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National Oceanic and Atmospheric Administration
National Marine Fisheries Service

The Use of Electricity in Conjunction With a 12.5-Meter (Headrope) Gulf-of-Mexico Shrimp Trawl in Lake Michigan

JAMES E. ELLIS

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The Use of Electricity in Conjunction With a 12.5-Meter (Headrope) Gulf-of-Mexico Shrimp Trawl in Lake Michigan

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ABSTRACT

The catching efficiency of a 12.5-meter standard shrimp trawl and the same trawl fitted with three different electrode array systems with power on and power off was investigated.

The standard trawl caught 1.54 times or 54.2% more kilograms of fish than the electrode-equipped trawl with power off. The electrode array hanging across the mouth area of the trawl acted as a visual stimulant and thus reduced the trawl's catch rate.

Overall the electrical trawl with power on caught 1.19 times or 19.0% more kilograms of fish than the electrical trawl with power off. Array 2 with power on had the best catch rate—1.86 times or 86.9% more kilograms of fish than the power off catch rate. The avoidance of fish to an electrode array was more than offset with the catch rate of array 2 with power on. The dominance patterns of the catches with each system tested did not change significantly with the exception of chub catches with array 2 with power on.

Length selectivity was highly significant for chubs caught with arrays 2 and 3 with power on. No significant length selectivity occurred with the other species landed.

INTRODUCTION

The work reported in this study is part of the National Marine Fisheries Service investigations into the use of electrical apparatus to improve the efficiency of trawl nets for commercial fishing and fishery resource assessment methods. It has been reported by many investigators that from 10 to 60% of the fish which enter a bottom trawl will escape (Kreutzer, 1964). McRae and French (1965) and Shentaykov (1965) have reported that electricity raises the overall catch of an ordinary trawl from 2 to 2.5 times.

From May 14 to June 14, 1968, an electrical fishing study was conducted in Lake Michigan. The purpose of this study was to investigate the effects of an electrical field upon the catch rate of a 12.5-m (headrope) Gulf-of-Mexico shrimp trawl. Accordingly, the specific objectives were: (1) to investigate the visually induced reactions of the fish to electrode array elements by comparing the catch rates of a standard trawl (no electrodes) to the catch rates of an electrode array-equipped trawl with electrical power off, and (2) to investigate the effects of changing electrical lines of force in the array system upon catch rates with power on.

STUDY AREA

The electrofishing study was conducted between Saugatuck and Holland, Mich., on the eastern side of Lake Michigan in 9 fathoms of water. The bottom in the study area was typically fine sand with some scattered boulders. The area afforded excellent trawling grounds owing to the gradual slope and regular contours of the bottom.

The fish population at the time of the study was predominantly alewife (*Alosa pseudoharengus*), chub (*Leucichthys hoyi*), and smelt (*Osmerus mordax*), with good populations of yellow perch (*Perca flavescens*) and lake trout (*Salvelinus namaycush*).

EQUIPMENT

Trawl

A 12.5-m (headrope) Gulf-of-Mexico shrimp trawl fitted with an electrode array system designed to retain fish once they enter the net was used. This nylon net had 3.2-cm mesh (stretched measure) wings and body and a 2.7-cm mesh cod end with a 1.3-cm mesh liner. The trawl was rigged with twelve 29.1-cm diameter plastic floats evenly spaced on a 12.5-m headrope and had 13.1 m of 0.9-cm diameter ground chain inserted in the 10.2-m diameter canvas hose along the 13.1-m footrope.

One electrode array with three variations in electrode element spacing was used, hereafter referred to as arrays 1, 2, and 3. The cathode was a vertical panel approximately 12.5 m long by 3.7 m high, composed of lengths of 2.5-cm hollow braided tinned-copper battery strapping. This strapping was fitted with an inner core of 0.9-cm diameter nylon and had a covering of 1.6-cm diameter nylon hollow braided rope. The anode consisted of two horizontal panels, 1.8 m long by 0.9 m wide, composed of copper screening (260 meshes per 2.5 cm).

Electrode Arrays

The array was positioned in the net as shown in Figure 1.

Array 1—The cathode was comprised of 42 vertical hanging electrode elements spaced 0.3 m apart and tied to the headrope and the footrope of the mouth area of the trawl. One of the anode panels was attached to the top of the net body, and the other was fastened to the bottom of the net body, 1.5 m behind the cathode.

Array 2—The cathode was the same as described under array 1 with the exception that every other electrode element was disconnected electrically. The anode was as described under array 1.

Array 3—The cathode was similar to that described for array 1. The anode was one section of copper screening attached to the bottom of the net body.

Electrical Shocker

Primary power was supplied by a portable 10 kw AC generator coupled to a commercial electrical shocker (Superior Electric Shocker). Pulsed directed current was supplied from the shocker to the electrode arrays through 152.4 m of two-conductor number 10 Type SO cable. We used 150 v DC at 12 amp at 10 pulses per sec with a pulse duration of 20 milliseconds and a duty cycle of 26%. Pulse shape was essentially rectangular. This set of electrical conditions was selected as the most effective from prior investigations in the field and laboratory by the author. The electrical cable was set and retrieved by a hydraulically powered storage reel. A diagram of the electrical system is shown in Figure 2.

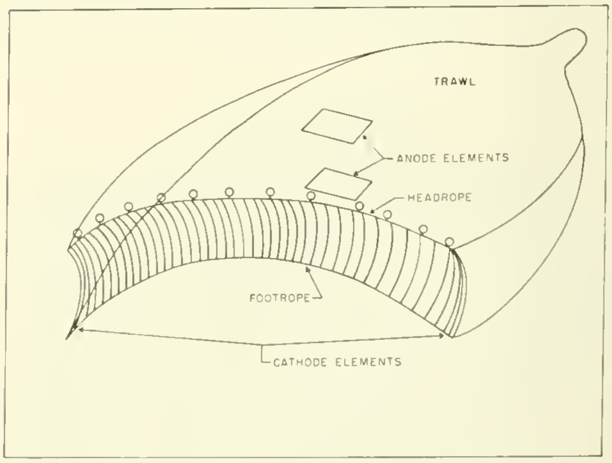

Figure 1.—Diagram of electrical trawl showing basic electrode arrays.

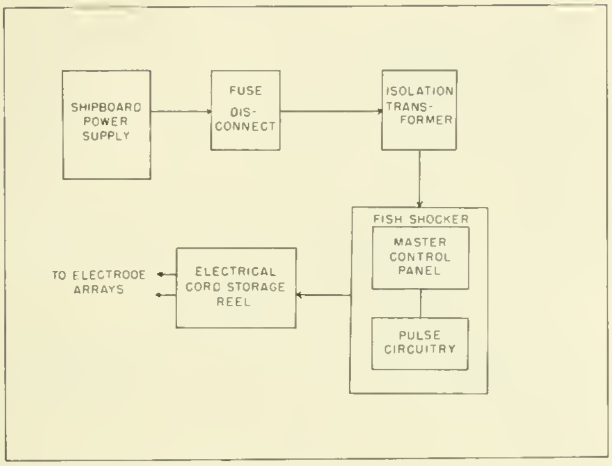

Figure 2.—Block diagram of fish shocker and allied equipment.

PHYSICAL QUALITY OF WATER

Water conductivity and temperature were measured at 12 noon each day. These variables did not noticeably affect the electrical current drawn by the electrode arrays.

Conductivity

Measurements of water conductivity at fishing depth were made with a conductivity bridge coupled to a temperature-compensated probe. Conductivity ranged from 210 to 250 micromhos per cm with a mean of 230 micromhos per cm.

Temperature

Measurements of water temperature at fishing depth were taken with a bathythermograph. The temperature ranged from 8.5°C to 9.5°C with a mean of 9.0°C.

METHOD OF TESTING THE ELECTRICAL TRAWL

To permit an evaluation of the electrical trawl, we designed two experiments:

1. To investigate the effects upon catch rates of visually induced avoidance behavior to hanging vertical electrode arrays.
2. To investigate the effects upon catch rates of electrical lines of flux with electrode arrays 1, 2, and 3.

During the first experiment to investigate visually induced avoidance, a 12.5-m trawl (no electrode arrays) was tested against the same trawl equipped with electrode array 1 without electrical power. Forty-eight drags were made—24 under each condition. The array was removed on alternate drags.

During the second experiment to investigate the effects of electrical lines of flux with arrays 1, 2, and 3 upon catch rates, the electrode array-equipped trawl was used. Forty-eight drags were made with arrays 1 and 2 respectively, and 46 drags were made with array 3. During the testing of each array, the procedure was to turn the electrical power on during alternate drags.

All drags were of 10-min duration in 9 fathoms of water at a vessel speed of approximately 2.6 knots. Scuba divers adjusted the electrode arrays in the net prior to testing.

The fish in each of the 190 drags were usually counted and weighed. However, when large catches were made, a subsample of the catch was counted and weighed and then expanded to cover the total catch. Fish length-frequency data was taken from the electrical trawl drags, power on versus power off.

RESULTS OF TESTING THE ELECTRICAL TRAWL

The test results were evaluated on the basis of total catch rates and gear selectiveness.

Catch Rates

For the first experiment, the average catch rate in kilograms per drag for the trawl fished with and without electrodes is shown in Table 1. The standard trawl averaged 42.7 kg of fish per drag and caught 1.54 times or 54.2% more kilograms than the electrode-equipped trawl with power off. The reduction in catch with the electrode-equipped trawl was obviously due to visually induced reactions of fish to hanging vertical electrode elements. Similar results were experienced by Russian biologists. Their investigations showed that fish avoid trawl nets when vertical hanging stimulants are placed in the

Table 1.—Catch results with 24 drags each of a 12.5-m (headrope) standard trawl—no electrodes, versus a 12.5-m (headrope) electrical trawl—power off with electrode array 1. RV *Kaho* cruise No. 48, Lake Michigan, May 14 - June 14, 1968.

Species	Standard trawl			Electrical trawl		
	kg	*no.*	*wt %*	*kg*	*no.*	*wt %*
Alewife	879.8	29,500	85.8	582.0	19,345	87.4
Chub	120.2	845	11.7	76.2	482	11.5
Smelt	9.5	2,444	0.9	2.3	330	0.4
Yellow perch	3.6	35	0.4	0.5	3	Trace
Lake trout	9.1	16	0.8	1.8	5	0.3
Other[1]	3.6	151	0.4	1.8	107	0.3
Total	1,025.8	32,991	100.0	664.6	20,272	100.0
Average kilograms caught	42.7			27.7		
Average number caught		1,375			845	

[1] Other species listed according to descending abundance were as follows by weight: spottail shiner, trout-perch, sculpin, lake herring, darter, logperch, stickleback, common whitefish. Other species listed according to descending abundance were as follows by number: spottail shiner, sculpins, trout-perch, darter, logperch, lake herring, stickleback, common whitefish.

mouth of a moving net (Shentaykov, 1960, 1965).

The results of the second experiment comparing the effects of electrical lines of flux for three electrode arrays on catch rates are shown in Table 2. The following results were obtained with the three different electrode arrays:

Array 1—The average catch per drag for power on and power off is shown in Table 2. Catches with power on averaged 56.0 kg of fish per drag, and those for power off drags averaged 48.9 kg of fish. The catch rate with power on was 1.34 times or 34.6% greater than that with power off.

Array 2—This array system with power on was the most successful method tested and an average of 4.3 kg of fish per drag were captured versus a catch of 2.3 kg of fish per drag with power off. In this case the catch rate with power on was 1.86 times or 86.9% more than the catch rate with power off.

Array 3.—This system with power on was the least effective of the three arrays tested. The average catch rate with power on was 25.8 kg of fish per drag versus 21.1 kg of fish per drag with power off. The power on catch rate was 1.22 times or 22.3% more than the power off catch rate.

Under the hypothesis that the electrical trawls with power on and power off have an equal chance of catching fish, about half of the total number of fish caught would be expected to occur during power on and half to occur during power off. This would also hold true for the standard trawl with and without electrodes.

The data in Table 3 show that the overall catch rate of the standard trawl was significant ($P < 0.01$, 1 degree of freedom). The lake trout catch rate with the standard trawl was not significant ($P > 0.01$, 1 degree of freedom). In general, we can assume the fish avoid capture when vertical electrode arrays spaced 0.3 m apart are placed across a trawl's mouth area.

Overall, the catch rate with arrays 1, 2, and 3 with power on was significant ($P < 0.01$, 1 degree of freedom); however, there was not a significant difference in the catch rate with individual species to each array tested. The catch rates of alewife with array 2 and lake trout with arrays 1, 2, and 3 were not significant ($P > 0.01$, 1 degree of freedom) with power on (Table 4). The difference in catch rates with power on lies in the reaction of species to the equipotential lines of flux created by the different arrays. By electrically disconnecting every other cathode, array 2, the equipotential lines of flux within the array system were changed. With this array system the lines of flux would be more dense in the immediate vicinity of each cathode element than with arrays 1 and 3. Since the electrical field is more "open" with array 2, the visual avoidance to electrode arrays per se experienced in the first experiment is offset by its increased catch rate.

Although statistically there is a significant difference between power on and power off catch rates, it does not follow that it has to be commercially significant since the commercial fisherman is interested in pounds of fish caught and not numbers of fish caught.

Straight line projection of the data with array 2 shows the potential of electrical trawling gear during a commercial fishing year in the Great Lakes of 150 days or 1200 hours with a commercially significant catch rate of $7.50 (ex-vessel value) per one-half hour of effort. These projections show that a commercial vessel would

Table 2.—Catch results with a 12.5-m (headrope) electrical trawl—power on versus power off versus electrode arrays 1, 2, and 3. RV *Kaho* cruise No. 48, Lake Michigan, May 14 - June 14, 1968.

Species	Array 1 42 cathode elements– 42 interconnected electrically Anode on top and bottom of net body						Array 2 42 cathode elements– 21 interconnected electrically Anode on top and bottom of net body						Array 3 42 cathode elements– 42 interconnected electrically Anode on bottom of net body					
	Power on 24 drags			Power off 24 drags			Power on 24 drags			Power off 24 drags			Power on 23 drags			Power off 23 drags		
	kg	*no.*	*wt %*	*kg*	*no.*	*wt %*	*kg*	*no.*	*wt %*	*kg*	*no.*	*wt %*	*kg*	*no.*	*wt %*	*kg*	*no.*	*wt %*
Alewife	1,273.3	43,411	94.8	1,122.2	32,195	95.7	47.2	1,349	45.6	39.0	1,288	69.6	571.1	28,533	96.0	478.5	18,959	94.5
Chub	51.7	367	3.8	30.8	198	2.6	46.3	338	44.7	13.2	94	23.6	18.6	127	3.1	24.2	140	4.8
Smelt	6.8	621	0.5	13.6	647	1.2	2.3	93	2.2	1.4	243	2.5	1.8	140	0.3	1.8	216	0.4
Yellow perch	2.7	31	0.2	0.5	2	Trace	5.4	64	5.3	1.4	16	2.5	1.4	13	0.2	0	1	Trace
Lake trout	6.8	19	0.5	5.9	10	0.5	1.8	2	1.7	0.5	1	0.9	0.9	5	0.2	0.5	1	0.1
Other[1]	2.7	77	0.2	0.9	24	Trace	0.5	7	0.5	0.5	1	0.9	0.9	1	0.2	0.9	2	0.2
Total	1,344.0	44,526	100.0	1,173.9	33,076	100.0	103.5	1,853	100.0	56.0	1,643	100.0	594.7	28,819	100.0	505.9	19,319	100.0
Average kilograms caught	56.0			48.9			4.3			2.3			25.8			21.1		
Average number caught		1,855			1,378			77			68			1,253			840	

[1] Other species listed according to descending abundance were as follows by weight: trout-perch, common whitefish, lake herring, spottail shiner, sculpin, logperch, darter, stickleback. Other species listed according to descending abundance were as follows by number: spottail shiner, trout-perch, logperch, sculpin, lake herring, common whitefish, stickleback, darter.

Table 3.—Number of species caught, expected frequency of catch, and chi-square values with the standard trawl and the electrical trawl with array 1, power off.

Condition	Alewife	Chub	Smelt	Yellow perch	Lake trout	Total
Standard trawl (no electrodes)	29,500	845	2,444	35	16	32,840
Electrical trawl (no power)	19,345	482	330	3	5	20,165
Expected frequency	24,422.5	663.5	1,387	19	10.5	26,502.5
Chi-square calculated (one degree of freedom)	2,111.250	99.298	1,611.028	26.946	5.760	3,030.532

Table 4.—Number of species caught, expected frequency of catch, and chi-square values with arrays 1, 2, and 3 with power on and power off.

	Alewife			Chub			Smelt		
	Array			Array			Array		
	1	2	3	1	2	3	1	2	3
	no.								
Power on	43,411	1,349	28,533	367	338	127	621	93	140
Power off	32,195	1,288	18,959	198	94	140	647	243	216
Expected frequency	37,803	1,318.5	23,746	282.5	216	133.5	643	168	178
Chi-square calculated (one degree of freedom)	1,663.870	1.410	1,930.040	50.550	137.814	0.632	0.776	66.964	16.224

	Yellow perch			Lake trout			Total		
	Array			Array			Array		
	1	2	3	1	2	3	1	2	3
	no.								
Power on	31	64	13	19	2	5	44,449	1,846	28,818
Power off	2	16	1	10	1	1	33,052	1,642	19,317
Expected frequency	16.5	40	7	14.5	1.5	3.0	38,750.5	1,744	24,067.5
Chi-square calculated) (one degree of freedom)	25.484	28.800	10.284	2.792	0.332	2.666	1,676.210	11.934	1,875.804

increase its income by a factor of 0.32 or 32.0%, up from $18,000 per year to $23,760 per year. This increase takes into consideration the reduction in catch experienced when arrays were added to the standard trawl in the first experiment. Out of the $5,760 increase would come the initial cost of the electrical gear, in this case approximately $1,200. With arrays 1 and 3, the fishing operation would show a loss of income.

Gear Selectiveness

To permit an evaluation of the gear's electrical selectivity to fish size, species composition and frequency of occurrence were taken for all commercially important species every fifth pair of drags.

Species Composition.—The species composition of the catches is presented in Tables 1 and 2 by a percentage of the catch by weight. The catches were dominated by alewife and chubs—over 95.0%—followed by smelt, yellow perch, and lake trout. The other eight species listed according to descending abundance made up less than 1.0% of the total catch.

The availability and vulnerability of alewife at the time of this study probably accounted for their dominance in the catches. Reigle (1969) found that during the April to June period, alewives were found at all depth zones and dominated the zone when present. With the exception of chubs, test results showed that the dominance pattern of all species did not change significantly, whether using the standard trawl or the electrictal trawl with power on or power off for arrays 1 and 3. Chubs did, however, show a significant increase in percent of total kilograms caught with array 2.

Length-Frequency Distribution.—The length-frequency of the alewife, chubs, and yellow perch with and without power are presented in Figures 3 through 11. Also presented with the figures are the results of statistical evaluations of the difference between two mean lengths. Overall, when all length data for alewife are combined, the mean length for power on drags was 165.7 mm compared with 163.1 mm for power

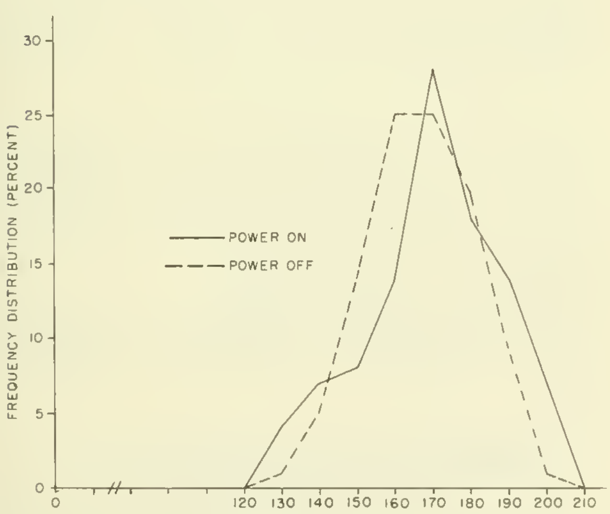

Figure 3.—Alewife length-frequency distribution with electrode array 1. Solid line, power on ($N = 146$; mean $= 170.2$); dashed line, power off ($N = 139$; mean $= 166.7$). Z test for difference between the two sample means at 0.05 level of probability: calculated $Z = 1.86$, tabular $Z = 1.96$; not significant.

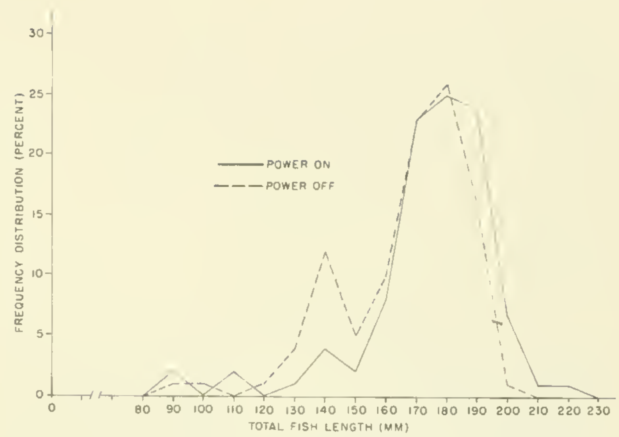

Figure 4.—Alewife length-frequency distribution with electrode array 2. Solid line, power on ($N = 77$; mean $= 174.5$); dashed line, power off ($N = 77$; mean $= 166.5$). Z test for difference between the two sample means at 0.05 level of probability: calculated $Z = 0.38$, tabular $Z = 1.96$; not significant.

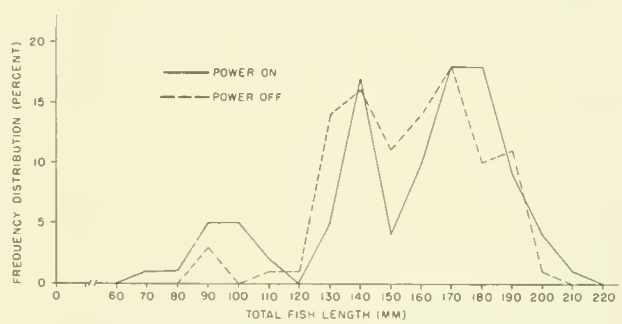

Figure 5.—Alewife length-frequency distribution with electrode array 3. Solid line, power on ($N = 144$; mean $= 155.3$); dashed line, power off ($N = 128$; mean $= 156.6$). Z test for difference between the two sample means at 0.05 level of probability: calculated $Z = 189$, tabular $Z = 1.96$; not significant.

off drags, a 2.0% increase in mean length with power on (Figure 6). Length selectivity between the arrays was not significantly different (Figures 3 through 6).

For chubs, the overall mean length for power on drags was 250.7 mm compared with 245.7 mm for power off drags, a 2.0% increase in mean length with power on (Figure 10). Length selectivity was only significant for fish taken with arrays 1 and 2 with power on (Figures 7 and 8).

For yellow perch, the highest mean length of 195.9 mm was obtained with array 2 with power on (Figure 11). This was 2.5% greater than the mean length of 191.0 mm obtained with power off. No length data was obtained for

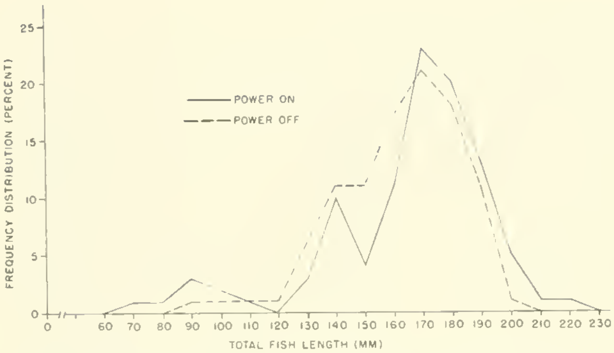

Figure 6.—Alewife length-frequency distribution with electrode arrays 1, 2, and 3 combined. Solid line, power on ($N = 387$; mean $= 165.7$); dashed line, power off ($N = 364$; mean $= 163.1$). Z test for the difference between the two sample means at 0.05 level of probability: calculated $Z = 1.54$, tabular $Z = 1.96$; not significant.

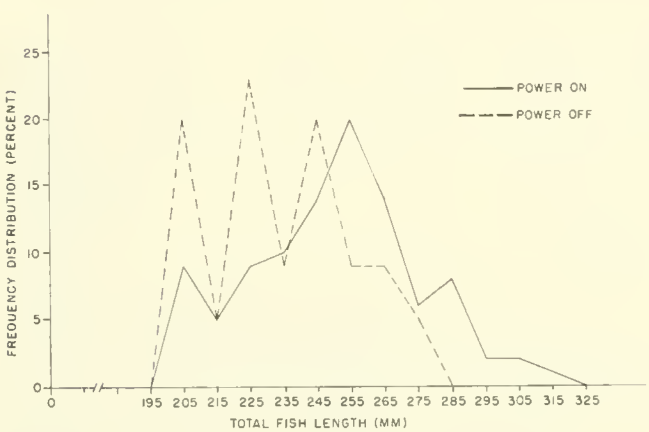

Figure 7.—Chub length-frequency distribution with electrode array 1. Solid line, power on ($N = 101$; mean $= 250.0$); dashed line, power off ($N = 35$; mean $= 234.1$). Z test for the difference between the two sample means at 0.05 level of probability: calculated $Z = 3.59$, tabular $Z = 1.96$; significant.

arrays 1 and 3. Length selectivity was not significantly demonstrated with power on or off.

The Z-test was used to analyze the difference between the sample mean lengths of fish caught with each array system. The only species to show selectivity of length toward pulsed direct electrical current were chubs. They were all significantly different except for the chubs taken with array 3.

SUMMARY AND RECOMMENDATIONS

These tests have shown that the overall catch rates (in kilograms of fish per drag) of a 12.5-m (headrope) electrical trawl with power on are increased by as much as 1.86 times or 86.9% over the same trawl with power off. This increase is much lower than that reported by other researchers. The catch rates were influenced by electrical lines of flux in the arrays tested. In addition, we have shown that fish exhibit visually induced responses to hanging vertical electrode arrays in the mouth area of a bottom trawl. This aversion to vertical electrodes was great enough to offset catch increases brought about by energizing the electrical apparatus.

Tests have also shown the overall catch rates (in numbers of fish per drag) to be statistically significant ($P < 0.01$) for the standard trawl (no electrodes) and for the electrical trawl with power on ($P < 0.01$). In some cases the catch rates for individual species were not significantly different with power on.

With the exception of chubs, the dominance patterns of the catches did not change significantly for the different test situations.

None of the test gear showed significant selectivity for alewife or yellow perch. Size selectivity was demonstrated for chubs when they were exposed to arrays 1 and 2.

It can be surmised from the results of these studies that the commercial use of electricity with a bottom trawl with array 2 is practical since a projected 0.32 times or 32% increase in income would more than offset the first year's investment in electrical gear.

Future application of electrode-array equipped trawls should take the following into consideration:

1. Array designs which lessen the visual reaction of fish to electrode elements.

2. Increase in power to the electrode arrays to overcome the loss of catch due to visual stimuli.

3. Investigate 0.6-m electrode element spacing on the cathode to lessen the effects of electrical lines of flux upon catch rates.

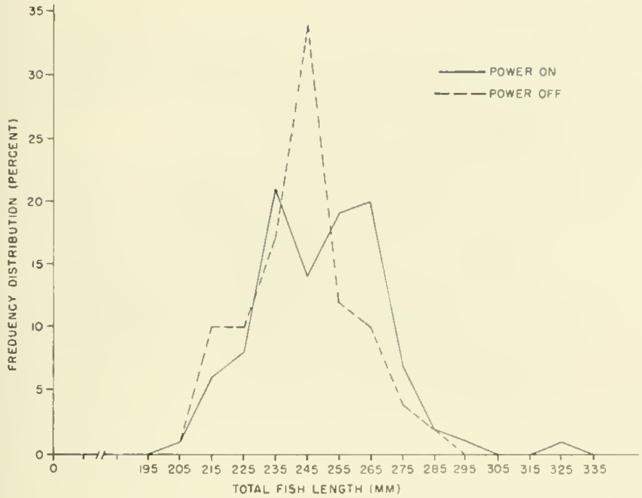

Figure 8.—Chub length-frequency distribution with electrode array 2. Solid line, power on ($N = 226$; mean $= 250.7$); dashed line, power off ($N = 92$; mean $= 243.2$). Z test for the difference between the two sample means at 0.05 level of probability: calculated $Z = 3.15$, tabular $Z = 1.96$; significant.

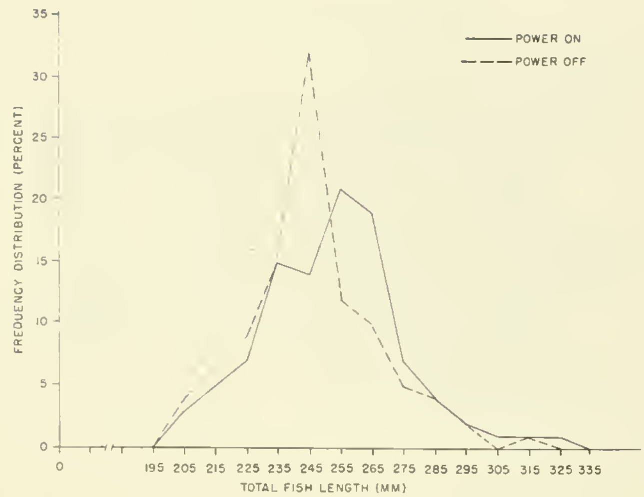

Figure 10.—Chub length-frequency distribution with electrode arrays 1, 2, and 3 combined. Solid line, power on ($N = 387$; mean $= 250.7$); dashed line, power off ($N = 208$; mean $= 245.7$). Z test for the difference between the two sample means at 0.05 level of probability: calculated $Z = 4.58$, tabular $Z = 1.96$; significant.

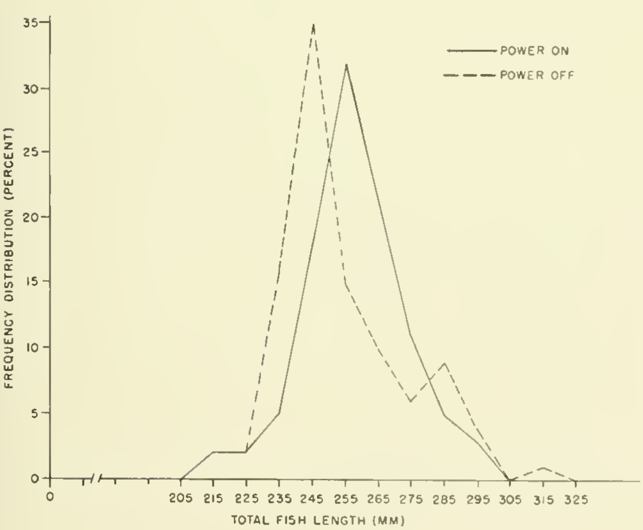

Figure 9.—Chub length-frequency distribution with electrode array 3. Solid line, power on ($N = 62$; mean $= 258.4$); dashed line, power off ($N = 81$; mean $= 253.7$). Z test for the difference between the two sample means at 0.05 level of probability: calculated $Z = 1.69$, tabular $Z = 1.96$; not significant.

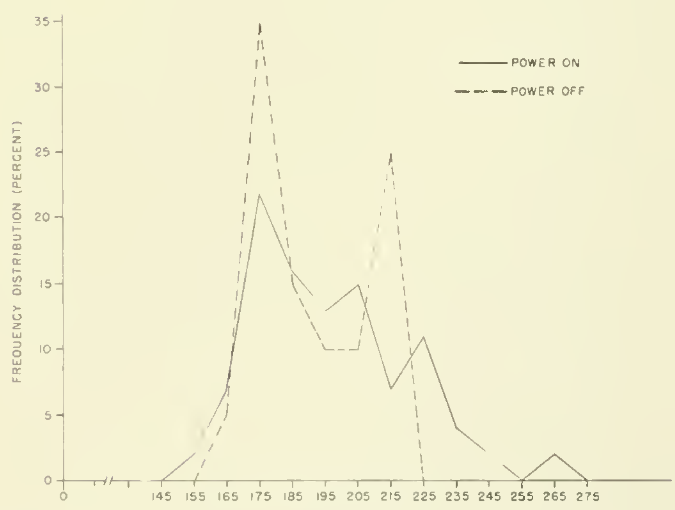

Figure 11.—Yellow perch length-frequency distribution with electrode array 2. Solid line, power on ($N = 55$; mean $= 195.9$); dashed line, power off ($N = 20$; mean $= 191.0$). Z test for the difference between the two sample means at 0.05 level of probability: calculated $Z = 0.75$, tabular $Z = 1.96$; not significant.

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