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SPAWNING GROUNDS OF SOCKEYE SALMON (Oncorhynchus  
nerka Walb.). (A REVIEW OF THEIR GEOMORPHOLOGY,  
TEMPERATURE CONDITIONS AND HYDROCHEMISTRY.)

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The evaluation of the fish production potentialities of rivers and lakes which serve as the spawning grounds of Pacific salmon often has to be continued quite beyond the period of spawning. In such a case there is great difficulty not only in recognizing the actual spawning places but also in estimating the total amount of spawning area in the various river or lake systems. Therefore knowledge of the objective criteria of spawning areas, and how they are distinguished from all other places in the rivers and lakes becomes most important. On the other hand, the special hydrobiological and hydrochemical conditions on the spawning grounds, especially within the gravel, determines the degree of favourableness of the external conditions for development of eggs and also for survival of the embryos during the early stages of existence, up to absorption of the yolk sac and emergence of alevins from the surface of the spawning grounds. From this point of view knowledge of the quality of water, which makes up the water supply for the redds throughout the spawning areas is of particular value. Finally, a rational selection of the sources of water supplies for salmon hatcheries must be made to provide the same quality of water as feeds natural spawning areas. To underrate this circumstance can adversely reflect on the productive effect of hatchery operation and result in the occurrence in the hatchery of weak salmon alevins or even heavy mortality among them.

The present report deals only with sockeye (Oncorhynchus nerka Walb.) spawning grounds and predominantly of their lake spawning areas. It is well known that sockeye spawn not only in rivers and springs but also in lakes; but of all the representatives of the genus Oncorhynchus only the sockeye actually spawn in lakes.

Our observations in the Bolshaya River system showed that, in comparison with the spawning grounds of the other species of Pacific salmon, the velocity of the current over the sockeye spawning grounds is the lowest, not more than 0.1 m/sec (Krokhin and Krogus, 1937). In the sockeye lake spawning grounds the rate of flow practically falls to zero. Hence there is clearly evident an intimate dependence of the sockeye spawning areas on the outflow of ground water: owing to the complete stagnation in the areas used by sockeye for spawning, the water exchange in their redds can result only from the constant action of the ground water.

Thus, the suitability of an area for sockeye spawning is, to a considerable degree, determined by the occurrence of an outflow of ground water through the bottom. Therefore [page] 90 documentation of sockeye spawning areas is closely associated with the dispersion of storage areas of ground water. A good storage of ground water depends, in turn, on the extent of precipitation and on the rocks which have a high porosity and excellent water yield. Such properties are possessed by alluvial, gravelly-sandy sediments, fluvio-glacial deposits and fractured and porous rocks: sandstone, lava and

volcanic tuff. Conversely, clay and muddy deposits do not accumulate ground water, since, in spite of its high porosity, they have but a very low water yield.

Alluvial deposits are widely distributed throughout Kamchatka and are the main storage medium for ground waters which supply the spawning grounds of the sockeye (and other salmon). Geomorphologically these deposits are represented by the river and lake terraces and alluvial fans, in which the surface water currents, which created the alluvial deposits, may now have quite disappeared (for example, along the west shore of Lake Dalnee).

According to F. I. Sovarensky (1934) ground waters often do not form actual outflows and may only keep the point of intersection of a water-bearing stratum with the surface of the ground quite damp. Evidently this applies not only to the surface but also to the underwater outflows of ground water. Precisely thus, in the majority of cases, is the outflow of ground water on the spawning grounds. In these cases they cannot be found visually, but only by means of thermometers and chemical analysis.

Little is actually known about fluvioglacial deposits (i.e., flowing-water-eroded glacial deposits) as storage for ground water in Kamchatka. Apparently the ground water of the fluvioglacial deposits feeds some sockeye spawning areas situated in the regions exposed to glaciation (for example, in the upper sections of the Kamchatka River, at the source of the Middle Avachi, in the basin of Nachikinsky Lake). It is not altogether improbable that the role of the fluvioglacial deposits as water supply areas for the spawning grounds of the salmon is quite extensive since these deposits occur frequently in Kamchatka (see, for example, Kushev and Liverovsky, 1940; Vlasov and Chemekov, 1949).

Sandstone in the vicinity of the sockeye spawning grounds is common at the present time along the shore of Lake Dalnee; it is possible that it is also of importance in the supplying of water to some of the spawning grounds in Blizhnee Lake.

Ground water, collected in lava and volcanic tuff areas, forms the second most important supply of water feeding the sockeye spawning grounds in Kamchatka. Such are the waters which supply the sockeye spawning areas in some parts of the Kamchatka River, which are adjacent to the Klifchevsky volcanic mass, and certain spawning beds of the sockeye at Kurile Lake. A classical region of distribution of ground water, associated with lava and tuff beds, is the shore of Kronotsk Lake. Outflows of ground waters in these cases are associated with the terminal parts of the lava flows or with the crumbling wearing-away of the tuff [or tufa] cover on the shores of lakes and in river valleys.

Stream sockeye spawning areas often are located by the accumulation of deposits and rocks. Erosion activity of the rivers opens up a water-bearing stratum of a certain kind and assures to it a supply of ground water for the spawning channels. It was earlier noted that as a result of the washing out of the upper part of such channels and a reduction in the level of the stream through erosion, the channel of the stream becomes a spawning spring (Krokhin, 1935; Krokhin and Krogus, 1937a). Once the supply of stream water to the former river channel has completely ceased [page 91] its cross section becomes reduced and tends to conform to the new water discharge; the stream bed becomes a narrow canal which connects the spring pool ("kurchazhinu") lying at its source with the stream which earlier filled the channel.

In the lakes the sockeye spawning grounds are located along the shore, at depths<sup>1</sup> not greater than 1-1.5 m. Water-bearing sections in lakes are opened up by abrasion or wearing away. At the base of the lake shore (cliffs) where abrasion takes place, there occur terrace-like ledges or benches, built up from the products of wearing-away of the shore; these benches usually serve as spawning areas. Often the abrasion wears down the terminal part of an alluvial fan which projects out into the lake; in other cases it may lay bare water-bearing strata imbedded in the lava flows or volcanic tuffs which are located on the lake shores.

As a rule, the spawning grounds along a lake shore originate mainly along the abraded beaches. Conversely along the shores where material has drifted and collected, no spawning grounds occur; on the other hand they are found in the valleys of the lake tributaries, creating sections along the lake shore where drifting material has settled out and in such cases they do not differ appreciably from the usual stream and spring spawning areas.

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<sup>1</sup>There is reason to assume that a certain number of sockeye spawn at greater depths. In Lake Dalnee two races of sockeye are found: an early, spring type and a later, summer, one; the latter appears to be the main one and these sockeye spawn along the shore beginning in September. Egg deposition by the spring race of sockeye was never observed although carcasses of spawned fish were found every day at the end of July. One has to assume that they spawned at depths beyond visual observation. It is apparent that some of the sockeye at Kronotsk Lake also spawn at considerable depths. There are records of sockeye spawning at considerable depths at Karluk Lake (Alaska; see Davidson, 1937). The question of how deep sockeye may go for spawning remains an open one requiring further evidence.

A variety of spawning areas may occur at the foot of the terminal parts of lava outflows. If an outflow does not extend to a stream channel or if it brings about a reduction in the amount of stream erosion there, where the lava outflow impinges on the stream channel, then the ground water coming in from the lava area will begin to break down the surrounding deposits; a series of flat stretches of water (reaches) will be built up, fed by the ground water from the lava outflows. The water from these reaches will drain into one general system of channels, having the status of a stream, bordering on volcanic formation. As an example of such basins we may cite the case of the system of "Roshchiki" springs in the central portion of the Kamchatka River at the north edge of the Klifuchevsky volcanic mass. To it also is indirectly related the Ozerna River in the River Tolbachik system, formed from the ground water of the lava streams of the Tolbachik volcano.

Let us examine the distribution of sockeye spawning areas in some of the lake systems in relation to the geological structure of their shore lines.

Kurile Lake. Most of the lake spawning beds for Kurile Lake sockeye are associated with the wearing away of the alluvial shores (lake terraces and alluvial fans); the spawning grounds at Cape Pulomynk and Cape Kikinaushchich, and also at the mouth of the Vatskumnyk River in Lake Etamynk are located at the foot of lava flows (Volcanoes Vin--Ilinskaya--and Diki peak). In the valleys of the tributaries of Lake Kurile, made up of the accumulation along the lake shores (the Khakyts, Etamynk, Kirushutk and Vychenkifa Rivers) and also at the outlet of the Ozernaya River are centred numerous stream and spring spawning grounds which are supplied primarily by the ground water from the alluvial deposits. Consequently, the water supply to the sockeye spawning grounds in the Kurile Lake area is supplied by the ground water from the alluvial deposits and the lava flows.

[page 92] Dalnee Lake. The spawning areas along the northern and southern shores are located at the foot of the cliffs which rise up steeply along the side of Lake Dalnee; the hills are composed of sandstone, with overlapping andesite, a porphoritic rock. On the west, south-west and south-east the spawning grounds adjoin eroded alluvial deposits (alluvial fans of the lake tributaries). Thus the Lake Dalnee sockeye spawning areas are associated with ground water from alluvial deposits and sandstone.

Lake Blizhnee. The sockeye spawning grounds in this area are concentrated exclusively along the shore of the west half of the lake. The lake tributaries are quite numerous but with the exception of one, they are not used for spawning since they are quite small. Nevertheless they produce extensive alluvial deposits on the north-west and south-west shores of the lake; the ground water from these deposits are the main

sources of water supply to these spawning areas. Furthermore, a certain significance apparently attaches to the ground water of broken-up rock; from it comes a supply of water to the spawning beds lying south-east of the Blizhnee River outlet.

Azabach Lake. The west and north-west shores of this lake consist of alluvial material from the many tributaries, which originate in the Kumroch range of mountains. The sockeye lake spawning grounds are principally found along these shores; they are supplied with ground water from the alluvial deposits. In the valleys of the lake tributaries the spawning beds are also associated with alluvial areas. It is possible that the spawning areas at the foot of the Azabach mountain are fed by the ground water from the broken rock but the lithology of this mountain area is not well known. The littoral areas, adjoining the accumulated deposits along the north shore, are composed of mud and are not utilized by sockeye for spawning.

Nachikinskoe Lake. Almost all the lake spawning areas for sockeye are concentrated in the northern part of the lake, along the western but mainly along the eastern shores. The origin of the deposits, occurring along the lake shores where spawning occurs, is at present not clear. The north-east shore is formed of a very wide, flat alluvial fan, issuing from the Vatskazhats mountain. According to A. E. Sviatlovsky (1956) the cone is composed of a fluvio-glacial deposit. These deposits, according to this author, are widely distributed also along the west shore of the lake. If this is so, then one can consider that the water supply for the lake sockeye spawning grounds in Nachikinsky Lake is provided by ground water from the fluvio-glacial deposits. Many of the sockeye spawn also in the beds of the tributaries to Lake Nachikinsky but there the water supply is undoubtedly provided by ground water of the alluvial deposits in these tributaries (the Verkhniâ, Babîa, Iagodniâ, Priamniâ Rivers). Moreover the question of the storage of ground water in the Nachikinsky Lake system cannot be considered solved and will require further investigation.

Kronotsk Lake. In this lake there is, at the present time, only a lake-resident form of sockeye. Its spawning areas are located both in the lake itself and in the lake tributaries. It may be noted that the lake spawning grounds are distributed exclusively along the abraded shores, made up of lava and tuff. In the built-up sections of the shore line along the margins of the outer piles of lava and tuff are found the spring spawning regions, connected with the lake tributaries. In the valleys of the western lake tributaries the spawning beds are concentrated in a series of old lakes, fed by ground water; the latter flows from the tuff plateau, bordering the lake on the west and north-west.

[page 93] Summary. The sockeye spawning areas in Kamchatka are associated with a definite geomorphological and geological formations, producing, by virtue of their special

structure, supplies of ground water. As a general rule, the spawning beds are located in places where abrasions or erosion or both have recently occurred to a marked degree. On the contrary, places where accumulation is prevalent are not used by sockeye for spawning. Geomorphological and geological formations with which the spawning areas are associated included: the erosion or washing away of the stream and lake alluvial terraces, the worn-away terminal parts of alluvial fans, abraded and eroded sections of fluvioglacial deposits on the shores of streams and lakes and, finally, frequently also the broken-up-by-abrasion and erosion marginal parts of lava flows, tuff deposits and broken sandstone. In these formations it is necessary, in the first instance, to give attention to the commercial fisheries drain on the spawning areas of Kamchatka.

Temperature Conditions on Sockeye Spawning Grounds

Since one of the most important features of sockeye spawning grounds is the supply of ground water to them, the temperature conditions of the spawning beds are closely related to the temperature trends of the ground water flowing through them.

The principal feature of the temperature trend of ground water is its relative stability, the small yearly amplitude of temperature fluctuation. For example let us consider the yearly trend of mean monthly temperatures in a small spawning spring on the left bank of the Dalnee River, not far from Lake Dalnee (Table 1).

Table 1. Yearly trend of mean-monthly temperatures in a spring on the left bank of the Dalnee River and its amplitudes (average of several years).

Month	Temperature, °C		Month	Temperature, °C	
	Mean	Range		Mean	Range
January	2.79	2.54-2.99	August	4.16	3.84-4.53
February	2.96	2.69-3.43	September	4.22	3.96-4.39
March	2.96	2.69-3.33	October	3.84	3.61-4.11
April	3.00	2.73-3.34	November	3.25	3.09-3.63
May	3.11	2.79-3.43	December	2.87	2.69-3.21
June	3.56	3.16-3.95			
July	3.85	3.57-4.15	For season	3.38	3.17-3.59

The data given in Table 1 are quite typical for ground waters which supply the spawning grounds. The yearly range of mean-monthly temperatures amounts to  $4.22 - 2.79 = 1.43^{\circ}$ , i.e., it is very small; even over a many-year period it amounts to a total of  $4.53 - 2.54 = 1.99^{\circ}$ . Somewhat greater but also quite insignificant is the annual amplitude of absolute temperatures.

At the point of constant temperature measurement, 50 m distant from the point where the water emerges from the bottom, it is  $4 - 6^{\circ}$ ; the minimal temperatures occur at the time of snow melt in December and [page 94] January, while the bed of the spring is still not covered with snow. The maximum temperatures (in the order of from  $4 - 6^{\circ}$ ) depend on the September rains; at this time the temperature of the rain water is much above that of the water in the spring; the addition of the rain water causes a brief increase in the temperature of the spring water. The amplitude of the temperature right at the place of outflow of ground water to the surface is quite low.

Such are the temperature conditions in the spring spawning areas. However, in lake spawning grounds they are substantially the same. Observations and calculations reveal that in Lake Dalnee the total discharge of all outflowing<sub>3</sub> ground water as an average for the year amounts to around  $0.2 \text{ m}^3/\text{sec}$ . The magnitude of this is very insignificant in comparison with the volume of the upper stratum of water 5 m thick equal to about  $6 - 7 \times 10^6 \text{ m}^3$ --which is the layer into which the ground waters supplying the spawning areas discharge; even over a day it amounts in all only to 0.3% of this volume. Therefore the temperature of the upper layer of lake waters is but very slightly affected by the temperature of the ground waters supplying the sockeye spawning grounds. On the contrary, the temperature of the water on the lake spawning beds is stored under the very intensive action of the temperature of the lake. The processes of mixing and the shallow depths of the shore areas combine to level off the water temperatures. However in calm weather or under ice cover it is possible to note differences in the temperature of the bottom layers on the spawning grounds from the temperatures of the same layer in the other parts of the littoral area.

The temperature of the water in the lakes is subjected to a much greater annual change than the temperatures in the springs. Thus, for example, the temperatures of the upper layer of Lake Dalnee changes during the year in the following manner (according to observations at the outlet stream, Dalnee River, Table 2).

Consequently, the yearly amplitude of even the mean monthly temperatures in the surface layer of Lake Dalnee exceeds  $15^{\circ}$ , and the absolute amplitude, over many years, is more than  $20^{\circ}$ . In accordance with this, the water temperatures on the spawning grounds at the surface of the ground in the period from June to October are higher than the ground water

Table 2. Mean monthly temperatures, over several years, of the water in the outlet to Lake Dalnee, the Dalnee River, and the absolute limits of variation of water temperature at the same place.

Month	Temperature, °C			Month	Temperature, °C		
	Mean	Max.	Min.		Mean	Max.	Min.
January	0.60	0.8	0.2	August	15.88	19.6	12.2
February	0.54	0.8	0.2	September	12.97	18.8	8.2
March	0.43	0.7	0.1	October	7.90	12.7	3.4
April	0.59	1.4	0.2	November	3.30	6.0	0.8
May	1.47	7.0	0.3	December	0.93	1.6	0.1
June	6.75	16.6	0.6				
July	14.02	20.5	8.0	For season	5.48	20.5	0.1

temperatures but, from December to May--they are lower. At the end of May - beginning of June and in November the water temperatures on the lake spawning grounds are close to the temperatures of the ground waters (see Tables 3 and 4).

[page 95] In order to measure the temperature of the water at the surface of the ground we used a simple device, designed and described by G. Iu. Vereshchagin (1927) under the name of a pseudobathometer. The instrument serves to draw up a sample of water from very thin strata and originally was intended for a study of the microstratification of substances dissolved in the water of shallow lakes; by this means it is possible to collect samples of water from a stratum immediately contiguous to the lake bottom. The temperature of the water was measured by a thermometer-sling, installed in the pseudobathometer prior to the collection of the sample; the hose of the pseudobathometer is placed on the ground in the lake shallows in order to collect the desired water sample.

However salmon deposit their eggs in the ground of spawning areas at a depth of 10-30 cm from the surface of the ground. Therefore a measurement of the temperature of the layer of water just above the bottom still does not characterize the temperature conditions in the salmon redds. In order to get the physico-chemical features which are typical of the environment in which the salmon eggs develop we used, in 1937, the following method. In the ground at a depth of 10-30 cm we placed a glazed tube; the upper end of the tube projected above the level of the water in the lake (Fig. 1). The hoses of the pseudobathometer were inserted into these tubes or placed in their upper end; the water for measurement of temperature and

chemical analysis was withdrawn from the layer of ground at which the lower end of the tube was placed. In the early 1950's a similar method was used by colleagues of the Faculty of Ichthyology of Moscow State University in a study of the spawning grounds of pink and chum salmon in the Amur River system; in principle, the same method has been used also by Canadian scientists, carrying out investigations on salmon spawning areas.

Later on we used, for measuring temperatures on the ground of spawning areas, electrothermometers with platinum resistances, produced by V. K. Altberg. The leads from the electrothermometer were placed at the required depth in the bottom of the spawning bed. Since on the spawning grounds the sockeye and other salmon prefer hard sand-pebble ground, [page 96] it was necessary to provide suitable safeguards for the electrothermometer terminals from damage when they are thrust into the ground. Later on we used for the purpose an electrothermometer with semi-conductor resistances<sup>1</sup> MMT-4.

In Table 3 are given the temperatures in the ground at different parts of the littoral region of Lake Dalnee, including those utilized by the sockeye for spawning and those not used. For comparison there are given also the temperatures of the layer of water lying on the surface of the bottom.

All the temperatures were measured with a sling-thermometer, inserted into a pseudobathometer. Readings were taken during the spawning season in Lake Dalnee.

The temperature of the layer of water immediately above the bottom cannot, in practice, be distinguished from the temperature within the ground of those areas not used for spawning. The temperatures, however, within the spawning ground bottom are much lower. In certain cases the difference can exceed 10° (for example, at one site on the west shore, 5 September 1938). In November the difference gradually becomes less due to the autumn drop in lake temperature and in November it disappears. With the later cooling of the lake and

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<sup>1</sup>Electrothermometers with semiconductor resistances were constructed and used in the experimental workshops of VNIORKh, Leningrad and in the experimental shops of the Agrophysical Institute (Leningrad). Apparently for measuring temperatures in the ground of spawning areas it is especially convenient to use the so-called soil semiconductor electrothermometer (Kaganov and Shlimovich, 1956). At the present time in the VNIORKh workshops a model of this thermometer is being constructed, for the fishing industry, which is longer and thus more useful for measuring the temperature in the ground at depths of 1-1.5 m from the lake surface. This thermometer must be tested out, however.

Table 3. Temperature of the underground waters in the littoral areas of Lake Dalnee and also the bottom during the sockeye spawning period. (September-November)

North shore				West shore			
Temperature, °C				Temperature, °C			
Dates	Underground flow		Above-bottom layer of water	Dates	Underground flow		Above-bottom layer of water
	On the spawning grounds	Away from spawning area			On the spawning grounds	Away from spawning area	
1937				1937			
13.ix	10.0; 11.6	11.9; 13.9	13.0	12.x	7.4; 7.5	9.0; 9.4	9.3; 9.8
12.x	7.8; 8.2; 8.7	10.5; 11.0	10.5; 11.0	17.xi	1.8; 3.2	2.3	2.3; 2.8
17.xi	3.5; 3.7	3.3; 4.0	3.3; 3.5				
1938				1938			
5.ix	15.1; 16.6	17.8	17.5	5.ix	6.7; 12.8	17.8	...
19.x	6.4	7.7	7.5; 8.0	17.x	4.9; 6.3; 6.5	...	8.0
				14.xi	4.0; 4.2	...	3.9; 4.0

Note: The underground temperatures were measured at a depth of 15-20 cm.

the establishment of an ice cover the difference between the temperature in the spawning ground and other parts of the littoral areas again become apparent.

In the winter the lake spawning areas often can be readily recognized by the occurrence of vapour above them and the disappearance of the snow cover. Commonly the spawning grounds become quite free of ice and are covered only by a layer of snow. [page 97] Regarding the absolute temperature reading in the spawning beds and on the surface of the ground in winter the data of Table 4 are of interest.

Table 4. Temperature reading of ground water in the shallows of Lake Dalnee and in the above-bottom stratum in winter.(for February-March, in °C).

Dates	In the ground		In the stratum of water above the bottom
	On the spawning areas	Away from the spawning areas	
<u>North shore</u>			
(near the Dalnee R. outlet)			
8 .iii 1944	1.2; 1.35	0.75; 1.0	0.35; 1.0
11 .ii 1958	1.8	1.0	0.5
<u>West shore</u>			
8 .iii 1944	1.45; 2.3	0.5	0.45; 0.65
12 .ii 1958	1.9; 2.0	...	0.8; 1.0
<u>North shore</u>			
(on rock)			
13 .ii 1958	1.1; 1.3; 1.3	...	0.5

The differences in the temperatures on the spawning areas and in other parts of the littoral lake areas in winter are much less than in the autumn and never exceed 1.0-1.5°. This, evidently, indicates that in the winter the water temperatures, as a rule, do not go beyond the limits of 0-4°, whereas in the summer and autumn the ranges of variation are wider (4-20°).

In summary, ground temperatures seem to be a good means of recognizing sockeye spawning grounds along the shallow lake

shores. In order to estimate the extent of the sections of the littoral areas used for spawning purposes examination by the thermometer method can be made. With the assistance of a resistance electrothermometer it is possible to cover quickly the littoral areas of a lake with a network of temperature readings and, on the basis of the data obtained, compute the extent and size of the spawning areas. This can be done quite easily in summer and early autumn. Sections with a relatively low ground temperature can be considered as the best spawning beds since, in these places one can assume that there will be a quite intensive outflow of ground water, assuming a good exchange of water. In Fig. 2 there is presented an example of a thermometric portrayal of the Lake Dalnee spawning grounds in September and October 1944. Examination of survival of sockeye eggs in the subsequent spring (1945) confirmed that areas of best survival coincided with the greatest differences between the temperatures of the above-bottom stratum of the littoral areas and the temperatures in the spawning grounds themselves.

#### Water Flow in Sockeye Spawning Areas

A most important characteristic hydrological feature on the spawning grounds is the rate of flow of the water, since on it depends the intensiveness of water exchange. According to our data, in stream sockeye spawning areas [page 98] the rate of flow of surface currents, as a rule, does not exceed 0.1-0.2 m/sec; in spring spawning areas the flow often falls to zero and in lakes there is practically none since in them there is no permanently established current (Krokhin and Krogus, 1937).

There is no information on the rate of flow of water in the ground of sockeye spawning areas. With regard to the rate of flow of ground water in spawning areas it is possible to a certain extent to consider the data obtained in chum spawning grounds (Wickett and Pollard, 1954). According to these data the rate of flow in chum salmon spawning beds varies from 5 to 36 mm/hr. It can be assumed that in sockeye spawning beds the rate of flow will be the same or even lower. In general, the speed of surface current in stream sockeye spawning areas exceeds the rate of ground water flow by 10,000 times.

#### Hydrochemical Conditions on Sockeye Spawning Areas

As far as I know, the first hydrochemical study of a sockeye spawning ground was made in 1932-1933 at Kurile Lake (Krokhin and Krogus, 1937). It was indicated that the water in the spawning beds is distinguished by a lower oxygen content and a higher [page 99] pH. The O<sub>2</sub> content of the water in the littoral areas of Kurile Lake in autumn was (mean data): in sections of the spawning grounds--11.47 mg/l (86.1%), but outside the spawning areas--13.05 mg/l (98.4%); the pH values

were, respectively, 7.0 and 7.6. Investigations, carried out there in the spring of 1933 widened the limits: on the spawning beds a high free  $\text{CO}_2$  content was observed (up to 14.25 mg/l) and  $\text{Si O}_2$  (up to 37.4 mg/l  $\text{O}_2$ ). These observations lead to two main conclusions:

1. The waters of sockeye spawning grounds possess features which contradict widely prevailing notions that these waters are rich in oxygen and poor in free  $\text{CO}_2$ .

2. According to all the features studied the waters of the spawning grounds vary in the direction of the spring waters; therefore it is concluded that the chemical properties of this water in the spawning ground areas depend on the outflow of ground water prevailing there.

However the method of collecting samples, used by us in 1935, was not too good: the sample was obtained by scooping up water from the surface of the spawning grounds. Later on, in the study on the Paratunka River, when collecting the water sample, 2-3 litre bottles were used with a tube at the bottom. In the drawing off of air through the pipe inserted in the neck of the bottle, a vacuum was created and water in the rubber hose, connected with the lower tube, commenced to collect in the bottle from that spot where the end of the hose had been inserted (Fig. 1). The samples for analysis were taken through the same hose, provided, for this purpose, with a Mora or Gofman clamp.

[page 100] In the first place it was of interest to study the chemical nature of the ground waters supplying the spawning grounds, in an uncontaminated state, so far as possible. For this purpose a suction hose was placed directly in the visually-observed outflow of the ground water in the spawning bed and a sample of water drawn off; at the same time temperature readings were made, as explained above. The results of the analyses of the samples, taken in this manner, are given in Table 5.

The oxygen content in the ground waters, which feed the spawning areas, are quite low (as a rule, less than 90% saturation); a high oxygen content was observed in the ground waters on the west shore of Lake Dalnee. The amount of free  $\text{CO}_2$  fluctuated widely (from 0 to 21.35 mg/l); usually it was relatively abundant. The pH of the ground water in the majority of cases was weakly acid or neutral; this corresponds with the relatively high concentration of free  $\text{CO}_2$ . An alkaline reaction was observed in the springs along the north and south shores of Lake Dalnee and in the bends of the Little Bystroi River; it corresponds to the high bicarbonate  $\text{CO}_2$  content (above 30 mg/l) and the low concentration of free  $\text{CO}_2$ .

Mineralization of the ground waters studied was generally low; a quite good amount of  $\text{Si O}_2$  may be noted. The

Table 5. Hydrochemical characteristics of the ground water in the Paratunka River system.

Spring	Date	Temp. °C	O <sub>2</sub>		CO <sub>2</sub> mg/l	pH	Bicarb. CO <sub>2</sub> mg/l	CaO mg/l	SiO <sub>2</sub> mg/l	P <sub>2</sub> O <sub>5</sub> mg/l	Acidity mg O <sub>2</sub> /l
			mg/l	%							
Tundrovyy	19.v 1935	4.6	11.34	87.1	12.32	6.8	20.7	11.7	12.0	0.167	...
	26.vii 1935	4.6	12.28	93.4	15.35	6.7	<del>27.7</del>	13.6	12.0	0.435	4.04
Yakutsky	21.v 1935	3.4	11.53	86.3	16.30	6.4	12.4	12.5	13.6	0.132	5.26
	29.vii 1935	4.2	12.18	92.3	21.35	6.2	12.5	...	13.4	0.833	2.65
Petrov	29.vii 1935	3.0	11.60	85.5	8.70	7.0	30.0	12.2	14.6	0.125	1.25
Minaevsky	29.iii 1935	3.4	11.58	86.3	7.45	7.1	30.3	11.4	14.6	0.111	2.89
Blizhnee	2.vi 1935	2.7	12.11	88.5	11.25	6.9	23.5	11.7	12.0	0.292	2.84
On the north shore, L. Dalnee	18.xi 1937	0.5	11.58	84.2	0.98	8.4	39.3	14.0	13.2	...	...
	17.x 1938	0.5	...	...	0.00	8.4	37.8	...	15.2	...	...
On the south shore, L. Dalnee	18.vi 1950	0.0	...	...	...	7.8	39.2	...	2.24	0.037	...
Domashnii	20.vi 1946	4.2	12.03	91.4	6.80	6.8	26.2	15.6	21.4	0.300	...
Bend in the Little Bystroi	17.vii 1952	3.4	11.20	83.3	1.16	7.5	34.7	...	16.9	0.124	...
Bend in the Left Topolev R.	26.x 1953	4.0	10.13	76.7	11.60	6.4	20.2	13.6	20.8	0.096	...
Danilovsky	25.xi 1957	2.9	10.77	79.2	...	...	21.0	...	24.9	...	...
Outlet of ground water on west shore, Dalnee L.	5.ix 1938	6.7	13.54	109.4	5.44	6.9	18.5	...	16.4	...	...
	17.x 1938	4.9	13.40	103.7	5.92	6.9	19.4	...	17.4	...	...
	14.ix 1938	4.2	13.10	99.5	6.15	6.9	19.3	...	17.8	...	...

Table 6. Gas content and pH values in Domashnii Spring.

Date	About 50 m below the ground water outflow					Where the ground water outflows				
	Temp. °C	O <sub>2</sub>		CO <sub>2</sub> mg/l	pH	Temp. °C	O <sub>2</sub>		CO <sub>2</sub> mg/l	pH
		mg/l	%				mg/l	%		
1950										
18.iii	3.1	13.63	100.7	3.19	7.1	...	...	...	...	...
23.iv	3.0	12.50	92.4	4.70	6.8	...	...	...	...	...
17.v	2.9	13.53	99.4	4.15	6.8	...	...	...	...	...
4.vi	3.2	13.76	101.8	3.83	6.8	...	...	...	...	...
27.vi	3.9	14.38	108.5	3.44	7.1	...	...	...	...	...
7.vii	4.9	13.28	102.7	2.98	7.4	3.7	12.17	91.2	5.19	7.0
22.vii	3.6	12.75	95.4	3.62	7.1	3.4	12.30	91.7	5.28	6.9
20.viii	5.4	13.00	101.7	3.15	7.3	4.1	12.20	92.6	5.05	7.0
28.ix	4.4	13.37	102.3	2.95	7.4	4.0	12.15	91.8	5.62	7.0
10.x	4.0	12.94	97.8	3.48	7.1	4.0	12.34	93.3	5.50	6.9
1.ix	3.6	12.83	96.1	3.77	7.2	3.7	12.42	93.2	5.72	6.9
25.xi	3.4	12.52	93.2	3.38	7.2	3.6	12.87	96.3	4.83	7.0
30.xii	3.0	12.62	93.0	4.04	7.1	...	...	...	...	...
1951										
3.ii	3.1	12.90	95.2	3.01	7.1	...	...	...	...	...
7.iii	2.7	12.54	91.7	3.86	7.1	...	...	...	...	...
3.iv	3.1	9.17	67.8	4.02	7.0	...	...	...	...	...

oxidizability of the ground waters was also quite low (not more than 5.26 mg O<sub>2</sub>/l), which is characteristic of the content of readily oxidizable substances in water.

The gaseous regime of the ground waters was studied in some detail in the case of the Domashnii Spring (in the Dalnee River system); the results are given in Table 6.

All the features of the ground waters, judging from these data, are quite stable: from 7 July to 25 November the water temperature at the ground water outlet [page 101] fluctuates from 3.4 to 4.1°, the O<sub>2</sub> content--from 12.17 to 12.87 mg/l (91-96% saturation), the free CO<sub>2</sub> content--from 4.8 to 5.7 mg/l, pH was around 6.9 to 7.0. Below the spring the quality of the water was quite different (O<sub>2</sub> content increased, free CO<sub>2</sub> reduced); however the seasonal changes also were quite small. In such a case the ground waters supplying the sockeye spawning areas are distinguishable not only by the stable temperature conditions but also by the extremely persistent gaseous conditions.

In the lake sockeye spawning areas, using the usual method, it was very difficult to obtain samples of the ground water, free from an admixture with the lake water since the former was seldom adequately localized and a usually-apparent outflow of ground water along the lake shores was but very rarely found. Samples of water from the lake spawning regions always contains some amount of mixed lake water and only in relation to the relative extent of this mixing, to a more less degree, does the lake water vary from the ground waters supplying the spawning beds. The results of analyses of the series of above-bottom samples from the shallows of Dalnee and Blizhnee Lakes are presented in Table 7. All samples were taken with the pseudobathometer and were taken at the beginning of the spawning period.

The bottom waters from the spawning beds on the shores of both lakes are distinguished by a drop in O<sub>2</sub> content. In them there is always present free CO<sub>2</sub> while in the shore areas of Dalnee [page 102] Lake, which are not used by sockeye for spawning, monocarbonates were noted. On the spawning grounds in the bottom layers there was also a rise in silicon dioxide. Consequently, the hydrochemical features on the spawning areas, established in Kurile Lake, were found also in the Paratunka lakes. Furthermore, in Lake Dalnee the spawning areas along the north shore were marked by a relatively high bicarbonate content (up to 42 mg/l CO<sub>2</sub>). It is natural to conclude that in the Paratunka lakes too the chemical nature of the water on the sections used for spawning is determined by the ground waters emerging from the bottom in the lake's littoral zone.

For an understanding of the conditions under which the sockeye eggs are developed, glazed pipes were set up at a series of points along the shore of Lake Dalnee; the lower end

Table 7. Hydrochemical characteristics of the bottom layer of water in the shallow areas of the Paratunka lakes (in 1935).

Date	Temp. °C	O <sub>2</sub>		CO <sub>2</sub> mg/l	pH	Bicarb. CO <sub>2</sub> mg/l	CaO mg/l	SO <sub>2</sub> mg/l	P <sub>2</sub> O <sub>5</sub> mg/l
		mg/l	%						
Northern shore of Dalnee Lake - on the spawning grounds									
5.ix	14.6	10.57	101.5	0	8.2	39.1	13.4	3.32	0.084
	15.3	9.97	96.9	0.94	7.9	38.6	13.0	3.40	0.075
	14.0	10.25	97.2	2.31	7.6	39.6	13.7	5.44	0.099
	14.1	10.43	99.2	1.41	8.1	...	...	...	...
	14.2	9.64	91.8	1.41	7.8	42.0	15.0	3.44	0.068
	10.6	10.75	94.8	0.94	8.1	...	...	...	...
Same area but outside the spawning grounds									
5.ix	14.5	11.34	107.7	2.42*	8.5	30.0	13.7	2.64	0.065
6.ix	15.8	12.02	118.2	6.75*	8.6	21.2	12.0	2.44	0.071
South-west shore, Blizhnee Lake, on spawning grounds									
15.ix	12.7	8.45	78.0	8.81	6.8	26.5	6.7	9.6	0.200
	13.5	8.17	76.7	7.48	6.8	...	...	...	...
Same area but outside spawning grounds									
15.ix	13.7	8.95	84.4	2.06	7.4	...	6.7	3.0	0.092

\*Monocarbonate CO<sub>2</sub>.

of each pipe was imbedded in the bottom to a depth of 10-20 cm. Samples of water were withdrawn by the pseudobathometer from the pipes, as explained above (for a description of the method of determining the temperature of the water in the spawning ground beds and selection of bottom samples for chemical analysis). The arrangement of the places where the pipes were imbedded for collection of water samples is shown in Fig. 3. The pipes were placed, firstly, in the spawning beds (over sockeye redds and not over others) and secondly, in parts of the shore zone not used by the sockeye for spawning. In a series of cases for comparison samples of bottom water around the pipes were taken. The results of these analyses are given in Tables 8 and 9.

First of all we looked at the bicarbonate content of the water coming from the various spawning areas. In this relationship the waters can be put into two groups. In the water of one, the bicarbonate content, as a rule, was greater than 30 mg/l (it goes as high as 44 mg/l), and, thus, higher than in Lake Dalnee, where the typical content was around 29-30 mg/l. In the other group of waters the bicarbonate content was much lower, namely 10-25 mg/l CO<sub>2</sub>. Both groups are strictly localized; the first is restricted to the northern side of the lake, the second--to the western. In the ground water of those shallows not used for spawning, the bicarbonate content varied from 19.7 to 30.4 mg/l; no regularity in their distribution along the shore was indicated. If the bicarbonate content of the bottom water be examined (see Table 7), then the bottom layer of water in the spawning beds, located along the north shore is distinguished by a higher concentration of bicarbonates (up to 42 mg/l CO<sub>2</sub>).

Finally, in the springs both of the north and south shores of Lake Dalnee the bicarbonates go as high as 38-39 mg/l CO<sub>2</sub>, and in the ground waters, issuing from the western shallows, only 18.5-19.4 mg/l CO<sub>2</sub> (see Table 5).

Besides the bicarbonate concentration, the ground waters of the north and west shore spawning areas clearly differ also in pH: in the former it is alkaline (pH to 8.2), in the latter weakly acidic (pH 6.4-6.9); the springs which flow into the lakes from the north and south are also alkaline (pH up to 8.4); there is a markedly lower concentration of silicates in the waters of the first group.

[page 105] The similarity of the water from the springs flowing out on the surface of the ground in the north and south shores of Lake Dalnee, to the water in the spawning beds along the north shore, suggests that the properties of the latter are due to the subterranean flow from the springs and that both this underground flow and the above-bottom water from the springs have the same chemical characteristics.

It may be recalled that geologically the north and south shores of Lake Dalnee differed quite markedly from the west and

east. The high, rocky, north and south shores were composed of sandstone, superimposed igneous rock (andesite); the low-lying west and east shores were covered with alluvial soil. In the geologically different sections of the shore line were produced different types of ground water: alkaline water from the relatively high bicarbonate content is associated with the andesite and sandstone of the north and south shores; the weakly-acid water from the comparatively low bicarbonate content comes from the alluvial deposits along the west shore of the lake. The latter waters are common over a wide expanse of Kamchatka, assuring the supply of water to the majority of spawning grounds examined by us (Krokhin and Krogius, 1937, 1937a). Alkaline ground waters are encountered very rarely in Kamchatka.

The heterogeneity of the ground waters which supply the spawning grounds, within the limits of individual river systems was determined in the case of the Bolshaya River [page 106] (Krokhin and Krogius, 1937a). The data given above indicate that even in a relatively small spawning area, such as Lake Dalnee, the water supply to the spawning grounds may be provided by an underground flow of water with distinctly different chemical properties.

It is necessary to consider the favourable hydrochemical division into areas of the whole of Kamchatka. Without exception one can, on this basis, approximate an understanding of the causes of the quite dissimilar distribution of representatives of the genus Oncorhynchus within both the separate river systems themselves and the peninsula as a whole.

The O<sub>2</sub> content of the underground water in the spawning areas along the shores of Lake Dalnee is always lower than the O<sub>2</sub> in the bottom layer of water in the same place (Table 7, 8, 9). Within the spawning beds, which are located along the north shore, the O<sub>2</sub> content varies from 1.46 to 9.41 mg/l (13.4-85.7%), while of 13 analyses only in 3 did it exceed 7 mg/l; in 8 samples the O<sub>2</sub> was less than 6 mg/l. The average was around 4.5 mg/l (less than 50% saturation). On the west shore of the lake the underground water contained 3.03-11.57 mg/l O<sub>2</sub> (24.9-85.7%); in 5 out of 8 samples the O<sub>2</sub> was less than 7 mg/l; the average was higher than along the north shore--about 7 mg/l (55%).

The amount of free CO<sub>2</sub> in the ground water of the north spawning grounds varied from 0.83 to 18.20 mg/l, the pH--from 7.1 to 8.2; on the average, the concentration of free CO<sub>2</sub> ran from around 5.5 mg/l, and the pH--7.5. On the west shore spawning beds the free CO<sub>2</sub> was higher: from 6.76 to 22.00 mg/l with a pH fluctuation of from 6.4 to 6.9; the average value for free CO<sub>2</sub> in the underground water in the west spawning areas was close to 12-13 mg/l with a pH of around 6.6-6.7.

Table 8. [pp. 103-104] Hydrochemical properties of the ground water in the Lake Dalnee littoral zone.

Date	Depth from bottom surface, m	Temp., °C	O <sub>2</sub>		Free CO <sub>2</sub> mg/l	pH	Bicarb. CO <sub>2</sub> , mg/l	CaO, mg/l	SiO <sub>2</sub> mg/l	N, mg/m <sup>3</sup>			Fe <sub>2</sub> O <sub>3</sub> , mg/l	Sample no., Fig. 3.
			mg/l	%						NH <sub>3</sub>	N <sub>2</sub> O <sub>3</sub>	N <sub>2</sub> O <sub>5</sub>		
North shore, in spawning area														
3.ix 1937	0.30	...	1.46	...	9.75	7.2	...	...	12.88	50	3.8	...	...	1a
13.ix 1937	0.30	11.6	1.49	13.4	18.20	7.2	...	...	...	..	...	...	...	1a
	0.30	10.0	4.41	38.5	6.95	7.2	...	...	...	..	...	...	...	2a
12.x 1937	0.20	11.0	2.22	19.8	8.96	7.1	29.6	...	11.40	..	...	...	...	1
	0.15	...	2.98	...	2.99	7.4	41.4	...	11.20	..	...	...	...	3
	0.13	8.7	3.78	32.0	3.06	7.4	39.5	...	12.00	..	2.6	...	...	4*
	0.19	7.8	2.98	24.7	2.48	7.9	32.3	...	10.60	..	...	...	...	5*
	0.16	8.2	4.54	37.2	0.83	8.2	33.4	...	10.40	..	tr.	...	...	6
17.xi 1937	0.15	3.5	5.85	43.7	3.94	7.4	39.3	18.6	10.00	30	0.0	700	...	3
	0.13	3.5	7.28	54.3	4.47	7.4	39.9	18.2	10.20	25	0.5	700	...	4*
	0.19	3.7	4.23	31.8	4.54	7.4	44.2	...	10.20	26	tr.	500	0	5*
	0.16	3.5	8.08	60.3	1.67	8.2	41.8	18.9	10.00	38	"	400	0	6
19.x 1938	0.10	6.4	9.41	75.6	4.49	7.2	30.9	...	11.60	..	...	...	...	2a
West shore, in spawning area														
12.x 1937	0.12	7.4	3.03	24.9	22.0	6.6	24.7	...	16.60	..	4.0	...	...	7
	0.13	7.5	9.02	74.3	11.74	6.6	10.6	...	16.20	..	1.9	...	...	8*
18.xi 1937	0.12	1.8	7.13	50.9	13.27	6.5	22.4	11.2	14.20	24	0.5	500	0	7
	0.13	3.2	11.37	85.7	11.13	6.4	20.7	11.2	16.60	40	0.5	700	0	8*

Table 8 (continued)

5.ix 1938	0.10	12.6	3.37	31.1	15.12	6.6	20.2	...	14.80	..	7.2	....	0.34	8*
17.x 1938	0.10	6.5	9.60	77.2	6.76	6.9	24.4	...	13.00	..	...	...	...	14
	0.10	6.3	7.30	58.4	10.99	6.8	24.0	...	15.60	..	...	...	...	8*
14.xi 1938	0.10	4.0	5.71	43.2	12.56	6.7	21.6	...	16.4	..	...	...	...	8*
North shore, in ground outside spawning area														
3.ix 1937	0.30	...	5.48	...	6.19	7.2	...	...	9.44	2	3.7	...	...	3a
13.ix 1937	0.30	11.9	4.81	43.7	7.11	7.1	...	...	...	..	...	...	...	3a
	0.30	13.9	5.62	53.2	7.52	7.1	...	...	...	..	...	...	...	4a
12.x 1937	0.13	10.5	4.54	10.1	7.67	7.2	30.4	...	10.20	..	...	...	...	2
17.xi 1938	0.13	3.3	3.46	25.7	11.37	7.1	25.0	13.4	15.20	64	0.4	300	...	2
19.x 1938	0.10	7.7	6.29	52.1	6.94	6.9	24.0	...	10.40	..	...	...	...	2
West shore, in ground outside spawning area														
12.x 1937	0.15	9.0	2.40	20.4	30.0	6.4	19.75	...	11.88	..	...	...	...	9
	0.14	9.4	4.48	38.4	19.26	6.6	30.4	...	13.00	..	5.0	...	...	10

\*Sockeye redd.

Table 9. [page 105] Hydrochemical properties of bottom layer of water along the shore of Lake Dalnee.

Date	Temp. °C	O <sub>2</sub>		CO <sub>2</sub> mg/l	pH	Bicarb. CO <sub>2</sub> mg/l	CaO, mg/l	SiO <sub>2</sub> , mg/l	N, mg/m <sup>3</sup>			Fe <sub>2</sub> O <sub>3</sub> mg/l	Sample st. no.	
		mg/l	%						NH <sub>3</sub>	N <sub>2</sub> O <sub>3</sub>	N <sub>2</sub> O <sub>5</sub>			
North shore, on spawning grounds														
12.x 1937	11.0	11.47	102.2	...	...	...	...	...	...	...	...	...	...	..
	10.5	10.62	93.6	...	...	...	...	...	...	...	...	...	...	4
17.ix 1937	3.5	13.58	101.5	2.5	7.4	29.65	15.6	...	232	0.5	600	...	...	4
22.iii 1938	...	10.03	...	3.47	7.4	40.20	...	9.48	44	0	200	0.06	...	6
	...	8.94	...	4.38	7.3	39.00	...	10.48	46	tr.	200	tr.	...	3
	1.4	9.86	69.7	4.96	7.4	38.50	...	11.48	30	0	...	...	...	6
13.iv 1938	1.4	9.54	67.5	2.66	7.4	34.75	...	11.04	38	...	...	...	...	5
West shore, on spawning grounds														
18.xi 1938	2.3	12.66	91.7	4.17	7.3	28.50	15.0	4.60	...	...	300	0	...	8
North shore, outside spawning area														
17.xi 1937	3.3	15.08	112.2	1.52	...	25.80	...	4.60	38	0	200	tr.	...	2
19.x 1938	7.5	...	...	...	7.5	...	...	...	...	...	...	...	...	2
West shore, outside spawning area														
12.x 1937	9.3	...	...	...	8.6	...	...	...	...	...	...	...	...	10
18.xi 1937	2.8	13.32	97.7	3.33	7.4	28.80	...	4.20	35	0.5	200	0	...	10

Note. Samples of water taken right at the surface of the ground.

Thus, according to the gaseous state, the underground water along the west shore spawning grounds differs from that in the spawning beds of the north shore by having a somewhat higher O<sub>2</sub> content, a greater amount of free CO<sub>2</sub> and lower pH.

The free CO<sub>2</sub> and pH values for the underground waters of the west shore spawning areas are typical for alluvial ground waters. The free CO<sub>2</sub> and pH values for the underground values of the north shore spawning regions are characteristic of the ground waters from sandstone and broken igneous and volcanic rock.

However one must not forget that concentrations of free CO<sub>2</sub>, and particularly of O<sub>2</sub>, in the water of both types vary within certain limits and that the ranges of these limits in both types overlap; therefore to distinguish them by these indices can only be on the basis of their average value, obtained from a large number of readings. The pH (in the same way as the amount of bicarbonate, on which it originally, to a certain degree, depends) is more characteristic for each of the two types of water.

What are the gaseous conditions in those parts of the shore of Lake Dalnee, where the sockeye do not spawn? In order to answer this question, let us compare the ranges of variation of gas content and pH in the spawning beds and elsewhere (Table 10).

The limits of variation for O<sub>2</sub> content are narrow; the upper limits are particularly significant; they are much lower than on the spawning beds. The same can be said of the limits of variation in pH and free CO<sub>2</sub> along the north shore. The limits of variation for free CO<sub>2</sub> along the west shore are however somewhat peculiar; they have a [page 107] high free

Table 10. Range of variation of pH and dissolved gases in water from the bottom of the littoral zone of Lake Dalnee.

Origin of samples	O <sub>2</sub>		CO <sub>2</sub>	pH
	mg/l	%	mg/l	
<u>North shore</u>				
On the spawning grounds	1.46-9.41	13.3-75.6	0.83-18.20	7.1-8.2
Outside the spawning grounds	3.46-6.29	25.7-53.2	6.19-11.37	6.9-7.2
<u>West shore</u>				
On the spawning grounds	3.03-11.57	24.9-85.7	6.76-22.00	6.4-6.9
Outside the spawning grounds	2.40- 4.48	20.4-38.4	19.26-30.00	6.4-6.6

CO<sub>2</sub> content in those shore areas where the sockeye do not spawn. The ranges of variation suggest that the O<sub>2</sub>, CO<sub>2</sub> and also pH values on the unutilized shore areas overlap the limits of variation prevailing for spawning beds, or intergrade to a certain degree. Therefore no one of the specifically studied features of the gaseous conditions of the ground waters along the shore can be considered a reliable index of a spawning ground. Nevertheless often closely approximate values for separate gaseous conditions in different parts of the shore area of a lake are produced by different causes. On the spawning grounds one determining factor can be the chemical quality of the underground water present in them; in some parts of the shore area the chemistry of the water in the ground is determined by its stagnant condition, leading to a deficiency in oxygen, accumulation of free CO<sub>2</sub> and low pH.

The wide limits of fluctuation in O<sub>2</sub> content, CO<sub>2</sub> and pH on the spawning grounds indicate that:

1) sockeye under natural conditions, seeking a place to deposit their eggs, are not in the least influenced by a high O<sub>2</sub> content and a low CO<sub>2</sub> concentration in the water;

2) sockeye eggs, contrary to generally-accepted opinion, are sensitive to a low O<sub>2</sub> concentration and a high CO<sub>2</sub>. This we have noted earlier (Krogus and Krokhin, 1948).

In the literature there is no information on the chemical conditions prevailing within sockeye spawning grounds. However certain authors have made studies of the chemical conditions in the spawning areas of chums and have obtained similar results. Thus, G. V. Nikolsky and S. G. Soin (1954) showed, that in nests of summer chums the O<sub>2</sub> content was 4.6-8.0 cm<sup>3</sup>/l. V. Ia. Levanidov (1954, 1954a) notes that chum eggs (as distinct from the genus Salmo) develop under a regular deficiency of oxygen. In Georgievsky Spring (the Khor River system) he found from 2.5 (20%) to 7.2 mg/l (55%) O<sub>2</sub>; according to his data the eggs developed at a much lower O<sub>2</sub> concentration; but with an O<sub>2</sub> content of less than 3.2 mg/l a drop in respiration was observed. Development is somewhat retarded with a CO<sub>2</sub> concentration of 20-25 mg/l (Levanidov, 1954, 1954a). According to Wickett (1954) in chum salmon spawning areas the O<sub>2</sub> saturation amounts to 56-88%. Finally, according to I. S. Vasilev (1957) the O<sub>2</sub> content in [page 108] summer chum spawning beds in the My River system is 3-4 mg/l. Thus, in chum salmon spawning areas the O<sub>2</sub> conditions are almost the same as those found by us for sockeye spawning grounds.

A. I. Smirnov (1954) surmised that the carotinoid pigmentation in the eggs and embryos--the unusual respiratory system and appearance of carotinoids in the eggs and embryos of the fish--serve as an adaptation to development in water, which is deficient in oxygen. S. G. Soin (1954) notes that the

intensiveness of carotinoid pigmentation varies in the different species of the genus Oncorhynchus: the stronger the pigmentation and the more intensive the colour then the lower the oxygen concentration required by the eggs for respiration. Since the sockeye eggs are most intensively coloured, in comparison with eggs of other Pacific salmon species, it can be thought of as an adaptation to development under particularly severe oxygen conditions. This is confirmed by the low oxygen concentrations often found in the sockeye spawning grounds in Lake Dalnee.

All of the above merely emphasizes once again an opinion long ago expressed by us (Krogius and Krokhin, 1948) that the role of ground water on the spawning grounds leads, in the first instance, to an intensification of the water exchange in the sockeye redds and to the removal of waste products. This opinion of the function of ground water was given by Levanidov (1954, 1954a) in regard to autumn chum spawning areas.

It remains briefly to check on the amount of nitrogen compounds in the ground of the spawning beds. In the spawning ground underground water was found 24-40 mg/m<sup>3</sup> ammonia, 0.0-7.2 mg/m<sup>3</sup> nitrogen nitrite, and 40-700 mg/m<sup>3</sup> nitrate nitrogen. Unfortunately, not a sufficiently adequate number of analyses of the nitrogen compounds was made of the areas of lake shore not used for spawning to give a good comparison with the corresponding nitrogen compounds in the water of the spawning areas. As regards the bottom water along the shores of Dalnee Lake, ammonia and nitrate nitrogen in all cases were found to be approximately the same as those found in the ground of the spawning areas; in the spawning grounds there was less nitrite nitrogen.

There are no adequate data available for an understanding of the seasonal changes in the chemical features in the underground waters along the Lake Dalnee shores and this phase of the problem we must leave without solution.

### Conclusion

1. The most important feature of the sockeye spawning areas appears to be the presence of outflowing subterranean waters percolating through the bottom. The sockeye spawning areas are localized in accordance with the expanding accumulations of such subterranean or ground water.
2. The storage of ground water in Kamchatka is chiefly in the alluvial pebbly-sand deposits and volcanic rock (lava and tuff). Less widely dispersed are the ground waters collected in sandstone and fluvioglacial deposits.
3. Geomorphological accumulations of ground water are represented by the stream and lake terraces and alluvial fans, lava flows and upland tuff.

4. As a general rule, spawning grounds are located in places where there has recently taken place abrasion and erosion of accumulated materials. No spawning grounds are found in places where the processes of accumulation are at work.

5. In the above-noted geological and geomorphological evolution it is necessary, in the first instance, to note the fish-productive potentialities of Kamchatka rivers and lakes.

6. The chief features of the temperature conditions prevailing in the ground water supplying the sockeye spawning areas are its stability, the small amplitude of fluctuations both daily and yearly and the low absolute readings (range 3-5°).

7. In the littoral areas of the spawning lakes the spawning places in summer and autumn are distinguished by a drop in temperature in the ground in comparison with those parts not used by the sockeye for egg deposition. In limiting cases, the difference between the temperatures of lake water and in the ground can amount to 7°, more often 2-2.5°. The difference depends on the outflow of cold ground water through the spawning areas. On the contrary, winter temperatures in the ground of sockeye spawning beds are higher than in other parts of the lake littoral areas.

8. Special devices make available to investigators of spawning lakes the thermometric warming of the surface layer of water (end of July-August). The most convenient instrument for this purpose is a resistance electrothermometer, adapted for measurement of temperatures in the ground in the littoral areas of lakes.

9. A convenient means of collecting samples of water for chemical analysis from ground flows on spawning grounds is a Vereshchagin pseudobathometer.

10. Ground waters, supplying sockeye spawning areas, are distinguished by a stable chemical condition. One characteristic feature is a decline in oxygen content.

11. Even within the limits of a relatively small spawning area (such as Lake Dalnee) the supply of water to the various spawning beds comes from ground waters with quite distinctly differing properties; this is because of the heterogeneous geological structure of the shores of the spawning ground areas.

12. The ranges of variation of pH and dissolved gas content in the water of the underground lake sockeye spawning areas are close to or overlap the ranges of variation of those same features in the underground water found in those sections of lake shores not used for spawning. However the similarity is due to a variety of factors; on the spawning grounds a drop

in O<sub>2</sub> content, a rise in free CO<sub>2</sub> and a low pH are associated with the qualities of outflowing ground water in different parts of the shore area--with the standing of water in the ground.

13. The wide limits of variation in content of dissolved gases and in pH on the spawning grounds indicate that sockeye, seeking their spawning areas, are guided there not by high O<sub>2</sub> content in the water nor a low free CO<sub>2</sub>; on the other hand, the often-occurring low O<sub>2</sub> and high free CO<sub>2</sub> in the ground water of the spawning areas suggests that sockeye eggs are not as sensitive, in such a case, to these factors as usually is presupposed. Under the circumstances it is necessary to emphasize the importance of the selection of sources of water supply for sockeye fish hatcheries and also for their operation.

[page 110] 14. All that has been written serves again to emphasize that the importance of ground water in sockeye spawning beds consists firstly in increasing the exchange of water in the ground and removing the waste products of metabolism liberated by the developing eggs.

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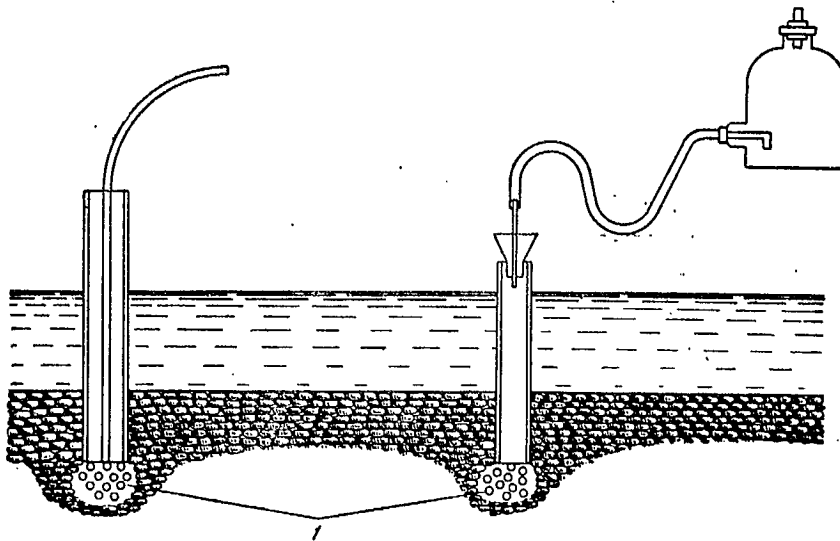


Fig. 1. [page 95] Sketch of arrangement of tubes for the collecting of water samples on the spawning grounds.

1--salmon redds.

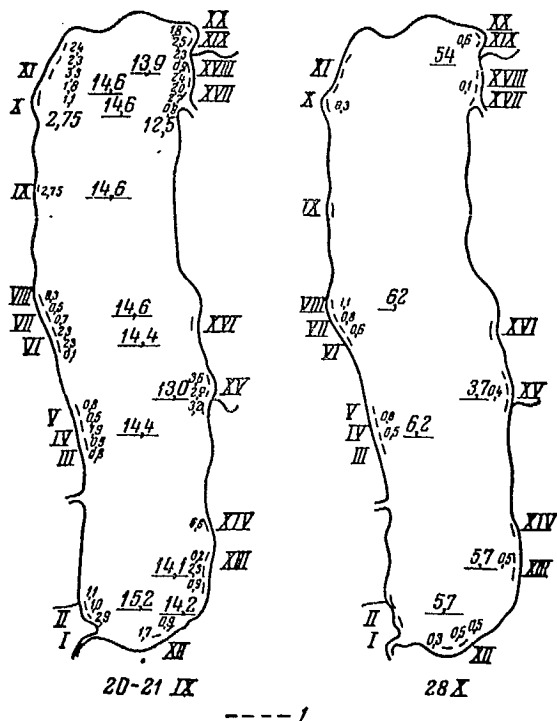


Fig. 2. [page 98] Variation in temperatures at the surface of the ground and in the ground of sockeye spawning beds in Lake Dalnee. The temperature readings taken at the surface of the ground are underlined; the Roman numerals refer to the number of the spawning ground.

1--sockeye spawning bed.

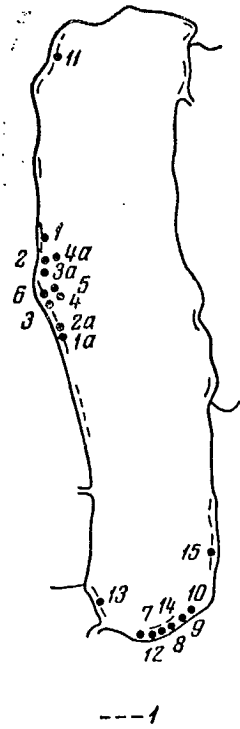


Fig. 3. [page 102] Location of collecting stations for samples of water from the littoral areas of Lake Dalnee.  
 1--sockeye spawning bed.