THE MIGRATION OF SALMON IN THE COLUMBIA RIVER

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ESTABLISHED FACTS AND THE UNSOLVED PROBLEMS.

The life history of the anadromous fishes is one of the most interesting subjects in biology. The detail of facts surrounding the migration of the young from the fresh water to the sea and the migration of the adults to fresh water for spawning purposes are indeed little enough known of themselves. How much more shrouded in obscurity, therefore, must be the causes operating during these migrations. The United States Bureau of Fisheries has never ceased in its efforts to untangle this thread of piscatorial history.

In the instance of the Pacific coast salmon of the genus *Oncorhynchus*, thanks to the labors of Evermann, Gilbert, Meek, Rutter, Chamberlain, and others, the following general facts are now established within a reasonable degree of certainty:

1. The young of the species of *Oncorhynchus*, which have been hatched in the fresh-water streams, migrate to the sea, where they can secure an abundance of food during their developmental period. Evermann [a] in 1894 and 1895 observed many young *O. tschawytscha* and *O. nerka* in the Salmon River headwaters in Idaho. He says: "We are not yet able to say just when the young salmon leave the waters where they were hatched and begin their journey to the sea, but it undoubtedly occurs between September of the first and July of the second year following that in which they were spawned. Later Rutter [b] followed the downward migration of young salmon in the Sacramento River, California. He found that young salmon fry "begin their down-stream migration as soon as they are able to swim." They reach the estuary in large numbers in from ninety to one hundred days or more. He found also that many young salmon "summer

[a] Evermann, B. W.: A preliminary report upon salmon investigations in Idaho in 1894. Bulletin U. S. Fish Commission, vol. xv, 1895, p. 253, 1896; and A report upon salmon investigations in the headwaters of the Columbia River in the State of Idaho in 1895, together with notes upon the fishes observed in that State in 1894 and 1895. Bulletin U. S. Fish Commission, vol. xvi, 1896, p. 184.

[b] Rutter, Cloudsley: Natural history of the quinnat salmon. Bulletin U. S. Bureau of Fisheries, vol. xxii, 1902, p. 102.

residents" remained in the headwaters of the Sacramento until the first winter rains, when they all went out.

2. The salmon feed in the ocean for a period of years. For the chinook salmon this period is believed to be from three to five years, though the evidence is not entirely conclusive. The feeding period continues until maturity is reached.

3. At the end of the feeding and maturing period the salmon migrate up the Pacific coast rivers to spawning grounds, which are sometimes only a few miles from the sea and scarcely beyond brackish water, but often for hundreds of miles, apparently always into cold fresh waters of the streams fed by springs, lakes, and mountain snow fields.

4. It has long been known in a general way that the migration of *O. tschawytscha* to the spawning grounds is made wholly without food.

5. The most striking and least expected climax to this interesting life cycle was discovered in 1894 by Evermann[a] for the species *O. tschawytscha* and *O. nerka*, namely, the fact that death invariably follows the spawning act. Evermann states, on page 260 of his preliminary report upon the 1904 expedition, that on September 13th he counted 72 dead salmon in a three-mile stretch of Salmon River and a mile or more of the lower portion of Alturas Creek in Idaho. Only one live salmon was noted on this date. He quotes numerous observations and conclusions of local men of the region tending to confirm the deduction expressed on page 153 of his final report as follows: "The chinook salmon which come to these waters die after spawning."

This brief salmon history is repeated here for the reason that it is the most effective way of presenting the setting for the problems that appeal to the physiologist. Of these problems I have in a previous paper[b] attacked the question of the acclimatization of the chinook salmon to fresh water after its life in the sea. That study was based on an examination of the blood and other body fluids. The special interest attaches to the osmotic changes during the passage of the fish through the various degrees of brackish water in the journey from the salt water of the sea to the fresh water of the rivers. The further osmotic change during the run up the river was also studied.

The changes in the blood and body fluids are relatively slight and are carried on very slowly and gradually. The osmotic changes in the body fluids give little or no intimation of the length of time consumed by the fish in the transition from salt to fresh water. Neither do the osmotic changes give any measure of the duration of the sojourn in fresh water. In order to arrive at any adequate explanation of the profound changes in the tissues and organs during the migration it becomes almost a necessity that the rapidity of change in the environment and the total duration of the period be determined. The time element in this change is indeed the most important factor, yet an almost wholly unknown one.

The present paper gives the results of a preliminary experiment designed to secure more tangible evidence as to the time element in the migration, especially on the Columbia

[a] Evermann, B. W., op. cit., vol. XVI, p. 151.

[b] Greene, C. W.: Physiological studies of the chinook salmon. Bulletin U. S. Bureau of Fisheries, vol. XXIV, 1904, p. 429.

River.[a] The question can be better understood when analyzed into the following points or questions:

1. How long do salmon remain in brackish water? Or, stated more fully, how rapidly do salmon pass from salt water through the various degrees of brackish water at the mouths of the rivers?

2. What evidence is there that salmon swim back and forth with the ebb and flood of the tide during the migration through brackish water?

3. When once quite within the fresh water of the rivers, how rapidly and how continuously do salmon travel on their course up the rivers to the spawning grounds?

4. What evidences do salmon give of special responses to unusual conditions, such as obstruction to their course, individual injury, etc.?

PRINCIPLE AND METHOD OF EXPERIMENT.

This experiment is based on the principle that an understanding of the details of the migration phenomena can only be had by a study of the movements of individual fishes. The information derived from the movements of large schools of fishes, while often of extreme value as corroborative evidence, can never be taken as conclusive evidence of the movements of individuals. Even if it were safe to assume that the movements of a given school of salmon represent the average of the movements of the component individuals, yet it is quite impossible to identify certainly any given school at different points along the river.

In order to subject the above questions to a preliminary test, I arranged a salmon marking experiment on the lower Columbia River. The experiment was accessory to a physiological investigation under my immediate direction during the summer of 1908. Fifty-nine fish were marked with individual tags and liberated in the Columbia River at the head of Sand Island, which is just within the mouth of the Columbia. The point at which the fish were liberated was about eight miles up the river above the Canby light-house on Cape Disappointment. This experiment was launched on August 14, 1908.

Superintendent Nicholay Hansen, of the Chinook (Wash.) fish hatching station, contributed the catch of the Washington state fish trap. He also generously furnished transportation to the trap and granted me the assistance of the hatchery foreman and crew. I was assisted also by one of the staff of the United States Bureau of Fisheries. On the above date the trap contained a two-days catch. We reached the trap at about 9 o'clock in the morning, just before extreme low tide, and the net was lifted soon afterwards. The fish were run from the net into a special live car used by the Chinook hatchery crew to transport fish from the trap to the retaining grounds. The fish were later dipped from the car with a large dip net, lifted out of the net by hand, and quickly measured for total length. The marking tag was next inserted and the fish turned loose into the current. It goes without saying that the utmost

[a] A briefer paper based on this experiment is published under the title, "An experimental determination of the speed of migration of salmon in the Columbia River," in the Brooks Memorial Volume of the Journal of Experimental Zoölogy, vol. 9, 1910.

dispatch was used to prevent asphyxiation and care taken to avoid injury during the necessary handling.

MARKING TAGS AND TOOLS.

The tags used to mark the salmon in this experiment were made of aluminum and were extremely light and very strong. The entire tag or button weighed 2.6 grams ($\frac{1}{12}$ ounce). The tag was made of two pieces on the general principle of a Yankee button (fig. 1). The piece *B* consisted of a circular disk, 1 mm. thick by 19 mm. in diameter, which was forged to a hollow shaft, 7 mm. long by 7 mm. in diameter. The shaft had a hole through its length some 4 mm. in diameter. A serial number was stamped on the face of the disk (fig. 1, *D*). Piece *A* was a disk similar to *B* but forged to a solid rivet, 4 mm. in diameter by 9 mm. long. On this face was stamped the words "U. S. Fish," as shown in *E*. When the rivet of piece *A* is inserted into the shaft of *B* (fig. 1, *C*), the rivet projects 2 mm., which gives ample length for securing. When the two pieces are adjusted and the rivet compressed, the soft aluminum fills the shaft and the end is mashed down so that the two pieces can not be torn apart (fig. 1, *D*).

The marking pliers (fig. 2) used in this experiment were supplied by the manufacturer of the marking buttons. They were of cast iron, quite large, and rather heavy for quick work. The pliers were 28 centimeters long and weighed 670 grams. Between the handles there was inserted a hollow punch that cut a hole 7 mm. in diameter. The width of the pliers was adjustable to the length of the button, the adjustment being made by threading in one jaw. It was not necessary to use this adjusting device in the salmon experiments, since the thickness of the salmon fin was never so great but that the pieces of the button could be completely thrust home with the fingers without the aid of the pliers.

CONDITIONS AND DETAILS OF MARKING PROCESS.

When a salmon is caught up in a dip net he struggles vigorously to get away. One should use a relatively large dip net with a wide flat bottom (i. e., not the usual round or kettle-shaped bottom). With such a net it is very easy to manage a fish through the struggling stage so that it does no injury to itself. It is not necessary that scales should be lost, even in such loose-scaled fish as the silver salmon.

In this experiment when a fish was caught it was held with the bottom of the net just deep enough in the water for the fish to struggle against the resistance of the water. While this method resulted in a goodly quantity of water being thrown over the operator, it had the very desirable effect of quickly producing a temporary fatigue of the salmon. As a result of this fatigue, the fish remained quiet for a number of seconds.

The instant a fish stopped struggling it was lifted out of the water, seized by the tail with a strong grip of the hand, swung free of the net, and over the free arm of the operator. The next instant it was quickly but gently laid out on the measuring platform and its length read off. The measuring platform consisted of a broad board with an upright at one end. A meter stick was tacked to the board with its zero against the upright. Loose folds of burlap were laid over the board and over the meter stick for

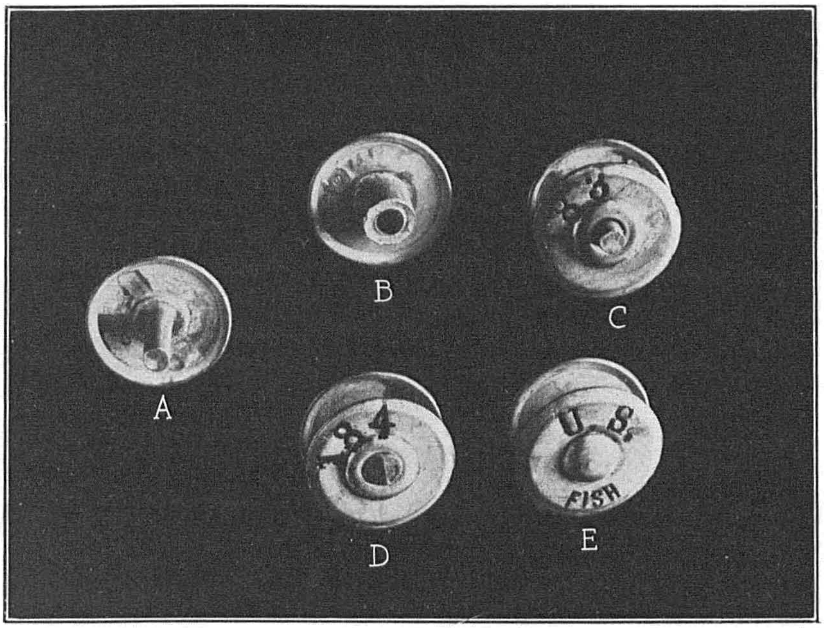

FIG. 1.—The two pieces of the marking button are shown in A and B, the former especially arranged to show the rivet, the latter to show the shaft. In C the two pieces are shown put together but not riveted. In D the parts are riveted together, and in E the converse side is figured.

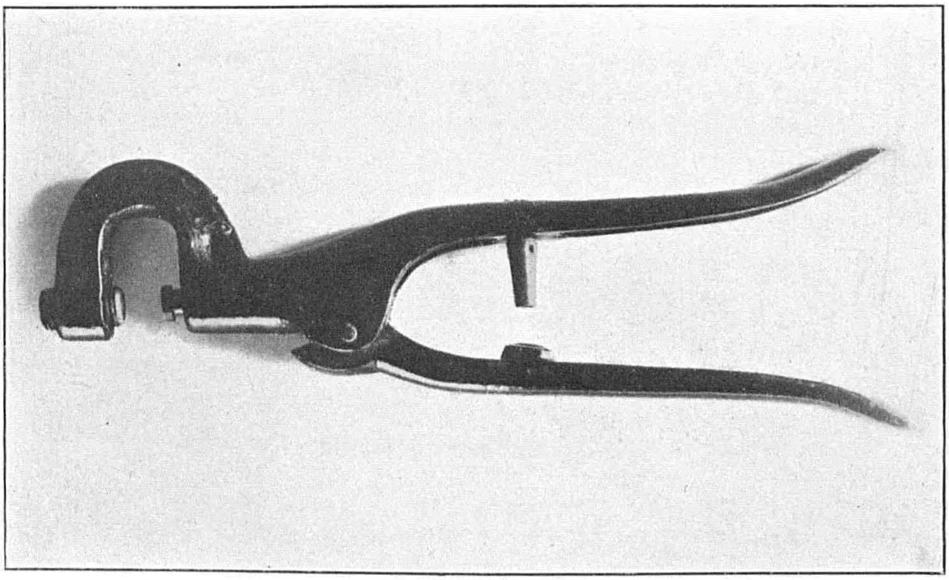

FIG. 2.—Pliers used in attaching the marking buttons.

the greater portion of its length. A fold of the burlap was so arranged that it could be quickly thrown over the middle portion of the body of the salmon whenever desir able, i. e., occasionally with the largest specimens.

When a fish was laid out on the measuring platform the tip of its nose was allowed just to touch the vertical piece and its tail was extended to full length. The total length was then read off by the measurer and announced to the recorder. The tail was, however, never released from the grasp of the operator during this move; a struggle is apt to begin at any moment, and if the fish struggles it must be swung free into the air to prevent pounding on the board and injury to itself. If the length was not caught by the measurer before struggling occurred, the process, of course, had to be repeated. Lifting a salmon from the water, taking it from the net, and reading its length on the measuring board really consumed only a very few seconds—not so long a time as required to describe the process.

After the length was read the next step was the insertion of the marking button. This was done by the person who did the measuring. The buttons in this experiment were all inserted in the caudal fin. The upper lobe was used except in a few cases where a cleft was present, in which case the lower lobe was used for the button. The inserting tool, previously described, although intended for use on the domestic animals, was reasonably workable on salmon. Its chief deficiency was in the fact that its use required two very different movements. The first movement was to slip the handle over the lobe of the fin in order to punch the hole for the button (see fig. 2). The second act was for the purpose of compressing the button and riveting it securely in place. If the fish began to struggle at the instant the button was being compressed, the button had to be released instantly lest it be torn from the fin. In cases where the tail was released, the unriveted button was usually thrown out and had to be reinserted. A special tool is being devised for future work that will punch the hole, insert the button, and rivet it home in one continuous movement. Such a tool will materially increase the rapidity of the work.

The salmon that came through the marking process in good condition were immediately released overboard in the direction of the open water. If there was any questionable degree of asphyxia, the fishes were released into the car and turned overboard only when fully recovered. In two fishes that were markedly asphyxiated it was necessary to use artificial respiration for a short time. Both were strong and active when ultimately released from the live car. The fishes took the water readily and quickly swam away. My previous experience in handling live salmon enables me to state that the present handling was well within the limits of treatment which salmon endure without danger or risk.

The weight of the fishes was estimated by Foreman Borkman, who has a reputation for skill in the accuracy of his judgments. Mr. Borkman's estimates have come very close to the actual weights of certain of the fish retaken. In at least one of the largest fish the actual weight tallied exactly. The judgments of the weight were arrived at during the handling of the fish in the net and on the measuring board. These estimates are only of relative value, however, as indeed are the measurements of length in this preliminary test, and no calculations are to be based on either set of measurements.

DISCUSSION OF TECHNIQUE.

It should be remembered that the procedure related here was done on the first and only attempt to tag fish in the migration run up the Columbia River. The details are given rather fully for the guidance of those who may in the future try this or similar experiments. The technique in handling can be improved as regards two factors; first in the convenience of arrangements for increasing the speed of dipping, measuring, and tagging the fish; second, in the skill which comes with continued handling which will reduce the chances of local injury and of asphyxiation of the fish.

The fishes suffer no physical injury up to the point where the hole is punched in the tail to receive the button. Careless or inexperienced handling, however, may lead to some injury. For example, if the meshes of the dip net are too large it requires care lest the fins be split or a gill torn in removing the fish from it. These injuries can be reduced by care and skill, as has just been stated. Silver salmon will also lose scales in struggling unless they are swung free of the operator's body. For example, if a silver salmon should begin to struggle just as it is swung into the arms of the operator and the operator should undertake to hold it firmly, a number of scales would almost invariably be lost. But if the fish be quickly swung by the tail free of the operator's body until the struggles cease no injury will be done.

Other fins, such as the dorsal or pectorals, might better have been tagged than the tail fin. The objection can be legitimately raised that, since the tail is the most active organ, it would be better to run no risk of its injury, even though the injury were slight, as in this experiment. On the whole, I am of the opinion that this is a well-founded objection. If the button is inserted a little too near the base of the tail, there will be some delay in the healing of the wound. Most of my fish were reported as retaken in fine condition, but some that were taken at The Dalles, Oreg., and had therefore made the longest runs, were reported to have buttons that had become very loose.[a] The holes for the insertion of the buttons had not healed—in fact, had grown larger. The dorsal fin, or even the adipose fin, are possible points that might prove more advantageous for the insertion of the marker. The possibility of tearing out the button in gill nets and the like must always be given consideration in making a choice of points for marking.

As for the tag or marker itself, various criticisms have or may be offered regarding it—that it is too large, that it is too heavy, that it may frighten the fish, since it is bright and shining, that "it may act to the fish like the proverbial tin can to a dog's tail." All of these have little basis in fact and reason. Considered in relation to the size and

[a] "[On August the 25] a 35-pound chinook salmon, in the very best of condition, button snugly in place without any sign of sore, was caught by seine about 15 miles upstream (from the state trap) in the Columbia River, in the main ship channel opposite Altoona, Wash."—Wm. H. Bailey, of the Miller's Sands Fishing Company, of Altoona, Wash.

"We got a steelhead to-day, No. 98. * * * This button wears a big hole in the tail, large enough almost to drop out."—Frank A. Seufert, The Dalles, Oreg., under date of October 5, 1908.

"I inclose herewith serial tag No. 87, taken from a 10-pound silver salmon on the 10th of October, caught by Mr. Ed. Le Roy in a trap at the head of Cottonwood Island. Mr. Le Roy states that the fish was in first-class condition when taken."—H. C. McAllister, master fish warden of Oregon.

weight of the fish, I regard this particular aluminum button as almost ideally light and strong and conspicuous for use in tagging salmon in fresh water. It is probably not visible to the fish that wears it, so can not frighten him, and the possible effects on other individuals are of little importance. As for the "tin can" comparison, this point makes a very good joke, but has no basis in fact. I have marked numerous salmon on the spawning grounds and find that the marked fish come and go with the unmarked fish without any disturbing behavior to distinguish them from the other fish of the schools.

For sea-run fish, where the sojourn in salt water lasts for a year or more, aluminum will not do. Salt water corrodes aluminum and the disk will probably drop off within a year. The corroding property of aluminum in salt water is, however, very valuable as an accessory check on salmon that are making the journey through tide water. (See figs. 3 and 4.) The degree of corrosion of the aluminum button indicates the relative immersion in salt water, although from this fact alone one can not distinguish between the corrosion due to a relatively short immersion in concentrated and that produced by a longer immersion in more dilute sea water.

LITTLE INJURY TO FISH IN HANDLING.

The necessary physical injury to salmon while marking them by the methods used in this test are two, or at most three. The first of these is the degree of asphyxiation produced by the handling of fish out of water. The second injury is that of cutting the 7 mm. hole through the caudal fin. The third is the physical effects of the handling.

By asphyxiation is meant the condition which results from the inability of the salmon to secure the usual quantity of oxygen and to get rid of the carbon dioxide rapidly enough. With fishes this exchange of oxygen and carbon dioxide takes place between the blood in the gills and the water flowing through the mouth and over the gills, the oxygen being absorbed from the water into the gills and the carbon dioxide exchanged at the same time passing in the opposite direction. If a fish is taken from the water and air is allowed to pass freely over the gills, the conditions for the gaseous interchange between the air and the blood through the gills is for a time as good, or even better, than with water. The trouble comes when the gill covers are tightly closed down and when the gill filaments, no longer supported by water, adhere together in a mass. These conditions sharply reduce the respiratory efficiency, and asphyxiation results. This is slight at first, but is more intense and more rapidly developed later. One who gives attention to the fact can not but be impressed by the degree with which salmon withstand asphyxiation and the ease with which asphyxiation can be overcome by artificial respiration. In the above experiments only two salmon required the artificial respiration. One of these was a fish weakened by old injuries that were quite severe. I do not consider ordinary mild asphyxiation of any particular injury to the fish unless it be so pronounced that the irritability of the respiratory center in the medulla is lowered enough to stop completely all respiratory movements.

The injury to the fish from cutting the small hole in the tail for the button is very trifling indeed. This cut is for the fish about like making a pin prick in the skin of the hand to a man. It gives a stimulation that produces physiological reflexes for the moment, and that is small. If the button is carelessly inserted, it might tend to further stimulate the skin during the succeeding two or three hours, but the effects even in this instance would be so slight that it seems to me there would be no very noticeable influence on the fish. Scarcely a fish is caught in the upriver fish wheels where I have worked but that shows physical injuries greater than this.

There still remains the general effect of the handling. No doubt a certain amount of fright and stampeding must have resulted from the handling of these fish, just as it would have resulted if the same fish had been turned loose directly by the lifting of the trap or from a seine. This effect will be discussed more fully in the next chapter.

EFFECTS OF MARKING ON MIGRATION.

The question that naturally presents itself is, What effect will all this have on the migration and on the manifestations of the migratory instinct of the salmon? In my opinion, it will have little or none, and the following pages will reveal my reasons.

First of all, one must divest himself of the customary attitude toward reactions of such complex animals as man and the domestic animals. These are far too complex for comparison with salmon. The reactions of a form so low as the salmon must be considered in the light of its biological development.[a] For example, the salmon brain is very simple in its type and low in its development. The cerebral lobes are relatively small and the so-called cortex layer consists of little more than a single and simple layer of nerve cells. That it possesses anything beyond the very simplest of association fibers is improbable. With such a low form of brain the salmon can not carry out very complex reactions; it has no machinery for such reactions.

The simplicity of the salmon's brain when compared with that of a bird or of a mammal is like the mechanical simplicity of the spiral screw in the ordinary cannery soldering device when compared to the most complicated intricacies of the vacuum solderless heading machines. This salmon brain is complicated enough to coordinate certain particular functions; for example, the circulation, respiration, muscular motions, etc. That the salmon may carry out consecutive nerve reactions such as psychic deductions is impossible. To illustrate, when the hole is punched in the tail in the tagging process, there are slight muscular movements in the region of the tail—local motor reflexes. Sometimes, but by no means always, there may be general motor reactions and the fish struggles to free itself. There are also momentary inhibitions of respiration involving one or two respiratory movements, and, judging by other experiments conducted to determine the fact, there are reactions on the circulatory apparatus. All these are of the simpler reflexes and are comparatively slight, and disappear within a few minutes at most. The mechanical stimulus of inserting the marking button furnishes an occasion for the repetition of the whole series of the above reactions, but in a milder degree. If one can rely on the observations made on sharks, which are not far removed from the salmon in their development, one must conclude that mutilations much more severe

[a] Edinger, L.: Ueber das Hören der Fische und anderer niederer Vertebraten. Zentralblatt für Physiologie, bd. XXII, 1908, p. 1.

will be ignored by the fish within a very short time—a time probably measured by minutes.

The chief objection one can raise here is to assume that the button when once inserted acts as a continuous source of stimulation to the individual fish, thus driving it into panic. One may assume that the button is not where the fish can see it and that it makes no sound which the salmon can hear, granting the questionable fact that the fish recognizes unusual sounds. The only other possibility is that the button is a continuous source of cutaneous sensory stimulation. This last seems plausible, but the fact is that either the wound will heal and adapt the surface to contact with the button or the injured surface will begin to degenerate, in which process the local nerve endings will soon lose their function and become insensitive.

Those conditions which lead to the migration of the salmon are the chief directive stimuli for the salmon at this phase of its existence. They overshadow all others. In comparison with this series of reactions, the so-called migratory instinct, small physical injuries are as nothing. If it were not so, the numerous fish that are injured by seals or sea lions, that are torn by hooks and the rocks, that are even more profoundly injured in the escape from the gill nets, would not appear in such vast numbers on the upper fishing grounds of the river. By my own count on different occasions net-injured fish in the catch of some of the wheels during the summer of 1908 amounted to from 25 to 60 per cent of the total, and I am reliably informed that at certain times the per cent may run to 80 or 90. My observations indicate that some of the salmon recover from these bruises received from the gill nets, though what per cent of recovery occurs I can not say. Salmon are, however, frequently taken on the Celilo fishing grounds with injuries so profound that one wonders how they could have survived so long, yet these severely injured fish are forging ahead toward the spawning grounds. The migratory stimuli overshadow even these most profound injuries and continue to do so until death ends the struggle, and death must inevitably end the struggle of these unfortunates long before the spawning act is consummated.

DETAILED RESULTS OF EXPERIMENT.

The location chosen for the marking of the salmon of this experiment is the Washington state fish trap, a few hundred yards above the head of Sand Island. The point is some 7 or 8 miles within the mouth of the Columbia, on the Washington side, and 10 or 12 miles below Astoria. The border of the channel above the island is bounded by a line which represents the legal limits regulating the setting of fish traps by the fishermen. The state trap is located just outside these limits, permission having been secured for the location by the Washington fisheries authorities from the United States engineers in order to catch fish for the Chinook hatchery. The point also marks the limits on the north to the area over which gill-net fishermen drift their nets. In fact, gill netters occasionally have their nets caught by the cross currents and thrown on this trap. Standing, as it does, just on the border of the north channel on the line that separates the gill netters' field on the one hand from the set traps on the other, this trap is especially well located for this experiment. It is in the area of brackish water, yet it is several miles upriver from the lower fishing limits, and therefore gives a chance to test whether the marked fish ever run toward salt water.

Of the 59 fish marked and liberated on August 14, there were 25 chinook salmon (*Oncorhynchus tschawytscha*), 16 silver salmon (*O. kisutch*), and 18 steelheads (*Salmo gairdneri*). These fish ranged in total length from 41 to 103 cm. for the chinooks, 47 to 78 cm. for the silvers, and 71 to 90 cm. for the steelheads. The largest chinook weighed 35 pounds. The fish, while few in number, were well distributed as regards size.

Information as to the import of the experiment was given out to the fishery interests on the Columbia. Fishermen were requested to record the place and details of the catch of any marked fish, to note any injuries or other facts of interest, and to report the same to me. Fishermen were also requested to send in the marking buttons with the tails of the fish. The various salmon-packing firms were especially helpful in reporting catches and in forwarding the marking buttons.[a]

Seventeen out of the 59 fish marked were retaken and reported to me. This number retaken represents 29 per cent of the fish liberated, a very favorable proportion considering the 12 to 15 days of closed season following the 25th of August. Of these fish 6 were chinooks, 6 were silver salmon, and 5 were steelheads. The time of the retaking extended from the date of the marking, August 14, to October 10, a total of 57 days. The general record of all the fish retaken is presented in table 1.

TABLE I.—DISTRIBUTION, TIME, AND OTHER FACTS CONCERNING THE 17 SALMON AND STEELHEADS RETAKEN OUT OF THE 59 MARKED AND LIBERATED AT THE WASHINGTON STATE TRAP, COLUMBIA RIVER, AUGUST 14, 1908.

Species, number, and sex.	Weight.	Length.	Date retaken.	Days out.	Place taken.
CHINOOK.	*Pounds.*	*Cm.*			
80♂	35	103	Aug. 25	11	Ship channel opposite Altoona.
109♂	5	54	Aug. 15	1	Chinook, Wash.
110♂	10	68	Aug. 15	1	Do.
113♀	15	82	Aug. 20	6	Republic spit.
115♂	1.5	45	Aug. 15	1	Chinook, Wash.
123♂	14	76	Sept. 14	31	Opposite Brookfield.
SILVER.					
75♂	9.5	69	Sept. 12	29	Celilo rapids.
76♂	14.5	78	Sept. 11	28	Do.
79♂	5	62	Sept. 16	33	Do.
87?	9	67	Oct. 10	57	Cottonwood Island.
89♂	8	66	Sept. 13	30	Celilo rapids.
97♀	9	67	Sept. 16	33	Do.
STEELHEAD.					
98	14	81	Oct. 5	52	Celilo rapids.
116	12	81	Aug. 14	0	Republic spit.
124	11	78	Sept. 18	35	Celilo rapids.
125	16	86	Bet. Sept. 14 and 20	31–36	Cottonwood Island.
?			Aug. 21	7	Chinook, Wash.

[a] Marked fish were caught by or reported to me by the following persons and firms: P. S. McGowan & Sons, McGowan, Wash.; N. Futrup, Chinook, Wash.; W. and M. McIrvin, Chinook, Wash.; Wm. Graham, Ilwaco, Wash.; Pillar Rock Packing Company, Pillar Rock, Wash.; Wm. B. Bailey, of the Millers Sands Fishing Company, Altoona, Wash.; "Sunderland Trap," Brookfield, Wash.; Ed Le Roy, Cottonwood Island; Seufert Brothers, The Dalles, Oreg.; B. Soderlund, Chinook, Wash.

TABLE I.—DISTRIBUTION, TIME, AND OTHER FACTS CONCERNING THE 17 SALMON AND STEELHEADS RETAKEN OUT OF THE 59 MARKED AND LIBERATED AT THE WASHINGTON STATE TRAP, COLUMBIA RIVER, AUGUST 14, 1908—Continued.

Species, number, and sex.	Distance from state trap.	How taken.	By whom taken or reported.
CHINOOK.	*Miles.*		
80♂	15	Seine	Millers Sands Fishing Co., reported by Wm. B. Bailey.
109♂	0	Trap	W. N. Futrup.
110♂	0	do	W. & M. McIrvin.
113♀	[a] 4	Purse seine	W. Graham.
115♂	0	Trap	W. & M. McIrvin.
123♂	15	do	Sunderland's trap, reported by H. C McAllister.
SILVER.			
75♂	210	Seine	Seufert Brothers Company.
76♂	210	do	Do.
79♂	210	do	Do.
87?	70	Trap	Ed Le Roy.
89♂	210	Seine	Seufert Brothers Company.
97♀	210	do	Do.
STEELHEAD.			
98	210	Seine	Seufert Brothers Company.
116	[a] 4	Purse seine	Pillar Rock Packing Company.
124	210	Seine	Seufert Brothers Company.
125	70	Pound net	Ed Le Roy.
?	½	Trap	B. Soderlund.

[a] Downstream.

The fact that aluminum is corroded by immersion in salt water has in a degree served to indicate the career of the marked fish after they were turned back into the Columbia. The degree of corrosion does not enable one to distinguish as between a relatively short time in concentrated salt water and a longer time in relatively dilute brackish water, but where corrosion occurs extensively in a short period of time, as in fish number 80, which was out only 11 days, it is pretty safe to assume that the fish spent most of the time in relatively concentrated sea water. Tables and figures are presented below for the purpose of showing the degree of corrosion of the marking buttons.* An examination of these tables and figures will show that each group of fishes of the three species liberated had certain individuals that had gone into sea water long enough to produce corrosion of the marking buttons.

TABLE II.—MARKED CHINOOK SALMON RETAKEN, SHOWING THE EXTENT OF CORROSION OF THE MARKING BUTTONS BY SOJOURN IN SALT WATER.

Number.	Time out in days.	Distance from state trap.	Corrosion of marking button.	
			"U. S. Fish" surface.	Numbered surface.
		Miles.		
80♂	11	15	Very light corrosion in groove around head of rivet.	Corrosion over four-fifths of raised rim of shaft and around rivet.
109♂	1	0	Smooth	Smooth.
110♂	1	0	do	Do.
113♀	6	[a] 4	do	Do.
115♂	1	0	do	Do.
123♂	31	15	Blackened and slight corrosion around head of rivet.	Deeply etched about rivet where it emerges from shaft, and on inner margin of shaft.

[a] Downstream.

CAREERS OF INDIVIDUAL SALMON RETAKEN.

CHINOOK SALMON.

Of the chinook salmon, three, numbers 109, 110, and 115, were retaken in traps in the immediate vicinity of the point where they were liberated. They were taken at the next lift of those traps on August 15 and may have entered the traps at any time during the interval of a little less than 24 hours following their liberation. These three salmon are the only fish of the marked series reported retaken by the traps of the vicinity. They are of interest chiefly as showing that the great majority of the fish took to the main channel in the direction in which they were liberated. The currents at the time of liberation were toward the trap field. On the theory that salmon stem the currents in the tide waters as well as in fresh water, it is obvious that the liberated fish would be directed away from the trap field. These observations are in the main in harmony with this theory.

Chinook number 113 was caught 6 days after liberation and by a purse seine operating near Republic spit. Republic spit is a point marked by the wreckage of a vessel which obstructs the channel off the south shore of Sand Island. It is located about 4 miles down the river from the state trap. The aluminum marking button of this salmon is quite smooth. Had the fish gone out into the pure sea water it might have shown some slight signs of corrosion. Six days in brackish water would scarcely lead to corrosion of the aluminum. It is probable, therefore, that this salmon had spent the time swimming back and forth in the tide water of the vicinity in the process of acclimatization. Whether or not it swam long distances, either upriver or out to sea, does not appear, but judging by the results of the comparison with specimen number 80 it is probable that the time of number 113 was spent in the relatively fresh water in the neighborhood of Sand Island.

Number 80 was taken 15 miles up the river from the state trap and on the eleventh day after liberation. The time required by a straightaway swim for the salmon to travel 15 miles could not be over one or two days (three of the silvers averaged over 7 miles a day, see numbers 75, 76, and 89); hence this fish had about 9 days in which its movements are not accounted for. The corrosion of its tag is slight on one side but quite extensive on the other. So much corrosion in the short time of 11 days can only be accounted for on the theory that the fish was in relatively salt water. My guess would be that this fish went well out toward the jetty or even beyond during its 11 days' stay, and that the average of its time was spent in water as salt as in the vicinity of lower Sand Island or of Canby light.

Chinook number 123 was out 31 days, yet this salmon had traveled upriver only 15 miles when taken near Brookfield. Its button was the second deepest etched of the series recaptured. The corrosion indicates a sojourn in salt water or in relatively concentrated brackish water. The evidence given by the corrosion of this button is to my mind conclusive evidence that its bearer had spent considerable time well below the point where it was liberated, probably at or beyond the lower end of Sand Island. I would

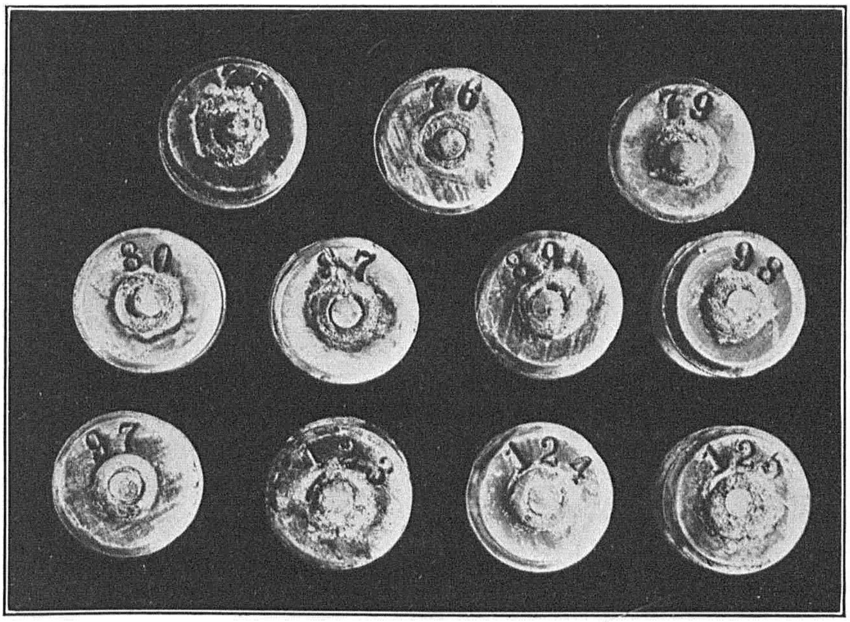

FIG. 3.—Photograph of eleven of the marking buttons after they were recovered from the marked fishes. This and the next figure show the corrosion of aluminum on the exposed surfaces. The buttons are shown natural size.

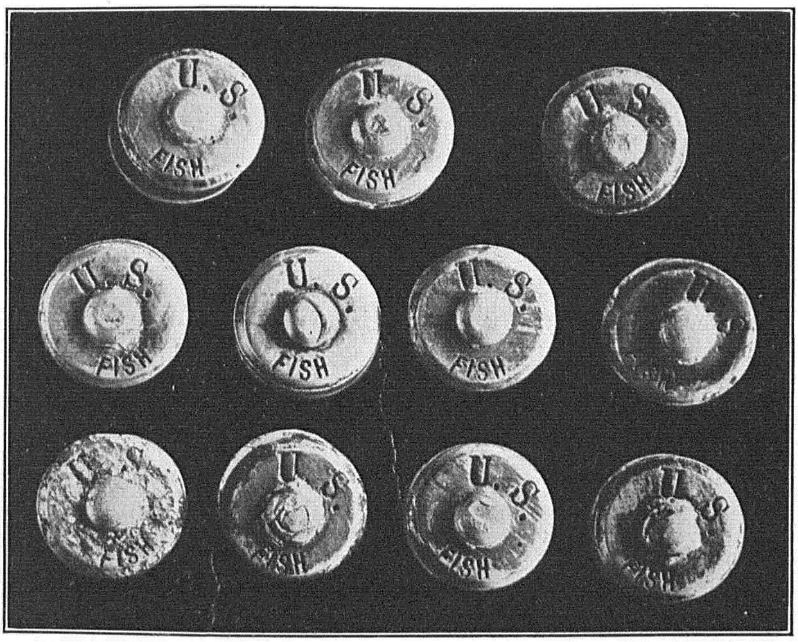

FIG. 4.—Photograph of the converse faces of the eleven marking buttons shown in figure 3. The buttons have the same relative positions in the two photographs. Reading from left to right the numbers of the top row are 75, 76, and 79; of the middle row 80, 87, 89, and 98; and of the bottom row 97, 123, 124, and 125. Buttons photographed natural size.

value this evidence second only to actually capturing the salmon out toward the sea from the state trap.

Marked chinooks were not recaptured above Millers Sands. Whether they got through during the closed season from August 25 to September 12, or from what other reason they were not retaken, is wholly a matter of conjecture. Sharp lookout was kept for them all along the river at the United States hatcheries, and especially at the Ontario (Oreg.) state hatchery, where I collected in early September. No marked fish appeared at the Ontario station up to the close of the fishing about November 1, and none were taken at the government stations.

SILVER SALMON.

The silver salmon, with a single exception, were all retaken by Seufert Brothers Company on the Celilo rapids at the Tumwater seining grounds. One, number 87, was taken at Cottonwood Island, by Mr. Ed Le Roy. This last fish was out the longest of all the fish retaken—57 days.

An examination of table III and of figures 3 and 4 will show that great diversity exists as to the degree of etching by corrosion shown by the buttons of these silver salmon. The button of number 79 was smooth and clean on both sides. This salmon was out 33 days, but evidently did not spend much if any of its time in brackish water after it was marked.

TABLE III.—MARKED SILVER SALMON RETAKEN AND EXTENT OF CORROSION OF MARKING BUTTONS BY SOJOURN IN SALT WATER.

Number.	Time out in days.	Distance from state trap.	Corrosion of marking buttons.	
			"U. S. Fish" surface.	Numbered surface.
		Miles.		
75	29	210	Smooth	Slightly corroded about rivet.
76	28	210	Slightly corroded about head of rivet	Deeply corroded on head of shaft and about rivet.
79	33	210	Smooth	Smooth.
87	57	70	do	Corroded over surface of head of shaft and about rivet, but not deeply pitted.
89	30	210	Slightly corroded about one-half the head of rivet.	Corroded over entire head of shaft, and deeply pitted about rivet and on inside of end of shaft.
97	33	210	Deeply corroded and pitted over this surface of the button except head of rivet; most corroded of all the buttons.	Corroded on one-third the head of shaft and slightly on end of rivet.

Number 97, which was out the same length of time and retaken at the same place as 79, had the most deeply corroded and pitted button of the entire series. It was even more corroded than chinook button number 123 which was out 31 days and was retaken only 15 miles up the river. Number 89 was also a deeply corroded button. These two fish, 89 and 97, bear evidence of a considerable sojourn in salt or strongly brackish water after they were tagged. The buttons of the 3 remaining silvers grade between the extremes just discussed, number 75 being almost smooth and 79 considerably corroded.

Yet it will be noted that these 5 fish were retaken by Seufert Brothers within the period of 5 days from September 12 to 16. Silver salmon number 87 is a decided exception in this list. It was retaken only 70 miles up the river and was out the longest time of all the marked fish, namely, 57 days. Its button, however, does not present a history of long contact with salt water. It is etched to some degree on one surface, but not more than would be possible by a long career in slightly brackish water.

STEELHEADS.

Of the 18 steelheads marked, only 5 were retaken. One of these, number 116, was caught down the river 4 miles below where it was liberated and between four and five hours after liberation. As already stated, the fishes were liberated on a strong flood tide and it is evident that this particular fish at once made about a mile an hour speed toward sea. It was taken by purse seine in the channel near Republic spit in the same locality where chinook number 123 was captured 6 days later. These two fishes give absolute proof of downstream movements of salmon. The fishing annals of the lower Columbia have many instances of similar outward movements of schools of salmon.

TABLE IV.—EXTENT OF CORROSION OF THE ALUMINUM MARKING BUTTONS OF THE STEELHEADS RETAKEN.

Number.	Time out in days.	Distance from state trap.	Corrosion of marking surface.	
			"U. S. Fish" surface.	Numbered surface.
		Miles.		
98	52	210	Slightly corroded about head of rivet	Markedly corroded over head of shaft and around rivet within the shaft.
116	0	[a] 4	Smooth	Smooth.
124	33	210	....do	Slightly corroded about rivet.
125	30-35	70	Corroded about head of rivet	Deeply corroded about rivet and slightly pitted.
	7	½	Button not preserved	Button not preserved.

[a] Downstream.

It is said that at certain times, following a period of stormy weather or when for other reasons the gill nets have not been operating on the lower river, the seines on lower Sand Island capture fish with definite marks received from fishing gear—marks that can be accounted for only on the theory that the fishes have moved seaward after receiving the marks.

One steelhead was reported captured in a trap only about one-half mile upriver from the state trap where it was liberated. This fish was out 7 days, but as its button number was not taken and since the button itself was not sent to me, no record could be made of the character and extent of its corrosion.

Of the two steelheads retaken by Seufert Brothers, number 124, out 33 days, shows slight corrosion, but number 98, out 52 days, shows marked corrosion. Evidently the former spent little time in tide water, while the corrosion of the button of the latter indicates considerable contact with salt water.

The steelhead number 125, which was caught only 70 miles up, shows a salt-water history similar to that of number 98, which had gone 210 miles up the river.

MIGRATION SPEED.

The speed of the total migration is unquestionably divided into two periods, first, the migration through the various stages of tide water, and, second, the migration up the river when once quite within fresh water. This preliminary experiment was launched in the tide-water zone, hence can not directly solve either speed period. In discussing the three groups of fishes a number of instances have been given to show that these fishes spent much time in brackish water after their marking. One may assume the broad working hypothesis that salmon travel at an average speed that is apparently uniform for different individuals under similar conditions. Table v shows the days out, total distance traveled, and the average speed made for the time. A glance at the table suffices to show either that the hypothesis is unsatisfactory or that a number of the salmon have not made direct runs upstream.

TABLE V.—MARKED FISH ARRANGED IN THE ORDER OF THE AVERAGE TIME TAKEN TO TRAVEL THE DISTANCE COVERED BEFORE RECAPTURE.

Species.	Tag number.	Days out.	Distance traveled.	Average speed per day.
			Miles.	*Miles.*
Silver	76	28	210	7.50
Do	75	29	210	7.24
Do	89	30	210	7.00
Do	79	33	210	6.36
Do	97	33	210	6.36
Steelhead	124	33	210	6.36
Do	98	52	210	3.85
Do	125	±35	70	±2.00
Chinook	80	11	15	1.36
Silver	87	57	70	1.23
Chinook	123	31	15	.48
Do	113	6	[a] 4	.66
Steelhead	116	0	[a] 4	24.00

[a] Downstream.

Rutter[a] branded a number of salmon on the Sacramento River in September, 1900, at Rio Vista, which is above the salt-water tides of the river. Three of these fish were retaken, two at the Mill Creek hatchery and one at Battle Creek. They covered the distance in an average speed of 4 to 5 miles per day. This speed was exceeded by six of the marked fish in the present experiment, these six making an average individual speed of from 6.36 to 7.50 miles a day with a general average of 6.8 miles.

The observations of the commercial fishermen on the Columbia River make it quite probable that the highest speed shown in table v is low for the migration rate of Columbia River salmon under favorable conditions of the river.[b] The statistics of the

[a] Rutter, Cloudsley, op. cit., p. 124.

[b] Mr. Frank A. Seufert writes me as follows: "Usually it is from 7 to 9 days from the time a run is reported entering the river in July or August when we get the effects of it here." Seufert Brothers' fishery is 210 miles up the river, which would give a speed of 23 to 30 miles a day for a heavy run.

commercial fisheries would indicate a maximal speed of three or four times that given by my highest rates. It is very probable, therefore, that the lack of uniformity in speed shown in the table is due to days consumed in ways not accounted for by the direct run through fresh water in the course up the river.

An interesting side light is thrown on these observations if the speed for all is computed on the basis of the average speed made by number 76, the highest on the list.[a] Table VI presents the results of this recomputation.

TABLE VI.—RESULTS OF COMPUTING TIME ACTUALLY TAKEN IN RUN, ON BASIS OF AVERAGE SPEED OF 7.5 MILES A DAY.

Species and number.	Distance traveled in miles from point of liberation.	Days out.	Days required to cover distance at an average speed of 7.5 miles a day.	Days unaccounted for.
Silver, 75	210	29	28	1
Silver, 89	210	30	28	2
Silver, 79	210	33	28	5
Silver, 97	210	33	28	5
Steelhead, 124	210	33	28	5
Chinook, 80	15	11	2	9
Steelhead, 98	210	52	28	24
Steelhead, 125	70	35	9	26
Chinook, 123	15	±31	2	29
Silver, 87	70	57	9	48
Chinook, 113	[a] 4	6	0	[b] 6

[a] Downstream. [b] Had not yet left tide water.

I fully recognize that table VI is based on an assumption. Nevertheless, it can not at present be displaced by observed facts, and serves better than any other method devised to illustrate the great discrepancy in the time consumed by numbers 80, 87, 98, 123, and 125. The last column of the table shows that these particular fishes must have played around in the lower waters of the Columbia. Certain of them have not gone beyond tide water—for example, 80 and 123. This last fish has taken a whole month to go only 15 miles up the river. By the computation there are three others that have about the same time available for playing around or resting quietly somewhere, and the history of number 123 renders it quite probable that they all spent this extra time in tide water.

We have, therefore, from this experiment two series of facts that throw light on the life history of salmon in tide water, namely, the etching or corrosion of the aluminum marking buttons and the probable time consumed by the salmon after they were marked at the state trap before they began the strictly fresh-water journey. Both observations show an unexpectedly long time in tide water, i. e., as long as 30 days (chinook number 80) or even 48 days (silver number 87).

Rutter[b] has advanced the theory that salmon make the journey through tide water by running up during the ebb and down during the flood tide, stemming the current each

[a] It is evident from the slight corrosion of the button of this fish that it spent some time in brackish or salt water. It made, therefore, a really higher average speed during the time in fresh water.

[b] Rutter, Cloudsley, op. cit., p. 122.

way. He applied this principle in his studies of the chinook salmon of the Sacramento River. Following the variations in the catch of the fisheries at the different towns along the bay and lower Sacramento, he estimated that a school of salmon made its way from Vallejo, on the lower bay, to Sacramento, on the river, in 4 days for the spring run when the river is relatively high. In the summer and fall they move more slowly. This he explains by the fact that the river is low and the tides in the bay therefore more nearly equal in time, thus requiring more time for the salmon to pass through the bay.

My fish were marked in August, hence are to be compared with the movements of fall fish as described by Rutter. I accept Rutter's hypothesis as partially explaining the movements of salmon in tide water. Undoubtedly currents in the rivers are directive on the movements of the migratory fishes. In tidal waters this factor is still active. In the tidal area at the mouth of a river the relative time of the flood and ebb currents rapidly changes toward the upper tidal limits, where the former entirely disappears. If salmon were directed by currents alone they would make the journey more and more continuously as they come within the brackish area. Figured on the basis of the difference of the duration of the flow of the flood and ebb currents as against the observed speed of salmon, it is obvious that the fish would pass through the tidal area in a much shorter time than these observations indicate. Other factors are operative, for currents alone are not sufficient to account for the movements. I believe that a much more influential factor is the condition of the water as regards its amount of salt. Salmon are sharply responsive to the stimulus that comes from variation in the degree of admixture of sea water and river water in the tidal area, a stimulus that is doubtless in the nature of a negative chemotaxis. Attention has already been called to the changes in the osmotic equivalents of the blood in fresh-water salmon as compared with those in sea water. These changes, though slight, are due in large measure to the transition from a sea-water environment to one of fresh water. Such physiological adaptations require a relatively long time. If a salmon entering the mouth of the Columbia should swim into an area of water relatively fresh before his gills and other epithelial tissues were sufficiently adapted to it, chemotactic reaction would stimulate him to increased activity, which, by the law of such reactions, would lead him in the end toward salt water. These journeys into areas now relatively fresh, now relatively salt, but in the balance ever toward fresh water, will continue until the epithelial tissues of the individual fish have become adapted to life in fresh water. The rate at which this adaptive process takes place determines the total time required for the passage through the tidal area. The observations recorded in this experiment indicate a very much longer time spent in tide water by the salmon on the Columbia River than allowed by Rutter for salmon on the Sacramento. While not numerous enough and not sufficiently varied to make the deductions absolutely conclusive, yet these experiments strongly indicate that salmon spend not less than from 30 to 40 days in passing the tidal area of the lower Columbia.

SUMMARY OF CONCLUSIONS.

Remembering that this experiment is preliminary and that the observations are entirely too few to make the deductions conclusive beyond question, still the following tentative answers may be given to the questions announced in the beginning of this paper.

1. Salmon may take from 30 to 40 days to pass through the brackish water within the limits of the fishing waters at the mouth of the Columbia River.

2. That salmon spend considerable time swimming back and forth in tide water during the acclimatization to fresh water is indicated (*a*) by the fact that two fishes were taken below the point at which they were marked, (*b*) by the corrosion of the aluminum marking buttons by salt water, and (*c*) by the long time spent by certain fishes in reaching the lower limits of fresh water.

3. When wholly within fresh water, the silver salmon and the steelhead make the migratory journey at an average speed of from 6 to 7½ miles a day and probably more.

4. There is little evidence that the process of marking or that the partial obstruction of the course by fishing gear does more than produce a temporary checking of the migratory journey.