ATTEMPTS TO GUIDE SMALL FISH WITH UNDERWATER SOUND

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Explanatory Note

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ATTEMPTS TO GUIDE SMALL FISH WITH UNDERWATER SOUND

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FOREWORD

This paper is submitted with the objective of providing other fishery investigators with a resumé of what has been accomplished in attempting to guide fish by means of subaqueous sonic vibrations. Preliminary studies were made under the direction of J. T. Barnaby, formerly Chief, North Pacific Fishery Investigations. Dr. George A. Rounsefell was responsible for all early arrangements with the U. S. Navy. Mr. D. W. Beecher of the Naval Ordnance Laboratory, White Oaks, Maryland, provided acoustical equipment and technical advice, assisted by Mr. W. R. Cook. The senior author was enthusiastically aided by Mr. Kingsley G. Weber, Mr. Ned C. Neal, and Mr. Clifford V. Lalonde in conducting the investigation in the field. Funds for the sonic studies were provided by the U. S. Corps of Engineers, Portland, Oregon.

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ATTEMPTS TO GUIDE SMALL FISH WITH UNDERWATER SOUND

One of the most uncertain and difficult problems in providing for the safe passage of migratory fish around high dams is created by the migration of the young salmon to the ocean from upstream spawning grounds. Experiments indicate that turbine and spillway hazards at one dam may cause a considerable loss of these small fish. This loss becomes of increasing concern when multiplied by each new dam under construction or proposed for the Columbia River. When this potential threat to the resource first became known, the Fish and Wildlife Service initiated studies to develop methods of providing safe downstream passage for fingerlings. Basic to the accomplishment of this objective is a knowledge of their distribution in the river.

Research on this problem revealed that fingerlings of chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River are found at all depths of the water and from shore to shore in nearly equal numbers. Thus we knew that fish were passing through turbines and spillways in proportion to the amount of water passing through these structures, and it became urgent that we develop methods of diverting the fingerlings into safe channels of migration. The desirability of sound as a means of guiding fish cannot be overlooked, because it does not require the use of structural equipment such as floating booms or screens and because it can be beamed and reflected much like light.

Through the cooperation of the U. S. Army Corps of Engineers and the U. S. Navy, the Fish and Wildlife Service was given the opportunity to test the effects of underwater sound of various frequencies and amplitude on fish. The tests were made during November and December, 1947, and March and April, 1949, at the Biological Station at Leetown, West Virginia. The tests were limited to four undersea warfare sound producing instruments involving three principles of sound production: (1) electro-magnetism, (2) Piezo-electricity and (3) the hydraulic turbine. Because young Pacific salmon were not available at the site, the physiologically similar rainbow (*Salmo gairdnerii*) and brown (*S. trutta*) trouts were used as experimental animals.

CHARACTERISTICS OF SOUND AND SOUND DEVICES

All sounds are the result of physical vibrations. Sound waves in the air are the result of molecules of air being pushed against one another to form compression waves. This distinguishes sound waves from radio, radar, or similar electronic impulses which are the result of wave motion *between* the molecules. Sound waves in the water develop when the medium is alternately compressed and expanded mechanically. In either of the two elements, sound waves travel from the source in a pattern similar to that obtained by dropping a stone into a quiet pool.[1/]

1/ Actually sound waves expand in all directions from a non-directional source, in a series of concentric spheroids.

Sound waves travel in air at a speed of 1,087 feet per second (0° C.: 76 cm. pressure) and in water at 4,890 feet per second varying with temperature and pressure. The greater elastic constant of water makes it nearly ideal for the transmission of sound waves. The same hypotheses and laws that apply to sound in the air are applicable to subaqueous sound.

Audible sound frequencies range from 16 to 20,000 cycles per second. However, the upper limit may be raised with sufficient power. The term subsonic or subaudible sound refers to that part of the sound range below 16 cycles per second. Ultra or supersonic refers to the inaudible frequencies extending above 20,000 cycles per second.2/ Some generators now in use are capable of producing inaudible ultrasound of 12,000,000 cycles per second. Recently this part of the sonic band has been developed to homogenize milk, mix oils and precipitate smoke particles. The high frequency sirens have also been used to kill bacteria, fish, froges, and other small organisms. They are effective only at extremely short range (50-60 mm.) with almost no "spread" and require tremendous operating power. These machines are for aerial use only, the organisms being held in containers directly in the sound blast. As yet no underwater "death ray" has been produced because of the difficulty of transducing energy into the water.

To the average fishery biologist, the difficulties of experimenting with sound waves seem almost insurmountable. Efficient, continuous, sound wave production lies almost entirely within the realm of electronic warfare. The equipment used to produce controlled sound is for the most part comprised of complex power amplifiers and underwater speakers containing electromagnetic, magnetostriction, or crystal oscillators. This is not a contradiction of the definition of sound given earlier. In devices of this type, the amplifier develops the power to operate a signal generator which in turn sends electronic impulses to the mechanical oscillator, or diaphragm. The vibrating diaphragm imparts sound waves by alternately compressing and rarefying the water. Electronic hydrophones measure the sound field by reversing this system.

There are however, simple mechanical means of making underwater sounds. One of the most productive is the turbine driven with water and air. There are many types of underwater bells, clappers, organ pipes, whistles and sirens. It is possible to release air and steam to cause noise in the water, and finally, there are explosives. Fishery investigators have experimented with nearly all of these types to obtain response in several kinds of fishes. Most of the investigators were unaware of the need for knowing how much sound energy they were creating in the water. Moorhouse (1932) used a tapper, a buzzer, a bell and a motor horn inside a rectangular can at one end of an aquarium. He found that the nervous system of the perch is quite capable

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2/ The term supersonic is now used to apply to airplane and rocket flight above the speed of sound.

of building up a conditioned reflex to sound, and that some species of fish were affected more than others.

The point to be made is that experimentation with sound need not necessarily involve complex equipment. Experiments such as those of Moorhouse could be duplicated by anyone. A simple device such as a pneumatic drill operating in a submerged tank might prove effective as a fish "scare". It would then be the province of the electronics experts to measure the sound and reproduce it in a controlled manner for the purpose of guilding small fish.

Although it has been mentioned in the literature that fish tend to be attracted to low frequency sound waves, such statements apparently are not based on more than single observations. The majority of the research work in relation to sound and fish has been concerned with the ability of fish to be conditioned to respond to a sound stimulus. Such experiments have shown that most fish condition readily and serve as evidence that most fish are capable of sound perception. There is, however, little if any indication that fish are consistently attracted or repelled by sound waves of any frequency or amplitude.

The evidence that the four pieces of professional sound equipment described in this report failed to produce a marked forcing or guiding response in young salmonoids does not detract from the desirability of presenting the methods and results of the experiments, nor should investigators consider that the frequencies tested have been exhaustively covered by these tests. Sound wave qualities and the kinds of transducers used to force this energy into the water are so diverse that the present work must be considered as only exploratory.

EQUIPMENT AND METHODS

Rainbow trout from 4 to 9 inches in length (Figure 1) and 1/2 inch brown trout were used in most of the tests. The fish were all normal healthy hatchery trout, taken for the most part, from natural raceways.

The physical equipment set up to measure the reaction of fish to sound by actual count is shown in Figures 2, 3, 4, and 5. This consisted simply of a 1/2 inch mesh wire trough, 100 feet long and 3 feet wide by 3 feet deep with just enough wood framing for support of the wire, plank gangway and the nine gates separating the trough into ten sections ten feet long each. No unnecessary wood was used under water because of possible reflection of sound waves from structural members. The bottom seams of the wire trough were joined by hog rings at 2-inch intervals (Figure 2), so that the entire trough was literally suspended from the 1 x 4 longitudinal members, with the wire bottom a foot above the mud bottom of the pond. The nine gates separating the trough into ten sections were so rigged that all could be raised or dropped simul-

Figure 1. Rainbow trout used in the Leetown sonic experiments.

Figure 2. Dry pond, trap structure completed, gates rigged and in place.

Figure 3. Pond half filled.

taneously at the beginning and end of each trial. Figure 5 shows the gates down. In Figure 4 they are all raised and held in position as during a sound or control run. The pond in which this structure was built is 450 feet long and 60 feet wide. The bottom and sides are almost pure marl mud, a carbonate, which absorbed sound very well. The structure was placed in the center of the pond to avoid standing or echo-waves of sound from interfering with the beamed signal.

In developing the method of investigation and in designing the trough with its gates and sections to measure the reaction of fish to sound, three basic assumptions were made: (1) if the trout were unaffected by or indifferent to sound waves, they would move within the trough and between sections in a pattern similar to that of the control; (2) if they were attracted by some frequency of sound they would tend to proceed to the end of the trough nearest the sound source or (3) if the fish were frightened by the sound they would travel away from the sound source. Obviously, it was assumed that other stimuli had no effect upon the movement of the trout. Insofar as possible precautions against such extraneous stimulation were taken.

"WATER HAMMER" - ELECTRO-MAGNETIC TRANSDUCER

For the first tests with low audible frequencies, the 600 pound audio speaker (Figure 6) was suspended in the water so that the round aluminum piston (lower center) was approximately 1-1/2 feet below the water surface, and 2-1/2 feet above the bottom. The heavy framework to support it was erected at the extreme end of the trough outside section No. 1. The greatest intensity of sound, therefore, was in section No. 1. The least intensity was found in section No. 10, as determined by hydrophones. The speaker was never moved from its position adjacent to section No. 1, predominantly because of the enveloping, non-directional nature of its sound pattern. The unit, designed as a sonic mine sweep, had a frequency range of 67 cycles per second to 3,500 cycles per second utilizing 110 volts D. C. at 3 amps. In order to use the full potential of the speaker, it was necessary to connect two 125 watt amplifiers in tandem to obtain 200 watts power. A signal generator or oscillator completed the low frequency equipment (Figure 7). It might be noted that 67 to 3,500 cycles per second is roughly the range of a piano. At a frequency of 60 cps. to 2,000 cps. at 3,000 dynes/cm^2 , the intensity was 70 decibels above 1 dyne/cm^2 at a distance of 3 feet, rising to 12,000 dynes/cm^2, or 82 db above 1 dyne/cm^2, at 2,500 to 3,500 cps.

The complex interference patterns caused by reflection from the surface and bottom prevented a uniform fall-off of the sound along the length of the trap structure and also prevented accurate measurements of the sound field.

Figure 4. Gates being held up as during a sound or a control run.

Figure 5. Fish being counted out to check on their reaction to a sound frequency.

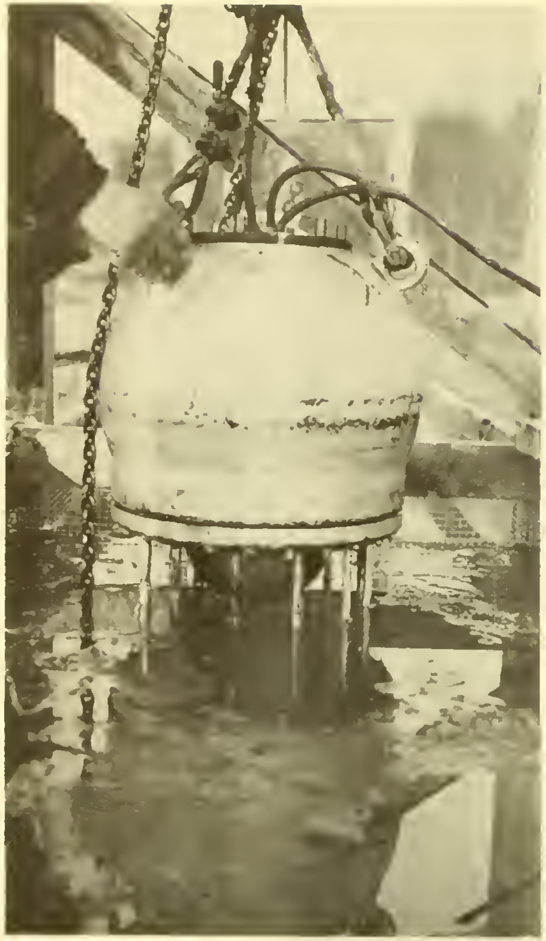


Figure 6. Audio speaker used to produce low frequency sound. (Here shown out of the water.)

Figure 7. Power amplifiers and signal generator used to provide sound to the underwater speaker shown in figure 6.

Before starting the sonic tests, 100 trout were placed in each of the ten sections of the trough. Fifty trout of the same stock were placed in one live car near shore and several large brood rainbow up to 24 inches in length were placed in another where their reactions to each frequency could be observed at close hand. Before the planned tests and controls were started, it was decided to try the full range of the low frequency equipment briefly to see if one particular frequency response could be singled out. Observations were made directly, with Dr. Rounsefell standing motionless at section no. 1. Mr. Neal watched the large brood rainbow in the live car near shore from a distance. The following notes were made:

(1) 67 cycles per second: Rounsefell noted fish appeared uneasy at low range especially when sound was first turned on. Fish started and faced away from the audio speaker but did not swim off when sound continued.

(2) Siren effect 67 cps. to 700 cps. Rounsefell observed whole school of fish face away from speaker, but returned to normal in seconds.

(3) Intermittent operation all frequencies from 67 to 3,000 cps. No effect.

(4) Neal reported no response from brood rainbow near shore.

Following the brief tests described above, those frequencies which elicited even the slightest response were tested systematically by octaves (i. e. 70 cps. to 140 cps. etc.). It was evidence from their reaction, that the fish were able to detect the source of sound at the moment of starting. It is doubtful, but entirely possible that a visual stimulus was received in addition to the audio stimulus. The aluminum piston of the audio speaker had a travel of less than 1/8 inch. It was located some distance from the fish and outside the wire trough.

Some sound emitted by the underwater speaker escaped into the air and could be heard plainly as a steady buzz at a distance of 50 yards. At a distance of 1 yard the escaping sound was likened to that of an irritating door buzzer at arm's length. The same sound intensity under water is multiplied nearly 100 times - a fact familiar to the small boy who strikes rocks together below the surface with his head submerged. The fish, therefore, were being subjected to an intensity of sound much greater than is perceived by the human ear above the water surface.

Figures 8-15 with histograms showing the results of each test are presented to give the reader an opportunity to compare the results of the sound tests and the controls. For the first several tests, fish were counted out 100 to a section and replaced 100 to a section after each test. In each case, the darkened portion of the histogram represents the numbers of fish found after each control or test run.

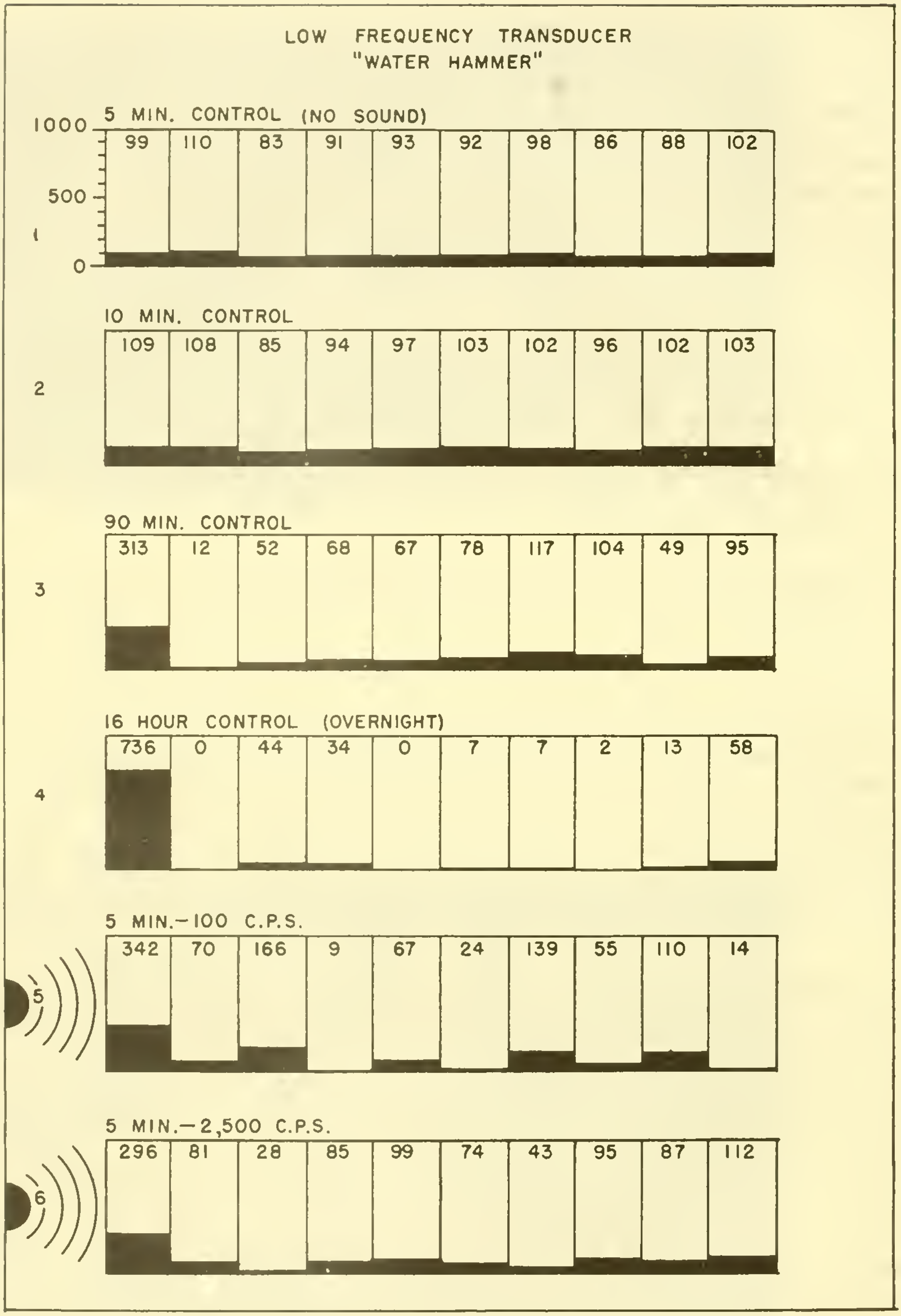


Figure 8. Distribution of fish in pens, experiments 1-6. There were 100 fish in each pen at the beginning of each experiment. In controls, gates between pens were lifted for periods indicated, then lowered. Tests differ only in that sounds of indicated frequencies (cycles per second) and durations were applied at indicated location while gates up. Numbers and dark bars indicate number of fish in each pen after gates lowered.

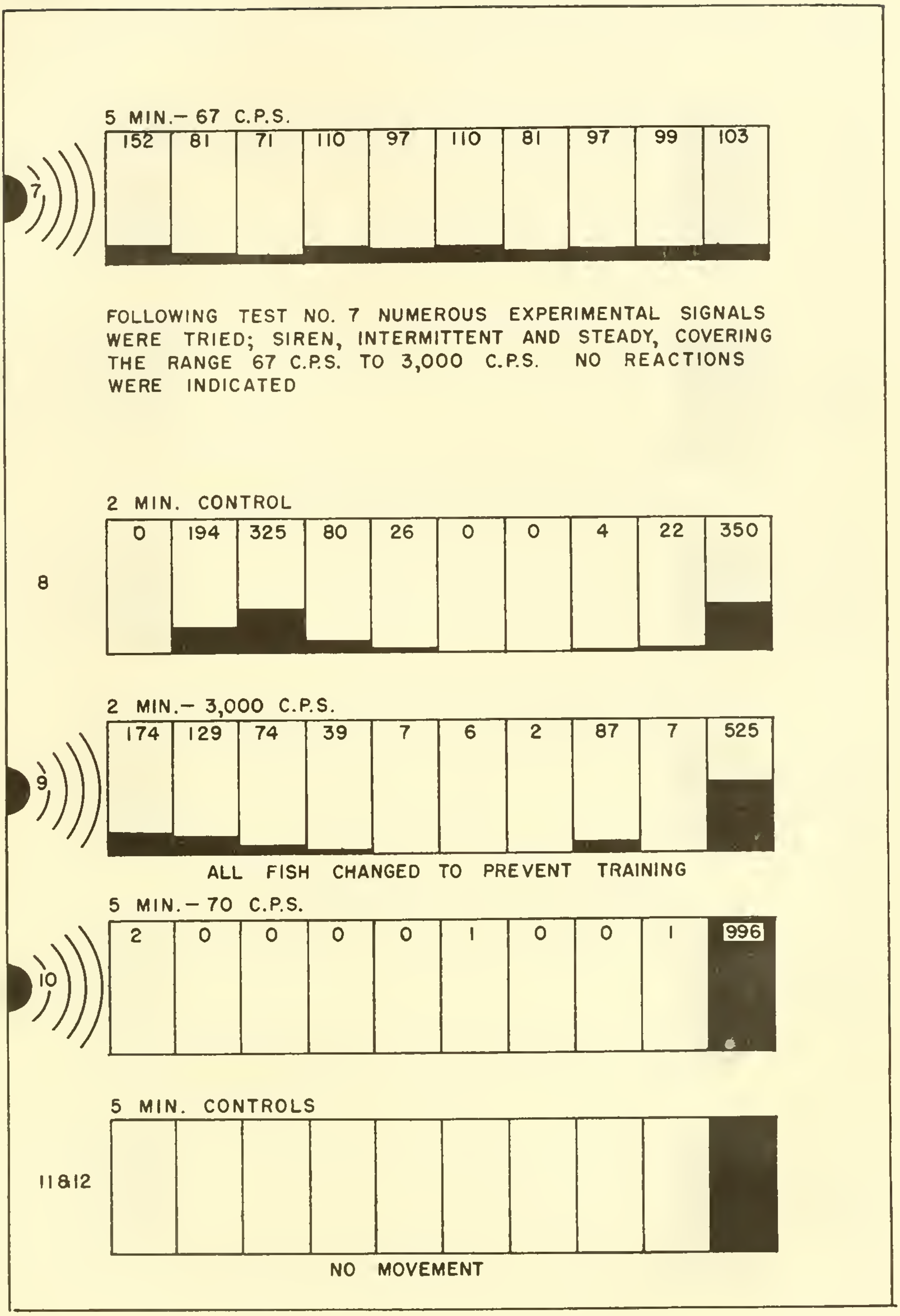


Figure 9. Distribution of fish in pens, experiments 7-12. Experiment No. 7 started with 100 fish in each pen, and sound was applied at indicated location and frequency (in cycles per second) while gates between pens were open for indicated period. Experiments 8-12 were started with 1,000 fish in pen No. 10 (far right). Procedure was as above, except that for tests sounds of indicated frequencies and durations were applied at indicated locations while gates up. Numbers and dark bars indicate number of fish in each pen after gates lowered.

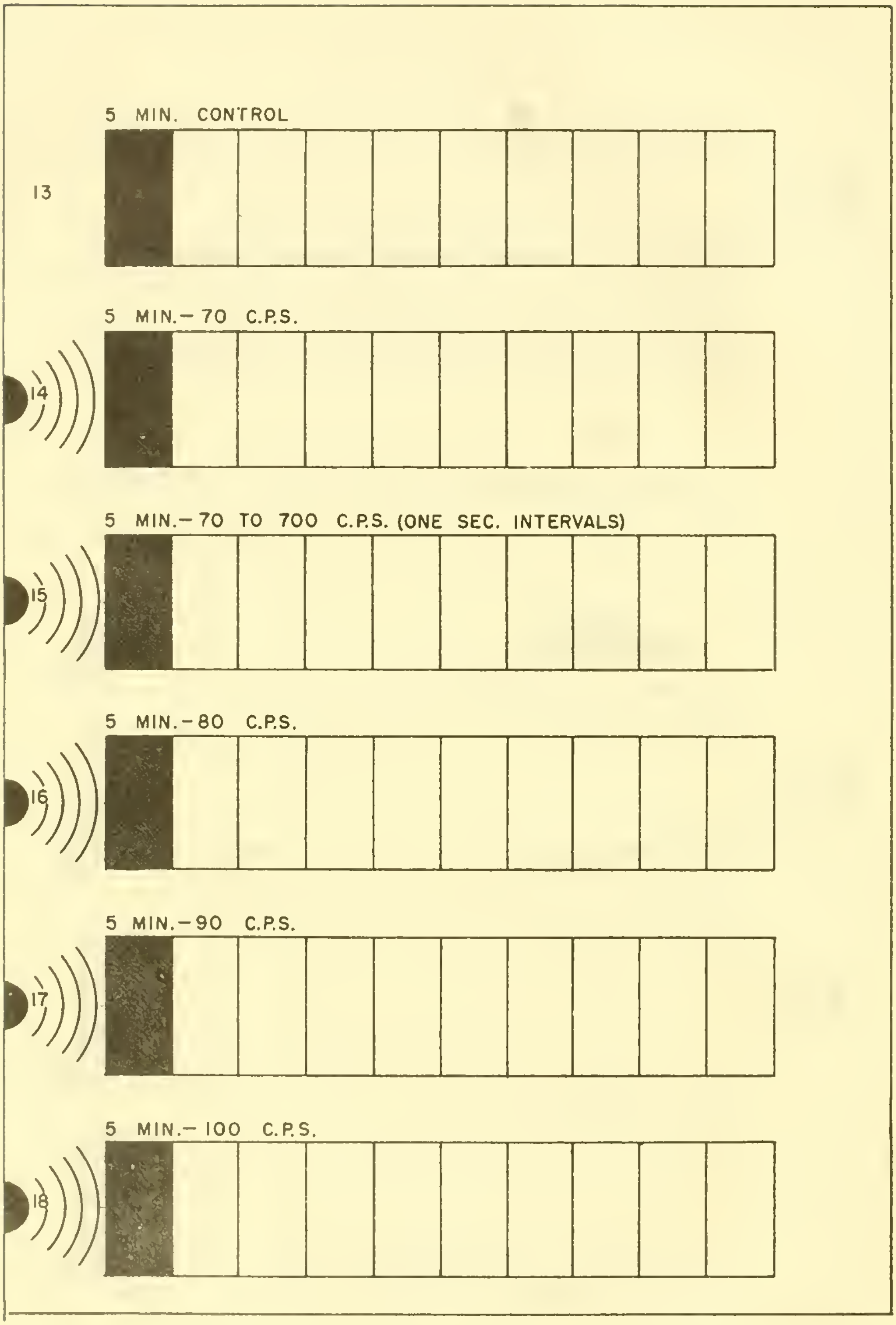


Figure 10. Distribution of fish in pens, experiments 13-18. Each experiment started with 1,000 fish in pen No. 1 (far left). In control, gates between pens were lifted for indicated period, then lowered. In tests, procedure was the same, except that sounds of indicated frequencies (cycles per second) and durations were applied at indicated location while gates up. Dark bars show number of fish after gates lowered.

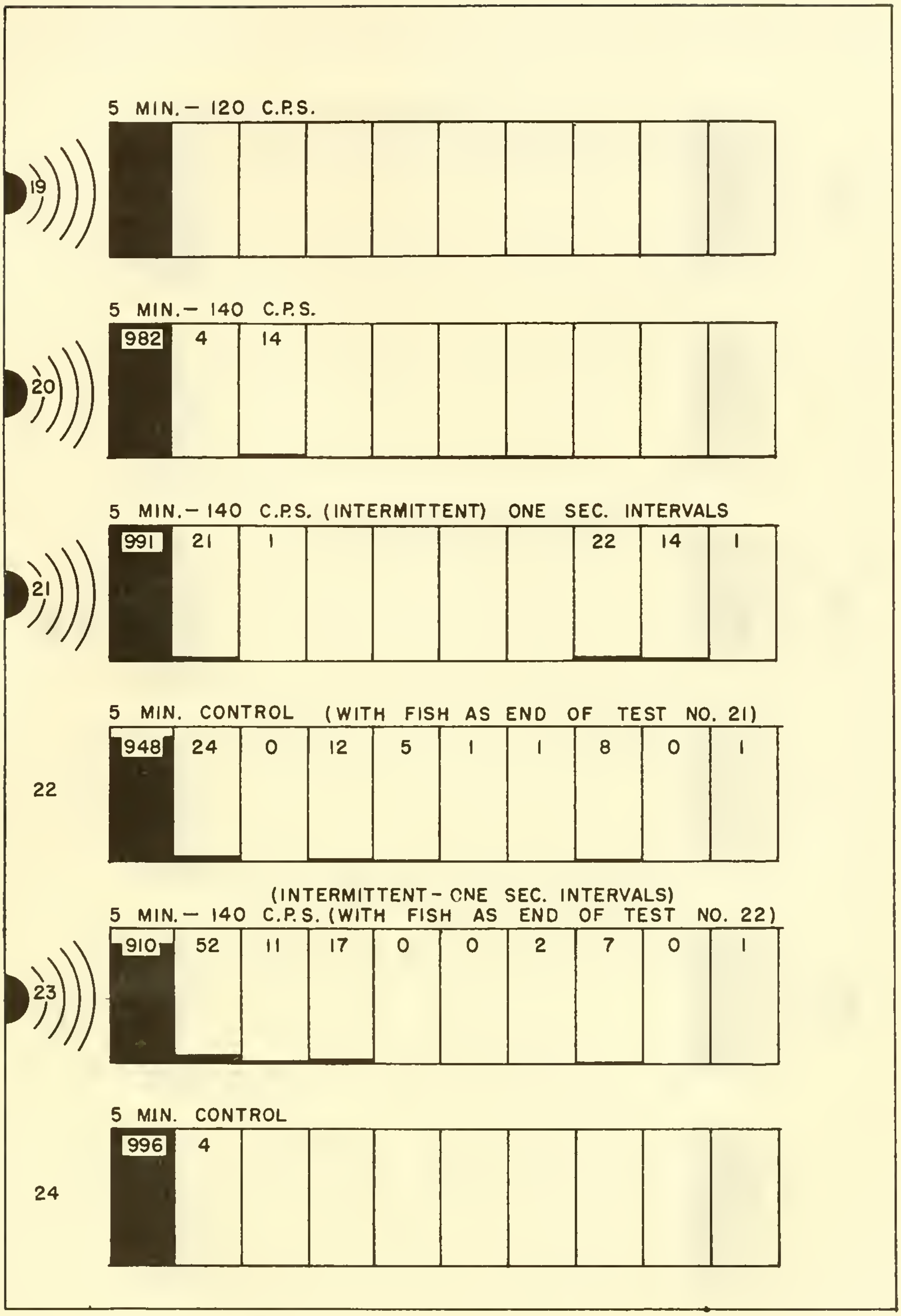


Figure 11. Distribution of fish in pens, experiments 19-24. Experiments 19, 20 and 24 started with 1,000 fish in pen No. 1 (far left); 20 started with 1,050 fish in pen No. 1, others as indicated. In controls, gates between pens were raised for indicated period, then lowered. Procedure same in tests, except sounds of indicated frequency (cycles per second) and duration applied at indicated location while gates up. Numbers and dark bars show distribution of fish after gates lowered.

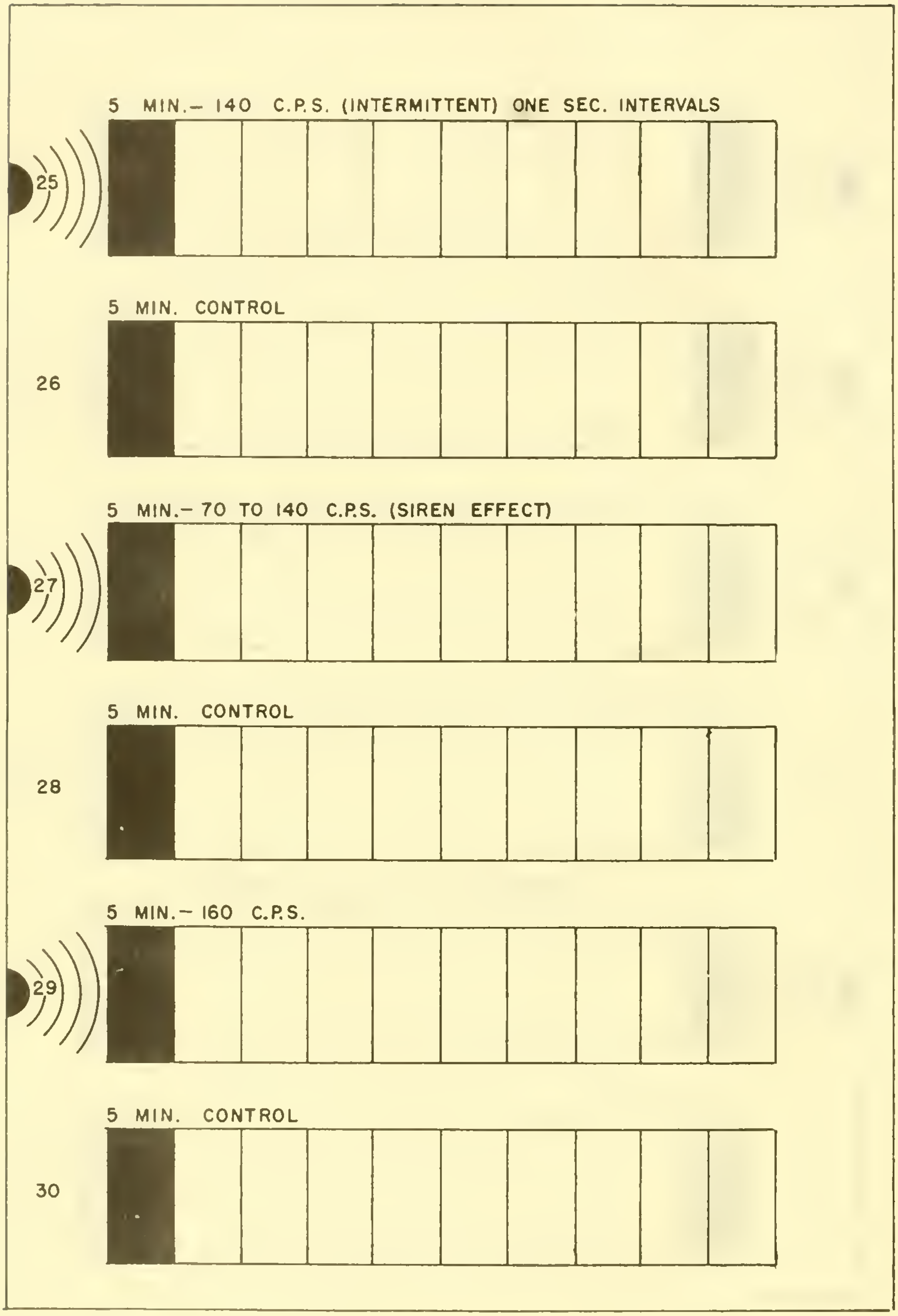


Figure 12. Distribution of fish in pens, experiments 25-30. All experiments started with 1,000 fish in pen No. 1 (far left). In controls, gates between pens lifted for indicated period, then lowered. Procedure same in tests, except sounds of indicated duration and frequency (cycles per second) applied at indicated location while gates up. Numbers and dark bars indicate distribution of fish after gates lowered.

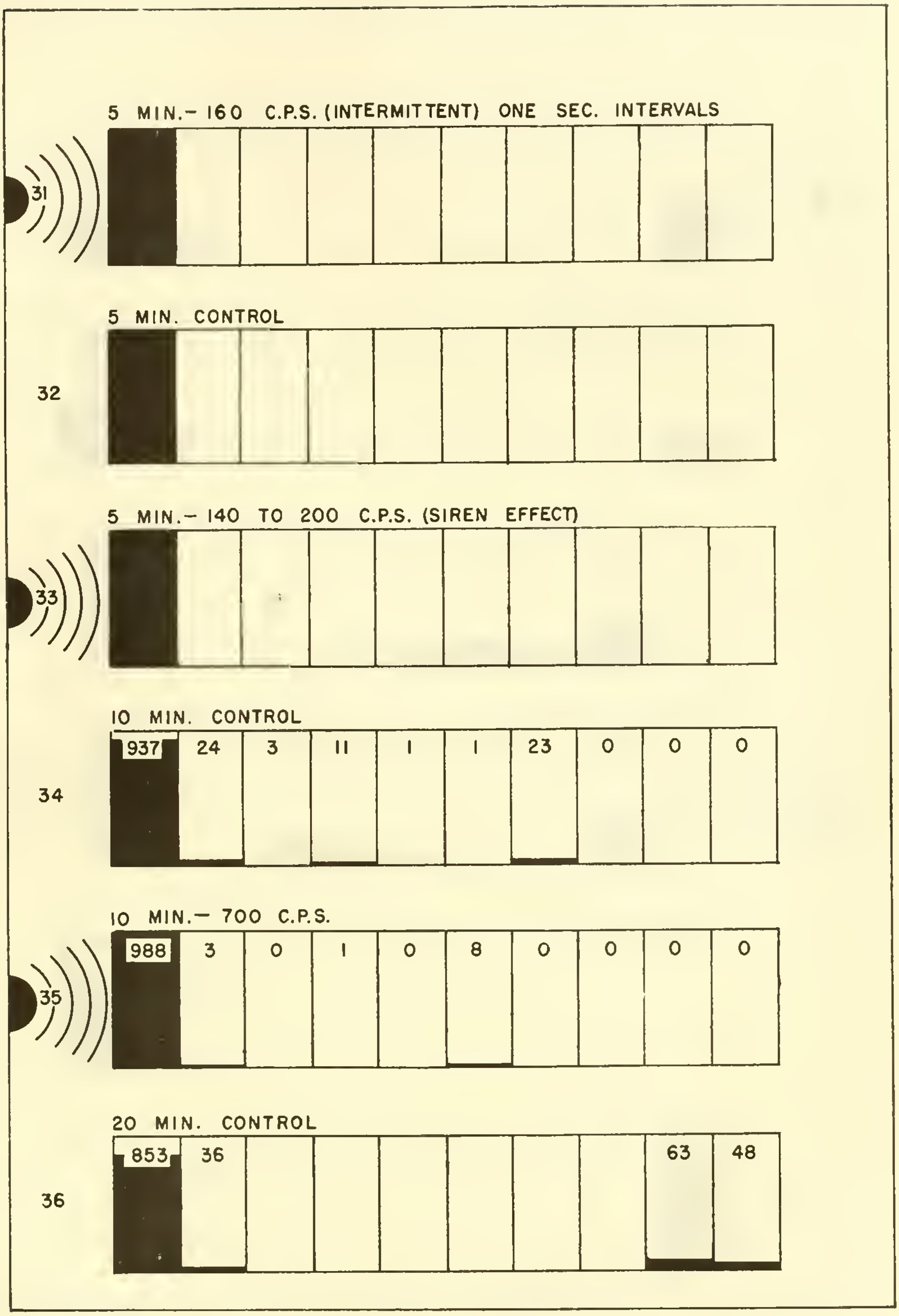


Figure 13. Distribution of fish in pens, experiments 31-36. All experiments started with 1,000 fish in pen No. 1 (far left). In controls, gates between pens lifted for indicated period, then lowered. Procedure same in tests, except sounds of indicated duration and frequency (cycles per second) applied at indicated location while gates up. Numbers and dark bars indicate distribution of fish after gates lowered.

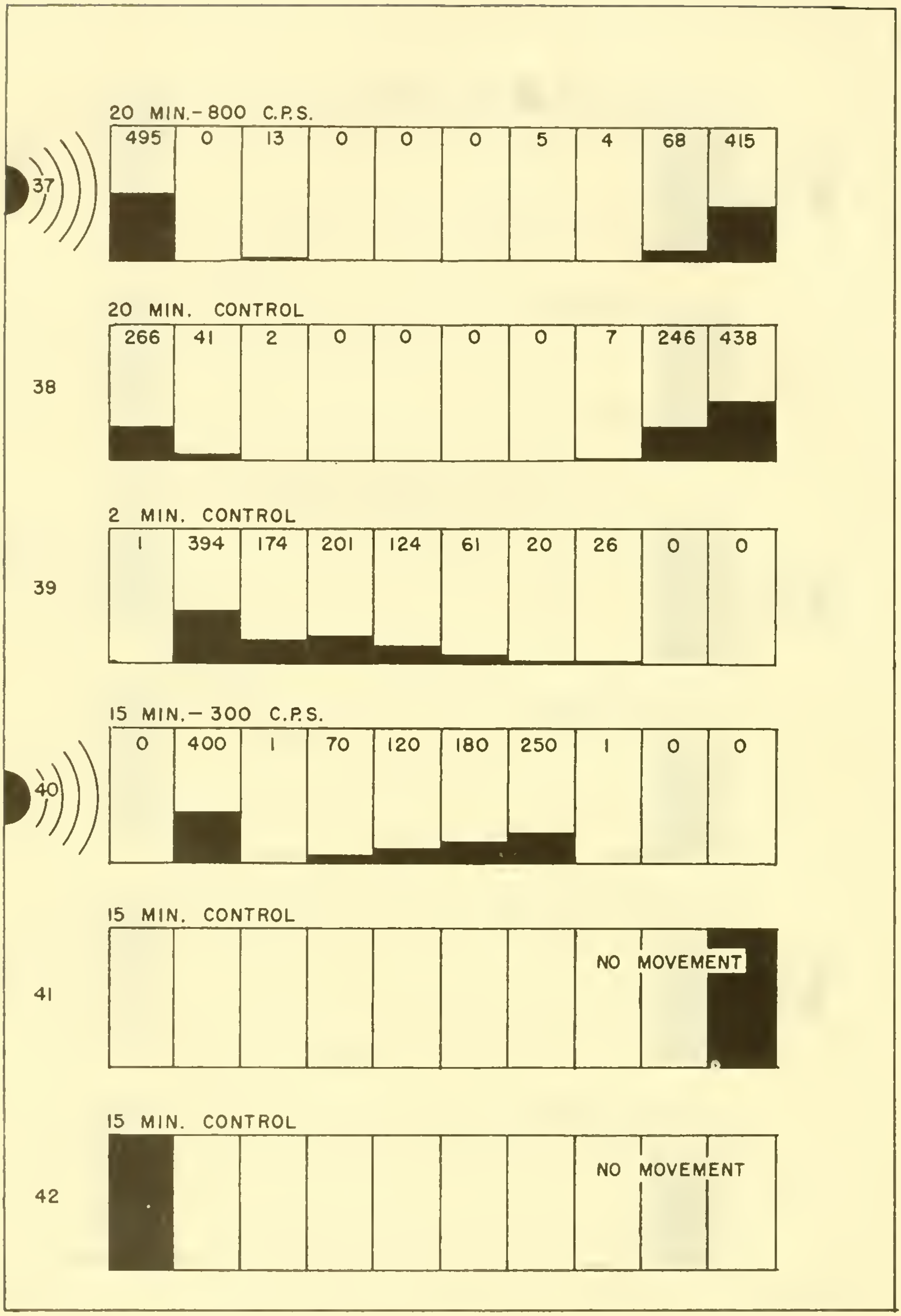


Figure 14. Distribution of fish in pens, experiments 37-42. Experiments 37, 38, 42 started with 1,000 fish in pen No. 1 (far left); 39, 40 with 500 fish each in pens 5 and 6 (from left) and 41 with 1,000 in pen No. 10 (far right). In controls, gates between pens lifted for indicated period, then lowered. Procedure same in tests, except sounds of indicated duration and frequency (cycles per second) applied at indicated location while gates up. Numbers and dark bars indicate distribution of fish after gates lowered.

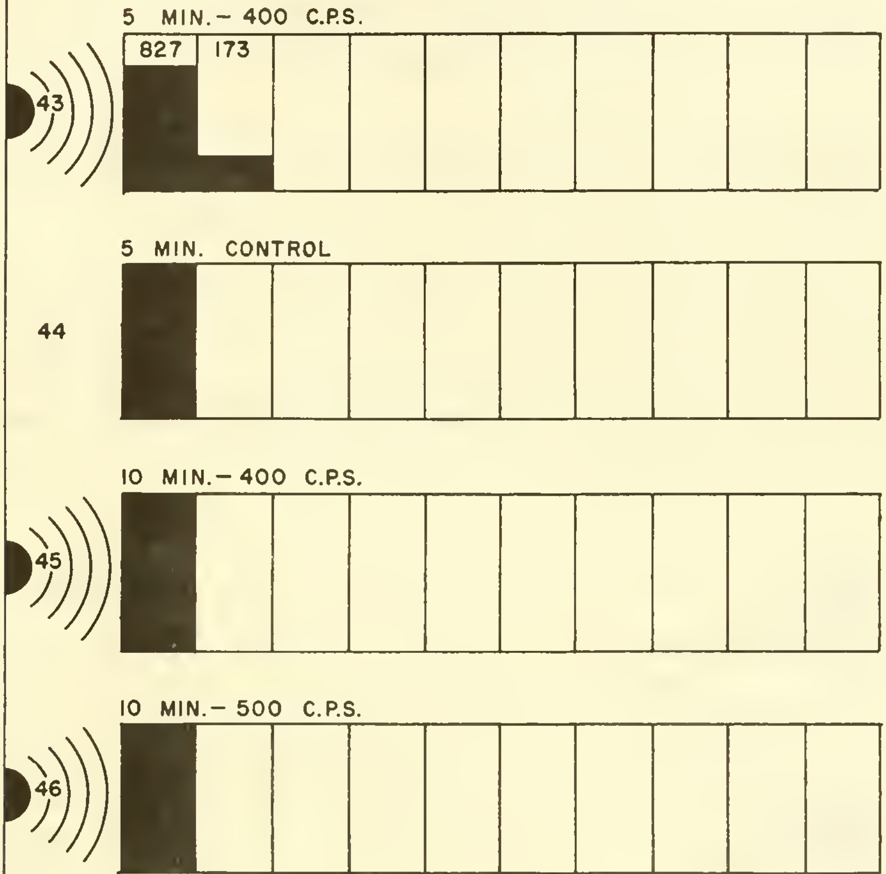


Figure 15. Distribution of fish in pens, experiments 43-46. All experiments started with 1,000 fish in pen No. 1 (far left). In control, gates between pens lifted for indicated period, then lowered. Tests same, except sounds of indicated durations and frequencies (cycles per second) applied at indicated location while gates up. Numbers and dark bars show distribution of fish after gates lowered.

As there were obvious differences in the sound test distributions and the control distributions it seemed desirable to apply contingency tests to the results to determine if the differences were significant. In all cases (comparison of sound tests and controls of the same duration of time) the results were highly significant, thus indicating a marked difference between the sound tests and comparable controls.

This significant difference, however, can not and should not be interpreted as evidence that sound waves either attracted or repelled the fish. There is nothing to suggest that the sound waves produced by this apparatus had any influence on the distributions.

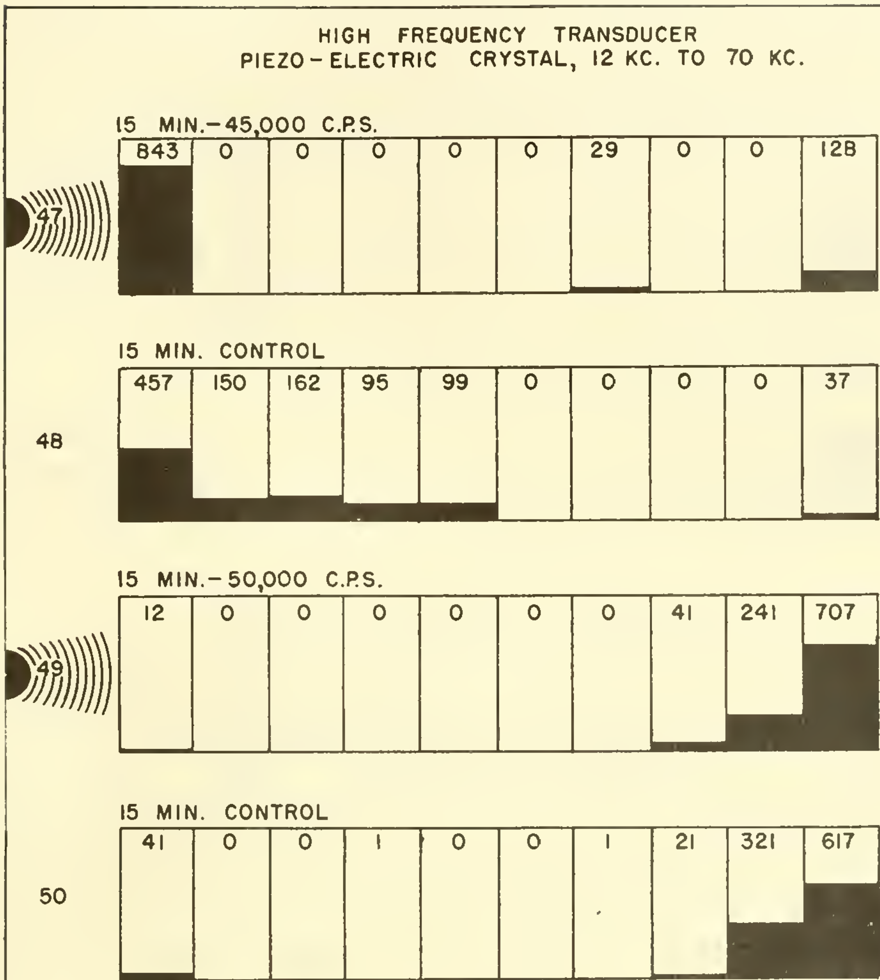
For practical manipulation of sound waves for leading and guiding fish into safe passages around dams and other stream barriers, it is necessary to have a stimulus which is very close to 100 percent efficient. None of the sounds produced by this first sound producing equipment showed results which in any way approach this efficiency. In no instance did the "water hammer" show a definite attracting or repelling effect on the fish during any of the tests.

PIEZO-ELECTRIC CRYSTAL TRANSDUCER HIGH FREQUENCY

On December 15, Mr. D. W. Beecher of the Naval Ordnance Laboratory assembled high frequency equipment for our use at Leetown. The oscilloscope and signal generator for frequencies of 12 kc to 70 kc were connected to the amplifiers used for the low frequency tests. The transducer was a four-inch brass cylinder containing quartz crystals and caster oil, covered with a rubber diaphragm. The crystals changed dimensions when subjected to a high frequency, alternating current The entire unit, a little over 8 inches in length, weighed approximately five pounds. The speaker could be beamed much like a flashlight and had approximately a 60° cone of divergence. The projector may be described as having the following characteristics: At frequencies of 12 kc to 60 kc - 4,000 dynes/cm^2 or 72 db above 1 dyne/cm^2 at 3 feet, except for 10 db dips at each end and at approximately 35 kc.

For the first tests the transducer was beamed directly upon the fish in section no. 1 in an attempt to frighten them out. Tests no's 47 and 48 (Figure 16) show that the fish moved even faster when the sound was not on. Test no. 49 appeared conclusive. The sound was turned on and all fish moved away from the transducer. The optimism was short-lived when in test no. 50, a control, the fish moved in a similar pattern in nearly identical numbers. This frequency (50 kc) was tried again and again informally, without results which could be assessed as conclusive.

Any frequency which elicited even a suggestion of a response, was repeated informally. The equipment was given a series of tests utiliz-



FOLLOWING TEST NO. 50 SEVERAL EXPERIMENTAL SIGNALS WERE TRIED COVERING THE RANGE 12 KC. TO 70 KC. NO MEASURABLE OR DISCERNIBLE REACTIONS WERE NOTED.

FOR THE FOLLOWING TESTS THE SOUND WAVES WERE BEAMED ACROSS PEN NO. 2 TO ACT AS A BARRIER OR FENCE

Figure 16. Distribution of fish in pens, experiments 47-50. All experiments started with 1,000 fish in pen No. 1 (far left). In controls, gates between pens lifted for indicated period, then lowered. Tests, same except sounds of indicated durations and frequencies (cycles per second) applied at indicated location while gates up. Numbers and dark bars show distribution of fish after gates lowered.

ing experimental signals ranging from intermittent pips to siren effects of several frequencies. The complete unconcern of the fish to any of these signals was convincing that they were unaffected. It was decided, as a final test of this conclusion, to beam the transducer across section no. 2 so it would act as a sound "fence" to keep the fish in section no. 1. Tests no. 51 through 58 (Figs. 17 and 18) showed no response. Tests no. 59 through 61 (Fig. 18) were thought o be indicative, so these tests were repeated but without success. The remainder of the high-frequency tests, both formal (Figs. 18 and 19) and informal were unproductive. There was no indication that this signal generator or any frequency produced by it would by of any use as a stimulus for leading or guiding small fish.

An incidental finding of the above tests was an indication of conditioning in the experimental fish. As the trials progressed, there was a distinct tendency for the fish to learn to remain in pen no. 1 (Fig. 20)

"WAMPUS" - UNDERWATER TURBINE

In the spring of 1949 experimentation with sound was continued at the Leetown station with the help of the U. S. Naval Ordnance Laboratory. The first piece of equipment tested was an underwater turbine (Fig. 21) used during World War II as a towed sound target for torpedoes and mines. This noisemaker required for its operation a 500 gallon per minute water pump and a 150 pound capacity air compressor (Fig. 22). An overhead trolley line was rigged to enable the sound head to operate at varying distances from the fish in the counting structure. Because of its use in naval warfare, the sound head, dubbed the "wampus" early in its development, is still in a classified category. It is not possible, therefore, to describe this underwater turbine in detail. Of greater importance, however, is the nature of the frequency band emitted, and its intensity, which we have obtained permission to discuss in general terms. The maximum signal recorded was about 3 volts, which at 56 microvolts per microbar, would correspond to a pressure of about 55,000 dynes/cm^2. This is real underwater thunder. By way of comparison, 1 dyne/cm^2 in underwater sound is a moderate sort of noise of the sort made by a small boat sloshing along nearby. A loud underwater sound level would be made by a large ship passing at close range, which might register 30-40 decibels above 1 dyne/cm^2. The standard for quiet used by the telephone company is .0002 dynes/cm^2.

Some frequency response curves were obtained on the wampus with and without air and at 100 p s i water pressure. With air there was a fundamental frequency of about 50 to 75 cps. and all harmonics up to 3,000 or 4,000 cps. Without air, the fundamental was about 75 to 100 cps. and with all harmonics up to 2,000 cps. The shifting of the

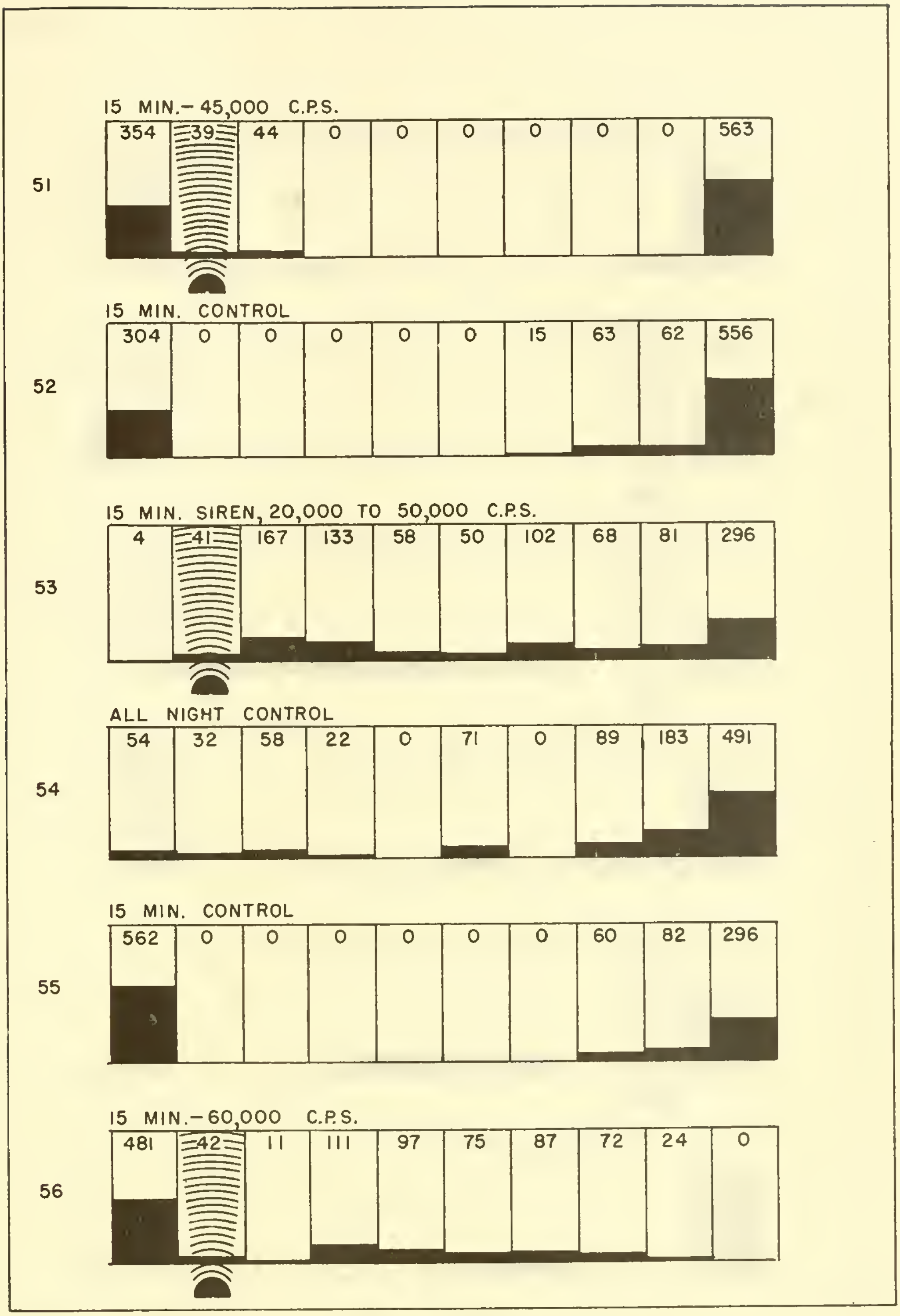


Figure 17. Distribution of fish in pens, experiments 51-56. Experiments 51-53, 55, 56 started with 1,000 fish in pen No. 1 (far left); 54 started with 1,000 fish in pen No. 10 (far right). In controls, gates between pens lifted for indicated period, then lowered. Tests same, except sounds of indicated durations and frequencies (cycles per second) applied at indicated location while gates up. Numbers and dark bars show distribution of fish after gates lowered.

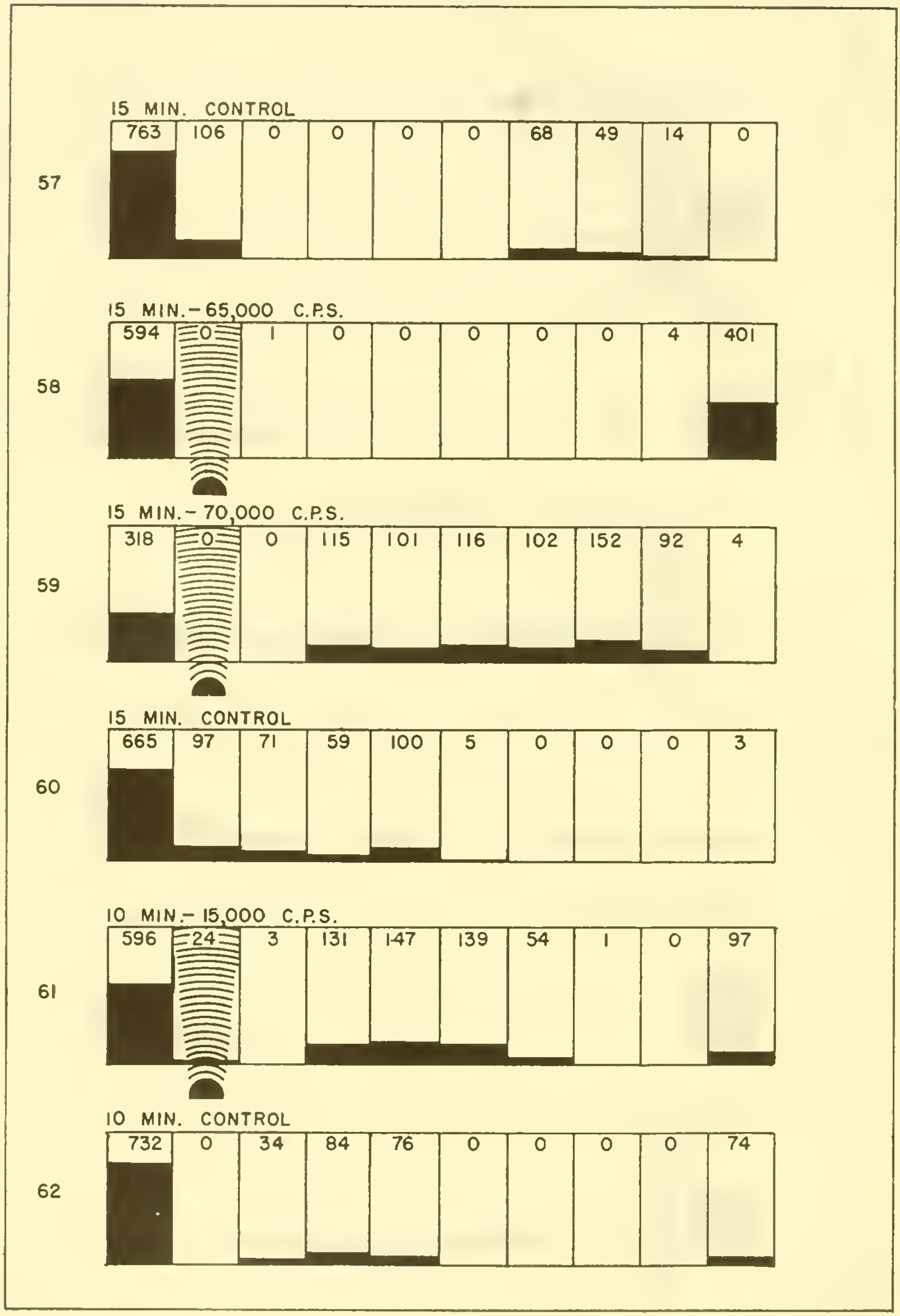


Figure 18. Distribution of fish in pens, experiments 57-62. All experiments started with 1,000 fish in pen No. 1 (far left). In controls, gates between pens lefted for indicated period, then lowered. Tests same, except sounds of indicated durations and frequencies (cycles per second) applied at indicated location while gates up. Numbers and dark bars show distribution of fish after gates lowered.

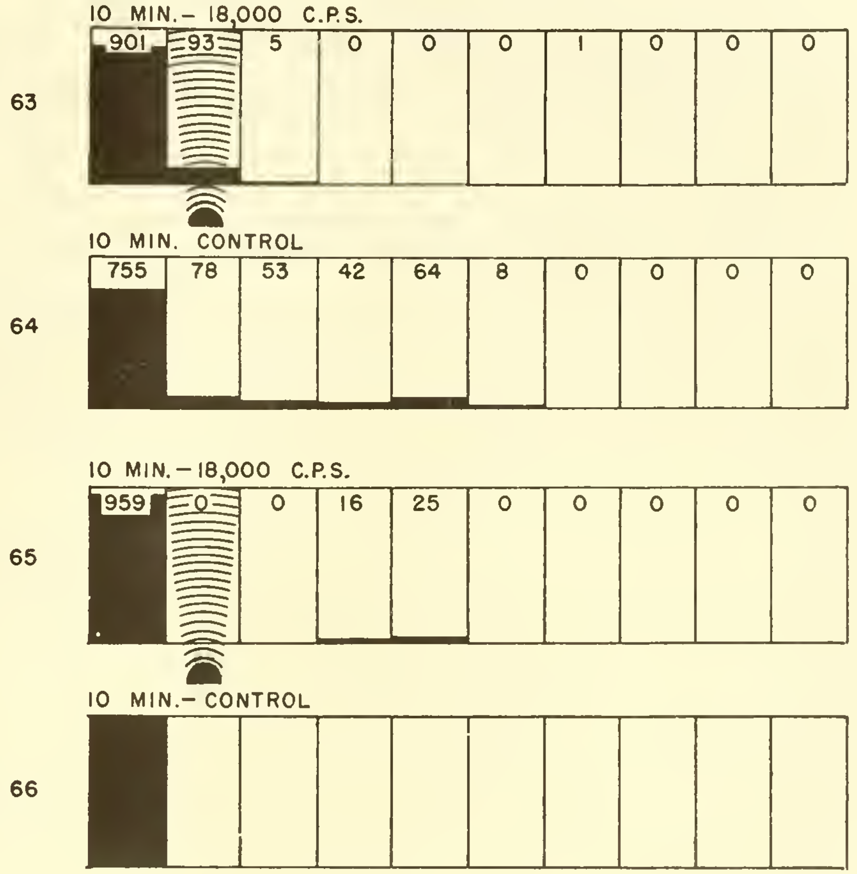


Figure 19. Distribution of fish in pens, experiments 63-66. All experiments started with 1,000 fish in pen No. 1 (far left). In controls, gates between pens lifted for indicated period, then lowered. Tests same, except sounds of indicated durations and frequencies (cycles per second) applied at indicated location while gates up. Numbers and dark bars show distribution of fish after gates lowered.

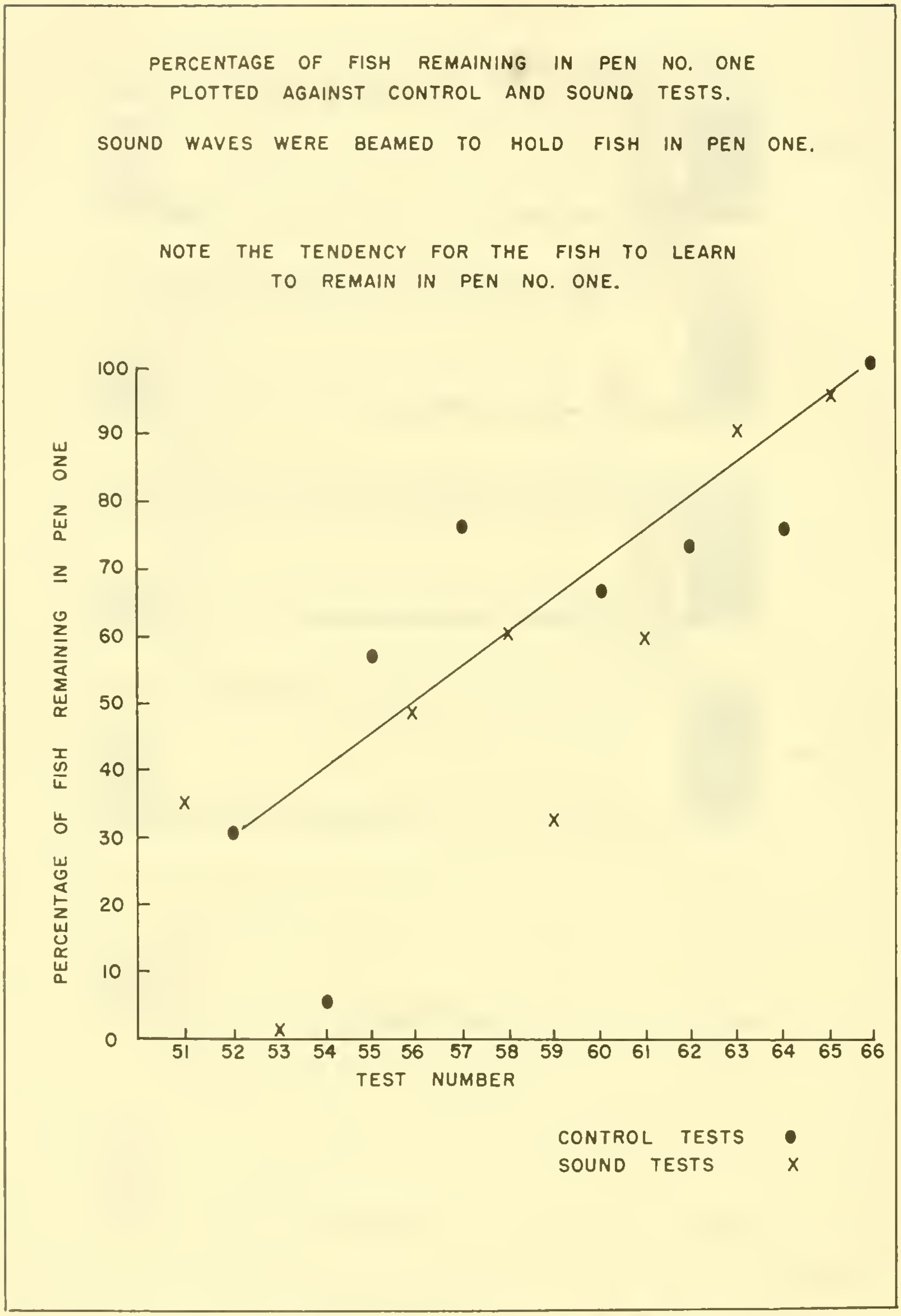


Figure 20. Effect of conditioning on experimental fish.

fundamental frequency made it difficult to keep the wave analyzer lined up on any harmonic long enough to get accurate readings. These levels were very much dependent on the standing wave pattern in the pond.

The optimism of those who hoped to find something that would "work" in guiding fish was never greater than on the day of the first trial of the equipment. The U. S. Navy fire department provided a fire truck to pump a sufficient stream of water to operate the wampus in a concrete torpedo testing tank. The noise produced in the result of the emission of interrupted jets of "slugs" of water and air being expelled from the sound head into the surrounding water as shown in Figure 21. The general effect at close range is rather awesome. The noise escaping from the surface might be compared to that produced by a medium size air cooled airplane engine and propeller running full speed at an equal distance away. The sound waves set up in the water of the torpedo tank were sufficiently strong to vibrate the surrounding concrete under foot. The observers felt peculiar prickling sensations of the skin and hair follicles when hands were placed in the water approximately six feet from the sound source. A slight nausea was experienced by a few.

For the first exploratory tests at Leetown, 1,000 rainbow trout 10 to 12 inches in total length were placed in the counting structure, 100 fish to a section, as in previous tests. The wampus was run out on the trolley to a position 100 feet from the fish in the counting structure, and 1.5 feet below the surface of the pond. The exploratory test of 10 minutes duration brought no observable reaction from the trout. Their distribution within the structure remained approximately the same. The level of sound intensity at 100 feet was measured and determined to be 4 microvolts or 12 db above 1 dyne/cm^2. Several hundred 2-inch brown trout fingerlings in a live box were unaffected or indifferent.

Having determined that the trout showed no reaction to the wampus at a distance of 100 feet, the head was moved to a point 30 feet from the fish in the first section. When the sound at that distance proved ineffective, the wampus was placed in its final position for the systematic trials; approximately 8 feet from the fish, and 1.5 feet below the surface. At no time, however, did the wampus noise drive the trout entirely from section no. 1 in a manner convincing enough to describe as a scare. Diagramatic results of the tests with this equipment are shown in Figures 23-27.

For two exploratory trials the wampus was taken to a midpoint in the counting structure and suspended in section no. 4. Operating at full power or capacity (water 150 pounds pressure, air 100 pounds pressure), the combination of visual, audible and mechanical stimuli served to drive the trout from sections 4 and 5 into sections 3 and 6 (determined by count). All the trout in sections 3 and 2 as well as those in 6 and 7 turned to head into the current from the sound head.

Figure 21. The "wampus" in operation.

Figure 22. The water pump and air compressor in position to operate the "wampus".

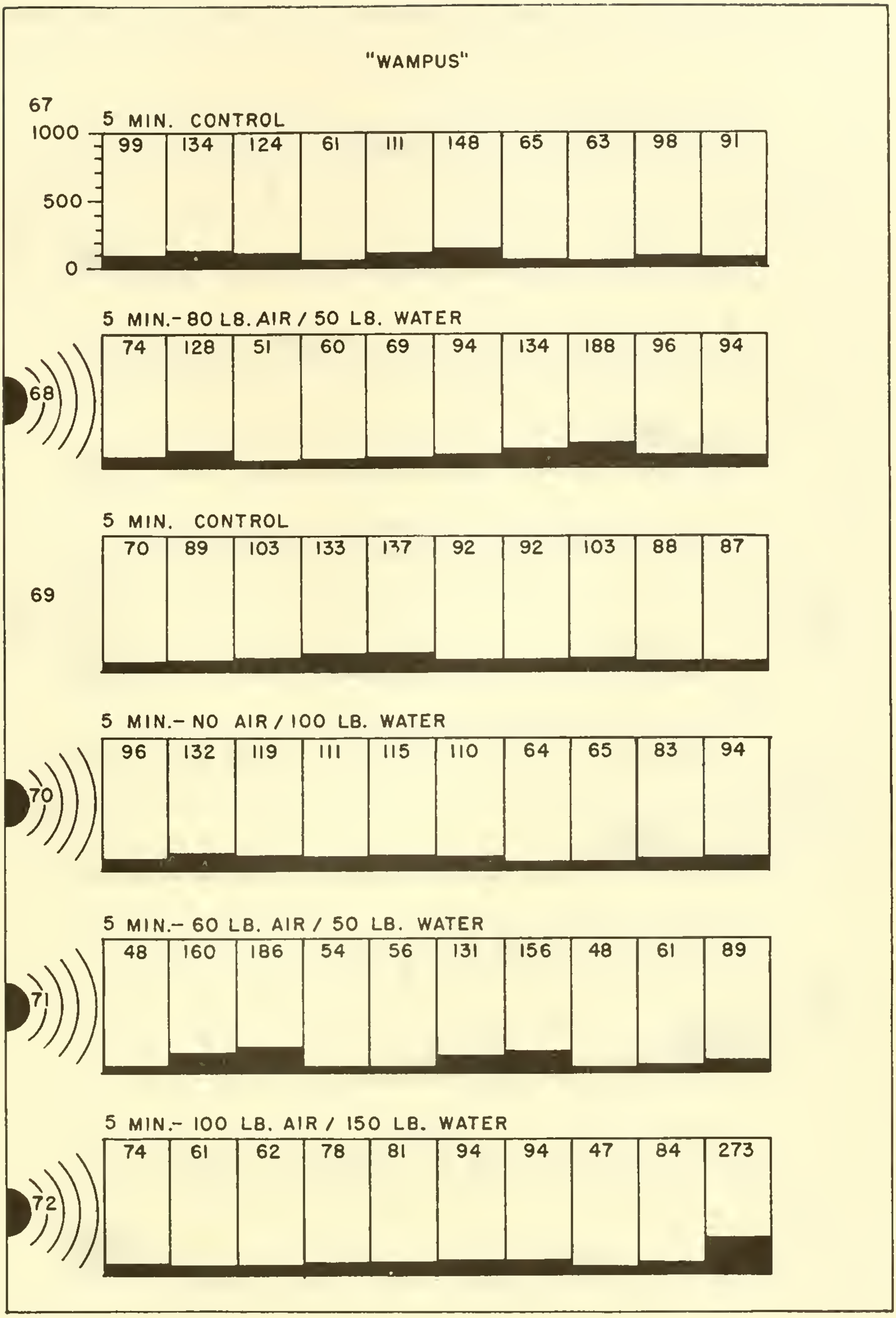


Figure 23. Distribution of fish in pens, experiments 67-72. All experiments started with 100 fish in each pen. In controls, gates between pens lifted for indicated period, then lowered. Tests same, except sounds under indicated operating conditions applied for indicated time at indicated location. Numbers and dark bars show distribution of fish after gates lowered.

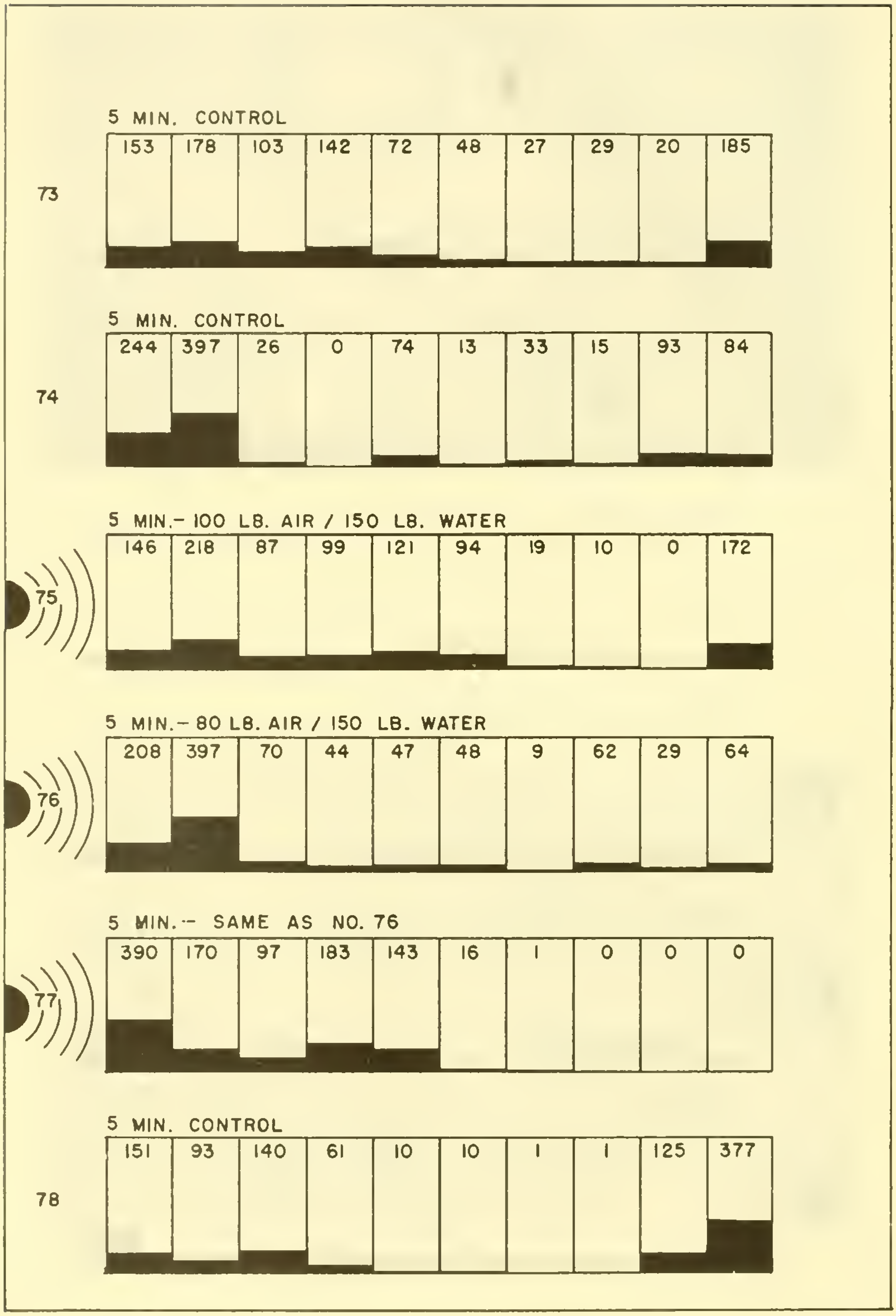


Figure 24. Distribution of fish in pens, experiments 73-78. All experiments started with 100 fish in each pen. In controls, gates between pens lifted for indicated period, then lowered. Tests same, except sounds under indicated operating conditions applied for indicated time at indicated location. Numbers and dark bars show distribution of fish after gates lowered.

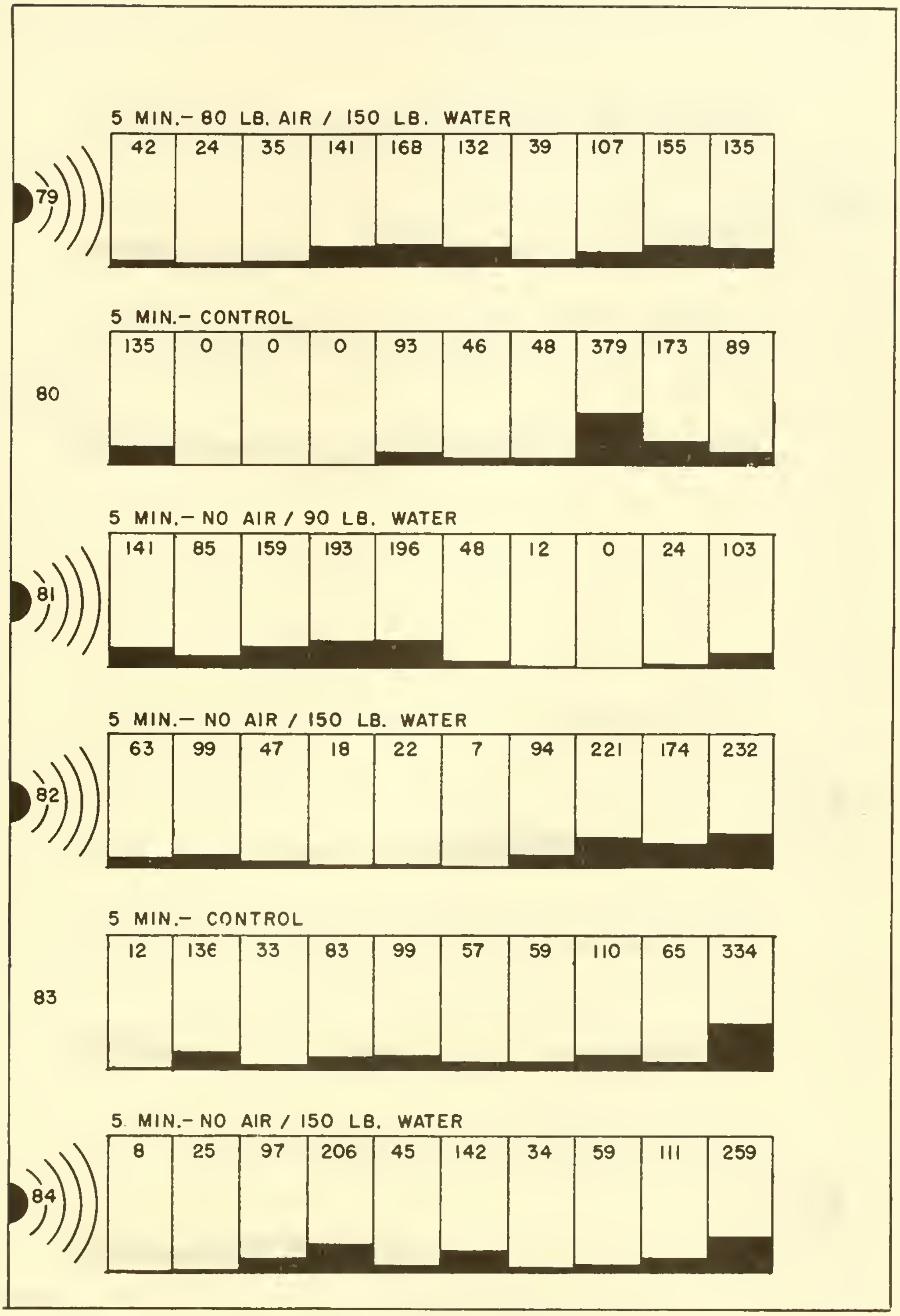


Figure 25. Distribution of fish in pens, experiments 79-84. All experiments started with 100 fish in each pen. In controls, gates between pens lifted for indicated period, then lowered. Tests same, except sounds under indicated operating conditions applied for indicated time at indicated location. Numbers and dark bars show distribution of fish after gates lowered.

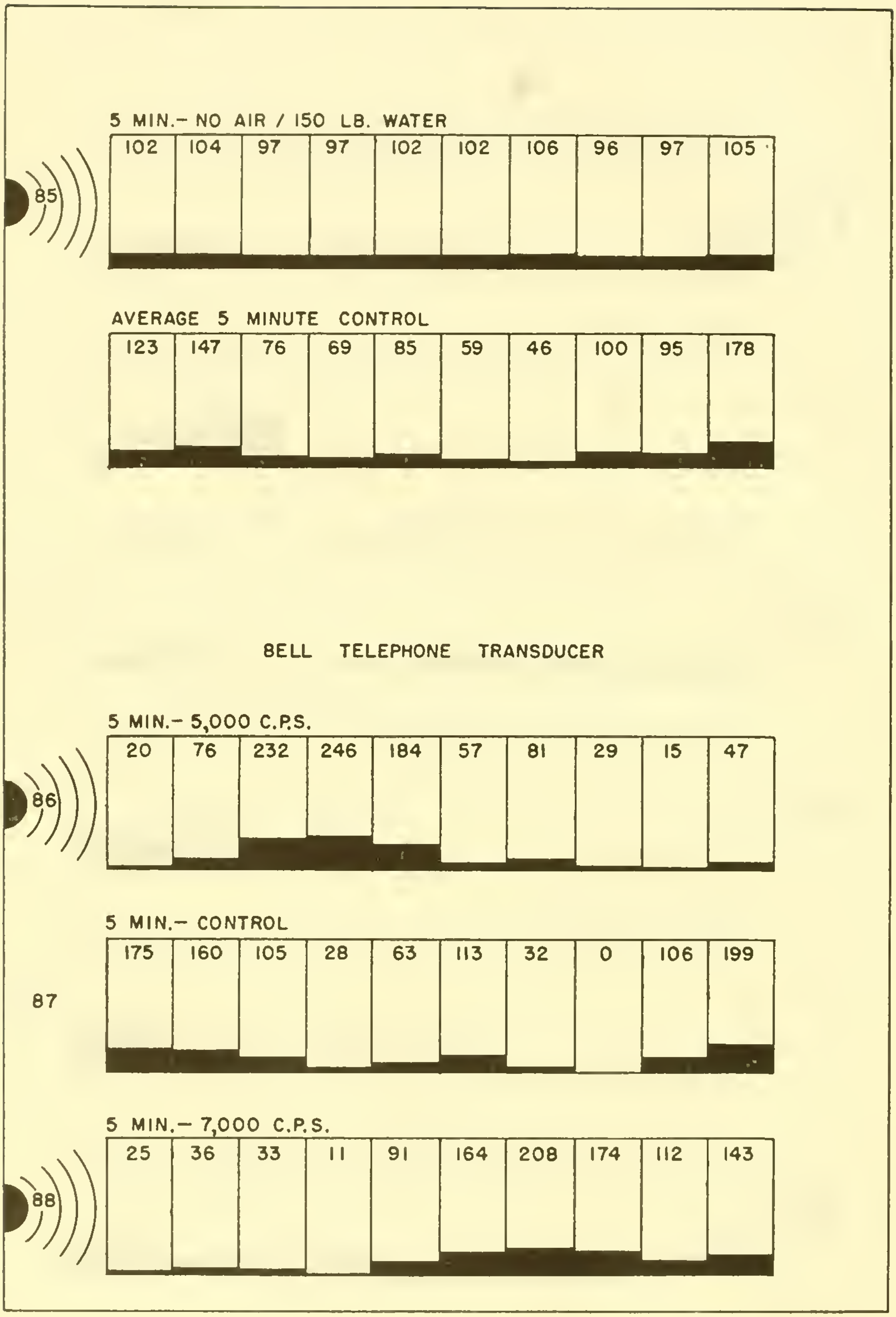


Figure 26. Distribution of fish in pens, experiments 85-88. All experiments started with 100 fish in each pen. In controls, gates between pens lifted for indicated period, then lowered. Tests same, except sounds under indicated operating conditions or at indicated frequencies (cycles per second) applied for indicated time at indicated location. Numbers and dark bars show distribution of fish after gates lowered.

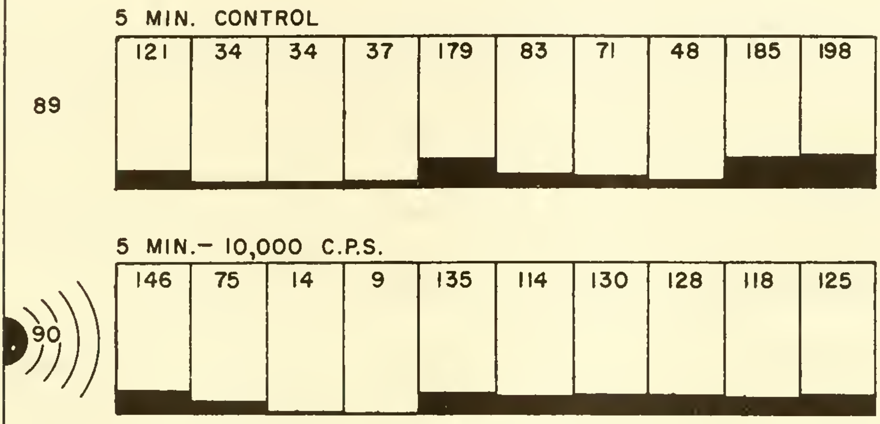


Figure 27. Distribution of fish in pens, experiments 89 and 90. Both experiments started with 100 fish in each pen. In control, gates between pens lifted for 5 minutes, then lowered. Test same, except sound of 10,000 cycles per second applied for 5 minutes at indicated location. Numbers and dark bars show distribution of fish after gates lowered.

This combination of stimuli, although producing the desired end result, might not be practical to use in rivers of large size and high turbidity. A test of this type might be simulated by using a submerged fire hose to force the fish into one or the other extremes of a pond.

For all other trials the wampus was placed where the visual and mechanical stimuli were minimized or absent. The powerful jets from the turbine were directed so that they did not impinge upon the structure or the fish. Upon one occasion, the transducer was inadvertently shifted so that a stream of turbulent water was directed into section no. 1. The trout immediately oriented themselves in an upstream fashion. At least one fish dashed into the jet and flipped at the surface as though feeding upon particles carried by the current. The majority remained at a distance of approximately 12 feet in a normal schooling pattern.

Small turtles, frogs, toads, snails and assorted aquatic insects were kept in live boxes during the trials. The pond was heavily populated with frogs and snails at all times. None of the organisms appeared to notice the sound. Even when the live box containing them was placed within 8 inches of the wampus (above the jets) they made no struggle or attempt to avoid the sound. Some of the small brown trout became quiescent when their cage was placed in close proximity to the noise, and remained on the bottom resting partially on their sides or on their fins as though exhausted. When they were removed, they resumed their normal swimming movements and appeared unaffected. All test animals, especially the fish, were carefully watched for injuries and abnormalities, but none appeared.

Calibrations, or measurements of the sound field intensity were made using standard hydrophones (Barcroft, Q-4, No. 29). The receiver was suspended near the mid-point of each section or compartment to give the readings shown in Tables 1 to 3.

Without air, the wampus seemed to produce a noise of greater intensity as judged from the hydrophone readings. When the air to the sound head was cut off, the sound escaping from the water changed from a throaty roar to a metallic hammering. This difference, and the measurement of it, is the result of a change from a loudness level to an intensity level - the difference between the boom of a cannon and the crack of a rifle. The wampus trials were then discontinued.

Again, contingency tests between sound trials and controls showed highly significant differ nces of distributions of fishes within the trough. No indication, however, that sound caused the differences was evident.

Table 1.--Sound field intensity produced by "Wampus" at 100 pounds air pressure and 60 pounds of water pressure.

Section No.	Distance from Wampus in feet	Decibels	Microvolt[1/]
END	8	50	300
1	13	41	110
2	23	35	56
3	33	29	28
4	43	27	23
5	53	20	10
6	63	18	8
7	73	17	7
8	83	15	5.6
9	93	13	4.5
10	103	12	4

1/ A convenient way to express the output of a hydrophone in terms of the acoustic input is by stating the number of microvolts response per dyne per square centimater. Hydrophones are constructed so that the sensitivity thus expressed is independent of the power input and the frequency of the sound.

Table 2.--Sound field intensity produced by "Wampus" at 150 pounds water and 80 pounds air.

Section No.	Distance from Wampus in feet	Decibels	Microvolts
END	8	52	400
1	13	41	110
2	23	33	33
3	33	28	25
4	43	24	16
5	53	20	10
6	63	14	5
7	73	12	4
8	83	12	4
9	93	8	2.5
10	103	7	2.2

Table 3.--Sound field intensity produced by "Wampus" at 90 pounds water and no air.

Section No.	Distance from Wampus in feet	Decibels	Microvolts
END	8	67	2,000
1	13	54	500
2	23	40	100
3	33	39	90
4	43	35	56
5	53	31	35
6	63	24	15
7	73	24	15
8	83	25	17
9	93	24	15
10	103	17	7

ELECTRO-MAGNETIC TRANSDUCER

In order to fill in an untested part of the range at the lower frequencies, the Bell Telephone manufactured transducer (1K-2) shown in Figure 28 was set up in the pond at Leetown. The sound frequencies it was capable of producing (200 to 10,000 cps) overlapped the range of the electro-magnetic water hammer tested in 1947 (67 to 3,000 cps.).

The familiar hum of the sine curve wave of sound could be heard by everyone, up to about 9,000 cps. Above that frequency the sound escaping from the water was not audible to most listeners due to the lack of intensity. The trout did not respond to any sound frequency within the range of the Bell transducer. The tests were carried out in conformity with previous runs with other equipment and the results are shown in Figures 26 and 27. The instrument was suspended at a distance of 2 feet from the fish in section no. 1, and with the diaphragm 2 feet below the surface. Contingency tests again showed significant differences in distributions of fish of sound tests and controls, but, as before, there is nothing to indicate that the sound stimulus was responsible.

Except for casual tests with detonating caps, the sound work with the U. S. Navy was concluded. In a test of the effect of small explosions upon trout, sumberged fulminate of mercury detonators were touched off in succession at regular intervals of one to two seconds. As before, the fish "started" at only the first blast and did not swim away as the explosions continued.

SUMMARY AND CONCLUSIONS

1. Guiding fishes by means of sound generating equipment installed at dams and diversions would be desirable because of its freedom from physical floating equipment and ease of maintenance.

2. Fishes have been conditioned to respond to sound as a signal for food, but the evidence of attraction to sound alone is rare and questionable.

3. Certain fishes may be frightened momentarily by any noise but adjust to disregard it (become conditioned) almost instantaneously.

4. The four sound propagating pieces of equipment tested at Leetown, West Virginia are described as follows:

(a) "Water Hammer" - electro-magnetic transducer producing sine curve sound ranging from 67 to 3,000 cycles per second.

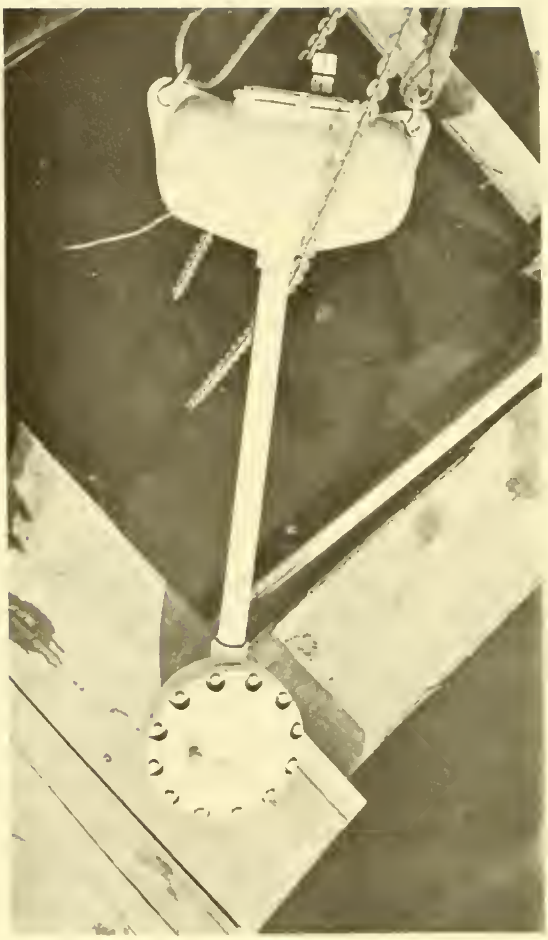


Figure 28. The Bell Telephone transducer, frequency 200 c.p.s. to 10,000 c.p.s.

(b) Piezo-electric type crystal transducer producing sine curve sound ranging from 12,000 to 70,000 cycles per second.

(c) "Wampus" - hydraulic (underwater) turbine noisemaker, sound frequency audible, disclosure of frequency charcteristics not permitted, but of low frequency. (U. S. Navy classified equipment)

(d) Electro-magnetic sound projector, 200 cps to 10,000 cps sine curve sound. Bell Telephone 1K-2.

5. The hatchery pond in which the tests were conducted was approximately 60 feet wide and 450 feet long. The bottom and sides were of marl mud, a carbonate which absorbs sound waves very well.

6. In the tests rainbow trout 4 to 12 inches long were used, as well as a few 14 to 24 inches in length, and several hundred brown trout approximately 1-1/2 inches long. Turtles, frogs, toads, molluscs, and aquatic insects were kept in live boxes.

7. In order to measure the reaction of the fish to the various sound waves a special structure was built in the pond. This structure was 100 feet long, 3 feet wide, and 3 feet deep, divided into 10 sections by sliding gates.

8. A typical test was as follows: One hundred fish were placed in each section (total 1,000). The transducer (previously adjusted to a given frequency), located at one end of the structure, was turned on simultaneously with the lifting of all gates. After a given length of time the gates were lowered and the sound turned off. The fish in each compartment were then counted to determine their distribution in the structure. From this (and from observations made during the test) the reactions of the fish to a given sound could be determined.

9. After the initial "start" the fish showed no response to continued sound waves of low frequency.

10. There appeared to be no response, either initial or otherwise, to the high frequency sounds.

11. The "wampus" or underwater turbine produced a sound intensity great enough to burst one's eardrums if he should put his head under water. Sound produced by this apparatus caused the fish in section no. 1 to "start". The reaction was only momentary and numerous tests indicated that this equipment had no value for guiding fish.

12. Successive, small, underwater explosions failed to cause trout to move away from their vicinity.

13. A total of 90 planned tests were made in addition to a number of exploratory and informal tests. Contingency tests applied to the data show the resulting distributions of control and sound tests to be significantly different. However, at no time did a sound frequency or intensity influence the action of the trout enough to be utilized in guiding young salmon into safe passages around dams and diversions.

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