STUDIES ON FISH MIGRATION II. THE INFLUENCE OF SALINITY ON THE DISPERSAL OF FISHES[1]

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In connection with an extensive study of the factors influencing fish migration, certain experiments were performed during the summers of 1919 and 1920 to determine the effects of different salinities on the reactions of fish under laboratory conditions. Besides testing the animals with the salts of sea water, preliminary experiments were made with changed temperature and stream flow.

Material and Methods

The apparatus consisted of a two-tributary unit of a river system so arranged that different solutions could be introduced, affording the fish an opportunity to select the more favorable one. Two almost parallel troughs were so directed as to let the solutions flow down into a long receiving trough that had adjustable outlets in the middle.

There was also an intake at the extreme end of the large receiving trough so that if desired three intakes could be used. When only the two converging troughs were supplied with currents, a partition was placed across the middle of the receiving trough so that the water could flow laterally and eventually escape from the pool by the regular outlet.

The two tributary troughs were each 10 feet long, 4 inches deep and 4½ inches wide and the receiving trough was 10 feet long, 8 inches deep and 8¾ inches wide. The twin troughs were marked off in feet and conspicuously

[1] Contribution from the Biological Laboratory of the U. S. Bureau of Fisheries at Woods Hole, Mass.

labeled at the proper points so that from a single observation post, record could be taken of the distances traveled by fishes responding to the streams flowing down the incline.

Streams were introduced after temporary storage in two barrels located above the ends of the experimental troughs. In some experiments the inflowing currents came directly from the circulation pipes of the laboratory.

Experiments were performed with sea water, fresh water and combinations of the two, followed by tests with the individual salts of sea water in $m/10$ solutions. Temperature and stream flow were varied and proved most important adjuncts to the salts in affecting behavior.

In order to be quite certain that habit formation as a factor was eliminated, it was customary to select a trough used during the night for sea water inflow and introduce a substance less attractive, for the first few experiments with a group. As conditions of illumination were uniform and the troughs were so near each other, this procedure probably reduced the error due to a habit factor.

The fish were males, selected for apparent vigor and averaged about 12 centimeters in length. They were used for a complete series of experiments in lots of ten, then replaced by another ten of similar size. In the majority of the experiments, the species used was *Fundulus heteroclitus*. Its habits throughout the year were already known to the writer (1916, 1920). Loeb, Thomas and others had already studied its susceptibility to toxic substances. It is anadromous, highly resistant, yet furnishes quick reactions.

Fundulus majalis was used less frequently as it is not so resistant to laboratory conditions and behaves differently with reference to tides. The observations of Mast (1915) made it especially desirable to study the reactions to currents and accordingly a series of experiments was made.

Clupea harengus dies quickly in captivity. Its responses are extremely delicate and it has been used quite successfully by Shelford, Powers and others in experiments on temperature, acidity, alkalinity and salinity. It proved too excitable for the experiments with which the present work was concerned.

Experiments

Fresh Water and Sea Water. (Temperature 20° C.)

With apertures $\frac{5}{8}$ in. in diameter in two glass tubes directing horizontal streams of fresh water and sea water to a point six inches from the ends of the experimental troughs, it was found that 10 fish responded during 25 trials in such a manner that 11.8 was the value for responses to fresh water and 44.6 was the value for the sea water. These figures were obtained by multiplying the number of fish responding by the feet traveled up the trough towards the current, adding the total of 25 trials and securing averages for control and experiment.

The fish responded readily to the flow of water and since there was an admixture of fresh and salt water in the lower ends of the troughs, they did not at first discriminate the sea water before reaching a point 6 or 7 feet from the pool, that is 3 or 4 feet from the intake. As their reactions to the currents became established, however, they came in smaller numbers and finally became aligned along the sea water current at a distance of not more than a foot from the intake.

On changing the flow of fresh water to salt and vice versa, it was noted that at first the fish came into the trough formerly salt, and proceeded beyond the point where they usually traveled in fresh water. This was in part due to the habitual response and partly to the presence of some salts in the trough. On reaching the intake, they rapidly returned to the pool, one or two pioneered in each trough, then the whole group explored the salt trough and finally came to a point near the salt water intake.

Reactions to Salts in Solution

A preliminary series of experiments was run with fish immersed in $m/10$ solutions of the salts of sea water, made up in fresh water. Results were obtained similar to those recorded by Loeb, Thomas and others with fish and corresponding ones known to the writer from experiments with the larvæ of mosquitoes (1916).

By using the barrels above the experimental troughs solutions of the salts individually and in combination were introduced into the apparatus, with fresh water or sea water run as the control current. At first temperature and stream pressure were kept constant. The temperature averaged 20.5° C. and the pressure was sufficient to send the currents horizontally to a distance of six inches from the $\frac{5}{8}$-in. glass tubes.

The reactions to individual salts as compared with fresh water are shown in the table below, only the averages at the end of 25 trials with 10 fish being recorded.

RESPONSES OF FISH TO SALTS

$MgSO_4$	46	Control, 0
NaCl	22.6	Control, 1
$CaCl_2$	6	Control, 20
$MgCl_2$	5.7	Control, 21.5
KCl	2	Control, 15

It is quite evident that with temperature and stream pressure the same, *Fundulus heteroclitus* will react quite definitely to salts. It is attracted to the less toxic ones, $MgSO_4$, and NaCl, and is repelled by those that are most toxic to it.

Similar experiments with sea-water solutions and sea water as the control current brought out quite clearly that for the species used, $m/10$ solutions of the more toxic individual salts were not strong enough to repel the fish. For example in the case of the most toxic, KCl, the score for 25 trials with 10 fish was 43 for the control sea water and 34 for the experimental current with KCl in $m/10$ solution.

Likewise, combinations of the salts showed only too well the attractiveness of the mixed solutions. With an $m/10$ solution of $MgCl_2$ plus $MgSO_4$ and fresh water as control, the record was 11.2 for the control and 34.2 for the mixture. Again, in the case of KCl plus NaCl in $m/10$ solution, the score was 31 for the control and 17 for the mixture. With double sea water (specific gravity 1.050) and ordinary sea water at 20° C., it was found that the fish were attracted at the ordinary pressure and temperature, reacting to the stronger solution an average of 19.3 and to the control sea water 17.8 times. Further experiments should be run to determine the influence of antagonistic action of the salts in pairs. Whether or not the results will coincide with the results of permeability experiments will probably depend somewhat on the factor of temperature (Loeb and Wasteneys, 1912).

Influences other than Salts

The foregoing experiments indicate clearly that the behavior of the fish under consideration is materially affected by the salts with which they come in contact in fresh water. However, the factors involved in the *migration* of fish are by no means thus explained. It is worthy of note that the reactions of *Fundulus heteroclitus* to toxic salts or even sewage are dependent on temperature and stream pressure.

Temperature

Numerous experiments were tried with varying temperature and it was found that a temperature greater than 23° C. repelled the fish and caused them to align themselves along the current of fresh water at 20° C. in preference to the slightly warmer sea water.

With a reduced temperature, even one degree less than the control (19° C.), the fish were markedly attracted. In fact it was possible to lure them into double sea water, KCl or fresh water if these were presented at the proper temperature. Further experiments and observations are necessary for these and other species in order to determine the relation between gonad development, bodily condition and the responses to temperature change.

As pointed out by Gurley (1902), the minnows migrate to warming water for the purpose of spawning, while the cod and the salmon migrate to cooling water for the same purpose. Chamberlain believes that the salmon come into water warmer than the sea water (1906).

Field records for *Fundulus heteroclitus* secured by the writer in connection with another investigation (1916) indicate the importance of temperature. The fish began coming inland in the spring when the water was about 15° C. and continued to run in and out until the inland pools had reached a temperature in August of about 24° C. Then for a period of over two weeks, they ceased running. About September 1, when the temperature had again lowered, they appeared again and continued to run until the temperature ran down to 10° C.

Stream Pressure

When sea water was introduced through the $\frac{5}{8}$-in. glass tube with a force sending it horizontally to a distance of 6 inches, while fresh water was introduced through the experimental tube into the adjoining trough with a force sending it 12 inches from the end of the tube, there was no difficulty in luring the fish away into the fresh water and keeping them directed towards it.

Many experiments were made, toxic substances such as KCl and double sea water also being introduced, but the increased pressure always proved the powerful factor. Chamberlain (1906), Prince (1920) and others have previously shown that in the case of the salmon, migration into fresh water is delayed until the floods come down into the bays and small streams. The arrival of a volume of rushing water furnishes the needed stimulus and the fish proceed forthwith to obey their instinct to swim against the current.

That fish can determine the presence of toxic substances in sea water or in fresh water is unquestionably demonstrable. But we have much evidence that those fish lying offshore and habitually migrating up a certain stream, will journey into polluted water, spawn in places where the eggs can not develop and in many cases, die in such water themselves.

Salmon are reputed to return to the lake-fed streams where they were spawned and there is considerable evidence that they are guided by temperature difference, probably also by the current pressure, number of waterfalls, oxygen content and even by food. There is no question (Meek, 1916), however, that salmon ascend streams where no salmon could hitherto have spawned.

The destruction of protecting forests, spoliation of natural waterways and the utilization of streams by manufacturers wishing to dispose of wastes are the factors which not only cause the death of fish embryos and adults, but prevent the natural control of insect pests by their destruction in the larval state.

Summary

1. *Fundulus heteroclitus* is able to discriminate toxic from non-toxic salts at a temperature and stream flow the same as the control.

2. Variations in temperature or in stream flow profoundly influence the reactions and are more powerful factors in the behavior of the fish than presence or absence of salinity.

3. In the apparatus used, errors due to the notable reactions of fish to currents of water have been reduced by presenting the control and experimental flows parallel to each other.

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