319

EFFECT OF FIELD POLARITY IN GUIDING SALMON FINGERLINGS BY ELECTRICITY

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EXPLANATORY NOTE

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EFFECT OF FIELD POLARITY IN GUIDING SALMON FINGERLINGS BY ELECTRICITY

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ABSTRACT

The relation of field polarity to fish guiding effectiveness was tested under controlled laboratory conditions by using a single-row electrode array sequentially energized so that: (1) positive polarity was always toward the upstream end, (2) positive polarity was always toward the downstream end, and (3) polarity alternated to cancel out polarity orientation. No difference in effectiveness was found demonstrating that fish guiding was due to avoidance rather than to electrotaxis. Variability, measured as variance, decreased as sample size increased but the mean effectiveness was similar for fish release lots of 15, 50, and 100 fish each.

INTRODUCTION

The practical application of electrical guiding to the protection of downstream salmon migrants requires a large amount of basic information on the reaction of fish to electrical fields. To provide this background information the U. S. Fish and Wildlife Service has been conducting laboratory research on the lethal effects of electricity (Collins et al. 1954), the effect of electricity upon reproductive ability [1/], the relative effects of various patterns of interrupted direct current in the control of fingerling movements [2/], and the effectiveness of several types of electrical arrays in diverting salmon fingerlings (Trefethen 1955). Raymond (1956) measured the effect of pulse duration and frequency in guiding salmon fingerlings.

The initial laboratory studies, measuring the ability of a short segment of an electrical array to divert fingerlings in flowing water, were made with a narrow directional field of pulsed direct current aligned at a relatively small angle to the direction of water flow (Trefethen 1955). The field was created by two rows of electrodes connected so that the upstream electrodes were always positive. The electrotactic response of the fish to the directional field between the rows of electrodes resulted in the fish being diverted in the desired direction. Several variations of electrical arrays using this principle were investigated. One of the chief disadvantages of this type of array was its failure effectively to divert fish of different lengths. The high voltage gradients required to divert small fish were injurious to large fish, while voltage gradients safe and effective for large fish were ineffective for small fish. To overcome this

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1/ Maxfield, Galen H., and Kenneth Liscom. Manuscript in preparation. "The effect of electricity on reproductive ability of rainbow trout."

2/ Volz, Charles D. Manuscript in preparation. "Effectiveness of interrupted d.c. in the control of salmon fingerling movements."

deficiency, a third row of electrodes was added to create a zone of lower voltage gradients on the upstream side of the array to divert the large fish before they were subjected to the high voltage required to divert small fish. When placed in the field, however, the result was a rather formidable mass of electrodes that immediately raised questions of practicability for large-scale installations.

Observations of fish behavior during field experiments at Jenkins Creek in 1954 [3/] indicated that a number of fish had been successfully diverted without having entered the field between the rows of electrodes. Attention in the laboratory was therefore shifted to a different type of electrical field requiring only a single row of electrodes. In laboratory tests the single-row array proved to be as effective as those with two and three rows. However, the directional relationship of the field to the water flow was so different from that in the earlier arrays that the question was raised whether the response was still due to electrotaxis. If the reaction to the field were simply one of avoidance of a disagreeable stimulus rather than a reflex reaction to the directional properties of the field, it would allow much greater flexibility in electrode pattern and electrical circuitry. If, on the other hand, electrotaxis were involved, knowledge was required of the most desirable relation of field polarity to the direction of water flow.

The major objectives of the tests described here were to determine whether reactions of the fish are caused by avoidance or by electrotaxis, and if the latter, to determine whether an upstream or downstream field polarity orientation is more effective.

3/ Hunter, Charles J. Manuscript in preparation. "Experimental guiding of salmonids by electricity, Jenkins Creek, 1955."

MATERIALS AND METHODS

The experiments were conducted in the spring of 1955 in the tank (fig. 1) used by Raymond (1956). In the experimental area (14 by 17 feet) the depth of the running water was 12 to 13 inches. A screened baffle designed to produce uniform water flow served to keep fish from moving upstream out of the experimental area; screens also blocked the lower ends of the trap area. The traps were fitted with swing-down gates which the operator could release simultaneously. Electric pumps of 1,000 gallons per minute combined capacity created a water flow of approximately one-half foot per second.

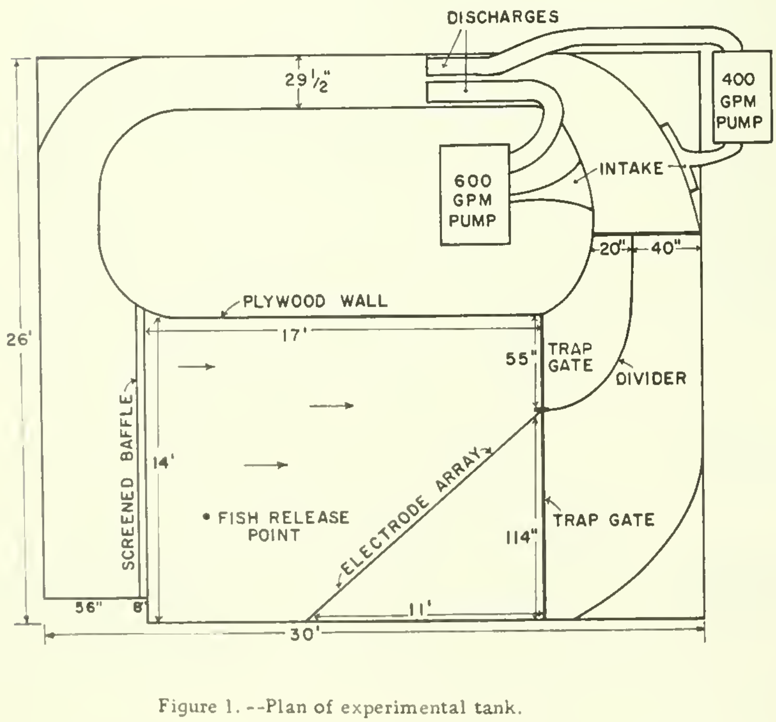

Figure 1.--Plan of experimental tank.

Although water temperatures ranged from 57° to 63° F. during the 12 days of the experiment, the daily fluctuation in temperature was less than 2° F.

The test fish were yearling silver salmon (Oncorhynchus kisutch) obtained from the Washington State Department of Fisheries hatchery at Issaquah, Washington. They ranged from 8.4 cm. to 12.9

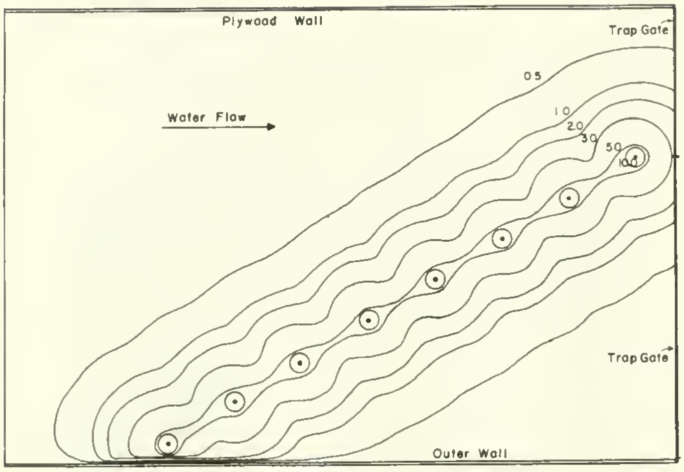

Figure 2.--Voltage gradient pattern in experimental area. Lines connecting points of equal voltage gradient (volts per inch) have been smoothed. Water temperature: 50° F. (10° C.) Water resistance: 6,300 ohms per cubic inch (16,000 ohms per cubic centimeter).

cm. in length, averaging 10.3 cm. (3 to 5 inches, average 4 inches).

In order to provide experimental continuity we used pulsed direct current, found most promising by Raymond (1956) and previous investigators. Water resistance was controlled by the addition of fresh water or table salt as required to maintain a resistance of 6300 to 7500 ohms per cubic inch. The electrical array was set at an angle of 40° to the direction of water flow, and the voltage was maintained at 210 volts across a 30-inch electrode spacing. The current, when interrupted, was pulsed at a frequency of 3 per second with a duration of 30 milliseconds--a duty cycle of 0.09. The measured voltage gradients (volts per inch) [4/] are presented in figure 2 as lines connecting points of equal voltage gradient.

All tests were conducted in as near total darkness as possible so that the fish, having little or no visual orientation, tended to move downstream to the electrical field without being crowded or forced. The fish which passed through the field were captured in the wide channel, while those which avoided the field were collected in the narrow channel. Previous observations showed that five minutes of darkness were sufficient time for the majority of the fish to move downstream; at the end of five minutes the traps were closed, the lights turned on, and the fish counted. We counted and removed those fish which had not moved down but did not consider their numbers in the guiding results. The results were measured by a comparison of the number of fish in the narrow channel with the total number of fish that moved downstream, expressed as a percentage.

EXPLORATIONS

We conducted preliminary trials in which the electrode array was energized in six different ways. This exploration was for two purposes: (1) To provide some comparison of 60-cycle alternating current with steady and pulsed direct current, a comparison not previously made here or reported elsewhere, and (2) to provide a basis for the design of another experiment involving the role of field polarity in electrical guiding. The six methods of array energizing are listed below, with a short title for each:

1.	60-cycle alternating current, 210 volts peak to peak	A.C.
2.	Continuous direct current, 210 volts	D.C.
3.	Pulsed direct current in which the polarity of the field was constant, 210-volt pulses	Pulsed D.C.
4.	Pulsed direct current with the field polarity alternated, 210-volt pulses	Alternate Polarity
5.	Pulsed direct current, electrodes sequentially energized with the positive polarity upstream	Positive Upstream
6.	Pulsed direct current, electrodes sequentially energized with the positive polarity downstream	Positive Downstream

4/ The electrode spacing and voltage gradient are expressed in English units in anticipation of practical field studies.

The short titles are used in the remainder of the text.

A.C. and Alternate Polarity are similar (fig. 3) in that electrodes are constantly reversing in polarity. A.C. and Alternate Polarity differ in cyclic rate and wave shape. D.C. and Pulsed D.C. are similar because the electrodes remained at the same polarity (fig. 3). If polarity is not of importance, these conditions may be expected to be as effective as sequentially energized arrays in which the field polarity remains constant.

In these exploratory experiments, the electrodes in the array were sequentially energized (Positive Upstream and Positive Downstream) with pulsed direct current. The current was applied to adjacent electrodes in pairs in sequence from one end of the array to the other, and after the last pair of electrodes had been energized the sequence started again with the first pair (fig. 4). The positive electrode was always in the same position relative to the negative electrode regardless of the direction in which the field moved (upstream or downstream). The direction of the movement of the field was controlled through a switching unit.

When sequential switching is used, the fish moving downstream with the water current always encounter an array in which the directional field is oriented at an angle to the direction of water flow, and if polarity of field is important, they will be more effectively guided than by other types of arrays. In arrays using A.C., D.C., Pulsed D.C., and Alternate Polarity, the direction of field is different in different areas; in effect, it is half one direction and half the other. In a sequentially energized array, the direction of the field polarity is constant.

The results of the two sets of preliminary trials are listed in table 1. These trials gave an estimate of the comparative effectiveness of the several types of energizing. Under the conditions used here,

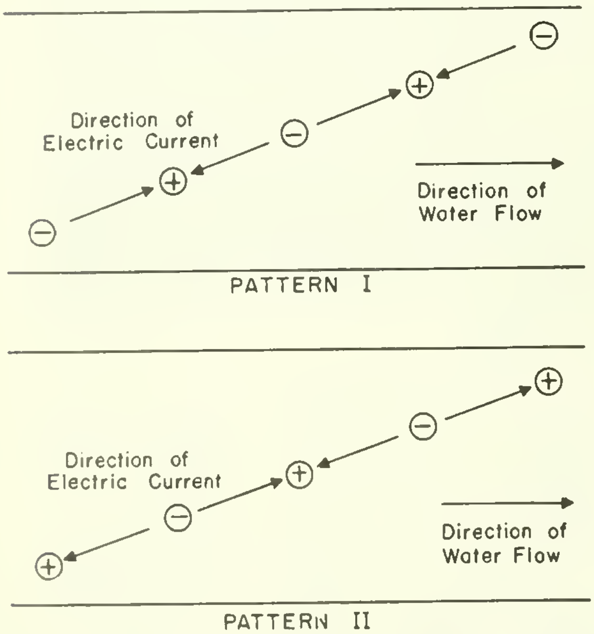

Figure 3.--Field polarity relations of a totally energized array. A.C. and Alternate Polarity changed from pattern I to pattern II continuously. D.C. and Pulsed D.C. produced either pattern I or pattern II, but not both. Circles represent electrodes in the array.

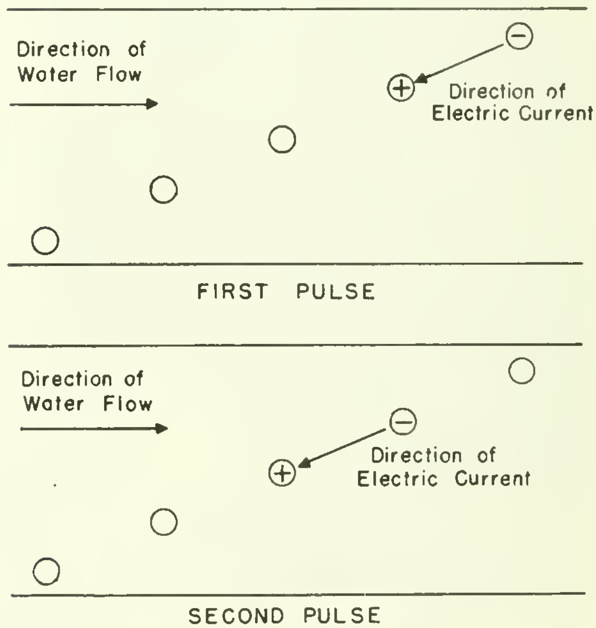

Figure 4.--Sequential energizing with the positive polarity always upstream. Only one pair of electrodes was energized with each pulse, and after the fourth pulse the first pair was energized again--direct current was pulsed in square waves; only two pulses are shown. Circles represent electrodes. When the sequential energizing was applied with the positive polarity downstream, the pulses started at the upper end of the array and were switched from pair to the lower end.

Table 1.--Exploratory tests of the guiding effectiveness of six methods of energizing an electrode array.

	Treatment percent	Control percent	Index of effectiveness [1/]	Number of fish
First set				
1. A.C.	22.2	36.2	-14.0	155
2. D.C.	42.6	19.4	23.2	187
3. Pulsed D.C.	62.9	29.4	33.5	308
4. Alternate Polarity	59.2	26.7	32.5	294
5. Positive Upstream	71.9	27.4	44.5	314
6. Positive Downstream	61.1	28.8	32.2	288
Second set				
1. A.C.	---	---	---	---
2. D.C.	47.4	45.2	02.2	130
3. Pulsed D.C.	72.3	45.2	27.1	138
4. Alternate Polarity	80.9	45.2	35.7	141
5. Positive Upstream	76.7	45.2	31.5	144
6. Positive Downstream	71.8	45.2	26.6	133

1/ Guiding effectiveness indicated by the ratio of the number of fish in the narrow channel to the total number recovered downstream, expressed as a percentage. A comparison is made between treatment and control by taking the difference between the percentage of each. This difference is called index of effectiveness.

A.C. was unpromising. The percentage of fish recovered in the narrow channel was the lowest for this condition and was actually less than that obtained with the control condition. Because there were numerous distressed and several dead fish in some of the A.C. explorations not listed, A.C. was eliminated from further tests in this series.

D.C. also did not appear to yield satisfactory results. In the first set of experiments, the effectiveness, as indicated by the percentage in the narrow channel, was intermediate between A.C. and the four types of Pulsed D.C., although more than twice the index in the control. In the second set, there was no apparent difference between the treatment and the control. Because of the apparent low effectiveness and because there were some distressed fish and some dead fish, D.C. was not considered for further use in the series.

We used sequential energizing with positive polarity both upstream and downstream. These two, with Alternate Polarity and Pulsed D.C. were similar in guiding effectiveness in both sets of explorations. In the small number of trials in the first set, there was a difference between Alternate Polarity and Positive Upstream, but this was not the case in the second set. Although it appeared that the four types of Pulsed D.C. and a control should be used in the main experiment, Alternate Polarity was a better test of polarity than Pulsed D.C; therefore, we omitted the latter.

THE EXPERIMENT

The main experiment was designed to test the relation of field polarity to the fish-guiding effectiveness of a sequentially energized single-row electrode array. It was also designed to obtain a measure of the extent of variability due to sample size in tests of this type. This was accomplished by the use of three types of energized arrays and a nonenergized array for control and by the use of three different sample sizes.

The two sequentially energized arrays were those described previously (fig. 4); fish moving downstream with the water current were subjected to electrical fields of different polarities. The other type of array was the Alternate Polarity type (fig. 3) and, as the direction of the field reversed at every pulse, any orientative effect due to electrotaxis was canceled.

Experiments, conducted on 12 nonconsecutive days, included a series of 12 tests each day.. The order of testing was varied from day to day to minimize any possible differences due to the time of day or sequence of tests. Fish were released in lots of 15, 50, and 100 so that the influence of sample size could be measured. For each size lot, a control (power off) was run. On each of the 12 days 660 fish were used, a total of 7,920 fish. The stock of experimental fish approximated only 4,000 fish, but because the tests extended over several weeks the fish were rested for a minimum of 12 days before a second use. With few exceptions, a minimum of 70 percent of each lot introduced moved downstream and were trapped in each 5-minute interval. The results are based on the recovery of 6,237 fish which entered the experimental field.

The numbers of fish and percentages recovered in the narrow channel are transformed by the arc sine method and the analysis of variance was used to determine whether differences existed (Snedecor 1950). The detailed data, transformation, and part of the statistical analyses are presented in the appendix.

RESULTS

The numbers of fish recovered in the narrow channel for each treatment have been summed and are listed with the total numbers of fish recovered downstream for each treatment:

Positive Upstream:
700 guided 1,607 total downstream

Positive Downstream:
735 guided 1,512 total downstream

Alternate Polarity:
681 guided 1,616 total downstream

Control:
237 guided 1,502 total downstream

This relative guiding effectiveness is portrayed in figure 5.

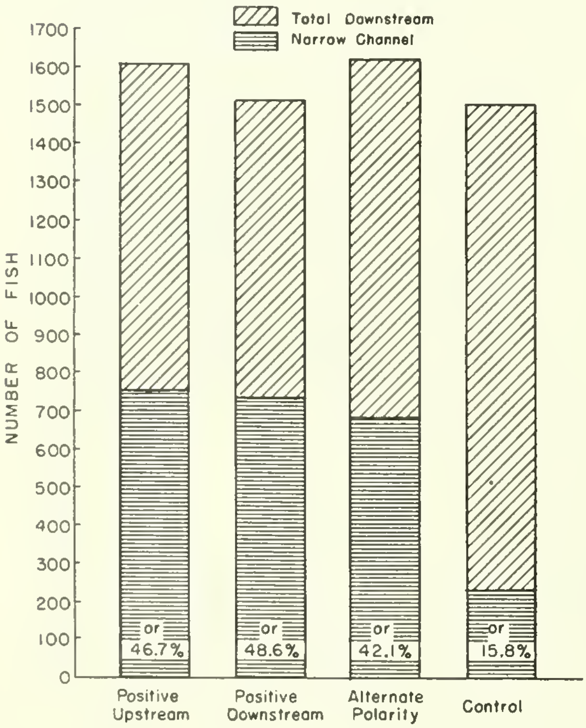

Figure 5.- Relative fish-guiding effectiveness of three methods of energizing an electrode array. The effectiveness is indicated by the ratio of the number of fish in the narrow channel to the total number recovered downstream. Totals for all release lots are combined.

The mean data, grouped by electrical treatments and release lots (table 2), give a comparison of the effects of the electrical treatments and the three release lots. These data were analyzed for differences between treatments, days, and sample sizes. Results show that fish group size and days experiments were conducted had no effect on guiding efficiency, but a significant difference was found in guiding efficiency by type of treatment (table 3).

DISCUSSION AND CONCLUSION

Sample Size

The daily behavior of the fish is rather variable. This variability was treated as variance (analyses in appendix) with the figures grouped according to the treatment by samples size (number of fish downstream). In each case the variance decreased from the 15-fish release to the 100-fish release, a relation portrayed in figure 6.

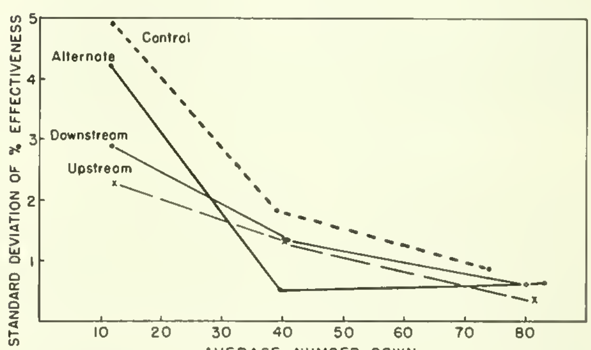

Figure 6.--Relation of standard deviation of percent effectiveness to average number of fish downstream (sample size).

In previous experiments and exploratory trials, release lots of 50 fish each were generally used. Following the explorations described in the beginning of this report, a complete experiment was carried out using releases of 50 fish. Eight replications of four conditions were tested in a period of 4 days. No differences were found between three electrical conditions,

Table 2.--Mean effectiveness by classification with respect to treatments and lot sizes.

Group (lot) size	Treatments: Positive Upstream	Positive Downstream	Alternate Polarity	Control	Over-all Mean
15	38.39	39.65	44.32	20.96	35.83
50	45.83	43.98	43.95	23.14	39.23
100	42.22	44.91	37.91	23.05	37.01
Over-all Mean	42.15	43.01	42.06	22.38	

Table 3.--Preliminary analysis of variance.

Source	Sum of squares	Degrees of freedom	Mean square	F
Treatment	10,774.51	3	3,591.50	57.49 1/
Group size	285.40	2	142.70	2.28
Interaction	584.15	6	97.36	1.603
Days	617.71	11	56.16	0.899
Error	7,349.97	121	60.74	
Total	19,611.74	143		

1/ Highly significant.

Table 4.--Analysis of variance.

Source	Sum of squares	Degrees of freedom	Mean square	F
Electrical vs. control	10,761.33	1	10,761.33	172.26 1/
Downstream vs. upstream and alternate	13.05	1	13.05	0.21
Upstream vs. alternate	0.14	1	0.14	0.002
Error	7,934.12	127	62.47	

1/ Highly significant.

but it was feared that any results might have been obscured by the seemingly high variance. This caused us to be concerned about the size of our releases and, in the last tests used for this report, numbers of fish in each release group were added as a variable. The mean effectiveness with respect to lot sizes (table 2) is summarized by over-all means:

Release of 15 fish	mean effectiveness 35.83
Release of 50 fish	mean effectiveness 39.23
Release of 100 fish	mean effectiveness 37.01

Mean effectiveness for all release group sizes was not significantly different, and we are assured that our previous samples of 50 fish were adequate.

Electrical Treatments

The analysis of variance shown in table 3 reveals no significant difference resulting from any of the variables, with one exception. This significant difference occurred among treatments and is almost entirely due to the difference between electrical treatments and control (table 4). This difference between electrical treatments and control is emphasized by a histogram (fig. 5) which portrays relative effectiveness by the ratio of the number of fish recovered in the narrow channel to the total number recovered downstream.

Under the conditions of these experiments it appears that polarity of the electrical field of a sequentially energized single-row electrode array is not an effective factor in guiding fish, as the analysis shows that the only differences were between electrical treatments and control. Because polarity of field is not a contributing factor, the response of the fish must have been a simple avoidance of an unpleasant stimulus, and thus electrotaxis was not involved.

This knowledge about field polarity provides a greater degree of freedom in the selection of methods of electrode energizing than formerly existed. Future selection of methods of electrode energizing will depend upon power consumption, cost of control equipment, and degree of simplicity in gear desired rather than upon the electrotactic effect of electrical fields.

SUMMARY

The relation of field polarity to the fish-guiding effectiveness of a single-row electrode array was explored under controlled laboratory conditions. Also explored was the extent of variability due to sample size in this type of test.

Three manners of energizing the array were compared: One condition maintained positive field polarity toward the upstream end, one toward the downstream end, and a third alternated the polarity in such a way

as to be non-orienting. No difference could be detected among them in guiding effectiveness, demonstrating that the effectiveness of a single-row array is due to avoidance rather than to electrotaxis.

When release lots of 15, 50, and 100 fish were used, a decrease in variance occurred with an increase in size of fish release groups. The mean effectiveness, however, for all the release lot sizes was similar.

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, C. E. Ellis, and personnel of the hatchery at Issaquah, Washington. Their cooperation and assistance are appreciated.

LITERATURE CITED

COLLINS, GERALD B., CHARLES D. VOLZ, AND PARKER S. TREFETHEN
1954. Mortality of salmon fingerlings exposed to pulsating direct current. U. S. Fish and Wildlife Service, Fishery Bulletin, No. 92, vol. 56, pp. 61-81.

RAYMOND, HOWARD L.
1956. Effect of pulse frequency and duration in guiding salmon fingerlings by electricity. U. S. Fish and Wildlife Service, Research Report 43, 19 pp.

SNEDECOR, GEORGE W.
1950. Statistical methods. 4th ed., 4th printing. Iowa State College Press, 485 pp.

TREFETHEN, PARKER S.
1955. Exploratory experiments in guiding salmon fingerlings by a narrow d.c. electric field. U. S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 158, 42 pp.

APPENDIX

The tables in this appendix contain the experimental design matrix, the numbers of fish and percentages recovered in the narrow channel, and the arc sine transformation to make means and variance independent. Tables of variance and average number recovered downstream are given also as they serve as a basis for a graphic presentation of their relation.

The experiment was a test of the relation of field polarity to the guiding effectiveness of a single-row electrode array and a means of measuring the variability of the test fish.

Appendix Table 1.--Distribution of conditions and release numbers (lots).

Days	1	2	3	4	5	6	7	8	9	10	11	12
Sequence within days	Cb	Bd	Ca	Ad	Bc	Ac	Ab	Aa	Bb	Ba	Cd	Cc
	Bd	Ca	Ad	Bc	Ac	Ab	Aa	Bb	Ba	Cd	Cc	Cb
	Ca	Ad	Bc	Ac	Ab	Aa	Bb	Ba	Cd	Cc	Cb	Bd
	Ad	Bc	Ac	Ab	Aa	Bb	Ba	Cd	Cc	Cb	Bd	Ca
	Bc	Ac	Ab	Aa	Bb	Ba	Cd	Cc	Cb	Bd	Ca	Ad
	Ac	Ab	Aa	Bb	Ba	Cd	Cc	Cb	Bd	Ca	Ad	Bc
	Ab	Aa	Bb	Ba	Cd	Cc	Cb	Bd	Ca	Ad	Bc	Ac
	Aa	Bb	Ba	Cd	Cc	Cb	Bd	Ca	Ad	Bc	Ac	Ab
	Bb	Ba	Cd	Cc	Cb	Bd	Ca	Ad	Bc	Ac	Ab	Aa
	Ba	Cd	Cc	Cb	Bd	Ca	Ad	Bc	Ac	Ab	Aa	Bb
	Cd	Cc	Cb	Bd	Ca	Ad	Bc	Ac	Ab	Aa	Bb	Ba
	Cc	Cb	Bd	Ca	Ad	Bc	Ac	Ab	Aa	Bb	Ba	Cd

Legend:

Condition

a Positive Upstream

b Positive Downstream

c Alternate Polarity

d Control

Release Number (Lots)

A 15 fish

B 50 fish

C 100 fish

Appendix Table 2.--Guiding effectiveness of three methods of energizing an electrode array as indicated by the ratio of the number of fish in the narrow channel to the total number recovered downstream, expressed as a percentage. Fish were released in lots of 15 each.

	Positive Upstream			Positive Downstream			Alternate Polarity			Control		
Day	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent
1	11	2	18.2	14	7	50.0	10	3	30.0	11	1	9.1
2	12	7	58.3	13	7	53.8	13	7	53.8	15	0	0.0
3	13	8	61.5	14	6	42.9	12	4	33.3	11	1	9.1
4	9	2	22.2	11	6	54.5	13	6	46.1	10	3	30.0
5	14	3	21.4	11	4	36.4	12	3	25.0	13	1	7.7
6	13	6	46.1	11	8	72.7	12	3	25.0	15	0	0.0
7	12	6	50.0	12	3	25.0	15	10	66.7	13	1	7.7
8	11	4	36.4	10	3	30.0	11	4	36.4	10	2	20.0
9	11	3	27.3	12	2	16.7	9	6	66.7	10	2	20.0
10	12	5	41.7	8	2	25.0	11	8	72.7	12	2	16.7
11	14	5	35.7	14	7	50.0	13	4	30.8	12	4	33.3
12	12	6	50.0	11	4	36.4	11	9	81.8	13	3	23.1
All day	144	57	39.6	141	59	41.8	142	67	47.2	145	20	13.8

Appendix Table 3.--Guiding effectiveness of three methods of energizing an electrode array as indicated by the ratio of the number of fish in the narrow channel to the total number recovered downstream, expressed as a percentage. Fish were released in lots of 50 each.

	Positive Upstream			Positive Downstream			Alternate Polarity			Control		
Day	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent
1	44	24	54.5	39	16	41.0	42	18	42.9	39	3	7.7
2	40	26	65.0	42	29	69.0	43	25	58.1	41	1	2.4
3	42	27	64.3	44	27	61.4	40	19	47.5	40	4	10.0
4	39	16	41.0	45	20	44.4	37	16	43.2	29	3	10.3
5	45	29	64.4	39	18	46.1	42	24	57.1	40	4	10.0
6	40	21	52.5	41	22	53.7	44	23	52.3	43	6	13.9
7	47	23	48.9	44	20	45.4	36	14	38.9	50	18	36.0
8	38	12	31.6	42	13	31.0	39	16	41.0	37	7	18.9
9	36	13	36.1	39	12	30.8	38	21	55.3	29	8	27.6
10	37	21	56.8	36	17	47.2	40	22	55.0	40	10	25.0
11	39	23	60.0	39	20	51.3	40	19	47.5	37	5	13.5
12	37	16	43.2	40	23	57.5	38	15	39.5	42	10	23.8
All day	484	251	51.9	490	237	48.4	479	232	48.4	467	79	16.9

Appendix Table 4.--Guiding effectiveness of three methods of energizing an electrode array as indicated by the ratio of the number of fish in the narrow channel to the total number recovered downstream, expressed as a percentage. Fish were released in lots of 100 each.

	Positive Upstream			Positive Downstream			Alternate Polarity			Control		
Day	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent	Total down	Narrow channel	Percent
1	84	28	33.3	80	44	55.0	85	28	32.9	78	9	11.5
2	86	43	50.0	89	48	53.9	84	30	35.7	86	7	8.1
3	87	38	43.7	80	55	68.7	91	39	42.9	76	8	10.5
4	83	39	47.0	94	47	50.0	63	11	17.5	49	9	18.4
5	79	47	59.5	--	--	----	89	34	38.2	82	16	19.5
6	88	38	43.2	77	39	50.6	88	41	46.6	77	5	6.5
7	85	38	44.7	80	36	45.0	89	34	38.2	82	7	8.5
8	80	39	48.7	85	36	42.3	85	34	40.0	70	17	24.3
9	74	31	41.9	77	32	41.6	77	31	40.3	77	14	18.2
10	78	33	42.3	76	31	40.8	86	35	40.7	79	17	21.5
11	79	35	44.3	72	39	54.2	79	31	39.2	58	13	22.4
12	76	33	43.4	71	32	45.1	79	34	43.0	76	16	21.0
All day	979	442	45.1	881	439	49.8	995	382	38.4	890	138	15.5

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Appendix Table 5.--Recoveries in the narrow channel. Figures are angles transformed (arc sin $\sqrt{\%}$) from percentage of total number of fish moved downstream.

		TREATMENTS				
Group size	Day	Upstream	Downstream	Alternating	Control	Total
	1	25.25	45.00	33.21	17.56	121.02
	2	49.78	47.24	47.24	00.00	144.26
	3	51.65	40.92	45.00	17.56	155.13
	4	28.11	47.58	42.82	33.21	151.72
	5	27.56	37.11	30.00	16.11	110.78
	6	42.82	58.50	30.00	00.00	131.32
A = 15	7	45.00	30.00	54.76	16.11	145.87
	8	37.11	33.21	37.11	26.56	133.99
	9	31.50	24.12	54.76	26.56	136.94
	10	40.22	30.00	58.50	24.12	152.84
	11	36.69	45.00	33.71	45.00	160.40
	12	45.00	37.11	64.75	28.73	175.59
	Total	460.69	475.79	531.86	251.52	1719.86
	1	47.64	39.82	40.92	16.11	144.49
	2	53.73	56.23	49.66	8.91	168.53
	3	53.31	51.59	43.57	18.44	166.91
	4	39.82	41.78	41.09	18.72	141.41
	5	53.37	42.82	49.08	18.44	163.71
	6	46.43	47.12	46.32	21.97	161.84
B = 50	7	44.37	42.42	38.59	36.87	162.25
	8	34.20	33.83	39.82	25.77	133.62
	9	36.93	33.71	48.04	31.69	150.37
	10	48.91	43.39	47.87	30.00	170.17
	11	50.18	45.75	43.57	21.56	161.06
	12	41.09	49.31	38.94	29.20	158.54
	Total	549.98	527.77	527.47	277.68	1882.90
	1	35.24	47.87	35.00	19.82	137.93
	2	45.00	47.24	36.69	16.54	145.47
	3	41.38	56.04	40.92	18.91	157.25
	4	43.28	45.00	24.73	25.40	138.41
	5	50.48	44.89	38.17	26.21	159.75
	6	41.09	45.40	43.05	14.77	144.31
C = 100	7	41.96	42.13	38.17	16.95	139.21
	8	44.31	40.63	39.23	29.53	153.70
	9	40.34	40.16	39.41	25.25	145.16
	10	40.57	39.70	39.64	27.63	147.54
	11	41.73	47.41	38.76	28.25	156.15
	12	41.21	42.19	40.98	27.35	151.73
	Total	506.59	538.66	454.75	276.61	1776.61
Grand total		1517.26	1542.22	1514.08	805.81	5379.37

Appendix Table 6.--Variance (S^2) of behavior of test fish, data grouped by size of release within treatments.

Release	Upstream	Downstream	Alternated	Control
15	78.54	92.41	140.53	164.53
50	43.93	44.01	16.83	61.07
100	12.28	20.70	21.48	29.01

Appendix Table 7.--Average (weighted) number of fish recovered downstream for each release group within treatments.

Release	Upstream	Downstream	Alternated	Control
15	12.00	11.75	11.83	12.08
50	40.33	40.83	39.92	38.92
100	81.58	80.09	82.92	74.16

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