checked first aboard the vessel. The predominant mass-groups of planktonic organisms were entered in a journal.[1/]

After finishing the routine survey, maps showing the distribution of plankton for this period were compiled. These maps, together with the other material, were passed on to the administration of the herring-fishing industry.

After returning to port, all the plankton samples were studied in the PINRO laboratory by means of binoculars. The qualitative composition of plankton, the approximate number or quantity

1/ This method was described in the work of B. P. Manteyfel' (17,19).

of the most characteristic planktonic organisms, but also the rare organisms, were carefully noted.

The number or quantity of individual organisms was established by means of a Petri dish[1/], which was accepted as a standard.

In cases where Calanus finmarchicus or some other species of animals covered the entire bottom of the Petri dish forming a single layer (this layer was carefully checked) we would assume that there was a "fair" amount of organisms in the plankton. If only one half of the bottom of the Petri dish was covered, it was looked upon as "little"; if only one-quarter, then it was regarded as "very little". If, when checking the sample of plankton, it became necessary to divide or pour into the Petri dish several times, then it was assumed that there was "much", "very much" or a "mass" of plankton (depending on the number of checked portions: two, three, or more than three). The volume of the deposit was also noted (for instance, 100 cm.). The number of large organisms (Hyperiidae, Euphausiacea, medusae jellyfish and Ctenophora) of the entire sample was counted. At the same time, the entire plankton sample was weighed after it had been strained through No. 23 gauze and dried on filter paper. The raw weight of plankton was then used to establish the contents of 1 m^3 (the plankton-titer according to Yanshov /32/). In view of the fact that during the spring-summer period usually one species of organism predominates in the plankton samples (rarely two or three), we regard this method as fully admissible for quick operative processing of extensive planktonic material. Under field conditions and in a laboratory, one person can, by means of this method, process about a thousand plankton samples in two to three months.

Principles Governing the Seasonal Development of Plankton and Their Influence Upon the Distribution of Herring

Extensive material on the composition and distribution of plankton obtained as a result of investigations in recent years has made it possible to establish the time of the beginning and of the duration of biological seasons in the Norwegian and Greenland Seas (Figure 1). The principal forms of plankton for every biological season were classified. Further, a chart of their distribution and vertical shifts in the water strata was compiled.

Figure 2 shows that the main mass of planktonic organisms winters in deep water; but, towards the end of the hydrological winter, Calanus finmarchicus and Euphausiidae rise in the water and form pre-spawning concentrations near the surface. The spawning of crustaceans coincides with the bloom of the alga Phaeocystis. These phenomena mark the beginning of the biological spring. Soon the "green bloom" (mass development of Phaeocystis) is replaced by a brown "diatom bloom". At this time, the young of Calanus grow into fat, red Calanus. During the biological summer, the development of diatoms continues. Ctenophora and jellyfish appear and, together with other planktophagous organisms, destroy the red Calanus. The crustaceans that survive descend into deep water. At the end of summer, when daylight is replaced by darkness, Calanus begins to perform diurnal vertical migrations. Towards autumn, the vertical migrations by Calanus decrease. Tiny Copepoda and thermophilic organisms, as well as peridineans algae, appear in the surface layers. With the onset of winter, the plankton concentrates in deep water.

Experience has shown that when studying the seasonal phenomena in plankton, it is necessary to bear in mind the likelihood of a shift in the times for the development of marine biological processes under the influence of a decrease or increase in the influx of warm waters from the Atlantic. Further, one must bear in mind the warming of the water due to solar radiation, the chilling of the waters due to melting ice, etc.

1/ A Petri dish has a diameter of 10 cm.

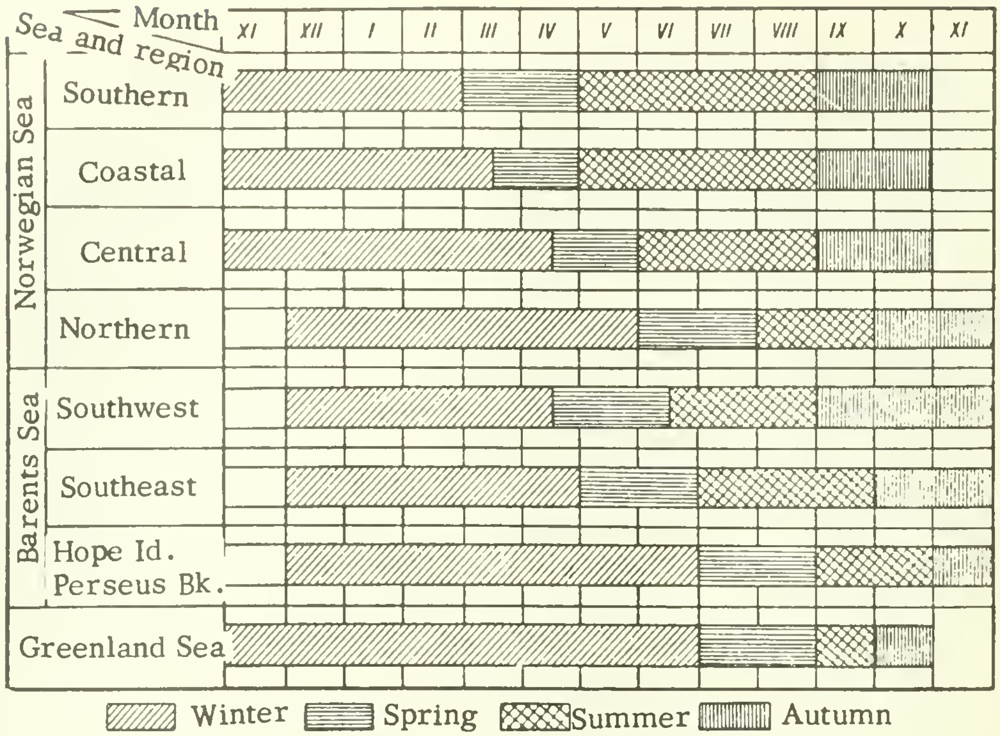

Figure 1. The duration of the biological seasons in the northern seas.

However, regardless of the fact that the time or length of the biological seasons in different years can change or vary somewhat, it is, nevertheless, possible to establish some regularity in the development and sequence of seasonal plankton phenomena.

Figure 1 shows how the beginning of the biological seasons change gradually from south to north. This is related, to a considerable extent, to climatic conditions.

The spring-summer period lasts for a half year in the coast waters of Norway and in the southern part of the Norwegian Sea. In the central deep-water regions, it does not exceed four months. But in the Greenland Sea it does not always last three months. The shortest winter occurs in the southern part of the Norwegian Sea, whereas the Greenland Sea has the longest winter.

The plankton of the entire area of the Norwegian and Greenland Seas is poor in the area during the winter time. Its quantity increases somewhat with depth, but even at more than 300 m. it does not exceed 10 mg/m^3. In the upper 100- meter layer during the winter months (December-March), the weight of plankton organisms is barely several milligrams per cubic meter. Copepoda and Euphausiacea occur only as individual specimens in plankton samples. For example, the composition of a sample of plankton obtained from the 0-25 m. level on February 4, 1954, in the southern part of the Norwegian Sea, reads as follows:

	Number of specimens.
Calanus finmarchicus IV and V stages	4
Oithona similis	4
Oithona atlantica	4
Pseudocalanus elongatus	3
Eukrohnia hamata	1

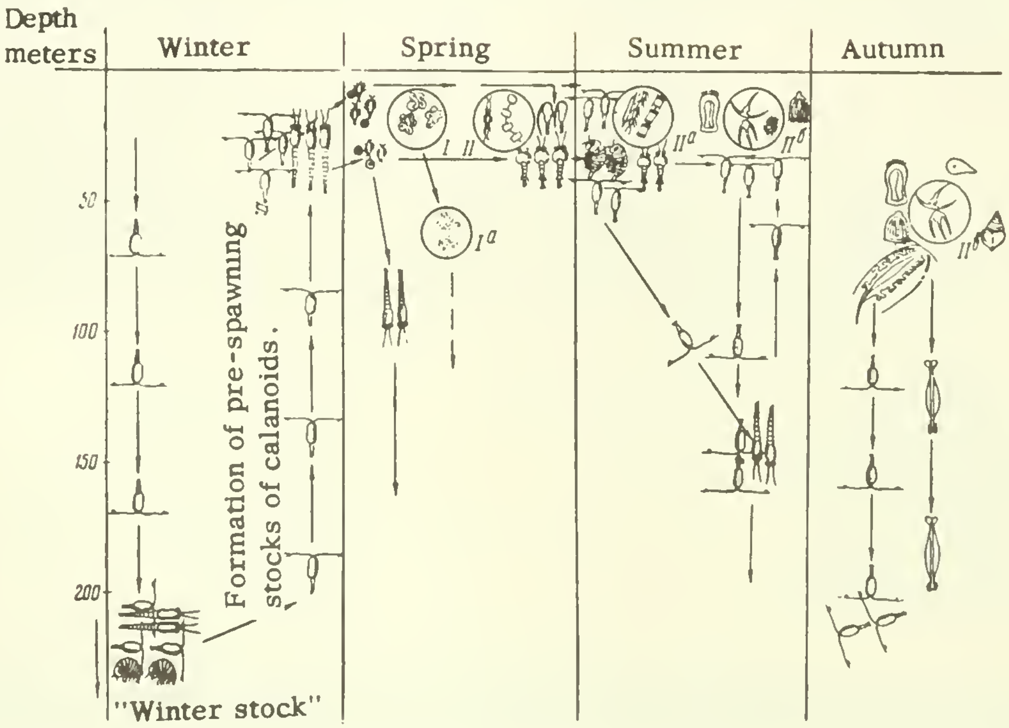

Figure 2. Chart of the distribution of the main planktonic organisms in the water during the various biological seasons. Spring -green bloom (I) and the reproduction of crustaceans. Their eggs and nauplii are in the plankton. The development of diatoms (II) and the growth of young Calanus, of euphausids and others. The descent of the euphausids that have spawned and the dying of the green bloom (I^a). Summer - the rapid development of diatoms (II^a and II^b). Fat, red Calanus and the young of euphausids. Diurnal vertical migrations of Calanus. Autumn- mass development of jellyfish and Ctenophora. Descent of Calanus and of other organisms into the deep. Formation of the "winter stock".

In certain places where there are depressions in the sea bottom, small concentrations of planktonic organisms, the so-called "winter stock", can be observed.

At the end of winter, sexually mature Euphausiacea and also individual specimens of Calanus finmarchicus that are getting ready for spawning leave the bottom layers. In the southern regions of the Norwegian Sea they begin their diurnal vertical migrations.

The pre-spawning concentrations of Euphausiacea, in particular of Meganyctiphanes norvegica, are encountered as early as the latter part of February.

These crustaceans are represented in the plankton catches only by individual specimens, but they were found in large numbers in the stomachs of individual herring (up to 65 specimens, according to data by V. A. Rudakova).

Two to three weeks later--in the second half of March--spawning concentrations of Calanus finmarchicus are formed in the coast waters of the southern and central regions of the Norwegian Sea.

The development of phytoplankton and the spawning of Euphausiacea are regarded by us as the first indications of the biological spring. Usually these phenomena were first observed in the coast regions in the southern part of Norway. The eggs and nauplii of Euphausiacea were encountered in plankton.

The spawning of Calanus finmarchicus begins in the latter part of March and in April in the Atlantic waters, which have a temperature of 7^{o} and in the mixed waters (with a considerable admixture of Atlantic waters) that have a temperature of $4\text{-}5^{o}$ (Figure 3 a, d). During this period, the principal mass of crustaceans is concentrated in the 0-10 m. layer. As a result of this, the biomass there rose to 400-500 mg/m^3. During the biological spring, the quantity of plankton is increased abruptly and its composition becomes more varied. For instance, the following organisms were encountered at station No. 262 in the waters of the Norwegian current north of the Faroes on March 31, 1954, in the 0-25 m. level:

Calanus finmarchicus - V and VI copepod stages	Few
Nauplii Calanoida	Solitary specimens
Calanus finmarchicus - I-II-III stages	" "
Pseudocalanus elongatus	Very few
Spinocalanus abyssalis	Solitary specimens
Oithona similis	" "
Oikopleura labradoriensis	" "
Thysanoessa inermis	1 specimen

At 50-100 m., besides the crustaceans enumerated above, the following were encountered, namely: Metridia longa, Metridia venusta, Ostracoda varia, Meganyctiphanes norvegica, Oithona atlantica, the pteropod mollusk Limacina retroversa and the chaetognatha: Sagitta elegans and and Eukrohnia hamata.

The vernal biological processes are considerably delayed in the central and northern regions of the Norwegian Sea as well as in the vicinity of the East Icelandic current. At the time when the nauplii and young of Calanus appear in the Atlantic waters near the shores of Norway in the latter part of March and in the early part of April, no concentrations of plankton are observed in the upper layers at the edge of the cold East Icelandic current in spite of a considerable admixture of warm waters (temperature of 7^{o} on the surface)(Figure 3 c). Calanus finmarchicus of the VI copepod stage adds a slight increase to the biomass of plankton in the 50-100 m. layer at a temperature of $4\text{-}5^{o}$. At a depth of more than 300 m. (below the thermocline) the cold-loving Calanus hyperboreus of the VI copepod stage predominates in the plankton.

In view of the fact that the maturing of Calanus begins during the wintering in deep waters, the temperature of the deep waters greatly influences the time of the formation of pre-spawning concentrations; the warming of the surface layers, so it seems, is of secondary importance. A similar phenomenon was observed by us on April 7, 1954, at station No. 274 (Figure 3c) at the edge of the East Icelandic current, where, at a comparatively high temperature at the surface, the development of the vernal biological processes was nevertheless delayed. It must be said that in this region the temperature drops sharply with increasing depth. The thermocline is at a depth of 100 m. At a depth of 300 m., the temperature drops to 1°. The low temperature in deep waters delays the maturing of Calanus as well as its surface concentrations. A still greater delay in the development of plankton is observed in the cold wedge of the waters of the East Icelandic current. The plankton is concentrated in deeper waters or deeper below the surface, in 50-100 m.

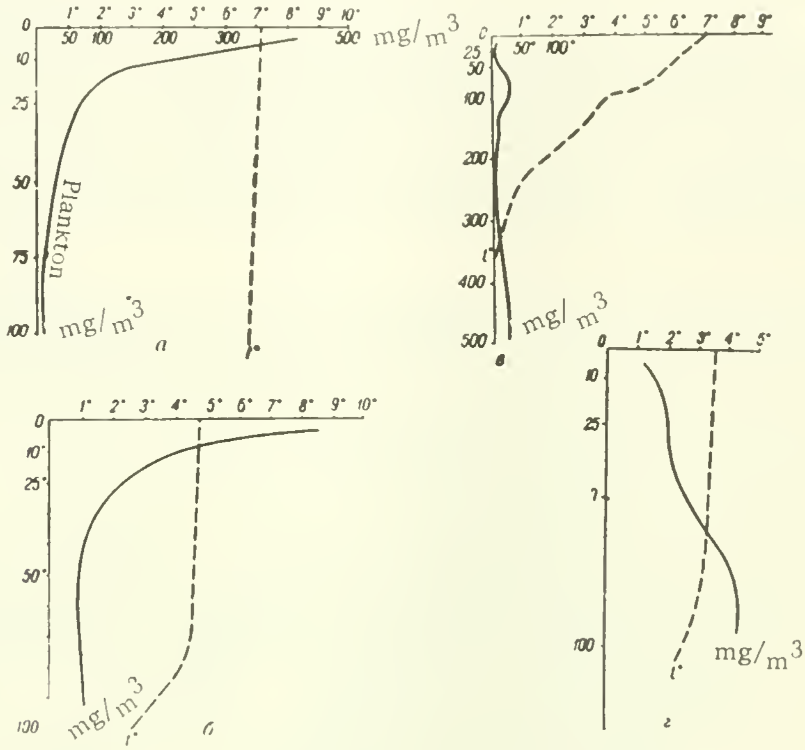

Figure 3. The vertical distribution of the biomass of plankton in relation to temperature (4th trip of E/S- "Professor Mesyatsev"). (a) In the waters of the Atlantic current (station No. 263, April, 1954). (b) In the intermixed waters near the edge of the East Icelandic current (station No. 262, March 31, 1954). (c) In the intermixed waters at the boundary of the East Icelandic current. At the surface-- Atlantic waters (station No. 274, April 7, 1954). (d) In Atlantic waters (in the southern part of the Norwegian Sea) with a large admixture of the waters of the East Icelandic current (station No. 266, April 2, 1954).

The formation of spawning accumu [illegible] Calanus in April has not yet been observed (Figure 3b).

The instances cited above show that the occurrence of pre-spawning concentrations of Calanus differ considerably in relation to regions and depend almost not at all on the increased temperature of the surface layers.

Prior to spawning, Calanus concentrates at the surface, increasing to 400-500 mg/m^3.

The spawning of Calanus usually coincides with the mass-development of the alga Phaeocystis.

In most regions, the mass-spawning of Calanus finmarchicus is accomplished in a short period. Immediately following reproduction, the large sexually mature Calanus specimens perish. Only their microscopic eggs and nauplii remain in the plankton. Due to this, the biomass of plankton is reduced to 80-100 mg/m^3.

The intensive "green blooming" (Phaeocystis) is seldom lengthy. In most cases it is over in 7 to 10 days.

Development of Phaeocystis begins along the shores of Norway in the latter part of March. "Green blooming" can be observed in April on the Lofoten Banks and in the region of the Norwegian shelf. In May, the zone of "blooming" shifts to the central deep-water regions and to the western regions of the Norwegian Sea. Towards June, the biological spring reaches the boundaries of the Norwegian and Greenland Seas. In July, Phaeocystis is already developing in the north, at the boundaries of the polar waters (Figure 4).

Diatom development follows that of Phaeocystis. The former produce the brown "blooming". The "diatom blooming" lasts longer than the "green blooming". It is longest in mixed waters, in shallows and on shoals. Favorable conditions for the development of phytoplankton are observed where the waters of the Norwegian current touch upon the waters of the East Icelandic and of the East Greenland currents. For the polar waters bring to these places of contact a large quantity of nutritive substances of phosphorous up to 25-30 mg/m^3.[1/]

In keeping with the exhaustion of the reserves of nutritive substances and the changes in the thermal conditions, some species of algae are replaced by others. In March-April, the "diatom blooming" in coast waters is caused by the mass development of Thallassiosira gravida and Th. Nordenskiöldi. After they have died off, there begins the development of Chaetoceras atlanticus, Ch. decipiens, and Ch. borealis. Rhizosolenia styliformis is well-represented in the Atlantic waters in June-July, whereas Chaetoceras concavicornis and Ch. convolutus are represented in the Greenland Sea.

The "blooming" of Rhizosolenia and of Chaetoceras always coincides with the development of the roseate or pink and red young of Calanus (Calanus finmarchicus of the I-II-III and IV -V copepod stages).

The diatoms form a layer of 3 to 5 m. at the surface. Somewhat deeper (down to 25 m.) are the young of Calanus that decrease in quantity with depth.

The dying-off of diatoms usually coincides with the beginning of the mass development of the medusa or jellyfish Aglantha digitalis in the Norwegian Sea and of the Ctenophora Beroë cucumis and of Bolina infundibulum in the north. About this time, the quantity of plankton in the upper layers of the water is sharply decreasing, because a considerable part of the crustaceans is being destroyed by plankton-feeding fish. Those specimens of Calanus finmarchicus that survive, namely, those of the III-IV-V copepod stages descend to a depth of more than 100 m.

Tiny Copepoda, Cladocera develop near the surface, there appear peridinean algae (Peridinea).

In the southern regions of the Norwegian Sea, it is possible in warm years to encounter also

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1/ The hydrochemical material was received from M. A. Istoshina. It refers to April, 1954.

the young Calanus finmarchicus of the second, that is the summer, generation.

Species-wise, the composition of the plankton sample that was taken from the central regions of the Norwegian Sea on August 3, 1953 (the 0-10 m. layer) appeared as follows:

Ceratium longipes C. fusus C. tripos C. macroceros Parafavelia gigantea	Single specimens of these species of plankton were encountered in the sample.
Calanus finmarchicus nauplii -I-II copepod stages	fair number (the second, the summer generation).
Oithona similis	few
Onceae borealis	"
Evadne nordmani	many
Fritillaria borealis	singly
Beröe cucumis juv	"
Gastropoda juv	"
Lamellebranchia juv	"
Limacina retroversa juv	"

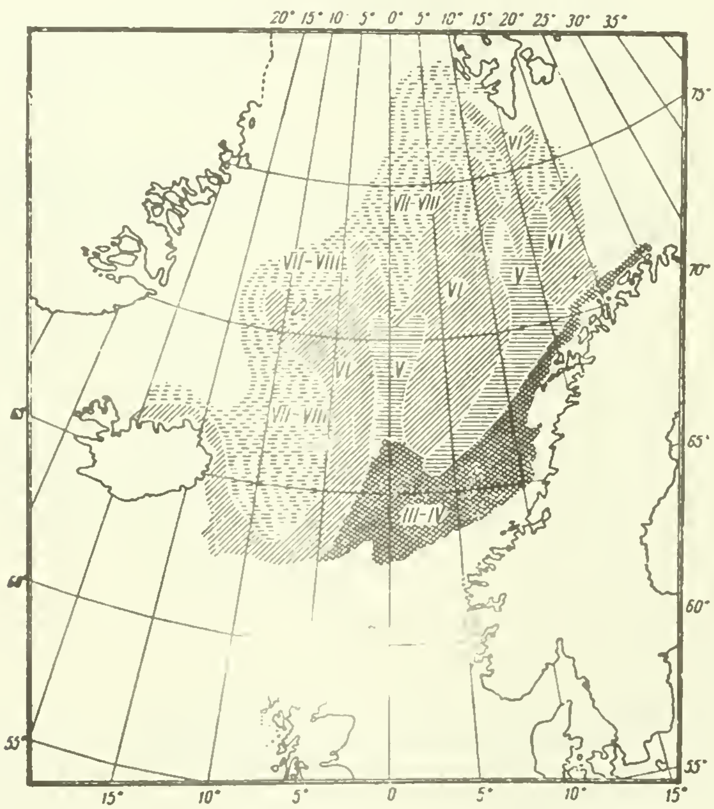

Figure 4. Times of the onset of the biological spring in the various regions of the Norwegian Sea (the Roman numerals indicate the months).

The production of plankton ceases in autumn, but the consumption of it continues. This causes a reduction or decrease in the number of the crustaceans.

With the onset of winter, most organisms descend to a depth of more than 600 m. In this layer of water, their number does not exceed 10 mg/m^3, but at depths of 100-200 m., the biomass of plankton hardly reaches 50-60 mg/m^3. During the winter, the amount of plankton continues to decrease, and towards spring it reaches the minimum.

The life cycle of the Atlantic herring was evolved during the process of the historic development of the species. It permits the herring to make the fullest use of the favorable periods in the life of the sea for its own reproduction, (providing the larvae and the young with microscopic nutritive substances at the time of the reproduction of Calanus) and for the rapid growth or fattening of adult specimens of herring at the cost of destroying the large forms of plankton.

The feeding or foraging migrations of the herrings, their departure after spawning into the western and north-western regions are brought about by the peculiar distribution and development of plankton, especially during spring and summer.

The development of plankton--as mentioned previously--can first be observed in the coast waters. There also begins the fattening of herring that have approached the spawning grounds. At first, the herring consume the spawning concentrations of Euphausiacea (February-March).

Pre-spawning concentrations of Meganyctiphanes norvegica can be observed in February. In the plankton net catches or hauls, these crustaceans are represented by only a few specimens. But in the stomachs of individual herrings, as many as 65 specimens were found. The main body of herring can not find sufficient food in early spring, seeing that the plankton of this period is extra-ordinarily poor.

In April, the stomachs of most fish were filled with Calanus (70-90%). But at this time in the Faroe region herring could be found with stomachs containing up to 90% of Thysanoessa inermis, because the spawning of Euphausiacea continues into April.

Toward the beginning of April, the spawning of Calanus comes to an end near the shores. The amount of plankton is sharply reduced. The adult crustaceans die off. The main body of the zooplankton is composed of the eggs and nauplii of the Copepoda, the larvae of bottom-dwelling animals as well as the eggs and larvae of fish that spawned in shallow water. These microscopic organisms are not suitable as food for herring of the older age groups. Large herring at first consume the pre-spawning concentrations of mature or sexually mature Calanus. Mature Calanus begin to concentrate in the upper layers, let us say, one to two months prior to the beginning of reproduction. This usually coincides with the flare-up of the development of phytoplankton (with the "blooming" of the sea). Near the surface, Calanus feeds actively at first upon the sparse phytoplankton and stores up a large amount of fat. In March-April, the alimentary tract of these crustaceans is usually stuffed with a green mass of algae. They themselves acquire a claret-red color because of an abundance of fat.

The fat pre-spawning Calanus is high-calorie food for the herring that were exhausted by winter starvation. In their search for food, the herring leave the spawning grounds for the western and north-western deep-water regions of the Norwegian Sea; for there the pre-spawning concentrations of Calanus appear later than in the coast waters. It must be said that the end of spawning and the departure of the herring of the older age groups from shallow waters usually coincides with the abundant development there of the "green blooming" (Phaeocystis).

Phenomena that are characteristic of the biological spring can be observed in the various regions of the territory of the Norwegian and Greenland Seas. The gradual shift of the zone of the "green blooming" to the north is depicted in Figure 4. Somewhat earlier, prior to the beginning of the mass development of Phaeocystis, large herring pass through the deep-water regions of the Norwegian Sea. Moving northward ahead of the "blooming", the herring of the older age groups have a sufficient feeding base--for the entire migration route--in the form of large mature crustaceans.

At the very beginning of the biological spring, the pre-spawning Calanus, which is comparatively large, concentrates near the surface. It is the most accessible food for the herring that were exhausted by winter starvation. This is the fact that compels the herring when moving northward to comply with the conditions that are characteristic of the beginning of the biological spring. In April-May in the southern regions of the Norwegian Sea, herring schools approach the boundaries of the East Icelandic current. There they continue to feed in the mixed waters that are rich in plankton. In these waters, we encounter comparatively large crustaceans such as Calanus finmarchicus in every stage of development or growth, Calanus hyperboreus, Themisto abyssorum, Th. libellula, Metridia longa, Paraeuchaeta norvegica, Oikopleura labradoriensis, in the composition of plankton.

In the regions where the warm Atlantic current and the cold East Icelandic current touch upon each other, an intense intermixing takes place. This causes the cold deep waters to rise to the surface, thereby enriching the upper layers of water with nutritive salts.

The regular replenishment of the reserves of nutritive salts facilitates the abundant and prolonged development of phytoplankton in the south-western regions of the Norwegian Sea. Not only algae thrive in the intermixed waters; there is also much zooplankton there. It is possible to observe simultaneously several plankton complexes in these regions. They usually develop or grow during various biological seasons (the "blooming", the pre-spawning accumulation of Calanus finmarchicus and Calanus hyperboreus, the young of Calanus, etc.). Successive generations of Calanus provide an abundant and reliable food for herring during the spring months (March, April, May). Somewhat later, in June (and at times even in July) the herring reach Mohn's Threshold (boundaries of the Norwegian and Greenland Seas) and penetrate farther into the warming polar waters of the East Greenland current.

The polar waters contain a large amount of nutritive salts. These salts are not used for the larger part of the year; for the ice hinders the development or growth of phytoplankton. In June-July, when a large part of the waters of the Greenland Sea is free from ice and the edge of the ice is retreating to the north-west, there is a tremendous plankton growth. The biomass of plankton near the melting ice reaches 4000 mg/m^3 in the 0-50 meter layer. The negative temperature (-0.61^{0})renders this rich food base inaccessible for herring.

Figure 5 shows how sharply the polar waters--during this time--differ from the Atlantic waters with regard to the amount of phosphorus, the oxygen content, and the amount of plankton.

At the beginning of spring, in the waters of the East Greenland current, Calanus hyperboreus rise to spawn. Many tiny young of Themisto libellula appear in the plankton. There is little phytoplankton; for it is consumed to a large extent by crustaceans (the alimentary duct of Calanus hyperboreus is stuffed with a green mass of algae; this is the case with regard to Calanus finmarchicus at the beginning of spring). The polar waters abound in phosphorus (25-30 mg/m^3). 1/ They are

1/ The hydro-chemical index (see Figure 5 and Table 1) obtained by M. A. Istoshina on the 5th voyage with the E/S "Professor Mesyatsev" in June 1954.

well saturated with oxygen (98-102%) and contain a large amount of zooplankton (on the average above 1000 mg/m^3).

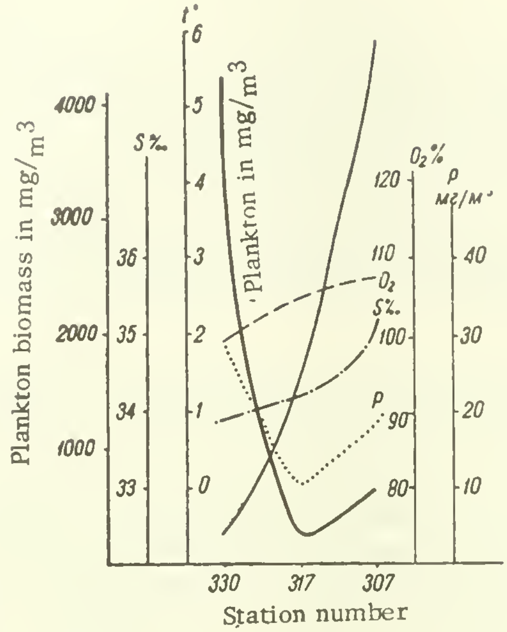

Figure 5. Description of the biomass of plankton in waters of various origins (Station No. 330- polar waters; station No. 317- mixed waters; station No. 307- Atlantic waters. Cross-section at 74°20' northern latitude, June of 1954, E/S "Professor Mesyatsev", fifth trip).

In the area where the waters of the Norwegian current meet and mix with the waters of the East Greenland current, spring was also in full swing at this time. The growing plankton had exhausted to a considerable extent the reserves of the nutrient salts of phosphorous (11-15 mg/m^3). Due to the photosynthetic action of algae, the upper water strata were saturated with oxygen (105-119%). "Diatom blooming" can be observed. The plankton biomass is somewhat reduced. It is possible that this resulted from the consumption of the crustaceans by herring. In the mixed waters, schools of feeding herring were often encountered at a comparatively low temperature (1.6-3.5°) in the month of June. We observed in 1955 especially good feeding conditions for herring in waters with a temperature below + 2° in the area of Jan Mayen.

Diatom development comes to an end at this time in the Atlantic waters of the eastern branch of the current. Red Calanus (Calanus finmarchicus of the III-IV-V stages) are developing. These phenomena characterize the end of the biological spring season. The nutrient salts that were used in the vernal development of phytoplankton are being restored (phosphorus 18-23 mg/m^3). There is still a fair amount of plankton on the surface (560 mg/m^3 on an average). Its main component is red Calanus, which is the staple diet of young herring (21-28 cm.). According to the material that was collected by us on the third trip of the E/S "Professor Mesyatsev" in June-July, 1953, in the central regions of the Norwegian Sea, it is evident that small herring were predominant in the hauls. Their stomachs were filled with the pink and red young of Calanus. Besides Calanus, the young of

Themisto abyssorum, Euphausiacea and Oikopleura labradoriensis were encountered, at times, in the stomachs of herring.

Sexually immature herring and herring that spawned for the first time (their spawning ends much later than is the case for herring of older age groups) keep to waters with a temperature of 4-6^{o} (and higher). They feed in the central regions of the Norwegian Sea and do not proceed far to the north.

Large herring (29-35 cm.) begin their feeding or fattening early in spring, i.e. prior to the development of new generations of Calanus. While feeding upon the adult crustaceans--their number is small--that had wintered, the herring accomplish long migrations. In some years they go far to the north. Often, when searching for large and easily accessible food, the herring enter the mixed waters near the cold East Greenland current. We observed in June, 1955, schools of large herring that had consumed great numbers of Calanus hyperboreus in waters with a temperature below 2^{o}.

The observations made in 1954-1955 speak of the abundance of large plankton in cold waters (Calanus hyperboreus and Themisto libellula). The concentrations of reproducing Calanus hyperboreus are formed in the surface layers of the water with a temperature of +3^{o} to -1^{o} (and even lower). Especially large numbers of these crustaceans were encountered north of Jan Mayen and Bank 600. While searching for food, the herring in June entered waters with a very low temperature from +1.6 to +3.5^{o}. The captain of "SRT M-1" (Medium Fishing Trawler M-1) "Korablestroitel," Comrade Dmitriev, caught herring in waters with a temperature of +1.8^{o}. Such catches of herring that feed in polar waters do not represent isolated cases. In 1947, the E/S "Cachalot" caught herring at the edge of the ice near 78 degrees north latitude at a very low temperature. From June 7-20, 1954, a group of boats of the North-Atlantic Herring Expedition caught herring at a temperature below 3 degrees on the surface (but, at a depth of 25 m. in this region, the Atlantic waters had a temperature of 3-4 degrees). In July, after the waters of the East Greenland current had been warmed by solar radiation to a temperature of 3-5 degrees, it is quite possible for herring to continue their feeding in actual polar waters. Towards August, the herring finish their feeding in polar waters; for even there the search for food is getting more difficult. There is a development of Phaeocystis and of diatoms; the spawning of Calanus is about to end and its tiny nauplii occur in the plankton. The adults of Calanus die after spawning. The feeding of the herring comes to an end; they turn southward and begin to enter the warm waters of the Norwegian current. The number of herring with empty stomachs is increasing (in July 18%, in August 40%), since they can not find sufficient food.

At about this time, the amount of surface plankton is sharply diminished. Furthermore, the bulk of plankton consists of tiny Copepoda; Pseudocalanus elongatus, Oithona similis, Oithona atlantica, Onceae borealis and the jellyfish, Aglantha digitalis. Peridineans are developed, which cause a slight "blooming". Tiny Copepoda are rarely eaten by large herring. For this reason, plankton--by the end of August--ceases to influence the distribution of herring.

Thus, on the basis of eight years of observations on the development of plankton and the movements of schools of feeding herring in the Norwegian and the Greenland Seas, we have come to the following conclusions:

1. The life cycle of Atlantic-Scandinavian herring is very closely related to plankton dynamics in the Norwegian and the Greenland Seas.

In connection with the fact that the food supply of herring changes radically when the biological seasons change (Figure 6) this species endued in the course of its historical development the ability to make annual feeding migrations, which make it possible to use to the fullest extent, when feeding, the vernal flourishing of the development of plankton.

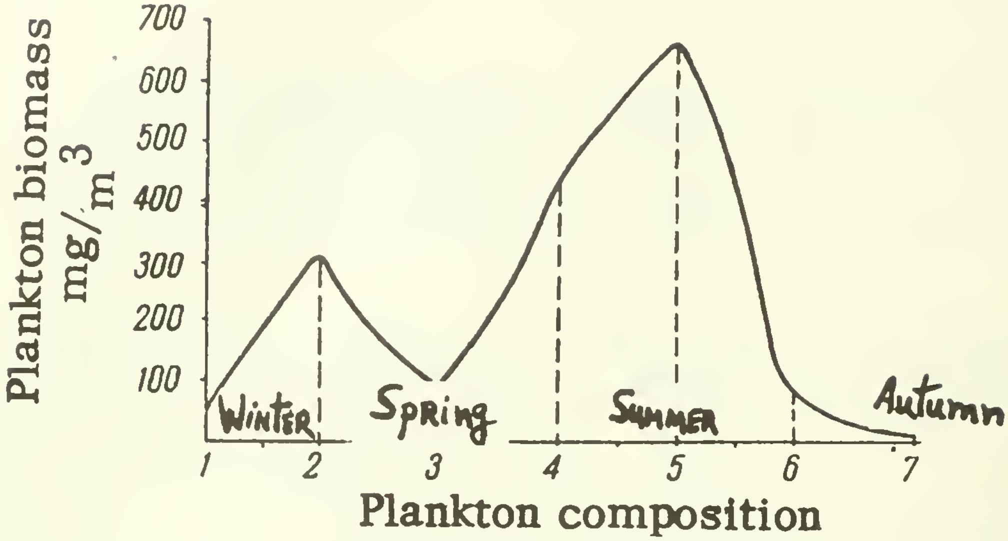

Figure 6. A. Biomass of plankton in mg/m^3. B. Winter. C. Spring. D. Summer. E. Autumn. F. Main plankton complexes.
Change in the average biomass of plankton when the biological seasons change (material of 1948-1954). 1. "wintering stock" of plankton on the bottom; 2. pre-spawning concentrations of Calanus at the surface (start of the feeding of large herring); 3. "green blooming" of Phaeocystis (the large herring move to the north); 4. "diatom blooming" and the pink fry of Calanus (feeding of the small fry of herring); 5. red Calanus at the surface (feeding of the young fry of herring); 6. red Calanus descends into the deep (end of the feeding of all herring); 7. development of tiny crustaceans and jellyfish (end of the feeding of all herring).

In this connection it must be said that the Atlantic herring is a very plastic organism and easily endures the changes that occur in the environment.

For instance, when there is a change in the hydro-meteorological conditions, one can often observe considerable deviations in the time of plankton development and a corresponding change in the speed with which herring move from one region to another.

2. The simultaneous development--in their areas--of several different biological seasons is characteristic of the Norwegian and the Greenland Seas as well as of the other northern seas. All the vernal biological processes begin in March-April in the coast and southern regions of the Norwegian Sea. After that, they begin in the waters of the Atlantic current.

A delay in the vernal development of plankton is characteristic of the regions of eddyings or vortexes between the individual streams of the warm current and of the boundaries of the cold East Icelandic current. The delay in the development of plankton in the mixed and polar waters of the Greenland Sea is still greater.

TABLE 1. A DESCRIPTION OF THE MASSES OF WATER OF VARIOUS ORIGINS (JUNE OF 1954).

Waters	Temperature in °C	Salinity in °/oo	Phosphorus in mg/m³	Oxygen in %	Average of biomass of plankton in mg/m³	Main complexes of plankton
Atlantic (Spitsbergen current)	4-6	35.07-35.10	18-23	102-107	560	Red Calanus (Calanus finmarchicus of III-IV-V stages).
Mixed	1.5-3.5	34.69*-34.74	11-15	105-119	238	Diatom blooming.
Polar (East Greenland current)	(-)0.7-(+)1.17	33.42-34.74	25-30	98-102	1193	Pre-spawning accumulations of *Calanus hyperboreus*.

*On the surface because of thawing ice, the salinity is 34.27°/oo.

3. Because the time of the development of plankton shifts when moving from the shores of Norway in a northern and north-westerly direction, the herring, when making feeding migrations, have the opportunity, apparently, to be always approximately, under the same conditions that prevail at the beginning of the biological spring.

By keeping somewhat ahead of the mass -development of phytoplankton (the "blooming"), the herring have a chance, over the entire distance of the migration route, to feed on accumulations of crustaceans that are preparing for reproduction. It must be said that in early spring the mature *Calanus* is the largest and most nutritious food for herrings.

Feeding upon comparatively large and fat crustaceans, the herring fatten quickly after winter starvation.

4. Young, immature herring and also those that spawned for the first time (21-28 cm.) in the Norwegian Sea, as well as the herring fry in the Barents Sea, feed upon the fat, pink, young *Calanus*. Later they feed upon the red young of *Calanus* (*Calanus finmarchicus* of the I-IV copepod stages).

5. In June-July, the herring of the older age groups reach the boundaries of the polar waters where they again meet the conditions of the beginning biological spring (spawning concentrations of *Calanus hyperboreus* and the beginning of the development of phytoplankton).

6. In August - October, the feeding of the herring comes to an end. During this period, the plankton is very poor and consists of tiny Copepoda, which are unfit as food for large herring. For this reason, the composition and amount of plankton have no influence upon the distribution of the

herring.

Annual Fluctuations in the Development of Plankton

During a number of years while observing the production of plankton in the Norwegian and Barents Seas, many researchers noticed considerable fluctuations in the time of the development of various complexes of plankton as well as in the composition and amount of planktonic organisms.

Most scientists link these phenomena directly with the changes in the flow of Atlantic waters into these seas /Linko (16); Deryugin (9); Virketis (7, 8); Boldovskiy (5)/.

B. P. Manteyfel' (19) is of the opinion that a number of factors influences the composition of plankton and the time of its development: The annual "pulsations" of the North Cape branch, solar radiation within the confines of the Barents Sea, the times of the atmospheric spring, the water run-off from the land, consumption of the plankton, etc.

Observing the composition of plankton for many years made it possible to establish that the years of the greatest influx of warm Atlantic waters into the Barents and Norwegian Seas are characterized by the appearance of large numbers of thermophilic representatives of plankton such as Collozoum, Physophora hydrostatica, Meganyctiphanes norvegica, Nematoscellis megalops, Tomopteris.

In connection with this the thermophilic organisms are carried by the current far to the north and to the east. It is known that the North Cape and the Norwegian currents are not monolithic currents; but, following the bottom contour, they divide into a number of branches or arms. The intensity of the flow of Atlantic waters along the various branches or arms of the currents in the Barents Sea as well as in the Norwegian Sea changes or varies from year to year. Helland-Hansen and Nansen (37), on the basis of oceanographic observations in 1900-1904, have already written about the existence of annual fluctuations in the temperature conditions of the waters in the Norwegian Sea.

Their hypothesis, as mentioned above, about more favorable conditions for plankton development in cold years is confirmed also by our observations. It seems that a larger influx of waters from the polar region, which contain a large amount of nutritive substances, creates conditions in the Norwegian Sea in cold years that are conducive to an abundant production of plankton and, subsequently, to a rapid fattening of the fish.

Figure 7 shows how great the fluctuations can be in the amount of plankton for the same month in different years. For a comparison, we took cross sections that cut across the two main branches of the Norwegian current: The eastern (at the latitude of Bear Island) and the North Cape branch (following the Kola meridian). Plankton was collected from these cross sections or profiles every year during the second half of June (the period of the maximum production of plankton in those regions).

Comparing the curves shows that their general character is retained from year to year. Their peaks correspond to the increase in the amount of plankton in the branches of the current. The position of the separate branches of the Norwegian current remains unchanged. But the amount of plankton in them for the same period in different years can change considerably. It is characteristic that in years of a maximum production of plankton in the waters of the eastern branch of the Norwegian current, the amount of plankton often becomes less in the waters of the North Cape current (1948) and, on the other hand, when the biomass of plankton becomes larger in the Barents Sea, then the biomass of plankton becomes smaller in the Bear Island-Spitsbergen region (1950). There were years when also a regular or uniform plankton production could be observed in the Barents Sea as well as in the Greenland Sea (1951).

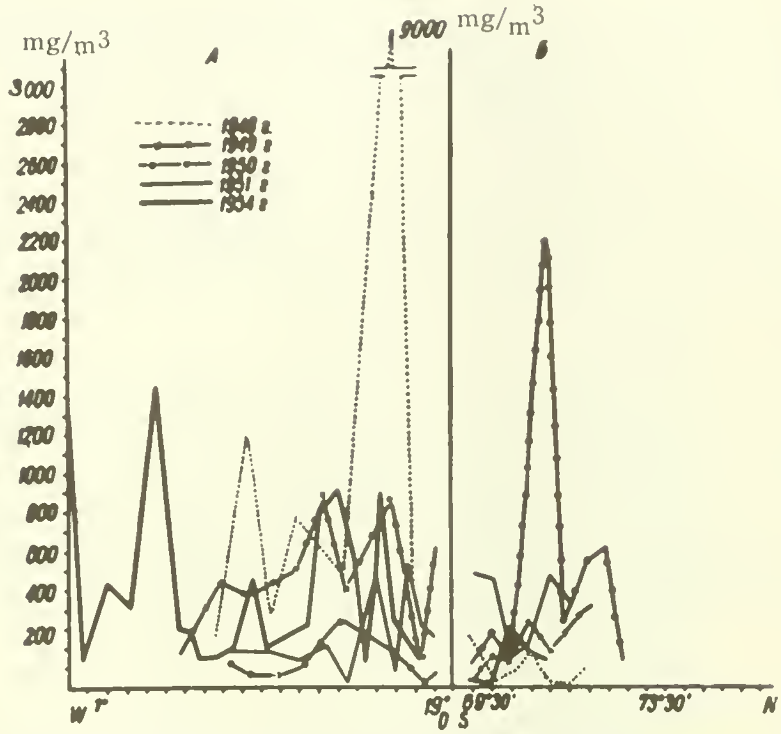

Figure 7. Biomass of plankton in the 0-50 meter layer in the Spitsbergen (A) and the North Cape (B) currents in various years.

K. M. Deryugin (10) was the first to take notice of the asynchronism of the change in intensity of the influx of Atlantic waters--with respect to the Barents Sea--along the separate streams of the current. The asynchronism in the change of the intensity of the North Cape current and of the eastern branch of the Norwegian current is also confirmed by hydrological observations made in recent years. In this connection, the change in the intensity of the inflow of warm waters is characteristic not only of the currents as a whole but also of separate branches of the aforementioned currents.

Some years, more warm water enters the western regions of the Norwegian Sea and in other years enters the eastern regions.

It seems that the years when there is an abundant production of zooplankton in the Bear Island-Spitsbergen region are distinguished by favorable conditions for the feeding of herring in the northern latitudes of the Greenland Sea. In connection with this, herring can penetrate far into the north (e.g. in 1949) or enter the polar waters of the East Greenland current. This was observed in 1954. The regions where herring feed and fatten do not remain unchanged from year to year; for they can shift to the north and to the south, so that the time and the regions where fish feed are closely related with the time of the plankton development. On the other hand, the development of plankton is strongly influenced by the present as well as the preceding hydrological and meterological conditions.

An earlier development of the vernal biological processes usually is observed in years when the intensity of the Norwegian current is accelerated, especially if the increasing intensity of the current coincides with favorable meteorological conditions.

For instance, the biological spring started 15-20 days earlier in the spring of 1954 than in 1953 in the warm Atlantic waters. This was facilitated by the high thermal condition of the waters in March-April, together with calm (in comparison with 1953) and sunny weather. During the period of plankton production in 1954, there were only half as many storms as in 1953.

Comparing the distribution of the principal plankton complexes (Figures 8, 9, 10, and 11) we see that the biological spring started about a month later in 1951 than in 1954. The plankton developed more actively in the warm waters of the Norwegian current than between the currents (especially on shoals and shallows). It was possible from the qualitative composition of plankton to identify the various branches of the warm current. Approximately the same distribution of plankton was observed by us in 1953 and in 1955.

It is characteristic that in 1951 such thermophilic Atlantic organisms as Collozoum and Tomopteris were very seldom encountered in the eastern branch of the Norwegian current. This serves as an indicator of a lowering in the flow intensity of Atlantic waters into the Norwegian Sea. It must also be said that in 1951 also cold Arctic waters penetrated into the area between the streams of the warm current. In June, these cold waters carried the cold-loving Calanus hyperboreus, which dwells there at depths of ca. 100 m., into the central regions of the Norwegian Sea. The penetration of these chilled waters, which abound in nutritive substances, into the central regions of the Norwegian Sea facilitated first the production of algae and later of plankton.

In June 1951, the biomass of plankton was fairly large (800-1, 200 mg/m^3) in the central and northern regions of the Norwegian Sea.

In the regions of great depths, the main bulk of plankton consisted of spawning Calanus, but near the slope their red fat young were also developing.

Feeding herring proceed northward very slowly, while feeding in the northern regions of the Norwegian Sea. In July, schools of herring reached Mohn's Threshold and began to enter the Greenland Sea along the continental slope, where, at this time, plankton production had just begun. The amount produced was small (Figure 12). It consisted mainly of the spawning crustaceans, Calanus finmarchicus and Calanus hyperboreus.

We observed quite different conditions of the development of vernal biological processes in the Norwegian Sea in 1954.

The wide dissemination of warm waters as a result of the acceleration of the intensity of the Norwegian current, the small number of stormy days, and the sunny weather in March-April facilitated the activization of vernal biological processes in the Norwegian Sea.

The spawning of Calanus was observed in March, i.e. 15 days earlier than in 1953 and approximately a month earlier than in 1951.

A homogeneity of hydrological conditions in the eastern regions of the Norwegian Sea is characteristic for 1954. A solid stream of Atlantic waters, which carried a large amount of Collozoum in the surface layers, was flowing northward. The slime of radiolaria stopped up the plankton nets to the same extent as when the mass production of the alga Phaeocystis occurs. Radiolaria were carried north to 80° north latitude by the Spitsbergen current.

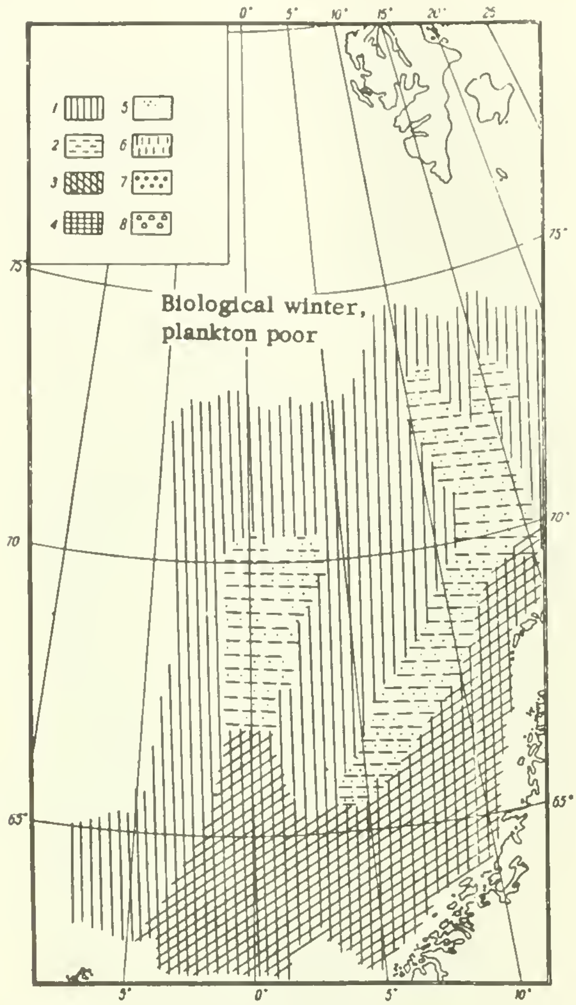

Figure 8. Distribution of the principal plankton complexes in May, 1951. 1. pre-spawning accumulations of Calanus; 2. nauplii and young of Calanus; 3. red Calanus at the surface; 4. red Calanus descended into the deep; 5. Phaeocystis; 6. Diatoms; 7. Calanus hyperboreus; 8. jellyfish.

According to our observations such an abundance of the radiolaria Collozoum was encountered only in 1948 and 1949. It suggests an acceleration of the intensity of the Norwegian current. In recent years, Collozoum was very scarce and individual specimens did not penetrate northward beyond 74-75° north latitude.

The acceleration of the Norwegian current intensity in 1954 facilitated the development of plankton in the Greenland Sea. As early as June, the reproduction of large crustacea; Calanus finmarchicus, Calanus hyperboreus, Themisto libellula and Th. abyssorum took place there. On the other hand, the acceleration of the intensity of the East Greenland current was the cause of a considerable chilling of the waters in the area of Jan Mayen. The low temperature of the water (below + 1°) delayed the reproduction of Calanus finmarchicus in the areas to the SE from Jan Mayen. This brought about a reduction in the plankton biomass. The biomass there at the beginning of June, 1954 was one-tenth that of June, 1953.

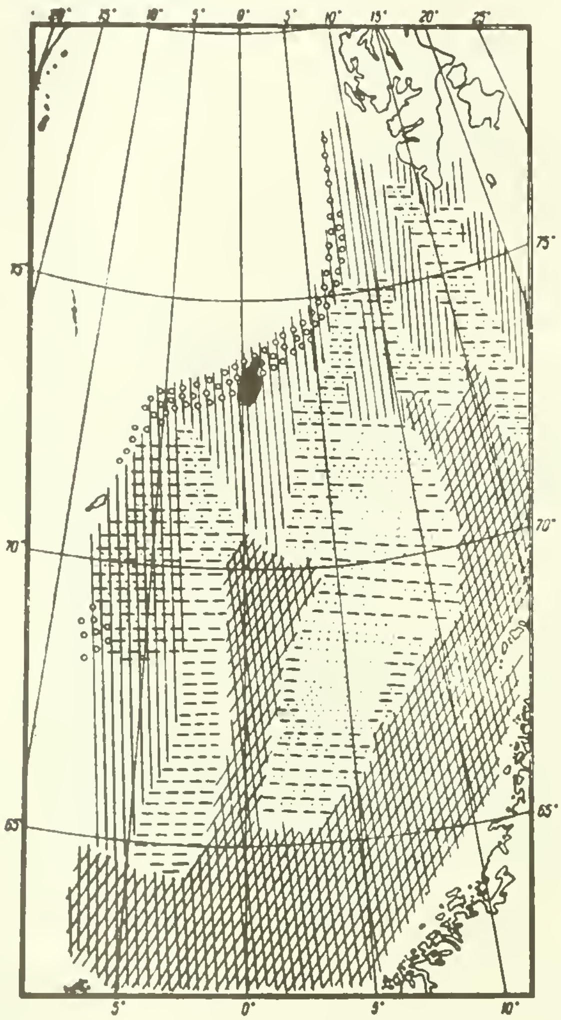

Figure 9. Distribution of the main plankton complexes in June, 1951. 1. pre-spawning accumulations of Calanus; 2. nauplii and young of Calanus; 3. red Calanus at the surface; 4. red Calanus descended into the deep; 5. Phaeocystis; 6. diatoms; 7. Calanus hyperboreus; 8. jellyfish. (See Figure 8).

The large number of dull or cloudy days and the homogeneity of hydrological conditions in June-July hampered the development of phytoplankton in the central and eastern regions of the Norwegian Sea. The "spots" and "zones" of abundant or luxuriant "blooming", common to this period, were not observed in 1954. Phytoplankton developed or grew everywhere; but only in small quantities.

The absence of clearly expressed or marked zones of "blooming" in June and July and the homogeneity of conditions over the entire area allowed the herring to feed or fatten over a large area and hindered the formation of solid concentrations of fish.

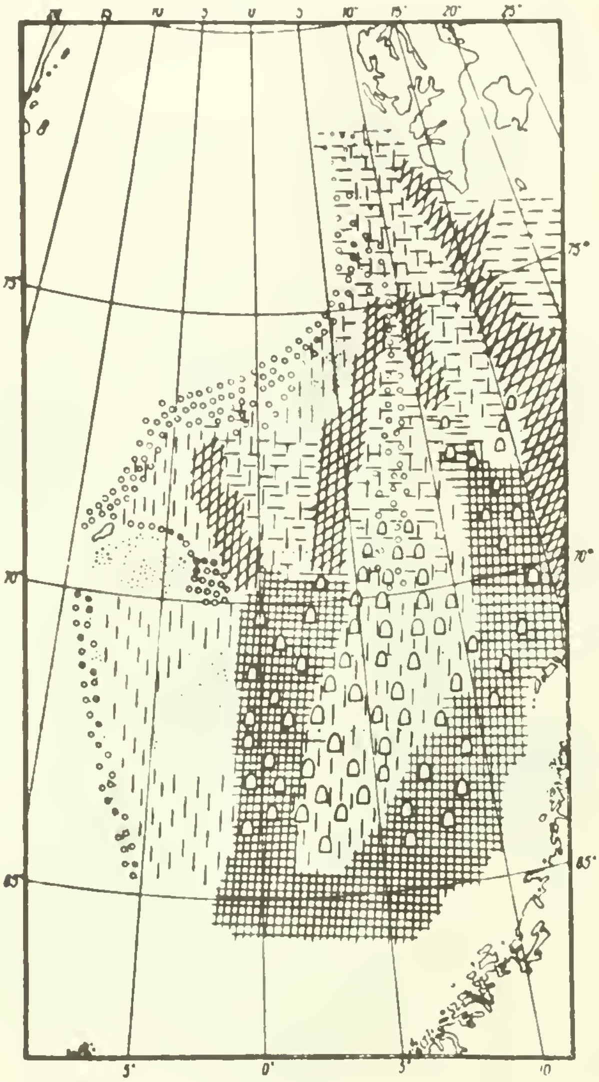

Figure 10. Distribution of the main plankton complexes in July-August, 1951. 1. pre-spawning accumulations of Calanus; 2. nauplii and young of Calanus; 3. red Calanus at the surface; 4. red Calanus descended into the deep; 5. Phaeocystis; 6. diatoms; 7. Calanus hyperboreus; 8. jellyfish. (See Figure 8).

Since spring plankton production began earlier than in 1953, i.e. 15 days earlier, the main bulk of the feeding plankton (red Calanus) had been destroyed by plankton-eating organisms towards June. The specimens of Calanus that survived the carnage as the surface temperature rose descended earlier than in previous years to depths of more than 100 m. In connection with this, the amount of plankton in the 0-50 meter layer decreased to 150-300 mg/m^3 (in a number of places even to 16-60 mg/m3). After the descent of Calanus, the main bulk of the plankton of the upper strata in the central regions of the Norwegian Sea was composed of organisms, which are not satisfactory food for large herring, namely: the young of the jellyfish, Aglantha digitalis, together with an abundance of the slimy radiolaria Collozoum, and the small Copepoda - Oithona similis and Pseudocalanus elongatus.

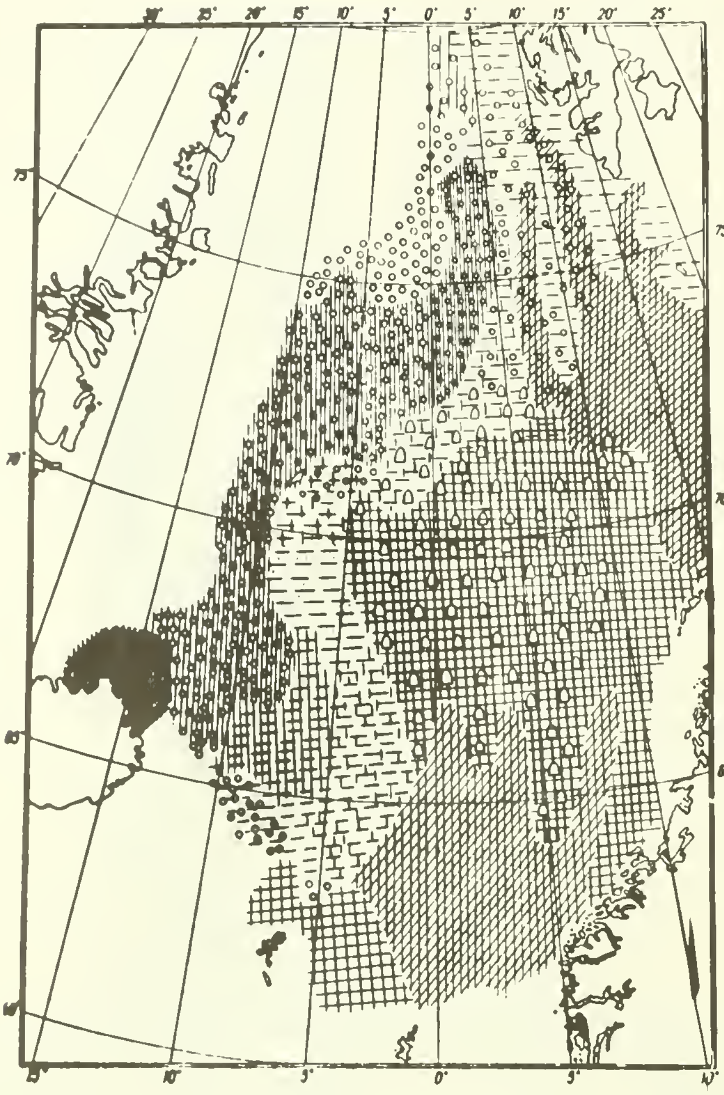

Figure 11. Distribution of the main plankton complexes in June, 1954. 1. pre-spawning accumulations of Calanus; 2. nauplii and young of Calanus; 3. red Calanus at the surface; 4. red Calanus descended into the deep; 5. Phaeocystis; 6. diatoms; 7. Calanus hyperboreus; 8. jellyfish. (See Figure 8).

Apparently lacking sufficient food, the herring of the older age groups quickly passed through the central regions of the Norwegian Sea. They appeared in the area of Mohn's Threshold one month earlier in 1954 than in 1951 and 15 days earlier than in 1953 (according to data by Marti).

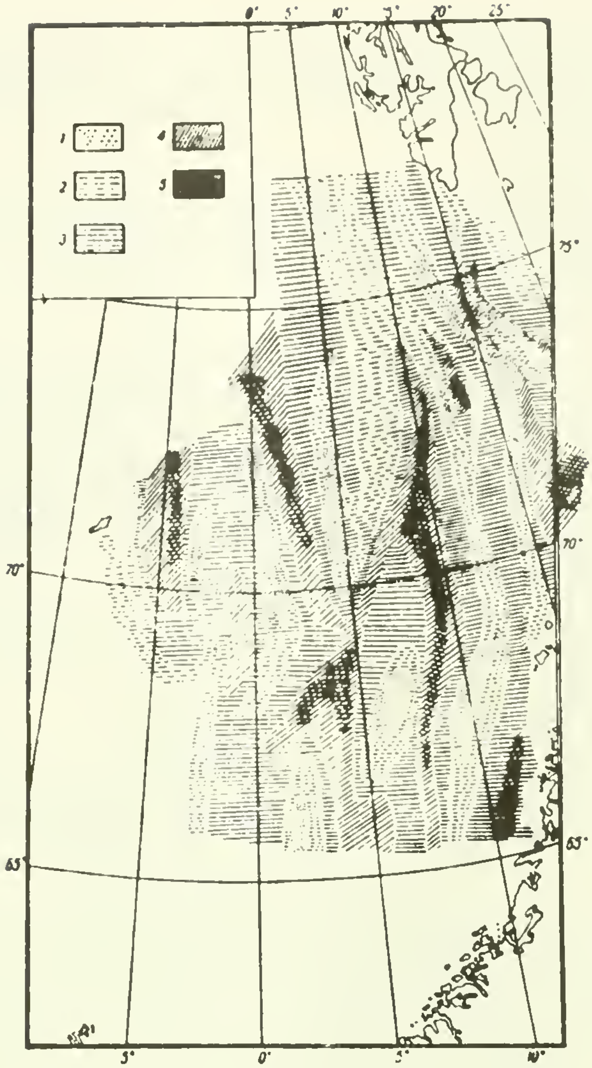

Figure 12. The distribution of the plankton biomass in the 0-50 meter layer in the Norwegian and Greenland Seas (May 27-June 9, 1951). 1. up to 100 mg/$_m$3; 2. 100-200 mg/$_m$3; 3. 200-500 mg/$_m$3; 4. 500-800 mg/$_m$3; 5. above 800 mg/$_m$3.

Favorable conditions for the feeding or fattening of herring developed in the Greenland Sea (see Figure 13) in June-July of 1954, where at this time large quantities of Calanus hyperboreus and young Themisto libellula had been produced.

The plankton biomass near the cold waters of the East Greenland current often exceeded 2000 mg/$_m$3. As early as June, schools of feeding herring entered these waters which had a temperature below 3^{o}.

In July, the water temperature in the southeast regions of the Greenland Sea had risen to 5-6^{o} and the herring that had arrived from the plankton-poor regions of the Norwegian Sea had a chance to advance far into the north.

The small percentage of herring with empty stomachs (18% in the north and 74% in the southern part of the Norwegian Sea) emphasizes the favorable feeding conditions for herring in July in the areas north of Jan Mayen.[1]

In 1954, the herring stopped feeding in the northern regions in August.

In 1955, the herring continued to feed until the end of September. The reason for this was found in a late biological spring (plankton production, in contrast with 1954, began 30 days later).

Under the influence of unfavorable hydro-meteorological conditions, (a large number of storms, murky days, and a general drop in the water temperature) the spawning of Calanus and the appearance of its fat red young was greatly delayed. The herring then--as a compensation for the lack or shortage of Calanus--turned to the young of Oikopleura labradoriensis and Themisto abyssorum. Herring of the older age groups entered the waters with a temperature of 2-3° as early as June and fed there upon the concentrations of the spawning Calanus hyperboreus.

In the area of Mohn's Threshold, red Calanus did not appear in 1955 until July and remained in the surface layers until the end of August. A general decrease in the intensity of the inflow of Atlantic waters (this accounts for the almost entire lack of the thermophilic organisms of Collozoum, Tomopteris, Physophora hydrostatica in plankton) delayed the development of jellyfish, which usually feed on the plankton.

The conditions outlined above had a favorable influence upon the feeding or fattening of herring. There was enough food for all the herring. They fed regularly during four months (June-October) and, regardless of the partly empty stomachs, the herring had become sufficiently fat by September.

Thus the observations of recent years have established that 1) during the time of the spring and summer feeding the herring of the older age groups inhabit the greatly transformed Atlantic waters--often close to cold currents--where they usually find a good feeding area composed of reproducing, comparatively large crustacea; 2) a change in the intensity of the inflow of Atlantic waters in different years influences to a certain extent the times of the production of plankton in the Norwegian and Greenland Seas as well as its species composition and its amount.

According to our observations the intensity of the North Cape current and of the eastern branch of the Norwegian current changes asynchronously. This is due, perhaps, to the fact that in some years more warm water enters the western regions of the Norwegian Sea, whereas in other years more warm water enters the eastern regions and the Barents Sea.

When the intensity of the inflow of Atlantic waters into the Norwegian Sea is lessened as well as when a lessening of radiation heating of the surface water layers occurs, then the biological spring is usually delayed, Calanus develops later and remains for a longer period in the surface layers, which is a favorable condition for the feeding of small herring. Furthermore, a general slackening in the water circulation brings about an increased temperature of the mixed waters and an earlier development of plankton in them. This facilitates the feeding or fattening of older herring there.

In warm years when there is a general acceleration in the circulation of Atlantic waters, an early biological spring can be observed in the Norwegian and Greenland Seas.

1/ Material by Rudakova, V. A.

In such years, the temperature in the waters of the Norwegian current rises. the early developing Calanus in July leave the surface layers, where there is an abundance of jellyfish, which are unsuitable as herring food.

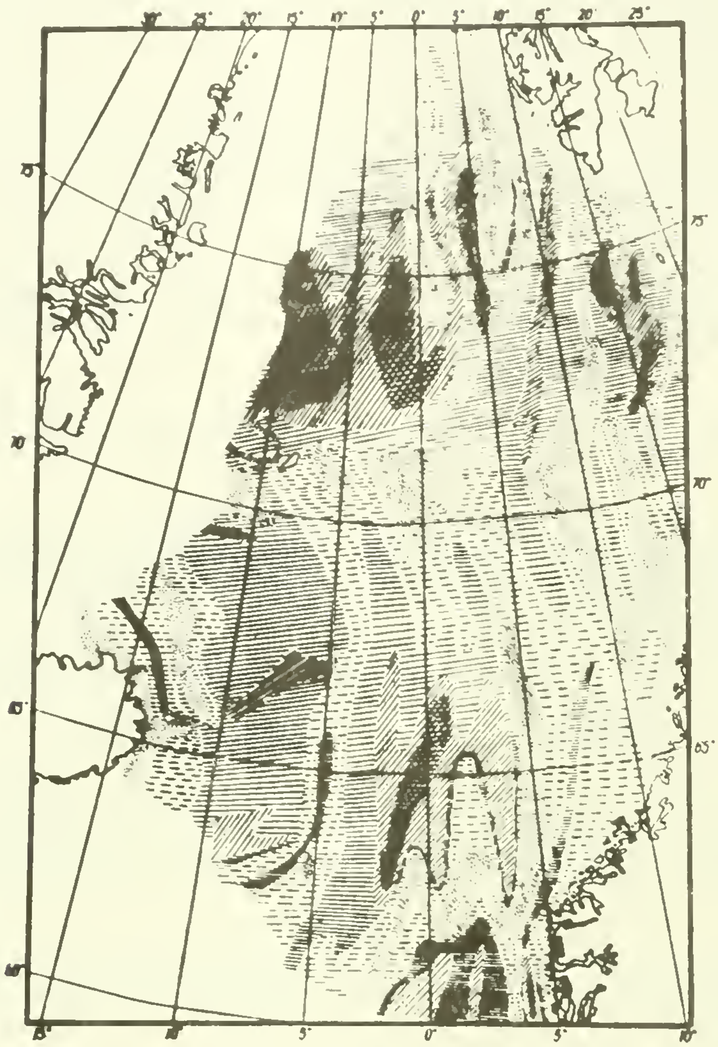

Figure 13. Distribution of the plankton biomass in the 0-50 meter layer in the Norwegian and Greenland Seas on June 1-26, 1954. 1. pre-spawning accumulations of Calanus; 2. nauplii and young of Calanus; 3. red Calanus at the surface; 4. red Calanus descended into the deep; 5. Phaeocystis; 6. diatoms; 7. Calanus hyperboreus; 8. jellyfish. (See Figure 12).

Due to the acceleration of the cold East Greenland current, linked with the Norwegian current, the zone of mixed waters becomes narrower and the herring of the older age groups do not enter the waters with a low temperature that are west of Jan Mayen. The main bulk of them leave for the far north in search of food; the length or duration of the migration routes increase. But these migrations help little with regard to the concentration or storing of fat in the herring.

These principles must be considered when organizing further research.

"Blooming" of the Sea and its Influence upon the Distribution of Herring.

The questions regarding the adverse or negative action of "blooming" (mass production of diatoms and Phaeocystis) upon herring were discussed in the works of Soviet research workers such as Mosentsev (25), Manteyfel' (19) as well as in the works of foreign scientists such as Hardy, Savage and Wimpenny (39, 40, 41, 42, 43).

B. P. Manteyfel' (19) came to the conclusion that herring almost never occur in the intensive "blooming" of Phaeocystis in the Barents Sea. In May and June, the commercial concentrations of herring are found to the west and south-west from the boundaries of the "blooming" and they follow these boundaries, which recede to the east. Individual schools of herring even penetrate somewhat into the rear of the "blooming" zone.

Manteyfel' believes that in the zone where the "blooming" is terminating, herring can maintain themselves in the 10-meter layer (above the zone of the descending Phaeocystis) and down to 70 meters (under the zone of the descending Phaeocystis).

The reason for the adverse effect or influence of phytoplankton upon herring has been explained by research workers in various ways.

Hardy (1925), for instance, supposed or suggested that phytoplankton clogs the gills of herrings, but this supposition was rejected by further research. Many research workers were of the opinion that the mass production of phytoplankton not only affects herring adversely, but also has the same effect upon zooplankton.

It is true that, during the greatest production of Phaeocystis, the zooplankton is very poor: only the eggs and larvae of crustacea are encountered in the "blooming", whereas a small number of adult crustaceans stay somewhat farther down--below the "blooming".

Such a composition and distribution of plankton, according to our observations, is characteristic of the biological spring season. Consequently, when studying the phenomenon of the "exclusion" of zooplankton by phytoplankton, one must always bear in mind the seasonal phenomena in plankton.

An intermixing of cold and warm waters, which carry with them the vernal plankton at the various stages of development, occurs in the areas where the Atlantic and the polar waters meet and mix with one another.

In such regions, the interrelations of plankton and herring are especially complex.

Here one can often encounter simultaneously the production of phytoplankton and zooplankton and the feeding of herring in the "blooming". It is also possible to encounter a "blooming" without zooplankton, where there are no herring.

We conducted a number of observations in 1953 in various regions of the Norwegian Sea to establish the relationship between herring and phytoplankton. The following problems or questions aroused our interest: Do herring react in the same way to "blooming" caused by the mass production of Phaeocystis and to "diatom blooming" and when do herring "avoid" a "blooming"?

All the observations were carried out in April and May of 1953 on the E/S "Professor

Mesyatsev".

In the early part of April, we worked near the Norwegian shores and in the Lofoten shallows, where at that time the spawning of herring of the older groups was coming to an end. Their larvae were found in the plankton.

In the shallow waters, the plankton was poor, the "blooming" was beginning and the post-spawning herring were leaving these regions for the Atlantic waters. In the latter part of April, the "blooming" included the Norwegian current near the continental shelf. Keeping ahead of the "blooming", the herring continued to leave for the north and north-west.

There is a heavy production of the "green blooming" (Phaeocystis) in the shallow waters and in the waters of the eastern branch of the Norwegian current. In the latter part of April, only isolated small spots of the Phaeocystis "blooming" could be observed. But during the first ten days in May, a considerable area had a great "bloom". The herring moved into the deep water, where the biological spring is somewhat delayed. In the second half of May, the Phaeocystis "blooming" was observed north of 70° north latitude (between the arms of the current) and in the region of vortexes or eddies at the borders of the East Icelandic current, between Jan Mayen and the Faroes.

What then caused the herring to leave or abandon the coast regions, to "avoid" the "blooming" that was brought about by a great development of Phaeocystis?

We are inclined to assume that the herring left the coast and shallow water regions in search of food. After spawning, the exhausted herring begin to feed ravenously on the pre-spawning concentrations of Calanus finmarchicus. The spawning of these crustaceans coincides with the beginning of phytoplankton production. Having spawned, the Calanus finmarchicus die, but the Euphausiacea leave for the deep. Due to this, the herring fail to find sufficient food for themselves and quickly shift to other regions.

Usually one can observe three phases in the development of Phaeocystis.

The beginning of the "blooming" of Phaeocystis is heralded by encountering a greenish sediment and large spawning Calanus in the plankton sample. The algae develop in the upper layer of the water (to a depth of 15-25 m.).

At the height of the "blooming", the amount of the greenish slimy sediment in the plankton samples greatly increases. Large mature Calanus are seldom encountered in the samples; there appear many eggs and nauplii of crustaceans.

At the end of the "blooming", brownish-green flakes of dying algae and large numbers of the small young of Calanus appear. When dying, the algae sink into the deep, but the herring (usually young) remain at the surface, where they feed upon the young Calanus.

In the developing "blooming", herring descend to a depth of more than 20 m. and head for the outside limits of the "blooming" where they usually find suitable food.

We are of the opinion that it is only the lack of planktonic food, instead of the great Phaeocystis production (for the nauplii of Calanus, because of their microscopic size, cannot be used as food by herring) that compels the herring to abandon the zone of "blooming" for waters that abound in plankton that is fit for food (Figure 14).

For instance, our observations at station No. 108 on June 16, 1953, indicate that Phaeocystis by itself has no harmful effect upon herring. There was a great deal of Phaeocystis in the surface layer (to a depth of 25 m.). There was little zooplankton at 0-10 m. and there were almost no herring. The best catches of herring were made in a layer from 10 to 20 m. There was as much Phaeocystis there as at the surface, but there was 4 times as much zooplankton there; therefore, the herring had sufficient food.

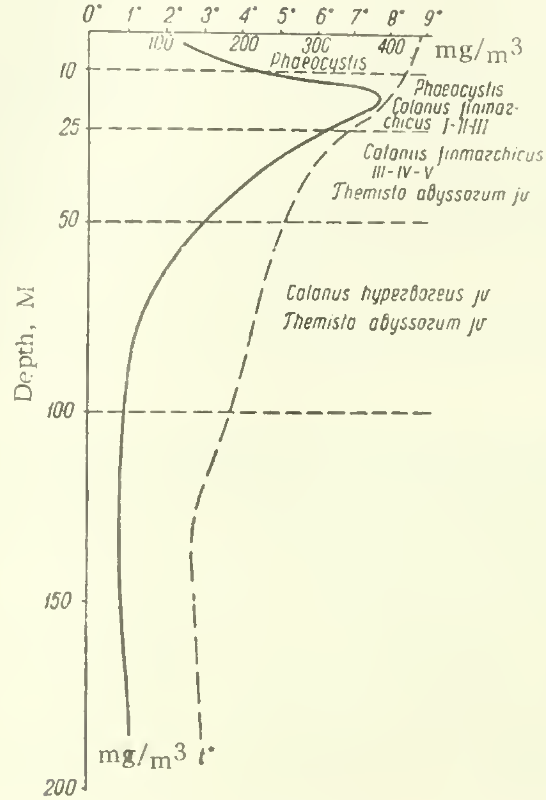

Figure 14. Change in the amount of plankton and the temperature of the water in the zone of the Phaeocystis "blooming".

In June-July, the diminishing Phaeocystis "blooming" is replaced by the production of diatoms.

Their production coincides with the appearance of a large amount of young Calanus (of the red Calanus). At this time, the spots of "diatom blooming" occur over the entire area of the Norwegian Sea. The production of diatoms is of especially long duration on the shoals, in shallows, and in the current eddies. Diatoms usually develop or grow in the thin (3-5 m.) surface layer. When they die they lose their buoyancy and, sinking, concentrate near the thermocline.

In all regions, the "diatom blooming" usually contains many young of Calanus finmarchicus, Calanus hyperboreus, Pseudocalanus elongatus, Oithona similis, etc. This enables the herring even during "blooming" to continue their feeding successfully. The feeding herring break up into small schools and keep mostly to depths of 10-15 m. During the summer months, at the borders of the East Icelandic and the East Greenland currents (region of the polar front), one can quite often encounter the simultaneous production of phytoplankton and zooplankton. In these regions, which have sharp temperature gradients, solid herring concentrations are quite often encountered, regardless of the abundance of phytoplankton.

There the herring usually stay at a depth of 20-40 m. The captains of fishing boats fish these schools successfully by using nets with long lines. But also here the herring do not enter far into the region engulfed by the "green blooming", since there is almost always less plankton in the center of the "blooming".

The formation of herring concentrations in the region of the polar front is usually facilitated by a good herring food yield there (up to 9000 $mg/_{m}3$). This production is a result of the simultaneous development of several populations of mass species of planktonic organisms that usually characterize the various biological seasons such as: spawning Calanus finmarchicus of the VI copepod stage, young Calanus finmarchicus of the I-II-III-IV stages, mature specimens and young of Calanus hyperboreus, young of Themisto abyssorum and Themisto libellula, Pseudocalanus elongatus, the young of Euphausiacea, and others. This varied plankton is encountered at various levels in the water in the Faroes and Jan Mayen regions. During the entire month of June, the surface layers are replenished by crustaceans that rise to the surface for spawning and also by those that were carried there from more southern regions. Here phytoplankton often develops on the surface and the herring feed at a depth of 20-40 m. upon the concentrations of Calanus hyperboreus and Calanus finmarchicus of the IV-V stages.

The vernal biological processes spread gradually also to the polar waters. The herring also leave for the polar waters. Towards the beginning of the abundant production of phytoplankton in the waters of the East Greenland current (latter part of July-August) the herring finish their feeding, turn south and enter the Atlantic waters, where the production of diatoms is almost finished. Only in patches do peridineans appear.

Thus our observations indicate that the relation of herring to the "blooming" must be studied, bearing in mind the season, and, of necessity, link it with the peculiarities of the hydrological conditions of the region that is being studied.

Herring of the older age groups usually begin their feeding migrations prior to the mass production of phytoplankton, i.e. at the very beginning of the biological spring, and move northward while feeding upon the spawning accumulations of Calanus along the route. The herring, so it seems, move away from the "green blooming" (Phaeocystis).

Young herring, those spawning for the first time or still immature, begin feeding somewhat later and move along the migration routes after the "blooming" while feeding upon the fry of Calanus.

Their relation to the "blooming" is the same as that of Murmansk herring: they do not form concentrations in the "blooming" but they can feed at some depths below the "blooming" (Manteyfel', 1941).

Thus, on the basis of the observations of the production of phytoplankton and the distribution of herring, which were conducted by us in 1953, the following can be stated:

1. Concentrations of large herring, as a rule, are not observed in the eastern and central regions of the Norwegian Sea during the mass production of Phaeocystis (of the "green blooming") since the herring of older age groups finish their spawning prior to the start of phytoplankton development. From the spawning grounds, the herring go northward. They start to feed or fatten upon

the pre-spawning concentrations of Calanus and Euphausiidae.

We are inclined to assume or to accept that herring "avoid" the regions with great production of Phaeocystis for the simple reason that they can not find food there. It is known that after spawning, the mature Calanus die; but their microscopic nauplii are not fit as food for herring. Furthermore, after the deaths of the spawned Calanus, the general biomass of plankton in the regions that have the "green blooming" is greatly reduced.

2. At the borders of the East Icelandic and the East Greenland currents, in the regions of the polar front, where the simultaneous production of several plankton complexes that characterize the different biological seasons occurs, the herring find food for themselves in the zone of the "green blooming"; for herring concentrations can be encountered here also during the mass production of Phaeocystis.

3. The growth of diatoms coincides in time with the mass production of young Calanus and does not interfere with the feeding or fattening of herring. During "diatom blooming", herring usually feed over a large area and do not form solid schools or concentrations.

Conclusions

1. Atlantic-Scandinavian herring make feeding migrations into the northern latitudes of the Norwegian Sea as well as to the west and north-west into the polar or arctic waters. These migrations are related most closely to the seasonal changes in the plankton production and distribution.

Lengthy migrations provide the species with food, regardless of the fluctuations in the dates of the development of plankton and its quantity.

2. The times when plankton develops depend on the intensity of the inflow of Atlantic waters into the Norwegian and Greenland Seas, on changes in the hydrological, hydrochemical, and meteorological conditions.

The development of seasonal phenomena shifts from the shores of Norway into the regions of greater depths, but also in a northern and north-western direction.

3. The herring of the older age groups that spawn in early spring usually penetrate far to the north into the Greenland Sea. All the time they keep to the conditions that are characteristic of the beginning of the biological spring. On the way, they feed upon the comparatively large crustaceans that are getting ready for spawning. Their staple diet originates in the mixed Atlantic waters near the cold or frigid masses of water of the East Icelandic current in the south and of the East Greenland current. During the feeding or fattening period large herring can also penetrate into the layers of the polar waters that were warmed up or heated by the sun at the moment of the beginning of the biological spring there.

4. Herring that spawn for the first time approach the shores of Norway at a later date than the older herring. At the time when they leave the spawning grounds, there appears in the plankton a large amount, at first, of pink and, later, of red--due to fat--young Calanus. It is these fat crustaceans that are the staple diet of young herring. The feeding migrations of herring that spawned for the first time, are considerably shorter than those of herring of older age groups.

5. According to our observations, herring avoid the "blooming" when they cannot find any food there. Most of the time, herring leave the southern and central coast regions of the Norwegian Sea at the moment of the "blooming"; for there the development of the alga Phaeocystis ("green

blooming") usually coincides with the reproduction of Calanus. After the shedding of eggs, the adults perish. In the plankton remain the microscopic nauplii of Calanus, which are unsuitable as food for large herring. While feeding upon the pre-spawning concentrations of Calanus, the large herring move northward at a quickened pace, "keeping ahead" as it were, of the "blooming".

6. Plankton complexes, which are characteristic of the various biological seasons, can exist at the same time in the various levels of the water where the Atlantic and polar waters mix. Even during blooming, it is possible to encounter in such regions an abundance of Calanus and herring. The latter feed upon the former.

7. The development or growth of diatoms in the Norwegian Sea coincides with the mass production of young Calanus.

The large herring leave for the north at this time. The young herring that feed upon red Calanus, as a rule, do not form solid or compact concentrations (except regions with radical temperature gradients).

In regions with radical temperature gradients and, especially, if there is a cold or frigid underlying layer, there occur compact concentrations of herring even when there is an abundance of diatoms.

8. The observations in recent years have shown that the annual fluctuations in the time of plankton production can cause a shift in the herring-feeding grounds.

9. In view of the fact that the feeding migrations of herring are connected with the time and the entire process of plankton production, we are compelled to study and analyze very thoroughly the causes for the annual differences in the plankton production of the Norwegian and Greenland Seas.

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DATA ON THE FOOD OF THE ATLANTIC HERRING

V. A. Rudakova

INTRODUCTION

Food is the most important factor influencing herring distribution during the spring and summer. Our present work is a study of the food of the Atlantic-Scandinavian herring (Clupea harengus harengus L.) and the interaction between its food and the individual stages in its physiological condition.

Regular observations of the nutritional conditions with due allowance for the hydrological regime, distribution of food organisms and composition, as well as the age structure of the stock will help towards a knowledge of herring migrations and will undoubtedly be of practical assistance to the herring fleet.

So far, the data obtained enable us to give only an outline of the annual feeding cycle of the herring and to discover some general rules governing the influence of food on the subsequent stages of biological development.

The data given in the literature on the feeding habits of the Atlantic-Scandinavian herring are limited to the composition of the herring's food during the summer.

In foreign countries, the Atlantic-Scandinavian herring has until very recently been the object of coast fishing. This fact has resulted in an almost total absence of research into the feeding habits of the herring in the open sea. Our data, which were collected in the North Atlantic seas during the period 1951-55 are the first collation of results of studies of the contents of herring stomachs.

A study of the food of Barents Sea herrings belonging to younger age groups has been carried out by G. V. Boldovskiy (3, 4), B. P. Manteyfel' (7) and others.

G. V. Boldovskiy considers that the seasonal fluctuations in the feeding rate of the herring are due to qualitative variations in the composition of the food. In the case of Barents Sea herring, the feeding rate was at its maximum in June and July, i.e. the season when the herring feeds on "red feed" (Calanus finmarchicus). The autumn decrease in feeding continues from August to October, the principal food at this season being Euphausiacea. During winter, the feeding rate declines, although feeding does not cease altogether. Boldovskiy also points out that the feeding rate of the herring is in inverse ratio to its fatness.

Pchelkina (10), in her work in the Barents Sea, draws attention to the relationship between the zooplankton and the herring - a connection which varies according to the season of the year. The positive correlation between the distribution of the herring and that of the copepod Calanus finmarchicus is particularly noticeable during the development period of the latter (in June). Large schools of intensively feeding herrings have been encountered in the zone of concentration of Calanus finmarchicus. During the spring months, no relation between the distribution of the herring and that of the plankton was observed.

Ambroz (1) notes that in the case of the Pacific herring there is no starvation period in the strict sense of the term and that this herring ceases to eat for only a brief period immediately before and during spawning.

Kun (6) considers that the herring behave in different ways at different biological stages. This author examines the seasonal variations in the feeding rate and comes to the conclusion that the Pacific herring does not feed uniformly throughout the year.

Material and Methods

For our study of the contents of the stomachs of herrings, we used adult specimens (caught by drift-nets on the fishing grounds) 30-33 cm. long, since the bulk of the catches during the period 1951-4 consisted of large herrings. Most of the stomachs were collected during the summer.

In 1955, owing to the large additions to the stocks of usable herring from the 1950 year class, when the material was analysed it was divided into two size groups: herring 30-33 cm. in length--the older age group, and herrings 26-29 cm.--the 1950 year class.

Upon comparing the stomach contents of the younger herrings (1950 year class) which had spawned once with those of the older herrings which had spawned more than once, we were unable to detect any difference whatever in the choice of food organisms in the same areas during the summer.

The material collected during the individual years is distributed as follows:

Year	Herring stomachs collected
1951	640
1952	280
1953	397
1954	395
1955	1,600
Total	3, 312

For the feeding pattern of the herring, we used the method of quantity-weight analysis proposed by V. G. Bogorov (2) and adopted by the Herring Laboratory of PINRO. We were unable to analyse the feeding of the herring by the quantity-weight method in February, March, and April, since, owing to circumstances beyond our control, the material was collected selectively, no record being kept of empty stomachs. We utilized this material not only for determining the qualitative feeding pattern of the herring but also for ascertaining the characteristics of the herring's capacity to feed actively during the pre-spawning period when food organisms are present.

The specific composition of the food was determined only from the stomach contents (those of the intestines were not taken into account).

The food mass, after being transfered to filter paper, was slightly dried, weighed, and examined under a binocular microscope.

The percentages of the individual components in the food mass were determined visually and then recorded as percentages by weight. The amorphous mass present in the stomach was distributed in proportion to the weight of those parts of the food mass which were being determined.

For the curve of the feeding rate of the herring and of the size of the separate food components, individual and average indices of stomach fullness (ratio of weight of food to body weight of fish, multiplied by 10,000) were calculated. For a number of reasons, the index of stomach fullness does not reflect the natural course of feeding of the herring with complete accuracy.

First of all, it should be noted that a herring is able to digest the food in its stomach after having been caught in a drift-net. A series of drift-nets is usually in the water for a period of 8-9 hours; a considerable portion of the food in the herring's stomach is undoubtedly digested during this time, since a herring can remain alive for a long while in a net.

The character of the food is also reflected by the digestion and, of course, it alters the fullness index, since different organisms are digested at different rates. The fullness index depends to a certain extent on enzymes whose activity does not remain constant throughout the year. Digestion activity is influenced, and therefore varied, by the temperature conditions of the environment. The higher the temperature, the more rapid are the digestive processes.

From the experimental data of G. C. Karzinkin (5) and K. R. Fortunatova (11), it has been established that the lower the water temperature the slower the food moves through the alimentary canal.

Battle (13), who studied the food of the herring off the American coast, came to the conclusion that the food digests eight times more quickly at a temperature of 9.5°C than at a temperature of 2.4°C.

Despite the above-mentioned defects and discrepancies in our investigation method (absence of analysis of different factors influencing the character of digestion, etc.), the results obtained nevertheless enable us to make a general comparison of the food of the herring from season to season and from year to year.

Apart from the quantity-weight analysis of the stomachs of herrings, we also used data obtained from field analyses during the period 1951-55 in which the degree of fullness of the stomachs was determined by a five-mark scale:

0 - stomach and intestines empty
I - small quantity of food present
II - moderate quantity of food present
III - stomach full, containing a large percentage of food
IV - stomach distended (walls of stomach distended to such an extent that food is visible through them).

A total of 36,821 stomachs were subjected to the field analysis.

Specimens of plankton were taken (by means of a Nansen net with a closing device) at the same time as the herring stomachs.

Composition and Quantity of Individual Organisms in the Food of the Herring

Our data show that the food of the Atlantic-Scandinavian herring consists of plankton organisms (zooplankton) and young fish, irrespective of season.

The ratios of food components vary in different years but some species always predominate.

Table 1 shows the organisms which constitute the food spectrum of the herring in the North Atlantic seas.

TABLE 1. ORGANISMS FOUND IN THE STOMACHS OF HERRINGS, FROM MATERIAL COLLECTED DURING THE PERIOD 1951-55.

Organism	Period during which the organism is used and its importance in the food spectrum
Copepoda	
Calanus finmarchicus	Principal food during spring and summer
Calanus hyperboreus	Summer - frequent
Pareuchaeta norvegica	Early spring - occasional specimens
Metridia longa	Spring and summer - occasional specimens
Pseudocalanus elongatus	Summer - occasional specimens
Cladocera, Ostracoda	
Evadne nordmanni Podon leucarti Conchoecia borealis	Summer - occasional specimens
Cirripedia	
Cypris - larvae	Summer - occasional specimens
Amphipoda	
Hyperia galba	Summer - occasional specimens
Hyperoche medusarum	" " "
Themisto abyssorum Themisto compressa f. compressa Themisto compressa f. bispinosa	Spring and summer - of substantial importance in the diet
Themisto libellula	Summer - frequent
Euphausiacea	
Young Euphausiacea	Summer and autumn
Meganyctiphanes norvegica Thysanoëssa inermis Thysanoëssa raschii Nematoscelis megalops	Principal food of the herring from January to October, with a slight decrease during the summer months
Young Decapoda	Summer - frequent as admixture
Spawn of crustaceans	Summer - occasional cases
Mollusca	
Limacina retroversa	Spring and summer - frequently found as admixture
Young Gastropoda	" " " " " "

Organism	Period during which the organism is used and its importance in the food spectrum
Mollusca (Cont'd)	
Young Cephalopoda	Summer - occasional specimens
Vermes	
Polychaeta	Spring and summer - occasional specimens
Chaetognatha	
Eukrohnia hamata	Spring and summer - occasional specimens
Appendicularia	
Oikopleura labradoriensis	Summer and autumn - substantial quantity in individual samples.
Coelenterata	
Siphonophora (physophora) Hydromedusae (Aglantha) Ctenophora (Beröe)	Summer - isolated cases
Pisces	
Clupea harengus harengus juv. Gadus sp. juv. Anarrhichas sp juv. Sebastes juv. Ammodytes juv. Myctophum glaceale juv.	Spring, summer and autumn - substantial quantities
Phaeophyta	
Fucus inflatus	One single case

For a fuller picture of the food of the herring, see Table 2, which shows the percentages of different organisms in the food of the herring for certain months (average for 4 years), and Table 3, which gives the results of observations made in 1955.

During the months of February, March, and April the Euphausiacea constituted the characteristic group in the food of the herring; Copepoda (Calanus finmarchicus, Calanus hyperboreus) and Amphipoda (Themisto) predominated during the summer.

Observations on the food of the herring during the autumn months have been negligible, al-

TABLE 2. QUANTITIES OF DIFFERENT ORGANISMS IN THE FOOD OF THE HERRING DURING DIFFERENT MONTHS FOR 1951-54 (AS PERCENTAGES OF THE MEAN INDEX)

Name of Organism	Month									Average for season
	February	March	April	May	June	July	August	September	October	
Euphausiacea										
Meganyctiphanes norvegica										
Thysanoëssa inermis	100.0	93.14	57.30	38.60	5.20	5.76	72.64	14.70	17.97	33.0
Copepoda										
Calanus finmarchicus	--	0.44	27.80	50.20	61.90	32.89	11.30	72.50	--	33.6
Amphipoda										
Themisto sp.	--	3.42	7.70	1.80	20.30	25.95	5.47	3.30	78.65	17.8
Appendicularia										
Oikopleura labradoriensis	--	--	--	5.20	6.00	22.33	9.33	2.40	3.38	4.0
Young fish	--	3.00	5.60	0.20	0.90	10.02	0.06	--	--	8.4
Others	--	--	1.60	4.00	5.70	3.05	1.20	7.10	--	3.2

TABLE 3. QUANTITIES OF ORGANISMS IN THE FOOD OF THE HERRING FOR DIFFERENT MONTHS DURING 1955 (AS PERCENTAGES OF THE MEAN INDEX)

Name of Organism	Month							
	February	March	April	May	June	July	August	September
Euphausiacea								
Meganyctiphanes norvegica and Thysanoëssa species	94.0	90.5	29.2	--	2.5	6.5	4.4	4.0
Calanus finmarchicus	--	2.6	39.6	--	28.0	36.1	27.8	56.6
Calanus hyperboreus	--	--	--	--	52.0	--	--	--
Themisto sp.	--	2.8	8.7	--	3.5	11.2	25.1	31.8
Oikopleura labradoriensis	--	--	0.9	--	13.0	45.7	42.1	--
Young fish	--	3.4	20.9	--	0.8	--	0.4	--
Others	6.0	0.7	0.7	--	0.2	0.5	0.2	7.6

though individual specimens show that the quantities of Euphausiacea and Themisto are increasing.

Food of the Herring throughout the Year

According to the data obtained from the field analysis of the food of the Atlantic-Scandinavian herring, the lowest average mark for stomach fullness for all the years in which observations were made is that for the winter months of February and March; it increases slightly in April and May, while the maximum is reached in June and July, i.e. the greatest number of feeding individuals are found during this season. The average stomach fullness index decreases from August onwards; this is due to the increase in the percentage of empty stomachs and to the decline in the weight of food in the stomachs of feeding herring (Table 4, Figure 1).

The field observations on the feeding rate of the herring in June and July 1955 were analysed separately for the different age groups. For this, the analysis of the younger herring which had spawned only once (the quantities of which were greatest in the commercial catches at this season) was carried out separately from that of herring which had spawned more than once.

The results of the analyses are given in Table 5, from which it will be seen that no differences in the rate of feeding according to age groups were observed during the months in question.

The stomach fullness indices for the summer months in different years are given in Figure 2 in the form of circular diagrams, which reflect fairly clearly the quantitative and qualitative variations in the herring food.

The average index for the different months is given under each circle. The sectors of the large circle correspond to the quantities of the different food types; the small circle in each diagram indicates the ratios of feeding (black sector) and non-feeding (white sector) fish.

Distribution of the Herring and Variations in the Composition of its Food

During the winter, the maturing herring concentrate in the south-western part of the Norwegian Sea. From mid-January, the pre-spawning shoals make their way to the spawning grounds, where they remain for some time, and the majority of the herring have finished spawning by mid-March. After spawning, the herring is in a very exhausted condition and goes off in search of food, travelling great distances to plankton-rich areas.

In the area of the Faroe-Shetland channel and of the Viking Bank (in the Atlantic current), pre-spawning congregations of Euphausiacea (Meganyctiphanes norvegica) begin to form in the surface layer as early as February.

The material at our disposal enables us to draw certain conclusions regarding seasonal variations in the food of the herring.

Figure 3 gives data on the qualitative composition of the food of the herring in the Norwegian and Greenland Seas for the period 1951-54 during its migrations (Table 6).

In the years during which there is a mass development of food organisms, a certain number of herring feed actively before the onset of spawning. Thus, in February 1951 and 1954, in samples 1 and 2 (Figure 3), the stomachs of individual specimens of mature herring at stage V or V-VI 1/

1/ V and V-VI correspond to the pre-spawning stages in the development of the gonads. VI is the spawning stage.

contained Euphausiacea in quantities meriting up to the index 3-4. 1/

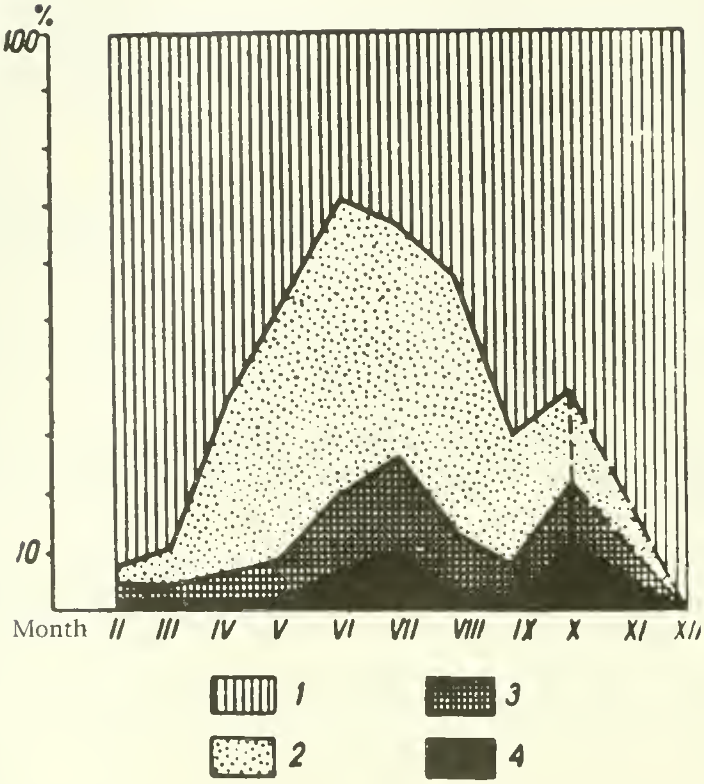

Figure 1. Stomach fullness of Atlantic-Scandinavian herrings in different months.
1. Stomach empty; 2. Small food content; 3. Moderate food content;
4. Stomach full and distended.

In March, Thysanoëssa inermis, Themisto abyssorum, Themisto compressa f. bispinosa, occasional specimens of Pareuchaeta norvegica, etc. are found in the plankton in addition to Meganyctiphanes norvegica. At this season, the herring, after spawning, leave the spawning grounds and begin to feed intensively in the northward-moving currents of warm water.

In March 1951 (sample 3, Figure 3), the principal food components of the herring were Meganyctiphanes norvegica and Thysanoëssa inermis, which constituted 55% of its diet. In addition to the above-named species of Euphausiacea, the food of the herring contained Themisto compressa f. compressa, Th. compressa f. bispinosa, C. finmarchicus and up to 20% young wolf fish. In 1954 (sample 4, Figure 3), the food of the herring consisted entirely of Euphausiacea.

In April, the accumulation of plankton increases and the composition of the food of the herring becomes more varied in kind. A number of species which are very numerous in some years make their appearance. Thus, in April 1952 (sample 5, Figure 3), Calanus finmarchicus amounted

1/ Index 3 = stomach full. Index 4 = stomach distended.

to 13.2%, Themisto abyssorum and Themisto compressa f. bispinosa 23.8%. Euphausiacea 42.3% and young of the lantern fish Myctophum glaciale 20.5%.

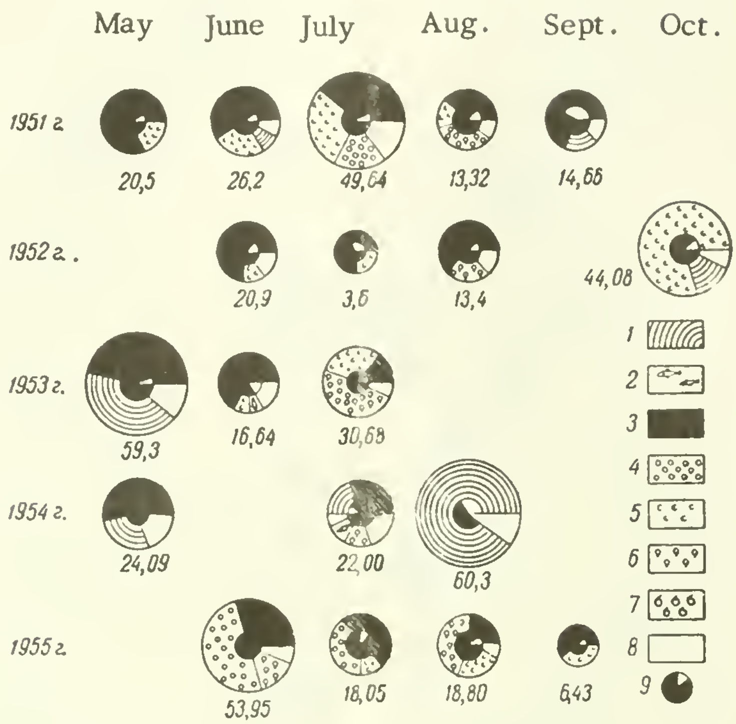

Figure 2. Average monthly food spectra of the Atlantic-Scandinavian herring for different years. 1. Euphausiacea; 2. Young fish; 3. Calanus finmarchicus; 4. Calanus hyperboreus; 5. Amphipoda (Themisto); 6. Oikopleura; 7. Limacina retroversa; 8. Others; 9. Feeding and non-feeding herrings.

In 1954 (in sample 6, Figure 3), the food contained a substantial quantity--65.1%--of adult Euphausiacea, 0.7% young Euphausiacea, 31% Calanus finmarchicus and 3.2% Oikopleura and Themisto.

In addition to the qualitative analysis of the food (Figure 3), we give, for all the years of the investigations from the month of May onwards, the results of the quantity-weight analysis of the herring food in the Norwegian and Greenland Seas for the same samples during the period 1951-54 (Figure 4, Table 6).

During all the years of the investigations, with the exception of 1955, the development of a summer complex of plankton was observed in May and June in the waters of the Norwegian current. The principal herring food during these months was Calanus finmarchicus, which accounted for 50 to 90% of the constituents of the stomach contents of all the samples for the period 1951-54, and only in one sample (9) was there a predominance of adult Euphausiacea (78.7%). The remaining components of the herring food were very small and consisted of forms of plankton which develop in the Atlantic waters during this season.

TABLE 4. AVERAGE STOMACH FULLNESS INDEX [1/] FOR HERRINGS IN DIFFERENT YEARS.

Year	Months								
	February	March	April	May	June	July	August	September	October	December
1951	0.27	--	0.42	0.78	1.17	0.92	0.93	0.51	--	--
1952	0.03	0.38	0.61	0.30	1.09	0.83	0.30	0.33	0.73	--
1953	--	--	0.50	0.41	0.65	1.19	0.91	0.29	--	--
1954	1.10	0.05	0.29	0.97	--	1.22	0.80	--	--	0.01
1955	0.07	0.09	0.54	--	1.58	1.12	1.30	1.10	--	--

1/ When the average index was being calculated, allowance was made for the number of feeding and non-feeding individuals.

TABLE 5. AVERAGE 'STOMACH FULLNESS' INDEX FOR HERRINGS ACCORDING TO AGE GROUPS IN 1955.

Age groups	June	July	August	September
Herrings having spawned more than once	1.58	1.12	1.30	1.10
Herrings having spawned once (1950 year class)	1.55	1.05	--	--

Figure 3. Distribution of the herring and seasonal variations in the qualitative composition of its food. For key to symbols see Figure 2 and Table 6.

In 1955, because the colder hydrological conditions were unfavorable for plankton development in the surface layer, the herring fed at greater depths (compared with the preceding years), in the layer inhabited by Calanus hyperboreus, during May and June. In contrast to the position during past years, in June 1955 the principal food of the large herring east and north-east of Jan Mayen was Calanus hyperboreus, (52%), Calanus finmarchicus (28%) and Oikopleura labradoriensis (13%). In June 1955, the young herring (1950 year class) concentrated in the eastern part of the Norwegian Sea, not passing beyond the boundaries of the polar front. At this time, the older herring occupied a much wider area and entered the cold polar waters. Owing to this territorial separation, the composition of the food eaten by the herring of the younger generation in June 1955 differed substantially from that of the food eaten by the older herring, whose principal food in the waters of the polar front and beyond its boundaries, further to the north, was Calanus hyperboreus. The principal diet of the herring of the younger generation (feeding in the eastern part of the Norwegian Sea) consisted of Oikopleura labradoriensis (60%), Calanus finmarchicus (20%) and Themisto sp.

(10%).

TABLE 6. TIME AT WHICH THE SAMPLES TO WHICH FIGURES 3 AND 4 RELATE WERE COLLECTED.

Sample No.	Date on which sample was caught				Sample No.	Date on which sample was caught		
	Day of month	Month	Year			Day of month	Month	Year
1[x]	22, 27	February	1951		23	23	June	1954
2[x]	28	"	1954		24	4	July	1951
3[x]	28, 31	March	1952		25	5	"	1951
4[x]	12	"	1954		26	8	"	1951
5[x]	8, 19	April	1952		27	10	"	1951
6[x]	--	"	1954		28	12	"	1951
7	31	May	1951		29	17	"	1951
8	3	"	1953		30	20	"	1951
9	21	"	1953		31	19	"	1952
10	5, 6, 11, 12	"	1954		32	5	"	1953
11	5	June	1951		33	16	"	1953
12	9	"	1951		34	3, 11, 13, 21	"	1954
13	11	"	1951		35	4	August	1951
14	14	"	1951		36	24	"	1951
15	15	"	1951		37	11	"	1952
16	17	"	1951		38	3, 5	"	1954
17	25	"	1951		39	12	"	1954
18	26	"	1951		40	6	September	1951
19	30	"	1951		41	23	"	1951
20	11	"	1952		42	27	"	1951
21	19	"	1952		43	16	October	1952
22	21	"	1952		44	27	"	1952

x/ The first six samples were not subjected to quantity-weight analysis and are therefore not included in Figure 4.

In the second half of 1955--July, August and the beginning of September--the area of distribution of the herring of different ages became common owing to the fact that some of the large herring left the polar waters. During these months, the presence of the summer plankton complex was still characteristic, and the food of all herring groups consisted of 42-45% Oikopleura, 27-36% Calanus finmarchicus, 11-25% Themisto abyssorum and 4-7% young Euphausiacea (Figure 5).

Figure 5 gives the results of the quality-weight analysis of the food of the herring in 1955 with separate figures for different age groups. The data given draw our attention to the relatively low mean indices for 1955.

Our material shows that, in all the years, the main feeding season of the herring is the spring and summer periods (April, May, and June). From June onwards, the herring's food requirements diminish. The amount of food present in the stomach is not large, except in the case of those individuals which spawned relatively late, were unable to attain the necessary nutritional condition during the spring months, and continued to feed intensively. The number of herring with empty stomachs begins to increase.

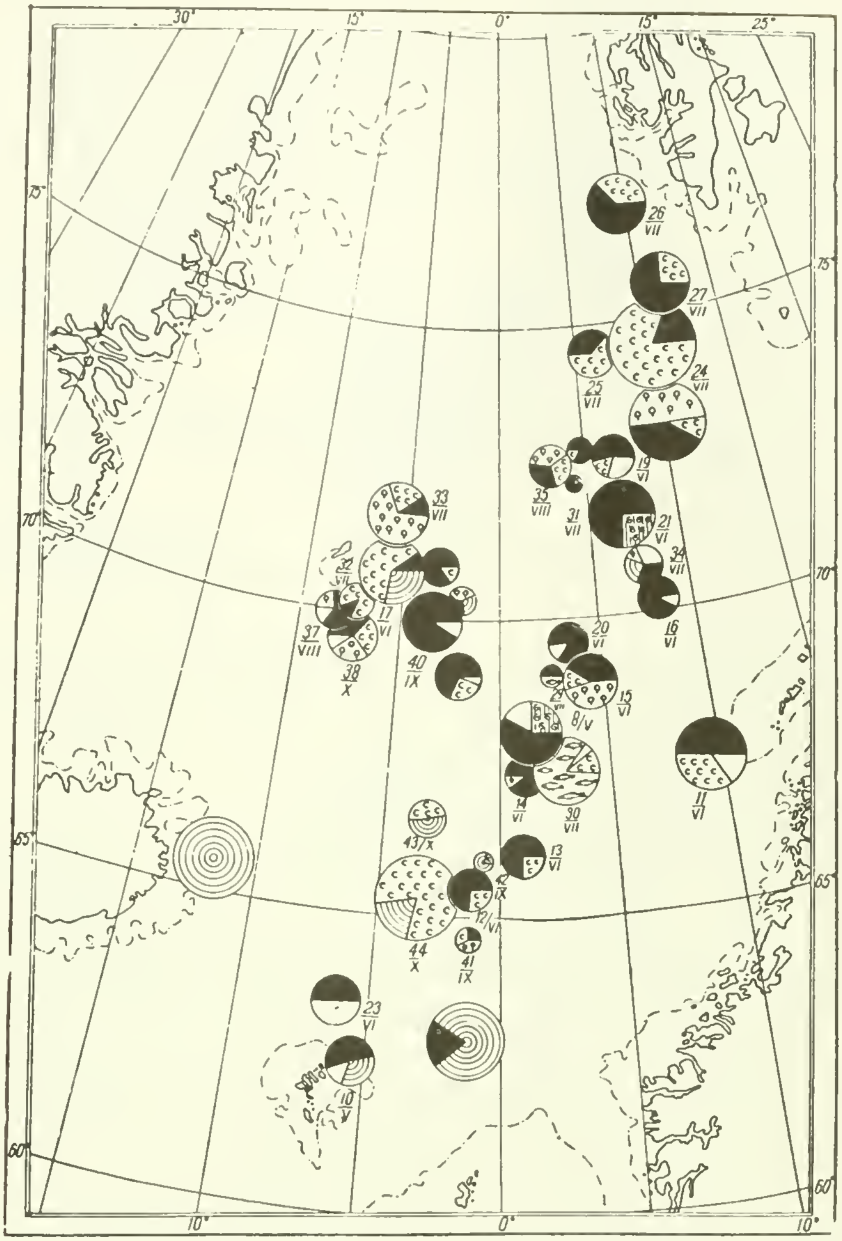

Figure 4. Quantity-weight analysis of the food of the Atlantic-Scandinavian herring during the period 1951-54. For symbols see Figure 2 and Table 6.

The presence of the summer plankton complex is still characteristic of July and August, but the quantity of Calanus finmarchicus eaten by the herring is reduced in comparison with the quantities eaten in May and June, and the quantities of Euphausiacea, Amphipoda (Themisto) and Appendicularia (Oikopleura) begin to increase.

The samples taken in August--with the exception of the bulk of spring-spawning herring--were found to contain a small number of specimens of summer-spawning herring, with their gonads at stage V-VI.

The mean stomach fullness index for the summer-spawning herring was 56.62; the food contained 86% Euphausiacea and 14% young fishes. The herring of the second sample, with a mean fullness index of 15.63, were feeding on Calanus finmarchicus (40%), Oikopleura and Themisto.

At the end of July and during August, after feeding, the large herring form into groups and begin to leave their northern feeding grounds for the southern areas, making their way towards their winter quarters and next year's spawning grounds.

For September, the data on feeding were collected in 1951 (samples 40, 41 and 42, Figure 4) and 1955 (Figure 5). All these samples of herring have a low mean index of fullness. Most of the plankton had already sunk to the deep waters, and the herring were feeding on the scarce plankton organisms which had still remained in the surface layer.

In the beginning of September, Calanus finmarchicus constituted 91.9% of the food of the herring, whereas in the next samples (41 and 42) Calanus finmarchicus was a minor component, with adult Euphausiacea and their young occupying first place.

Two samples, 43 and 44, were taken in October 1952. According to these samples, the principal diet of the herring consisted of Euphausiacea, Themisto abyssorum and Themisto compressa f. bispinosa.

We have no data on the feeding of the Atlantic-Scandinavian herring during the winter months of November, December, and January, but ship captains' reports to the Council for Marine Research Vessels in January and February 1954 and 1955 give the following data:

29th Jan. 1954 "Mature roe, some food in stomachs".
20th Feb. 1954 "Herring having spawned, stomachs full of food".
26th Feb. 1956 "Herring about to spawn, 70% with full stomachs (Euphausiacea)".

From these data, it can be concluded that when food organisms are available the herring also feeds during the winter months. The result of a field analysis also confirms that the herring feeds during the winter months, although very little, a fact which was also observed by G. V. Boldovskiy (3) in the case of the herring overwintering in the Barents Sea.

Analysis of Food of the Herring and Composition of Plankton

The principal food of the herring is plankton and young fish, but during the feeding period not all the forms of plankton organisms are included in the diet.

Hardy (14) notes that the entire community of plankton inhabiting the sea is not represented in the food of the herring, and on the basis of this finding he concludes that the herring is capable of selecting its food.

Pchelkina (10), after comparing the different foods of the herring and the different forms of plankton, notes two groups of animals which can be regarded as the favorite food of the herring (Calanus and young Euphausiacea).

In order to determine the selective capacity of the herring, we compared the composition of its food with the composition of the plankton obtained at checking stations during the drifting season.

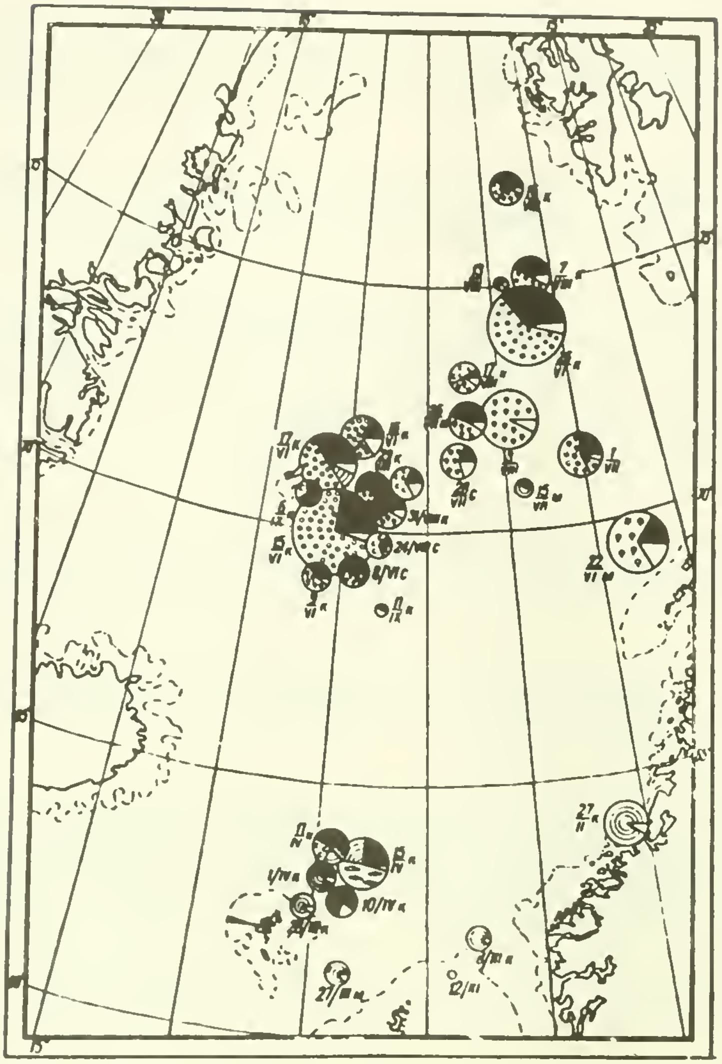

Figure 5. Quantity-weight analysis of the food of the Atlantic-Scandinavian herring in 1955. Symbols: M. small herring in the sample (1950 year class); C. mixed herring (large, medium-sized, and small); K. large herring in the sample. The day of the month on which each sample was taken is shown as the numerator, the month as the denominator.

The plankton was analysed visually[1/]. When the food and plankton are being compared, it must be remembered that the Nansen net is not a perfect catching instrument and is a poor means of catching the more active forms of plankton, such as the Euphausiacea, fish larvae, young fish, and other organisms which form a substantial portion of herring food but which are hardly ever found in samples of plankton collected with a Nansen net. For instance, in February 1951 and 1954,

1/ E. A. Pavshtiks (9) describes the rules governing the distribution of those plankton organisms which serve as food for the herring.

a comparison of the contents of herrings' stomachs with plankton collected at the same time showed the composition of the plankton in the 0-50 m. layer to be extremely poor; the plankton consisted of Calanus finmarchicus (IV-V-VI stage of maturity), Pseudocalanus elongatus, Oithona atlantica and young Gastropoda.

All these organisms were represented in the catches in minute quantities, whereas the principal diet of the herring in February consisted of adult Euphausiacea (mean 'fullness' index for a feeding herring was 96.7 and 70.3).

In March 1952 and 1954, the composition of the plankton in the fishing grounds was somewhat richer than in February. The principal organsims characterizing the plankton samples in these years were the following: Calanus finmarchicus, stage V-VI - very little, Pseudocalanus elongatus, Oithona similis, Oithona atlantica, Acartia clausi, young Gastropoda, eggs of Euphausiacea, Oikopleura labradoriensis, etc. All these forms, with the exception of Calanus finmarchicus, were found only in occasional specimens in the samples.

The food of the herring at the corresponding dates in 1952 consisted of 3% Calanus finmarchicus, 24% Themisto abyssorum and Themisto compressa f. bispinosa, 52% adult Euphausiacea and 21% young wolf fish. Only adult forms of Euphausiacea were found in the stomachs in 1954.

The composition of the plankton on the fishing grounds was qualitatively identical in April 1952, 1953, and 1954. The plankton samples contained the following organisms: Calanus finmarchicus, Pseudocalanus elongatus, Oithona atlantica, Oithona similis, Oikopleura labradoriensis, young Themisto abyssorum and Collozoum.

The principal food of the herring during this month in all the years consisted of adult forms of Euphausiacea (55%), Calanus finmarchicus (40%), Themisto abyssorum and Oikopleura labradoriensis. The food of the herring did not contain all the plankton forms found in the plankton samples; at the same time, organisms not represented in the plankton samples were found in the stomachs.

The number of different plankton forms present in all the plankton samples taken during the spring and summer periods was much greater than the number of organisms used by the herring for food.

We can therefore conclude that the herring feeds on those organisms which populate the water in its habitat, but that it actively selects the larger organisms instead of passively filtering the water through its branchial apparatus.

Of all the forms of plankton which populate the water, the herring selects two or three, while the rest are of no importance to its food spectrum. Our findings show that in the winter-spring period the most favored herring food is adult forms of Euphausiacea. During the spring-summer months, the most frequently selected organisms were Calanus finmarchicus, Calanus hyperboreus, Themisto sp., young Euphausiacea and Oikopleura; in the summer-autumn period, adult Euphausiacea again predominate in the food.

Weight, Nutritional Condition, and Fatness of Herring in Dependence on Food

The influence of the food on the weight increase of herring, their nutritional condition, their fatness and the development of their gonads can be seen from the tables and Figure 6.

Figure 6 shows graphs of indices of the physiological condition of adult Atlantic-Scandinavian herring throughout the year. Owing to the lack of data from quality-weight analyses for the winter-spring months, we have given in Figure 6A the mean weight of food in the stomachs of feeding herring, disregarding empty stomachs.

The mean weight of food in the winter-spring months is very high, but the number of feeding fish at this season is very small. During the following months, the mean weight of food in the herring stomachs declines slightly, whereas the number of feeding fish increases sharply.

The maximum mean stomach fullness index for all the years (1951-55) falls in the summer months (June-July) when the maximum number of feeding fish were observed (Figure 6Б).

In order to illustrate the fat accumulation in the body cavity we used the data from biological analyses in which the quantity of fat in 36,450 herrings was assessed visually and evaluated by a system of grades 1/.

A noticeable accumulation of fat on the internal organs appears from May onwards and continues to increase during the following months. Visual observations show a slight reduction in fatness by September-October. An abrupt fall in general fatness occurs at spawning time - in February and March (Table 7, Figure 6B).

On the fatness of the flesh of the herring, we have the data obtained in 1953 by the Industrial Chemical Laboratory (Figure 6Г).

The flesh has the minimum fat content, 8%, in March, after which the fatness increases and reaches its maximum of 22.5% in August; it then gradually falls until the end of the year.

A good index of the condition of the herring after spawning and feeding is its weight. We observed the variations in weight for different size groups during the course of the year; in 1954, the weight was calculated from 1,678 specimens and in 1955 from 3,329 specimens (Table 8, Figure 6Д).

We find that herrings of all size groups show the minimum weight immediately after spawning, in March or April.

The reduction in weight after spawning is in fact relatively abrupt, since the release by the fish of its gonads immediately reduces its weight by 20-25%.

The weight is at its minimum during the period of intensive feeding.

There is a gradual increase in the weight of the herring during May and July. The maximum weight is attained in August, a month after the highest average stomach fullness grade. The average weight of the herring in 1955 for all size groups was somewhat below that of the preceding year (Table 8).

The nutritional condition factor 2/ of the fish varies in complete conformity with their weight (Table 9, Figure 6Г).

1/ 1 grade = small deposit of fat on the stomach and intestines; 2 grade = fat in considerable quantities on the stomach, intestines and pyloric appendages; 3 grade = abundant fat - stomach, intestines and pyloric appendages covered in a thick layer of fat.

2/ The nutritional condition factor is calculated from the formula $K_y = \frac{\text{weight} \times 100}{L^3}$

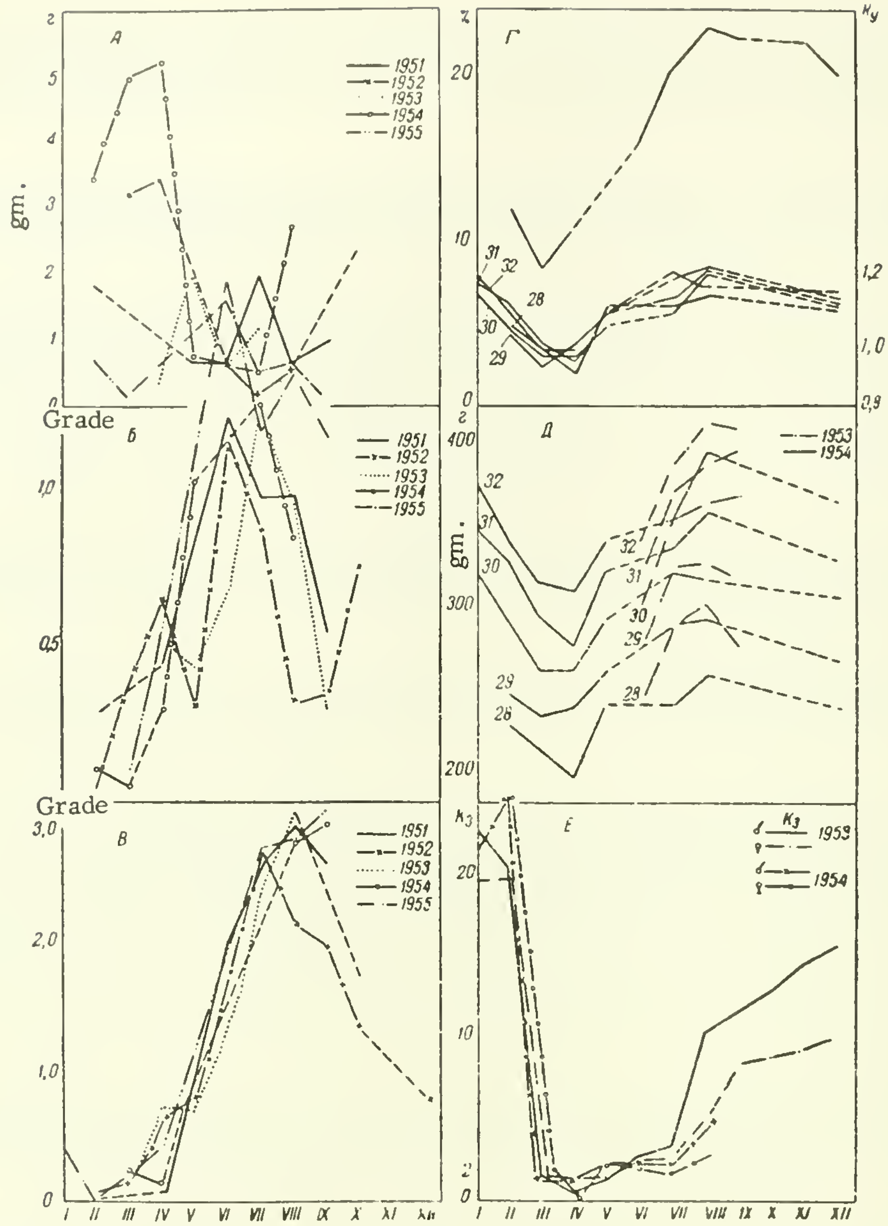

Figure 6. Graphs of indices of the physiological condition of adult Atlantic-Scandinavian herring throughout the year. A. average weight of food in the stomach of feeding herrings; Б. average stomach fullness grade for herrings in different years; B. average fatness grade; Г. chemical analysis of fatness (flesh) of herring in 1953 expressed as % and nutritional condition factor for five age groups of herring in 1954; Д. variation in the weights of herring of different size groups throughout the year; E. maturity factor (K3).

TABLE 7. AVERAGE FATNESS GRADE OF HERRINGS IN DIFFERENT YEARS.

Year	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
1951	--	0.03	--	0.06	0.93	1.93	2.51	2.78	2.41	--	--	--
1952	--	0.03	0.14	0.65	0.78	1.70	2.72	2.09	1.94	1.30	--	0.76
1953	--	--	0.07	0.71	0.69	1.33	2.37	2.91	--	1.70	--	--
1954	--	--	0.24	0.09	0.87	--	2.70	2.84	--	--	--	0.53
1955	0.41	--	0.16	0.47	--	1.95	2.66	2.75	3.00	--	--	--

TABLE 8. AVERAGE WEIGHTS OF HERRINGS OF DIFFERENT SIZE GROUPS IN 1954 AND 1955.

Year	Length in cm.	Month							
		January	February	March	April	May	July	August	December
1954	27.1-28	--	228.5	211.6	195.5	240.5	240.5	257.8	237.6
	28.1-29	220.5	246.2	231.5	237.3	260.5	288.5	291.8	267.1
	29.1-30	320.5	291.1	259.3	260.5	292.5	320.5	315.6	305.1
	30.1-31	345.9	327.2	291.5	273.9	321.4	334.7	357.5	327.8
	31.1-32	372.5	338.9	311.4	307.2	340.1	349.6	391.4	362.8

Year	Length in cm.	Month							
		January	February	March	April	June	July	August	September
1955	27.1-28	219	215	220	198	220	249	252	262
	28.1-29	241	230	204	215	241	266	288	288
	29.1-30	269	276	235	233	250	284	302	307
	30.1-31	314	260	273	268	278	311	337	334
	31.1-32	351	323	317	293	316	324	364	373
	32.1-33	371	345	330	312	318	344	373	395

The lowest nutritional condition factor is observed in March-April and the highest in the second half of July and in August, this factor being higher for the herring 27-28 cm. long than that for larger herring. From August to December, despite the gonad development, the nutritional condition factor declines.

A comparison of the nutritional condition factor with the fatness factor gives grounds for thinking that the decrease in the nutritional condition of the herring during the autumn is mainly due to consumption of the fat deposits.

The maturity index of the herring for different seasons of the year is subject to sharp variations. During the winter pre-spawning period K_3[1] reaches its maximum value of 25-29% of the body weight. In March-April, there is an abrupt fall in the gonad weight, which is characteristic of the post-spawning period, when K_3 is equal to 1-1.5% in males and females alike. During the spring-summer months (May, June and July), the period of maximum feeding, the gonad weight does not vary and K_3, at 2-2.5%, is almost the same for males as for females, and only from August onwards, when the fish has attained its maximum nutritional condition, do the gonads begin to increase rapidly in weight, although the gonads of the females weigh less during the autumn months (in conformity with their lower degree of maturity), in consequence of which the sexual maturity of the females lags somewhat behind that of the males. By spawning time, however, during the ovulation period, their K_3 indices again catch up.

In Table 10 and Figures 6E, the maturity factors are given separately for males and females.

The figures for 1955 again show the regular development of the gonads of the herring ob-

1/ K_3 (maturity coefficient according to G. V. Nikol'skiy) is the gonad weight expressed as a percentage of the body weight.

served in 1953-54. The individual indices for the different stages of maturity show considerable fluctuations.

TABLE 9. NUTRITIONAL CONDITION FACTOR FOR HERRINGS IN DIFFERENT MONTHS (OBSERVATIONS MADE IN 1954 AND 1955).

Year	Length in cm.	Month							
		January	February	March	April	May	July	August	December
1954	27.1-28	--	1.07	1.00	0.93	1.15	1.15	1.23	1.13
	28.1-29	0.98	1.06	0.98	1.02	1.13	1.23	1.25	1.15
	29.1-30	1.25	1.12	1.02	1.03	1.13	1.24	1.22	1.18
	30.1-31	1.23	1.15	1.02	0.97	1.12	1.18	1.26	1.15
	31.1-32	1.18	1.08	0.98	0.96	1.08	1.12	1.25	1.15

Year	Length in cm.	Month							
		January	February	March	April	June	July	August	September
1955	27.1-28	1.05	1.02	1.05	0.95	1.06	1.17	1.20	1.25
	28.1-29	1.03	0.98	0.87	0.93	1.03	1.13	1.22	1.22
	29.1-30	1.03	1.08	0.92	0.91	0.98	1.10	1.17	1.19
	30.1-31	1.10	0.92	0.96	0.94	0.97	1.08	1.18	1.17
	31.1-32	1.12	1.02	1.01	0.94	1.02	1.04	1.18	1.19
	32.1-33	1.07	1.00	0.97	0.92	0.94	0.98	1.07	1.13

Development of the herring gonads is the final stage in the feeding period.

From a comparison of the individual factors - feeding rate, fatness, weight and maturity of the gonads, shown in Figure 6, we conclude that they are all closely interrelated and that they determine the physiological condition of the herring.

Conclusions

1. The physiological condition of the herring is determined to a large extent by its seasonal distribution. During the winter, pre-spawning schools of herring concentrate in the southwestern part of the Norwegian Sea, near the spawning grounds. The majority of Atlantic-Scandinavian herring spawn during February and March.

During the spring, in an exhausted condition after spawning, the herring begins to feed actively, and its distribution also depends on the accumulation of plankton. In the summer, the herring continues its migration in search of food, travelling to northern latitudes with the warm Norwegian current. During the summer-autumn period, after it has finished feeding, the herring forms into groups and begins to leave the northern feeding grounds for its winter quarters and spawning grounds.

2. The food of the Atlantic-Scandinavian herring consists of 39 species of plankton organisms belonging to the following orders: Copepoda, Cladocera, Cirripedia, Amphipoda (Themisto), Euphausiacea, Mollusca, Vermes, Appendicularia and young fish, but the principal of these are Euphausiacea (Meganyctiphanes norvegica and the genus Thysanoëssa), Copepoda (Calanus) and

TABLE 10. MATURITY FACTOR OF THE HERRING FOR 1953, 1954 AND 1955.

Year	Sex	January	February	March	April	May	June	July	August	September	October	November	December
1953	Male	22.50	20.10	1.50	0.45	1.30	2.67	3.44	10.36	11.50	12.9	14.60	15.6
	Female	19.20	19.50	1.40	1.48	1.40	2.65	2.67	5.16	8.20	8.85	9.30	10.1
1954	Male	21.00	24.30	1.40	1.30	2.20	--	2.20	4.30	--	--	--	16.2
	Female	--	24.40	1.90	1.20	2.30	--	1.80	2.90	--	--	--	11.7
1955	Male	22.0	21.8	1.20	1.40	--	1.20	2.3	5.20	9.60	--	--	--
	Female	17.3	20.5	1.60	1.50	--	1.70	1.6	3.10	5.30	--	--	--

Amphipoda (Themisto).

3. The quantities of individual plankton organisms in the food of the herring vary with the month. During the winter-spring months (February-April), Euphausiacea are the characteristic group in the food of the herring, in summer Calanus finmarchicus, Calanus hyperboreus, and Themisto, and in the autumn months Calanus, Themisto, and Euphausiacea.

4. During the winter months (February-March), the stomach fullness grade is low, a fact which is due to the absence of food organisms during this period. After spawning, however, the herring--owing to its exhausted condition--is in great need of food, and individuals with very full stomachs have been found where food organisms have been available.

The average fullness grade increases during the spring months (April-May) and reaches its maximum in June-July, at which season we observe the greatest quantity of feeding individuals. The feeding rate declines towards the end of the summer, because a high nutritional condition has been attained.

During the autumn-winter months, the number of feeding individuals declines sharply and the feeding rate of the herring during this period is extremely low.

5. The number of species of plankton organisms is much larger in the samples than in the stomachs of herring.

Of all the forms of plankton which populate the water, the herring selects two or three. The following most frequently serve as food for the herring: Meganyctiphanes norvegica, the genus Thysanoëssa, Calanus finmarchicus, Calanus hyperboreus (Copepoda) and the genus Themisto (Amphipoda).

The food conditions are of great importance in the biological rhythm of the Atlantic-Scandinavian herring, since they determine the time at which fat is accumulated and the gonads develop.

A noticeable quantity of fat is observed on the internal organs of the herring in May. The herring attains its highest nutritional condition and maximum fatness at the end of July and in August, after fattening ceases. At this time intensive development of the gonads begins, and this subsequently results in reduced fatness. An abrupt reduction in fatness occurs in early spring, during the spawning and post-spawning periods.

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INVESTIGATION INTO THE LIFE-CYCLE OF SUMMER-SPAWNING HERRING OF ICELAND

K. A. Liamin

Herring from the Iceland region were established by Heincke (7) as an independent race distinguished by a number of morphological characteristics. Heincke did not know the spawning time for these herring, but he supposed that spawning occurred in spring or summer.

Saemundsson, one of the first Icelandic ichthyologists, was the first to bring to light spring-spawning and summer-spawning herring in Iceland waters.[1/]

Extensive researches on herring larvae in the Iceland region were carried out at the beginning of the present century by the Danish scholar I. Schmidt on the expedition ship 'Thor' from 1903 to 1908.

On the basis of his own observations and I. Schmidt's data, Saemundsson established the periods and regions of spawning of the summer race herring off Iceland.[2/]

Jespersen (13) worked over the material collected by Schmidt from 1903 to 1908, analysed the distribution of the larvae, taking into account their length and the periods when they were caught, and confirmed Schmidt's and Saemundsson's conclusions that there were summer-spawning herrings in the waters of Iceland.

From the distribution of larvae of the early stages (less than 10 mm. in length) Jespersen established that the spawning region of the summer race lay in the waters off the southern coast of the island during July through August.

Exploiting the researches of Saemundsson, Schmidt, and Jespersen, Johansen (11, 12) produced the first plan of the migrations of the summer-spawning herring, according to which the spawning of this race takes place along the south coast while the fattening-up region lies to the north of the island.

From 1924 to 1934, considerable research on the distribution of the larvae of the herring was carried out by Tåning (17). In subsequent years (1939, 1946, 1950), he also carried out research on board the "Dana" off Iceland from July through September, and this enabled him to collect a large amount of material on the larvae of the summer-spawning race.

In a report on the Icelandic herring which came out in 1944, Fridriksson (4) summed up the results of the many years of herring research in the region of Iceland. Fridriksson confirmed the conclusions of all previous investigators that there were summer-spawning herring in Iceland waters. At the same time, the author of the monograph comes to the conviction that the summer race is not very numerous. Fridriksson determined that the summer-spawning herring accounts for 1.2% of Iceland's herring fishery.

1/ See Fridriksson (4).
2/ " "

During the Soviet researches in the Norwegian and Greenland Seas with the object of discovering the base of the raw materials of the Soviet fishing industry, material on the summer-spawning herring was collected in the region of Iceland.

In 1948 and 1949, Soviet vessels fished for herring in the regions customarily exploited by the Icelandic boats. Later the catching regions were considerably extended, and the season too was extended into June and September. This gave us the opportunity of collecting considerable material on the summer-spawning race and of tracing the distribution of pre-spawning and post-spawning schools. However, our investigations were not able to supplement the data on the conditions of reproduction since the spawning of the summer race occurs in Icelandic territorial waters or near them.

In various regions, summer-spawning herrings comprised up to 20-25% of the catches of our fishing industry.

We have investigated the age composition and the growth rate of the Icelandic herring and studied the structure of the scales, in particular the first ring, which, according to our observations, is formed during the first winter - which is denied by previous investigators. This enabled us to single out summer herrings not only according to the stage of growth but also according to the scale structure.

In the Iceland region, during the period of our investigations, more than 65,000 specimens of herring were measured and of these 8,000 were subjected to a complete biological analysis.

The age of the herrings was determined under a microprojector (7 x 11). The growth rate was calculated by the method proposed by V. R. Aleev /Suvorov (1)/.

Fertility was determined by the usual method. To verify the fertility, a sample of roe equal to 1 gm. was taken from various parts of the ovary. The quantity/number of the eggs in the sample was multiplied by the total weight of the gonads. The total quantity of the roe was approximated to 0.1 thousand. In addition to the number of eggs, the dimensions of the eggs were determined too, by measuring the diameters of 10 eggs.

Making use of our observations on the conditions of distribution of adult herring and the investigations of Icelandic scientists into the diffusion of the larvae of the summer herring, we endeavored to reproduce the peculiarities of the life cycle of the summer-spawning race, which, as the experience of our fishing industry has shown, may be of fundamental significance for the Soviet herring fishery.

Region, Periods and Conditions of Reproduction

The regions and periods of reproduction of the summer-spawning herring can be established from the stages of maturity of the gonads and the early stages of the larvae.

In the first half of the season (June), off the north-west coast of Iceland, herring having a gonad maturity stage VII-II and II to III dominated in the catches. These herring must be included in the spring race. Simultaneously with these, fish having gonad maturity of stages IV and V were found. These specimens must be included among herring of the summer race. Herring with running/flowing gonads (VI stage) were observed in the northern regions every year during July and August, but only in single numbers. From the second half of August, the presence of individuals which had spawned--of the VII and VII-II stages, and also the III, III-IV and IV stages--was established. The former must undoubtedly be included in the summer-spawning race; the latter, in the spring race, in which, after fattening-up, a rapid gonad development begins.

Herring near to spawning, in V and V-VI stages, were observed by us from the end of June to the middle of September.

In 1948, males and females with running sexual products were observed in the second half of July and first half of August to the north of the island.

Summer-spawning herring, near to spawning, comprised 4% of the commercial catches.

In 1949, a sexually mature male was found to the north-east of Grimsey Island.

In 1950, individual specimens of herring with running sexual products, males and females, were found in catches from the 12th July to 30th August to the north of the island. One must note especially that, at the end of June and beginning of July, herring in maturity stage V were caught fairly frequently, and there were relatively few spawning individuals in the following period. In 1951, individuals with running sexual products were noted from 27th July to 1st September. The largest quantity was discovered in the region of Langanes and on 16th August to the south of Reykjanes Island.

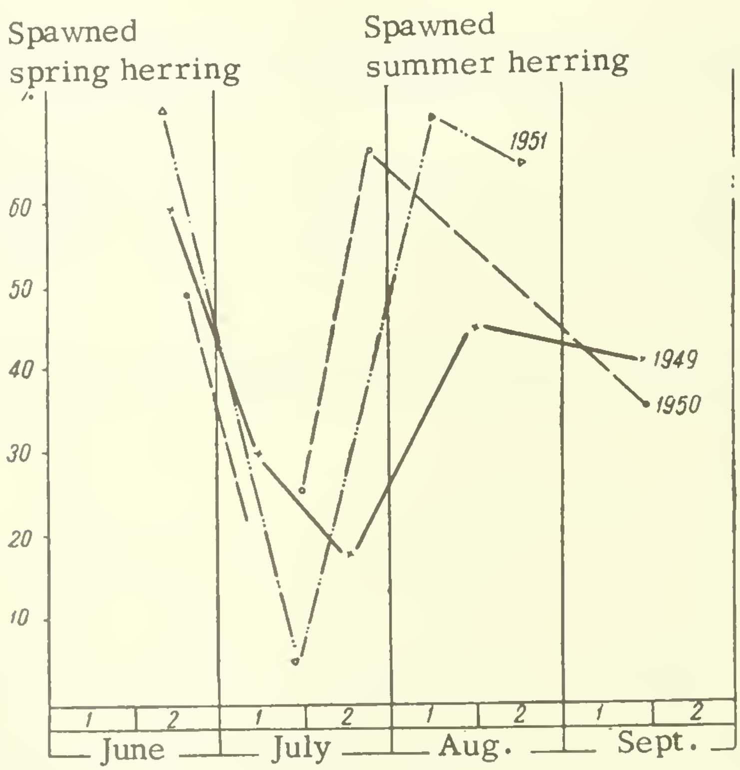


Figure 1. Specific weight of herrings after spawning (VII-II stage) in Iceland waters, by years and percentages. 1/

1/ Editor's note: The translator has used the term "specific weight" here and on the following page. "Relative numbers" would be a more appropriate translation.

The spawning time of the summer herring in Icelandic waters can be particularly well determined from the observations of post-spawning individuals by months. In June 1949, herring (with gonad maturity stage VII-II) which had reproduced in the spring were dominant.

In the first half of July, their numbers fell to 30% and in the second half to 17%. In August and September, the number of individuals having completed spawning (stage VII-II) increased to 42-46%.

In 1950, at the beginning of June, post-spawning individuals with gonads in the process of being restored (stage VII-II) numbered from 40% to 60%. The number of fish which had recently completed spawning increased considerably. In one sample taken after 22nd July, they comprised 95%. The specific weight of post-spawning individuals in the sample remained high even in August. Thus, on the 9th August in the region to the north of Grimsey Island they comprised 90.5%. In September, percentages of this type fell to 30-40.

In the first catches of 1951, taken to the north-east of the island, herring with developing gonads (VII-II) were dominant in June - 74.4%. In July, their specific weight fell to 2.6%; on August 2, herring which had just finished spawning comprised 73%. In the second half of August and in September, their number dropped sharply.

No eggs of summer-spawning herring were found in the region of Iceland and the Faroes. According to published material, fertilized eggs of the summer herring have been found off Greenland by Hansen(9) and fertilized eggs of the spring herring to the south of Iceland by Fridriksson (6). Hence the location of the spawning grounds, the times of reproduction, and hatching-out of the larvae can be established merely on the basis of the early stages of larvae less than 10 mm. in length, the distribution of which is a reliable index of the spawning regions.

During I. Schmidt's researches[1/] from 1903 to 1908, larvae were caught from April to September. The number of larvae caught was at its lowest in May and June. A small number of larvae of this herring was obtained by Tåning (17) as well in May and June, during the first period of his investigations (1924-34). Later (1939-41, 1946, 1950), Tåning (18, 19, 20) collected larvae only in the second half of the summer. Data about larvae less than 10 mm. in length are given in Table 1.

In June, neither Schmidt nor Tåning found larvae of less than 10 mm. in length. The largest number was found in July. Particularly large numbers of larvae were taken by Taning in this period from 1924 to 1934 and again in 1939.

On the 18th July 1903, Schmidt discovered larvae of the summer herring less than 10 mm. in length above a depth of 65 m. off the southern coast of Iceland (Figure 2). On the 29th and 30th August 1904, he caught larvae of the same dimensions in the region of Cape Reykjanes and to the south-west of that cape and also near Cape Snaefellsnes.[2/]

In 1925, early stages of larvae were found by Tåning in August above 74 m. in the region of Cape Snaefellsnes.

In 1927, Tåning also caught small herring larvae at three points in the region of Westmannaeyjar Island, off Cape Reykjanes and off Cape Snaefellsnes above depths from 33 to 121 m.

1/ According to Jespersen's work (14).

2/ Western part of the peninsula, separating Faxa Bay from Breida Bay.

In 1933, on the 27th July, Tåning observed a very large quantity of larvae off the south-east coast of Iceland. In 1950, he discovered larvae less than 10 mm. in length in August along the entire south coast: Cape Reykjanes, Selvogsbank, Ingolfschjovdi and Mjoa Fjord (east Cape Chodn): at 6 stations he made catches at depths above 55 to 164 m.

TABLE 1. DISTRIBUTION OF HERRING LARVAE LESS THAN 10 MM. IN LENGTH IN ICELAND REGION.

Year and month of investigation	April	May	June	July	August	September	Total
1903-1908 (I. Schmidt)	219	0	0	90	194	--	503
1924-1934 (V. Tåning)	125	0	0	5.051	752	--	5,928
1939 (V. Tåning)	Collecting not undertaken			1,950	7	--	1,957
1946 (V. Tåning)		"		--	--	1,146	1,146
1950 (V. Tåning) 1/		"		--	434	--	434
Total	344	0	0	7,091	1,387	1,146	9,968

The largest number of larvae --3,976 specimens-- was caught at station 591 (64°13'N, 14°48'W), above a depth of 87 m, in the middle layers. In 1939, Tåning found early stages of herring larvae in two places: 63°33'N, 20°55'W (21st July) and 64°25'N, 25°03'W (29th July).

On the basis of the data presented, one can consider that spawning of the summer-spawning herring takes place along the entire south and south-west coast of Iceland. Very considerable spawning was discovered off Cape Stoksnes, in the region of Portland (Cape Dircholei), near Cape Reykjanes and off Cape Snaefellsnes. In the first region herring larvae were discovered in 1933, in the second in 1903 and 1927, off Reykjanes in 1904, 1927 and 1933 and near Cape Snaefellsnes in 1924, 1925 and 1927 (see Figure 2). The largest quantity of small larvae was found above depths of 74 to 110 m. At station 4583 (65°56'N, 13°40'W), larvae were caught above 175 m. Tåning supposes that these larvae had been carried down from shallower depths.

On the basis of catches of early larval stages and an analysis of gonad maturity stages, one can assume that spawning of the summer race begins at the end of June and beginning of July and lasts to the end of August. The periods in which early stages of the larvae were found correspond completely with the periods in which mature individuals are found. In the waters to the north of Iceland, larvae of the early stages are not found. Hence, one may consider that the basic spawning grounds are distributed in the southern regions.

According to Tåning's observations, the summer-spawning herring deposits its eggs at a temperature of 7° to 9.5° in a salinity of about 35.

1/ From the number measured.

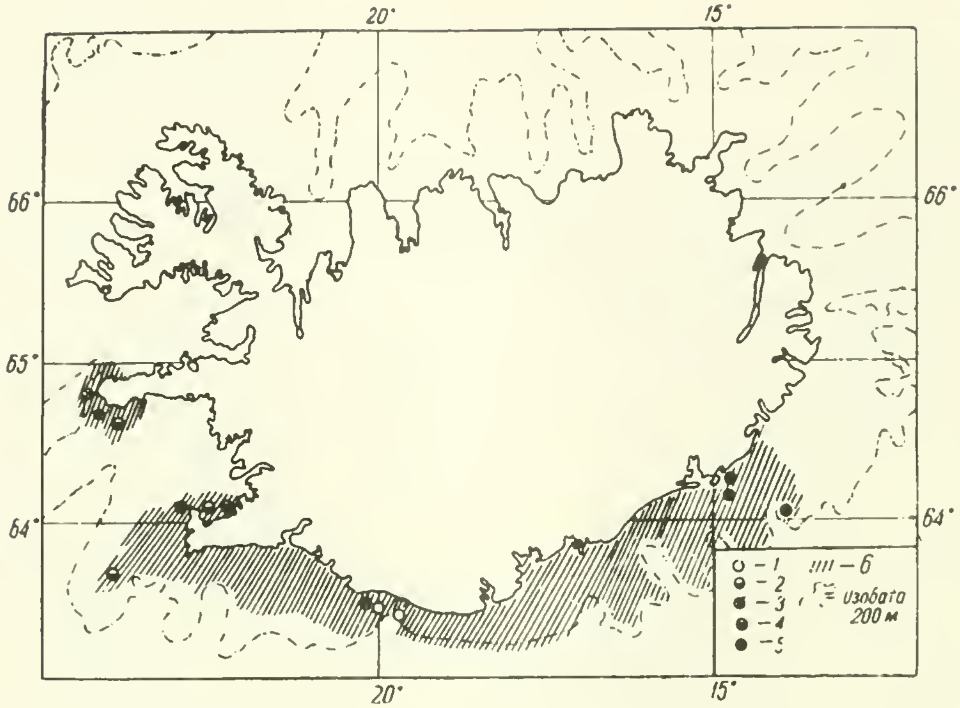


Figure 2. Distribution of larvae of summer-spawning herring less than 10 mm. in length in region of Iceland, caught by Schmidt and Tåning.

1-1903; 2-1904; 3-1925; 4-1947; 5-1933; 6 - spawning grounds.

Distribution of Large Larvae

Large larvae of the summer herring --20 to 25 mm. in length-- were found by Schmidt at the end of July and beginning of August 1904 off the south and west coasts of Iceland. In July, larvae from 10 to 15 mm. in length were caught by Schmidt to the west of Cape Dircholei (63°23'N, 19°25' W). In August, he found large larvae to the west of Westmannaeyjar Island. He discovered the largest number of larvae in August further north, at the entrance to Breida Bay (65°15'N, 24°45'W) and to the west of Cape Reykjanes (63°45'N, 23°45'W). At the same time, he made about 40 stations along the eastern and north-eastern shores, but no larvae were discovered in these regions.

A. (sic.) Tåning (20, 21, 22, 23) found large larvae of summer herring in the region from Stoksnes along the south, south-western and western coasts to Cape Isa Fjord. Off the south-eastern coast, larvae were found in 1933 and 1950, the rest in earlier years. In 1939, he found them to the east of Westmannaeyjar Island and Faxa and Breida Bays. Lastly, in 1946, he found larvae in September in the same regions and to the north-west of Isa Fjord (Figure 3). Observations of the change in size of the larvae in conjunction with the times at which they were caught give an idea of their growth. In July and early August, larvae about 10 mm. in length appear (undoubtedly herring of the summer race), in the second half of August their length increases to 15-20 mm. In September, the average length reaches 18 mm.

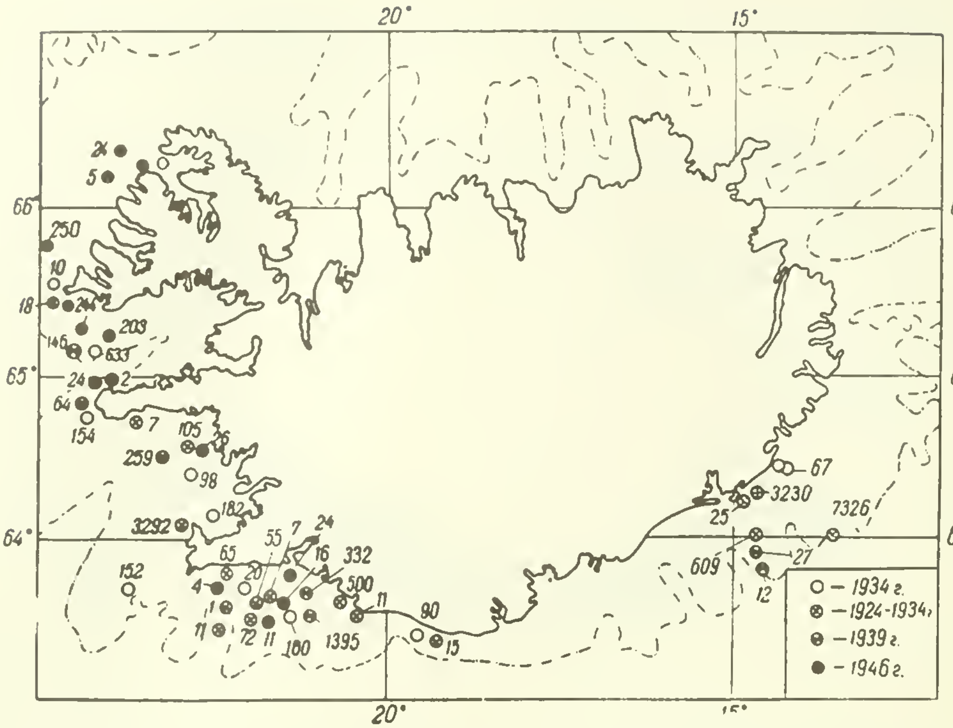


Figure 3. Distribution of summer-herring larvae longer than 10 mm., in Iceland region, caught by A. (sic.) Tåning during his investigations. Figures on map indicate number of larvae caught at the stations.

Comparing the distribution of larvae of early and later stages, one notices that the bigger larvae are found over a considerably greater area. The largest number was found to the west of the presumed spawning-grounds. Large summer herring larvae were found by Tåning in 1934 and 1936 off Isa Fjord.

One may presume that a large part of the larvae remains in the bays of the west coast (Faxa, Breida and Isa Fjord), which are not accessible to boats of large draught.

The large larvae found at considerable depths to the south-east of Iceland are of undoubted interest. One may presume that these larvae are carried from the spawning grounds of the Iceland region (south-east coast) or are carried into the Iceland region from the spawning grounds of the Faroes. The question of the westward drift of larvae with the waters of the Irminger current has not been clarified.

Data about year-old herrings are extremely fragmentary. In February 1936, Fridriksson (5), searching for reproduction centers of the spring-spawning herring in the regions of the south and south-west coasts, found spring herring at a few stations. The dimensions which he gives obviously testify to the presence of the young of summer- and spring-spawning herring (Figure 4). The length of the young of the summer herring is 4-5 cm. (M = 4.78) and the length of the year-old spring herring is 8-10 cm. (M = 9.02). The proportion of the young of both types in these catches was about the same.

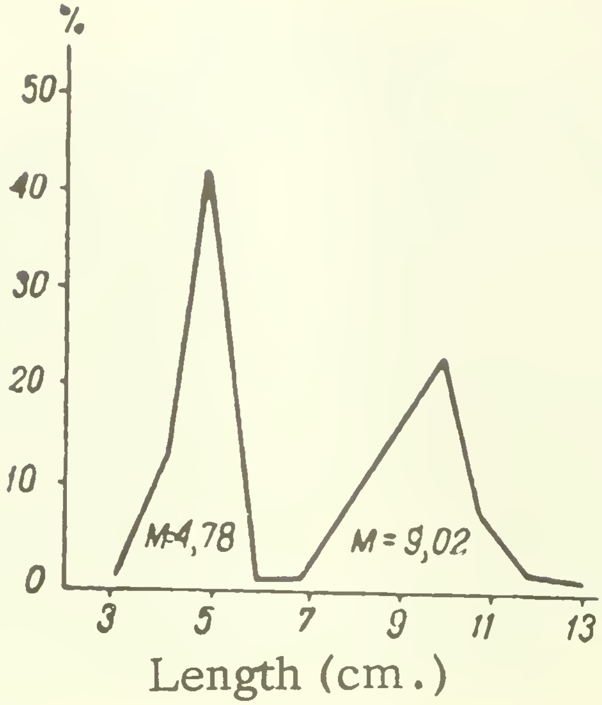


Figure 4. Dimensions of young herring caught in February 1936. (Fridriksson).

Age and Rate of Growth

According to our material, the length of life of the summer-spawning herring reaches in individual cases 17-19 years.

Of all the herring that have summer and autumn spawning in the north-east sector of the Atlantic, the summer herring of Iceland and the Faroes have the greatest life-span, and this sharply distinguishes them from the bank herring of the North Sea, the life-span of which does not exceed 8-10 years /Schnakenbeck 1931 (16), Le Gall 1935 (14)/. Throughout the entire period of our researches in the Iceland region, summer-spawning herring were discovered from 2 to 19 years and in the region of the Faroes, according to the material for 1954, from 3 to 15 years (Table 2). The dominant groups in the first region were herring from 4 to 15 years and in the second region from 4 to 12 years.

In determining the age of bank herring which reproduce at the end of the summer and in autumn, /one must take into account that/, according to Johansen's observations (10), no ring is formed in the first winter. In the works of other authors devoted to study of bank herrings, the ring formed in the second winter is counted as the first ring. No ring is formed in the first winter in the autumn-spawned sprat either (L. A. Rannak, 1947).

Examining the very large quantity of scale material for the summer-spawning herring, we came to the conclusion that in a large number of the specimens the first annual ring is formed in the first winter. According to the data of the converse calculation it corresponds to a length of 3 to

5 cm. Sharply outlined rings, corresponding to the first winter, are few. Well marked rings can be seen in Figure 5 (structure of annual rings of summer-spawning Iceland herring) and Figure 6 (structure of first ring of same scale greatly enlarged).

TABLE 2. AGE COMPOSITION OF SUMMER-SPAWNING HERRING IN ICELAND AND FAROE REGIONS.1/

Region	No. of annual rings										
	2	3	4	5	6	7	8	9	10	11	12
Iceland (1948-51)	0.2	4.3	9.6	8.5	8.4	8.2	8.8	8.6	9.1	9.1	8.7
Faroes (1954)	--	1.0	29.5	15.3	9.4	4.2	4.7	8.4	7.8	7.8	3.0

Continued

Region	No. of annual rings							%	No. of fish
	13	14	15	16	17	18	19		
Iceland (1948-51)	7.7	5.4	2.2	0.9	0.3	--	0.05	100.0	2199
Faroes (1954)	4.2	3.1	1.0	--	--	--	--	100.0	190

The first ring on a scale can be traced much better by modifying the lighting of the preparation.

A characteristic peculiarity of the structure of the scale of the summer-spawning herring are the fragmented sclerites /?/ in the center of the scale (Figure 7, greatly magnified). Such a structure of the center of the scale in the spring herring is never observed (Figure 8).

For calculating the rate of growth of the summer-spawning herring, we used a sample obtained on August 16 in the region south-west of Iceland. Table 3 gives the rate of growth in separate growth categories.

The average increment for the first year (increment for the first 5-6 months of life) varies from generation to generation within the limits 3.3 to 4.6 cm., the average being 3.8 cm. At the end of the second year, the young reaches 9.2 cm., varying from generation to generation within the limits 8.4 to 10.0 cm. The average length of a herring with three rings is 16.0 cm., the limits of variation being 12.0 to 18 cm.

Thereafter, beginning at 4 years, the annual increments decrease; herring with 5 rings are 24 to 25 cm. in length; at age 9-10 years herring reach a length of 29-30 cm.

It is characteristic that the younger age categories, examined in Table 3, have a higher rate of growth than the older categories. For example, the length of a herring at the age of three in the four-year-old categories is 18.9 cm., in the seven-year-olds 16.8, in the ten-year-olds 16.9 cm.

1/ Number of annual rings counting first ring, which is formed in the first winter.

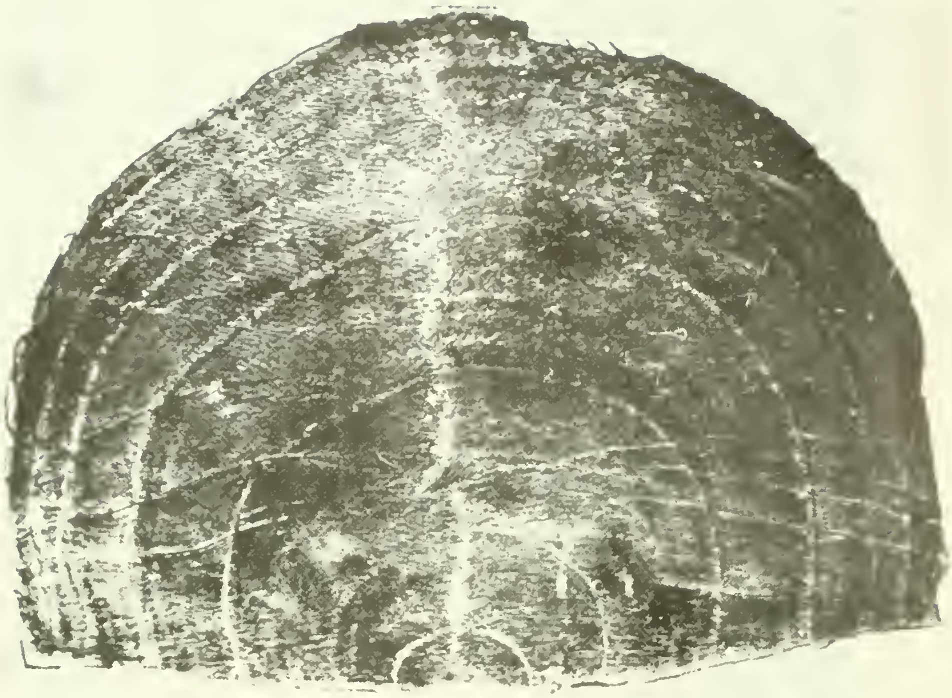


Figure 5. Structure of annual rings of summer-spawning Iceland herring with sharply marked first ring.

Scale of herring at age 9 years, length 291 mm. 1 = 34 mm. male V stage of maturity, first spawning in 7th year (sample 139, No. 19, 1951 - 17/IX).

The increment for the first year, obtained as a result of inverse calculation, is near to the direct measurements. According to the inverse calculation l_1 = 3.8 cm., varying from 3.3 to 4.6 cm., according to the direct measurement it is 4.8 cm., varying from 4 to 5 cm. The observed difference in the dimensions of one-ring herring, which was obtained from an inverse calculation and direct measurements of the young, could arise as a result of the smallest of the young summer-spawning herring escaping from the trawl. According to Fridriksson, the absolute length of the young of herring at the age of 1 year and 5-6 months is 11.2 cm. (first ring according to Fridriksson). According to the data of our calculation, the length of the young at this age, up to the middle rays of the tail fin, is 9.2 cm. (in our method, second ring). If one takes into account the remarks made above, then the growth rate in the first and second years, according to our data and Fridriksson's material, is almost identical.

The growth rate of the summer herring in the Faroes region, given in Table 4, does not differ fundamentally from the data in Table 3.

It is interesting to compare the growth rate of the spring-spawning race and the summer herring in the first period of their lives.

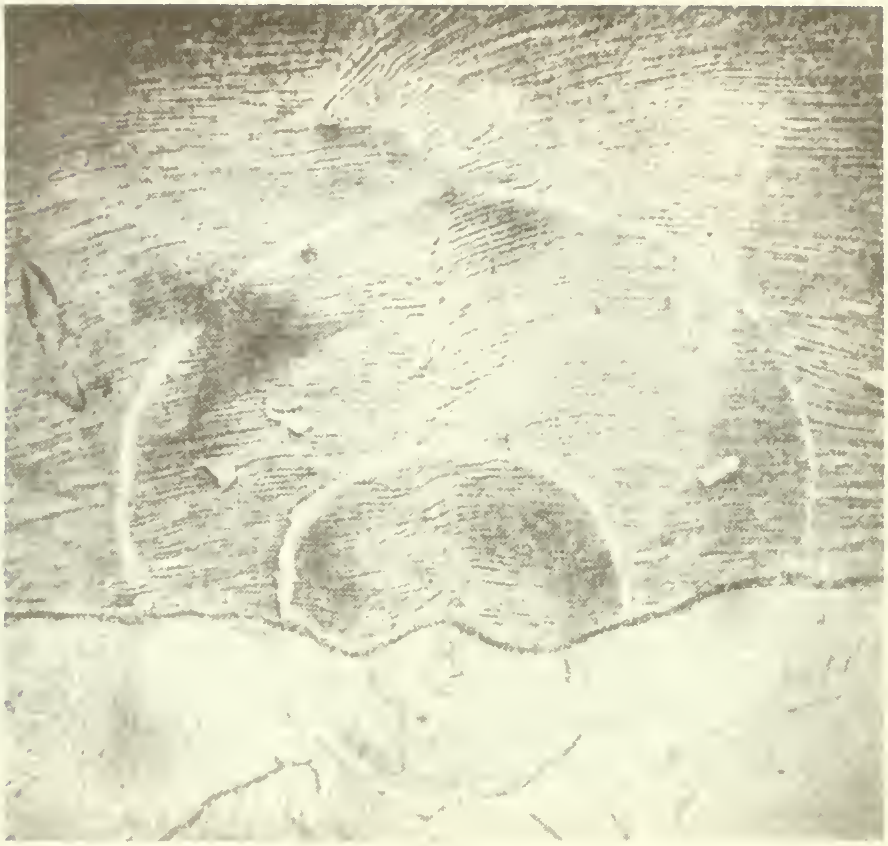


Figure 6. Structure of first annual ring of summer spawning Iceland herring. (Enlargement of Figure 5).

The young of the summer-spawning herring during an incomplete first year reach 4 to 4.5 cm. The summer-spawning herring has the same dimensions in March, i.e. at the moment when the larvae of the spring race hatch out. During the second year, the young of the summer-spawning herring reach 9-10 cm., increasing, that is, by 5 to 5.5 cm. The young of the spring-spawning herring during the same period of growth reach 8 to 8.5 cm. Thus, the young of the summer race in their second year have a smaller increment than the young of the spring hatching during the same period of time.

These data create the impression that the young of the summer-spawning race have no growth advantages in their second year of life over the young of spring origin, in spite of the fact that at the beginning of the second growing period they already have a length of 4 cm. We shall have to draw a different conclusion if we reproduce the weight increments of the young of the two races during the same period of time. The weight of the young of the summer race at the beginning of the second year of life should be about 0.3-0.5 gm. By the end of the summer, their weight should reach 5-6 gm. For example, the weight increment for the second summer is 5 gm. The weight increment for the young of the spring race for the first year of life is 3-3.5 gm. Thus, in weight indices the young of the summer spawning herring during the first year grows more than the spring race by 1.5-2 gm., i.e. by more than 1.5 times.[1/]

1/ In determining the weight of the young for the above calculations we used the proportions of weight to length in young herring collected at Murmansk.

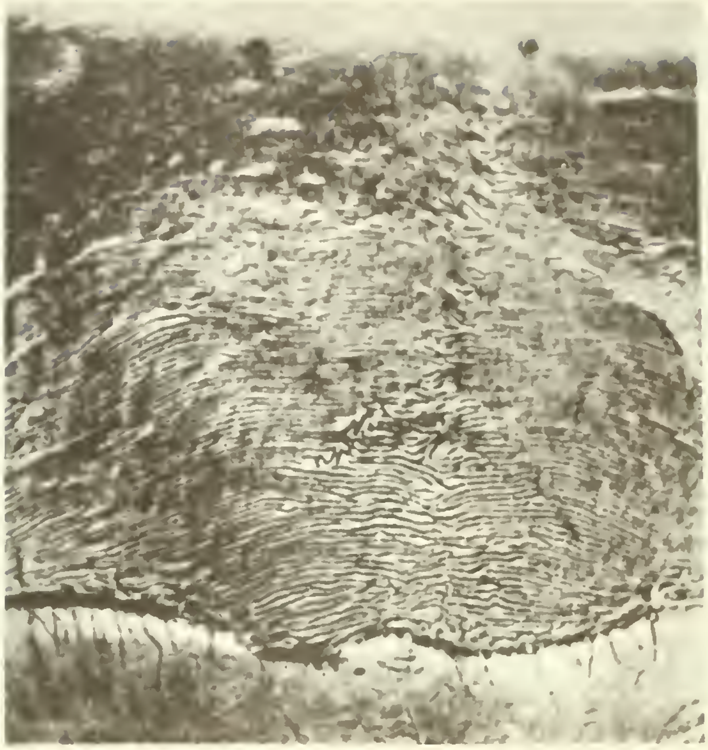


Figure 7. Structure of first ring of summer-spawning herring. First ring weakly marked. Characteristic are the fragmented sclerites /?/ corresponding to the growth of the first year scale.

Table 5 gives data for the growth of the summer-spawning herring in comparison with the spring-spawning Atlantic-Scandinavian herring. The lag in growth of the summer herring in the first year of its life is to be explained by the shorter growing period.

In ensuing years, the observed lag in growth is levelled out, and by 8 or 9 years the spring and summer herrings hardly differ in size.

Fertility and Time of Onset of Sexual Maturity

On the basis of the material treated, one can state that some individuals of the summer race reach sexual maturity at the age of 3 to 4 years, the sexually mature at this age being mostly males.

In the general mass of herrings, the gonads mature in the 5th and 6th years, when the body-length is 25-27 cm.

In order to determine the fertility of the summer-spawning herring, we used 25 specimens caught in late June and early July 1951 to the north-east of Iceland and 52 specimens caught, on May 20, 1954, to the north-east of the Faroes.

In these samplings, all the individuals had developed gonads. In the sampling from the Iceland region, the herrings were at the V and VI gonad maturity stage.

Figure 8. Structure of first ring of spring-spawning Iceland herring. Fragmented sclerites /?/, characteristic of summer herring (Figure 7), are not present. Scale of herring aged 8+ years, length 302 mm., 1_1 - 73 mm., male II-III stage, 1st spawning at 4 years (sample 189, No. 2, 1957 - 27/VIII).

In the Faroes sampling, some specimens were also at the V stage, but the majority were at V-VI gonad maturity stage.

Study of the material reveals that the individual fecundity of the summer herring varies considerably.

The lowest individual fecundity, 55, 300 eggs, was found in a female 24.3 cm. long, 4 years old (Iceland sample) and the highest number of eggs (294, 200) was found in a female 32.3 cm. long, 13 years old, from the Faroes sample.

Table 6 gives the fecundity of the summer-spawning herring from the Iceland and Faroes regions.

Because of the considerable similarity in fecundity of the herring from these regions, we can hereafter consider the material for both together.

A general regularity is noticeable in the females of the summer race: as size, weight, and age increase, a growth in general fecundity is observed.

TABLE 3. GROWTH RATE OF SUMMER-SPAWNING HERRING OF SOUTH-WEST ICELAND REGION (STAGES OF MATURITY VI, VII, VII-II, AND II, 16th AUGUST 1951).

Rate of growth	Categories									
	1948 (3+) n-10	1947 (4+3) n-22	1946 (5+) n-28	1945 (6+) n-13	1944 (7+) n-13	1943 (8+) n-12	1942 (9+) n-7	1941 (10+) n-5	Σ	M
l_1	3.95	3.7	3.3	3.8	4.6	4.4	4.0	3.6	110	3.8
l_2	9.95	9.6	8.3	10.0	9.7	9.1	8.4	10.0	110	9.2
l_3	18.95	17.6	13.6	16.8	17.8	14.9	12.0	16.9	110	10.1
l_4	23.35	23.2	19.3	21.0	22.9	19.8	18.3	22.3	110	21.2
l_5		25.6	24.0	24.7	26.1	23.6	22.1	25.9	100	24.7
l_6			26.4	27.1	27.7	26.3	25.3	27.9	78	26.8
l_7				28.3	28.7	27.7	27.7	29.3	50	28.3
l_8					29.7	28.9	29.0	30.2	37	29.4
l_9						29.4	30.1	30.9	24	29.9
l_{10}							30.5	31.4	12	30.9
l_{11}								31.9	5	32.0

TABLE 4. GROWTH RATE OF SUMMER SPAWNING HERRING OF FAROES REGION IN SEPARATE GENERATIONS (STAGE IV-V and V, SAMPLE NO. 253, 15th MAY 1954).

Rate of growth	Categories											Σ	M
	1948 6 n-3	1947 7 n-2	1946 8 n-4	1945 9 n-6	1944 10 n-21	1943 11 n-18	1942 12 n-12	1941 13 n-8	1940 14 n-4	1939 15 n-2	1938 16 n-1		
l_1	4.8	5.2	4.1	4.4	5.0	4.2	4.1	4.4	4.1	4.4	4.1	81	4.5
l_2	9.9	9.8	8.7	10.7	10.3	9.2	9.0	9.2	9.7	8.6	8.1	81	9.5
l_3	15.9	17.3	16.2	17.6	17.4	15.7	14.5	14.9	15.0	12.2	12.5	81	15.9
l_4	21.1	21.3	21.4	22.5	22.5	21.0	20.9	19.5	19.5	16.8	15.0	81	21.1
l_5	24.1	26.5	25.2	25.9	25.9	25.5	25.0	23.5	24.1	22.5	17.9	81	25.1
l_6	27.1	29.1	27.4	28.1	27.9	26.5	27.1	26.5	26.3	24.5	21.5	81	27.1
l_7		30.2	29.1	29.7	29.1	28.0	28.2	28.5	27.7	25.9	25.5	78	28.5
l_8			30.2	30.7	30.2	29.2	29.3	29.0	28.8	26.9	27.9	76	29.6
l_9				31.9	31.1	30.2	29.9	29.9	29.5	27.8	29.1	72	30.4
l_{10}					32.0	31.0	30.6	30.7	30.3	28.2	30.0	66	31.1
l_{11}						31.9	31.5	31.3	31.0	29.4	30.9	45	31.4
l_{12}							32.1	32.0	31.5	30.1	31.4	27	31.5
l_{13}								32.5	32.5	30.9	31.9	15	32.2
l_{14}									32.9	31.5	32.2	7	32.4
l_{15}										32.0	32.9	3	32.3
l_{16}											33.3	1	33.3

TABLE 5. GROWTH RATE OF SUMMER-SPAWNING HERRING OF ICELAND AND FAROES AND ATLANTIC-SCANDINAVIAN SPRING HERRING.

Rate of growth	Summer herring				Spring herring (Atlantic-Scandinavian)	
	Iceland		Faroes			
	n	M	n	M	n	M
l_1	111	3.8	81	4.5	55	6.6
l_2	111	9.2	81	9.5	55	12.6
l_3	111	16.1	81	15.9	55	19.2
l_4	110	21.2	81	21.1	55	23.8
l_5	100	24.7	81	25.1	51	25.7
l_6	78	26.8	81	27.1	46	28.3
l_7	50	28.3	78	28.5	40	29.5
l_8	36	29.4	76	29.6	20	30.0
l_9	24	29.9	72	30.4	5	30.2
l_{10}	12	30.9	66	31.1	--	--
l_{11}	5	32.0	45	31.4	--	--
l_{12}	2	32.3	27	31.5	--	--
l_{13}	--	--	15	32.9	--	--
l_{14}	—	--	7	32.4	--	--
l_{15}	--	--	3	32.3	--	--
l_{16}	--	--	1	33.3	--	--

TABLE 6. VARIATION WITH AGE OF FECUNDITY OF SUMMER-SPAWNING HERRING, BY REGIONS (IN THOUSANDS OF EGGS).

Age	Iceland				Faroes			
	n	Minimum	Average	Maximum	n	Minimum	Average	Maximum
4	2	55.3	66.5	77.7	--	--	--	--
6	4	80.4	110.4	140.3	1	--	190.6	--
7	4	80.4	112.5	120.5	--	--	--	--
8	2	128.2	130.5	132.8	2	147.6	152.2	156.9
9	5	133.8	165.3	234.6	5	178.4	210.1	270.1
10	3	120.4	131.2	138.6	11	163.2	199.6	228.0
11	3	182.6	195.9	205.5	11	167.2	202.1	242.8
12	1	--	169.6	--	11	158.5	197.8	260.4
13	--	--	--	--	6	180.0	233.0	294.2
14	1	--	169.7	--	4	188.1	208.2	218.6
15	--	--	--	--	1	--	197.6	--

However, considerable variation in the number of eggs is noticeable in herring of the same size.

Table 7 gives variation in fertility with increase in linear dimensions. The coefficient of the correlation between length and fertility is 0.53 ± 0.08.

The lowest fecundity (55,300) is in the proportion 1:3.8 to the highest (294,000).

Table 8 gives an idea of the increase in fecundity with age. The coefficient of correlation between the age of the fishes and their fertility is 0.53 ± 0.08.

On the average, an increase in age of one year brings an increase in fertility of 19,400 eggs.

Table 9 shows the dependence between weight and fecundity. The coefficient of correlation between these two magnitudes is 0.70 ± 0.07. An increase in weight of 25 gm. brings a fecundity increase of 21,200 eggs.

When the coefficients of correlation between fertility and size, weight, and age are compared, the highest coefficient is observed to be that of weight and fecundity.

The weight of the ovaries of summer-spawning herrings at the same maturity stage of the gonads varies, depending on the size and weight of the fish.

TABLE 7. CORRELATIONAL DEPENDENCE BETWEEN LENGTH AND FECUNDITY OF SUMMER-SPAWNING HERRING.

Length in cm.	Fecundity										Σ	M
	50 - 75	- 100	- 125	- 150	- 175	- 200	- 225	- 250	- 275	- 300		
24.1-25.0	1										1	55.3
25.1-26.0											--	--
26.1-27.0											--	--
27.1-28.0		2									2	87.3
28.1-29.0		1		1							2	111.8
29.1-30.0		1	3	5	2	1					12	138.0
30.1-31.0				3	3	3					9	163.0
31.1-32.0				1	3	9	3		1		17	195.5
32.1-33.0					1	10	8	6	1	1	27	212.3
33.1-34.0					1	1	3	1	1		7	213.0
Σ	1	4	3	10	10	24	14	7	3	1	77	

From the data of Table 10, it can be seen that the relation of the weight of the roe to the body weight increases in the large specimens. In fish 290-300 cm. long, the proportion is 16%, in the largest specimens it is 20%.

A macroscopic examination of the ovaries and the dimensions of the eggs leads one to conclude that, like all marine herrings of the genus Clupea, the summer-spawning herring does not have portional maturing.

The ovaries of the summer herring are fairly fine, the diameter of the individual eggs varying from 0.8 to 1.1 mm. Table 11 gives a comparison of the diameter of the eggs of the summer-spawning and spring-spawning herrings. The average diameter of the eggs of the summer-spawning herring is less than 1 mm., while that of the spring-spawning herring is greater than 1 mm.

A count of 1 gram of ovary taken from a herring in the stage near to reproduction (V and V-VI) established that the minimum number of eggs is 1,230, the maximum 3,710 and the average 2,300. A count of 1 gm. for the spring Atlantic herring, also in the stage approaching reproduction, gives the minimum number of eggs as 620, the maximum as 3,080 and the average as 1,315 eggs.

Table 12 gives an idea of the number of eggs in a 1 gm. sample.

One gram of ovaries from the summer herring holds on the average about 2,500 eggs, while the average for the spring herring is about half of this --1,300 eggs.

TABLE 8. CORRELATIONAL DEPENDENCE BETWEEN AGE AND FECUNDITY OF SUMMER-SPAWNING HERRING.

Age	Fecundity										Σ	M
	50 - 75	75 - 100	100 - 125	125 - 150	150 - 175	175 - 200	200 - 225	225 - 250	250 - 275	275 - 300		
4	1	1									2	66.5
5											--	--
6		1	1	2		1					5	140.1
7		2	1		1						4	112.5
8				3	1						4	141.4
9				3	2	2	2		1		10	187.7
10			1	2	2	3	5	1			14	184.9
11					1	8	1	4			14	200.7
12					2	6	3		1		12	195.5
13						2		2	1	1	6	233.0
14					1	1	3				5	200.5
15						1					1	197.6
Σ	1	4	3	10	10	24	14	7	3	1	77	

TABLE 9. CORRELATIONAL DEPENDENCE BETWEEN WEIGHT AND FECUNDITY OF SUMMER-SPAWNING HERRING.

Weight	Fecundity							Σ	M
	125 - 150	- 175	- 200	- 225	- 250	- 275	- 300		
325									
350	1	1	1					3	163
375		1						1	163
400			6	1				7	192
425		2	5	5	1			13	203.5
450		1	8	5	3	1		18	206.0
475			2	1	3	1	1	8	231.7
500				1		1		2	238.0
Σ	1	5	22	13	7	3	1	52	204.0

TABLE 10. RELATION OF WEIGHT OF OVARIES TO BODY WEIGHT (1954 DATA)

Length of body in cm.	Average body weight in gm.	Average weight of ovaries in gm.	Relation of weight of ovaries to body weight	Number of specimens
29.1-30.0	343.0	56.0	16.3	2
30.1-31.0	382.5	66.5	17.3	4
31.1-32.0	417.3	77.3	18.5	13
32.1-33.0	415.5	80.1	19.3	27
33.1-34.0	454.0	91.4	20.1	6

TABLE 11. DIAMETER IN MM. OF EGGS OF SUMMER-SPAWNING AND SPRING-SPAWNING HERRINGS (PERCENTAGES).

Diameter in mm.	0.71-0.80	0.81-0.90	0.91-1.00	1.01-1.10	1.11-1.20	1.21-1.30	No. of fish	M
Summer race	--	15.4	55.8	28.8	--	--	52	0.96
Spring race	1.5	10.3	26.5	38.2	17.6	5.9	68	1.03

TABLE 12. NUMBER OF EGGS IN 1 GM., FOR SUMMER AND SPRING-SPAWNING HERRINGS (PERCENTAGES).

No. of eggs in 1 gm.	501-1000	1001-1500	1501-2000	2001-2500	2501-3000	3001-3500	3501-4000	n	M
Summer race	--	3.9	10.4	48.1	24.6	9.1	3.9	77	2430
Spring race	19.3	56.4	19.6	3.2	1.2	0.3	--	319	1310

As a result of the considerable difference in the size of the eggs in the two races, the summer herring has a higher fecundity than the spring Atlantic-Scandinavian herring.

Table 13 gives data on the fecundity of summer and spring herring of the same size and this gives even stronger grounds for declaring that there are fundamental differences in the fecundity of the two races.

Thus, the fecundity of the summer-spawning herring is somewhat more than twice as high as that of the spring-spawning herring of the same size.

Figures 9 and 10 show the fecundity in conjunction with age and size of the summer herring of Iceland and the Faroes and the spring Atlantic-Scandinavian herring. The difference between the two races as regards fecundity is great, as Figures 9 and 10 show.

One should note the non-parallel nature of the fecundity curves of the two races. Figure 9 shows the dependence of the fecundity on the length of the fish. In the summer herring, fecundity increases as the size changes, up to and including the largest fishes; in the spring herring, after a length of 30-31 cm. has been reached, the fecundity increases only slightly.

Farran notes in his work (3) a higher fecundity in the autumn-spawning herring of the Sea of Iceland. According to L. A. Rannak, a higher fecundity is to be noted in the autumn sprat as compared with the spring sprat.

The higher fecundity of the summer and autumn populations in comparison with the spring-spawning herring is their distinctive characteristic and this, in our opinion, should be considered an adaptation which compensates for the greater mortality of the young of the summer and autumn herrings in the first winter of their lives.

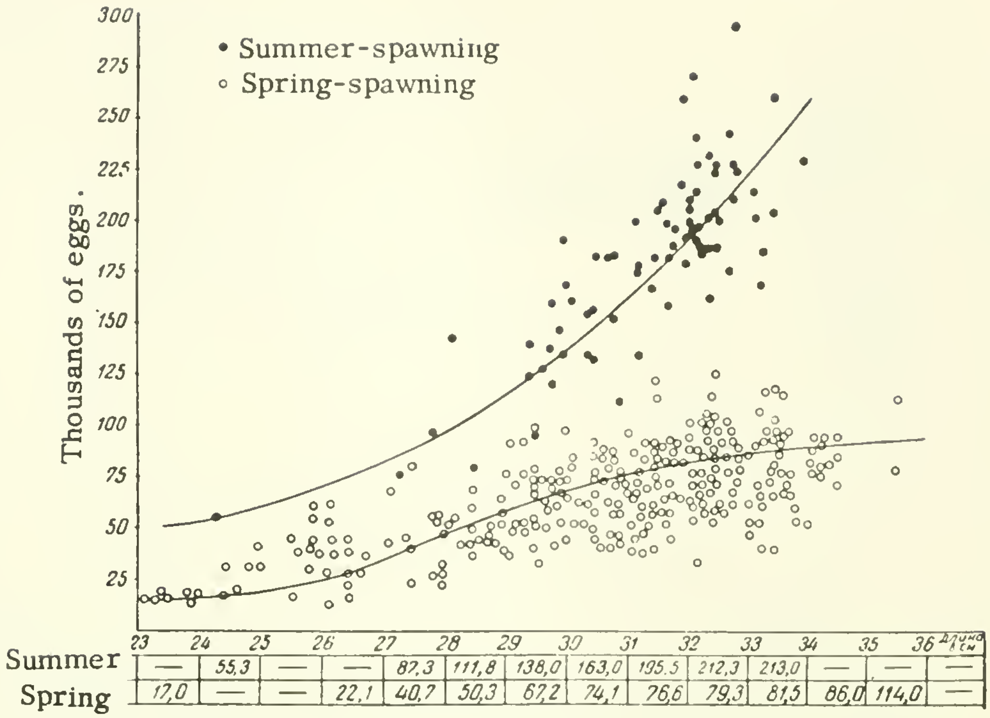
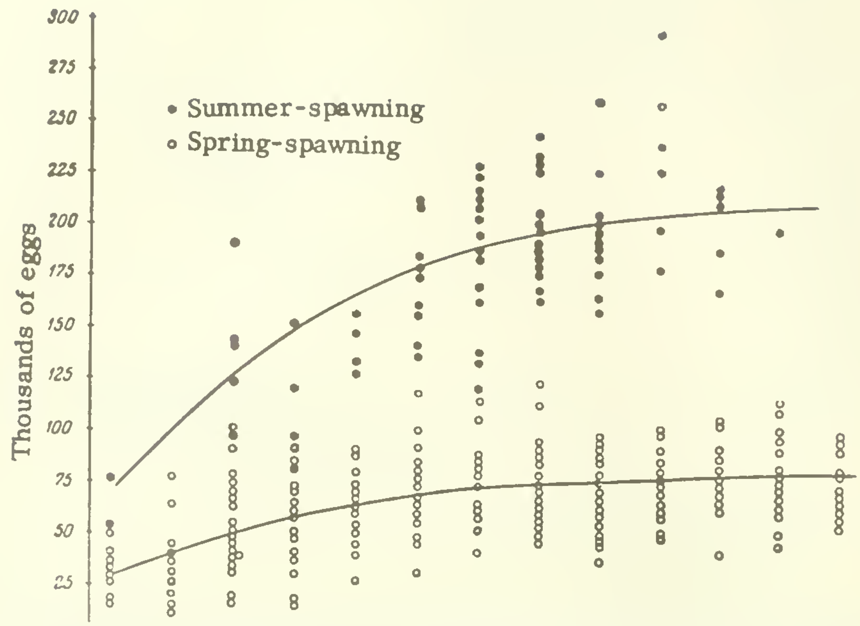


Figure 9. Fecundity of summer and spring herring. Dependence of fecundity on length.

TABLE 13. RELATIONSHIP OF FECUNDITY OF SUMMER AND SPRING HERRING OF SAME SIZE (THOUSANDS OF EGGS).

Race of herring	Length in cm.	Average maturity of sex glands	Weight of gonads in gm.	Fertility	
				General	Greater in summer herring
Summer	30.0	V	56.0	190.6	3.2 times
Spring	30.0	V	56.0	59.2	
Summer	31.0	IV-V	49.5	156.9	1.8 times
Spring	31.0	IV-V	50.0	88.9	
Summer	31.0	V	62.0	182.2	2.4 times
Spring	31.0	IV-V	65.0	74.9	
Summer	32.0	V	62.0	198.9	3.1 times
Spring	32.0	V	62.0	62.9	
Summer	32.0	V-VI	66.5	191.8	2.5 times
Spring	32.0	V	67.0	75.3	
Summer	32.0	V	71.0	218.6	2.4 times
Spring	32.0	V-VI	71.0	90.7	



Age	4	5	6	7	8	9	10	11	12	13	14	15	16
Summer	66,5	—	140,1	112,5	141,4	187,7	189,9	200,7	195,5	233,0	200,5	197,6	—
Spring	34,2	40,5	64,5	66,0	70,5	75,9	74,5	78,8	76,4	74,4	78,8	78,6	78,0

Figure 10. Fertility of summer and spring herrings. Dependence of fertility on age.

Weight and Fatness

The weight of the herring depends on its size, fatness and the stage of gonad maturity. After spawning, the herring feeds intensively. Average weight and fatness increase with the amount consumed.

According to our observations, the indexes of weight by years do not show any sharp divergences, and this allows one to combine the material on weight over a period of three years.

Table 14 gives average weight of adult herring of the summer race by times of capture. For comparison with changes in weight in the summer herring, we give data for the spring race.

The weight of the summer herring increases during June and July. In August, the average weight decreases and this is related to the approach of the period of large-scale spawning. The weight of the spring herring increases steadily during the whole summer period. The small divergence from this rule in the case of young specimens is to be explained by the paucity of the material.

Table 15 gives the coefficients of fatness before and after spawning. In all cases, the coefficient is considerably higher in the pre-spawning period than in the post-spawning period, which is to be explained by the sharp change in weight consequent upon the loss of the sexual products.

The fattening of the summer herring takes place apparently in two periods: before spawning, in April to June, and after spawning in August-September.

TABLE 14. AVERAGE WEIGHT OF HERRING (IN GM.) BY SIZE AND TIME OF CAPTURE.[1]

Length in cm.	Summer			Spring		
	June	July	August	June	July	August
27	252.2	264.3	214.5	225.5	267.5	260.5
28	259.5	293.0	243.4	270.5	269.2	263.8
29	303.0	310.6	272.0	273.6	282.6	298.1
30	325.3	342.6	306.4	315.7	319.6	324.6
31	332.1	364.6	321.5	316.3	344.9	345.8
32	383.3	403.6	370.6	328.4	364.8	376.6
33	406.3	411.1	398.3	344.2	383.5	384.3

1/ Weight analysis for summer herring based on 484 specimens, for spring herring on 3,216 specimens.

TABLE 15. AVERAGE WEIGHT AND COEFFICIENT OF FATNESS OF SUMMER HERRING BEFORE AND AFTER SPAWNING.

Dimensions in cm.	Pre-spawning period			Post-spawning period		
	Weight in gm.	K	n	Weight in gm.	K	n
27.5	277.5	1.33	6	262.6	1.26	7
28.5	304.5	1.32	19	270.3	1.10	23
29.5	318.9	1.24	41	294.4	1.15	46
30.5	343.4	1.21	33	313.3	1.10	37
31.5	377.3	1.21	65	330.0	1.05	19
32.5	406.0	1.18	44	351.0	1.02	11

Material on fat content. based on visual estimation, is given in Table 16.

TABLE 16. FAT CONTENT OF INTERNAL ORGANS OF HERRING FROM 1948 TO 1951 EXPRESSED IN POINTS.

Month	Year											
	1948				Total	M	1949				Total	M
	0	1	2	3			0	1	2	3		
June	22.3	48.7	29.0	--	100	1.06	59.7	1.4	--	38.9	100	1.18
July	6.6	21.1	40.9	31.4	100	1.97	4.8	34.9	40.4	19.9	100	1.75
August	1.9	15.6	51.2	31.4	100	2.17	7.4	1.6	53.7	37.2	100	2.20
September	1.0	2.9	18.4	77.7	100	2.33	--	1.1	30.3	68.5	100	2.67

Continuation

Month	Year											
	1950				Total	M	1951				Total	M
	0	1	2	3			0	1	2	3		
June	63.9	22.5	9.8	3.3	100	0.52	12.9	21.6	39.9	31.6	100	1.96
July	22.6	46.6	28.7	2.1	100	1.10	14.6	24.4	19.5	41.4	100	1.87
August	13.3	48.5	36.5	1.7	100	1.26	11.7	17.5	17.4	53.3	100	2.12
September	0.4	6.0	37.9	55.8	100	2.49	0.3	7.5	21.4	70.7	100	2.62

For all the years during which observations were made, the lowest fat content was in June, the highest in September. In June, no fat deposits were laid down in a considerable number of fish. In July and August, a fat content of 1-2 points is prevalent, in September - 3 points.

The drop in the fat content during reproduction is short-lived and cannot be traced from monthly average indices.

Future researches should clarify the fattening conditions of the summer herring and the change in its fat content before and after the spawning period.

Data on Sexually Immature Summer Herring

There is no regular trade in young herring in Iceland waters. It may well be that it has not eveloped because of the extremely favorable conditions for trade in the older age groups off the northern coasts of the island. Up to 1946, the catch of fat herring in the Iceland region did not exceed a few thousand centners.

Young herring 22-26 cm. in length are found annually in the waters of northern Iceland, being constantly present in the catches of large herring. There was a specially large number of young herring in August and September 1949.

During the winter of 1946-7 and 1947-8, large numbers of immature herring were observed in Faxa Bay (Kolla Fjord). In the first winter, about 139,000 centners were caught, in the following year about 1,800,000 centners. According to the biological analysis made by Fridriksson (6), spring and summer herring were represented in the catches in almost equal proportions. The percentage ratio of the two types was determined by Fridriksson on the basis of an analysis of the gonad maturity stages and the number of vertebrae (Table 17).

TABLE 17. CHARACTERISTICS OF HERRING CAUGHT IN FAXA BAY DURING 1946-1948 (AFTER FRIDRIKSSON).

Number of vertebrae	Stage of Maturity					
	I	II	III	IV	V	Total
59	5	1	12	8	19	45
58	50	112	468	210	424	1264
57	156	269	1909	395	902	3631
56	29	84	546	51	131	841
55	1	1	18	2	3	25
54	--	--	5	2	3	10
53	--	--	2	--	--	2
Total	241	457	2960	668	1482	5818
%	4.1	8.0	50.8	11.4	25.7	100.0
M	57.120	57.060	56.965	57.247	57.213	57.073
±	0.041	0.030	0.012	0.025	0.017	0.009

The average number of vertebrae in these two groups of herring varies somewhat. Herring of stage III have on the average about 57 vertebrae (56.96) and V stage herring have 57.21. One can agree with Fridriksson that herring with a small number of vertebrae in stages II and III should be considered summer-spawning herring while those with a large number of vertebrae in stages IV, V should be considered spring-spawning herring. This assumption is confirmed by the following observations on the departure of stage V herring from Kolla Fjord in the middle of February (Table 18).

Spring-spawning herring left Kolla Fjord in the middle of February, after which summer herring were left in the bay. The general catch of summer herring in Kolla Fjord was about 800,000 centners.

One should note that these numbers of herring were a great surprise for the Icelandic investigators and in particular for Fridriksson (4), who for several years before these observations had asserted that the number of summer herring was small.

There was a considerable number of sexually immature summer herring in the catches off the south-western coasts of Iceland. In this region, we found large numbers of young herring in

TABLE 19. AGE COMPOSITION OF SUMMER HERRING IN AUGUST AND SEPTEMBER IN REGIONS OF NORTH AND SOUTH COASTS OF ICELAND IN 1951 (PERCENTAGES)

Region	No. of Annuli																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	n
North	--	7.6	6.0	4.0	4.7	8.5	7.2	10.1	9.3	9.3	11.8	9.2	7.2	2.9	1.4	0.9	926
South	0.5	6.1	26.8	24.6	18.1	9.1	9.2	3.5	1.8	0.3	--	--	--	--	--	--	564

September 1951. In 1950, fish of three to five years also comprised here a considerable percentage in August and September, which is indicated in Einarsson's work (2).[1/]

TABLE 18. RELATION OF STAGES OF SEXUAL MATURITY OF HERRING IN AUTUMN-WINTER CATCHES 1947-48 (PERCENTAGES).

Stage	Period			
	November to January 15	January (16-31)	February (1 to 15)	February (16 to 29)
I-II	9.9	5.3	4.4	3.0
III	43.3	40.1	55.2	84.5
IV	14.9	14.1	9.4	8.0
V	31.9	40.5	31.0	4.5
Total	100.0	100.0	100.0	100.0

Thus, sexually immature herring are found in all the Iceland regions but a specially large number is observed to the south-west of the island, where in the winter of 1946, 1947, and 1947-48 they were caught in large numbers by the Icelanders.

Off the northern coasts of Iceland, according to our observations, young herring are particularly common at the end of the fishing season--in August and September.

Distribution of Adult Summer Herrings

Our researches show that the fattening of the older age categories of the summer herring before and after reproduction takes place to the north of Iceland, where the older age groups are always predominant. Young individuals comprise only an insignificant percentage of the catch in this region.

Table 19 gives a comparison of the age composition of the summer herring in the regions of the north and south coasts of Iceland, based on the materials for 1951.

As regards the age composition of the summer herring, these two regions differ sharply from each other. To the north of the island, herring from 7 to 14 years are predominant, while in the southern region those from 4 to 8 years are predominant. Herring aged 9 years or more make up 5.6% in the south and 62.1% in the north. These data lead to the conclusion that the areas of distribution of young and older age groups of the summer herring are fundamentally different. Only the older age categories come to the northern coasts of Iceland from the south.

Observations made in 1951 give grounds for supposing that the older herring leave for the fattening grounds earlier than the younger individuals. Thus, in August 1951, herring of 7 years and more made up 26.5% while in September the percentage of the same age categories had fallen to 18.7%, since the younger ones had arrived.

Our conclusions on the distribution of the young of the summer race are confirmed also by

1/ In December 1950, the Icelanders caught 14,000 hectolitres of small herring in purse-seines.

the observations of Icelandic scientists. Table 20 gives the age composition of the herring along the southern coast, based on our data and Einarsson's observations (2).

The age composition of the summer-spawning herring of the northern regions of Iceland does not remain constant. In June, to the north of the island, herring of 6 to 12 years are predominant (Table 21).

At this time, there are no fish of the older ages and younger ages. In July and August, the number of fish of the older groups increases, and fish of 7-15 years predominate in the catches. Along with them, younger age groups, 3-5 years were found in the catches, the majority of them not yet having spawned. In September, the number of fish of the younger groups increases still more.

In the first half of the fishing season--in June--summer herring were found as far north as 67° N. The majority of them were found to the north-east of Iceland, in the region of Langanes peninsula. After reproduction, the summer herring were found much further north, as far as 68° N. Thus, the fattening area of the summer herring coincides with the distribution of the spring race; it is found everywhere within the limits of the Irminger current, up to the fringes of the polar waters. Summer-spawning herring were found at the following times in the following regions:

In June 1949, to the north-east of Langanes peninsula, they comprised about 18% of the total catch in this region.

TABLE 20. AGE COMPOSITION OF SUMMER HERRING IN CATCHES MADE OFF THE SOUTH COAST OF ICELAND IN 1950 AND 1951 (PERCENTAGES).

Age	2+	3+	4+	5+	6+	7+	8+	9+	10+	>10+	%	No. of fish
Generation	1948	1947	1946	1945	1944	1943	1942	1941	1940			
Aug. and Sept. 1950 (Einarsson's observations)	0.3	4.6	12.7	60.2	17.3	3.0	1.3	0.4	0.1	0.1	100	1765
Generation	1949	1948	1947	1946	1945	1944	1943	1942	1941			
Aug. and Sept. 1951 (author's observations)	0.5	6.0	27.1	22.9	18.6	9.4	9.4	3.7	2.0	0.4	100	564

In 1950, summer herring in this same region in June comprised about 7%. In 1951, at the end of June, the summer race in the north-eastern Iceland region did not exceed 9%.

In the first half of July 1949, the summer herring to the north of the island made up about 13.5% and in the second half of July the number caught had fallen to 2%. In July 1950, they comprised 7.2% in the first half of the month and about 60% in the second half. In July 1951, they made up 6% to 11%. A considerably higher percentage of summer herring was found in the second half of the season. In August 1949, post-spawning herring of the summer race comprised 44% of all catches, in 1950 --about 50% and in 1951, to the north-west (Isa Fjord), up to 70%, and to the south of Iceland at this time up to 75%.

TABLE 21. AGE COMPOSITION OF SUMMER RACE IN REGION OF NORTHERN COAST OF ICELAND, BY MONTHS FOR THE PERIOD 1948, 1949, 1950 AND 1951 (PERCENTAGES).

Month	Number of Annuli																		
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	n
June	--	--	2.2	3.7	9.5	11.8	20.7	14.0	15.5	8.8	7.3	3.7	2.8	--	--	--	--	--	136
July	--	--	1.7	2.4	5.9	5.0	7.3	10.0	13.6	15.0	15.6	12.0	6.8	3.1	1.0	0.5	--	0.1	730
Aug.	--	5.7	6.1	3.8	4.9	10.8	7.8	10.2	9.6	9.0	10.2	9.6	8.2	2.8	1.0	0.5	--	--	577
Sept.	0.2	10.6	6.0	4.4	5.5	6.4	9.8	8.7	9.8	9.8	14.1	8.4	5.8	3.2	2.1	0.5	--	--	349

The specific weight of summer herring in September 1949 reached 40% in the north-eastern region of Iceland, 35% in the same region in 1950 and, to the south of the island, from 40 to 70% in 1951.

Concentrations of post-spawning summer herring to the north-west of the island in 1951 were distributed over a large area of water. Average catches were of an entirely adequate commercial character. Concentrations of the summer race in the second half of August to the south-east of Cape Reykjanes also covered a great area. Average catches throughout the fleet in this region were high. In September, the vessels continued to catch in the south summer herring which were fattening.

In the northern Iceland regions, the summer herring has its highest commercial significance at the end of the fishing season-- the second half of August and September --and also at the beginning of the season-- in June.

The wes.ern region of the island was not explored in detail until 1951 and then the summer race was found in late July and early August. To the south of Iceland, summer herring was found in the second half of August and in September. Distribution of adults of the summer herring is shown in Figure 11.

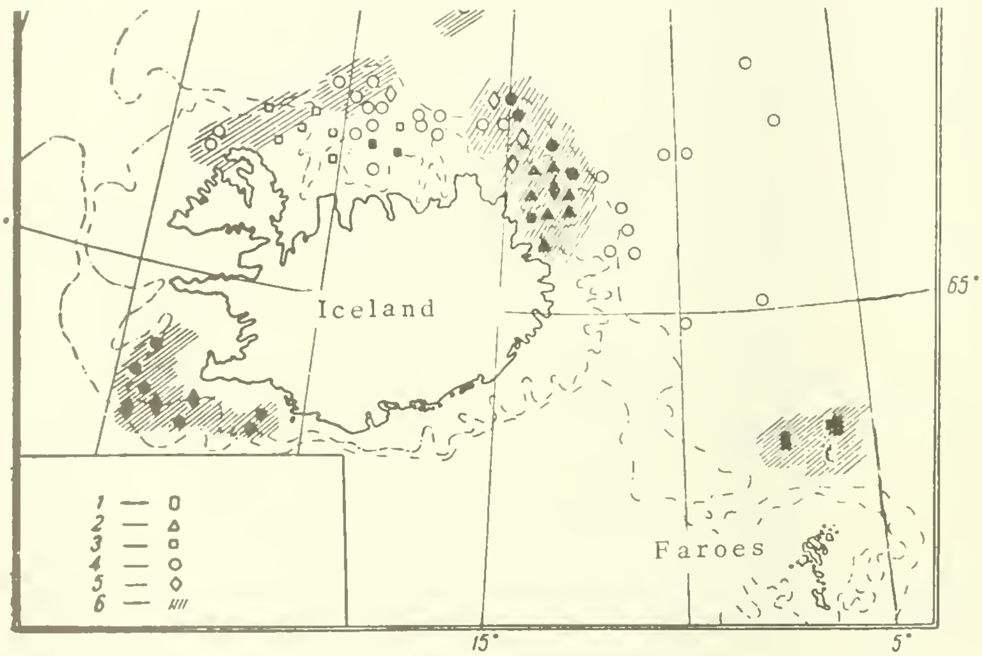


Figure 11. Distribution of adult summer herring by months: 1. May 2. June 3. July 4. August 5. September; 6. Shading shows zones of commercial concentrations. Black: pre-spawning herring. Blank: post-spawning herring.

On the basis of the results of the researches, we can give a preliminary plan of the migrations of the summer herring, a plan which after future researches will undoubtedly be made more exact.

The wintering zones of the summer herring are concentrated to the south of the island. After wintering in the spring-summer period (May, June), the summer herring begins to move along the east and west coasts and by the beginning of the fishing season it has reached the northern fattening grounds, which it does not leave until the reproduction period. Then the maturing fish of the summer race depart for the southern coasts. Probably this departure is also made along the west and east coasts since the largest number of herring of this race are observed always to the north-east and comparatively few are found in the northern and central regions. The second fattening period occurs immediately after spawning. Part of the younger herring, which spawn later, apparently fatten in the southern regions. There is no doubt that the herring which we found in late July and early August to the north-west of Isa Fjord was moving to the north along the west coast. The feeding ground after spawning is considerably broader than the feeding ground of the pre-spawning period. The limit of the latter may be considered 67°N while the limit of the post-spawning feeding ground is wider and reaches 68°N. One may assume that with the approach of winter the summer herring leaves for the southern regions.

The fundamental difference in the age composition of the summer herring in the northern regions as compared with the south - namely the predominance of the older age groups in the north and of the younger age groups in the south - lead one to the conclusion that there is a certain dis-association in the areas of their distribution. The northern coasts of the island are frequented principally by the older age groups; the younger herring of the summer race keep to the southern shores.

A plan of the life cycle of the Iceland summer herring is given in Figure 12.

To conclude our work, we may mention that the area of the summer herring is more limited than the area of the spring Atlantic-Scandinavian herring. The spawning grounds of the summer herring are known at present in the Iceland region; there is every reason to suppose that spawning also occurs in the Faroes region. Summer herring are found very rarely off the coasts of Norway (15) and even more rarely in the northern part of the Norwegian Sea.

The Iceland summer herring is sharply distinguished from the bank herring of the North Sea, which has a much lower growth rate and a comparatively short lifetime (not more than 8-10 years).

Summer-spawning herring are known on the south-west coast of Greenland and also in the region of Nova Scotia and Fundy Bay. Off Greenland, the summer herring reproduce along the south-western coast in the region of Cape Farewell, where its spawning has been established by Paul Hansen (8). In the same regions, herring reproducing in the summer were discovered in 1914-1918 by a Canadian expedition. The summer herring of Iceland is more closely related to the herring of the Greenland region, and it is possible that these two groups of summer-spawning herring may intermix within the Denmark Strait.

According to Hansen's latest researches (1953), adults of the summer herring off Greenland have a wider distribution. They are found along the northern coast from 65°37'N to 72°20'N and along the west coast to 62°N.

Hansen says that from the number of vertebrae the young sexually immature herring of the Greenland region may be assigned tentatively to the summer race.

In the waters of the Julianehaab region, 20 young herring aged one year were once fetched up in a seine. In the Frederikshaab region, there have on several occasions been catches of a fairly large number of small herring aged 2-3 years. From this, Hansen concludes that in some years the herring may spawn in Greenland waters and the young may grow up here.

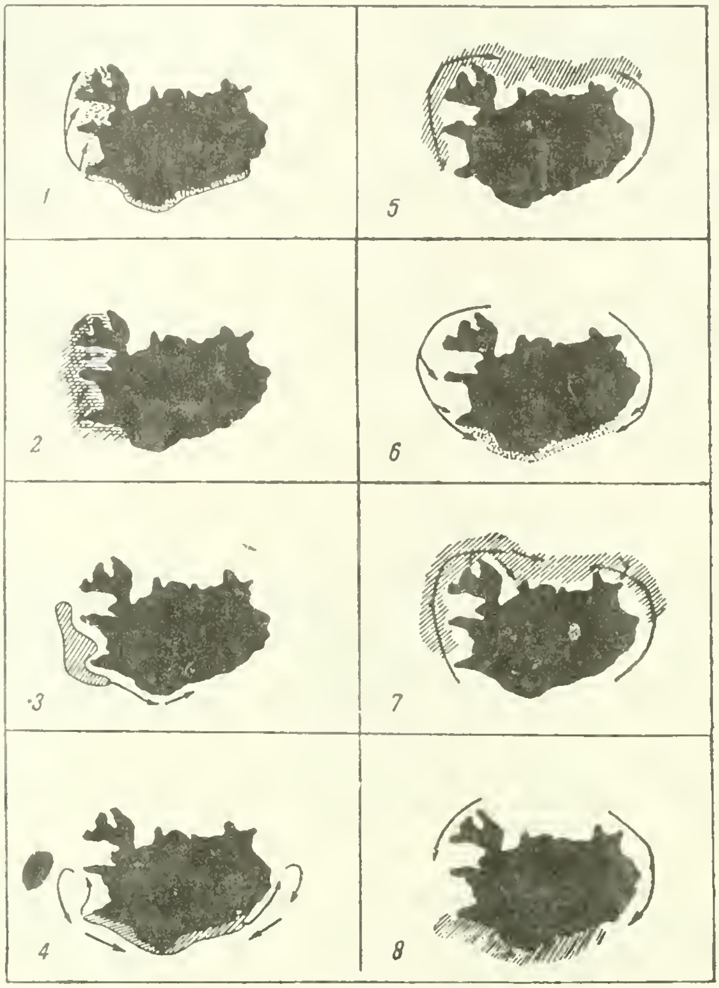


Figure 12. Plan of life-cycle of Iceland summer herring. 1. Drift of young to western shores of Iceland and settling in bays and fjords. 2. Spread of small and fat herrings. Departure from coastal zone as they grow up. 3. Spawning migration of the "recruits". 4. Fattening and spawning migrations of young sexually mature fish. 5. Fattening migration of older stages to northern shores at beginning of summer. 6. Spawning migration of older stages to southern shores in July-August. 7. Fattening migration of older stages to northern shores at end of summer. 8. Departure of older stages for winter.

Conclusions

1. The summer spawning herring of the Iceland region are undoubtedly more numerous than the Icelandic investigators imagine. The reason for this underestimation is that the Icelanders

begin catching summer herring off the north coast in July, when the summer herring is leaving for the reproduction grounds in the southern regions, and finish catching in the last week of August, when a large proportion of the post-spawning herring have not yet reached the northern regions. It is precisely in these two periods --at the beginning of the season and at the end-- that, according to our observations, the summer herring is found in large quantities in the northern regions.

Fridriksson (5) explains the large influx of young herring into the fjords of the west coast in 1946-48 by an increase in the numbers of the summer race in those years. One can hardly agree with this assumption.

Large catches of larvae of the summer herring were observed by I. Schmidt in 1903-1904; Taning in 1925, 1933, 1936, and 1946. There were large numbers of summer herring in Faxa Bay in 1946-47, 1947-48. Finally, we found large concentrations of summer herring off the west coast in 1951. All these observations confirm that the summer herring during the last 50 years has had considerable weight in the total stock of herring in the Iceland region.

2. The basic spawning grounds of the summer herring are along the southern, western and south-eastern coasts of Iceland and are distributed along the slopes of the continental plateau, in the zone of the warm waters of Irminger current. This is confirmed by the distribution of the early stages of larvae (less than 10 mm. in length) and also by the departure of the summer herring from the northern Iceland regions during its spawning period. PINRO investigations in 1954 (Yudanov) revealed pre-spawning concentrations of summer herring in the region to the north of the Faroes. The most important spawning grounds of the summer herring in the Iceland region are known: in the south-east (Cape Stoksnes), in the south - in the region of Westmannaeyjar Island, in the region of Cape Reykjanes and also around Snaefellsnes peninsula. It is highly likely that there are summer race spawning grounds in Faxafloui Fjord, Breida Bay and Isa Fjord. The largest number of early stages of larvae has been found above depths of 30-40 m. and 100-110 m. Apparently the basic spawning grounds are disposed in these depth zones.

The spawning of the summer herring begins at the end of June and continues in July and August. It is quite likely that in some regions spawning may occur in the first half of September. Spawning occurs at a temperature of 8^{o}-9.5^{o} in a salinity near to 35%.

3. Tåning's researches, especially in recent years (1939, 1946), show a drift of larvae in a westerly direction along the south coast and further to the north along the western coast of the island. It was in fact in the latter region that he found the largest larvae - 18-25 mm. in length.

One may assume that a large part of the young remains in the relatively shallow bays of the west coast, where the warm waters of the Irminger current penetrate.

The western shores of Iceland are the regions where the younger age categories fatten. There, in the region of Cape Reykjanes, Fridriksson discovered wintering young of the summer race. In Faxafloui Fjord, numbers of fat, sexually immature herring were observed.

4. A fundamental difference in the age composition of the summer herring of the northern regions and the southern regions, namely the predominance of the older stages in the north and the younger in the south, leads to the conclusion that their respective areas of distribution are somewhat dissociated. The northern shores of the island are frequented principally by the older age groups, the younger ones keeping to the southern regions.

The plan of the feeding migration of the summer herring appears as follows. After wintering, which takes place in the southern regions of the island, the summer herring at the beginning of the summer broadens the area of its habitat by entering the northern regions, approaching them both from the west and the east. This first fattening period, before reproduction, occurs in May and June; then the maturing herring leave for the south coast. Apparently this departure is accomplished also along the west and east coasts, since the largest numbers of summer herring have been observed by us to the north-east, and relatively few were found in the northern and central regions.

The second feeding period begins immediately after spawning. Part of the younger herring, which spawn later, feeds up in the southern regions. Herring of the older stages, however, which spawned first, leave for the northern regions. The herring which we found in late July, early August to the north-west of Isa Fjord was moving to the north along the west coast. The feeding region after spawning is considerably wider than that of the pre-spawning feeding; the limit of the latter may be considered 67^{o}N, while the limit of the post-spawning feeding ground extends to at least 68^{o}N. As winter approaches, the summer-spawning herring apparently moves into the southern regions.

The migrations of the summer herring in the Faroes region have not yet been tracked. In all probability, after reproduction the herring leave the spawning grounds in a northerly direction. Their area, like that of the Iceland summer herring, is limited. Thus, in the region of Jan Mayen (71^{o} N) only occasional specimens were found in the catches.

5. In the first year of life, the young of the summer race reach 4-4.5 cm., in their second year of life the increase in growth is 5-6 cm. In subsequent years, the growth rate of the summer herring hardly differs from that of the spring herring. Summer herring reach sexual maturity for the most part at 4-5 years but some individuals become sexually mature at 6-7 years. Summer herring of Iceland and the Faroes are distinguished by a high fecundity. The average number of ova in the summer herring is almost twice as great as in the Atlantic-Scandinavian spring herring.

The lifetime of the summer herring reaches 15-18 years and, as an exception, one may find individuals as old as 19 years.

6. The Iceland summer herring are a race which is highly distinctive by virtue of its biological characteristics and above all its periods of reproduction. The times of reproduction of the summer and spring herring are separated by at least two months and therefore intermixing at the spawning grounds is completelv excluded.

At the same time, they have some common characteristics which are determined by the conditions of their existence. Such characteristics include: growth, time of onset of sexual maturity, and life-span.

Future researches on the summer-spawning herring of Iceland should aim above all at discovering the region of their pre-spawning schools. If these schools turn out to be considerable, then undoubtedly the development of the catching of this herring will be worth while.

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THE OVOGENESIS AND ECOLOGY OF THE SEXUAL CYCLE OF THE MURMANSK HERRING (CLUPEA HARENGUS HARENGUS L.)

V. M. Naumov

The life cycle of the Murmansk herring can be studied on the basis of the sexual cycle. Items of importance to the catch of the herring, such as pre-spawning concentrations, migrations, and spawning are related to the sexual cycle of the fish.

In contradistinction to other workers who have investigated the sexual cycle of fish, we find it necessary to compare the stages in this cycle with the ecological conditions in the different habitats and with other indicators of the physiological state of the herring.

The material for the present paper was collected by the author on four cruises, three in the Barents Sea (1938-39), and one in the Greenland Sea (1947). Data from the Polar Institute (PINRO) have also been used.

The investigation of the sexual cycle of the Murmansk herring is not only of theoretical interest, but may also be useful to the commercial fishery, especially for predicting the spawning migrations of the herring.

The Types of Spawning in Herring

In recent years Soviet ichthyologists have distinguished between two types of spawning, namely, 1) all the eggs are spawned in one batch, and 2) in several portions.

Gerbil'skiy (12), by the character of the ovogenesis and ovulation, divides the fish into two groups, those with "total" or "complete" spawning, and those with "partial" (in portions) spawning. At first we will define these two ideas, and then state to which group the Murmansk herring belongs.

In the type with total spawning the ovaries may be characterized in the following way: Once a year a certain quantity of ripening ovocytes are simultaneously separated from the total reserve of ovocytes. This takes place in ovaries in stage II-III (in a scale with 6 stages). The ovocytes are spawned in one batch, or in portions during a few hours or days.

A partial spawning is observed in those species in which the ovocytes that are ripening simultaneously are separated into stage II-III groups three or four times during one spawning period.

The type of total (isochronal) spawning is characterized by the presence of a complex of ovocytes in the ovary: 1) non-developing ovocytes (pre-ovogonia, ovogonia and ovocytes in the single-layered follicle phase) which constitute the so-called reserve of the next year (the ovogonia constitute the so-called reserve, not only of next year, but also of a series of years), and 2) developing ovocytes, always in one single stage of development only.

The ovaries of the type of partial spawning are characterized by the presence of 1) non-developing ovocytes, such as in the preceding type, and 2) ovocytes in different phases of development. For example, in the ovary one part of the ovocytes may be in the first yolk-forming phase, another part in a later yolk-filling stage, and a third part of the ovocytes may be full of yolk.

If the spawning had to be characterized only by the external features of spawning, all the known fishes might be referred to the partial spawning type. We do not know any fish in which all the ripe eggs are discharged in one batch. Interruptions in the spawning process are evidently observed in all species of fish, but these breaks may last from a few minutes or hours to a few weeks.

If we were guided only by the intervals between the different extrusions of ripe eggs, would it then be possible to draw a definite limit between partial and non-partial or total spawning?

In our opinion, this is only possible in those species of fish in which the time needed for the development of the single portions of developing eggs is at least one and a half weeks. An exact idea of the character of the spawning can only be obtained from a study of the processes in the organism itself.

From a histological picture of the ovary the type of spawning may be determined without any error. By studying a series of histological preparations, we came to the conclusion that the Murmansk herring had a proper total spawning (Figure 1, a, b). In addition, a count of the eggs in the ovaries indicates that their number does not vary during the ripening. During the whole spawning period only as many eggs are spawned as were separated in the ovaries at the beginning of the ripening process.

Several papers mention partial spawning, i.e., in the genus Alosa, which is related to the herring, in carp, and several other species (in cyprinoid fishes partial spawning has been thoroughly described by Dryagin (17), but he did not undertake any histological study of the gonads).

The conclusion of Hickling and Rutenberg (88) that the oceanic herring has partial spawning is explained by the incertitude in the method used (the ovocytes were measured in histological sections). From the measurements the authors divided all the ovocytes in the ovary into two diameter size groups: 1) 0.1-0.2 mm., and 2) 0.5-1.2 mm. In the graph they showed two separate and clearly expressed peaks. The authors inferred that after the ripening of the ovocytes of 0.5-1.2 mm., the size group 0.1-0.2 mm. would mature and be extruded after having reached a size of 0.5-1.2 mm. Accordingly, the Atlantic herring would discharge the eggs in two portions. It is to be regretted that the authors in their paper had neither drawings nor photographs of the ovaries investigated. It is therefore difficult to decide to which development phase the ovocytes in the first or second size-group can be referred.

We do not think that the ovocytes of the Murmansk herring differ very much in size from those of other varieties of the oceanic herring Clupea harengus. The ovocytes of the first size group are probably in the phase of the follicle with one layer of cells.

In our paper (52) ovocytes in the phase of the single-layered follicle measure 86.87-148.7 mu, average 103.66 mu. In this phase the ovocytes from the Murmansk herring correspond in size with those of the first size group from the oceanic herring. The development of the ovocytes from single-layered follicles to the ripe ovocytes (the ovulation) requires not less than 8 months. It would therefore be incorrect to conclude that the ovocytes of the first size group (single-layered follicle) would attain the size of the ripe ovocyte (the second size group - 0.5-1.2 mm.) during say 2-3 weeks.

On this basis we arrive at the following conclusions: 1) in the ovaries of the oceanic herring only a certain part of the ovocytes ripens, and 2) the ovocytes of the first size group (0.1-0.2 mm.), constituting the so-called reserve of the coming year, will partly ripen and be spawned in the following spawning season. The two size groups of eggs, which might perhaps correspond with two spawning periods, are explained by other causes. Different periods in the spawning of the same species of fish, in this case the Atlantic herring, are not caused by a spawning in distinct periods, but occur because the sexual products do not mature at the same time in the individual populations of herring.

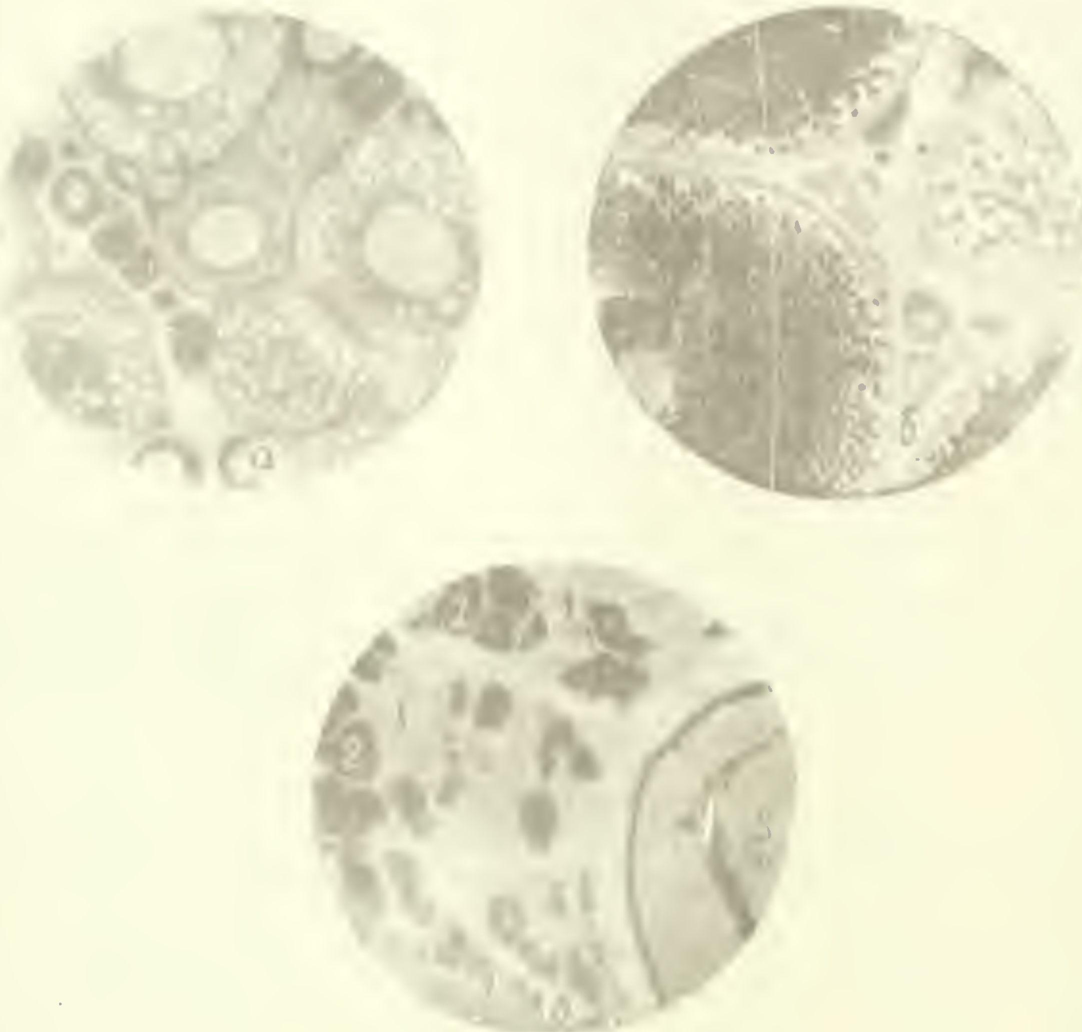

Figure 1. Ovary of Murmansk herring. a: 21 Jan., 1939, NW edge of the Murmansk Bank, length of fish 248 mm., weight 126 gm., age 6+, stage III, x 100. b: 1 March 1937, western part of the Murmansk Bank, stage IV, x 79. B: April 4, 1939, Ringvassøy, fish length 239 mm., weight 89 gm., age 5+, stage VI.

In the sections are seen: 1) numerous empty follicles, 2) a complex of ovocytes in stage II, 3) a ripe ovocyte, which has not been spawned. x 100.

From a study of our preparations Meien (49) came to the conclusion that the Murmansk herring and the Caspian genus *Alosa* (very nearly related systematically) resembled each other very much in the morphology of the ovocytes, but had different types of spawning. In *Clupea harengus* there is a total spawning; in *Alosa*, a partial one. The difference is ascribed by Meien to the different ecological conditions of the spawning.

Ivanova (23) observed ovocytes in different phases of development in the ripe ovaries of the Brazhnikov herring and concluded that this species had a distinct, partial spawning.

Having stated that both total and partial spawning exist, with real examples from two genera of herring, we shall mention another feature in the spawning, namely, the character of the extrusion of the ripe eggs from the ovaries. As already mentioned, the Murmansk herring has a total spawning; but the character of the spawning in the oceanic herrings has been unsufficiently treated in the literature. From the analysis of one sample of spawning herring from the area near Ringvassøy we determined how the Murmansk herring spawns the ripe eggs. With only one sample at our disposal, we cannot, of course, answer the second, but not less important question: when are the ripe eggs spawned, and how many spawning intervals may exist. We shall once more mention that, regardless of how many extrusions of eggs there may be, there is in all one single portion of ripe eggs in the ovary, and they are all extruded during the spawning period.

An analysis of ovaries in the maturity stage V gives an idea of the character of spawning in the Murmansk herring. In the individuals of a spawning school the extrusion is proceeding in various ways; a total extrusion is observed in some individuals, a partial one in others. In addition, each ovary discharges the ripe eggs unequally. We may therefore restrict ourselves to the discussion of the various moments of extrusion of one single portion of ripe eggs in one certain year.

For the stock of Murmansk herring as a whole, the spawning lasts very long, but in the single individuals the spawning is total and rapid. The long duration of the spawning in the total stock (1 1/2 - 2 weeks) is caused by the non-isochronal ripening of the sexual products in the individual populations. For this reason all the herring do not come to the spawning places at the same time. This means evidently an adjusting of the competition for spawning places, and for the feeding of the young after the spawning. In the Caspian herring, the partial spawning is an adaption for the conservation of the species by increasing the fecundity, an adaption which is widely distributed in nature.

Fecundity

There are very few data on the fecundity of the Murmansk herring, except from Esipov (19), but he had only very limited material at his disposal (Table 1.).

TABLE 1. THE FECUNDITY OF THE MURMANSK HERRING (AFTER ESIPOV).

Length after Smitt cm.	Weight of the fish gm.	Weight of the sexual product gm.	Index of maturity	Sample in gm.	No. of eggs per gm.	No. of eggs in the ovary
22.9	100	7.65	5	9676	1935	14803
25.0	135	16.30	5	6738	1348	21972
24.4	124	13.30	5	8240	1648	21918
23.4	119	11.60	5	9710	1942	22527
23.5	124	15.80	5	5636	1127	17807
24.4	140	14.40	5	8097	1619	23314

The herring laboratory of the PINRO has placed at our disposal material for a study of the fecundity of the Murmansk herring. We calculated the number of eggs in a weighed sample, and the total fecundity was computed by weighing the ovaries.

A more complete material for the fecundity was collected on the Nordkyn bank (Table 2).

TABLE 2. THE FECUNDITY OF THE MURMANSK HERRING (FROM THE MATERIAL OF PINRO).

Length after Smitt cm.	Weight of the fish gm.	Age	Weight of the sexual product gm.	Index of maturity	Sample gm.	No. of eggs per gm.	Absolute fecundity
238	105	6	19.39	18.47	5	870	15425
242	130	6	17.38	18.64	5	2286	18197
239	130	5	15.9	12.33	5	1060	16856
234	110	5	7.42	6.75	5	1542	11442
236	114	5	5.28	4.63	5	2722	14372
246	126	6	21.82	17.32	5	1102	24046
241	125	6	21.43	17.14	5	1034	22159
243	142	6	16.52	11.63	5	1460	24119
235	118	5	6.47	5.48	5	2266	14651
232	117	5	4.04	3.45	2.5	4896	19780
243	126	6	9.70	7.70	5	2374	22028
252	142	6	5.32	3.79	5	2832	15066
248	129	5	7.01	5.04	5	2334	16361
234	135	5	12.82	9.42	5	1410	18076
236	110	7	16.89	15.35	5	924	15601
238	134	6	11.20	8.34	5	1982	22198
251	130	6	14.80	11.38	5	1710	25380
236	114	5	4.22	3.70	2.5	4396	18556
239	124	5	14.68	11.83	5	1044	15526
256	155	6	17.47	11.27	5	1780	31098
245	132	5	11.04	8.36	5	1722	19011
232	105	5	13.17	12.54	5	1300	17121
230	110	5	11.27	10.20	5	1472	16590
232	110	5	11.02	10.02	5	1578	17390
235	112	5	7.20	6.43	5	2440	17568
234	120	5	8.63	7.19	5	2118	18278
228	95	5	5.95	6.26	5	2740	16303
237	115	5	6.61	5.75	5	2352	15547
236	115	5	8.56	7.44	5	2250	19260
232	110	5	3.33	3.03	2.5	3030	10090
237	138	6	11.42	8.27	5	2238	25558
239	117	5	5.90	5.04	2.5	3094	18255
256	142	6	9.95	7.01	5	2062	20517
236	109	6	15.42	14.15	5	1912	29483
230	115	5	7.81	6.79	5	1786	13949

TABLE 2. (CONT'D).

Length after Smitt cm.	Weight of the fish gm.	Age	Weight of the sexual product gm.	Index of maturity	Sample gm.	No. of eggs per gm.	Absolute fecundity
237	115	5	15.82	13.76	5	1220	19300
251	148	5	6.28	4.25	2.5	2838	17883
253	156	6	17.27	11.07	5	1896	32743
232	110	6	8.68	7.89	2.5	2254	19565
244	125	7	18.10	14.48	5	1076	19476
238	115	6	6.52	5.67	2.5	2656	17304
240	128	6	13.25	10.35	5	1198	15873
231	105	5	4.45	4.23	2.5	4542	20212
535	103	7	9.49	9.0	5	2068	19025
233	126	6	12.62	10.0	5	1766	22286
236	111	6	11.52	10.04	5	1220	14079
239	126	6	18.22	14.42	5	1412	25727
236	110	6	12.20	11.10	5	1224	14933

The sexual products of the herring investigated were in stages III-IV (Table 2). The fecundity was determined by counting the eggs in three samples, each of 5 grams. The size of the samples was adjusted according to the size of the eggs; for example, for eggs in stage III (very small) samples of 2.5 gm. were sufficient.

The error in computing the number of eggs by the weighing method was very small, as only the ripening ovocytes were counted. The primordial germ cells without yolk (single- and double-layered follicles) were not counted.

The Murmansk herring has a proper total spawning. Accordingly, no difficulties exist in separating the ripe ovocytes from those which will mature during the following years.

From the analysis of the material we have been able to find the relation of the fecundity to various factors. For example, the fecundity increases with increasing length of the fish (Table 3).

TABLE 3. THE VARIATION OF THE FECUNDITY IN RELATION TO THE LENGTH OF THE FISH.

Length groups, mm.	Average number of eggs	Number of observations
227-233	16209	10
233-239	18212	23
239-245	19950	7
245-251	20881	4
251-257	23013	4

The relation of fecundity to age was investigated for two age groups, five- and six-year-old herring, as shown below:

	6--9	--12	--15	--18	--21	--24	--27	--30	--33 thousand eggs
5-year old	2	1	2	10	9	--	--	--	--
6-year old	--	--	2	4	3	6	3	1	2

M 5 years = 16,380	m $\pm$ 0.69	$\sigma = \pm$ 1.37	n = 24
M 6 years = 21,620	m $\pm$ 1.11	$\sigma = \pm$ 5.27	n = 21

The average fecundity of the 5-year-old herring is 16,380 eggs, of the 6-year-old herring 21,620 eggs.

Approximately the same figures were obtained by Esipov for 6 Murmansk herrings (see Table 1). Unfortunately, the age of the herrings is not given in this table, and we have therefore no opportunity of comparing our results completely with those of Esipov.

The great variation in the data on the fecundity of the North Atlantic herrings is, according to Esipov, explained by the fact that up to the present no systematic investigation has been carried out on the racial composition of the herring shoals.

We do not agree with this conclusion, and find it necessary to add two more reasons.

First, various authors state the fecundity without taking into account the age of the fish. In the Murmansk herring there are considerable variations in relation to the age of the fish.

Second, some authors, for example, Mitchell (100), are of the opinion that all the ovocytes present in the ovary will mature during one single season. Our investigations have given the opposite result. Of the total crop of ovocytes only a known part, from which the size of the fecundity is determined, will be spent during the next spawning period.

If one would agree with Mitchell's arguments we had to expect that only empty follicles were seen in the histological sections of the spent ovary. All our preparations of ovaries in stage VI show a quite different picture. Among the empty follicles many young ovocytes without yolk are present. These ovocytes belong to the crop of the next season, and will not ripen and be extruded until the following spawning period. Such ovocytes were not taken into consideration in the determination of the fecundity of the Murmansk herring.

Mitchell counted all the ovocytes, and, accordingly, over-estimated the fecundity of the Atlantic herring, with a maximum number of 280,000 eggs.

In fish with total spawning, in this case the Murmansk herring, the number of ripening eggs must be the same in the various stages of development. At the end of the summer a certain number of ovocytes begin to ripen, the ovaries gradually pass into stage III. The same number of ovocytes evidently reaches the IV and V stages and will be extruded in the approaching spawning period.

From our computations there are on an average 17,113 eggs in ovaries of stage III, 16,660 eggs in ovaries of stage IV, and 20,670 eggs in stage V. The absolute number of eggs in herring in stage III and IV does not differ essentially from each other. The difference is only 0.98%.

However, in stage V, the absolute number of eggs in the ovary is 8.3% above that of stage III. This discrepancy is probably caused by an error in the computation of the eggs, and also by computing the average number from a small number of observations.

The variation in the number of eggs in samples of an order of size 1 gram is completely regular in relation to the stage of maturity of the ovaries. In the various stages the number of eggs per gm. varies in the following way: stage III - 3,255 eggs, stage IV - 2,148 eggs, stage V - 1,443 eggs. The relation between these figures is approximately 3:2:1.

With a great number of observations, the coefficient of error will be of a minimum size, and from the number of eggs per gm. it is therefore possible to judge the stage of maturity.

The histological investigations indicate that the Murmansk herring has a proper total spawning, without any transition between the ripening ovocytes filled with yolk, and the ovocytes in the follicle with one single layer of cells, and younger ovocytes (the complex of ovocytes in ovaries of stage II). This is confirmed by a number of photomicrographs shown in our paper. The insignificant fecundity in the Murmansk herring is possibly explained by the total spawning (all the eggs extruded in one batch).

In the Caspian herring, the fecundity is, as is very well known, considerably higher than in the Murmansk herring. During the process of evolution, the faculty of adaptation increased in the Caspian herring, as expressed in the partial spawning, assuring the conservation of the species. During the year, or more exactly, one spawning period, the Caspian herring spawns several times. As one portion of the ripe eggs is extruded, another portion will in time be mature, and so on, up to 3-4 times.

One may assume that, because of the partial spawning, the latest phases in the ripening of the ovocytes (the 2nd, 3rd and 4th portion) pass on more quickly than in the Murmansk herring. Accordingly, more ovocytes can be contained in an ovary of the same volume, ripen and be discharged in spring during several intervals of time. In the single individuals of the Caspian herring, the spawning period therefore lasts longer than in the Murmansk herring. In the Murmansk herring, the total portion of eggs which is going to be spawned at the same time in spring is separated simultaneously at the end of the summer of the preceding year. The spawning proceeds rapidly, but the total number of eggs discharged by one single female is smaller than in the Caspian herring.

The simultaneity in the development of the portion of eggs which was separated at the end of the summer, is confirmed not only by the histological analysis, but also from the direct counts of the eggs. As already mentioned, the number of eggs in ovaries of stage III and IV is nearly identical.

The Structure of the Ovaries, Phases in the Development of the Ovocytes, and the Stages of Maturity.

Material and Methods for the Macro- and Microscopical Investigation.

For the macro- and microscopical investigation of the ovaries we used in main samples collected at different times of the year. Our attention was also drawn to samples taken by other investigators for the study of morphological questions, food, condition, and so on. Such samples were usually very badly fitted for a histological investigation, as the herrings most often were preserved whole in formalin, alcohol, or merely salted. Sometimes we obtained satisfactory histological preparations, but usually these samples were useful only for a macroscopical description of the gonads.

From the material collected in 1938 we analyzed 46 samples containing 5,500 individuals;

from 1939, 54 samples, - 9,000 herrings. The samples consisted of adults, first-time maturing, spawning, and recently spent Murmansk herrings 2-7 years old.

The material was taken principally in the southern part of the Barents Sea, and in the areas frequented by concentrations of pre-spawning and spawning herring along the coast of northern Norway. During the Greenland Expedition in 1947, 19 samples were taken, consisting of 1,570 large adult herring, 8-14 years old. On the whole more than 16,000 herring have been investigated during the whole period of investigation (1938, 1939, 1947).

The histology of 133 ovaries, representative of the total mass of the investigated herrings, has been studied. Also, 10 more ovaries of Norwegian herring from the Vesterålen region (the material of Yu. Yu. Marti) have been used in this study.

In addition to the usual biological data (length, weight, intensity of feeding, fatness, condition, age), the composition of the blood has also been investigated. The ovaries from each herring were weighed, and the index of maturity calculated as per cent of the weight of the fish. For the description of each stage of maturity of the ovaries, macro- and microscopical data were given. In addition, the geographical distribution of the herring in the sea was plotted, according to the stage of maturity all the year round.

The ovaries in stage I (juvenile) and II were sometimes preserved in whole. A small piece was often cut out from the middle part of the ovary and preserved. For the determination of the synchronous development of the ovocytes, pieces were cut out from the caudal, median and cranial parts of the ovary. The ovaries were mostly preserved in Bouin's fluid with 4% of neutralized formalin, not later than half an hour after the fish had been caught.

The ovaries which had been preserved in formalin, were also kept in this fluid. Ovaries preserved in the fluid of Bouin or Zenker, were transferred to 80% alcohol or glycerin after 24 hours.

The preparations were transferred to xylol and ultimately imbedded in paraffin. Sometimes ovaries of the later stages (IV, V) were imbedded in celloidin, because these objects were comparatively large, and the layers with ovocytes were of varying consistency. By the imbedding of ovaries of stage IV and V into paraffin, the lumps of yolk were very often "stained" during the cutting. This was never observed in the celloidin blocks.

The sections were 6-7 mu thickness, sometimes in a longitudinal direction. The sections were stained with Heidenhain's haematoxylin. In a few cases, Mallory's stain was used. The method of fixation and staining gave very satisfactory results. From the photomicrographs, one may be convinced that the basic cell elements (the membranes, inclusions of nuclei and protoplasm, and in some preparations the chromosomes also) are easily discerned. The study of the single cytological elements does not come within our task.

The photographs and photomicrographs were enlarged for a better comparison of the various stages and to elucidate the different details in the structure of the ovaries.

The ovocytes were measured by the aid of an ocular micrometer at a six-times enlargement. The divisions of the ocular micrometer for the given enlargement of the Leitz microscope with the tubes in were measured with an objective micrometer. The divisions of the ocular-micrometer were measured for different enlargements. Because of the great variation in size of the ovocytes, it was necessary to use different objectives.

The absolute size of the ovocytes was expressed in mu. The number of ovocytes in a certain area of a histological section was calculated in the following way: by the aid of an ocular-grid all the ovocytes in 5 adjacent fields were counted at a magnification of 80 times. The area of each field, approximately corresponding to the field of the microscope, was exactly 0.81 $mm.^2$. In order to count the ovocytes in all 5 fields, the preparation was shifted by a movable stage. After the determination of the number of ovocytes in different phases of development in an area 5x 0.81 $mm.^2$, the arithmetical mean was found for each field. The figure found was recalculated for 1 $mm.^2$.

Phases in the Development of the Ovocytes.

Most of the present scales of maturity of fish are based on macroscopical criteria, which do not characterize the maturation processes with sufficient accuracy, neither of the ovocytes nor of the ovary as a whole. More exact results are obtained from histological investigations, which have unfortunately been undertaken in the ovaries of only very few species. For the herring group, the single paper existing is that by Loewe (1903), containing a small amount of data on the maturation of the ovocytes.

If a histological investigation is carried out parallel with the macroscopical description of the gonads, it is possible to work out a scale of maturity, based on objective criteria, reflecting the maturation processes of the gonads. Such a method has been used in the present work.

Before describing the single stages, we shall shortly give the anatomical structure of an ovary. In the Murmansk herring, the roe is asymmetrical; the left ovary on an average is 2-4% longer than the right one. The walls of the ovary consist of connective tissue and smooth muscles. Transversal ovigerous lamellae protrude from the walls of the ovary (Figure 2). In the upper part of the ovary there is a main blood vein with numerous capillaries to each ovigerous lamella. Each ovary contains a central cavity. On the dorsal side the cavities unite to form an oviduct.

The growth of the egg cells (ovocytes). Each maturity stage of the ovary is characterized by a certain complex of egg cells in various stages of growth (in the further report the term phase is used in order to characterize the various epochs in the growth of the egg cells, and stage for the maturity stages of the ovaries).

The main purpose of this paper is to give a total histological description of the changes in the ovary of the Murmansk herring during the maturation cycle. Cytological details are therefore avoided. The earliest phases in the development are of no special significance for the description of the maturity stages. As will be shown later, they are always present in the ovary. In addition, they do not differ essentially from the descriptions already given in the literature.

The juvenile phase of the ovocytes (Meien 1939). The ovocytes are of an irregular, angular shape, diameter 43.8-73.0 mu, average 56.94 mu. The cytoplasm forms a thin layer without any visible structure, surrounding the ovocyte. The nuclei of the follicle tissue lie close to the membrane, in some distance from each other.

The cells of the follicle epithelium are of an extended, compressed shape, similar to connective tissue. The protoplasm is granular. The nucleus, occupying most of the cell, has a diameter of 21.9-36.5 mu, average 27.89 mu. At the periphery of the nucleus numerous nucleoli of an irregular, rounded shape are distributed. The chromosomes lie in a thin, delicate net-work of achromatin. In preserved material, the chromosomes look like thin threads with small granules of chromatin. During the growth of the ovocytes, the nucleus occupies relatively less room, but increases in absolute size, and the ovocyte is passing over to next phase.

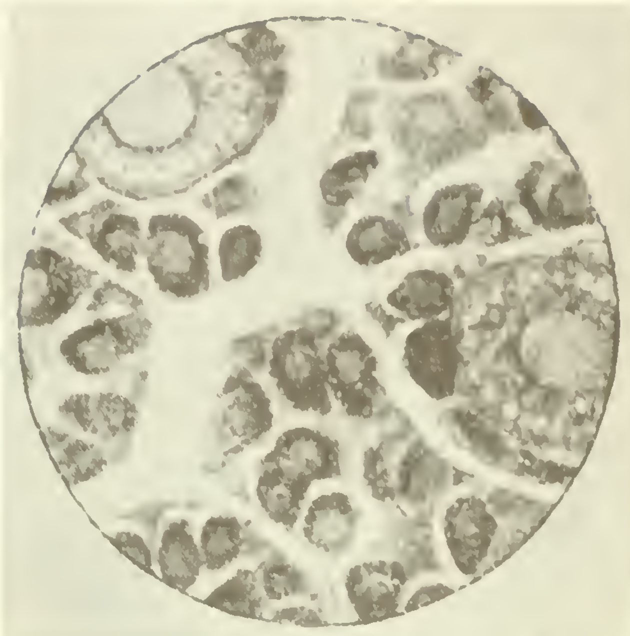

Figure 2. Ovary of a Murmansk herring, Jan. 17, 1939. Northern edge of the Murmansk coast-bank. Length of fish 225 mm., stage II-III. The transversal lamellae of eggs, and the cavity of the ovary are visible. The youngest ovocytes are found in the periphery of the ovigerous lamella.

The phase with follicle tissue in one single layer. The pellicle (membrane) surrounding the egg cell is still slender, without any structure. The nuclei in the follicle epithelium lie at a short distance from each other, forming one single layer. The cytoplasm is granular. Numerous nucleoli are distributed at the periphery. The chromosomes are as before. The diameter of the ovocytes varies from 86.87 mu to 138.7 mu, average 103.66 mu. The diameter of the nucleus, 56.21-76.85 mu, average 65.70 mu. During the further growth the ovocytes pass over to next phase. This transition takes place by degrees.

The phase with formation of yolk. In this phase, the ovocytes form a follicle in two layers. In the inner layer the nuclei have an extended, oval shape, comparatively larger than the slim, compressed nuclei in the outer layer.

The diameter of the ovocytes varies from 240 to 352 mu, average 292.8 mu, the nucleus, 96-128 mu, average 113.6 mu.

In the transitional phase the pellicle of the ovocyte is structureless. During the growth of the ovocyte, however, the pellicle gets a fine, radiate structure, i.e., the "Zona radiata" is formed. (In his monograph on the cell Vilson (108) remarks that in fish a pronounced zona radiata is formed on the egg itself). The early formation of a zone with radiate structure (zona radiata) is also found in Alosa fallax (Loewe). (In other species of fish, plaice (Frantz), perch (Meien), vobla (Meien), the zona radiata is not yet formed in this phase).

In the periphery of the cytoplasm, small vacuoles appear at first, later being filled with yolk during the growth of the ovocyte, and moving towards the centre of the cell (Figure 3).

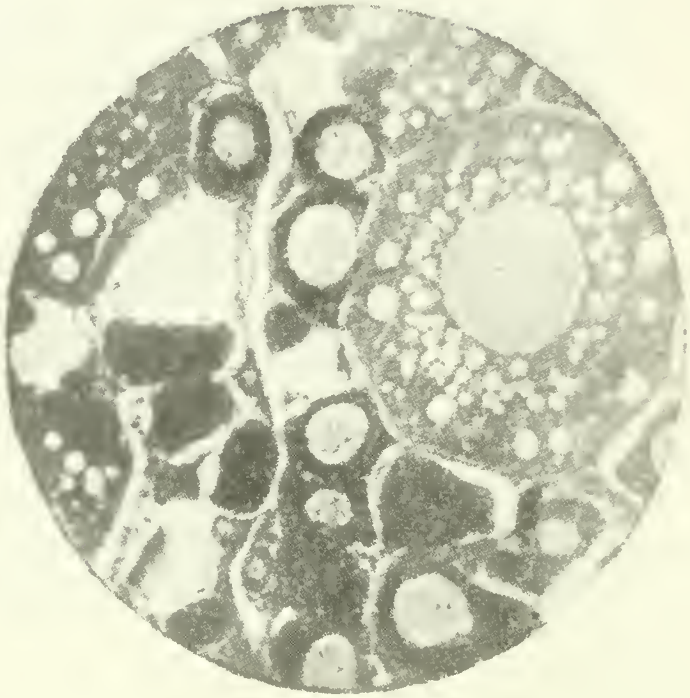

Figure 3. Ovary of a Murmansk herring, Oct. 14, 1938 near the Karlov Islands. Length of fish 239 mm., age 5+, stage III, x 100.

Single vacuoles lack the yolk globules. The protoplasm is granular. There are many karyosomes, of an oval-rounded shape, situated close to the cell membrane. In preserved preparations the membrane of the nucleus looks very undulated. The chromosomes resemble "lamp-brushes".

During further development the yolk globules migrate towards the centre of the egg cell. By degrees they fill most of the cytoplasm. The oval-rounded yolk globules are faintly stained in Heidenhain's hematoxylin.

Granules of an irregular, cubical shape, appearing in the cytoplasm together with the oval-rounded yolk globules, are an indication of the transition to the following phase (Figure 4). They are coloured intensively black by Heidenhain. This yolk mass is spread by degrees to the centre of the ovocyte, occupying nearly all the space between the nucleus and the membrane. When the formation of cubical yolk is finished, the ovocytes pass over to the next phase.

The phase of ovocytes filled with yolk. Diameter of the ovocytes 592-736 mu, average 675.2 mu. The nucleus has no definite shape, and cannot be measured. As in the foregoing phase, the ovocytes form two layers in the follicle.

The zona radiata has increased in thickness, being very clearly defined. Close to the zone is a thin layer of granular protoplasm, free of yolk. Next comes a small layer with round-oval yolk globules, then follows cubical yolk, occupying nearly the whole ovocyte. The peripherical yolk mass is only traced as single granules in the cubical yolk, in main close to the nucleus (39, ref.).

Figure 4. Ovary of a Murmansk herring, Nov. 3, 1938, Finmark Bank. Length of fish 231 mm., weight 106 gm., age 5+, stage III-IV (the beginning of formation of cubicle yolk). x 79.

The nucleus is of a somewhat extended shape, situated somewhat eccentrically in the cell. Along the periphery are found numerous karyosomes, sometimes close to the membrane of the nucleus, sometimes at some distance. Chromosomes are not present as "lamp-brushes", but numerous granules have appeared. They are intensively stained by Heidenhain, and sometimes concentrically distributed.

The nature of these granules and their relation to the chromosomes are purely histological questions, and will not be treated here.

The phase of the ripe ovocyte. Diameter 640-1120 mu, average 892 mu. The nucleus cannot be discerned. As long as the ripe ovocyte remains in the stroma of the ovary, the follicle has the same structure as in the preceding phase. The completely ripe ovocytes leave the follicles and are accumulated in the inner cavity of the ovary. In the Murmansk herring the ripe ovocytes are characterized by a distinct zone with radiate structure, without a downy surface or an additional membrane, characteristical of vobla, bream, perch, and others.

The whole mass of ovocytes is filled with large, transparent lumps of yolk, sometimes fused together. The latter phenomenon is possible caused by the fixation.

The Maturity Stages of the Ovaries

Stage I (Figure 5 a, b). In Stage I or the juvenile stage the sex cannot be discerned by the naked eye. The ovaries are long narrow threads lying close to the upper wall of the body cavity (close to the spine). The color of the ovary is light-yellow. In this stage the ovaries are already asymmetrical, the left being longer. The blood circulatory system is slightly developed. The length of the ovary varies from 40 to 50 mm., average weight 0.5% of the fish weight.

In the juvenile stage, most of the ovary consists of egg cells in the juvenile phase, close together, of an irregular, angular shape. Along the edge of the ovigerous lamellae the germinal tissue and the youngest ovocytes are found. In herring up to 4 years old, ovaries in the juvenile stage can be found all the year round in all the fishing areas of the Barents Sea. In spring and summer the young, immature herring are subject to fishery from the Murmansk coast to the fjords of Kola and the Motovski Bay.

Stage II. Whereas stage I comprises exclusively young herring which have not yet spawned, the fish in stage II may as well be immature, as in the transition from spent to stage II.

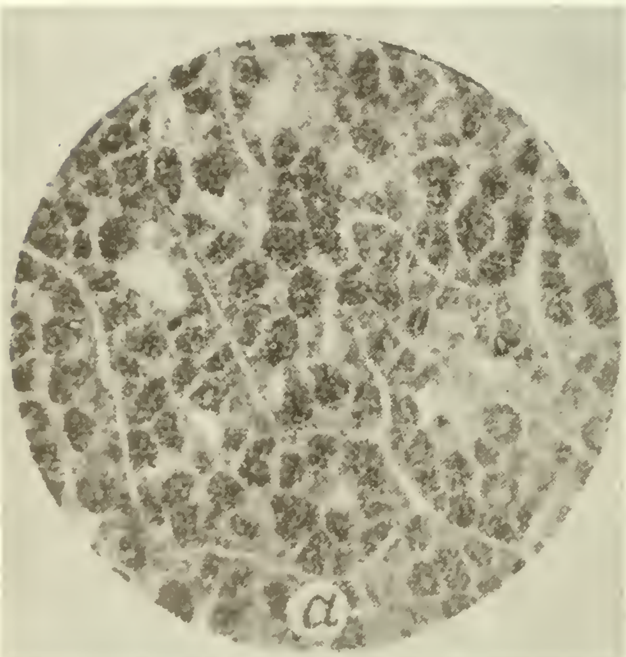

Figure 5. Ovary from Murmansk herring in the juvenile stage (I) a, from the eastern part of the Murmansk Bank, July 9, 1937, length of fish 137 mm., age 2 years; b, from the Motovski Bay, Oct. 21, 1938, length 105 mm., age 2+. x 100.

In herring which have not yet spawned, the ovaries in stage II are by 1 1/2 times larger than in stage I, and more roundish. In immature herring the ovaries are light yellow, in mature fish more dark, yellow, or brownish yellow, because of the development of the blood vessel system, giving the ovaries a darker color. The ovocytes are visible with the naked eye. The weight of the roe is 1 to 5, on an average 3% of the body weight. When the ovaries are opened, the ovigerous lamellae are visible.

Histologically, the ovary in stage II is distinguished by the following criteria; the bulk of the ovary consists of single-layered follicles. Ovocytes in the juvenile phase are also present, but in small numbers only. Along the edge of the ovigerous lamellae, towards the cavity of the ovary, germinal tissue and ovocytes in the youngest phases are found.

Ovocytes are developed at the same time in the various parts of the ovary. This is proved by cross sections made from the cranial, median, and caudal parts of the ovary.

The juvenile stage (I) usually passes into stage II in June, more rarely in July. Ovaries in stage II can be found all the year. It is therefore assumed that in immature herring the ovary may remain in stage II during several months, or even years.

According to our observations the ovaries of mature herring do not remain very long in stage II, but rapidly pass into stage III. The transition is probably completed during 2-2 1/2 months. In mature herring, ovaries in stage II are observed from the end of April to the middle of July. Stage II may be called the critical stage, as it is followed by a rapid development of the ovaries.

Stage III. The ovary has increased considerably, occupying approximately two-thirds of the body cavity. The ovary reaches more than two times the height of stage II. Small, round eggs are easily visible with the naked eye, and among them there are still smaller ovocytes, of an irregular, polygon shape. These ovocytes belong to the phase with follicle tissue in one layer, which constitute the majority in ovaries in stage II.

The blood circulatory system is well developed. The capillaries start from a main (feeding) artery as small bundles of blood vessels, ending on the lower side of the ovary. The weight of the roe varies from 3 to 11%, averaging 6% of the body weight.

The bulk of the ovary is composed of ovocytes at the beginning of formation of yolk. In addition are found young ovocytes, characteristic of stage II, but as to volume they play an insignificant part. In spent herring, empty follicles may be seen at the beginning of stage III (Figure 6).

Herring in stage III may be found from June to March, with a maximum in August-September in the southern part of the Barents Sea. The transition from stage III to stage IV is gradual. (Figures 7-8).

Stage IV (See Figure 1, b). The ovaries occupy most of the body cavity. Blood vessels are well developed. The eggs are of an irregular, polygon shape, close together. If the ovisac is torn, the eggs run out, attaining a rounded shape. The membrane of the ovary is very thin and easily torn. The roe has a yellow-red color. The weight varies from 5 to 15%, averagely 9.6% of the body weight.

In histological respect, stage IV is characterized by ovocytes filled with yolk. Some young ovocytes are also present, inclusive of the single-layered follicles. Ovocytes with incipient formation of yolk are lacking.

Herring in stage IV occur from November to April, mainly in the western part of the Barents Sea, and in September along the west coast of Spitsbergen. Single males and females in stage IV are also taken at the beginning of July.

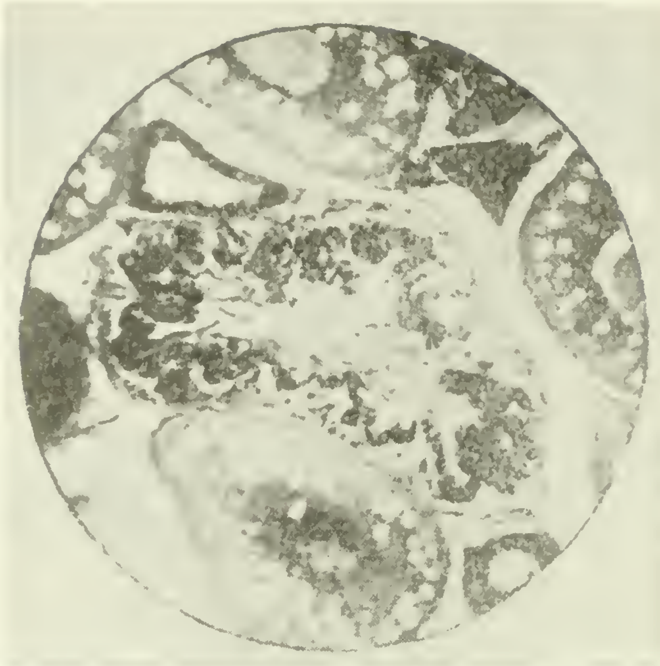

Figure 6. Ovary of Murmansk herring July 22, 1947, west coast of Spitsbergen. Length of fish 325 mm., weight 330 gm., age 11+, stage III, weight of roe 7.5 gm., index of maturity 2.25%. In the centre, an empty follicle; along the edges, ovocytes at the beginning of yolk formation, and follicle tissue in one layer. x 147.

Stage V (Figure 9, a). The ovaries occupy the whole body cavity. The digestive organs and other organs are vigorously compressed by the roe. At this time of the year the herring nearly do not feed at all, probably because it is impossible to digest the food. The membrane of the ovary is transparent, and large, light eggs are easily seen through it. Ripe ovocytes fill the oviduct, which is sharply separated from the lower part of the ovary. The weight of the roe varies from 9 to 21%, averagely 13.9% of the body weight. By squeezing the abdomen the roe will run.

The transition from stage IV to stage V occurs very quickly to judge from analyses of roe from herring on their way to the spawning places, and away from them, after spawning. The roe remains a very short time, not more than a few days, in stage V. Herring in stage V are found from the end of March to the beginning of May, with a maximum in April. Single individuals are still found in June.

Stage VI (Figure 9, b). The roe has shrunk considerably, is withered (flaccid), of a purple-brownish color, containing much blood. Degenerating eggs, which have not been spawned, are often found. The roe has shrunk, constituting 0.5-2%, on an average 1% of the body weight.

In histological respect, the roe is characterized by empty follicles and a complex of young ovocytes related to stage II.

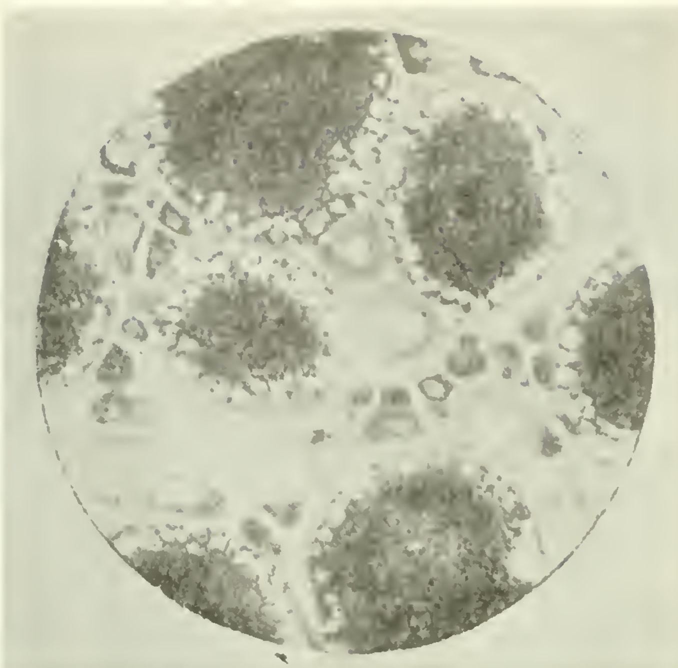

Figure 7. Ovary of Murmansk herring Nov. 6, 1938, Finmark Bank. Length of fish 246 mm., age 6+, stage IV. x 67.

How long a time the roe will remain in stage VI, may be found by determining the time needed for the eggs left from the previous spawning to be resorbed, and the empty follicles to disappear.

Immediately after spawning the roe is of a purple color, by degrees changing into red, rosy, and at last into a light yellow color. The histological investigation indicates that the change in color is caused by the gradual resorption of the empty follicles. Herring with roe in stage VI occur in April, May and June.

The total spawning in herring is proved by the histological investigation. The occurrence of herring in stage V during a longer period of time, and in different areas of the Barents Sea indicates that the different schools do not mature simultaneously. The occurrence of herring in stage V during a comparatively long period cannot be explained by the spawning in batches, as the histological investigation clearly indicates that the spawning is total. This is characterized by a simultaneous ripening of all the ovocytes which are going to be extruded during the next spawning. From the occurrence of herring in stage III the time of next spawning can be determined approximately.

The transitional stages. In practice, it is often difficult to decide the stage of some individual. In such cases the use of transitional stages is necessary, i.e., II-III, III-IV, and so on. (D. Talin used the scale of Kiselev for the Don herring, using the stage IV-V to characterize the gonads in the transition from maximum of maturity to the beginning of spawning).

There are two reasons for the use of transitional stages. Firstly, there is a continuous transition from one stage to another, secondly, with the present scale of maturity, based on subjective criteria, the line between two subsequent stages cannot always be determined exactly. Such difficulties will disappear to a great extent, if the macroscopical description of the gonads is combined with a histological investigation.

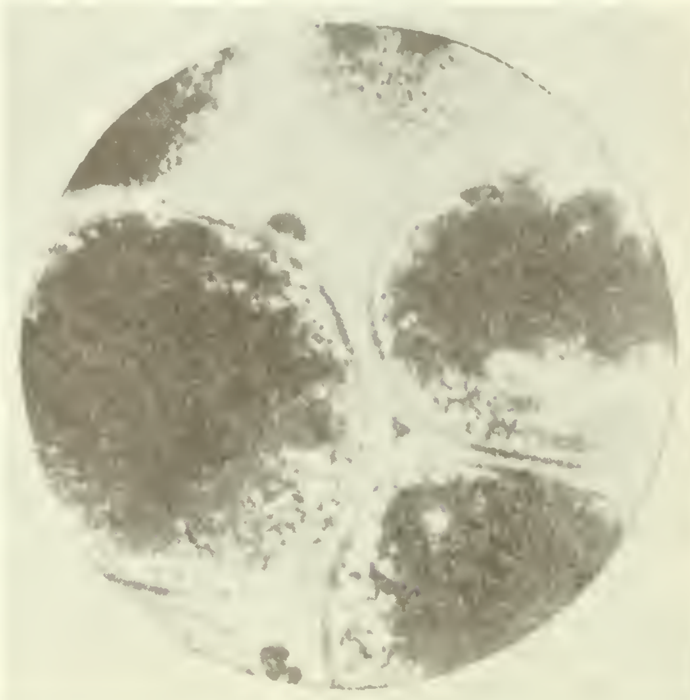

Figure 8. Ovary of Murmansk herring Nov. 12, 1938, Nordkyn Bank. Length of fish 240 mm., age 5+, stage IV. x 67.

The most important of the macroscopical criteria are those which can be expressed in mathematical terms, i.e., the index of maturity of the sexual products, the number of ovocytes in various phases of development which can be counted in a square unit of a histological section, the extent to which the ovaries occupy the body cavity, and so on.

The use of transitional stages cannot be entirely avoided, as the scale indicates a continuous development of the ovaries, with a gradual transition of the ovocytes from one phase to another.

The ovary shown in Figure 2 can neither be referred to stage II nor stage III, but must be characterized as a transitional stage between II and III, named II-III. The presence of a few ovocytes (in the field of view) in the phase of the beginning of formation of yolk cannot justify the reference of this ovary to stage III. On the other side, the great quantity of ovocytes in the single-layered phase, and in the juvenile phase, does not give reason to ascribe the ovary to stage II, because there are at least two ovocytes at the beginning of yolk formation.

In the further development of the ovary, ovocytes at the beginning of yolk formation, increase in quantity, and the ovary as a whole is passing over to a typical stage III.

A typical stage is characterized by ovocytes in one phase or another occupying nearly the whole ovary. In ovaries of the stages III, IV, and V, ovocytes in early phases of development (juvenile, or single-layered cells) are poorly represented. In other cases the ovary had to be characterized as belonging to a transitional stage.

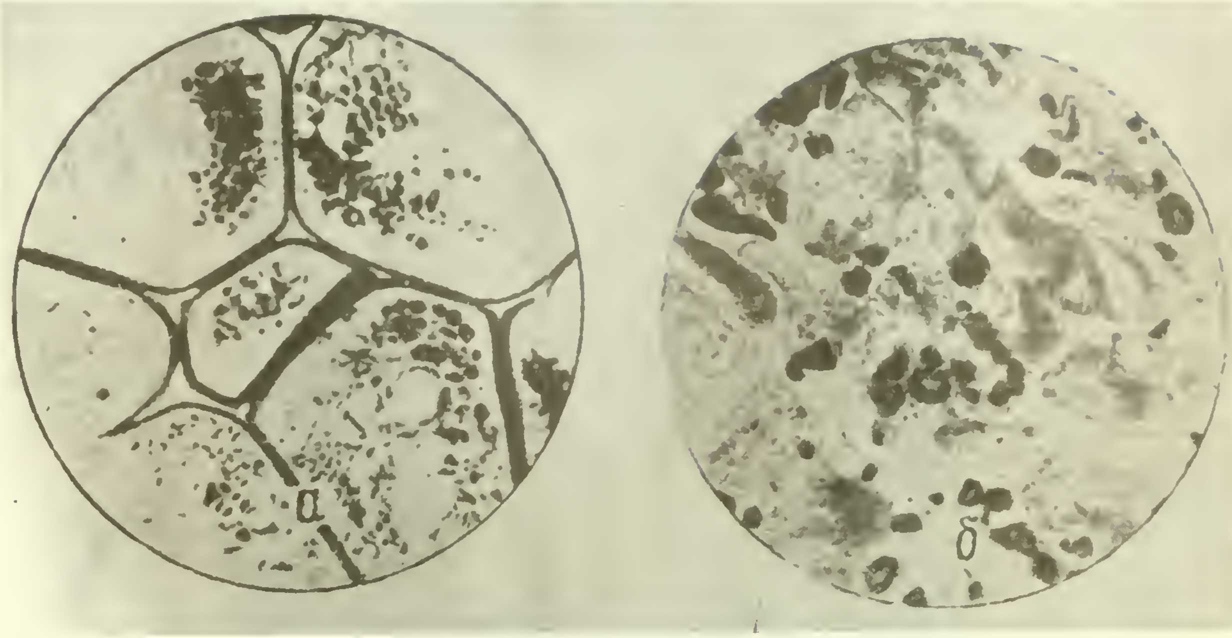

Figure 9. Ovary from Murmansk herring April 4, 1939. a, fish 241 mm., 87 gm., age 6+, stage V, x 67; b, fish 226 mm., 70 gm., 6+, stage VI. The empty follicles and the whole complex of ovocytes found in stage II are visible.

Stage III is especially characterized by a large number of vacuoles in the protoplasm. The site of these vacuoles can be given schematically as follows: comparatively few vacuoles with the yolk intensively colored are found in one layer; larger, light-colored vacuoles in two layers, along the periphery, and surrounding the nucleus. From this we can conclude that the vacuoles are of a double character: they may originate from the epithelium, either distributed at the periphery, or around the nucleus. In Figure 10, drop-like vacuoles are seen close to the nucleus, as if pushed out from it. When the vacuoles fill all the protoplasm, the picture is characteristic of a typical stage III.

For the sake of simplicity we do not divide stage III into sub-stages, as such features are seen in histological sections only.

The Determination of the Maturity Stages of the Ovary from the Number of Ovocytes in Histological Sections

The number of ovocytes in the various phases of development, per square unit of histological section, may serve as an additional criterion for the objective judgement of the stage of maturity of an ovary. In order to verify this assumption, some calculations have been made. The method has been described previously. The results are shown in Table 4.

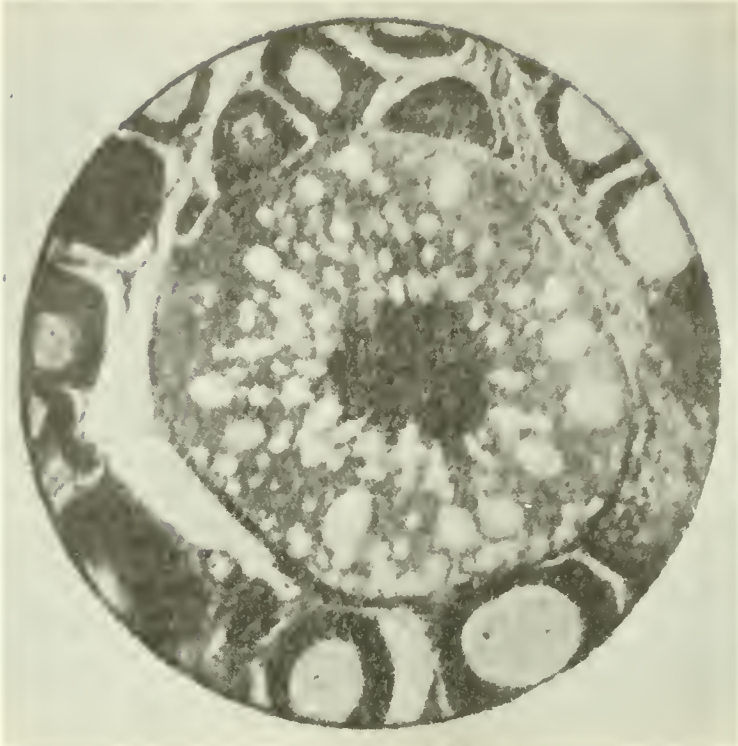

Figure 10. Ovary from a Murmansk herring, Oct. 8, 1939, Motovski Bay. Length of fish, 197 mm., weight 70.2 gm., age 5. In the center an ovocyte in the beginning of formation of yolk. x 267.

TABLE 4. THE AVERAGE NUMBER OF OVOCYTES PER SQUARE MM. IN A HISTOLOGICAL SECTION (MEAN OF 14 PREPARATIONS).

Stage of maturity of the ovaries	Development phases of the ovocytes									
	Juvenile		Single-layered follicle		Beginning of yolk formation		Full of yolk		Ripe ovocytes	
	n[1/]	%	n	%	n	%	n	%	n	%
I	175	100	--	--	--	--	--	--	--	--
II	47	29.0	116	71.0	--	--	--	--	--	--
III	26	34.2	40	52.5	10	13.3	--	--	--	--
IV	11	51.0	8	37.3	--	--	2.5	11.7	--	--
V	10	61.5	5	30.8	--	--	--	--	1.25	7.7
VI[2/]	18	36.0	32	64.0	--	--	--	--	--	--

1/ Number of ovocytes per square mm. of a histological section.

2/ In stage VI, 10-30 empty follicles can be found in addition to the juvenile ovocytes and ovocytes in the single-layered follicle.

The maturing process of ovocytes begins with the single-layered follicle phase, therefore on the basis of the existing data the percentage relationships of the quantity of maturing ovocytes in various maturation stages of the ovaries will be the following (Table 5).

As is apparent from the data introduced in Table 5 each maturation stage of the ovaries corresponds to a specific percentage relationship of ovocytes of different growth phases. In the ovaries of the VI maturation stage, moreover, there is a certain quantity of empty follicles.

The maturation process of ovaries is characterized, on the one hand, by a proportioned increase in the weight (mass) of the ovaries and, on the other hand, by a disproportionate decrease in the quantity of ovocytes in one and the same area.

TABLE 5. VARIATION IN NUMBER OF OVOCYTES PER SQUARE MM. DURING THE RIPENING (IN PER CENT OF NUMBER OF OVOCYTES IN THE PHASE OF THE SINGLE-LAYERED FOLLICLE).

Stage of maturity of the ovaries	Development phases of the ovocytes							
	Single-layered follicle		Beginning of yolk formation		Full of yolk		Ripe ovocytes	
	n	%	n	%	n	%	n	%
II	116	100	--	--	--	--	--	--
III	--	--	10	8.6	--	--	--	--
IV	--	--	--	--	2.5	2.1	--	--
V	--	--	--	--	--	--	1.5	1.0

The method of counting the ovocytes may be used as a supplementary method for an objective evaluation of the maturity stages of the ovaries. With an average from a large number of observations. one may avoid transition stages, which are more ascribed to unsufficient knowledge, than to the objective state of the ovaries.

A Comparative Characterization of Ovaries in Stage III from Mature Herring and from Herring Maturing for the First Time

From the microscopical investigation of ovaries in stage III, some conclusions may be drawn of both theoretical and practical interest. We have compared ovaries in stage III from herring caught in the southern part of the Barents Sea with ovaries in the same stage from Greenland Sea herring. The Barents Sea herring were 5-7 years old, those from the Greenland Sea, 7-13 years.

From the microscopical preparations of ovaries in stage III, it has been stated that the herring only stay in the Barents Sea until they have attained maturity. An exception is the herring found in the western part of the Barents Sea, along the border-line of the Norwegian Sea, whereto they migrate after the first spawning.

In herring from the southern part of the Barents Sea no empty follicles can be seen in the ovaries. A section of an ovary in the same stage from Greenland Sea herring (southern part of the Spitsbergen bank) shows quite a different picture. In addition to the complex of ovocytes characteristic of stage III, numerous empty follicles are seen, proving that the herring has spawned earlier. (Figure 1, b, and Figure 11).

Figure 11. Ovary from Murmansk herring Sept. 15, 1939, caught 70 miles west of North Cape. Length of fish 235 mm., weight 117 gm. Membrane of an ovary with an empty follicle. x 267.

It was not unexpected for us to find spent herring near western Spitsbergen in spring and early summer. By the opening of herring on board the vessel, indications of a recently finished spawning (roe purple-colored, containing much blood) were seen in a large number of individuals. Having spawned along the Norwegian coast, large herring (7-13 years, 30-35 cm.) migrate to Spitsbergen waters to feed.

The presence of empty follicles in Murmansk herring of various age groups indicates that the herring spawn each year.

In herring of stage III empty follicles are present beside the ripening ovocytes, indicating a new cycle in the sexual development. From this we may conclude that: (1) the theory maintained by various scientists, i.e. Frantz (84) that all the reserves of the organism are mobilized to fulfill one stage in the development of the gonads, and then completely pass over to be used in the next stage, does not hold good. This has been shown above in examples from the Murmansk herring.

In adult herring, the ripening process of the gonads (i.e., the transition from stage II to III) takes place during the same period in which the empty follicles are resorbed. The energy balance of the herring (fat content, condition) is evidently sufficient to resorb the remaining ripe eggs, as well as the empty follicles, - and to start a new sexual cycle.

2) From the histological state of the ovary it can be decided at any time of the year if one or other individual has spawned.

From the Polar Institute we received 10 roes from Norwegian herring taken in February 1947 near Ålesund (Table 6), sufficient for a brief characterization.

TABLE 6. A TYPICAL SAMPLE OF NORWEGIAN HERRING IN THE PRE-SPAWNING PERIOD.

Length mm.	Weight gm.	Age	Weight of sexual product gm.	Index of maturity	Maturity stages of the sexual products
266	227	10	15	6.6	III
287	250	10	25	10	III--IV
290	305	9	65	21.3	IV
293	307	9	52	17	IV
298	310	10	60	19.4	IV--V
300	295	8	69	23.4	IV
305	309	10	52	16.7	IV
309	345	10	66	19.2	IV
312	330	11	48	14.6	IV
316	344	11	64	18.6	IV

The macro- and microscopical structure of the ovary of the Norwegian herring is very similar to that of the Murmansk herring.

Histological Control of the Maturity Stages

In field work, the scale of maturity used is based on macroscopical criteria. The estimate of the degree of maturity will then be mostly subjective. It is very important to know the time when the gonads pass from stage VI into stage II, and from II to III. In the first case gonads from spent fish (VI) in which the re-establishment of the gonads already started some time ago, may very well be determined as stage II in field work. However, the same stage may also be found in immature fish. In the second case (transition from II to III) one may miss the time when the sexual products begin to ripen.

In order to get an exact picture of the degree of maturity it is proposed to supplement the field determinations with a histological control in the laboratory. A freezing microtome may be used to make sections within one hour.

The Scale of Maturity for Sexual Products in Fish

The necessity of establishing a "scale of maturity", also called "table of maturity" of the sexual products, arose long ago in fishery investigations. In 1937, Meien (47) numbered 20 such scales. At present there are about 30 scales.

Scales for maturity have been worked out for many of the important food fishes. The following items must be taken into account:

1. For Aspius, Lucipperca, Esox, Cyprinus, Chalcalburnus and Abramis there is in fact one scale only, according to which the criteria of maturity are only schematic and not real.

2. The greater part of the scales (18 of 27) are only adapted for 9 species in all, although they have been worked out for marine fishes. There are 12 scales for clupeoids, 4 scales for codfish, and 2 scales for flatfish. The remaining 9 scales have been worked out for semi-migratory fishes and freshwater fishes (sterlet, pike-perch (Lucioperca) perch, carp, bream, vobla, Aspius, carp (sazan), and Coregonus lavaretus).

During the development of the investigations the principles of the maturity scales were changed. The first scales (Heincke 1898, Maier 1906, Lea 1910, and others) were based on subjective criterions (color of the gonads, transparency, visibility of the ovocytes with the naked eye, and so on). Later, measurements of the ovocytes and their nuclei were very much used.

In 1927 Meien introduced the index of maturity, the relation of the weight of the sexual products to the weight of the fish. This index is a very important indicator of the biological state of the herring (Table 7).

TABLE 7. STAGES AND INDEXES OF MATURITY OF THE SEXUAL PRODUCTS IN FISH.

Stage of maturity of the ovaries	Perch	Vobla	Atlantic herring	Don herring (Talin)		Murmansk herring (Naumov)	
				Mean	Variation	Mean	Variation
I	--	--	--	--	--	0.5	--
II	0.72	0.77	1-2.5	--	--	3	1-5
III	3.53	3.26	2.5-10	4.67	3.35-6.68	6	3-11
IV	8.8-13.0	8.3	5-12.5	9.2	2.37-22.5	9.6	5-15
V	26.4	20.9	10-25	--	--	13.9	9-21
VI	2.78	1.3	--	--	--	1	0.5-2

Some of the criteria used in the determination of the maturity stages are given below:

Macroscopic criteria:

1. Relation: roe weight to body weight.
2. Degree of transparency of the ovaries.
3. Shape of the ovaries as a whole.
4. Color of the ovaries.
5. Elasticity of the ovaries.
6. Characteristic feature in the membrane of the ovary (macroscopical).
7. Degree of development of the blood vessels in the ovary.
8. Degree of filling of the body cavity. a) relation: length of the ovaries to length of the cavity. b) relation: height of the ovaries to height of the cavity.
9. Degree of development of the cavity of the ovary and its filling with ovarial fluid.
10. Shape of the eggs.
11. Diameter of the ovocytes.
12. Pigmentation of the yolk.
13. Degree of transparency of the various eggs.
14. Visibility of the nucleus and egg cells.
15. Degree of separability of the sexual products.

16. Degree of extrusion of the ripe eggs.
17. Presence of single white, opaque, and degenerating eggs.
18. Presence of single ripe eggs which have not been spawned.

Microscopical criteria:

1. Visibility of single eggs with a magnifying glass or microscope.
2. Presence of a certain complex of ovocytes in various phases.
3. The degree to which the single egg cells are filled with yolk.
4. Characteristic features in the egg pellicle (microscopical).
5. Presence of empty follicles.

The majority of the criteria mentioned above are thus macroscopical.

In 1909, Frantz (84) described the maturity stages of the plaice from a microscopic point of view. From that time, the histological method was steadily used in similar investigations, especially by the Soviet investigators (Gerbil'skiy, Meien, Gryazeva and others) in competition with the macroscopical method.

There is no need for giving a thorough characterization of the maturity scales. Many of them are too old, and those which are still of any value will be treated critically in the present paper.

All the known scales of maturity are given in Table 8, with information on the criteria on which they are founded.

The first scales were merely based on the visual description of the gonads (color, the consistency of the gonads, visibility of the ovocytes with the naked eye, and so on), and the evaluation is accordingly very subjective.

Several investigators found the scales of maturity at hand insufficient, and tried to adapt them for other species of fish. The scale of Heincke was supplemented by Maier (1906).

In turn Lea (1910) improved the Heincke-Maier scale, and at last Vukotich in 1915 changed and adapted the scale for the Caspian herring. These authors did not add anything new to the scheme of Heincke.

Maier supplemented the scale of Heincke and adapted it to the plaice, assuming that the new scale might be used for all kinds of fish. In our opinion it was a mistake of Maier to extend one scheme to be valid for "all fishes", as it is even impossible to work out a satisfactory scale for one family, genus, or species of fish.

"The egg of each species has its own specific character of development" (Vilson 109). In the development of the species and subspecies, the maturing of the gonads as a whole proceeds in different ways. This is conditioned by the great biological differences within the species itself, and still more within large taxonomic groups. This circumstance is evidently explained by the presence in one species only, viz. Clupea harengus, of seven different scales of maturity. Most of the authors certainly do not bring in any new facts, and their scales are not essentially different from the scheme of Heincke.

This item is of interest in other respects. As our knowledge of the herrings of the North Atlantic is extended, and the species Clupea harengus is split into small taxonomical units, it will be necessary to establish new scales of maturity, adapted to the forms present. But such an adaption has not given satisfactory results. Earlier investigators studied the cyclic changes in the gonads isolated from the corresponding changes in the organism as a whole. The ecological conditions of the surrounding medium and their influence on the cyclic development of the gonads of the fish were not taken into account.

For the following species no special scale of maturity has as yet been worked out: lamprey, skates, sharks, salmonids, Thymallus, Osmerus, Silurus, Esox, mackerels, gobiids, Mugil, and eels. (Only commercial fish have been included). For the families of herring, carps, perches, codfish, flatfishes and sturgeons the scales do not satisfy the demands of the practical-scientific investigations. Scales have been worked out for some fish of these families, taking into account the biological peculiarities of the fish and the corresponding basic demands of the practice. These scales are not free of elements of subjectivity, do not describe the characteristic features of the fish in full detail, and are not always well suited for the field investigations.

There are many scales of this kind, i.e. those of Meien for perch and carp, of Gerbil'skiy for the mirror carp, of Lukin and Molchanova for the sturgeon (we have combined the macroscopic description by Lukin with the microscopic one by Molchanova into one scale).

In this way no satisfactory scales exist for most of our commercial species of fish. It is therefore absolutely necessary to begin an all-round systematic investigation on the sexual cycle of the most important species of fish. To work out new scales for the maturity is a very urgent task.

The scale must satisfy several demands.

1. The scale must describe the variations of the gonads during their development in a correct way.
2. The scale must be worked out in correlation with the biological qualities of the fish.
3. Both macro- and microscopic data are needed for the determination of the number of stages in the scale.
4. The number of stages must be moderate.
5. The scale must be simple and well suited for field work.

The scale of maturity described later (page....) is built upon the above-mentioned principles for the description of the maturing of the ovaries.

TABLE 8. A TABLE OF MATURITY SCALES FOR FISH.

Species	Criteria, on which the descriptions are based	Author
Herring, C. harengus	Color, elasticity of the ovaries, visibility of ovocytes with the naked eye and with a magnifying glass, degree of transparency of the ovary, fluidity.	Heincke (1898)
Plaice, Pleur. platessa	Transparency, form, color of the ovocytes, development of the cavity of the ovary.	Maier (1906) altered and supplemented the scale of Heincke.

TABLE 8. A TABLE OF MATURITY SCALES FOR FISH (CONT'D).

Species	Criteria, on which the descriptions are based	Author
C. harengus	The height of the sexual glands.	Broch (1908)
Pleuronectes platessa	Color, transparency of the ovary, presence of ovocytes in certain stages of development.	Frantz (1909) supplemented the Heincke-Maier scale with a microscopic description.
C. harengus	Color, transparency, form of the ovocytes, thickness of the ovaries.	Lea (1909), completed the Heincke-Maier scale.
Genus Alosa	Diameter of the eggs, volume of the ovaries	Vukotich (1915) Combined and somewhat changed the Heincke-Maier scale.
Genus Alosa	Form, volume of the ovaries, color, diameter of the ovocytes, fluidity.	Kiselevich (1923). This scale is used in the Volga-Caspian fishery.
C. harengus	Diameter of the ovocytes.	Johansen (1924).
Cod (G. morrhua)	Color of the gonads, fluidity.	Graham (1924).
Group I: Aspius, Lucioperca, Esox. Group II: Abramis brama, carp, Chalcalburnus.	Size, form, and transparency of the ovocytes.	Filatov (1926).
Perch (Perca f.)	Presence of a certain complex of ovocytes in various stages of development, index of maturity.	Meien (1927). Stated the duration of the individual stages.
Sturgeons	Pigmentation of the ovocytes, and how easy they are separated from the ovary.	Nedoshivin (1929).
C. harengus	Color, length of the gonads, index of maturity, fluidity of the eggs.	Wood (1930). The scale accepted by the ICES.
Cod (G. morrhua)	Diameter and color of the ovocytes, thickness of the ovaries.	Poulsen (1931).

TABLE 8. A TABLE OF MATURITY SCALES FOR FISH (CONT'D).

Species	Criteria, on which the descriptions are based	Author
Whiting (Odontogadus merlangus)	Color and transparency of the membrane of the ovary, vacuolization of the protoplasm of the ovocytes.	Hickling (1935)
Abramis brama	Volume of the ovaries, development of the oviducts (egg-carrying strings), distribution of yolk and development of the membrane of the ovocyte.	Gryazeva (1936). Supplemented the scale of Nedoshivin with microscopic description.
Engraulis encrassicholus	Color and transparency of the membrane of the ovary, form, volume of the ovary.	Kuz'min (1935)
Don herring (Alosa pontica)	Color of the gonads, transparency of the eggs, degree of filling of the body cavity by the gonads, maximum size of the eggs, development of blood vessels.	Talin (1936). Based on the scale of Kiselev.
The Kam sturgeon (Acipenser ruthenus)	Degree of filling of the egg cells with yolk.	Oljshvang (1936). Supplemented the scale of Nedoshivin with a histological description except for stages IV and V.
Murmansk herring (C. h. harengus)	Presence of a certain complex of ovocytes in various phases of development, color and transparency of the membrane and ovary.	Naumov (1939). The different stages of maturity were distributed in time and space.
Vobla (Rutilus rutilus caspicus)	As for perch, with addition of the transparency of the ovocytes.	Meien (1939). Supplemented the scale of Nedoshivin with a histological description except for stages V and VI.
Mirror carp (Cyprinus carpio)	Diameter of the nucleus of the ovocytes, vacuolization of the protoplasm, structure of the membrane of the ovocytes.	Gerbil'skiy (1939). Slightly different from the scale of Meien for perch.
Sterlet (Acipenser ruthenus)	Color of the ovaries, transparency, pigmentation of the eggs, diameter of the ovocytes and nuclei, presence of ovocytes in various phases of development.	Lukin, Molchanova (1941). In principle different from Meien's scale for teleosts. Molchanova supplemented the scale of

Species	Criteria, on which the descriptions are based	Author
		Lukin with histological criteria.
Lucioperca lucioperca in the Don river.	Color, transparency of the ovaries, visibility of the eggs with the naked eye.	Trusov (1947). Somewhat changed and supplemented the scale of Filatova. Distinguishes the stages IV-A, IV-B, IV-V.
Coregonus l. laveretus ludoga	Color of the gonads, presence of ovocytes in various phases of development, form of the gonads.	Lapitskiy (1949)

A Scale of the Maturity Stages of the Ovaries in the Murmansk Herring

Stage I (juvenile). The sex cannot be distinguished by the naked eye. The ovaries are long, thin threads lying close to the dorsal spine. The left ovary is usually longer than the right one. Color - light yellow. Blood vessels feebly developed. Length of the roe 40-50 mm. Weight not more than 0.5% of the fish weight. At an enlargement of 40-60 times, the main mass of the roe is seen to consist of egg cells in the juvenile phase, of an irregular, polygon shape.

Stage II (preparatory). The egg cells are easily seen with the naked eye. In first time spawners the roe is light yellow, in herring which have spawned earlier, more intensively colored, yellow, to brownish yellow. Weight of the roe- 3% of the body weight. The main part of the roe is made out of egg cells in the single-layered follicle phase.

Ovaries in stage II may be found in immature herring in the Barents Sea all the year round. The transition from stage II to III starts in the Barents Sea during the second half of July, in the Greenland Sea about one month earlier.

Stage III (ripening). The roe occupies about 2/3 of the body cavity. The height of the roe is about double that of stage II. Small, rounded eggs are visible with the naked eye. Among them are found a few smaller eggs of an irregular, polygon shape. Blood vessels are well developed. They branch off from a main vessel as bundles, which end towards the lower part of the ovary.

The weight of the roe is about 6% of the body weight. The main part of the roe consists of ovocytes at the beginning of yolk formation.

Stage IV (ripe). The roe fills the whole body cavity. Blood vessels are well developed. The eggs are large, irregularly edged, lying close together. If the membrane of the roe is torn, the eggs keep together in the stroma, but assume a rounded shape. The membrane of the roe is very thin and easily torn. The roe is yellow-red, constituting 10% of the weight of the fish. In a histological respect, stage IV is distinguished by the presence of ovocytes filled with yolk, constitituting the main mass of the roe. In addition, there is a complex of ovocytes, inclusive of the phase with follicle tissue in one single layer.

Stage V (spawning). The roe occupies almost the whole body cavity. The membrane of the roe is transparent. Large, light eggs are visible. Ripe eggs fill the oviduct which is sharply separated from the lower part of the ovaries. The roe constitutes about 14% of the fish weight, ranging from 9 to 21%.

Stage VI (spent). The roe is strongly shrunk, withered, containing much blood, and of a purple color. A few, degenerating eggs which have not been spawned, are very often found in the ovary. The roe now is smaller, merely constituting about 1% of the fish weight. Histologically, the ovaries in stage VI are characterized by empty follicles and a whole complex of the ovocytes characteristic of stage II.

The Distribution of Herring According to the Stages of Maturity

The duration of the various stages of maturity is shown in Figure 12.

The first stage may be observed throughout the year; in adult specimens during 2-2 1/2 months (May-July), in immature fish it may last a few years.

Stage III is most often observed from July to December, but never in April and May.

Stage IV usually occurs from January to April. Stage V is especially observed in April. As the maturation proceeds, the duration of the stages is shortened. During the maturation process, the weight of the ovaries (the index of maturity) is increasing by degrees. A sudden, jump-like decrease in the weight of the ovaries is observed during the transition from stage V to VI.

In the eastern areas of the Barents Sea, young herring with feebly developed sexual glands are dominant. Maturing herring, constituting approximately 85% of the catches in the central areas of the Barents Sea, are observed in March and April in pre-spawning and spawning concentrations along the northeastern coasts of Norway (see Figure 12). The pre-spawning concentrations consist mostly of herring in stages III and IV.

The spawning of the Murmansk herring culminates in April.

The subdivision of the herring according to uniform physiological condition (length, fat content, stage of maturity and so on) takes place long before the spawning. It is assumed that still another subdivision takes place in the spawning places according to what extent the herring are ready to spawn.

In areas adjacent to the spawning places, herring in stages II and VI dominate in May. These stages only differ with respect to the degree of restoration of the sexual glands. The presence of stage VI only indicates the end of the spawning and beginning of the regeneration of the gonads, whereas stage II in the mature specimens in May, indicates the culmination of the regeneration. The nearer to the spawning area during the period of spawning, the more individuals in stage VI dominate. The farther towards northeast and northwest, the more individuals in stage II.

The end of the spawning period is indicated by an inconsiderable number of herring in stage V. In June, spawning herring have not been observed at all.

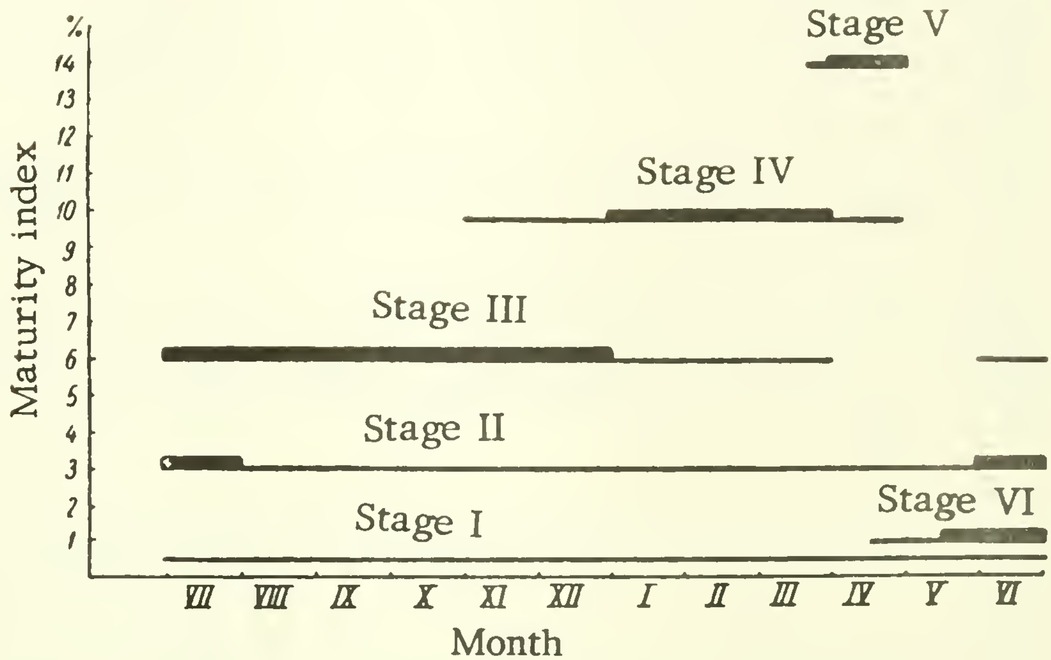

Figure 12. Index and duration of the maturity stages in the Murmansk herring (the periods in which the stages are most often found, are signified by thick lines). (Vertical, -index of maturity, horizontal, - months).

In summer, a considerable number of herring which have not yet spawned for the first time, is again observed in the Barents Sea.

The bulk of the summer catches consists of fat herring in stage II. Herring, maturing fo. the first time, are found in July, and especially in August. In the autumn, the maturation has proceeded further, characterized by the transition from stage III to IV.

In the herring catches in the Barents Sea, the maturing herring constitute from 15 to 65% (Table 9).

The Numerical Relation between the Sexes

The numerical relation of males to females varies in the same area during the course of the year.

As yet we have no reason to assume that this variation is conditioned by selection of the drift nets. First, the fishery itself is still not so intensive that it may influence the structure of the schools to any remarkable extent; second, the sexual dimorphism is very feebly expressed in the herring (the females are about one per cent larger than the males). Finally it is assumed that males and females do not appear in equal numbers in the various areas at different times of the year. For example, from April 4 to May 16, 1939, male herring dominated in the samples from

TABLE 9. THE DISTRIBUTION OF THE MATURITY STAGES OF THE MURMANSK HERRING IN SAMPLES FROM 1939 (FOR EACH STAGE, THE FIRST FIGURE INDICATES THE NUMBER OF FISH; THE SECOND FIGURE - THE PERCENTAGE OF FISH OF THE GIVEN STAGE FOR THE MONTH IN QUESTION).

Maturity stages \ Months	January	February	March	April	May	June	July	August	September	October	November	No. of fish	In % of the total no. of fish investigated
I	--	345 95.5	--	--	--	--	222 47.5	4 7.1	5 1.7	12 2.7	12 4.4	60	11.9
II	169 30.3	10 2.83	45 8.90	29 6.7	653 52.7	386 95.73	244 52.1	20 35.7	276 93.5	294 68.2	145 52.5	2271	45.2
III	343 61.5	6 1.67	63 12.45	--	--	--	1 0.2	32 57.2	13 4.4	118 27.4	76 27.5	652	13.1
IV	46 8.2	--	308 60.71	8 1.85	12 0.18	--	--	--	1 0.4	7 1.7	41 14.7	423	8.2
IV-V & V	--	--	73 14.3	231 53.65	38 3.19	3 0.74	1 0.2	--	--	--	2 0.9	348	6.9
VI	--	--	18 3.56	163 37.8	539 43.9	14 3.53	--	--	--	--	--	734	14.7
Quantity of fish	558	361	507	431	1242	403	468	56	295	431	276	5018	--

the western parts of the Barents Sea.

This is fully in accordance with our ecological-physiological and histological investigations. The males are the first to appear in the feeding areas after the spawning. The regeneration of the gonads proceeds more rapidly in males than in females. The males' rate of feeding exceeds that of the females, which fact leads to an increase in the fat content and accordingly, to an increase in the condition in comparison with the females. The numerical dominance of the males in the Bear Island-Spitsbergen area in June and July is explained by the males' leaving the spawning places before the females.

From the middle of July, the numbers of males and females are equal in the samples, and later the females even predominate. The equalization occurs to the same degree to which the females emigrate from the spawning places.

As is known, the spent herring after the spawning migrate to the western areas of the Barents Sea (herring 6-7 years old) and northwards to the area near western Spitsbergen (7-14 years old). In this connection, the following rule may be of interest: the farther from the spawning place (Lofoten), towards the east, the Barents Sea, - and towards the north, - the area of western Spitsbergen, - the later the numbers of males and females will be equal in the spent herring.

At last we will draw some general conclusions.

1. Mainly young herring, which have not attained sexual maturity, spend the winter in the eastern parts of the Barents Sea. The maturing herring is met with in small numbers in the central area, and in large numbers in the western parts.

2. In spring, herring with developing sexual products are found in small numbers in the western areas of the Barents Sea, along the border-line of the Norwegian Sea.

3. The Murmansk herring spawns along the northwestern coast of Norway near the Lofoten Islands and somewhat to the east and west. Spawning has also been observed near Sørøy. In the western Barents Sea, spent herring appear in the catches in May.

4. In summer, the herring in the Barents Sea are characterized by feeding herring in stage II. In the adult herring, the regeneration of the gonads is largely at an end in June. The maturing of the sexual products begins in the 5- and 6-year-old herring, partly also in the 4-year-old individuals, characterized by the transition from stage II to III.

5. In the autumn, the development continues, the gonads passing over from stage III to IV. During the maturing, the herring migrate still farther towards the west, and at the end of the winter they have reached the border-line of the Norwegian Sea, where they form pre-spawning concentrations.

The Stages of Maturity and the Conditions of the Medium
The Influence of the Temperature

In order to understand an organism, it is necessary to study its relation to the surrounding medium. This question has been very slightly investigated with respect to the sexual cycle. We have therefore emphasized the study of the ripening of the sexual products in relation to the hydrographical conditions.

Of the hydrographical factors, we have only the possibility of studying the temperature and salinity of the water, and the influence of light. By observing and stating the facts, we will try to find the possible laws in the development of the gonads in the various stages.

In the Barents Sea, the hydrographical conditions are very complicated. The Atlantic current has a great influence, but the amount of warm water introduced with this current in the Barents Sea is not the same in different years. We will therefore compare the findings of herring in certain stages with the temperature and salinity of the water during the same periods.

The physical-chemical factors undoubtedly influence the processes of life in fish, but it is difficult to state how important they are. Some scientists infer that the temperature is influencing nearly all the life processes of the fish (migrations, feeding intensity, time of spawning, and so on).

Glebov (13) infers that the migration of the herring to the coast is mainly governed by the hydrographical factors, and that any periodicity in these factors will be reflected in the migrations of the herring (will cause a similar periodicity).

Ambroz (4) is of the opinion that the spawning migration of the Pacific herring into the Bay of Peter the Great is determined by the temperature conditions in the bay. He divides the herring from this locality into three groups: herring older than three years are cold-loving; three-year-old herring love the mean temperatures, and herring one-and two-years-old are heat-loving.

The results of Ambroz were obtained by comparing the catch statistics with the temperature of the water, and may therefore be regarded with a great deal of scepticism. We do not agree with his argument that the spawning migration of the herring is determined by the temperature only, without considering the physiological state of the fish, especially the stage of maturity.

If the Pacific herring get more and more cold-loving with increasing age, then the Murmansk herring, according to the "temperature theory", become more and more heat-loving. The temperature theory merely states facts without any explanation. It may be said that the 0-group of the Pacific herring is heat-loving, but the 0-group of the Murmansk herring is cold-loving.

The real conditions can only be understood by studying the total life cycle of an organism with allowance for all factors.

With this point of view, the process takes place in the following way: a great number of the fry of the Murmansk herring are carried to the eastern areas of the Barents Sea by the North Cape branch of the Atlantic current. The fry are also drifting into the White Sea. The eastern parts of the Barents Sea, being very shallow, are warmed during the summer. A great development of plankton takes place in these areas. The distribution of the fry is not limited to the narrow branch of the Atlantic current. As the warm water of the Atlantic current is likely to be very poor in food, the fry is forced to migrate beyond the borders of the current (towards the east, into the White Sea, and into the fjords).

During the growing period, the herring accumulate a large reserve of fat. The sexual instinct still does not induce the herring to migrate westwards. In winter, when the temperature sinks very rapidly in the coast areas and in the eastern parts of the Barents Sea, the herring move to near the bottom, where the temperature is somewhat higher than at the surface. This migration to the water layers near the bottom in winter is a very economical utilization of the energy of the organism. Having wintered under comparatively severe conditions in the eastern area, the young herring will find an abundance of food in spring, without migrations to any great extent.

With increasing age, the herring's distribution is more and more connected with the branches of the Atlantic current. The explanation is not that the herring have been more heat-loving, but instead a change in food habits and also a westward migration towards the spawning places.

The westward movement, to areas of higher salinity and temperature, may have a positive influence on the development of the gonads of the herring. Shelford and Powers (105) have shown by experiments that the Atlantic herring react to differences in temperature as low as 0.2°C.

Nasonov and Aleksandrov (51) infer that temperature acts as a physical factor causing colloidal changes in the cell. As a result, chemical processes will follow. The authors are of the opinion that the colloidal changes may act as a physiological stimulus inducing some or other physiological process. The living cell, being a complicated colloidal system, is undoubtedly influenced by the surrounding medium.

The influence of temperature on the ripening of the gonads may be illustrated with some examples from fish culture.

Carp, held in culture ponds in the central part of the USSR, spawn at a very definite temperature, 18-19°C. At other temperatures, no spawning takes place. In spring, when the carp are transferred to the spawning ponds, the following may be seen: in the winter ponds, the temperature is considerably below 18°C. The breeding carp in these do not show any sign of spawning, but only a few hours after they have been placed into the spawning ponds, the spawning begins. In this case the temperature acts as a stimulus.

Kazanski and Nusenbaum (26) studied the spawning in Misgurnus fossilus in the Leningrad area at temperatures of 12-14°C. Below 11°C, the beginning of the ovulation might be retarded or completely stopped. The authors concluded that the ripening of the females was closely connected with temperature. Frantz (84) states that in plaice the development of the gonads is retarded in winter.

There are also examples that the development of the gonads may also be accelerated in winter. In pikeperch and whitefish a rapid filling of the ovocytes with yolk is connected with a decrease in temperature (Gerbil'skiy, 12). In the burbot (Lota lota) the spawning usually takes place in December below the ice in the central part of the European USSR.

Among the herrings of the North Atlantic may be found spring-spawners, as well as summer-, autumn-, and winter-spawners. In some races of herring, the ripening of the sexual products evidently takes place at an increasing temperature, in others, - at a decreasing temperature.

The temperature itself does not induce spawning, as the reproduction is dependent on a series of complicated processes which take place in the organism itself. The spawning will not take place until the sexual products have reached a certain stage of maturity. Under other conditions, no spawning will take place, even if the temperature conditions are favorable. It is therefore evident, that we will not be able to obtain direct observations of the influence of temperature on the life processes in the Murman herring. At a certain time, and in a particular locality, we merely record the presence of herring in certain stages of maturity, simultaneously with certain hydrographical conditions.

If this is done all the year round, we will have a possibility of comparing the distribution of herring in various stages with the temperature of the water. In a section along the Kola meridian, the temperature in January-March is about 4°C. At this time of the year the stages I and II dominate; stage III is less frequent. Herring with the sexual products more advanced, are taken west of the North Cape bank, and near North Cape.

In April, the temperature reaches a minimum. At this time, only immature herring occur in the Barents Sea; in the western part there are also some spent herring.

During this period, herring with the sexual products well developed and spawning herring are distributed along the northwestern coast of Norway (according to the observations in 1939 from the trawler "Beluga" from North Cape to Ringvassøy; in this period the temperature was above 5^{o}C. Near the bottom the herring spawned at the same temperature).

After the spawning, the herring in large schools migrate to the feeding areas, following the North Cape current to the northwestern parts of the Barents Sea, and the Spitsbergen current to the area near western Spitsbergen, to 78 degrees N., possibly still farther.

Near the surface, the temperature is now rapidly increasing, and a great quantity of zooplankton, the main food of the herring, appears. We shall once more recall that the movement of the herring is induced, not so much by the warming of the water, which took place in the northwestern area, but mainly by the physiological stage of the herring, i.e., the demand for more energy because of the high catabolism during the maturing and spawning.

This demand for increased feeding following spawning is connected with certain temperature conditions. This correlation cannot be measured quantitatively, as we still do not know the optimum feeding temperature for the herring.

In summer, the herring are dispersed over a wide area of the southern Barents Sea. The temperature of the surface layers reaches a maximum in July-August, that of the deeper layers in September-October. During all this time, there is an intensive development of the gonads.

In young herring which have not yet spawned, the ovaries pass from stage I to II; in immature herring, 4-5 years of age, from II to III. In herring which spawned during the spring, empty follicles and eggs which were not spawned, are now resorbed, and simultaneously the ovocytes are ripening, i.e., there is a transition from stage II to III.

At the beginning of the winter, herring with developing gonads (stages III and IV) as already mentioned, migrate westwards, as the water starts cooling. Along the border-line of the Norwegian Sea and near the spawning places, pre-spawning concentrations are formed at a higher temperature. Only immature herring, which will not spawn in spring, are found in the east.

The Influence of Salinity

Investigations on salmon, eel, sterlet, and other fishes have shown that the osmotic pressure of the blood is dependent on the salinity. During the course of the year, the salinity of the Barents Sea varies, and this variation is influencing the herring. In May-July, when the sea receives most admixture of fresh water, the mature herring migrate to the western areas (Finmark Bank, the Demidov and Nordkyn Banks). Farther to the east, no concentrations of adult herring have been observed, nor have any spent herring been found near the coast, where the water is less saline.

In summer, the salinity is comparatively low in the eastern areas, in the Kanin-Kolgujev area, below 34^{o}/oo in July 1938. At the same time, the salinity near the Murmansk coast was below 32^{o}/oo. The gradual increase in salinity, beginning in August, coincides with an intensive development of the gonads in the maturing herring. In analogy with what has been observed in other fishes (salmon, eel, sturgeons and others (Betesheva 5)), we may assume that the osmotic pressure in the blood of the Murmansk herring is directly correlated with the salinity of the water. The adult herring live in water of a comparatively high salinity; accordingly, the osmotic pressure of the blood is also high.

In herring maturing for the first time, the osmotic pressure of the blood evidently increases as the gonads develop and the herring migrate westwards. It is assumed that in young, immature herring living in water of a lower salinity the osmotic pressure of the blood is reduced.

The Influence of Light

It has been proved by experiments, first in warm-blooded animals, later in fish, that the cyclic development of the gonads is related to the light conditions.

In this connection Svetozarov and Shtraich (62) state that the influence of light in relation to the sexual cycle in adult organisms has been investigated very thoroughly. In her paper on the spawning of fish and its dependency on the surrounding medium, Polikarpova (58) stresses that following the work of Rouen (1929) stating the active influence of light on the development of the gonads in vertebrates, a large number of papers has been published by various authors, confirming this fact[1/].

We shall linger a little on the examples given by Polikarpova. Hoover and Hubbert (1937) stated that the length of the light days had an influence on the sexual products in trout. Under the influence of light, they matured up to 4 months earlier than usual. The authors drew the conclusion that it might be possible to direct the sexual cycle of the trout according to the influence of light. Polikarpova admits that some fishes react on light, but is of the opinion that the regulation of the rhythm of propagation must largely be ascribed to the temperature of the water. She arrived at this conclusion from experiments with small Callichtys fasciatus and guramy (Osphromenus trichopterus). The histological pictures of the ovaries were different in the control fish and in the experimental fish.

Other authors deny the influence of light on the maturing of the sexual products (Gasterosteus (Bennet), perch (Bissone)). In common with Polikarpova, they consider the temperature as the most important factor.

Mathews (99), from experiments with Fundulus heteroclites concluded that during the period of sexual repose light had no influence on the development of the sexual glands.

Svetozarov and Shtraich infer that the light only may act as a stimulus in cold-blooded animals under normal temperature conditions. Each change in the light regime in itself leads to a disturbance in the development of the sexual glands. In cold-blooded animals, in which the degree of self-regulation in this respect is less than in warm-blooded animals, the development of the gonads is more dependent on the influence of the surrounding medium. Shtraich and Svetozarov (78) observed the stimulating influence of the light on frogs, shown in photomicrographs of the ovaries.

Samochvatova (61) studied the influence of sunlight on the growth and reproduction of gambusia (Gambusia affinis holbrooki) but came to a very uncertain conclusion. From the experiments, she could not decide if the sunlight had any favorable influence on the fish, or if this influence worked in an indirect way, related to a change in the rate of feeding.

Smirnov (63) compared the development of the sexual products in some species of Caspian

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1/ Craig-Bennet (1931) (quoted by Svetozarov and Shtraich) investigated the influence of light on the development of the sexual glands in the stickleback (Gasterosteus aculeatus) and came to the conclusion that the light was without any special influence.

herring at different times of the year. In winter, the sexual glands are slightly developed, in March they double their size, in April they are more than four times the winter size.

In 1946, Smirnov (64) made experiments in order to show the direct connection between the development of the sexual glands of the Caspian herring and the magnitude of the radiation from the sun. He stated that the weight of the gonads of the Caspian puzanok (Alosa) increased with the increase of the direct radiation.

We have tried to compare the development of the roe in the Murmansk herring with the light conditions (Table 10). This comparison must necessarily be a mechanical one, for in most of the experiments with living creatures no positive correlation has been found between the development of the gonads and the light. This question can only be answered correctly by experiments, as the influence of light cannot be treated in an isolated manner, but must be considered in connection with other factors.

TABLE 10. THE VARIATION IN WEIGHT OF THE ROE OF MURMANSK HERRING AND THE VARIATION OF THE AMOUNT OF SOLAR RADIATION.

Months	VII	VIII-IX	X-II	III-IV	V-VI
Amount of heat from the direct solar radiation in cal/cm.^{2}	5400	2138	5	1592	3931
Weight of the ovaries in per cent of the body weight	3	6	9.5	13.9	1
Maturity stages of the ovaries	II-III	III	IV	V	VI

With respect to the light conditions, the Polar Basin is sharply distinguished from the southern oceans. Even in summer, bright days without clouds are comparatively rare. From the data (Table 10), it might be concluded that a connection exists between the sexual cycle of the herring and the order of magnitude of the solar radiation. The greatest radiation corresponds with the two most important steps in the sexual cycle, the beginning of the ripening of the sexual products, and the period of maximum mature gonads.

In the Murmansk herring, the gonads usually begin to ripen in July. This period corresponds with a maximum of the direct solar radiation (5400 cal/cm.^{2}). In immature individuals, the gonads pass from stage I to II, in adults from II to III.

During the Polar night the direct radiation from the sun decreases to 5 cal/cm.^{2}. In this period, the growth of the gonads continues, until they constitute 9.6% of the fish weight. The correlation between the development of the gonads and the solar radiation is therefore very poor. In March and April, the radiation increases very strongly (1592 cal/cm.^{2}) for we have the largest number of bright days and maximum weight of the roe of the herring (13.9%). Most of the herring spawn in these months, but the spawning process itself has probably no relation to the light. The spawning is the climax of the sexual cycle. After the spawning, a new cycle begins.

Before the spawning period, the organism is biologically prepared for the spawning. A great accumulation of fat on the intestines and in the muscles is caused by the heavy feeding during the period previous to the spawning. This fact probably explains the increase in the hemoglobin content of the blood.

The culmination of the preparation of the organism for spawning corresponds with the maximum of the direct solar radiation. If each stage in the sexual cycle shall be carried through normally, certain ecological conditions are needed. Dement'yev (16) states that during the life cycle there is a reciprocal action between the internal and external factors. No cycles will arise without the action of external factors.

In addition to other factors which act as a whole, the light is of great importance. As a result of the work of several scientists, the influence of light on the living organism is now better understood. The light is acting as a catalyst, influencing the hypophysis, and through the hypophysis the gonads of the fish. According to Knipovich, the sunlight which penetrates the water layers, is not only a source of warmth, but may also have a chemical effect.

In a series of experiments with living organisms, light has been shown to be important as a stimulus for the development of the sexual organs. Without experiments, we may only assume that during the period of maximum solar radiation the gonads of the herring receive a maximum of stimulation from the sunlight, corresponding to the beginning and ending of the annual cycle (stages II, III and V).

Only by special experiments may exact data be obtained on the correlation between the development of the gonads and the influence of light. The light probably plays an important part in the ecology of the herring. Even if the period of intensive sunlight in the Polar Basin is very short, it is evidently sufficient for a normal life cycle for the organisms living there.

The Maturity Stages and the Composition of the Blood

In contradistinction to the warm-blooded animals, the blood of the fishes is subject to very great variation in its composition.

The ecological conditions have a great influence on the composition (59). Puchkov measured the seasonal variation in the quantity of the erythrocytes and hemoglobin in the blood of fishes. The infection of fish with parasites has also a great influence on the composition of the blood (Liamin (41)).

Our investigations support the theory that in schooling fish, especially the Murmansk herring, the degree of infection with parasites is more or less uniform. More reliable results might be obtained from samples taken in the same areas during the same periods of the year. As we still do not know the normal composition of the bloodof the Murmansk herring, the figures that we have are not entirely reliable for an evaluation of the biological state of the herring. It is very important, not only to know the absolute quantity of hemoglobin and leucocytes, but also the factors which control them.

An over-all consideration of similar problems is subject to a special investigation and is not our responsibility. We will only discuss the variation in the composition of the blood of fishes in relation to the maturity stages of the gonads. According to Pavlov and Krolik (57) the hemoglobin and erythrocytes in the blood of fresh-water fishes increase in quantity in connection with the ripening of the sexual products. In the species investigated, the carp, the sex of the immature individuals could be determined from the quantity of hemoglobin in the blood. The authors also mention the possibility of estimating the degree of maturity of the sexual products by the aid of this indicator.

Kalashnikov (31) determined the degree of maturity in sturgeon by referring to the physiological condition of the fish. He investigated only one of the physical-chemical properties of the blood, namely, the sedimentation rate. The author concluded that as the maturing of the gonads proceeded, the sedimentation rate increased.

Working conditions in the open sea have unfortunately prevented us from carrying on similar experiments with the Murmansk herring.

Drabkina investigated the change in the composition of the blood in pikeperch and bream in the IV and V stages of maturity. She found that the quantity of hemoglobin and the leucocyte formula in the bream differed considerably during the ovulation (stage V) from the corresponding figures during the pre-spawning period (stage IV) of the fish.

Plehn (101), directing the work on fish diseases, states that in healthy fish there are about 1,200 red blood corpuscles for each white one. During spawning, fattening, and various infectional diseases, there is a considerable displacement in this ratio, in the favor of the white blood corpuscles.

The relation between the various kinds of leucocytes and the amount of hemoglobin in the blood is thus strongly dependent on the physiological condition of the fish, especially on the stage of maturity of the sexual products. In our study of the sexual cycle of the Murmansk herring we have therefore also concerned ourselves with the composition of the blood.

Very little is known, not only of the blood, but also of the physiology of the Murmansk herring as a whole. The remark by Glebov (13) is very characteristic in this connection. He says that even if a great amount of material has been collected for the study of how the outer factors influence the behavior of the herring, almost no information is available on its physiology.

For the study of the composition of the blood we used 273 smears and 157 determinations of hemoglobin.

The blood was taken from the fishes at approximately the same time, between 8 and 11 a.m., because the nets were hauled at that time. The herring died very quickly after capture. Only individuals which were alive, and not injured, could be used.

The coagulation of the flowing blood took place in 5-10 seconds. The blood was taken from the gill artery. The smears were preserved with methyl alcohol for 3 minutes and stained after the method of Giemsa in 50 minutes. The dye was prepared with two drops of Giemsa dye per 1 cc. of buffer solution.

We were interested in the correlation between the composition of the blood and the physiological state of the Murmansk herring, particularly the degree of maturity of the gonads. At first, the morphological properties of the blood cells had to be studied. In the literature, no information is available on the blood of the herring, and we had to use the blood morphology classification used for fresh-water fishes.

From the study of 200 preparations of blood from herrings of varying physiological condition, we obtained a certain idea of the morphological structure of the blood cells. The non-granular leucocytes are represented by lymphocytes, monocytes and polymorpho-nuclear leucocytes. Of the granular leucocytes, only the eosinophile ones were found, containing eosinophile granules of an irregular, rounded shape, and of a dark-brown color. The nucleus is oval, 3.0-5.5 mu in diameter, usually situated at the periphery.

The structure of the non-granular leucocytes in the blood of the Murmansk herring is similar to analogous forms described from other fishes by Puchkov (59), Golodets (14), Drabkina and Antipova.

The dimensions of the blood cells of the Murmansk herring are different than those of, for example, bream, pikeperch and trout (according to Drabkina) (Table 11).

TABLE 11. THE SIZE OF FISH BLOOD CELLS IN MU.

Form element of the blood	Bream	Pikeperch	Trout	Murmansk herring
Lymphocytes	2	--	2.5	3.6-5.6
Monocytes	5	--	7	8.0-10.8
Polymorpho-nuclear leucocytes	4	--	6	8.5-14.4
Eosinophile	--	--	--	8.0-10.0

Cheisina (68) divided 53 species of fish from various families into 5 groups according to the leucocyte formula. For our work such a classification is not necessary. According to the composition of the leucocytes, Cheisina referred the Clupeids to group I, characterized by both lymphocytes and monocytes. In the blood of the Murmansk herring, lymphocytes (Figure 13, a), monocytes (Figure 13 b), polymorpho-nuclear leucocytes (Figure 13 B) and eosinophiles are present.

If the grouping of Cheisina is followed, the Murmansk herring may be referred to the groups II and III, and in addition to group I.

Zavarzin (20) characterized the classification of fish made by Cheisina as being very formal. In his opinion the distribution of fish families according to the blood cell groups is entirely occasional.

From the material collected in 1947 we have tried to explain the correlation between the amount of hemoglobin and the age, fat content, and maturity stages of the ovaries. The investigation showed that in herring 5-8 years old the mean quantity of hemoglobin was 53.3% (3 individuals), in herring 9-13 years old 61.9% (30 individuals). Thus the hemoglobin content of the blood increases with age. This increase takes place simultaneously with the accumulation of fat on the intestines. One mark (ball) of fat corresponds with 51.7% of hemoglobin, two marks- 67%, three marks- 65.6%. (Editor's note: see Rudakova's article in this volume).

The amount of hemoglobin is also strongly correlated with the maturity stages of the sexual products. For example, stages V-VI correspond with 42.9% of hemoglobin, stage II, -61.4%, stage III, - 64.5%. In individuals with trace of the recent spawning (stages VI-II) the hemoglobin content is very low.

According to Table 12, the hemoglobin content of the blood from Murmansk herring varies considerably during the year. The maximum quantity of hemoglobin corresponds with the period of maximum fat content and condition (October-November).

After the spawning (May-June), when the fish has just begun to feed vigorously, and has scarcely begun to establish the metabolic level, the hemoglobin content is comparatively low.

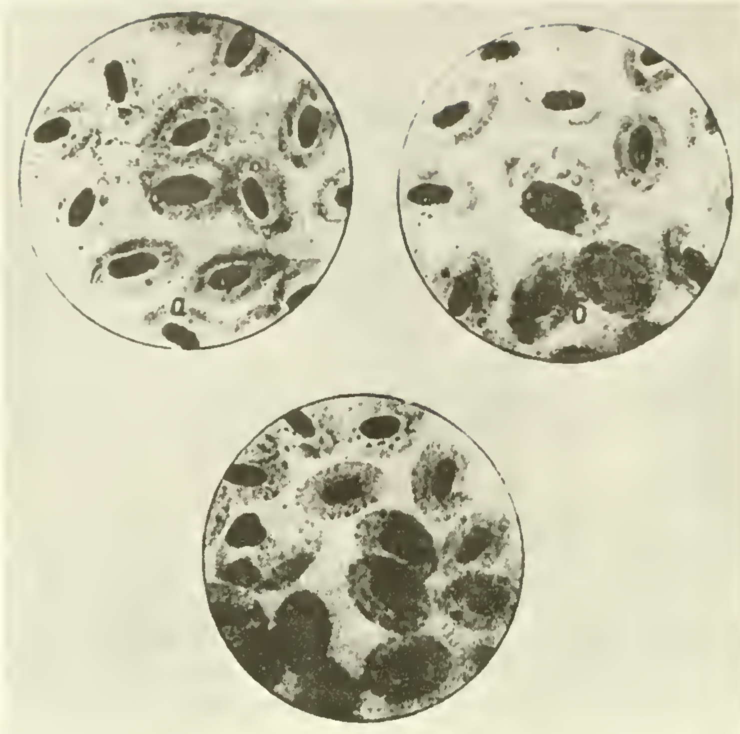

Figure 13. Blood from Murmansk herring. a- a lymphocyte in the center, b- a monocyte right, B- a polymorpho-nuclear lymphocyte.

In this period, the remains from the spawning, empty follicles and eggs which were not spawned, are resorbed in the ovary. The increasing quantity of monocytes and polymorpho-nuclear leucocytes in the blood during this period is evidently caused by their acting as phagocytes during the process of regeneration of the gonads.

TABLE 12. MEAN QUANTITY OF HEMOGLOBIN AND BLOOD CELLS OF MURMANSK HERRING (IN %).

Date	Hemoglobin	Lymphocytes	Monocytes	Polymorpho-nuclear	Eosinophiles
October 1938	64.0-64.1	87.5-80.7	8.0-13.3	4.5-5.0	1.0
November 1938	64.5-65.5	78.1-73.5	15.3-19.1	5.3-5.3	2.1
May-June 1939	53.4-53.6	37.2-43.9	44.0-37.1	18.8-19.0	--
June-July 1947	55.1-57.5	63.3-65.6	20.7-18.7	16.0-15.6	--

After the restoration of the gonads at the beginning of the new sexual cycle (July, stage II-III), there is a corresponding decrease of the phagocyte cells of the leucocytes.

The Ecological Conditions and the Speed of Maturing of the Sexual Products

As long as the sexual products have not developed beyond stage IV, the immature Murmansk herring do not migrate outside the Barents Sea. On the other side, the adult herring form pre-spawning concentrations in the Norwegian Sea, spawn along the coast of northern Norway, and then migrate to western Spitsbergen, where they feed some 4 months. The living conditions for the mature herring near Spitsbergen and in the Barents Sea are not uniform, the distance between these two areas being nearly a thousand kilometres.

The habitat of the adult Murmansk herring reaches the 78 degrees N., and westwards from the coast of Spitsbergen to the zero meridian.

In the absence of direct observations, the living conditions of the herring before or during the spawning cannot be discussed.

The immature Murmansk herring live in an area in main limited by the 75 degrees N. lat., 25 degrees E. long., and 50 degrees E. long. The Spitsbergen branch of the Atlantic current is of great importance for the hydrographic conditions in the Bear Island-Spitsbergen area, while the North Cape current influences the southern part of the Barents Sea.

The sea water in the Spitsbergen area is very similar to that of the North Atlantic (transparency, color, salinity, and temperature). The coast water near the Murmansk coast is colder and less saline, being near to the continental shelf. This explains the well-known earlier development of plankton along the Norwegian coast and the coast of western Spitsbergen. The farther into the Barents Sea, the later the mass development of the zooplankton. From this it follows that the food uptake of the herring is different in the two areas. Finally, the great difference in the magnitude of the solar radiation emphasizes the dissimilarity between the two areas.

It is concluded that the feeding period of the herring is shorter near western Spitsbergen than along the Murmansk coast. If the summer is shorter, but the hydrographic conditions more favorable, the development of the plankton takes place more rapidly, the herring are feeding more intensively, fattening in shorter time.

Accordingly, all the physiological processes will proceed more rapidly in the mature herring than in the immature individuals. Our observations indicate that the mature herring pass into stage III at the beginning of July. In the immature herring, the ovaries do not begin to ripen until the end of July/beginning of August. The final ripening of the ovaries will accordingly take place one month earlier in the mature herring than in the small, immature individuals. This is the explanation why large adult herring arrive in the spawning area earlier than the younger first-time spawners.

The separation of the two groups creates favorable conditions for a better utilization of the spawning area, and is evidently also of importance in securing the food conditions for the numerous offspring, especially before they leave the spawning area.

The herring begin to feed intensively in April, the maximum in the amount of food in the stomachs is observed in May, and the decrease in July. During the feeding period, fat is accumulated on the intestines, with a maximum accumulation in the autumn. At the end of July, great quantities of intestinal fat may be observed. The herring continue to feed, and fat is also accumulated in the muscle tissue.

During the autumn, the condition coefficient is increased considerably because of the accumulation of fat. In August, this coefficient is still as high, and no decrease takes place until September. The decrease is gradual for two reasons; the rate of feeding is first decreasing, causing a depletion of the fat reserves in order to maintain life. The intestinal fat is consumed first, then the fat of the muscles. Second, energy is used for the development of the gonads.

The increase in the food uptake is observed in May, coinciding with the ending of the spawning period. Spent herring dominate the catches.

In order to re-establish the energy level the herring are fattening very rapidly. The rate of feeding decreases in July. In the adult spent herring a very important physiological process takes place at that time, namely, the resorption of the eggs not spawned, and of the empty follicles. At the same time, the ovocytes, which shall be spawned next time, begin to grow rapidly.

A rapid development of the gonads takes place during the following months at the expense of the fat accumulation; in spite of that, the feeding of the herring is at that time decreasing to a minimum.

July is a critical month for the bulk of the herring, as the feeding rate decreases, while the fat content and the coefficient of condition still keep the same level.

Now the sexual organs finish their state of "relative rest", passing from stage II to III. In the Barents Sea, young herring, 5-6 years old, begin their first sexual cycle. According to Marti (45) the largest individuals of some year classes mature first.

At last we will discuss a little more the change in the physiological state of the herring in connection with the development of the gonads. In the autumn-winter period, the herring have a high fat content and a high condition coefficient. At the same time, the gonads are developed further, from stage III to IV. The condition is decreasing by degrees until the second half of March, but later it decreases very rapidly. As already mentioned, the rapid decline is explained by the fact that the spawning starts in the second half of March. At this time, the herring reach the highest degree of exhaustion, decreasing considerably in weight.

The Biological Composition of the Adult Atlantic Herring in the Area near Spitsbergen

In 1947, the first commercial-scientific expedition, consisting of 4 fishing vessels and 2 research vessels, was sent to the Bear Island-Spitsbergen area. The author of the present paper participated in the expedition. During the cruise, 2,000 adult herring were investigated from June 14, to July 10, 1947. A typical sample of the age distribution is shown in Table 13.

TABLE 13. THE AGE DISTRIBUTION OF THE HERRING.

Age	5+	6+	7+	8+	9+	10+	11+ ·	12+	13+	14+	n
No. of fish	1	--	2	5	22	34	17	13	4	1	99
In per cent of the total No. of fish	1.0	--	2.0	5.1	22.3	34.3	17.1	13.1	4.1	1.0	100

In the summer of 1947, the catches consisted of herring from 6 to 15 years of age, with predominance of the 10-13-year-olds (86.9%). The length distribution of the herring is shown below.

Length in cm.	29.0--29.5	--30.0	--30.5	--31.0	--31.5	--32.0	--32.5	--
	1	11	70	91	213	209	242	158

Length in cm.	33.0--33.5	--34.0	--34.5	--35.0	--35.5	n	M	± m	σ
	180	64	21	12	7	1279	32	0.05	2.08

The first herring schools were composed of large herring 33 cm. in length. These were only a small group of forerunners of the main schools. Later, the schools consisted of herring with a mean length of 31.5 cm.

On comparing age and length of the herring, a clear disproportion is seen between the annual growth and the age. For example, individuals of an age of 5+ years measure 27 cm.; those 14+ years old, 33 cm., an increase of 6 cm. during 9 years. Such a disproportion is to a greater or less extent found in the entire mass of adult herring. As a comparison, we shall give some data from Yudanov (80) on the growth of small, immature Murmansk herring. From the first to the 6th year of life the length increased from 9 cm. to 23.7 cm., an increment of 14.5 cm. during 5 years. In the Murmansk herring, the growth rate is thus 4 times greater than in the adult herring at Spitsbergen. This feature may be explained by general biological laws; with increasing age and the ripening of the gonads the growth is reduced.

Although the investigations at Spitsbergen were only carried out during a short period, sufficient material was obtained for a characterization of the maturing process of the gonads in adult herring (Table 14).

We shall give a series of variation for the coefficient of condition in relation to the maturity stages (males and females together), based on the samples taken July 4, 1947.

Stage VI-II

Coefficient of condition	0.70--0.75	--0.80	--0.85	--0.90	--0.95	--1.00	--1.05	--1.10	n	M	± m
No. of fish	4	5	7	10	8	7	6	4	51	0.882	0.69

Stage II

Coefficient of condition	0.70--0.75	--0.80	--0.85	--0.90	--0.95	--1.00	--1.05	--1.10	--1.15			
No. of fish	3	7	5	7	13	10	5	3	3	56	0.925	0.71

Stage II-III

Coefficient of condition	0.80--0.85	--1.90	--0.95	--1.00	--1.05	--1.10	--1.15			
No. of fish	5	5	10	6	4	5	2	42	0.929	0.39

Stage III

Coefficient of condition	0.70--0.75	--0.80	--0.85	--0.90	--0.95	--1.00	--1.05	--1.10			
No. of fish	1	3	5	8	9	10	6	3	45	0.930	0.63

According to Figure 14, the small schools contain more individuals in stage VI-II than the relatively larger schools. The herring evidently emigrate from the spawning places in small schools, later uniting into larger ones. The number of fish in stages VI-II is gradually decreasing.

Figure 14. Ovary from a Murmansk herring taken June 29, 1947 near western Spitsbergen. Length of fish 335 mm., weight 450 gm., age 10+. Filling of the stomach 1, fat 1. Length of body cavity 170 mm., of the ovaries 155 mm. (90% of the cavity), weight of the gonads 34.5 gm., index of maturity 7.6. Stage IV. 2/3 natural size.

For the period of investigations as a whole, 1.1% of the males and 8.8% of the females were in stage VI-II.

In the females the resorption of the empty follicles is more complicated than in the males. Females in stage VI-II therefore may be found in the same stage during a longer period than males.

At the beginning of July, the bulk of the herring had completed the reorganization of the gonads. Stage II was dominating (83.6% of the males, 71.6% of the females). A new cycle is beginning in the ripening of the gonads, more rapidly in the males than in the females.

Of the males, 14.3% were in stages III and IV, of the females only 9.9% were in the same stages.

From the series of variations it may be concluded that the stage of the gonads after the spawning (stage VI-II) corresponds with a low condition coefficient (0.882) together with a complete

TABLE 14. THE PERCENTAGE STAGE DISTRIBUTION OF THE MATURITY STAGES OF THE HERRING IN THE AREA OF WESTERN SPITSBERGEN IN 1947.

Date	Maturity stages of the sexual products																Total No. of fish
	VI-II				II-III								IV				
	Males		Females		Males		Females		Males		Females		Males		Females		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
20 June	2	28.6	3	42.8	2	28.6	--	--	--	--	--	--	--	--	--	--	7*
21 June	9	8.0	17	15.2	60	53.5	26	23.3	--	--	--	--	--	--	--	--	112*
22 June	--	--	10	16.5	41	67.0	10	16.5	--	--	--	--	--	--	--	--	61*
23 June	--	--	8	13.6	10	51.0	21	35.4	--	--	--	--	--	--	--	--	59*
24 June	--	--	--	--	8	50.0	--	50.0	--	--	--	--	--	--	--	--	16*
25 June	1	2.0	1	2.0	20	40.0	28	56.0	--	--	--	--	--	--	--	--	50
26 June	--	--	--	--	18	56.2	14	43.8	--	--	--	--	--	--	--	--	32*
27 June	--	--	23	20.7	55	49.5	32	28.7	1	1.1	--	--	--	--	--	--	111
28 June	--	--	4	3.7	56	51.5	17	13.0	2	1.8	--	--	--	--	--	--	109
29 June	--	--	6	18.2	15	45.3	10	30.2	1	3.1	--	--	--	--	1	3.1	33*
30 June	1	1.0	1	1.0	53	53.0	16	36.0	6	6.0	3	3.0	--	--	--	--	100
1 July	--	--	1	0.9	40	35.7	50	44.6	14	12.2	5	4.5	1	0.9	1	0.9	112
2 July	--	--	2	2.1	37	39.0	41	43.2	9	9.0	5	5.2	1	1.5	--	--	95
3 July	--	--	7	8.8	26	32.5	30	37.5	10	12.5	6	7.5	--	--	1	1.2	80
4 July	--	--	11	11.0	33	35	30	30.0	17	17.0	6	6.0	1	1.0	--	--	100
5 July	--	--	11	11.0	27	27.0	24	24.0	15	15.0	17	17.0	3	3.0	3	3.0	100
6 July	1	1.0	8	8.0	35	30	30	30.0	13	12.0	11	11.0	1	1.0	1	1.0	100
Total Males	14	2.1	--	--	558	83.6	--	--	88	13.2	--	--	7	1.1	--	--	667
Total Females	--	--	113	18.5	--	--	437	71.6	--	--	53	8.7	--	--	7	1.2	610

*Total catch investigated.

reorganization of the gonads, stages II-III and III (0.930).

The bulk of the Murmansk herring spawns in March and April along the coast of northern Norway. In May and June, the gonads are in stages VI-II and II. A new cycle of maturation starts in July, with the transition from stage II to III. Such is the scheme for most of the large adult herring. With this background, the catch of 14 herrings in stage IV near Spitsbergen in June and July is of a certain interest.

Marti, leading a cruise with another vessel in the same area at the same time, also found a few herring in stage IV.

Very often only a part of the total catch was investigated. It is assumed that only an inconsiderable part of the individuals with the sexual products well developed (stage IV) appears in the catches, and that such herring may be more frequent in this area.

All the 14 gonads were investigated very thoroughly. Externally, they could not be distinguished from the gonads of the bulk of the herring (Figures 14 and 15). Neither was the histological structure of any essential difference (Figure 16). The total physiological development had evidently proceeded normally, and, accordingly, the gonads had developed to stage IV at a normal rate. It is therefore assumed that in the autumn an inconsiderable, nearly abortive, spawning of large herring takes place near Spitsbergen.

Figure 15. Milt of a Murmansk herring, July 2, 1947, western Spitsbergen. Length of fish 305 mm., age 8+. Filling of stomach 1, fat 1. Length of body cavity 166 mm., of milt 147 mm. (88% of the body cavity), weight of milt 40.5 gm., index of maturity 10.5. Stage IV, 2/3 natural size.

Figure 16. Roe of Norwegian herring taken near Ålesund, February 1947. Length of fish 298 mm., stage IV-V. Weight of roe 60 gm. Index of maturity 19.4. -x 67.

SUMMARY

1. The maturity stages of the sexual products of the Murmansk herring have been worked out from a macro- and microscopic study of the ovaries.

2. In the females, the sexual products mature during 8-9 months. The beginning of the maturing (transition from stage II to III), as well as the transition from the juvenile stage to stage II, takes place in July. Sexual maturity (stage V) is attained in March-April.

3. The Murmansk herring will be sexually mature in the 5th-6th year of their life. From our observations the herring spawn each year until they are 14 years old or older. Adult, "sterile" individuals have not been found.

4. The Murmansk herring belong to the fishes that have a type of total spawning. The extrusion of the mature eggs takes place at intervals during a few hours or days.

As the different schools of herring do not attain maturity at the same time, the period of spawning is extended.

5. The transition from one stage to another takes place by degrees until stage V; but from V to VI, very suddenly, in a leap. The duration of each stage is not the same. The transitions between the various stages can therefore not be compared.

6. Each stage of maturity is normally found under special ecological conditions (temperature, salinity, light, feeding).

7. Each period in the life cycle of the Murmansk herring corresponds with certain stages in the maturity of the ovaries. Each stage may be characterized by a certain state of the fish (fat content, amount of hemoglobin in the blood, the leucocyte formula).

8. No appreciable differences have been observed in the macro- and microscopic structure of the ovaries from herrings taken in the Barents Sea, on the west coast of Spitsbergen, and on the coast of northern Norway.

9. When the time of the occurrence of stage III is known, it is possible to determine the time of spawning approximately.

From the study of the maturity stages we may establish a map of the distribution of the herring according to these stages.

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EXPERIMENTAL TAGGING OF HERRING IN KANDALAKSHA BAY

IN 1953-1954 1/

A. P. Vilson

> "Tagging of fish is an excellent method that should be accepted and applied to commercial fish, but on one imperative condition: that the method be applied en masse and a record be kept."
>
> Averintsev, 1935.

Tagging is the most effective method for studying the migrations of fish. This method enables us to establish their migration paths as well as the speed of movement of individual specimens in relation to their physiological state and factors of external environment. Under certain conditions, tagging may enable us to estimate fishing intensity and growth rate of fish.

Large-scale application of this method has already enabled us to establish the migration paths of a number of commercially important fish, including cod, flounder, and salmon.

For a long time, herring were not tagged, because the operation was thought to be rather injurious and to harm the viability of these fish.

The first experimental tagging of herring was done in 1892 by the Scotch researcher, Fulton (3). The experiments proved unsuccessful. Fulton attempted to tag Atlantic herring by cutting small openings in the caudal fin. In 1932, herring were tagged in Alaska by Rounsefell and Dahlgren (4), who carried out a series of tagging experiments on the Pacific herring and thoroughly studied the survival rate of tagged fish. Their tags were silk ribbons that passed through the gill cover and caudal peduncle, metal tags attached to the gill cover and caudal peduncle, and small metal plates that were introduced into the abdominal cavity of herring.

The tests showed that tags in the caudal peduncle resulted in a high mortality of fish and an insignificant tag return. The ribbons passed through the gill cover formed wounds that never healed, and the tags soon fell off. Stapled tags attached to the edge of the gill cover did not cause death, but were easily lost. The survival rate of herring tagged with abdominal tags proved to be the highest. With this method, the tag cannot get lost. In 1950 (5), sardines of the Gulf of Gascoyne were tagged with celluloid tags made in the form of yellow plates 5 mm. x 25 mm. in size with a fastening hook made of stainless steel wire 0.4 mm. in diameter. The tag weighed about 0.10 gm. It was attached to the back of the sardine between the occiput and dorsal fin by means of the pin.

Wood (6) used similar tags for North Sea bank herring.

Abdominal tags have been widely used in Norway and Iceland during recent years. Celluloid capsules containing a label were used as control tags. The latter were attached by a wire to the dorsal muscles anterior to the dorsal fin.

In the early stages of Soviet research in the Norwegian and Greenland seas, tagging to study

1/ Fisheries Research Board of Canada, Translation Series No. 168.

herring migrations was not carried out on a scientific scale, because the fishing itself was on a small scale. Now that herring fishing is a year-round industry, tagging is the most effective method for establishing the migration paths of herring. In view of this, the Polar Institute set up tagging experiments in 1953, using herring from the White Sea. When selecting the type of tag, the technique and organization of fishing, as well as the methods of processing, must be kept in mind.

Internal abdominal tags undoubtedly offer numerous advantages; however, this method can be employed only where there are special magnetic installations for detecting the tags.

Abdominal tagging of herring is highly effective in a fishery which supplies large oil-rendering plants (Alaska, Norway, Iceland). Abdominal tags cannot be used in our fishing industry where the fish are salted on board the ship and, at the end of the cruise, delivered in barrels to the floating or shore bases. The use of these tags would require installation of special magnetic instruments on board all the ships, which would greatly complicate herring-processing operations.

Therefore, the herring laboratory of the Polar Institute chose the external type of tag, which, we found, the herring tolerate quite satisfactorily. These tags are clearly noticeable, which ensures a high tag return.

Tagging experiments were set up in 1953 and 1954 in Kandalaksha Bay. Apart from enabling us to solve the problems connected with the organization of tagging of oceanic herring on Soviet fishing grounds, tagging of White Sea herring provided us with interesting data on their migrations.

Small Kandalaksha herring were tagged during their spawning movements toward the shores. The tagging was carried out in Valas-Ruchey and Zhemchuzhnay inlets of Kandalaksha Bay.

Herring were obtained from traps during the test fishing.

In 1953, we used tags made in the form of red plastic plates 20 mm. x 8 mm. in size. On one side, the tag bore an inscription of its index number in China ink, on the other U.S.S.R. The inscriptions were coated with a thin layer of acetone varnish.

A nickel wire 0.5 mm. in diameter was threaded through the edge of the plate, then attached to the back of the herring 1 cm. in front of the dorsal fin (Figure 1). In 1954, we used identical tags; however, they were made of pink celluloid, and the index and U.S.S.R. were not inscribed, but stamped.

Wooden blocks were used (Figure 2) to keep the fish in water during tagging. The front section of the block where the head of the fish is placed must be closed. In the region of the dorsal fin, the block has openings through which the tag can be attached without hindrance. Tagging blocks of different sizes must be available because of the varying lengths of fish.

The tagging was done in the following manner: live herring were transferred from traps into a water pail, carried to the tagging place, and carefully transferred to a "net tank" whence the fish were removed one by one, placed into tagging blocks containing water, then tagged. Having fastened the tag, the fish were carefully released into an ice hole. Herring survived the tagging satisfactorily, when the operation was performed correctly and rapidly. After the tagging operation was completed, the fish moved rapidly to the depths. Fastening the wire to which the tag is attached to the direct proximity of the spinal column is lethal to the fish; therefore, the wire must be fastened to the upper dorsal region. Herring are not harmed when tags are attached behind the dorsal fin.

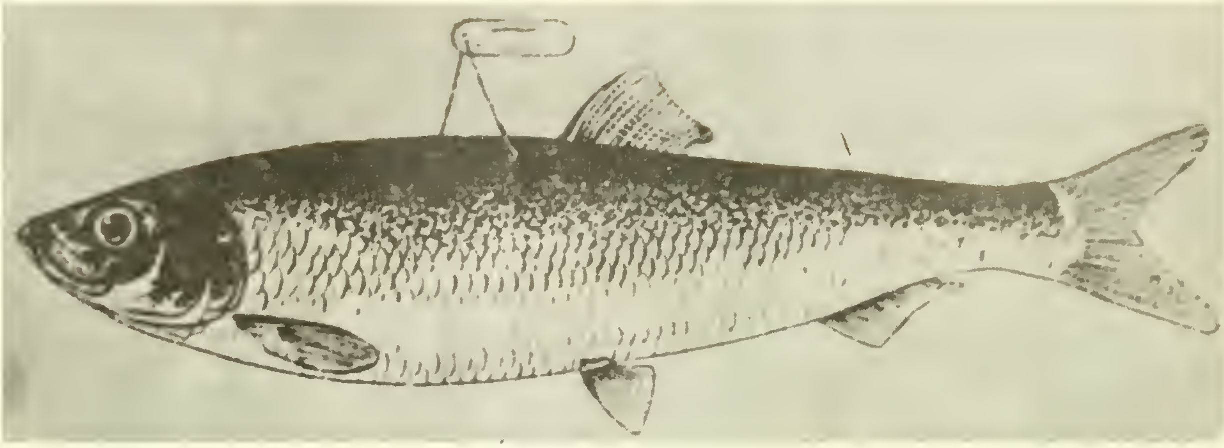

Figure 1. The method of fastening the tag.

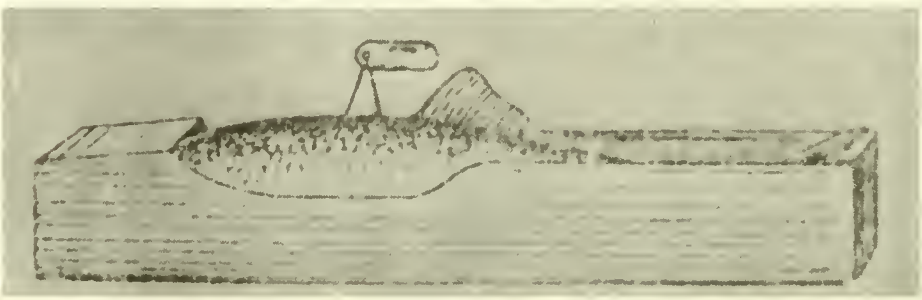

Figure 2. Tagging block.

In 1953, the tagging was carried out in April during the spawning of herring in Valas-Ruchey Inlet. Tagged herring were released into special ice holes half a kilometer from the shore, in the region of Valas-Ruchey, Boloto and Elovaya (Figure 3).

The tagging was performed on sexually mature herring 15 to 25 cm. in length (five-year-old specimens of the 1948 year class prevailed among the tagged fish). The total number of fish tagged between April 20 and April 29, 1953, was 1,070; the total tag return amounted to 9.2% (99 tags). Tag returns began on the day following the tagging operations, 1 - 2 km. from the place where tagged fish were released. During the period of tagging (6 days), we recaptured 79 tagged specimens, i.e., 7.4% of tagged fish. The highest tag return was from the fish tagged on April 28 on the Elovaya fishing grounds where we released 315 tagged herring, 40 of these specimens, i.e., 12.7% were caught again between April 29 and May 3. The tagged herring caught were in good condition, and some of them were released for the second time (Table 1).

Somewhat later, the Polar Institute received 18 tagged herring specimens that were caught during June and July, 1953, in Valas-Ruchey, Ulyashikha, Maly Pitkul, and Luvenga inlets.

In 1953, the greatest number of tagged fish were caught in the tagging region of Valas-

Ruchey Inlet and the remaining few in the vicinity of that inlet. The farthest recapture was made approximately 15 km. from the tagging place.

In the spring of 1954, tagging operations were carried out in Knyazhaya, Valas-Ruchey, Palkina Inlets and Kandalaksha Bay. The tag return amounted to 401 specimens or 20% (see Table 1). From 250 specimens tagged on April 26, we caught 50 specimens or 20% of the released fish three days following tagging. One of the specimens was caught 2 km. from the place where it was released on the Zolotaya Korga fishing grounds 4 hours following tagging. The return of herring tagged on April 27 reached 19.0% within the first three days. The herring tagged in Palkina Inlet on April 29 were caught again in Valas-Ruchey Inlet, and the herring released in the region of Valas-Ruchey receiving point were caught in Palkina Inlet.

One hundred and thirty specimens were tagged on April 21, 1954, in Zhemchuzhnaya Gulf. No tag returns were observed during the first few days, due, probably, to the short period of fishing. The herring tagged in April and May, 1954, in Kandalaksha Bay, were caught in June and July in the region of the Tersky coast. Thus, the herring tagged on April 21 in Zhemchuzhnaya Inlet were caught on May 8 in the vicinity of Kuz River, 120 km. from the place where the herring were released. During June and July, in the region of the Tersky coast, we caught 20 herring specimens released in Valas-Ruchey and Zhemchuzhnaya Inlets.

The mean speed of movement of herring from the spawning grounds in Kandalaksha Bay to the Tersky coast, where their feeding grounds are undoubtedly situated, was about 4.5 km. a day. The herring tagged as No. 2179 in April 29, 1954, in Palkina Inlet (Tables 2 and 3) covered that distance (7.7 km.) at the greatest speed.

The herring tagging carried out in the White Sea showed that the tag type selected by the Polar Institute is sufficiently effective. The herring stand the tagging satisfactorily. A number of tagged specimens were recaptured 1.5 - 2 years later[1/]. A herring specimen bearing an analagous tag spent 202 days in the Norwegian Sea. We must nonetheless assume that herring thus tagged can scarcely endure that type of tag for more protracted periods of time. The tag is clearly noticeable and may be easily detected even in large catches.

The tagging of White Sea herring showed that reserves of these fish are very limited. Only thus can we explain the exceptionally high percentage of tag returns-- 9.2% in 1953, 20% in 1954 (Table 3). Moreover, we must keep in mind that no real fishing was conducted on herring during the spring of these two years.

We set 5 test traps in the spawning grounds where a considerable number of tagged fish were caught. We wish to point out that 30-35 traps were set in Valas-Ruchey Inlet. It is evident that by using such a large amount of fishing gear, the fishing intensity was multiplied several times, and, therefore, the fishing industry thoroughly exploited different year classes within two, at most three years, even when the year classes in question were more than ordinarily abundant.

In 1953, all recaptures of tagged herring were obtained in the vicinity of the tagging region, a fact that deserves particular attention. In 1954, twenty specimens were caught off the Tersky coast, in the vicinity of the River Kuz in Olenits Inlet and near the Varzuga estuary.

1/ In 1955, 9 tags, taken from herring caught from July to October 1955 in Kandalaksha Bay were brought to PINRO. Specimen #976 was caught in 890 days, three specimens in 780 days, five specimens - 407 to 525 days.

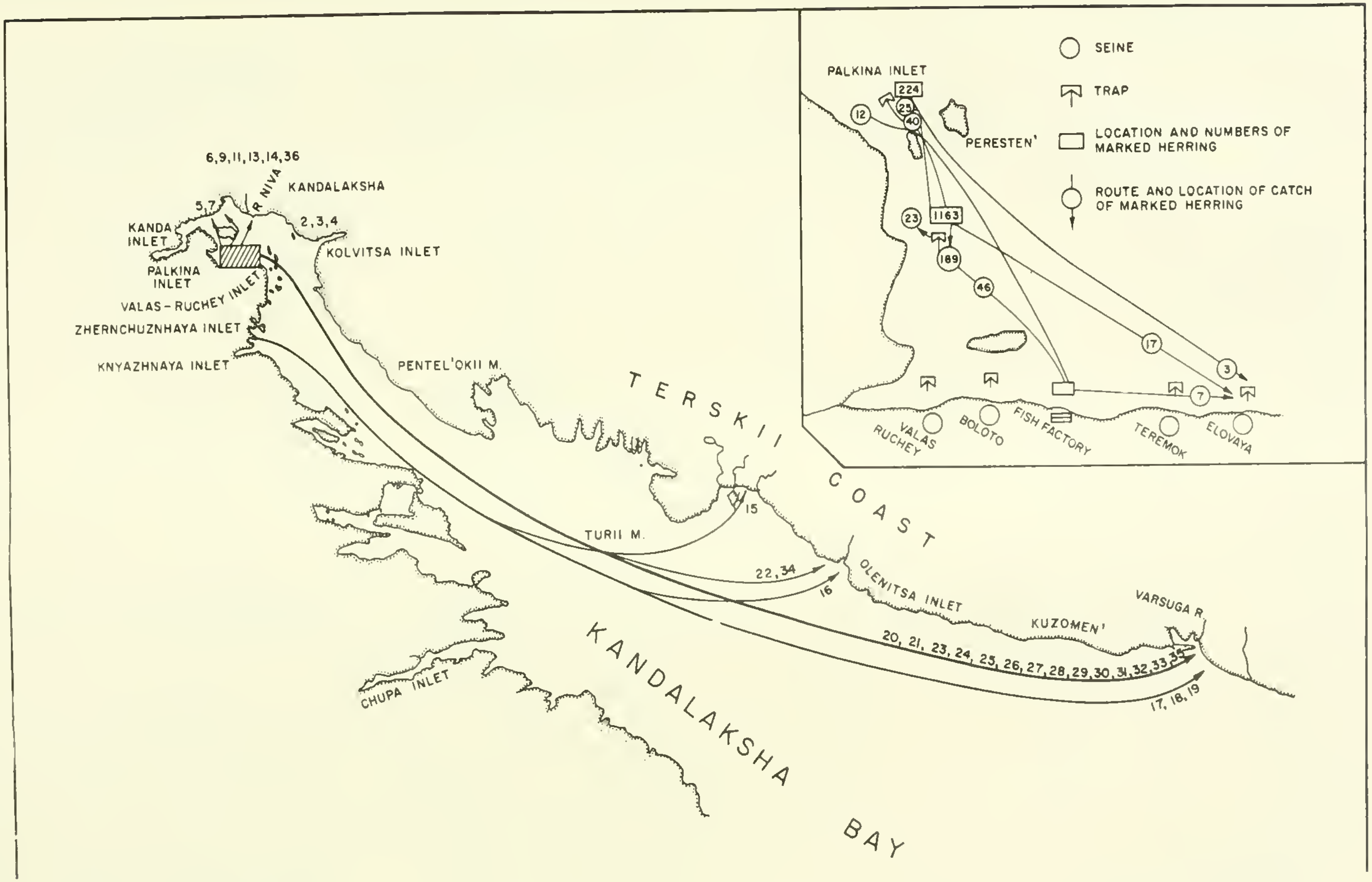

Figure 3. Map showing tagging points and points of return of tagged herring in Kandalaksha Bay during 1953-1954. Figures in the drawing correspond to the numbers of tags in Tables 2 and 3: 1-175; 2-233; 3-325; 4-389; 5-447; 6-666; 7-737; 8-742; 9-791; 10-810; 11-812; 12-826; 13-1000; 14-596; 15-12; 16-41; 17-66; 18-107; 19-126; 20-1090; 21-1103; 22-1131; 23-1143; 24-1380; 25-1384; 26-1478; 27-1479; 28-1560; 29-1628; 30-1714; 31-2179; 32-2188; 33-2381; 34-2402; 35-2455; 36-2460.

TABLE 1. INFORMATION ON THE RECAPTURE OF HERRING, TAGGED IN THE YEARS 1953, 1954.

Data about the tagging			Recapture (return in days) after:										
Date	Region	Quantity of marked fish	1	2	3	4	5	6	in all	from 7 to 30 days	to 60 days	More than 60 days	Total recapture
	1953												
April 20		48	--	1	--	--	--	--	1	--	--	--	1
April 22	Valas-Ruchey Inlet, Valas-Ruchey Fishing Grounds	169	4	2	1	2	1	--	10	1	--	--	11
April 23		114	--	1	2	1	--	1	5	2	--	--	7
April 24		121	1	1	--	--	2	1	5	5	--	--	10
April 26	Valas-Ruchey Inlet, Bolotnaya Fishing Grounds	135	4	--	1	1	1	--	7	1	--	--	8
April 27		151	1	6	1	1	1	1	11	2	--	--	13
April 28	Valas-Ruchey Inlet, Yelovaya Fishing Grounds	315	19	14	3	3	1	--	40	2	3	3	48
April 29	Valas-Ruchey Inlet, Bolotnaya Fishing Grounds	17	--	--	--	--	--	--	--	1	--	--	1
	Total	1070	29	25	8	8	6	3	79	14	3	3	99
	Return in % of tagged herring		2.8	2.4	0.7	0.7	0.5	0.3	7.4	1.4	0.2	0.2	9.2
	1954												
April 21	Zhemchuzhnaya Inlet	130	--	--	--	--	--	--	--	1	2	2	5
April 26	Valas-Ruchey Inlet, Bolotnaya Fishing Grounds	250	35	11	4	16	1	--	67	--	2	2	71
April 27	Valas-Ruchey Inlet, Zolotaya Korga Fish. Grounds	456	41	12	36	9	4	1	103	--	6	--	109
April 28		373	34	45	7	7	--	--	93	--	--	1	94
April 29	Palkina Inlet	220	29	5	6	2	--	--	42	--	2	--	44
April 30	Valas-Ruchey Inlet, Bolotnaya Fishing Grounds	239	29	9	12	--	--	--	50	--	2	--	52
May 2	Valas-Ruchey Inlet, Zolotaya Korga Fish. Grounds	146	3	--	--	--	--	--	3	--	--	--	3
May 3		70	--	--	--	--	--	--	--	1	1	--	2
May 7	Kandalakshskaya Inlet, Sal'nyy Is.	125	16	3	--	--	--	--	19	--	2	--	21
	Total	2090	187	85	65	34	5	1	377	2	17	5	401
	Return in percent of tagged herring		9.2	4.4	3.1	1.7	0.3	0.05	18.75	0.1	0.8	0.3	19.95

TABLE 2. INFORMATION ON HERRING TAGGED IN KANDALAKSHSKA BAY IN 1953 AND RECAPTURED AFTER MORE THAN 8 DAYS.

Number of tag	Facts about the tag		Facts about Recapture		Number of days in sea	Distance travelled in Km.	Average speed per day in Km.
	Date	Region of Valas-Ruchey Bay	Date	Region			
175	April 22		April 30	Valas-Ruchey Bay, Yelovaya Fishing Grounds	8	3	0.4
233	" 23		June	Kandalaskshskaya Inlet, Luvenga Fishing Grounds		15	
325	" 24	Valas-Ruchey Fishing Grounds	"	Same		15	
389	" 24		"	"		15	
447	" 26		"	Kandalakshskaya Inlet, Ul'yashikha Inlet		13	
		Bolotnaya Fishing Grounds					
666	April 27		June	Same		10	
737	" 28		"	"		14	
742	" 28		July 3	Valas-Ruchey Inlet	67		
791	" 28		June	Kandalakshskaya Inlet		10	
810	" 28	Yelovaya Fishing Ground	July 10	Valas-Ruchey	74		
812	" 28		June	Kandalakshskaya Inlet		10	
826	" 28		July	Valas-Ruchey Inlet			
1000	" 28		June	Kandalakshskaya Inlet			
596	" 29	Bolotnaya Fishing Grounds	June	Same		10	

TABLE 3. INFORMATION ON HERRING TAGGED IN KANDALAKSHSKAYA BAY IN 1954 AND RECAPTURED AFTER MORE THAN 8 DAYS.

Number of tag	Facts about the tag		Facts about Recapture		Number of days in sea	Distance travelled in Km.	Average speed per day in Km.
	Date	Region	Date	Terskyy Coast Region			
12			May 8	S. Kuzreka	17	120	7.1
41		Knyazhaya Inlet,	June 28	Olenitsa Inlet	67	138	2.1
66	April 21	Zhemchuzhnaya Inlet	June 18	Varzuga Estuary	57	220	3.9
107			June 29	Dvininskaya Fishing Grounds	68	220	3.2
126			June 15	Varzuga Estuary	54	220	4.1
1090			June 18	" "	55	240	4.4
1103	April 26		July 2	Dvininskaya Fishing Grounds	68	240	3.5
1131			June 28	Olenitsa Inlet	64	153	2.4
1143			June 19	Varzuga Estuary	55	240	4.4
1380			June 1	" "	36	240	6.6
1384		Valas-Ruchey Inlet,	June 17	" "	52	240	4.7
1478	April 27	Zolotaya Korga Fishing Grounds	June 6	S. Kuzomen'	41	240	5.8
1479			June 11	Varzuga Estuary	46	240	5.2
1560			June 15	" "	50	240	4.8
1628			June 19	" "	54	240	4.6
1714	April 28		June 29	" "	63	240	3.8
2179	April 29	Palkina Inlet	May 31	S. Kuzomen'	33	254	7.7
2188			June 9	Varzuga Estuary	42	254	6.0
2381	April 30		June 15	Varzuga Estuary	47	240	5.1
2402			June 28	Olenitsa Inlet	60	150	2.5
2455, 2460	May 3	Valas-Ruchey Inlet, Bolotnaya Fishing Grounds	June 11	Varzuga Estuary	39	254	6.5
			May 11	Kandalakshskaya Inlet region, Sal'naya Fishing Grounds	8	10	0.8

It is quite probable that the migration of a number of herring to the Tersky coast, beyond the borders of Kandalaksha Bay at the end of the spawning period of 1954, was conditioned by the large size of these herring, since the six-year-old specimens formed the prevalent age-group among the fishes tagged in 1954.

Deductions

1. The method of tagging herring that has been developed by the Polar Institute proved fully effective. The herring endure the tagging operation satisfactorily and develop quite normally following tagging. Several specimens were recaptured 1.5 - 2 years after tagging. The tags are clearly seen even in large catches.

2. The tagging of White Sea herring showed that during the feeding season these fish migrate from the arm of Kandalaksha Bay to Tersky coast.

3. The high return of tagged herring confirmed the theory that White Sea herring are not numerous.

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THE BIOLOGICAL FOUNDATIONS OF THE FISHERY

OF THE WHITE SEA HERRING

B. M. Tambovtsev

Investigations of the White Sea herring can be divided into two periods: 1) the study of the systematic position and 2) the study of the biological structure or composition of catches.

Even the first investigators Lepekhin (13), Danilevsky (8) pointed out the heterogeneity of the White Sea herring, and thus a study of the racial composition constitutes the sum of the work of the first period /Rabinerson (14, 15, 16), Averintsev (1, 2), Antipova (5)/.

The studies of the second period, carried out by the Kandalaksha station of VNIRO in the years 1934-1941, and continued in the years 1942-1951 by the White Sea station of PINRO, were concerned principally with the biological composition of catches. They made it possible to proceed to the estimation of fish stocks and to catch forecasting /Averintsev (3), Dmitriev (9, 10), Tambovtsev (17, 18)/.

Observations of the biological composition of catches allowed us even as early as 1939 to note the diminution of the White Sea herring stock.

Researches into reproduction and distribution in the period of fattening and in the winter period led to a deeper understanding of the biology of the White Sea herring and made it possible to plan measures towards the organization of a rational fishery for this fish.

One of the biological peculiarities of the small form of the White Sea herring is the restricted area over which it is found and the fact that it lives close to the coast. These herring are peculiar to the White Sea, where they form separate biological schools /Dmitriev (11)/. The small herring spend their whole life cycle in the White Sea, beyond the bounds of which they do not venture.

A characteristic peculiarity of the White Sea herring is their attachment to the coastal zone. This peculiarity is most marked in the reproductive period. The wintering of the small White Sea herring is also bound up with the coastal zone. The small herring of the Onega and Dvina gulfs winter in the stretches of sea in front of rivers near the shore, where the inflow of fresh water creates more favorable temperature conditions than in the open parts of these gulfs where, as a result of the absence of a solid covering of ice, there is a marked fall in the temperature of the water. Only the small Kandalaksha herring winters at a depth of from 25 to 50 metres in the region of a warmer stratum of water with a temperature near 0. In the period of fattening, the area of distribution of the small White Sea herring extends into the coastal waters of the Tersky coast.

According to the researches of Borodatov and Dmitriev, in June and July the herring remain near the coast and only in August-September move out into the open parts of the gulfs /Dmitriev (11)/.

Our researches allow us to conclude that numerically large year classes of small White Sea herring are more widely distributed than numerically poor year classes. Researches of the year 1951 showed a migration of small Kandalaksha herring to the Tersky shore, and also southwards, to the region of Keret'-Gridino. The numerically strong 1948 year-class, when four years of age, was caught soon after the end of the spawning period in great quantities on the Tersky shore, west of the village of Tetrino.

At the present time, marking has demonstrated the migrations of small Kandalaksha herring. In May and June 1954, at various points of the Tersky shore - from the river Kuz to the mouth of the Varsuga - herring were caught which had been marked at the end of April and beginning of May 1954 in the inner part of the Kandalaksha Gulf, in the Palkina, Valas-Ruchey and Knyazhaya inlets /Vilson (7)/.

However, the extension of the area of distribution of the small Kandalaksha herring is limited to the coastal zone; in the open region of the central part of the White Sea, fishable concentrations of this fish have not been found. Our observations on the 14th voyage of the "Tropik" and the findings of search vessels have shown that in the summer of 1951 in the region of the Tersky bank this herring was caught only by shore-fishing gear, but was almost absent from the hauls of drifter nets.

Another characteristic peculiarity of the biology of the small White Sea herring is their comparatively short life-span. Only the small Kandalaksha herring live as much as ten years, whereas the other small herring have a shorter life-cycle. The life-cycle of the Onega herring is limited to eight years and that of the Dvina herring to six.

The most important small herring for fishery, however, are: the Kandalaksha herring - up to 6 years of age; the Onega and Dvina herring - up to 5 years.

The fertility of the small White Sea herring is not great. In the Kandalaksha herring, for three-year-old fish it is 3-4 thousands; for four-year-old fish, 6-7 thousands; and for five-year-old fish, about 12 thousand eggs. During its whole life, one female of the small herring produces: Kandalaksha herring, 25-30 thousand; Onega, 20-23 thousand; and Dvina, around 20 thousand eggs. In comparison with other herring (Atlantic, Caspian), the White Sea herring are markedly less fecund. The change in fecundity in connection with the general weight of the fish in the White Sea herring has been already studied /Bezrukova (6)/.

The reproduction of the White Sea herring takes place in a narrow coastal zone at a depth of 2-5 metres, chiefly at a depth of 2-3 metres. In spite of the fact that the coastal character of the reproduction of these herring has been known for a long time, Dmitriev (9) nevertheless suggested the possibility of the spawning of White Sea herring far from the shore. He also (11) considered possible the autumn-spawning of White Sea herring. More recent researches have not upheld these suppositions.

Searches for the spawning-places of small White Sea herring in the Dvina Gulf and in the eastern part of Onega Gulf and of large herring in Kandalaksha Gulf and in the region of the Solovetsky Islands, which were carried out by us in post-war years, also showed that the spawning of these fish takes place in the narrow coastal belt at a depth of no more than 5 metres.

Spawn of the small herring was found in the region of the Letni (Summer) shore and in the inlets of Unskaya and Yandovaya (Dvina Gulf), on the Seldyanye Ludy, at Kiy Island and in Pokrovskaya Inlet (Onega Gulf); the spawn of large herring was found in the region of the Solovetsky Islands (Glubokaya Inlet and other places) and in Kandalaksha Gulf (Kiberinsky shore). All the spawning-places of White Sea herring thus discovered are situated in the coastal zone at depths of from 0.5 to 5 metres /Altukhov (4)/.

The development of the eggs of White Sea herring takes place in a littoral distinguished by great inconstancy of external conditions, especially in the spring period.

For example, the development of the eggs of the small Kandalaksha herring begins at a below-zero temperature and ends when the water has been considerably warmed up. Other herring in this connection enjoy more favorable conditions. Thus the spawning places of the Atlantic herring are at a depth of more than 50 metres, and the development of the eggs of this herring takes place under more uniform environmental conditions.

The biological peculiarities we have mentioned have a great importance for the organization of a rational herring fishery in the White Sea. They show that the stocks of White Sea herring are in need of cdreful conservation and that the conditions of reproduction have a big influence on the number of these herring. And yet the reproductive ability and the conditions of reproduction of the fish are considerably vitiated by the present fishing methods.

During the last 30 years, very real changes have taken place in the White Sea herring fishery. A spring catch of herring has become general in all regions. As late as the 20s, in most fishery regions of the White Sea, herring were caught only in autumn or winter. A spring catch either did simply not occur, or else it was insignificant. At the present time, it has become fundamental everywhere (Table 1).

TABLE 1. HERRING CATCHES IN DIFFERENT YEARS OF THE FISHERY (IN PERCENTAGES).

Fishery Regions	Years of fishery	Fattening	Herring pre-spawning	Spawning
Onega Gulf West Shore	1932-1941	6.8	37.7	55.5
	1942-1951	1.3	33.1	65.6
East Shore	1932-1941	18.0	40.0	42.0
	1943-1951	5.9	20.0	74.1
Dvina Gulf	1933-1941	7.2	48.2	44.6
	1945-1951	20.0	16.1	63.9

Already in pre-war years, the spawning herring were caught in a larger quantity than the fat herring; in the post-war period, the catch of this herring increased still more. During the last few years, both in the Onega and in the Dvina gulfs, the greatest quantity of herring was caught during its spawning period. At the same time, there was a decrease in the fishery for fat and especially for pre-spawning herring.

If, in pre-war years on the eastern coast of Onega Gulf, the winter catch of herring amounted to 40% of the yearly catch, in post-war years on the other hand, catches of pre-spawning herring dropped by half. At the same time, the catch in the spring period increased and the catch of spawning herring began to constitute about three-quarters of the annual catch. In Dvina Gulf, the catches of spawning herring have latterly increased notably, but those of pre-spawning herring have fallen off sharply. In Kandalaksha Gulf, the spring fishery has latterly undergone very great changes. The use of zaveski[1/] has greatly increased the productivity of the fishery and has increased the catch of spawning herring. Fishing has been transferred right to the spawning grounds and has begun also to utilize the movement of the herring into those sectors where in the past, owing to the absence of suitable places for sweep-net fishing, no herring were caught.

The use of zaveski has also lengthened the duration of the spring catch; furthermore this lengthening took place principally in the direction of a greater catch of spawning herring. The spawning migrations of small herring in Kandalaksha Gulf usually begin in the first ten days of April. To begin with, the herring are caught in gill-nets; first in nets stretched before the entrance to the inlets, afterwards in nets standing in the inlets themselves. Afterwards the herring are caught in drag nets and still later in zaveski. The greatest number of herring fall into the zaveski in the period when the sweep-net fishing is in fact ending.

In 1936, net fishing for small Kandalaksha herring in the inner part of Kandalaksha Gulf (inlets Valas-Ruchey, Palkina and others) went on from the 7th to the 17th of April, fishing with drag nets - from the 16th to the 23rd April and with zaveski - from the 20th to the 26th April. The biggest catches were in the zaveski from the 23rd of April, when herring were no longer being caught in sweep-nets.

Observations of sexual maturity showed that the most intensive spawning of herring in 1936 in Valas-Ruchey Inlet was from the 20th to the 25th of April and was accompanied by massive catches in the zaveski. Furthermore, it was noticed that the nets and the drag nets caught principally herring still preparing to spawn; whereas, in the zaveski, spawning herring with flowing sexual products. Thus the use of zaveski prolonged the duration of spring fishery by way of the massive catches of herring on the spawning-beds themselves.

As a result of the fact that the reproduction of the White Sea herring takes place in a narrow coastal zone where fishing is easy and the fact that all the adult herring swarm together by the shore for the spawning, its fishery in the period of reproduction is the principal factor influencing the stock of White Sea herring. In the spawning period, a great quantity of reproducing herring are taken out and thus the reproductive ability of the herring as a whole is sharply reduced.

It is characteristic that the stocks of herring have fallen most sharply in those fishery regions which have been subjected to the most intensive fishing and in which, consequently, the conditions of reproduction of the herring have been the most adversely affected. It is therefore quite understandable that in Kandalaksha Gulf where the spring fishery for the last 30 years has been the most developed, the herring stocks have dropped very sharply.

On the left shore of Onega Gulf where the spring fishery began comparatively recently and where the same equipment and aids to fishing have not been employed as in the Kandalaksha Gulf, the herring stock is in a noticeably better condition, and indeed there is even noticeable some increase in catches.

As a result of the intensification of the spring fishery, the composition of the spawning population of small White Sea herring has markedly changed, and the fishery has begun to be based on the catch of younger age groups (Table 2).

1/ Author's footnote: "A construction of fixed traps". Various meanings of this word: 1. curtain; 2. curtain-rod; 3. (leaf) hinge. Presumably a local word in the sense in which the author uses it. Trans.

TABLE 2. THE MEAN AGE COMPOSITION OF THE SPAWNING POPULATION OF SMALL WHITE SEA HERRING (IN PERCENTAGES).

Form of herring	Years	Age						
		2	3	4	5	6	7	8
Kandalaksha herring	1923-1934	0.3	25.7	38.1	22.1	10.5	3.1	0.2
	1935-1950	21.7	50.1	23.5	3.9	0.6	0.2	0.1
Onega "	1934-1943	22.8	59.2	14.5	3.2	0.3	--	--
	1944-1951	34.3	49.2	14.2	1.8	0.4	--	--
Dvina "	1941-1946	33.4	50.8	12.0	3.8	--	--	--
	1947-1951	42.4	48.7	8.5	0.4	--	--	--

In the first period of fishery from 1923 to 1934, the great mass of the spring population of small Kandalaksha herring consisted of 3 age groups: 4-year-old fish in first place; 3-year-old fish; and 5-year-old fish. In the second period from 1935 to 1950, the great mass of herring was composed of 2-year-old, 3-year-old and 4-year-old fish. The number of 5-year-old and 6-year-old fish had fallen sharply.

If, in 1923-1924, herring over 4 years old constituted 35.9%, in 1935-1950 they only constituted 4.7%; on the other hand, the number of younger herring, 2-year-old and 3-year-old, rose in the second period to 72% as against 26% in the first period. The number of 2-year-old fish rose especially sharply. In the spawning population of small Kandalaksha herring in 1923-1934, 2-year-old fish were hardly found at all, but in 1935-1950 they constituted a fifth of the spawning population.

Thus observations over many years have shown that in the last period the age composition of the small Kandalaksha herring has greatly changed (see Figure).

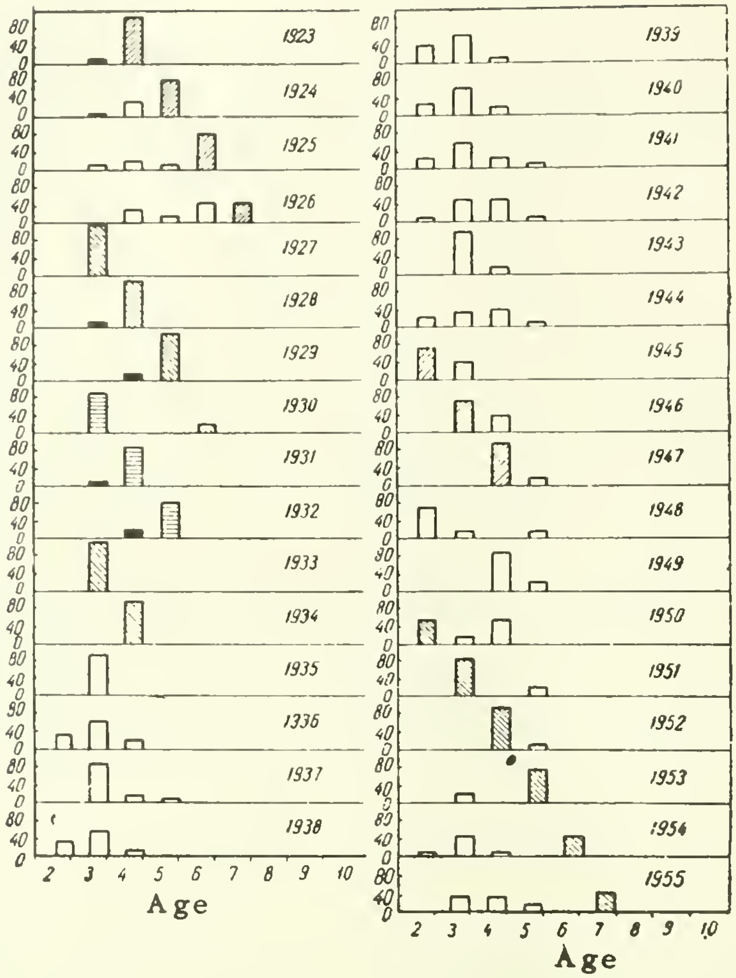
If before 1934 the predominance of one and the same year class over a series of years was strongly marked, since 1935, on the other hand, the fishery has been based every year on the catch of two-year-old and three-year-old fish.

The 1919, 1924, 1927, and 1930 year classes were all extremely numerous, and each one of them predominated in the composition of the spawning population for several years. Thus the 1919 year class constituted the main part of the spawning population from 1923 to 1926; the 1924 year class, from 1927 to 1930; and the 1927 year class, from 1930 to 1932.

In the years 1934-1950, the age composition of the spawning population became more uniform. The influence of individual numerically strong year classes was no longer to be seen, and the spawning population began to consist each year of three-year-old fish, i.e., each time of a new year class.

The simplification of the composition of the spawning population caused a sharp lowering of the number of small Kandalaksha herring and resulted in a decrease in the reproductive capacity of the species and a drop in catches.

The structure of the spawning population of the small herring of Dvina Gulf has also changed in the direction of the increase in number of two-year-old fish and a decrease in the number of older fish.



Age composition of the spawning population of small Kandalaksha herring in the years 1923-1955.

Thus in the summer of 1944 in this gulf, large-scale influxes of the young of the small Dvina herring were observed everywhere, which indicated the size of the 1943 year class and gave reason to expect an increased catch of this herring in 1945-46 when the aforesaid year class would be due to be caught. In reality there was to be no increased catch, although the 1943 year class predominated in the spring catches over two years and constituted, in the spring of 1945, 96% and, in the spring of 1946, 98% of the spawning population. The maximum catch of herring was in 1944. The catch in 1945 turned out to be much smaller, and the catch in 1946 the smallest. This state of affairs in the fishery was caused by the premature catching of the 1943 year class at the age of 1+.

A similar picture was presented by the 1948 year class, which was numerous in all parts of the White Sea; one might have expected that its advent into the fisheries in 1951 would have resulted in a notable catch increase. In the Kandalaksha and Onega gulfs, this is what happened; the catches of herring in these gulfs in 1951 were the biggest for some years. On the other hand, in

Dvina Gulf, there was an increased catch in 1950 but not in 1951. The smaller catch in 1951 is explained by the premature catching of the 1948 year class when two summers (1+ years) and when two years old.

The introduction of the prohibition of spring catching of the small Kandalaksha herring had a double aim: the restoring to strength of the spawning population and the use in fishery of the 1948 year class at a more mature age and greater weight. As a result of the prohibition, the 1948 year class was almost entirely protected from being caught in spring 1950 and became the object of a fishery only when three years old. In the spring of 1951, on the spawning grounds there were caught, by means of a controlled catch, 2,000 centners of herring. In the summer and autumn of 1951, the catch amounted to about 11,500 centners. In the spring of 1952, there were caught 800 centners of spawning and 4200 centners of fat herring. In the spring of 1953, there were caught about 800 centners of herring. In the summer and autumn of the same year, as many as 2,000 centners and finally in 1954 about 500 centners were caught.

Thus the catch of the 1948 year class was spread over several years.

Two thousand two hundred centners were caught at the age of three full years; 3+ year-olds and 4-year-olds amounted to 12,500 centners; 4+ year- and 5-year-olds --about 5,000 centners, 5+ and 6 around 2,000 centners. The exploitation of the 1948 year class provided the fishing industry with around 20,000 centners of herring. In addition, thanks to the abovementioned interdiction, the 1948 year class was caught at a maturer age, when the herring had reached a greater weight. The increase in weight of the 1948 year class according to A. P. Vilson's data, can be seen from the following figures:

Years	Age groups of herring	Weight in grammes
1950	Two-year-olds	15
1951	Three-year-olds	27.5
1952	Four " "	37.5
1953	Five " "	55
1954	Six " "	70

The annual increases in the weight of the herring constituted: for the third year 12.5 grammes, for the fourth year 10 gm., for the fifth year 17.5 gm., for the sixth 15 gm.

If we allow for an annual natural mortality of not more than 25-30%, the biomass 5-30%, the biomass of the year class is bound to increase from year to year.

If the 1948 year class had been used at the age of 2-3 years, then the catch would have been less by half. It follows that the restriction on the fishery on the spawning grounds has increased the catches of fat herring and in the final total has shown a greater productivity of fishery than there could have been if there had been an intensive catch of the generations when young. As a result of the interdiction, the spawning population of the herring was increased, and the fecundity of the individual herring and of the species grew (Table 3).

Marking showed the great intensity of the herring fishery in Kandalaksha Gulf. In the region of marking, there were along a stretch of 4-4.5 km. in the spring of 1953 five control sets of fishing gear in all. In the course of five days, 99 out of 1070 herring marked were caught for a second time. In 1954, the number of fish caught for the second time constituted 20% [Vilson (7)]. Earlier in the region of Valas-Ruchey Inlet in the spring there had been from 25 to 35 fish-traps, i.e., the intensity of the fishery had been several times greater. Therefore, we are entitled to assume that every year there had been caught not less than half of the spawning school and that year classes of medium strength had been caught over 2-3 years, and numerically weak year classes over 1-2 years.

TABLE 3. THE INDIVIDUAL FECUNDITY OF THE SMALL KANDALAKSHA HERRING OF THE 1948 YEAR CLASS ACCORDING TO THE DATA OF A. P. VILSON (IN THOUSANDS).

Years	1951	1952	1953	1954
Age	3	4	5	6
Fertility	6.3	10.8	12.7	19.5

In the spring of 1955, at the end of April and the beginning of May, great numbers of small herring 9 to 12 centimetres long and 11 to 15 grammes in weight began to appear in Kandalaksha Gulf.

Biological analysis of the 25 centners of herring caught on the 11th May in Kolvitsa Inlet showed that 90% of the catch consisted of young Kandalaksha herring two full years old.

The appearance in spring catches of two-year-old herring entitles us to assume that the 1953 year class is an exceedingly numerous one. This year class had partially matured by spring 1955 inasmuch as sexually mature individuals were all male. When it is three full years old and after, this year class will have reached full sexual maturity and in 1956-1958 will be the object of the fishery.

Thus the interdiction of spring catches is bound to protect the 1953 year class from premature catching and to give it the opportunity for unimpeded spawning.

In our opinion, the re-organization of the herring fishery in the White Sea must, principally, proceed in two directions:

1) the conservation of the ability of the species to reproduce itself, and
2) the best and most economically profitable fishing of the stock.

The first may be attained by the limiting of the fishery in the spawning period; the second by prohibiting the catching of the young and by fishing the older White Sea herring.

The use of the older age groups in the fishery is of great importance not only in connection with Kandalaksha herring but also for all other small White Sea herring. In particular, it will prevent the catching of the young of the herring in Dvina Gulf and will enable us to use this herring at 3 and 3+ years of age.

The catching of older age groups will enable us to increase the yield of White Sea herring even if their number remains the same.

For the organization of a rational fishery, the following are essential: constant observations of the condition of the herring spawning grounds; their biological amelioration; and the conservation of the vegetation which forms the substratum for the depositing and the development of the eggs of the White Sea herring.

On the spawning-beds, it is essential to organize the catching of stickleback, cod, Gadus navaga, smelt, and sculpin, which eat the eggs and young of the White Sea herring, and also to forbid the dredging of seaweeds and Zostera.

The present state of the White Sea herring fishery has led some fishery workers to doubt the possibility of the reconstruction of the White Sea herring industry.

In this connection, there have appeared in print suggestions for the raising of the productivity of the White Sea by the introduction into its fauna of fish from other areas /Kuznetsov (12)/. We consider, however, that it is possible to increase this productivity by means of the herring also.

As well as the introduction of new inhabitants into the White Sea, it is essential to concern ourselves with the restoration of the herring stock. The example of the small Kandalaksha herring seems sufficiently conclusive. It shows that by regulating the fishery we can change the composition of the spawning population in the desired direction.

This example also shows that one of the causes of the diminution of the stock of small Kandalaksha herring is undoubtedly the faulty organization of the fishery. The introduction of the inderdiction of spring fishing has lessened the effect of the fishing industry and as a result the reproductive ability of the small Kandalaksha herring has been able to increase.

Thus we see that the condition of the White Sea herring stocks is to a great extent determined by the organization of the fishing industry, and depends therefore to a great extent on the man's activity.

In addition to all this, the number of White Sea herring is greatly influenced by factors connected with the development of the spawn and the survival of the young in the early stages of their development.

Therefore, the task of further research is to establish what these factors are and to work out additional measures for the re-constitution of the stocks of White Sea herring.

Conclusions

1) The small small-boned herring which constitute the foundation of the herring fishing industry in the White Sea are distinguished by several biological peculiarities, the principal of which are a limited habitat, a comparatively short life-span, and low fecundity.

2) These peculiarities show that the stocks of White Sea herring are in need of serious conservation.

The introduction of the prohibition of the fishing of the small Kandalaksha herring during its spawning period protected the 1948 year class from premature catching and spread its yield over a period of time.

As a result of this prohibition, the herring spawning population increased, and the individual reproduction and the reproduction of the species also increased.

3) The example of the small Kandalaksha herring shows that it is possible, by regulating fishery, to change the composition of the spawning population in the direction we need. Therefore, the prohibition of herring fishing in the spawning period should be extended to other schools of

White Sea herring (the Onega and Dvina stocks).

4) The number of White Sea herring is greatly influenced by factors which determine the development of the eggs and the survival of the young.

In this connection, the prohibition of the fishing of spawning herring is clearly not the only means of increasing the stocks of White Sea herring.

5) The aim of further research must be to establish the abiotic factors influencing the survival of the young, and to work out additional measures for the re-constitution of the White Sea herring stocks.

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