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RESULTS OF A STUDY OF THE BIOLOGY OF SOCKEYE SALMON, THE CONDITIONS OF THE STOCKS AND THE FLUCTUATIONS IN NUMBERS IN KAMCHATKA WATERS

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ee zaposov i kolebanii chislennosti v vodakh Kamchatki

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The world's stocks of salmon are relatively low. In pre-war years around 8 million centners of these valuable fish were taken of which more than a third consisted of Kamchatka salmon. In the Kamchatka catches sockeye amounted to from 6 to 12%. But, since this species constitutes the most valuable raw material for the canning industry, their value increased to 25% of the value of the whole catch of salmon in Kamchatka.

P. 3 (2) Pacific salmon are taken at the time of their spawning migration and the fishery can be very intensive. Spawning once, with a comparatively low fertility and reproducing in fresh water where the conditions are very variable, places a limitation, for all species of Pacific salmon, on their reproductive capacity and requires an extremely attentive and careful concern for the stocks of salmon and, in particular, the sockeye.

P. 3 (3) The sockeye occupy a special place among Pacific salmon. They have the longest and most complicated life cycle (with the exception of *O. tshawytscha*); for spawning they require special water areas; the young spend the longest time in fresh water; for sockeye there is a most pronounced instinct for return to the natal river. These characteristics explain the variable occurrence of sockeye within their areas and complicate their reproduction (Krogius, 1951).

P. 3 (4) Sockeye, as in the case of the rest of Pacific salmon, spawn in the rivers of the Asiatic and American coasts of the northern parts of the Pacific ocean. Their feeding areas are in the North Pacific ocean. The major part of the Asiatic population of sockeye reproduce in the rivers of the Kamchatka peninsula and only a small part in the rivers of the west coast of the Okhotsk Sea and the north-west coast of Bering Sea. The great distance of travel from the feeding areas to the spawning rivers facilitates the possibility of catching the schools of sockeye during the migration period. 90% of all the local fishery for sockeye is obtained from the catches of those schools, produced in the Ozernaya River system on the western shore of the Kamchatka peninsula and in the Kamchatka River on the eastern.

P. 3 (5) From the end of the 1920's up to 1955 there were very great fluctuations in the catches of sockeye, caused not only by differences in intensity of fishing effort, but also because of the changes in the abundance of these fish. The highest level was reached at the end of the 1920's and in the second half of the 1930's (p.4); at the beginning of the 1930's a reduction in numbers of sockeye was noted, particularly clearly indicated on the east coast of Kamchatka. Consequently, under such conditions, the activities of the Kamchatka Division of TINRO were directed especially to a study of the sockeye.

HISTORY OF INVESTIGATION

P. 4 (1) At the time of the organization of the Kamchatka Division of the Pacific Institute of Fisheries Research and Oceanography (TINRO) in 1932, the Kamchatka sockeye had been very little studied. Individual observations on the biology of the sockeye had been made by P.U. Schmidt (1916) and A.N. Derjavin (1916); there should be mentioned especially the work of I.I. Kuznetzov (1928) which contains most detailed data on the reproduction of sockeye, and also the work of M.P. Somov (1930, 1930a) on the sockeye of the

Kamchatka River system. Therefore, in the initial period, in addition to the investigations directed toward the solution of the main problem - an understanding of the causes of the fluctuations in the numbers of sockeye - it was important to accumulate general information on them. Investigations were conducted in the Ozernaya River system by E.M. Krokhin and F.V. Krogius in 1932/33; on the Kamchatka River by V.S. & V.B. Bool, M.V. Jeltenkov, B.F. Kurnaev, D.G. Manizer, I.I. Lagunov, A.I. Synkova, K.A. Laumin, V.A. Rudakov from 1932 to 1944; in the Bolshaya River system by F.V. Krogius, E.M. Krokhin, A.S. Baranenkov, R.S. Semko from 1932 to 1934. The results of these studies have been published, in part (Krokhin & Krogius, 1937, 1937a).

P. 4 (2) These expeditions of investigation emphasized the necessity of studying salmon, particularly sockeye, at a specific site. Studies were undertaken in 1937 in the Paratunka River area and endeavoured to elucidate the relation of fluctuations in numbers of sockeye to the conditions of reproduction and to establish production coefficients for this species, which would be necessary for the development of methods of making up predictions of the fishery (Krogius and Krokhin, 1948).

P. 4 (3) In 1940 there was established an observation station on the Ozernaya River, for the purpose of checking on the huge stock of sockeye, reproducing in the Kurile Lake area. The studies were conducted by V.I. Gribanov and V.V. Azbelev and from 1950 to the present time have been carried on by T.V. Egorova and F.E. Lashko.

P. 4 (4) Prior to 1948 the investigations on the Kamchatka River consisted chiefly in the collection, in the Kamchatka delta, of bio-statistical information and its subsequent analysis. Investigations in the river basin were of a general nature. More intensive and specific investigations began in 1949, after the sudden decline in the numbers of sockeye, observed in 1948. To these studies were assigned V.V. Azbelev and V.I. Cineukova and in 1950 they continued their work under the guidance of I.I. Kurenkov. The investigations were directed to make known the present-day conditions in the reproduction of sockeye and to develop measures for increasing their numbers, and also for the acclimatization of the fish (transplanting to new areas, presumably. R.E.F.).

P. 4 (5) In 1935 V.I. Gribanov and E.M. Krokhin proposed a scheme for introducing a run of adult sockeye into Kronotz Lake. In the spring of 1935 the lake was investigated by E.M. Krokhin and M.L. Alperovich (Krokhin, 1936). This question was again raised in 1952 and in the autumn of that year, during the period of spawning in the lake, E.M. Krokhin and I.I. Kurenkov surveyed the Kronotz River and the eastern part of the lake (Krokhin & Kurenkov, 1954).

P. 5 (1) In 1954 F.V. Krogius carried out a brief study of the Palana River and Palana Lake, formerly the location of spawning of schools of sockeye, which provided, at the end of the 1920's, catches of up to 23,000 centners, but at the present time none of commercial significance. Since 1951 F.V. Krogius has been using an aerial method of study of the condition and abundance of the spawning adult sockeye in the Kamchatka River system (Krogius, 1955).

P. 5 (2) Studies of sockeye in the sea were limited to certain investigations in coastal sections; thus, in the jurisdiction of the Kamchatka Department of the Pacific Institute of Sea Fishery Research & Oceanography (TINRO), during several summers under the direction of W.W. Korslev, M.L. Aplerovich and N.N. Spassko, drift netting for sockeye was carried out in the Gulf of

Kronotz. For the purpose of determining the route of approach of salmon to the mouths of the rivers in the Kamchatka gulf marked sockeye were used by V.A. Rudakova and K.A. Lyamin and in Avachi Bay by P.A. Dvinin. Young salmon in Avachi Bay were studied by P.A. Dvinin and F.V. Krogius in 1939-1940. A.I. Synkova published data on the feeding of salmon on their approach to the spawning rivers (Synkova, 1951). In 1954, in the course of a commercial scouting expedition, L.D. Andrievsky, a colleague of the Division, collected interesting material on salmon.

CONDITION OF THE STOCKS OF SOCKEYE

P. 5 (3) From the time of the conclusion in 1907 of a fishery convention with Japan up to 1944 there has been in Kamchatka a Japanese coastal set net fishery for salmon in the Convention Areas. In the first half of the 1930's a Japanese salmon fishery was initiated and began to develop rapidly in the open sea along the south-east coast of Kamchatka and along the north of the Kurile Islands, reaching maximum intensity at the end of the 1930's. The huge catch of sockeye along the coast of the peninsula caused, early in the 1940's, a decline in their abundance in the Kamchatka River and in the Ozernaya (to a lesser degree).

P. 5 (4) The Ozernaya stocks of sockeye, the spawning runs of which reach 8 million individuals, have been under complete check now for 14 years; for this period we have authoritative information on the fluctuations which have taken place in their abundance. Usually the sockeye return to spawn in the Ozernaya River in the 6th year of life, therefore in the 6th year after an abundant spawning there was noted a run of increased numbers (1943-1949, 1945-1951, 1947-1953). Since prior to 1940, the distribution of spawners in the Ozernaya River system was not checked, it is not known what fluctuation in adult sockeye occurred in the pre-war fishery for those sockeye migrating to the rivers on the west coast of Kamchatka. The fishery amounted to 250,000 centners, of which around 200,000 were taken in the Ozernaya River area. From 1940 to 1944 when there existed a Japanese fishery in the open ocean and in the Concession Area, the catch of Ozernaya sockeye amounted, on the average, to around 80% of the number of migrating schools and reached 85%; from 1945 to 1951 the catch was, on the average, 56% and never exceeded 76% of the total migrating run. After 1944 it was not just a question of the catch but the passage of adult sockeye in the spawning run to the Ozernaya River system increased, therefore the abundance of the Ozernaya River sockeye stock began to increase.

P. 5 (5) In 1953 the total catch comprised 77%, and in 1954, 94% of the whole migration of Ozernaya River sockeye. As a result, into Kurile Lake there escaped in 1953, 1.2 million sockeye, but in 1954 only 0.32 million. On the basis of many years' observations it has been determined that for the maintenance of brood years (p. 6) of sockeye above the average it is necessary to let through to the spawning grounds of the Ozernaya system 2.0 - 3.5 million adults. The spawning of 1.2 million adults, however, can, under good conditions for reproduction, give a brood year close, in numbers, to the average but 0.32 million adults, even under very excellent conditions, will give only an extremely small year class.

P. 6 (1) In the Kamchatka River the sockeye return chiefly in the 5th year of life. After the huge catch in 1937-1939 there occurred a reduction in abundance in 1942-1944. In 1942-1947 the sockeye catch was stabilized at a lower level than in the pre-war years. But, apparently, such a fishery was not able to improve the condition of the runs except under favourable conditions for reproduction; since these conditions did not prevail, the numbers in the run were sharply reduced in 1948, the decrease continued and in succeeding years made it necessary to introduce, as of 1951, a complete prohibition of sockeye fishing in the Kamchatka River and Kamchatka Gulf which continues to the present time.

P. 6 (2) A sudden drop in the abundance of sockeye occurred in 1948 also in the runs to other rivers of the east coast, for example the Paratunka system. Here, a complete count of the adult sockeye proceeding to spawn was made by the Kamchatka Division of TINRO in the rivers flowing out of Lakes Dalnee and Blizhnee. The fluctuations in the numbers of sockeye in the Kamchatka River and the sockeyes reproducing in Dalnee and Blizhnee lakes are very similar but they differ markedly from the variations in numbers of these fish in the Ozernaya River (Fig. 1).

RUNS AND NUMBERS OF SOCKEYE

P. 6 (3) The characteristic of Pacific salmon to return to spawn in their natal stream makes it possible to predict the numbers of them in the runs. In sockeye the adherence to the natal stream theory prevails to the greatest degree, and applies to local runs going to the principal tributaries of a river; for example, in the Paratunka system there are three separate populations of sockeye, each reproducing in its own river and in the springs which flow into it, which rivers flow into Dalnee and Blizhnee Lakes.

P. 6 (4) The fish of each population differ from one another in biological indices, in particular, in the structure of the scales. Quite apparent differences in the pattern of the scales in sockeye from known sections of the Paratunka system can be utilized to distinguish, in the ocean catches of set nets, the sockeye of different populations. Lately this method has been used to determine the sockeye of the Ozernaya and Bolshaya Rivers in the set net catches. For ocean investigations this method can be of help in distinguishing different populations of sockeye.

P. 7 (1) A determination of the principal factors that direct the movement of salmon to the spawning area is a matter of paramount importance both for the industry and for the development of measures to increase abundance. However, up to the present this question has been but little studied. The only investigations in this regard were carried out in 1950-1953 in the Paratunka system. It was established that sockeye proceed up-river preferably in the evening and morning hours under a minimal influence of temperature, oxygen and monocarbonate content, and their movement does not take place in direct relation to the light conditions. The physiological nature of this phenomenon up to the present time has not been studied. This makes it difficult to extropolate the results obtained to other areas (Krogius, 1955).

P. 7 (2) The timing of the runs of different biological groups and local populations of sockeye are not identical: in the Ozernaya sockeye occur from mid-June to mid-September; the principal run of early sockeye in the Kamchatka River takes place during June, but the late run - azabach - prior to the end of August.

P. 7 (3) The number of generations (year classes) of sockeye, as with other salmon, depends on the number of spawning parent fish and on the conditions in which took place the spawning, the development of the egg, the feeding of the young and their migration to the sea. A total of nine year-classes of sockeye in the Ozernaya River (from information of V. I. Gribanov, V. V. Azbelev and T. V. Egorova) reveals a direct relation between the quantities of parent fish (0.5 - 4.2 million) and the numbers of offspring (2.3 - 7.8 million). However, the effectiveness of reproduction was considerably greater in the cases of the spawning of relatively small quantities of adults: the correlation between these values changed from 1:1.5 for the spawning of large quantities of fish up to 1:5.7 and even higher in the case of small spawnings.

P. 7 (4) For the sockeye of Lake Dalnee, this correlation was somewhat different: instances were observed when from large quantities of spawning fish there resulted year-classes of small extent (1937 and 1944) and, on the contrary - when from spawning of small numbers of adults there resulted year-classes of large numbers (1935, 1942, 1949; Fig. 2).

P. 7 (5) Each spawning basin possesses a certain amount of spawning area; to it must conform the numbers of adults which succeed in passing to the spawning grounds and which can be determined with adequate accuracy. Studies of the spawning areas and the distribution of spawners in the Ozernaya and Bolshaya systems were undertaken earlier by the Kamchatka Division of TINRO (Krokhin & Krogius 1937, 1937a). At the present time similar studies are being carried out on the Kamchatka. The Kamchatka Division has developed and put into practice a new speedy method of determining the distribution of spawning salmon by the use of aeroplanes. (p. 8). These tests were made in the Kamchatka system for three seasons at the time of the spawning of early sockeye. In 1954 the aeroplane method was used for estimating the distribution of spawning chum salmon in the rivers of the Karagin Gulf. The air method permits in a very short period of time the making of a general estimation of the distribution of a spawning population of salmon and the comparing of the annual distribution with preceding ones (Krogius, 1955a).

SPAWNING

P. 8 (1) The time of spawning of the different biological groups and local populations of sockeye conforms to the time of the run. The sockeye of the Ozernaya differed the most in this respect, the spawning taking place from the end of August to February, in contrast to the early sockeye in the Kamchatka River which spawn from the second half of July to mid-August. Sockeye enter the river and arrive at the lake in silvery condition; spawning commences a month or more after arrival.

P. 8 (2) The spawning grounds of sockeye differ considerably from that of the other species of Pacific salmon; only sockeye utilize the lake spawning grounds, though they, like other salmon, spawn also in the rivers and springs. An unmistakable sign of a sockeye spawning area is the appearance of ground-water outlets during the day in the spawning area. By this one can deduce, in principle, the difference in the place of spawning of sockeye from that of pink salmon. For the latter, the most effective spawnings are in the river channels, where they deposit the eggs in the gravel at considerably shallower depths (10-20 cm), than the sockeye (up to 40 cm); washing of the pink salmon eggs results from this flow of filtered river water, but the sockeye eggs - from the flow of ground water; on the spawning areas they select as locations for nests (redds) places with the strongest current of ground water. Experiments at Lake Dalnee have shown that sockeye, established in a partitioned area in the littoral section, when deprived of a flow of ground water, do not deposit eggs and perish.

P. 8 (3) All the spawning grounds of sockeye are located in coarse - sandy alluvial ground. The lake spawning grounds occupy, as a rule, cones of deposits of lake tributaries, in some instances no longer now existing. The temperature of the ground in the spawning areas in the summer period is considerably lower than in the other parts of the littoral zone; thus, in Lake Dalnee the temperature difference could reach 6 - 7° (6 - 7° in the spawning areas and 13 - 14° in other sections). Both these peculiarities give, in river investigations, a simple means of determining the places suitable for spawning, in the case of absence of sockeye on the spawning grounds at the time of the regular inspection of the river system.

P. 8 (4) After deposition of the eggs in the ground the females guard the nests for 10 - 20 days. If the number of spawning adults is great, the late spawning fish often scatter on the surface of the gravel all the earlier-buried eggs and these perish. This explains the high mortality of sockeye eggs in the case of a superfluous quantity of adults on the spawning grounds.

P. 8 (5) The embryonic development of sockeye continues under natural conditions and in hatcheries, for 5 months; from the data of M. Ya. Ievleva, 547 - 600 degree-days are required for this; from her observations also, of all the Pacific salmon, the sockeye have the slowest rate of embryonic development.

P. 8 (6) As prevails for the other salmon, the development of sockeye eggs takes place during the autumn - winter period, at the time of lowest water levels. A decrease in the ground-water flow in years with small quantities of precipitation frequently is (p.9) the cause of considerable loss of eggs during incubation. Freezing of the spawning grounds, frequently observed in the Amur, rarely occurs under the conditions present in the Kamchatka and does not involve the large spawning areas. As a rule, the ground water, providing a circulation of water in the nests, in comparison with the surface waters are poor in oxygen and richer in free carbon dioxide. These peculiarities were discovered during investigations in 1932 at Kurile Lake and in later more detailed studies at Dalnee.

P. 9 (1) Successful development of eggs under conditions of a decrease in oxygen content and an increase in carbon dioxide content shows that (1) sockeye eggs are not very sensitive to scarcities of oxygen and abundance of free carbon dioxide, as was once assumed to be the case, and (2) the role of ground water in the spawning grounds in the first instance, is to assure the removal from the sockeye nests of the harmful products of metabolism (Krokhin & Krogius, 1937 and Krogius & Krokhin, 1948). B. Ya. Levanidov (1954) came to this same conclusion in regard to autumn chum salmon. These conclusions have special significance in the case of the selection of a water supply source for the artificial propagation of sockeye.

P. 9 (2) The necessity to provide a favourable exchange of water for the development of sockeye, chum, and coho eggs in the spawning beds shows how important it is to maintain, in the beds of the spawning rivers, all the conditions which promote the cutting down of the amplitude of flood and drought waters and provide a high level of flow of ground waters. In the light of these requirements, particular significance attaches to the preservation of the forests in the water sheds of the spawning areas.

P. 9 (3) The loss of eggs under natural conditions during the time of their development can be very considerable. In Lake Dalnee they varied from 20 to 80% and on the average amounted to around 50%. In Lake Kurile the mortality of eggs reached an average of 25 - 30% and only once attained 65%.

P. 9 (4) Under artificial propagation, the survival of eggs can be much higher; experiments at the Ushkov hatchery demonstrated that under hatchery-incubation conditions there can be obtained up to 90% egg survival. But, as will be shown later, the loss of young, prior to downstream migration to the sea, is very great, therefore a high general efficiency of artificial propagation can be achieved only with a high survival of the young to the time of migration to the sea.

FEEDING OF THE YOUNG IN FRESH WATER

P. 9 (5) The development of sockeye larvae, as with other species of salmon, takes place in the gravel of the spawning grounds. In 1-2 months after hatch, with the completion of the absorption of the yolk sac, the fry appear on the surface of the bottom and begin to eat intensively. The time of emergence of the fry from the gravel in the different basins is not the same: the young of early sockeye in the Kamchatka River system appear in January - February, but in the Ozernaya system the young of the summer sockeye - from April to the beginning of September. The young, which appear in the spring and early summer, find at once better conditions than those appearing in the winter, but they have at their disposal less time for growth during the first year of life. The attainment, as a result of winter and first-year growth, of relatively large sizes increases the probability of seaward migration of yearlings. The loss of young in the early stages, i.e. immediately after emergence from the gravel, is very great; therefore studies of this period are extremely essential for discovering methods of increasing the efficiency of both natural and artificial propagation.

P. 9 (6) Investigations at Lake Dalnee have shown that after emergence from the gravel, young sockeye for a certain time (around 1 - 2 months) live in the littoral (p.10) part of the lake, feeding on small crustaceans, larval chironomids and terrestrial insects. Then they retreat to the pelagic part of the lake, where they live until they go to sea, feeding on Cyclopidae, Diaptomidae and Daphnidae. Similar data were obtained by Ricker for young sockeye in Canadian lakes (Ricker, 1937). In the rivers and springs the young sockeye feed in a similar manner on larval Chironomids, terrestrial insects and small crustaceans (Synkova, 1951).

P. 10 (1) In the lakes, the young perform vertical and horizontal migrations, feeding or escaping from predators. In the vertical shifts the young follow the food organisms but their means of communication may be organic hydrological factors. Vertical migrations are associated with the occurrence of autumn and spring circulations in the lakes and the shifts in the thermocline (Krogius & Krokhin, 1948; Krogius, 1953).

P. 10 (2) In connection with the investigations of the vertical migrations of the young new views developed, in principle, on the appearance of the thermocline in lakes. E. M. Krokhin showed that thermocline forms in the deep strata of the lakes and gradually rises upward but not the reverse, as was previously thought to occur. The vertical migration of the young sockeye at that time fully conforms with the hydrological processes in the lake (Fig. 3).

P. 10 (3) An investigation of the horizontal movements of the young in the lake is particularly important in connection with studies of the start and development of their seaward migration. It was found that the horizontal migration of the young in the period prior to seaward migration was dependent on the horizontal transfer of the water masses, associated with the off-and-on-shore appearances in the lake. Investigations of the horizontal migration and a determination of their directive processes have only been begun and require further continuation.

P. 10 (4) In the nursery water areas of the Kamchatka system in addition to the young salmon there dwell other fish: three-spined and many-spined sticklebacks, smelts ("inyashka") and char. The interrelationships involved in this ichthyological community have an intimate influence on the reproduction of sockeye.

P. 10 (5) In the Paratunka lakes, in addition to the young sockeye, there live three- and many-spined sticklebacks, anadromous and resident char and young coho. The three-spined (p. 11) sticklebacks live on the same plankton crustaceans as the young sockeye and therefore are their food competitors. The resident char are predators as regards the young sockeye and sticklebacks since they, to a large extent, devour sticklebacks. Therefore, to achieve improvement, it is necessary to attempt to reduce the populations of char and sticklebacks simultaneously (Krogius-Krokhin, 1948). It was established by us that approximately the same interrelationship exists among the fish in Azabachi Lake, but the competition there is not only with sticklebacks, but also with smelts. On the basis of an analysis of the interrelationships in the ichthyological community in Dalnee Lake there was conceived the idea of arranging a large-scale removal of sockeye-eating fish in Azabachi Lake as a preliminary improvement of the lake by means of reducing the numbers of predators and competitors (Krogius and Krokhin, 1954).

P. 11 (1) Valuable investigations on the food interrelationship were carried out in the Karymaisky springs (Bolshaya system). It was established that the predators of young sockeye appeared to be not only char but also the young of older age groups of other species of salmon and even sometimes sockeye themselves (Semko, 1948). These studies deserve continuation and should be verified in other river systems.

P. 11 (2) In the Kamchatka River system at the beginning of the 1930's there were introduced silver goldfish. Studies have shown that goldfish do not have an adverse influence on young salmon and, in particular, sockeye; this was the basis for recommending a wide distribution of goldfish in other spawning-nursery areas; this is being done at the present time in Kamchatka fish waters (Kurenkov, 1954).

P. 11 (3) For an accurate appraisal of the food relationships of the young with other fish, it is necessary to have quantitative evidence. A determination of the food ration of sockeye was undertaken at Lake Dalnee by three methods: feeding under experimental conditions, quantitative analysis of the stomach contents of the young captured in the lakes, and a method developed by us, based on the consumption of oxygen and the expression of this value in its equivalent in calories of quantity of food. All three methods gave consistent results (Krokhin, 1955a).

P. 11 (4) It has been shown that the daily (24-hour) ration of fingerlings varied during the year from 1.5% of body weight in winter to 11% in summer, but for yearlings - from 1.5 to 6.7% (Fig. 4).

P. 11 (5) The mean yearly daily ration of the young represents around 3% of its body weight. The daily ration for adult three-spined sticklebacks varied from 1.8 to 5.1% with a mean yearly ration of 2.7%. The yearly consumption of food by young sockeye and sticklebacks exceeded by 8-9 times their final weight, which is typical for plankton-feeding fish (Bokova, 1940).

P. 12 (1) In connection with the question of selection of food in the rearing of young salmon where different natural foods in Lake Dalnee are present, experiments were conducted with young sockeye, chums and cohos. It was noted that young chums and cohos thrive much better when reared on larval chironomids than on plankton. Young sockeye, on the contrary, grow more quickly on plankton foods. Therefore, for artificial development of young sockeye it would be most reasonable to rear them on plankton food.

P. 12 (2) Furthermore other factors, both biotic and abiotic, which are active in the rearing basin, influence the yield of young sockeye. Here reference may be made to feeding conditions which do not remain constant in different years. The annual biomass of plankton crustacea in Lake Dalnee varies from 2 to 4 g/m^3, in Lake Blizhnee - from 0.6 to 2 g/m^3, in the Kurile Lake - from 0.3 to 2 g/m^3. It has been established by us that the fluctuations in abundance of plankton are closely associated with the variations, in the different years, of the seasonal progression of hydrodynamic processes in the lakes (presence or absence of a complete spring circulation and its intensivenes, the position of the thermocline, etc.). With the shift of water masses in the lake is associated a rotation of the biogenic elements, and consequently - of the abundance of plankton. Inasmuch as the characteristics of the hydrodynamic phenomena, progressing through spring and summer, are, to a considerable extent, already predetermined by the large or small heat loss or heat uptake of a lake during the preceding winter, the possibility arises of making a prognosis of the favourability of conditions for development of plankton approximately a half year ahead. Differences in the dynamics of the water masses in the lakes to a very great degree are determined by the peculiarities of their morphometry. In a calculation of this kind one can successfully apply the general principle relating the dynamics of the water masses to the development of plankton, as derived in the Paratunka lakes, to the prevailing conditions in other lakes in Kamchatka (Kurile, Hachikin, Kronotzk, Azabachi, Palani).

P. 12 (3) In the regime of the biogenic elements of the spawning and nursery basins the carcasses of the spawned-out adult salmon have a special fertilizing effect (Krokhin, 1954). Our calculations have indicated that from the mass of sockeye carcasses in the lake there is produced a positive balance of phosphorus. An increase in the phosphorus content of the sockeye spawning - nursery lakes is confirmed by chemical analysis and also by comparative tests of the waters of different lakes by the method of biological productivity (Krokhin, 1955).

P. 12 (4) Questions of the food supplies in the rearing basins have been intensively undertaken accordingly in the Kamchatka River system. It has been shown that the biomass of benthic food organisms in the lakes of the Kamchatka River system exceed in some instances 200-500 kg/hectare and are not completely consumed by the young salmon; these studies showed that in the Kamchatka River system it is possible to introduce additional species of benthic-feeding fish, under the condition that this action will not adversely affect the propagation of Pacific salmon and in the first instance - sockeye (Kurenkov, 1953). Among such fish, in the opinion of the Kamchatka Division of TINRO, can be included carp, sterlet (small sturgeon) and sturgeon.

P. 12 (5) For an estimate of the food supply of the basin it is far from sufficient to consider the matter only of the biomass. It is much more accurate to deal with production of the food organisms. We have devised a method of calculating the production of one of the important food items of young sockeye - Cyclopidae. The method is based on almost a complete consumption of a summer generation of Cyclops by the young sockeye and the number of Cyclops generations per year. The calculation showed that production of Cyclopidae exceeds by approximately 2 - 2.5 times their biomass. (p.13). But this is only the first test of the determination of production, far from perfection.

P. 13 (1) On the basis of a relation observed by us, between the consumption of food crustaceans during the summer period and the number of seaward migrating young in the following 2 years, in the first test being expressed as a straight line, one may tentatively predict the number of migrating fish in the year ahead. Such a method of predicting the numbers of young in the seaward migration was checked by us under the conditions prevailing at Lake Dalnee; the results confirmed in principle the possibility of prediction. In addition it turned out that the noncoincidence of the supposed number of young in the seaward migration with the actual number was explained by the presence in the lake of consumers of food which did not take part in the seaward migration; here sticklebacks and dwarf (residual) sockeye were involved, the quantity of which could be approximated by computing from the size of the divergence between the predicted and the actual seaward migration.

P. 13 (2) The average size of yearling young sockeye in the Kamchatka system varies from 5 to 12 cm. and in weight - from 5 to 20 grams. The rate of growth of the young was very different not only in the different areas, but also in different years in the same area. Young sockeye have a very quick growth in the Dalnee and Achchyon (Chukotok) lakes and slower in Kurile Lake.

P. 13 (3) Studies at Lake Dalnee revealed that there exists an inverse relationship between the size and weight of migrating young and the number of plankton consumers in the Lake (Krogius, 1953). Consequently, in the lake, in spite of a relatively high plankton content, strained inter- and intra-specific relationships exist. Extensive competition for food unfavourably affects the growth and development of the young and caused them to be detained in the lake. Under the conditions of considerable retardation of growth during the first year of life the young fish remain in fresh water for a second or even a third year.

P. 13 (4) In certain lakes, for example in Dalnee, a portion of the young sockeye do not migrate to the sea and, reaching maturity, proceed to spawn. Like the males of Atlantic salmon, which spawn without going to sea, we designate these as residual sockeye. This applies chiefly to males which spawn in the third or fourth year of life. Residual females are quite a lot scarcer; they spawn chiefly in the fourth but sometimes also, in the fifth year of life.

P. 13 (5) From the spring and rivers, the young sockeye migrate chiefly as yearlings. At Kurile and Achchyon Lakes, the young migrate seaward as two- and three-year fish, in spite of a considerable difference in size. But in one lake the relation of numbers of young migrating seaward at different ages, does not remain the same from season to season. This indicates that the conditions for existence have an important bearing on the attainment of the migratory stages. Apparently, seaward migration is determined by the attainment, on the part of the young, of that stage of development which completes the preparation of the young for transition to another stage; the precise nature and character of this stage have as yet not been determined.

DOWNSTREAM MIGRATION OF THE YOUNG

P. 13 (6) The number of seaward migrants is the final result of all the complex processes of reproduction, which take place in fresh water. A count of the young sockeye (and in general all young salmon) was first made by the USSR at Lake Dalnee. Thus, in 1935 there was constructed in the Dalnee River a special weir. Later a count of young salmon was commenced at Karymaisky Spring, and now these are conducted also at fish-cultural (p.14) stations throughout Kamchatka. Because of the difficulty of installing a counting weir in a large river, up to the present time a count of the young, migrating down the Ozernaya River from Kurile Lake, has not been successful. For this same reason, in spite of the fact that for five seasons a fish-cultural station has been operated on Azabachi Lake, up to the present no count of the migrating young has been made, but only of the adult sockeye in the Azabachi River.

P. 14 (1) The relation of the number of downstream-migrating young to the number of eggs, contained in the mature females on the spawning grounds, reveals the index of efficiency of reproduction. At Lake Dalnee in the years of observation there spawned from 2,500 to 140,000 sockeye. The number of downstream-migrating young from a single generation (brood year) varied from 14,000 to 300,000 and represented 0.04 - 1.3% (the average for 17 seasons, 0.31%) of the eggs contained in the females present on the spawning grounds. For sockeye, produced in Karluk Lake (Alaska), this value amounted to 0.13 to 1.38% (average for 5 seasons - 0.45%) (Holmes, 1934). From calculations of the results of natural spawning in Cultus Lake (Canada) it was found that the seaward-migrating young amounted to 1.13; 1.05 and 3.16% of the eggs contained in the females. Substituting, for natural spawning, the planting in the lake of artificially-reared fry or eggs in the eyed stage did not give an appreciably higher efficiency of propagation and only destruction of predator fish in the lakes increased the survival index to 7.81% (Foerster, 1938; Foerster & Ricker, 1941).

P. 14 (2) The loss of young during the migration to sea is very great; the survival of the young in this period has, for reproduction, not a smaller but often a greater significance than survival of eggs during incubation; such as in those cases when loss of eggs does not exceed 50%.

P. 14 (3) The number of sockeye, returning to spawn in Lake Dalnee constitutes 10 - 38% (on the average around 20%) of the seaward-migrating young, i.e. these fluctuations are 10 times less than in the case of the relation of numbers of seaward-migrating young to the number of deposited eggs. Consequently, during the marine period of life the loss of sockeye is much less and more consistent than during the fresh-water period; therefore, the abundance of a brood year in the mature state is predetermined by the number of descending young (Fig. 2). This circumstance makes it possible to predict, with a good degree of accuracy, the abundance of a year class of sockeye from the count of descending young. At Cultus Lake the number of returning sockeye amounted to around 10% of the seaward migration of young, but at Karluk Lake 21% (Foerster, 1948). Foerster places great importance on the size of the descending young for survival during the time of seaward migration and also in the sea, and shows a direct relationship of percentage production of sockeye to the length and weight of the descending young (Foerster, 1954). For sockeye, produced in Lake Dalnee, such a relation has not been observed. Apparently, this lack of coincidence is explained by the fact that the mean size and weight of the young, migrating downstream from Lake Dalnee in different years, are much larger and regular (length 10.9 - 12.8 cm, weight 12.5 - 20.9 g.) than the young from Cultus Lake (6.3 - 10.7 cm., weight 2.7 - 12.8 g.).

P. 14 (4) The most general survival (i.e., the relation of returning fish to the number of eggs contained in spawning females), computed on the mean fecundity, distinctive for fish of different schools, has been given for sockeye, produced in Kurile Lake - 0.26% (according to the data of V.V. Azbelev) and for sockeye from Cultus Lake - 0.20% (Foerster, 1945); the general survival was lower for sockeye from Lake Dalnee - 0.14% (from the data of F. V. Krogius) and for sockeye from Karluk Lake - also - 0.14% (Holmes, 1934). Since the general survival and mean fecundity are different both the number of fish returning from each spawning group of females and, furthermore, the presumed percentage of the catch, will differ substantially in the different populations of sockeye.

AGE GROUPS

P. 15 (1) Among Pacific salmon the sockeye possess the most complex life cycle. After residence of the young in fresh water, the sockeye proceed to the sea, as a rule, for two, three and (rarely) four years; a minor part of the females return to spawn after one year of life in the sea. The schools of sockeye, migrating to the different rivers, differ in the characteristics of the age groups, usually varying within comparatively small limits. In the Kamchatka River around 70% of the sockeye migrate at an age of 4_1+ years; in the Ozernaya around 70% return at 5_2+ ; the age group of sockeye at Lake

Dalnee is quite variable (Krogius, 1949).

P. 15 (2) Sometimes quite wide deviations from the average relationship in an age group occur, caused by an unusual rate of maturing in certain brood year groups and associated with the conditions for life in the sea. These deviations complicate the prediction of numbers of fish, returning from the sea at a specific age.

PREDICTION

P. 15 (3) The great importance to the fishing industry of a sound prediction of the numbers of salmon approaching to spawn is unquestioned. Prediction is necessary also for the regulation of the fishery so that there may be allowed passage to the spawning grounds of an adequate number of adult spawners.

P. 15 (4) Methods of making up a prediction were first worked out for sockeye in the case of those populations propagating in Lake Dalnee. The first prediction was made for the run of sockeye in 1939 and since then it has been made annually with subsequent comparative analysis of the actual run and the prediction, so as to ascertain the causes of error of the latter.

P. 15 (5) Two methods were developed for obtaining predictions. The first of these is based on the calculation of the number of adults in the spawning run, of the age groups of sockeye in the runs and on a qualitative estimation of the conditions for reproduction. A test of the adequacy of this method was made on the basis of available observations on the numbers of sockeye at Lake Dalnee and the conclusion was reached that although it will give, in the majority of cases, satisfactory results, they are all still subject to large-scale errors. In 1946 this method with some improvements (with the addition of data on survival of eggs and a qualitative estimate of the seaward migration) was successfully used for the Ozernaya River sockeye (Fig. 5); out of nine predictions only one was off the mark. This method then was adopted for tabulating the predictions on the runs of salmon to the Kamchatka River.

P. 15 (6) The basis of the second method is the condition of relative constancy of the return of sockeye from the sea, expressed as a percentage of the number of seaward-migrating young. This more thorough method also was first used for the sockeye of Lake Dalnee; the predictions were prepared on the basis of the data from the calculations of descending young, on the mean percentage return of sockeye from the sea (taken to be equal to 25% of the seaward migration of the young) and on the average age composition of the brood years of sockeye (Krogius & Krokhin, 1948). This same principle was later used as a basis for the predictions drawn up for the salmon of the Bolshaya River system.

P. 16 (1) The development of predictions is divided into 2 parts. On the one hand it is necessary to forecast the number of brood years which will participate in a spawning migration, on the other - the number of that portion of the brood years which will return in that year for which the prediction is made.

P. 16 (2) When the data are available on the count of descending young as, for example, at Lake Dalnee, the number of brood years can be forecasted with good accuracy; but in the absence of information on the results of reproduction or even though separate stages (concentration on the spawning grounds, survival of eggs) be known, the accuracy of prediction of the number of brood years is reduced. Therefore the accuracy of prediction of the sockeye in the Ozernaya River is lower than for Lake Dalnee, and for the Kamchatka River sockeye prediction was made only in a qualitative way.

P. 16 (3) For a determination of the second part of the prediction - the number of different age groups which may return in a given year, we can, up to the present time, with but little knowledge of the sea period of life of the sockeye, base our estimates only on the means of many years' data regarding the age groups per brood year and this, as has already been explained, introduces the possibility of much error.

DIRECTION OF FURTHER INVESTIGATIONS

P. 16 (4) It is obvious that the direction, in which further studies of sockeye and other salmon must go, depends on the problems put forward pertaining to the scientific development of the fisheries industry. At the present time, there would appear to be clearly three such problems.

1. Present day fishery conditions in the waters adjacent to Kamchatka, require studies of the ocean period of life of the salmon.

2. The stocks of sockeye in Kamchatka, especially those populations whose reproduction is connected with the spawning basins on the east coast of the peninsula, are in a depreciated state. There arises the necessity of: (a) the application of effective measures of improving natural propagation of sockeye; (b) greater expansion of artificial (p.17) propagation of sockeye; (c) availability as spawning-rearing areas of the basin, of parts not now utilized by sockeye. In this case it is necessary to extend considerably the studies connected with measures for increasing the efficiency of natural and artificial propagation of sockeye and also for the creation of new commercially-utilizable populations of sockeye.

P. 17 (1)

3. The great importance of fishery predictions of salmon runs for industry and the whole salmon resource requires an increase in their quality.

P. 17 (2) For a solution of these three basic problems it is necessary to conduct studies along the following lines:

P. 17 (3) For a knowledge of the ocean period of the life of salmon it is necessary to study their feeding areas and routes of the spawning migrations from the hydrological standpoint, and from the point of view of the food supplies for salmon, and thus investigate the behavior of salmon in relation to the conditions of their environment.

P. 17 (4) In connection with the management of an active ocean fishery for salmon, and especially sockeye, it is necessary to take into consideration the timing of the reproduction of each school in the appropriate river systems. Therefore, it is necessary to investigate the degree of isolation of the schools of sockeye, propagating in the different rivers, with respect to the feeding areas and routes of migration.

P. 17 (5) Inasmuch as sockeye start on their spawning migration at different ages, there inevitably arises in the ocean a reorganization of the schools of the young. Therefore the catch of salmon in the different periods of their residence in the sea reflects quite differently on the numbers of fish returning to spawn. This makes it necessary to study the reorganization and forming of the schools of sockeye in the ocean.

P. 17 (6) It is possible to suppose, on the basis of studies of the rate of growth of sockeye at Lake Dalnee, that the rate of maturity in the ocean is in direct relation to the rate of growth, associated probably, with feeding conditions: this means that the hydrological and feeding conditions must be elucidated annually. Lastly, in order to ensure the organization of a coastal ocean fishery and improve the operation of a stable fishery, it is necessary to study the behaviour of sockeye and the daily rhythm of their travel in the fishing areas under the prevailing environmental conditions.

P. 17 (7) The greatest problems at the present time facing the fish industry in the field of sockeye propagation, require the transfer of research to this field at the highest level, conforming to a new large problem. An insufficiency of theoretical studies hinders the solution, in practice, of important questions. One of the basic deficiencies of preceding investigations was this almost complete absence of fundamental studies of the fish themselves, such as how they react to this or that change in external conditions and why just that and not otherwise. These gaps must be and can quickly be filled.

P. 17 (8) Problems facing the fishing industry in the field of sockeye propagation, require the following investigations.

P. 17 (9) In the Kamchatka River basin there usually reproduce not one but several populations of sockeye. For accurate results the catches in the fishery and the runs of adults to the spawning grounds should be studied at the time of the run, also the localization and, in particular, the reproduction of each separate population in the large river systems and, in the first instance, in the Kamchatka River system.

P. 17 (10) For improvement of the bio-techniques of artificial propagation of sockeye and a more detailed examination of the causes of the low efficiency of natural propagation, it is necessary to examine the requirements of the eggs and fry of sockeye of the different biological groups with respect to environmental conditions and find out the optimal (p. 18) conditions for development of eggs and fry. In those instances, when the construction of fish-rearing plants presents great difficulty, there must be developed a method of incubating the artificially fertilized eggs in gravel. A considerable increase in efficiency of natural and artificial propagation of sockeye can result from biological improvement of the productivity of the river system area, such as a reduction in the numbers of predators and competitors; therefore the development of methods to achieve such results are problems of primary importance.

P. 18 (1) In many cases there arises the question of increasing the food-producing capacity of the area, which brings up the necessity of developing theoretical bases and methods of fertilizing the nursery areas; a second means of increasing the food supply lies in the introduction into the nursery waters of new food forms for young sockeye. An extremely desirable possibility is that of reducing the length of residence of the young sockeye in the rearing areas to one year. it is necessary, therefore, to understand the causes of different rates of attainment by the young of conditions for seaward migration and to develop the means of managing them.

P. 18 (2) In order to define more accurately the survival of the young under different conditions valuable results may be obtained by the use of marked atoms. For this purpose, it is necessary to develop methods of introducing radioactive isotopes into the body of the young fish and methods for detecting the marked fish. In order to improve the quality of the prediction for the commercial catch it is necessary to obtain an estimate of the young in the larger rivers; for this there must be established counting weirs designed to be operated by electricity.

P. 18 (3) For success in developing measures for the creation of new populations of sockeye, besides the recapitulation of investigations, it is necessary to conduct studies which will throw light on the specificity of conditions for reproduction in fish producing areas (for example, in Kronotz Lake).

P. 18 (4) Ocean investigations and perfecting of counts of the young, and also further examination of the regularity of the factors which determine the dynamics of the number of salmon, offer possibility of an increase in the quality of prediction.

PRIMARY MEASURES FOR THE RESTORATION OF THE NUMBERS OF SOCKEYE

P. 18 (5) Since a reduction in numbers of populations of sockeye has resulted from an excessive fishery and from deteriorating conditions for reproduction, it becomes necessary, in order to restore the numbers of sockeye, to apply measures for the regulation of the fishery and an increase in propagation efficiency. In perspective, one must aim at those conditions for propagation which will result in the possible attainment of maximum catches. To achieve this goal one must, first of all, regulate the fishery for sockeye. At the present time regulations for the catching of salmon are, in essence, lacking. It is necessary to continue and intensify the studies on fish management on a permit system per river, to watch the conditions of the spawning stocks in the rivers and to introduce the practice of the broad use of inspection by air of the distribution and abundance of spawning adult salmon. On the basis of available data and predictions it is feasible to regulate the catch so as to provide an adequate escapement of adults to the spawning grounds.

P. 18 (6) Since in future years only natural propagation will be able to provide high levels of populations of sockeye, it is necessary to take as strong measures as possible to increase its efficiency.

P. 18 (7) There is required an endeavour to put into effect all the proposed measures for preventing the pollution of the spawning-nursery areas (p. 19) and also the rivers, which are the migration routes for salmon. In particular it follows rationally to combine the interests of the fish and forest industries by means of the creation of water-protection zones, the prohibition of pollution and the blocking of the rivers with logs. It is necessary to have real improvement in guarding the spawning areas and the approaches to them.

P. 19 (1) Improvement in the spawning and rearing areas is one of the most effective measures; in those cases, when it can be adopted without extra investigation, it should now be put into practice.

P. 19 (2) The artificial propagation of sockeye should be expanded, perfecting its techniques, chiefly with respect to the rearing of the young.

P. 19 (3) It is recommended that the number of spawning and rearing areas be increased by hydraulic measures for improving the means of approach to them.

P. 19 (4) Specifically we can dwell on two measures which can contribute much to the increase in the stocks of sockeye; the first step is to examine both the expansion and intensive cultivation of salmon in Kamchatka.
It is required to maintain in every way the organization of the spawning-rearing developments at Azabachi Lake (Kamchatka system) and to create in Lake Kronotz a large-scale population of anadromous sockeye.

P. 19 (5) One may acknowledge quite freely the organization of a broad propaganda of rational forms of the knowledge of salmon cultivation by means of giving lectures, publishing informative placards and popular brochures.

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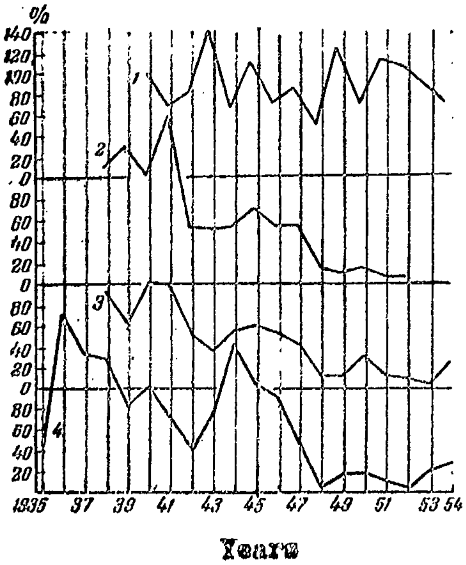


Fig. 1. Fluctuations in numbers of spawners in the sockeye runs from 1935-1954, as percentages of the run of 1940:
1 – Ozernaya R.; 2 – Kamchatka R.;
3 – Blizhnee R.; 4 – Dalnee R.

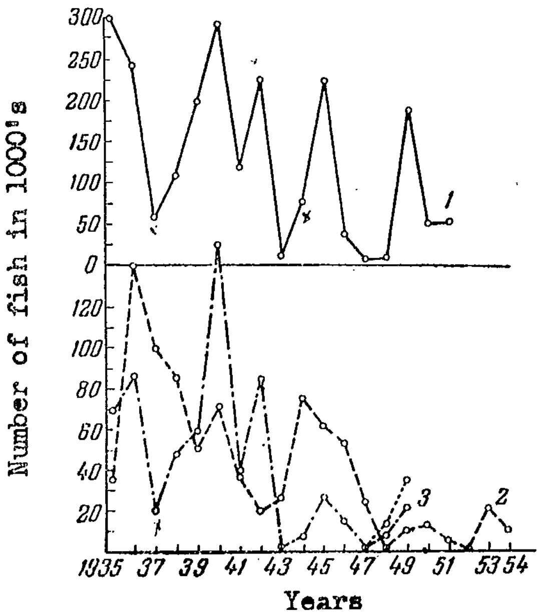
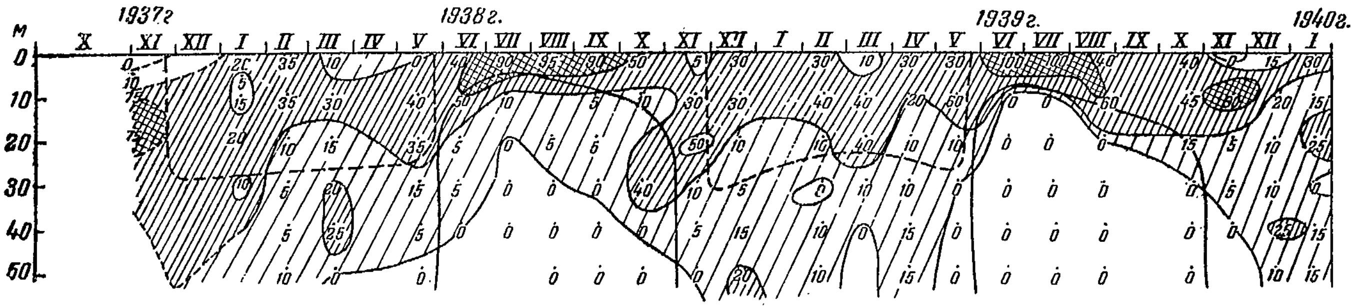


Fig. 2. Count of adults (1), downstream migration of young (2) and return of spawners (3) in the Dalnee River from 1935-1954.



3° isotherm Location of temperature change

Fig. 3. Vertical distribution of young sockeye in Lake Dalnee (in percentage of all young in each series) from 1937 to 1940.

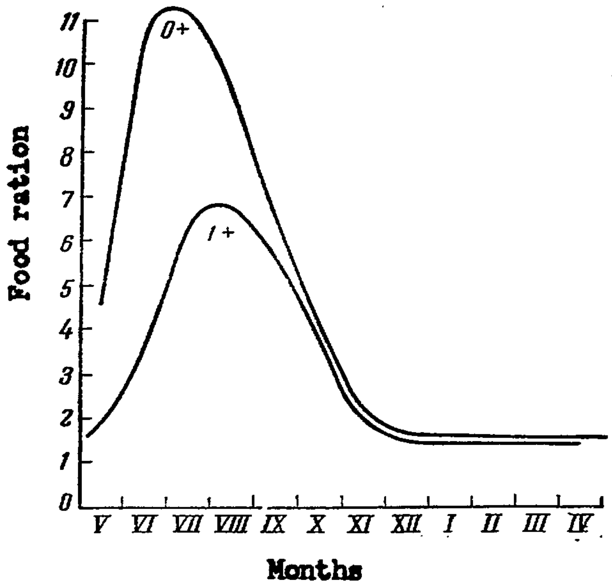


Fig. 4. Food ration of young sockeye (fingerlings and yearlings) in percentage of body weight.

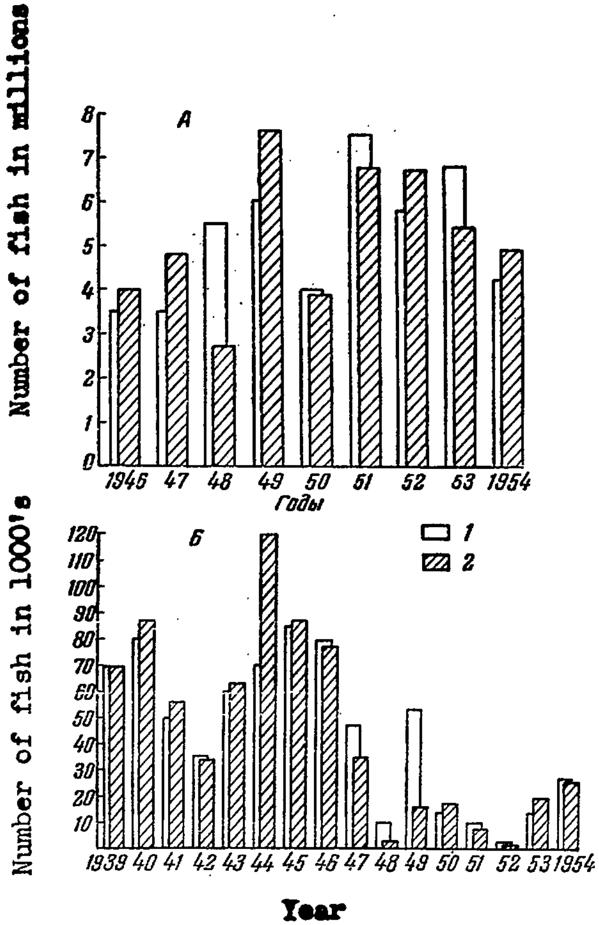


Fig. 5. Predicted and actual runs of sockeye to the Ozernaya River (A) and to Lake Dalnee (B): white parallelograms - predicted runs; cross-hatched-actual runs of sockeye.