SOUND AS A DIRECTING INFLUENCE IN THE MOVEMENTS OF FISHES

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The detection of the direction of a sound by the human ear is not generally accomplished with great accuracy, especially when the source of the sound is placed symmetrically in reference to the two ears. In man the one sense organ concerned in these operations is the ear. In fishes there are at least three sets of organs that may be involved in like operations, the skin, the lateral-line organs, and the ear, for though the function of hearing has been denied to fishes by some recent workers, there seems to be sufficient evidence to warrant the conclusion that at least certain fishes hear. Whether, however, fishes respond to sounds in a directive way or not is a matter that, so far as I am aware, has never been subjected to experimental test. It is the purpose of this paper to discuss the directive influence of sounds on the movements of fishes, and it is believed that work such as this will throw light on the question of the temporary distribution of fishes in reference to such centers of sound production as are afforded by naval gun practice, etc.

In attempting to test the question of the directive influence of sounds upon the movements of fishes, experiments were first tried in a large floating cage anchored in open sea water, but it was soon found that the disturbances produced by the wind and the sunlight were too great to admit of conclusive work, and recourse was finally had to experiments conducted in running sea water indoors. These experiments were carried out in the Biological Laboratory at the Woods Hole Station of the United States Bureau of Fisheries.

The fishes were tested in a tank about 50 cm. wide, 60 cm. deep, and 100 cm. long. The tank was made of wood 3.5 cm. thick; on the inside its walls were painted black, its bottom white. At one end of the tank there was a controllable inlet of sea water and at the other end an outlet. When the water in the tank was high enough to flow out at the outlet it was within a few centimeters of the top. The tank stood on a strong table and its upper edge was provided with a low black curtain so that persons moving about the laboratory could not be seen by the fishes. The tank was illuminated by an incandescent electric light hung directly over its center and some feet above the level of the water, or by diffusely reflected daylight from a white ceiling above. At each end of the tank a cord was attached to the ceiling and from a hook on the end of the cord an iron ball was suspended, the whole device being so adjusted that when at rest the ball just touched the middle of the end of the tank. The ball, like the bob of a long pendulum, could be withdrawn from the end of the tank, and when released it would strike the end a blow that could be kept reasonably constant by a gauge to mark the point at which the ball was liberated. The ball weighed about 4,300 grams and was ordinarily released at such a point that it struck the end of the tank with a calculated velocity of 84 cm. per second; in other words, at the moment of impact with the end of the tank the ball had a momentum of about 361,200 C. G. S. units. This blow produced in the tank a low booming noise which was used as the stimulus for the fish. It probably affected the nerve endings of the skin, of the lateral-line organs, and of the ears of the fishes that were tested.

In experimenting with a given species of fish, five individuals were placed in the tank and allowed to remain there till they were thoroughly accustomed to their surroundings, often a matter of half a day or so. Then the current of water was shut off, and shortly afterwards the stimulus was applied by allowing the ball to fall once every 10 seconds against the end of the tank. This was continued for 50 blows, and between blows the interior of the tank was cautiously inspected from the middle of one side, and a record was made of the distribution of the five fishes by noting the number in the half of the tank at whose end the blow had been struck. This form of observation was facilitated by marking on the white bottom of the tank a transverse line that divided the area in halves and that could be used as a line of reference in deciding on the distribution of the fishes. After 50 trials had been made with blows delivered at one end of the tank, the ball was shifted to the cord at the other end of the tank and an equal number of blows was delivered at that end; the combination of the two sets of records thus obtained showed whether the fishes tended to approach the sound center or retreat from it. The whole operation was then repeated on five new individuals, and this process was kept up until reasonably constant results were obtained. In all, eight species of fishes were tested, and these fell more or less naturally into three classes.

The first consisted of those fishes that on stimulation tended to retreat from the region of sound production. They are well illustrated by the tautog (*Tautoga onitis*), whose reactions are summarized in the following table:

TABLE I.—DIRECTIVE RESPONSES OF TAUTOGA ONITIS TO SOUND.

Lot numbers.	Number of occurrences in a possible 250 in half of tank nearer sound.		Totals.
	West half.	East half.	
1–5	83	80	163
6–10	85	87	172
11–15	79	86	165
16–20	90	84	174
21–25	82	86	168
Grand total	....	....	842

The grand total of occurrences in a possible 2,500 in the half of the tank nearer the sound was 842, or 34 per cent.

In this table are recorded the reactions of 25 fishes in lots of 5 each. Each lot was subjected to 50 individual stimuli from the concussion of the iron ball against the end of the tank, and after each blow the number of individuals in the half of the tank next the sound center was recorded. The addition of these 50 records in the first lot of fishes (1–5) when the blows were delivered at what may be called the west end of the tank was 83; when the blows were delivered at the east end it was 80. Had all the fishes remained all the time in the half of the tank next the sound center, these records would have been 250 each. It is, therefore, quite clear that in both instances the fishes avoided to a considerable degree the half of the tank next the sound center, and this same feature, of course, appears when these records are added together. The same is true for the other four lots of fishes (6–10, 11–15, 16–20, and 21–25), and the grand total shows that out of a possible 2,500 records only 842, or rather less than 34 per cent, were from the half of the tank next the sound center. Had the fishes been indifferent to the direction of the sound, we should have expected 50 per cent of the records to have been from the half of the tank next the sound center and the same proportion from the other half; had they been attracted by the sound, the record would have been something over 50 per cent for the region next the sound center; as it was, they have shown themselves as distinctly repelled by the sound, in that in only about 34 per cent of the total number of possible records were they in the half of the tank nearer the sound center. It is quite clear from these records, then, that *Tautoga onitis* tends to swim away from a sound center.

The same condition as that seen in *Tautoga*, though a little less pronounced, is to be observed in the scup (*Stenotomus chrysops*), as table II shows.

TABLE II.—DIRECTIVE RESPONSES OF STENOTOMUS CHRYSOPS TO SOUND.

Lot numbers.	Number of occurrences in a possible 250 in half of tank nearer sound.		Totals.
	West half.	East half.	
1–5	87	81	168
6–10	93	85	178
11–15	89	92	181
16–20	88	89	177
21–25	96	90	186
Grand total	....	....	890

The grand total of occurrences in a possible 2,500 in the half of the tank nearer the sound was 890, or 36 per cent. In *Stenotomus*, though the individuals avoided the sound center in a well-marked way, they were found somewhat more frequently (36 per cent) near the center than were the tautogs (34 per cent).

Young kingfishes (*Menticirrhus saxatilis*), as table III shows, also avoided the region of the sound center, though they were found there somewhat more frequently (39 per cent) than *Stenotomus* (36 per cent).

TABLE III.—DIRECTIVE RESPONSES OF MENTICIRRHUS SAXATILIS TO SOUND.

Lot numbers.	Number of occurrences in a possible 250 in half of tank nearer sound.		Totals.
	West half.	East half.	
1–5	85	109	194
6–10	98	110	208
11–15	102	90	192
16–20	89	86	175
21–25	103	96	199
Grand total	....	....	968

The grand total of occurrences in a possible 2,500 in the half of the tank nearer the sound was 968, or 39 per cent.

Young swellfish (*Spheroides maculatus*), as can be seen from table IV, show much the same condition as the kingfish, though they were found rather more frequently (42 per cent) in the region of the sound center than the kingfish (39 per cent).

TABLE IV.—DIRECTIVE RESPONSES OF SPHEROIDES MACULATUS TO SOUND.

Lot numbers.	Number of occurrences in a possible 250 in half of tank nearer sound.		Totals.
	West half.	East half.	
1–5	101	107	208
6–10	112	103	215
11–15	106	98	204
16–20	101	110	211
21–25	96	105	201
Grand total	....	....	1,039

The grand total of occurrences in a possible 2,500 in the half of the tank nearer the sound was 1,039, or 42 per cent.

The butterfish (*Poronotus triacanthus*) is by no means easily kept in confinement and records were obtained from only one lot of five such fishes. These records show that the occurrences of this fish in the half of the tank next the sound center were 47 per cent of the total; in other words, this fish had apparently a slight tendency to keep away from the sound center. This tendency, however, was so slight and the records were based upon such a small number of individuals that not much confidence can be placed in these results.

Of the five fishes thus far discussed, four (*Tautoga*, *Stenotomus*, *Menticirrhus*, and *Spheroides*) showed unmistakable evidence of the avoidance of a sound center and are in strong contrast with a second class of fishes which we found to approach such a center.

The second class of fishes is well represented by the sea robins (*Prionotus carolinus and Prionotus strigatus*).

TABLE V.—DIRECTIVE RESPONSES OF PRIONOTUS CAROLINUS AND PRIONOTUS STRIGATUS TO SOUND.

Lot numbers.	Number of occurrences in a possible 250 in half of tank nearer sound.		Totals.
	West half.	East half.	
1–5	129	143	272
6–10	152	137	289
11–15	124	162	286
16–20	131	148	279
21–25	139	136	275
Grand total	....	....	1,401

The grand total of occurrences in a possible 2,500 in the half of the tank nearer sound was 1,401, or 56 per cent.

As table v shows, young specimens of *Prionotus carolinus* and *Prionotus strigatus* exhibited unmistakable tendencies to gather near the sound center. In each of the five groups tested the total numbers of occurrences on the side of the sound center were well above 250, the point of indifference. These species, therefore, afford a good example of fishes that move toward a sounding body in contrast to the four species mentioned as forming the first group. It is a matter of some interest to note that sea robins make a grunting noise themselves, and it may be that they hold together in schools by following this noise, in which case their movements toward a sound center such as was used in these experiments would be entirely natural.

The third class of fishes consist of those which move neither toward a sound center nor away from it. This class includes fishes that are much disturbed by sounds, but instead of being directed by these disturbances cease locomotion after a moment or so of swimming and remain quiescent till the sounding has come to an end. The best illustrations of this class are the killifishes, *Fundulus heteroclitus* and *Fundulus majalis*. After they had become accustomed to their surroundings they swam about freely near the surface of the water but when the sounding began they went at once to the bottom of the tank and remained quietly in seclusion in any nook or corner that they could find till the sounding had ceased. The cunner, *Tautogolabrus adspersus*, probably also belongs to this class, though when under the influence of sound it often moves about and its distribution indicates at times some tendency to move toward the sound center.

From all these records collectively it is quite clear that some fishes move away from sound centers, others move toward them, and still others, though much disturbed by sounds, move neither toward nor away from the sources. Throughout these experiments it was generally noticed that after the sounding ceased the fish very quickly returned to a state of normal locomotion and equal distribution. This condition is well illustrated by records taken from *Stenotomus*. Five of these fishes were placed in the tank, and after they had become quiet their distribution was recorded in the usual way; they were then subjected to sound till they assumed a characteristic distribution for this condition; and finally they were allowed to come to rest again. The time occupied in these operations is recorded in the following table:

TABLE VI.—NUMBERS OF INDIVIDUAL STENOTOMUS, OUT OF 5, OCCURRING IN THE HALF OF THE TANK NEXT THE SOUNDING APPARATUS BEFORE THE FISHES WERE SUBJECTED TO SOUND, DURING SOUNDING, AND AFTER THE SOUND HAD CEASED.

Number of the stimulus.	No sound.			Sound.			No sound.					
	7.35	7.40	7.45	7.50	7.55	8	8.05	8.10	8.15	8.20	8.25	8.30
1	2	4	3	0	1	0	0	0	2	3	2	3
2	3	3	2	1	1	0	0	0	2	4	2	4
3	3	4	2	3	1	0	0	1	3	2	2	2
4	3	0	1	3	1	0	0	1	2	3	4	4
5	4	1	2	2	1	1	0	0	1	4	0	3
6	0	3	4	4	1	1	0	1	3	0	2	3
7	3	2	4	3	2	1	0	1	2	4	2	2
8	2	3	4	1	3	1	0	1	0	2	1	3
9	4	5	1	3	2	2	0	1	1	2	3	4
10	5	5	0	1	2	2	0	2	0	3	2	3
Totals	29	30	23	21	15	8	0	8	16	27	20	31

An inspection of this table shows that during the period preceding the application of the sound (7.35 a. m. to 7.45 a. m.) the distribution of the fishes was fairly uniform, that during the application of the sound (7.50 a. m. to 8 a. m.) the fishes gradually withdrew from the sound center, and that within 15 to 20 minutes after the sound ceased a condition of distribution was attained fairly comparable with that seen at the beginning of the test (7.35 a. m. to 7.45 a. m.). The conclusion to be drawn from these observations is that, though the direction of the locomotion of a fish can be very considerably influenced by sound, this influence ceases very shortly after the sound ceases.

In attempting to apply these conclusions to the problems presented in the handling of fishes, several considerations must be kept clearly in mind. It is quite obvious that in one way or another many fishes are stimulated by sound. But most of the sounds that we deal with are generated in the air, and these sounds either fail to enter water or enter it to so slight a degree that they are of little or no significance for the fishes. The surface between water and air is an extremely difficult one for sound to penetrate in either direction, so that most sounds that are generated in the water or in the air stay in the medium of their origin. Hence many of the sounds that are produced by the discharge of guns, etc., in the air enter the water to so slight a degree (as can be ascertained by immersing oneself in the water at the time the sound is produced) as to be unstimulating to the fishes, though they may be deafening to the observer in the air. Such sounds as reach the fishes, however, not only stimulate them to move, but, as these observations show, influence the direction of their movements. But this directive influence is almost as short in duration as the stimulus. It is, therefore, improbable that sounds of brief duration can have much effect on the temporary distribution of fishes within their reach. That fishes should be attracted over any considerable area or repelled from that area by sound would seem to demand some more or less *continuous* source of sound production.