Proceedings of the Montana Academy of Sciences 19:84-90.

Relationship of Fish Size and Water Velocity to the Fish Guiding Effectiveness of a Single-Row Electrode Array

H. William Newman and Alan B. Groves

Providing safe passage for fingerlings around obstacles is a major undertaking of fishery, reclamation, power, and flood control agencies in the Pacific Coast region. Investigations into this problem have included attempts to utilize screens, louvers, sound, pumps and electricity. Of these means, perhaps the one creating the most interest has been the use of electricity for guiding fingerlings.

The U. S. Fish and Wildlife Service began a systematic program in 1951 to develop electrical fish screens. This program, begun as laboratory studies at the Seattle Biological Laboratory (formerly known as Pacific Salmon Investigations), is now undergoing large-scale field trials at Lake Tapps in Pierce County, Washington. Laboratory tests have outlined the factors which contribute to mortality (3), conditions which are best for electrical control of swimming, types of electrodes and array orientation (9), duration and frequency of pulsed d.c. (8), and orientation of the electrical field with respect to water flow.

The purpose of this report is to present data of an experiment designed to test the relationship of both fish size and water velocity to the fish-guiding effectiveness of a single-row electrode array. Since we realized early that fish of different sizes are affected to a different degree by an electrical field, we had planned to experiment with fish size as a variable. The results of field trials in the spring of 1955 indicated that certain unknown factors at times reduced guiding effectiveness. Laboratory explorations into the problem indicated that water velocity might be a significant factor. Therefore, water velocity and fish size were examined simultaneously in August of 1955.

Materials and Methods

The facilities (Fig. 1) used for these tests imposed certain limitations on the attainable water velocities, which ranged from 0.28 feet per second to 0.56 feet per second. At the upstream end of the experimental area a screened baffle restricted the fish and spread the water flow across the entire area. At the downstream end of the experimental area two raised gates could be released remotely to hold the fish in the trap areas. The downstream ends of the traps were screened just ahead of the pump intakes. The electrical array was placed diagonally across the experimental area at an angle of 40 degrees to the water flow with the lower end at the junction of the two gates. Fish were introduced from a pail suspended from a fixed point near the upstream baffle.

We apportioned the width of the experimental area with the trap gates at the lower end of the array to represent guiding and nonguiding sections. The guiding portion was one third while the nonguiding portion was two thirds of the total width. This division combined with positioning of the fish release point on the array side insured that as small a number of fish as possible would pass into the diversion channel due to chance alone when the array was not electrified. We felt that a chance distribution of 50-50 is not realistic when establishing criteria for guiding fish in streams.

Three water velocities were used: 0.28 feet per second; 0.45 feet per second; and 0.56 feet per second.

During the experiment the water temperature fluctuated, with daily weather changes, between 62 and 67^{o} F. The depth of the running water was approximately 12 inches. The electrical resistance of the water was maintained at 3,900 ohms per inch cube by the addition of fresh water or table salt.

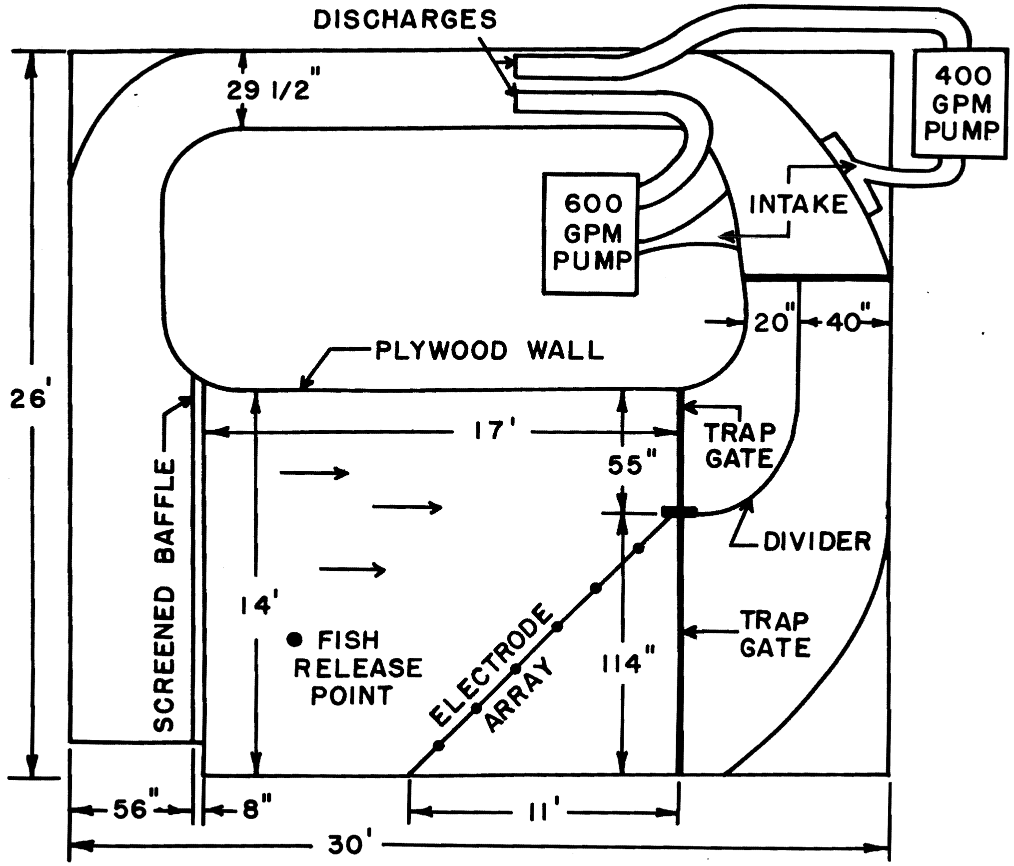

Figure 1.--Plan of experimental tank. Diverted fish are captured in narrow channel trap, non-diverted fish in wide channel trap.

With the same electrical generating and control equipment which was used in the preceding test 1/, we established the following electrical conditions: Direct current was pulsed in "square waves" at a frequency of three pulses per second and a duration of 30 milliseconds; the pulsed current was applied at a potential of 210 volts across electrode spacings of 30 inches; at each pulse the entire array in the water was energized and at each pulse the polarity of each electrode was reversed.

Silver salmon fingerlings (Oncorhynchus kisutch) of three distinct sizes were obtained from hatcheries of the Washington State Department of Fisheries. We held the largest fish from the brood of the previous year (Issaquah hatchery) but fed them a reduced diet to prevent too great a growth. The next size came from the brood of the current year, also from the hatchery at Issaquah, and the third group from the brood of the current year from the Toutle River hatchery where low water temperature depressed the growth rate. Thus, these size ranges (or length) were available: 86-120 millimeter total length, mean of 105 millimeters; 70-90 millimeter total length, mean of 80 millimeters; 40-74 millimeter total length, mean of 59 millimeters.

Every effort was made to reduce extraneous stimulation of the fish before releasing them in the experimental tank. The fish required for a day's tests were left to settle over night in separate compartments of light-proofed holding troughs adjacent to the experimental tank. The tests were conducted in the same manner as those described by Newman.

The experiment was designed as a block of nine treatments repeated on nine days. "Power off" controls were not required because each combination of variables was repeated each day at a different time. Fifty fish were released in each trial. The total number of fish recovered from the traps was 3,112; these constituted the sample for analysis. Fish which remained above the array were removed after each trial but were not considered as part of the sample. The number of fish captured in the narrow channel was related as a percentage to the total number caught in both traps.

Results

The experimental design and the data of each day with preliminary tables of statistical treatment are not included in this report. However, they are available as a supplement in processed form from the authors.

The numbers of fish recovered in the narrow channel for each fish size and for different water velocities and the total numbers of fish recovered downstream in each case are shown in Table 1.

Table 1. Guiding influence under different velocities and different fish sizes.

	Total Downstream	Guided		Total Downstream	Guided
"Small fish"	794	322	"Low velocity"	885	378
"Medium fish"	1,072	423	"Medium velocity"	1,056	393
"Large fish"	1,066	445	"High velocity"	1,171	418

The mean data, grouped by water velocities and fish sizes, are shown in Table 2 and give a comparison of the effects of the velocities and fish sizes. These data were analysed for differences between water velocities, days, and fish sizes

1/ Newman, H. William, MS. "Effect of field polarity in guiding salmon fingerlings by electricity."

Table 2. Mean guiding effectiveness by classification with respect to fish size and water velocity. Percentages are based on total numbers for each condition.

Average Fish Size	Water Velocity 0.28 Ft./Sec.	0.45 Ft./Sec.	0.56 Ft./Sec.	Overall Mean
59 mm.	36.3%	34.5%	29.4%	32.5%
80 mm.	49.3	35.9	35.6	39.4
105 mm.	42.0	41.3	41.9	41.7
Overall Mean	42.7%	37.2%	35.7%	

as shown in Table 3.

Table 3. Analysis of variance.

Source	Sum of squares	Degrees of freedom	Mean square	F
Fish size	369.47	2	184.735	6.252**
Water velocity	260.29	2	130.145	4.404*
Interaction	245.47	4	61.368	2.227
Days	300.44	8	37.555	1.271
Error	1,763.95	64	27.562	
Total	2,939.62	80		

** Highly significant
* Significant

In tests previously completed, Newman (op. cit.) used fish equivalent to the large size (84-129 mm.) and a water velocity close to the high velocity (0.50 feet per second). With an alternated polarity condition of energizing the array a mean guiding effectiveness of 42.8 percent was obtained; the random distribution during "power off" was 15.8 percent. This random distribution cannot be used here to reveal the true effect of the electrical barrier, but it serves as a relative base and suggests that about one third of the guided figure is due to random movement.

Discussion and Conclusions

Fish Size

Fish size may vary the effectiveness of an electrical field because of two conditions. First, fish size has a direct relationship to the electrical stimulus received. Second, fish of increasingly larger sizes are able to maintain position better at a given velocity.

Various experimenters have noted that the amount of electric current received (or the magnitude of the stimulus) is effected by the size of the fish. Groody, Loukashkin and Grant (6) say, "The current density required to produce directional swimming appeared to vary inversely with the size of the fish tested." Bary (1) graphically shows the relationships of fish size, electrical potential, and minimum response or electrotaxis.

In the instances cited above, fish size has a direct relationship to the effectiveness of an electric field. This agrees with our data in which there is an increase in effectiveness at each velocity of water due to increase in fish size (Table 2). This increase in effectiveness is highly significant for all velocities combined (Table 3). The linear effect (over the range tested here) of fish size on guiding effectiveness is shown in Figure 2.

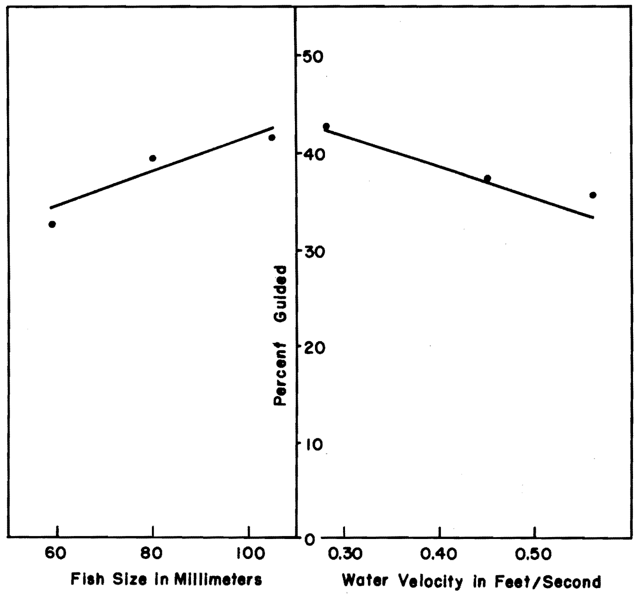

Fig. 2. The effect of fish size and water velocity on the guiding effectiveness of an electrode array.

Larger fish, better able to swim against the current, can stay out of the electrical field, gradually working toward the bypass, and are then "guided" fish. Some smaller fish, unable to swim as well, drop downstream into the electrical field and pass through it, becoming "non-guided" fish. Fields, Adkins and Finger (5), reporting on the swimming ability of immature silver salmon, say that a difference in numbers swept out of a flume was due to size differences, the smaller fish being swept out sooner than larger fish.

Studies at the Central Valley Project in California included some tests of swimming ability of young salmon and striped bass. A "velocity endurance curve" was shown for these fish, demonstrating a linear increase in swimming speed with increase in standard length of the fish (10).

Water Velocity

Our preliminary laboratory trials with fry indicated that water velocity contributed to a lack of success in one phase of a field trial. The effect of water velocity has been noted by others. Holmes (7) refers to the critical nature of water velocity in his review of electric fish screens. Although he apparently was not able to obtain observations over a series of velocities, he quotes California Fish and Game representatives as stating that 0.5 foot per second is to be considered a maximum at which electricity can be used for screening downstream migrants. Brett, et al. (2), after measuring cruising speed of young sockeye and silver salmon, state in regard to the actual swimming rate, ". . . it is apparent that if approach velocities above dams exceed 1.0 ft. per sec. (30 cm./sec.) a real problem for safe-guarding underyearlings is presented."

The data of the present tests show the decrease in guiding effectiveness as the velocity increases (Table 2). It is apparent also that an increase in velocity caused a larger number of fish to move downstream, increasing the sample size. As larger numbers moved downstream in response to increased velocity, a greater proportion passed through the array. The decrease in effectiveness is significant and linear for all fish sizes combined (Table 3). The inverse effect of velocity is compared in Figure 2 with the effect of fish size.

In guiding tests using a light barrier at velocities from 0.35 to 3.336 feet per second, Fields, et al. (4) found an increasing number in the unguided portion as the velocity increased.

The findings made here with a limited range of velocities, the results of tests by Fields (5), and the remarks of Holmes (7) and of Brett (2) should not signify that guiding is impossible in streams of velocities higher than 0.5 to one foot per second. Rather it is suggested that it may be found profitable to maintain some control over velocity at sites chosen for installation of electrical (and other types of) guiding arrays.

Summary

The relationship of fish size and water velocity to the fish-guiding effectiveness of a single-row electrode array was tested under controlled laboratory conditions.

Three sizes of fingerling salmon were used: 59 mm, 80 mm and 105 mm mean total length. Also, three water velocities were used: 0.28 feet per second, 0.45 feet per second and 0.56 feet per second. Significant differences were found associated with each change in fish size and water velocity. Guiding effectiveness increased as the size of fish increased but decreased as the water velocity was increased. The relationship of each variable to guiding effectiveness was linear.

Acknowledgments

The stock of silver salmon fingerlings and the necessary fish food were provided by the Washington State Department of Fisheries through the cooperation of the Supervisor of Hatcheries, Mr. C. E. Ellis, and the personnel of the hatcheries at Issaquah and Toutle River.

Literature Cited

1. Bary, B. McK. 1956. The effect of electric fields on marine fishes. Scottish Home Department, Marine Research. No. 1. 32 pp.
2. Brett, J. R., M. Hollands and D. F. Alderdice. 1958. The effect of temperature on the cruising speed of young sockeye and coho salmon. J. Fish. Res. Bd. Canada, 15:587-605.
3. Collins, Gerald B., Charles D. Volz and Parker S. Trefethen. 1954. Mortality of salmon fingerlings exposed to pulsating direct current. U. S. Fish and Wildl. Serv., Fish. Bull. No. 92, 56:61-81.
4. Fields, P. E., and others. 1954. Factors influencing the efficiency of light barriers in the guidance of young salmonidae. University of Washington, School of Fisheries, Technical Report No. 8. 25 pp. Ozalid process.
5. Fields, Paul E., Ronald J. Adkins, and Gary L. Finger. 1954. The swimming ability of immature silver salmon (Oncorhynchus kisutch) measured in an experimental flume. University of Washington, School of Fisheries, Technical Report No. 9. 22 pp. Ozalid process.

6. Groody, Tom, Anatole Loukashkin and Norman Grant. 1952. A preliminary report on the behavior of the Pacific sardine (Sardinops caerulea) in an electrical field. Proc. Cal. Acad. of Sci., fourth series, 27:311-323.
7. Holmes, Harlan B. 1948. History, development, and problems of electric fish screen. U. S. Fish and Wildl. Serv., Spec. Sci. Rept. No. 53. 62 pp.
8. Raymond, Howard L. 1956. Effect of pulse frequency and duration in guiding salmon fingerlings by electricity. U. S. Fish and Wildl. Serv., Res. Rept. No. 43. 19 pp.
9. Trefethen, Parker S. 1955. Exploratory experiments in guiding salmon fingerlings by a narrow d.c. electric field. U. S. Fish and Wildl. Serv., Spec. Sci. Rept. No. 158. 42 pp.
10. U. S. Bureau of Reclamation and U. S. Fish and Wildlife Service. 1957. Fish protection at the Tracy pumping plant, Central Valley Project, California: development of a fish salvage facility. U. S. Dept. of the Interior: Bureau of Reclamation, Region 2, Sacramento, California and Fish and Wildlife Service, Region 1, Portland, Oregon. 96 pp. Processed.

U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Biological Laboratory, 2725 Montlake Boulevard, Seattle 2, Washington.

Proceedings of the Montana Academy of Sciences 19:91.

Preliminary Notes on the Vertebrate Faunas of the Montana Alpine

Robert S. Hoffman and Richard D. Taber

Abstract

Extensive work during the summer, 1958, indicates that, of the areas surveyed, the Beartooth Plateau has the most diverse fauna, including the following species: birds - Lagopus leucurus, Anthus spinoletta, Eremophila alpestris, Salpinctes obsoletus, Leucosticte t. atrata, Zonotrichia leucophrys; mammals - Sorex vagrans, S. nanus, Marmota flaviventris, Citellus lateralis, Eutamias minimus, Thomys talpoides, Peromyscus maniculatus, Phenacomys intermedius, Clethrionomys gapperi, Microtus montanus, M. richardsoni, Ochotona princeps, Lepus townsendi. In other alpine areas one or more of these species are lacking. In Glacier Park, Sorex nanus, Clethrionomys, Microtus montanus, and Lepus townsendi are not known to occur in the alpine, and Marmota flaviventris is replaced by M. caligata. In the Big Belt and Crazy Mountains, Lagopus, Sorex nanus, Microtus richardsoni, and Lepus townsendi are apparently absent; in the Little Belts the absent species are Lagopus, Sorex vagrans, Citellus lateralis, and Microtus richardsoni. The most depauperate alpine fauna studied was on the Big Snowy Mountains, where Lagopus, Eremophila, Leucosticte, Sorex sp., Marmota sp., Citellus lateralis, Phenacomys, Microtus sp., and Ochotona were not found. In the Big and Little Belts, Crazies and Big Snowies, Eutamias minimus is replaced by E. amoenus. Only in the Little Belts and Big Snowies was Microtus longicaudus taken in the alpine.

Particularly noteworthy is a series of four Leucosticte taken in the Little Belts which are intermediate between L. atrata and L. tephrocotis, and the capture of two Sorex nanus on the Beartooth and one in the Little Belts. The latter is the first record for Montana.

This work was supported in part by National Science Foundation Grant No. 5174, and by the Montana Cooperative Wildlife Research Unit.

Department of Zoology and School of Forestry, Montana State University, Missoula, Montana.