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VOLUME 18

DECEMBER, 1927

NUMBER 12

PROCEEDINGS

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PUBLISHED MONTHLY

Publication Office: Mack Printing Company, Easton, Pa.

Editorial Office: Harvard School of Public Health, Boston 17

Home Office of the Academy: Washington, D. C.

Entered as second-class matter June 21, 1920, at the postoffice at Easton, Pennsylvania, under the act of August 24, 1912.
Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917. Authorized June 18, 1920.

Price per annum, \$5.00

THE INFLUENCE OF A POWER DAM IN MODIFYING CONDITIONS AFFECTING THE MIGRATION OF THE SALMON¹

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Read before the Academy October 19, 1927

The life history of the Pacific salmon includes a period of oceanic life followed by the migration of the adult fish to spawning grounds which are near the headwaters of coastal streams. The young hatched on these spawning grounds proceed down the same streams to the ocean but with this difference: that whereas the adults press their way vigorously and insistently upstream, taking no food in the journey and using every effort to overcome at once the obstacles met in the course of the ascent, the young fish move downstream very slowly spending considerable time feeding on the way and manifesting none of the apparent anxiety to complete the journey that the adults show.

The coastal streams which are utilized by the Pacific salmon come out of mountains near the shore. They are characterized by a rapid flow of water and considerable drop within a short distance. In the main, they are fed by glaciers or snow fields of the high mountains so that the water temperature is relatively low and the water flow in summer high. By virtue of these features these streams are peculiarly adapted to furnish a water supply for industrial purposes. Waterpower sites along the course of the streams have been taken up for industrial purposes and numerous power dams already built. The demand for water power makes it reasonably clear that a still larger number of high dams is likely to be constructed

within the near future. It is important both from the economic and from the scientific standpoint to ascertain in what way this modification of natural conditions affects the abundance and movements of the salmon.

The movements of the fish towards spawning grounds has been studied by a considerable number of investigators and certain of the influences which direct that movement have been traced to environmental conditions. The two influences which have been clearly recognized are the direction of the stream flow and the temperature of the water. It has long been known that once the salmon have entered the fresh water, it is impossible to make them turn back or to divert them from the established course. They move upstream with such determination that even when some insuperable obstacle is encountered they will not change their course but continue to utilize all their energies in the effort to surmount it. When in some way a natural barrier has been suddenly created in the course of such a stream or an artificial barricade erected, the fish remain at this point striving to find or make a way over or through the obstacle until they are totally exhausted. Efforts to persuade or compel them to retrace their course and select another route have thus far proved unsuccessful.

The route followed by these salmon is often fairly complex. First of all they select only certain streams and never are found in adjacent apparently similar waters. As they mount the stream they pass by certain tributaries and choose another without apparent reason, making year after year in every case the same definite choice and rejecting opportunities for ascending to regions that appear to afford better opportunities for spawning than the points actually utilized. For many years I have been studying particularly the species known as the sockeye or red salmon. Some years ago² I was able to show that in certain instances at least this species which always spawns in a lake is moved at the junction of two streams to select the one having the lower temperature. Further studies on different streams have furnished confirmatory evidence of this condition and no instance has been found in which a sockeye salmon has at the fork of a stream taken the branch which showed a higher water temperature. Its progress upstream is determined by the impulse to buck the current and the route followed is fixed by its selection of the cooler water whenever a choice is offered.

The installation of power dams has evidently modified natural conditions considerably, and indeed most strikingly in those two features which influence the migration of the salmon. This year in studying such a situation definitely evidence was secured to show that the changes in natural conditions are exercising on the migration of these fish an influence definite enough and extensive enough to bring about changes in the previous life cycle of the individual in these waters. These obser-

vations were made on the Baker River in the State of Washington.³ Since I had studied the sockeye salmon on this stream during several previous summers and had extensive records of current and temperature conditions, it was possible to determine definitely the changes wrought by the erection of the power dam in question. This dam is located near the town of Concrete, just about the junction of the Baker with the Skagit river, and in a deep, narrow canyon. It is 260 ft. high. During the period of construction in 1925 and 1926, the movements of the salmon were necessarily greatly interfered with. At the present time the installation of a fish ladder and a cable hoist makes it possible to convey to the top of the dam those fish which can be persuaded to enter the pockets at the base of the fish ladder which is immediately adjacent to the tailrace and the power house and at the end of a rack built directly across the river.

Such a dam offers evidently an insuperable physical obstacle to the upstream movements of the fish. This fact which was recognized long ago furnishes the basis for provisions incorporated in certain state laws requiring the construction of fish ladders and of fish ways at dams. Such by-passes have been constructed in numerous instances and while in some cases they have worked with a certain degree of success, it is equally clear that in other cases they have failed to appeal to the fish and have not served the purpose of their installation. This may possibly be due to other less evident changes in the environment which nevertheless have been an influence in directing the activities of the fish. Some of these changes will be brought out by further consideration of the effects produced by the dam.

With the erection of the dam a considerable extent of the stream, often covering many miles, has been transformed from a rapid broken stream of relatively shallow water into a large deep reservoir or lake in which little or no current is discernible. Thus in Lake Shannon, formed by the Baker River dam at Concrete it was impossible to measure the current by means of a current meter and while a slight movement of the water could be detected it was nevertheless so insignificant that one may well question whether it would actually influence the fish. A rapidly moving stream has been replaced by a body of water at rest.

In the next place, the form of the installation has resulted in separating the lake into two very different regions. Water was flowing over the top of the dam only at occasional periods of excessive rainfall. Ordinarily the outflow took place through a tunnel opening at high water about 90 feet below the surface of the lake. Evidently the little current which actually did exist was limited to the region above that level whereas below the level of the intake canal the water was entirely devoid of current. The outflow after passing through the turbines was led away from the power house by a tailrace in which the water was in exceedingly rapid

movement. The tailrace joined the original stream only a short distance below the dam and some water was still flowing in the old channel between the foot of the dam and this point. Moreover, the water in that section was abundant and deep enough to afford opportunity for the ascent of salmon, though, excepting at periods of excessive rainfall, it did not approach in volume or strength the current passing through the tailrace.

Owing to its quiet surface and lack of movement, the water in the artificial lake formed by the dam was less highly oxygenated than in the rapid, rock-filled stream which previously occupied that region. Apparatus was not available last summer for testing exactly this condition but some crude tests that were made incline me to believe that under present conditions no serious modification in oxygen content has been brought about.

Temperature conditions in the newly formed lake have been most radically modified and differ from the original stream conditions in several respects. It was originally on this stream that I secured the evidence which led me to consider the difference in water temperature as the directive influence in bringing the sockeye to choose one branch of a stream rather than another. The Baker River is flowing nearly southeast at the point where it joins the Skagit while the latter stream at that point is flowing almost due west. In passing upstream the red salmon thus turns partly back on its course from the standpoint of compass directions when it leaves the Skagit which is the larger stream to enter the Baker River. But this shift is made by all the red salmon and no one of that species follows the Skagit upstream above the mouth of the Baker even though the upper regions of the Skagit and its tributaries furnish an abundance of apparently attractive lakes and spawning gravels. Temperatures taken at and near the junction of the two streams in former years showed that during the migrating season of the sockeye the Baker River is 1°F. or more lower in temperature than the Skagit. These observations were repeated this year and it was found that the same difference in the temperature existed but was even more marked in degree. Consequently, if the temperature of the water is the directive influence which determines the choice of route at stream junctions that influence has even been heightened by the construction of the power dam. However, one can foresee a temporary condition under which the reverse may be true. Should the power house be shut down the water from the surface of the lake flowing over the top of the dam would make the river water higher in temperature than before and, to judge from records obtained this year, higher than the Skagit at the junction, thus reversing the temperature relations of the streams. Somewhat similar conditions might be produced by excessive rainfall that would drive over the dam the warm surface water of the lake in large volume. Such conditions would naturally be infrequent and of

brief duration but the influence on the migrating sockeye would be most interesting to follow.

The next opportunity which the salmon has for making a choice between two streams is found only a short distance above the junction of the two rivers, namely, where the tailrace from the power house joins the Baker River. Here the stream from the tailrace offers usually a much larger volume of water and always water of much lower temperature. It was observed both last year and this year that the migrating salmon could not be kept out of the tailrace. Apparently they entered this on arrival from the lower waters and stayed in it fighting the current and striving to force an entrance into the turbines until thoroughly exhausted. They then drift out and congregate in the quieter waters of the old channel just above the junction with the tailrace. Here they could be observed in numbers, at different times making no more effort than sufficient to maintain themselves in position. Many of them bore evidence in wounds or fungused areas of struggle with the unfavorable conditions that they had encountered. I should mention that after such periods of rest some of these fish at least started up the old channel toward the dam and spent time and effort in fighting the rack which had been built to prevent access to the waters at the foot of the dam and which on the power house side of the river led to the base of the fish ladder mentioned before.

The temperature conditions in the lake are most highly modified and in two respects sufficiently radically to influence unfavorably the migration of the fish. These two features are, first, the greatly increased temperature of the surface water and, second, the very low temperature of the deep water.

The lake created by the dam is of considerable size being 8 to 10 miles in length and varying up to two miles in width. It is also rather deep, having a considerable area that is from one to two hundred feet in depth. A series of water temperatures was taken on three occasions and disclosed the general conditions which might be expected in a lake of that type and location. During the first week in August the surface water was about 66° to 68°F. in temperature. The thermocline was found at a depth of 12 to 15 ft. The observations showed a little greater variation in temperature on different occasions between this point and the level of the intake tunnel than is usual in such lakes. Below the level of the intake the temperature dropped very gradually. At 200 ft. it stood at this time about 41°F. The surface of the lake shows thus the existence of a considerable mass of water which is much warmer than would have been found previously in the river. On the other hand, there is a deep basin in the lake having a temperature at this time very considerably lower than the water flowing into the lake from the river above.

The salmon lifted over the dam sounded almost immediately but were

observed to return to the surface several times at short intervals before they finally disappeared. Only those which were fungused or otherwise in bad physical condition lingered in the surface waters.

Now the records for the summer of 1926 and for the past summer (1927) show that a considerable portion of the sockeyes lifted over the dam failed to reach Baker Lake. This is the normal spawning ground of this species; it is located 20 miles upstream from the dam. Thus 3578 fish were put over the dam in 1926 and only 2823 were caught at the lake. As a fish trap closes the entire channel where the river leaves the lake, the record is hardly open to question. During the past year 4158 fish were put over the dam and only 1328 reached the lake. Part of this difference is to be accounted for by the fact that some of the fish which were put over the dam were physically incapacitated and probably perished before they could have completed the upstream trip. On the other hand, it is clear that such an explanation is not adequate to account for the entire difference.

In other streams when red salmon have entered a lake with deep cold water, they rest and ripen in that water, continuing there until they rise to the shore zone to spawn. It is evident in that this deep cold area of Lake Shannon the fish would not be subject to a current stimulus such as under earlier conditions would have impelled them to continue the migration upstream and the temperature stimulus would tend to hold them in place since movement in any direction would bring them into warmer water. It is, of course, evident that such part of the fish as might continue along shore waters or through the upper water strata would find the river at the upper end of the lake and be impelled by the current stimulus to continue their ascent of the stream. These would then ultimately reach Baker Lake and the normal spawning grounds. Those fish which were trapped in the deep cold basin and ripened there would probably not find suitable spawning grounds or in the event that they did select some new place, the considerable variation in water levels in the new lake would imperil and very likely destroy the eggs in the course of the winter.

The downstream movement of the young fish has not yet been investigated. It is clear that their movement is seriously interfered with by the construction of the dam and the formation of the new lake. Some who have observed conditions at the dam maintain that the young fish go over the top with the excess water and reach the river at the foot of the dam successfully in spite of the drop of over 200 ft. It has also been stated that young fish go through the turbines without being killed. Both of these statements are deserving of careful study. It is certainly true that large numbers of what are probably red salmon remain in the lake and after the surface waters warm up, seek the deeper spots. They apparently retire below the thermocline when it is formed and spend the summer

in the deeper waters. There is no evidence to show whether they return to the surface after the fall overturn and continue their downstream migration or whether by virtue of the stop in their oceanward migration, they become a landlocked variety. Studies on these problems are in progress and it is believed that the situation will furnish valuable evidence regarding the effects of power dams on the migration of the sockeye salmon.

¹ Contribution from the Zoölogical Laboratory of the University of Illinois, No. 307.

² Ward, H. B., "Some of the Factors Controlling the Migration and Spawning of the Alaska Red Salmon," *Ecology*, 2, 234-254, 2 figs., January, 1922.

³ Research prosecuted under the auspices of the Department of Commerce, Bureau of Fisheries, Washington, D. C.
