EFFECTS OF SOUND WAVES ON YOUNG SALMON

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EXPLANATORY NOTE

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United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

EFFECTS OF SOUND WAVES ON YOUNG SALMON

by

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ABSTRACT

The objective was to determine whether any quantity or quality of underwater sound would attract or repel young salmon. Frequencies from 5 to 20,000 cycles per second were tested in an experimental tank and in open water. Two types of transducers were used. Other than an initial "start" by the fish, no reaction was demonstrated. Apparently, fish are conditioned almost instantaneously to sounds. It was concluded that sound waves were ineffective as an attracting or repelling force.

ACKNOWLEDGMENT

We are deeply grateful to the following engineers for their generous and patient help in planning and aiding in the execution of this research project: Wayne M. Ross and Hyman Pollack of Ross Laboratories, Seattle, Wash., Jay W. Atherton of the United Control Corporation, also of Seattle, Wash.

This study was conducted by the Fish and Wildlife Service under Contract No. DA-35-026-eng-20685 with the Corps of Engineers, as part of the Fisheries Engineering Research Program. With the publication of this report, the underwater sound studies conducted under the above contract are terminated.

EFFECTS OF SOUND WAVES ON YOUNG SALMON

INTRODUCTION

The valuable salmon runs in the Columbia River system face a serious reduction in size due to the construction of dams. While the effects of a series of dams are not yet known, Schoeneman and Junge (1954) determined that survival rates of two Elwha River dams varied between 63 and 100 percent. Hamilton and Andrew (1954) estimated survival rates at Baker Dam at between 36.5 and 71.7 percent. A single dam may not cause a critical reduction in numbers of fish, but a series of dams, each taking its toll, most certainly would have catastrophic effects on salmon populations.

The serious problem brought about by the construction of dams is twofold: (1) It requires planning for the safe passage of adult fish moving upstream to the spawning grounds, and (2) it makes it necessary to guide or force the young fish which are making their way downstream, into safe passages around the dams. If fish ladders prove unsatisfactory for the very high dams, it may be economically feasible (considering the value of the salmon runs) to collect and transport the adults around the dams by mechanical means. The downstream movement of the young fish presents an entirely different problem.

In the waters above Bonneville Dam on the lower Columbia River, Burner (1949) 1/ found that young salmon moving downstream are distributed throughout the water mass. Because of this random distribution, only a limited number of young fish enter the bypass channels provided for them. Large numbers are caught in the powerful currents of water passing through the hydroelectric plant and over the spillway during periods of high water.

Collins (1954) has reviewed this problem and has outlined the coordinated program of the several fisheries agencies directed toward developing a means of safely passing fish around the dangerous areas. One approach to this problem is the use of physical stimuli to lead, direct, or force the fish into safe passages. The use of sound waves as a possible stimulus held promise and resulted in this investigation.

LITERATURE SURVEY

A search of the literature, which will be published separately as an annotated bibliography, revealed that little work has been done with the use of sound as a leading or guiding force, but that there has been a considerable amount of investigation on the conditioning of fishes to respond to various sound stimuli. It has been determined that some fish are capable of perceiving sound and that some species produce sound in their normal life. It is therefore reasonable to assume that fish might show a positive or negative audiotropism.

Before this investigation, no conclusive research had been undertaken to determine whether fish could be attracted or repelled by sound waves. In fact, no research, except that of Burner and Moore (1953) and Brett and others (1954), had been directed toward this end. The most promising field appeared to be in the low-frequency range of audible sound, and possibly in the subaudible sound range, because other investigators were able to condition fish to react to sounds in these frequency ranges. Supersonic and ultra-

1/ Burner, C. J., (1949). Vertical distribution of downstream migrating chinook salmon fingerlings in the Bonneville Forebay, with a note upon the rate of migration. Mimeo. Rept.: U. S. Fish and Wildlife Service, Seattle, Wash., 11 pp.

sonic sounds were limited by the characteristics of the waves and by their lethal effects under certain conditions.

The primary objective of this study was to determine whether any quantity or quality of underwater sound would attract or repel young salmon.

LABORATORY METHODS AND EQUIPMENT

The literature survey suggested that the most promising field of study was in the low-frequency range; therefore, frequencies from 5 to 20,000 cycles per second (c.p.s.) were chosen for use in the systematic testing program. The United Control Corporation of Seattle, Seattle, Washington, was awarded a contract for the development and fabrication of a transducer keyer and the necessary transducers to cover this range of sound. An electromagnetic transducer was designed for covering the range from 5 to 5,000 c.p.s. (fig. 1). For frequencies from 5,000 to 20,000 c.p.s., a piezoelectric transducer, using barium titanate crystals, was applied (fig. 2).

Each of the sound-producing units was driven by an amplifier-oscillator-keyer unit consisting of a 50-watt amplifier, into which an audio oscillator was fed. The transducer keyer was included in the circuit to control the signal from the oscillator to the amplifier and to allow for the variation of both the repetition rate and width of the pulse of any frequency being tested. The transducers and the keyer proved highly satisfactory in the test.

The research project was divided into a laboratory phase and an open-water phase. The laboratory work consisted of testing fish in an experimental tank designed especially for this study. The tank, constructed of 2-inch cedar, was 11 feet long, 2 feet wide, and 14 inches deep (fig. 3). The tank, with its five separate compartments, was built to measure the distribution of fish within the tank before and after subjecting them to various sound situations. This method of measuring the effects of sound on fish required compartment separators that could be raised and lowered quickly and simultaneously. The problem was solved with separators of weighted sheet aluminum.

The tank was designed with the aid of underwater-sound engineers, who were familiar with problems experienced in underwater sound research. The most difficult problem encountered in underwater sound research within a confined area is that of reverberation and standing waves. Following the advice of the sound engineers, the entire inner surface of the tank was lined with 3 inches of rubberized horsehair. This material, commonly used in the manufacture of furniture, proved satisfactory as soundproofing down to a frequency level of about 50 c.p.s. The later addition of a 1-inch layer of waterproofed foam rubber under the horsehair added to the efficiency of sound absorption.

During the first exploratory testing in the laboratory, the low-frequency electromagnetic transducer was mounted directly on the end of the experimental tank. This arrangement proved satisfactory for frequencies above 500 c.p.s. However, below this level vibrations were carried through the walls of the tank. In effect, the entire tank served as a transducer, and sound was introduced into the water from all solid surfaces. It was obvious from the pattern of surface wave action that the sound within the tank was nondirectional and that standing waves were being created.

The problem of standing waves was eliminated by mounting the transducer

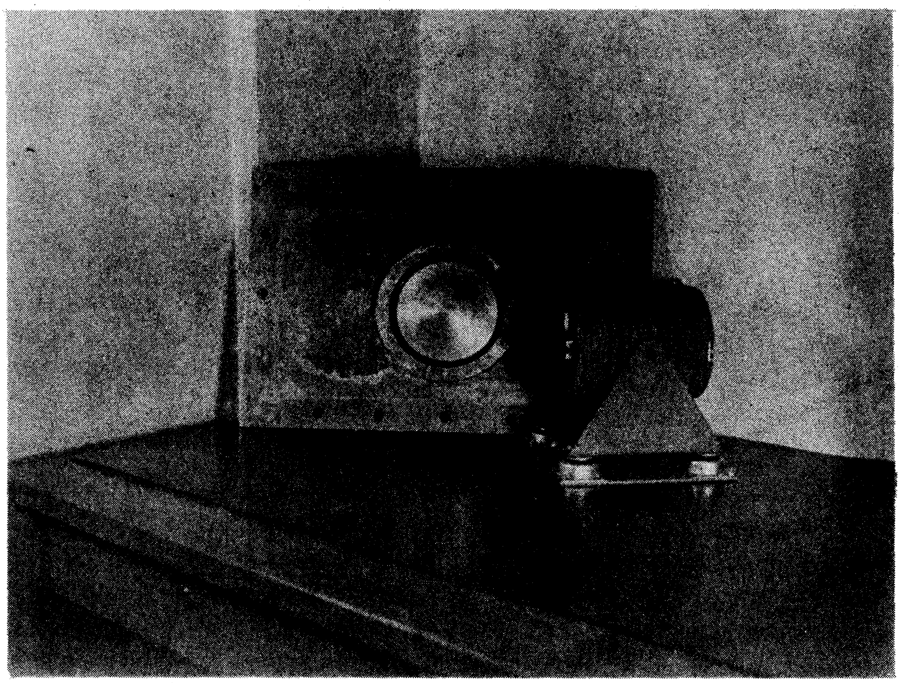

Figure 1.--Electricmagnetic transducer and the end plate from the experimental tank. Note the piston face and the surrounding rubber diaphragm. The piston, when driven by the transducer, created the sound or pressure waves and transferred them into the water. This unit is rated at 100 watts.

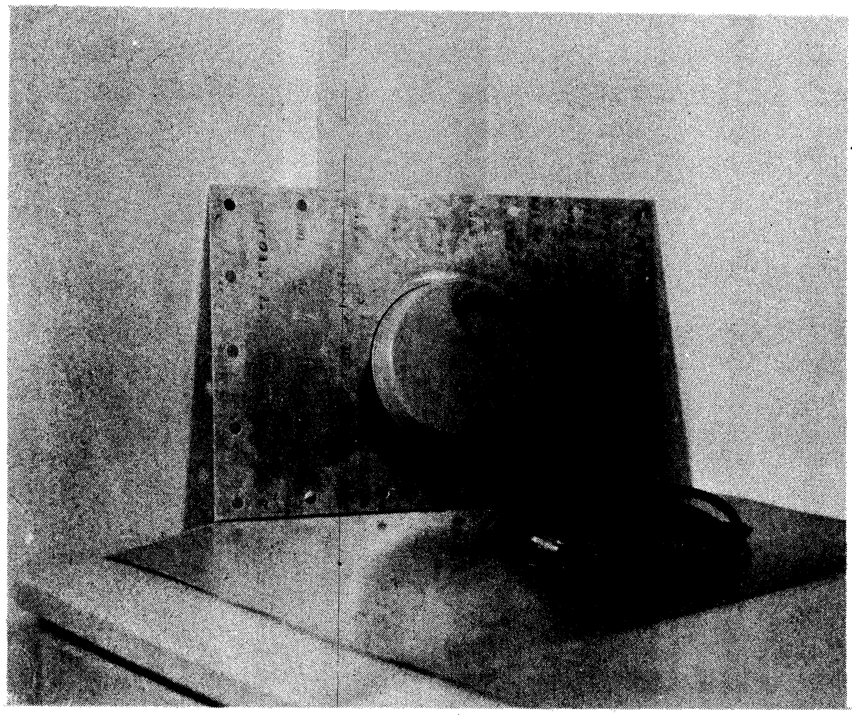

Figure 2.--Piezoelectric transducer mounted in the end plate of the experimental tank. The expansion and contraction of the crystal elements, when energized, creates the sound or pressure waves. These waves are transferred into the water through the front of the "can" which is of thin flexible metal. The "can" is filled with castor oil for more efficient expansion and contraction.

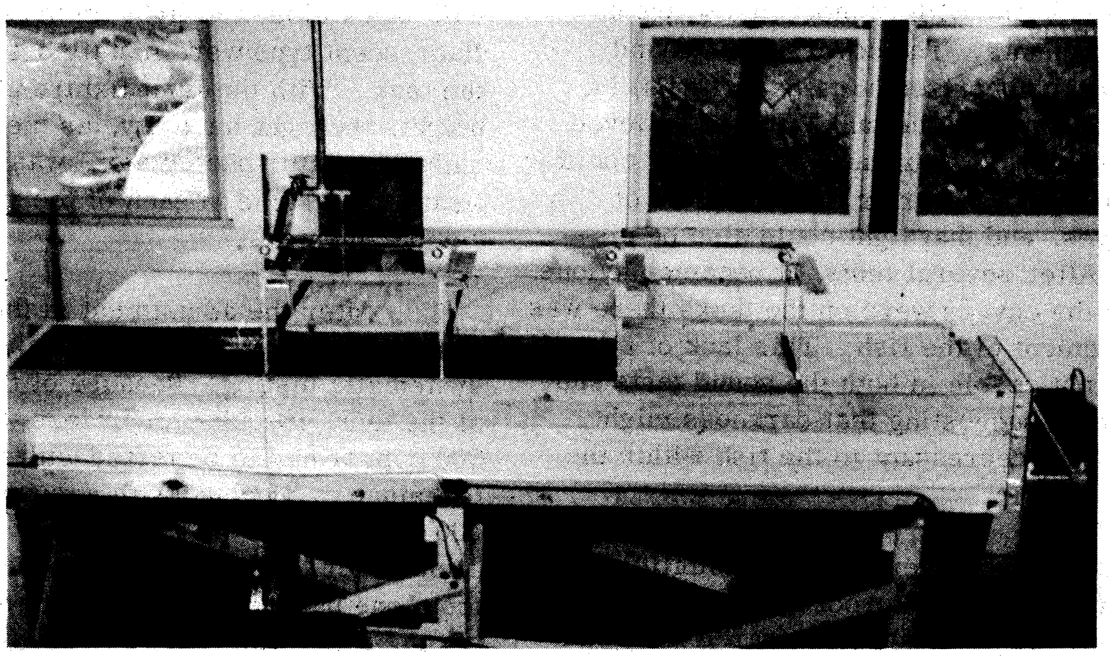

Figure 3.--Experimental tank showing the compartment separators in the "down" position. Note the covers on the tank and the transducer mounted on the end plate. This mounting proved unsatisfactory, and the transducer was later mounted on a separate table.

on a table bolted solidly to the concrete floor. Although this method of mounting proved satisfactory, and in spite of the special lining, below 50 c.p.s. there were limitations because of standing waves. This situation limited the usefulness of the tank in testing fish in the lower frequency range.

In addition to the problem of standing waves, early in the exploratory testing we discovered that light was a very effective stimulus. Original plans called for testing fish in the experimental tank with soundproof covers on all compartments. The covers were soundproofed with rubberized horsehair (fig. 4) in the same manner as the tank. It was believed that in this way, the surface of the water could be eliminated as a barrier for reflection of sound waves, and that light could also be dismissed. After several tests, it became obvious that when the covers were on the tanks there was little movement of the fish. This lack of movement was noticeable in both the sound tests and the controls, suggesting that darkness might be acting as a depressant to the fish within the tank.

In an attempt to verify this possibility, a test was made in a lightproof tank, where fish could be viewed by means of infrared light and and infrared viewer. It had been previously determined that infrared light does not act as a stimulant to young salmon (Duncan, 1956). Fish in total darkness in this lightproof tank demonstrated no movement whatsoever when the sides of the tank were subjected to heavy pounding. In the same tank, under incandescent lights, pounding immediately set the fish into fast and erratic swimming movements. Each of these observations was made through a panel of one-way glass. This simple test convinced us that the tank covers were affecting the results of the sound tests, and therefore they were eliminated.

In addition to these findings, Fields and Finger (1954)[2/] demonstrated that young salmon respond without training by actively seeking darker areas to avoid light. It appeared that such a phenomenon might also be influencing our tests. Bright spots of light from windows in the laboratory were often concentrated in the tank. The fish were always reluctant to pass through these bright spots and leave the "protection" of the darker areas. Because of this, all windows were covered with black cloth and light fixtures of the fluorescent type were installed 4 feet above the tank. With the light fixture at this height, the light intensity, as measured by and underwater photometer, was approximately the same in each of the five compartments.

After the adjustment in the problem of lighting, we felt prepared to begin systematic testing. Because of the length of the tank, frequencies of less than about 500 c.p.s. had to be tested with a pulsing technique — 3 pulses with a duration of 400 milliseconds in 5 seconds. This method allowed for the dying-off of the sound waves from one pulse before the next pulse was begun, thus eliminating to some extent the standing-wave problem in the low-frequency range. Exploratory testing had shown, however, that even when using pulsed sound, accurate testing below 50 c.p.s. was not possible.

As in the investigations at Leetown (Burner and Moore, 1953), three basic assumptions were made prior to testing: (1) If the fish were unaffected by, or indifferent to, sound waves, they would move within the tank and between compartments in a pattern similar to that of the controls;

2/ Fields, Paul E., and Gary L. Finger, 1954. The reaction of five species of young Pacific salmon and steelhead trout to light. Univ. of Washington School of Fish. Tech. Rept. No. 7, 24 pp. (Processed.)

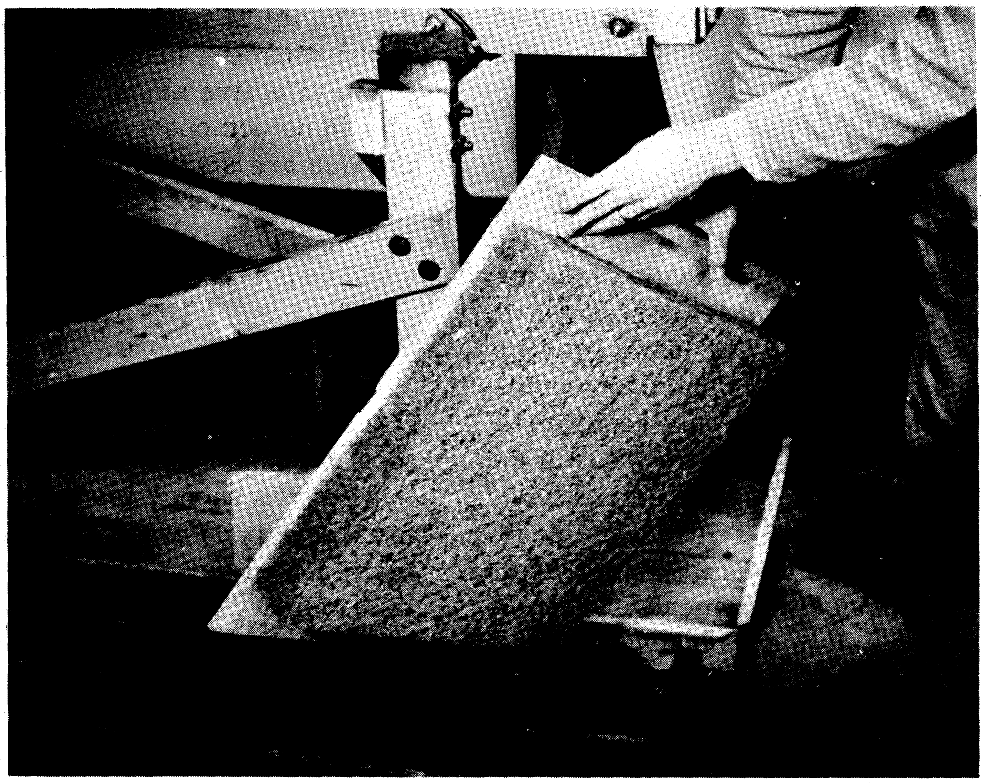

Figure 4.--One of the covers from the experimental tank showing the 3-inch layer of rubberized horsehair used to soundproof the entire inner surface of the tank. In the tank, there was a layer of 1-inch foam rubber under the layer of horsehair.

(2) if the fish were attracted by some quality or quantity of sound, the fish would tend to proceed to the end of the tank nearest the sound source; (3) if the fish were frightened by the sound, they would travel away from the sound source. It was also assumed that other stimuli had no effect on the movement of the fish. As explained previously, precautions were taken so far as possible against extraneous stimuli such as light, movement of persons, and other disturbing factors.

LABORATORY PROCEDURE

The final procedure for testing was the result of numerous exploratory trials. For systematic testing, the method adopted was to place 25 fish in the first compartment of the tank, with the separators in the "down" position. When the fish had settled down and had become adjusted to their surroundings, the separators were raised. While the separators were in the "up" position, the fish were free to move any place within the tank. After a 10-second period, the separators were lowered, thus trapping the fish in the various compartments. The distribution of the fish within the tank was then recorded.

Each sound test was accompanied by a control, the only difference between test and control conditions being the introduction of sound during the 10-second period when the separators were in the "up" position. Controls were without the introduction of sound. For each condition of sound being tested, there were five controls and five sound tests. In conducting a test, first a control was run with all the fish in compartment No. 1, which was adjacent to the transducer. Immediately following the control, a sound test was run under exactly the same conditions except for the introduction of sound during the 10-second period. This procedure was repeated in compartments Nos. 1 to 5, thus constituting a test series of the particular noise condition as a repelling force. Some test series were duplicated for ease in statistical analysis.

This method of testing was chosen after a considerable amount of exploratory testing. The Service's statistical service unit in Seattle advised that this method be used, on the basis of the following reasoning: If sound proved to be effective to any measurable degree as a repelling force, it is logical to assume that it would be demonstrated more easily when the fish are started in the compartment closest to the sound source. Likewise, if sound should prove effective as an attracting force, it should be demonstrated most readily when the fish are started in compartment No. 5, the most distant from the sound source.

OPEN-WATER METHODS AND EQUIPMENT

Because frequencies below about 500 c.p.s. were not giving a reliable pattern of sound in the tank, it was concluded that low-frequency testing should be done in a large body of water. Open-water testing would eliminate such problems as the limited dimensions of a tank and would permit testing with relatively few obstructions to the sound waves. Consultations with underwater-sound engineers verified this conclusion, and plans were made for the construction of a floating laboratory for use on Lake Washington. Permission was granted to the Fish and Wildlife Service by the Navy Department to moor the floating laboratory at the Sand Point Naval Air Station, Seattle, Washington.

The floating laboratory was a raft, 16 by 32 feet, constructed of four large cedar logs with 30-inch-minimum butts held together by 6- by 8-inch stringers placed 18 inches on center. The decking was of 2- by 6-inch fir. As shown in figure 5, there was a rectangular opening in the deck just forward of the cabin. The opening was between the two innermost float logs and allowed easy access to the underwater pens for counting the test fish in the various compartments.

Along both sides of the deck opening, or well, overhead garage-door rails were mounted for hanging the underwater pen. These rails extended 14 feet beyond the raft, and were held by cables running from the afterdeck forward over a large tripod, as shown in figure 5. Side-to-side motion of the rails was controlled by cables extending from the forward corners of the raft to the ends of the rails. The underwater pen was constructed of small cedar strips hung on two larger main stringers. The entire pen (2 by 2 by 12 feet) was covered with 1/4-inch mesh galvanized hardware cloth, except for the top. Under normal weather conditions, the top of the pen was about 4 inches above the surface. Each of the six compartments formed a 2-foot cubicle separated by a sliding curtain of nylon bobbinette. The pen could be rolled forward of the raft and back into the well by means of garage-door hangers and rails.

For use in the open water, a watertight container was fabricated out of heavy aluminum sheeting for submerging the electromagnetic transducer (fig. 6). The barium titanate crystal transducer was watertight, and submerging this unit presented no problems.

The move from tank testing to open-water testing required additional equipment and facilities. Several problems were encountered that had not been evident in the laboratory. The main difference was the background noises in the lake, which were always present to some degree. Frequent measurements of the ambient-noise levels showed them to be highly variable in both quantity and quality. This variability was quite closely associated with wind force and the resulting surface condition of the lake. In addition, directional noises from both known and unknown sources also proved worthy of consideration. These findings made it essential to evaluate the noise conditions prior to each systematic test. Without this knowledge, the results of the tests could be misleading.

The sounds that were picked up through the hydrophone were monitored with earphones. A recorder was incorporated in the circuit, as shown in figure 7, to make a permanent record of these sounds.

It was noted, while listening to recordings of the same frequency made at two different times, that the background noises were often of different magnitude; at times it was almost impossible to recognize the frequency being introduced into the water. This finding demonstrated that it was not always possible to measure the effects of a frequency on the distribution of fish, without considering the background noise at the time of testing.

For further analysis of the problem, the recorded noises were fed into a recording voltmeter. This provided us with a permanent visual record of the noise levels in the water. The effects of various background noises could be seen superimposed on the primary frequency introduced by the transducer (fig. 8). It was evident from these findings that there were times when accurate testing of fish in the open water was not practicable. In the majority of cases, however, testing could be done with little concern for ambient noises in the water. Occasionally, temporary cessations in testing were necessary, when inboard motorboats or boats with large outboard motors were passing near the raft.

OPEN-WATER PROCEDURE

In testing from the floating laboratory, 25 fish were introduced into the first compartment of the underwater pen, the pen was rolled out to a position in front of the raft, and the transducer was submerged between the raft and the underwater pen.

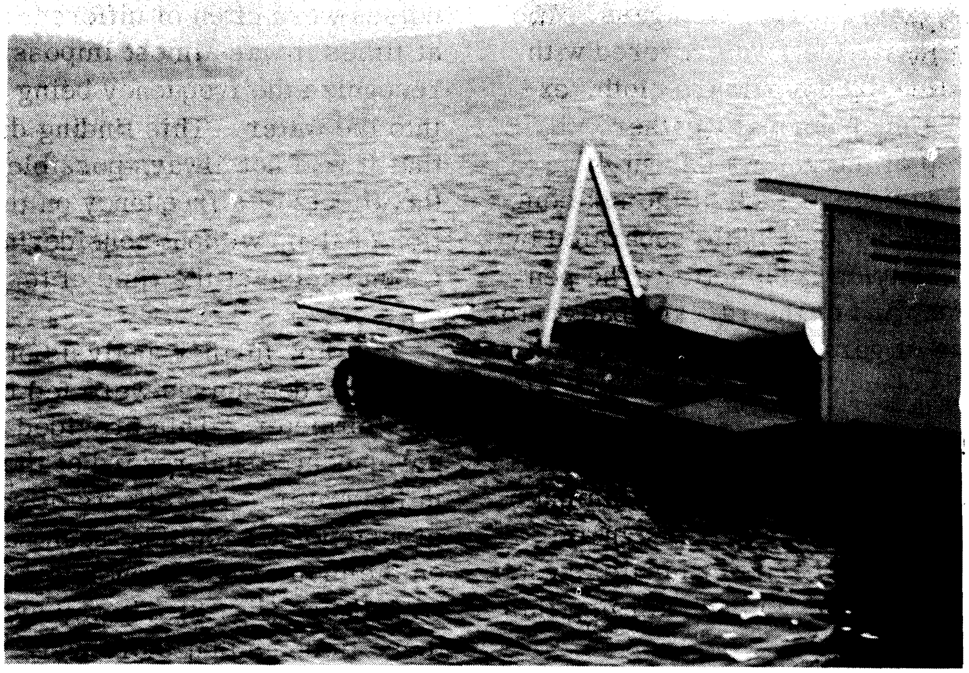

Figure 5.--The floating laboratory on Lake Washington. (Note the rails extending forward, upon which the underwater pen is supported.) The well forward of the cabin allows for easy handling of fish in the pen.

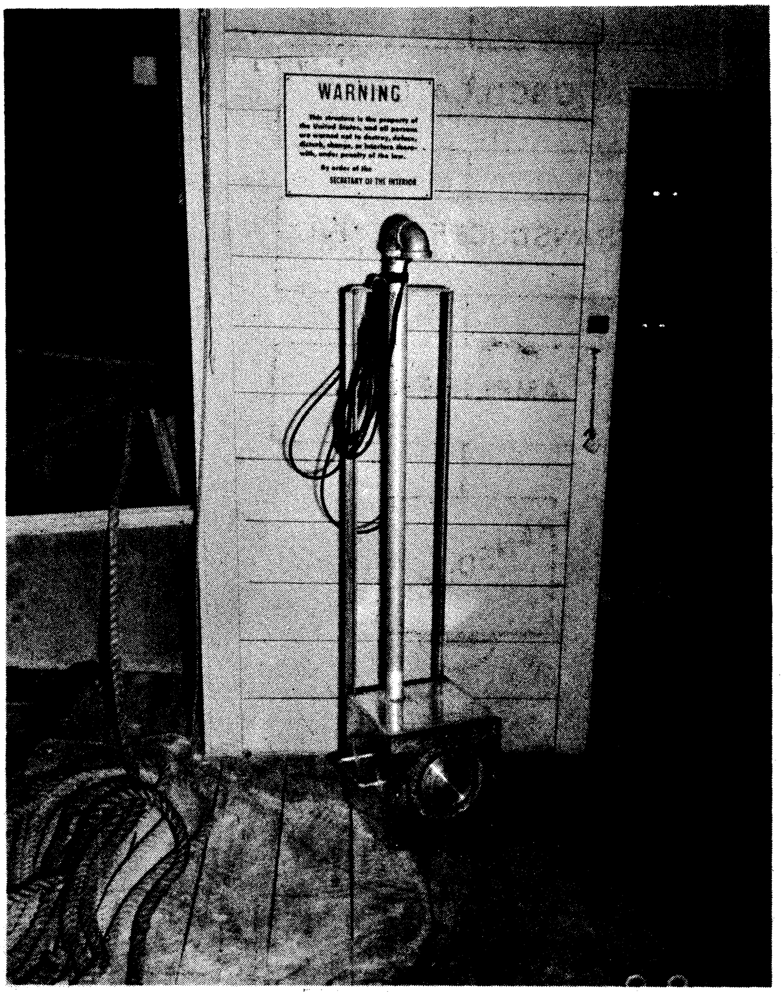

Figure 6.--Watertight aluminum container for submering the electromagnetic transducer.

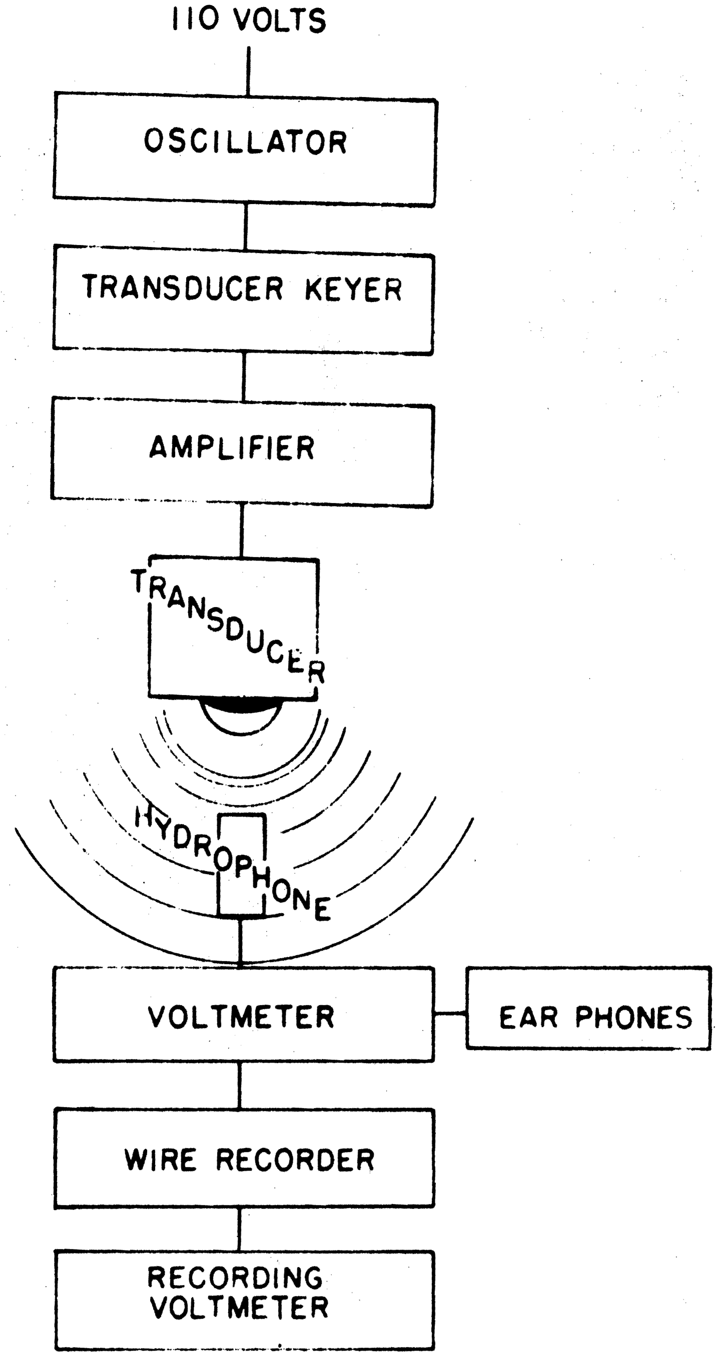

Figure 7.--Block diagram showing electron-unit arrangement.

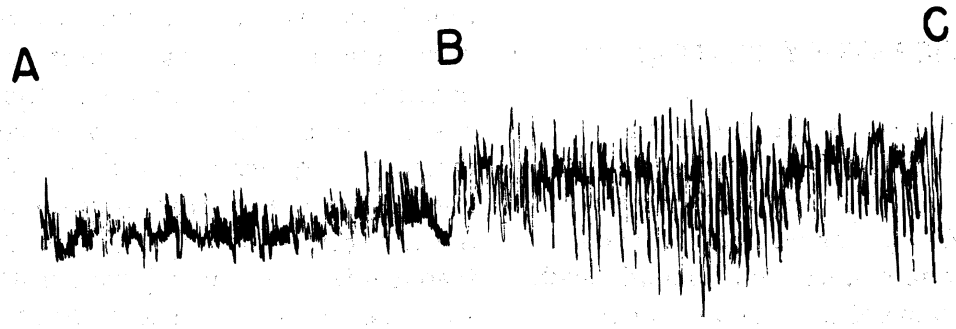

Figure 8.--A tracing of a typical recording of underwater sounds, as received by hydrophone and recorded by wire recorder, then transcribed on the recording voltmeter. The section between "A" and "B" is a recording of ambient noise only; "B" to "C" is a frequency of 20 c.p.s. superimposed upon the ambient noise.

The fish were allowed to "settle down", and the 10-second test was run. The transducer was then raised, the pen was rolled back into the well in the raft, and the number of fish in the various compartments was recorded. Testing from the raft was more time-consuming than laboratory testing.

RESULTS OF LABORATORY TESTING

The laboratory phase of the research covered the range of sound from 10 through 8,000 c.p.s. (table 1). Testing included the use of continuous sound, various pulsed sound, and other qualities and quantities of sound, such as the siren type. More than 13,000 young silver salmon, 3 to 5 inches long, were tested in the experimental tank in the laboratory. Some of the exploratory testing was conducted upon young chinook salmon 2 to 3 inches long, but these were not used for any of the systematic testing.

Although some frequencies looked more promising than others, none of the frequencies demonstrated either an attracting or a repelling force great enough to be considered for further investigation. A sample page of test results is found in figure 9.

Early in our exploratory testing, it was clearly established that young silver salmon were capable of perceiving sound. Upon the introduction of sound, the test fish always exhibited a typical "start", or quick-swimming movement. This act was almost instantaneous, and the distance covered, being only an inch or two, was negligible. After the initial "start", there was no other noticeable reaction by the fish, and it was assumed that they had become conditioned or adjusted to the presence of the sound. This result was common for all the laboratory testing. Even the various types of sounds, such as the siren, pulsed or continuous, made no apparent difference in the reaction of the fish. The initial "start" was the only noticeable response.

As water is a much better medium for transmitting sound than is air, it is difficult to understand why sounds of the intensities recorded in our investigation did not cause the fish to react. Intensities were measured with a hydrophone connected to a vacuum-tube voltmeter. Intensity measurements were made at the horizontal and vertical center of each compartment. Sound intensity in the water was measured in millivolts and converted to dynes per square centimeter. There was considerable variation in intensity among the different frequencies, even though all frequencies were being transmitted at the same power input. The highest intensity recorded was at a frequency of 1,810 c.p.s.; in the experimental tank, this frequency produced amplitudes as high as 7,200 dynes per cm^2 in compartment No. 1; falling off gradually to a level of 2,800 dynes per cm^2 in compartment No. 5. In contrast, some frequencies were so low that a measure of their amplitude was impossible with our equipment. Some intensity levels at various frequencies are shown in table 2.

Even though some frequencies were so intense that comparable noise in the air would be almost unbearable to the human ear, there was no apparent reaction by the fish.

During a study of the sound patterns within the experimental tank at different frequencies, it was determined that particularly in the low frequencies there was no gradual fall-off or decay of sound away from the transducer. As was expected, sound intensities in the different compartments varied with the frequencies. It was concluded that in some cases the sound was nondirectional, owing to reverberation and standing waves. Sound patterns of this nature were of little use in testing their effect as either an attracting or a repelling force.

Table 1 —Schedule of frequencies (C.P.S.) used in testing effects of underwater sound on salmon fingerlings.

Frequency	In laboratory	In open water	Frequency	In laboratory	In open water
5		x	750	x	x
10	x	x	1000	x	x
15	x	x	1500	x	x
20		x	1810	x	
25	x	x	2000		x
30		x	2040	x	
32	x		2500		x
35	x		3000		x
40		x	4000		x
50	x	x	5000		x
75		x	6000		x
100	x	x	7000		x
150		x	8000		x
200	x	x	8195	x	
300	x	x	9000		x
400		x	10, 000 through 20, 000 in 1000-cycle steps		x
500	x	x			

Table 2. —Energy levels measured at the horizontal and vertical center of the tank compartments at selected frequencies.

Cycles per second	Units of measure	Compartment No. 1	2	3	4	5
10	Dynes*	360	360	180	150	260
	Db. **	11.58	11.58	8.57	7.78	10.17
20	Dynes	1, 900	2, 200	780	1, 150	1, 950
	Db.	18.81	19.44	14.94	16.63	18.92
40	Dynes	1, 450	1, 550	1, 250	570	360
	Db.	17.63	17.92	16.99	13.58	11.58
50	Dynes	1, 050	1, 025	720	370	100
	Db.	16.23	16.13	14.59	11.70	6.02
100	Dynes	540	230	180	25	25
	Db.	13.34	9.64	8.57	0.00	0.00
1375	Dynes	38	25	--	--	--
	Db.	1.82	0.00	--	--	--
1810	Dynes	7, 200	6, 050	3, 800	3, 800	2, 800
	Db.	24.59	23.84	21.82	21.82	20.49
3110	Dynes	980	720	100	340	25
	Db.	15.93	14.59	6.02	11.34	0.00
4950***	Dynes	4, 100	2, 050	1, 950	1, 400	520
	Db.	22.15	19.14	18.92	17.48	13.18

Table 2.—Energy levels measured at the horizontal and vertical center of the tank compartments at selected frequencies. (Cont'd.)

Cycles per second	Units of measure	Compartment No.				
		1	2	3	4	5
9350***	Dynes	2,950	2,200	470	1,150	260
	Db.	20.72	19.44	12.74	16.23	10.17

* Dynes per cm.^{2}

**Decibels, with reference to the lowest reading, 25 dynes per cm.^{2} calculated by the formula $Db = 10 \log \frac{P_2}{P_1}$ where P_1 is the reference level in Dynes per cm.^{2} and P_2 is the level to be compared.

***Produced by piezoelectric transducer; all other frequencies were produced by the electromagnetic transducer.

The results of the laboratory phase of the research were not encouraging. There was no indication that the sound waves either attracted or repelled the young salmon. In view of the fact that the experimental tank had demonstrated definite limitations, we were hopeful that the move into Lake Washington would produce more promising results.

RESULTS OF OPEN-WATER TESTING

Open-water testing in Lake Washington covered the range of sound from 5 c.p.s. through 20,000 c.p.s. (table 1), and more than 23,500 young silver salmon were tested while covering this range. As we were aware of the limitations of testing in the laboratory tank, we felt it advisable to cover the entire range of sound as originally planned.

During the entire testing of the range from 5 to 20,000 c.p.s., there was never any indication that the sound was either attracting or repelling the fish. As in the laboratory, fish responded to the sound with the typical "start" reaction. This response was more pronounced in the lower frequencies than in the higher. When tests had reached the level of approximately 15,000 c.p.s. there was a noticeable decrease in the "start", and by the time 20,000 c.p.s. was reached it was seldom evident. Results of a typical open-water test are shown in figure 10.

After studying the waters and the natural noises contained within them, it is not difficult to understand why fish do not react to sound waves. The volume of sound to which fish are constantly subjected is almost unbelievable. Until one has had the opportunity to listen to the natural noises in a lake, it is difficult to realize the noise level which can be attained. Because the fish are subjected to such noises, it is understandable why the addition of another noise, such as we were introducing, does no more than give them a "start". We do not feel that this reaction is caused by fear as much as an alertness to a new and different noise. This reaction lasts only momentarily, and then the noise becomes just another part of the constantly changing background to which the fish has become adjusted.

Figure 9.—Sampe of test data from a laboratory sound test.

SOUND TEST NO.: 27
Date: 5-24-54
Observors: Moore, Newman

TEST CONDITIONS:
Cycles/sec.: 1810
Power: 25 W
Duration: 1 sec.

Pulses/sec.:
Pulse length:

Species: silver Length: 6"

CONTROL

Repl.	START Section					Total		END Section					Total	Dead
	1	2	3	4	5			1	2	3	4	5		
1	25	-	-	-	-	25		24	1	0	0	0	25	-
2	-	25	-	-	-	25		1	22	2	0	0	25	-
3	-	-	25	-	-	25		0	0	21	4	0	25	-
4	-	-	-	25	-	25		0	0	3	21	1	25	-
5	-	-	-	-	25	25		0	0	0	1	24	25	-
6	25	-	-	-	-	25		25	0	0	0	0	25	-
7	-	25	-	-	-	25		2	23	0	0	0	25	-
8	-	-	25	-	-	25		1	1	16	6	1	25	-
9	-	-	-	25	-	25		0	0	0	19	6	25	-
10	-	-	-	-	25	25		0	0	0	1	24	25	-
Total								53	47	42	52	56	250	-

TREATMENT

Repl.	START Section					Total		END Section					Total	Dead
	1	2	3	4	5			1	2	3	4	5		
1	25	-	-	-	-	25		23	1	0	1	0	25	-
2	-	25	-	-	-	25		3	16	5	1	0	25	-
3	-	-	25	-	-	25		0	3	19	3	0	25	-
4	-	-	-	25	-	25		0	1	1	17	6	25	-
5	-	-	-	-	25	25		0	0	0	2	23	25	-
6	25	-	-	-	-	25		24	1	0	0	0	25	-
7	-	25	-	-	-	25		1	23	1	0	0	25	-
8	-	-	25	-	-	25		0	0	21	1	3	25	-
9	-	-	-	25	-	25		0	0	0	16	9	25	-
10	-	-	-	-	25	25		0	0	0	1	24	25	-
Total								51	45	47	42	65	250	-

REMARKS: Maximum dynes/cm^2 at this setting.

Figure 10.—Sample of open-water test data

Test No. 15
50 cycles/second
Time = 10 seconds
Pulse length = 50 mil/sec.
Repetition rate = four pulses in 10 seconds.
All fish started in compartment No. 1.

Test No.	Distribution after test in compartment No.—					
	1	2	3	4	5	6
15 A (C)*	20	5	0	0	0	0
15 B (S)**	18	3	1	0	0	3
15 C (C)	19	0	0	0	2	4
15 D (S)	20	2	1	0	0	2
15 E (C)	18	4	0	0	1	2
15 F (S)	10	9	0	0	3	3
15 G (C)	13	9	1	0	1	1
15 H (S)	11	10	2	0	2	0
15 I (C)	9	4	2	5	3	2
15 J (S)	20	2	2	0	0	1
Total (C)	79	22	3	5	7	9
Total (S)	79	26	6	0	5	9

* Control
** Sound test

SUMMARY AND CONCLUSIONS

The results of this study on the effects of sound waves on young salmon are in close agreement with the results obtained in the Fish and Wildlife Service's study on trout at Leetown, W. Va. (Burner and Moore, 1953). In both series of experiments, the only positive reaction noted at any time was the "start" exhibited by fish the first time they are subjected to a new sound. After the initial "start", which is instantaneous, the test fish apparently are no longer aware of the sound.

There is, of course, the possibility that there is a particular frequency or quality of sound that will either attract or repell these young salmon. Within the limits of our work, however, we have found no such sound. Should such a sound ever be found to be effective under laboratory conditions, there seems to be no likelihood that it would be effective under field conditions. The fact that natural noises in the water are so great, even in a relatively calm lake, makes the use of sound in the undoubtedly noisier waters of streams, rivers, or around hydroelectric or other dams most unlikely. Here, the noises already present could easily obliterate any noise introduced for guiding purposes.

The results of the testing did not show sufficient response to analyse statistically. The sound waves were ineffective as an attracting or repelling force. Minor differences in distribution following the tests were attributed to chance rather than to an effect of sound waves.

LITERATURE CITED

Brett, J.R.D. MacKinnon and D.F. Alderdice.
1954. Trough experiments on guiding sockeye salmon fingerlings. Fish. Res. Bd. Canada, Prog. Repts. Pac. Coast Sta's., No.99: pp. 24-27.

Burner, Clifford J. and Harvey L. Moore.
1953. Attempts to guide small fish with underwater sound. Fish and Wildlife Service Spec. Sci. Rept. No. 111, 38 pp.

Collins, Gerald B.
1954. Research on anadromous fish passage at dams. Trans. 19th North American Wildlife Conf., pp. 418-423.

Duncan, Rea E.
1956. The use of infrared radiation in the study of fish behavior. Fish and Wildlife Service Spec. Sci. Rept. No. 170 (in press)

Hamilton, J.A R., and F.J. Andrew.
1954. An investigation of the effect of Baker Dam on downstream-migrant salmon. Internat. Pac. Salmon Fish. Comm., Bull. No. 6, 73 p.

Schoeneman, Dale E., and C.O. Junge, Jr.
1954. Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River. Washington Dept. Fish. Res. Bull. No. 3. 51 p.