THE EFFECT OF WEAK ELECTRICAL FIELDS ON TROLL SUCCESS FOR SPRING (*ONCORHYNCHUS TSCHAWYTSCHA*) AND SOCKEYE (*ONCORHYNCHUS NERKA*) SALMON

By

DANIEL KENICHI NOMURA

B.Sc., University of British Columbia, 1975

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Dept. of Zoology)

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May, 1979

Department of Zoology

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date June 8, 1979

ABSTRACT

The purpose of this study was to determine whether or not weak electrical fields affect salmon troll success in target species *Oncorhynchus tschawytscha* Walbaum and *Oncorhynchus nerka* Walbaum. The study was conducted aboard a commercial salmon troller in two fishing areas of the Strait of Georgia, British Columbia. The two fishing areas were Canadian fishing statistical areas 29A and 17. There were two experimental fishing periods, 20 March to 22 May, 1978 and 2 September to 24 September, 1978 during which the target species were *O. tschawytscha* and *O. nerka*, respectively.

The fishing experiments used a single-vessel split-gear design where the replicated sets of troll gear were used as a paired treatment and control condition. The control condition was a zero volts potential difference between the fishing gear and the vessel. Applied voltages of both polarities made up the treatment conditions.

A preliminary field experiment investigated characteristic differences in troll success between port and starboard sets of gear. No significant differences were found and it was assumed that there was no difference between sides.

The voltage tests were Test 1(+0.5 vs 0.0), Test 2(-0.5 vs 0.0), Test 3(+1.0 vs 0.0) and Test 4(+0.5 vs -0.5) for target species *O. tschawytscha*. The voltage tests for target species *O. nerka* were Test 1(-0.5 vs 0.0), Test 2(+1.0 vs 0.0), Test 3(-1.0 vs 0.0), Test 4(-2.0 vs 0.0) and Test 5(+0.5 vs 0.0).

Differences in troll success between paired treatment and control voltage conditions were examined. Troll success was

measured by both catch and catch rate data. Differences in troll success were found in all voltage tests conducted during spring salmon trolling except for Test 3(+1.0 vs 0.0). Significant increases in troll success were found in Tests 1 and 4 whereas a significant decrease was found in Test 2. The effect of applied voltage conditions on sockeye salmon troll success was different than that on spring salmon troll success. Sockeye salmon troll success was not different between paired treatment and control conditions for the low voltages tested, positive 0.5 and negative 0.5 volts. However, a high positive voltage(+1.0) increased the troll success and and a high negative voltage(-1.0) decreased the troll success.

Further analyses were done on the effect of voltage conditions on troll success for O. tschawytscha of different ocean ages. Prior to investigation, a functional ocean age-total length regression was developed using ocean age data based on scale readings. Each target spring salmon captured was recorded with information on total length in order that the target fish could be put into ocean age groups. Differences in troll success were apparent in the older spring salmon(combined .2+,.3+,.4+ ocean years old) but not in the younger spring salmon(combined .+,.1+ ocean years old). Investigation of size distributions for paired treatment and control catches of spring salmon showed no apparent differences in all voltage tests done. Ocean age analyses were not done on O. nerka because all troll-caught sockeye salmon were assumed to be four year old Adams River spawners.

The effect of available fish density on the change in troll success caused by the treatment voltages were examined for both O. tschawytscha and O. nerka. Differences in troll success in older spring salmon(combined .2+,.3+,.4+ ocean year olds) seem to be affected by the available fish density. In contrast, the younger spring salmon(combined .+,.1+ ocean years old) as well as the sockeye salmon do not demonstrate this available fish density phenomenon.

TABLE OF CONTENTS

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

ACKNOWLEDGEMENTS

I would like to thank my father for his valuable help and use of his fishing vessel, and British Columbia Packers Ltd. for funding the project. This project was also partially funded by a National Research Council Grant to Dr. Norman Wilimovsky.

I would also like to thank my thesis committee including Dr. Gosline, Dr. Kharadly, Dr. Liley, Dr. Northcote, and especially Dr. Norman J. Wilimovsky for supervising this project. Also, special thanks to my wife, Colleen, for her understanding and encouragement throughout this entire project.

INTRODUCTION

There are basically three methods of commercially harvesting salmon in British Columbia; purse-seining, gillnetting and trolling. Trolling is one of the oldest fishing methods(Milne, 1953,1955). A brief history of trolling and its past and present role in the commercial salmon fisheries has been written and included in Appendix I.

Trolling is a type of hook and line gear where a number of weighted lines bearing numerous lures at different depths are dragged through the water at a slow speed(Milne, 1955; Fridman, 1973). A detailed description of trolling including vessel, gear and operation has also been included in Appendix I. The unique ability to capture high quality salmon during their ocean migrations or early in their spawning migrations has made trolling the largest supplier to the fresh fish market. In the past, trollers concentrated on catching only spring(Oncorhynchus tschawytscha Walbaum) and coho (Oncorhynchus kisutch Walbaum) salmon but now sockeye (Oncorhynchus nerka Walbaum) and pink (Oncorhynchus gorbuscha Walbaum) salmon have also become popular target species.

The evolution of any fishing method includes development in both its fishing gear and fishing technique. There has been relatively little development in modern salmon troll gear during the last thirty or more years. In the present salmon troll fishery trolling gear is standard such that every troll vessel is rigged essentially in the same manner(Browning, 1974). However, trollers have begun to focus their attention on their fishing techniques, more than in the past(Scofield, 1956).

Fishing techniques including fishing speed, fishing depth, trolling courses, soaking time, gear retrieval have all been more seriously considered than in the past years.

Variations in fishermen and vessels have been suggested as a possible factor causing differences in their troll success(Argue, 1970; Browning, 1974). Fishermen claim that noises from the fishing vessel affect success in troll catch(Browning, 1974). Preliminary findings from acoustic research done by Oregon State University's Sea Grant Program seem to suggest that trolling may be affected by the underwater sound generated by fishing vessels(Anonymous, 1976; Erickson, 1978).

Commercial trollers also claim that electrical fields due to electrolysis affect their catch success. Russell (1977), in co-operation with the Oregon State University Sea Grant Program(Kolbe, Mate and Jacobson, 1975), described the electrical theory involved in this phenomenon. At least two commercial firms(Scientific Fishing Systems, Oregon; Russell Electronics, Victoria) manufacture electronic devices which output low-magnitude positive voltages on troll lines, these devices are claimed to increase troll success. However, no proper scientific study has been conducted to investigate the effects of weak electrical fields on troll catch.

Although there is very little literature on weak electrical fields and non-electric fish behaviour or behaviour of fish with no special electric receptor organs , researchers have suggested that non-electric fish, including salmon, are able to detect and discharge weak electrical fields(Regnart, 1931; Harden Jones, 1968; Royce, Smith and Hart, 1968; Protasov, Basov, Krumin and Orlov, 1970; MacCleave, Rommel and Cathcart, 1971; Rommel and MacCleave, 1973b). A review on this subject has been included in Apppendix II.

Therefore, this study was done to investigate the effects of weak electrical fields on salmon troll success.

Hypotheses

Ho: Changes in the voltage gradient and polarity of an electrical field around the fishing gear will not affect salmon troll success.

H_1: Salmon troll success will be affected by changes in the voltage gradient and polarity of an electrical field around the fishing gear.

METHODS AND MATERIALS

The study was done aboard a commercial trolling vessel(see Figure 1). The fishing technique was kept as 'normal' as possible.

Prior to field experimentation, the vessel was drydocked and all potential underwater electrodes were commonly grounded(see Figure 2). This procedure is called bonding and is necessary for applying the electrical fields(Kolbe, Mate and Jacobson, 1975; Russell, 1977), as discussed in Section II.

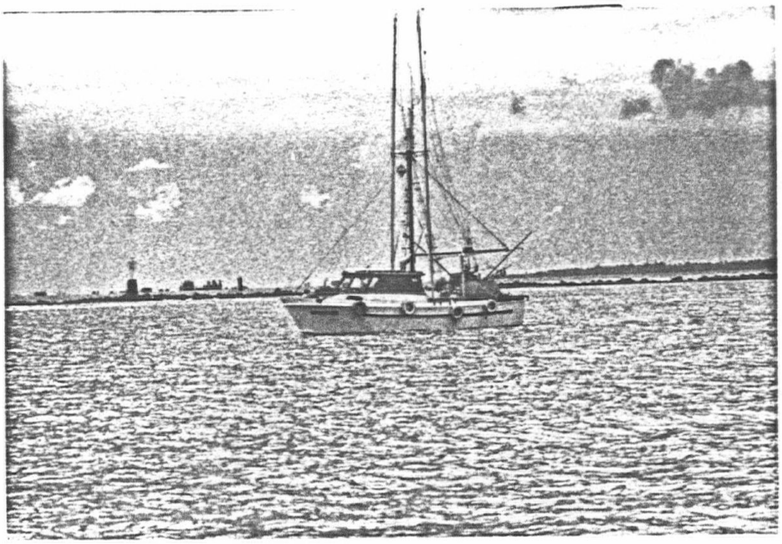
A preliminary field experiment was conducted from 16 February to 26 February, 1978. Troll catch(recorded by numbers of fish) between replicate sets of troll gear(port and starboard), without treatments, were tested for any significant differences.

The skipper of the vessel, an experienced salmon troller, was asked to use his own discretion in choosing the types and arrangements of terminal gear effective in catching the target species. The terminal troll gear consisted only of hoochie-flasher combinations, Appendix III includes a description of sample sets of gear used for target species *O. tschawytscha* (spring salmon) and *O. nerka* (sockeye salmon).

A few modifications were made to ensure a reasonable scientific investigation. Each arrangement of troll gear was replicated for a single-vessel split-gear experimental design, using one set of gear(port or starboard) as a control condition and the other as a treatment condition. The control condition was a potential of zero volts between one set of troll gear and the vessel while the treatment condition included a range of applied voltages between the other set of gear and the vessel. A discussion on the experimental design is included in Section II. Several other measures were taken to reduce possible differences in fishing conditions between the control and treatment sets on troll gear. Areas of fast tides were avoided and experimental trolling was not conducted in directions where winds pushed against the vessel's side such that the vessel was displaced from the centre position between the two sets of gear. All trolling tows were made under a reasonably straight course, turnarounds were done quickly and the fishing speed was increased greatly to avoid capture of fish during turns. All these measures were taken to reduce dissimilar fishing conditions, such as trolling depth and trolling speed, between the control and experimental sets of gear.

The different voltages and polarity conditions were randomly scheduled. The treatment condition for each test was initially assigned randomly to either the port or starboard set of troll gear and was then alternated daily between port and starboard sets of gear for the duration of the test. The treatment condition was always paired with the control condition. The length of each test was determined by the number of target fish caught but was limited to the length of fishing time which would enable the other tests to be completed within the total time period the commercial troller was available. The low availability of target fish and the unfavourable sea conditions on a number of fishing days caused some tests to be extended over a longer length of time than tests with adequate catches.

Figure 1: The commercial salmon troller M.V. DANMARK was used for the fishing experiments.



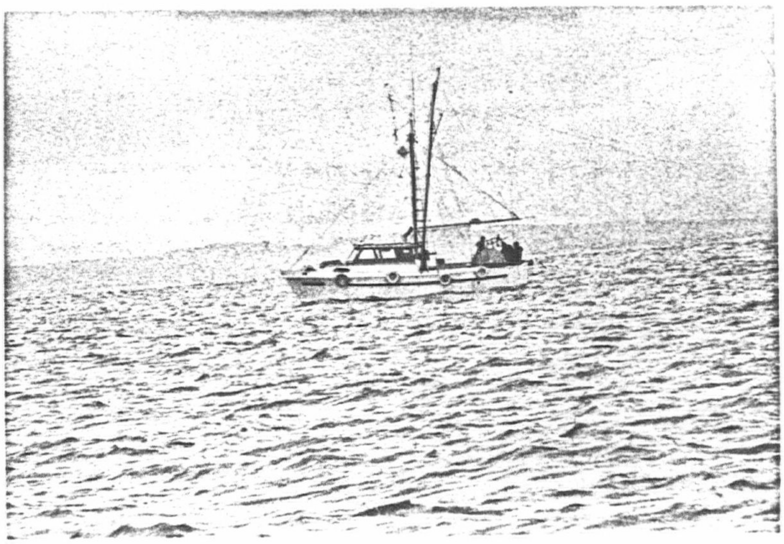
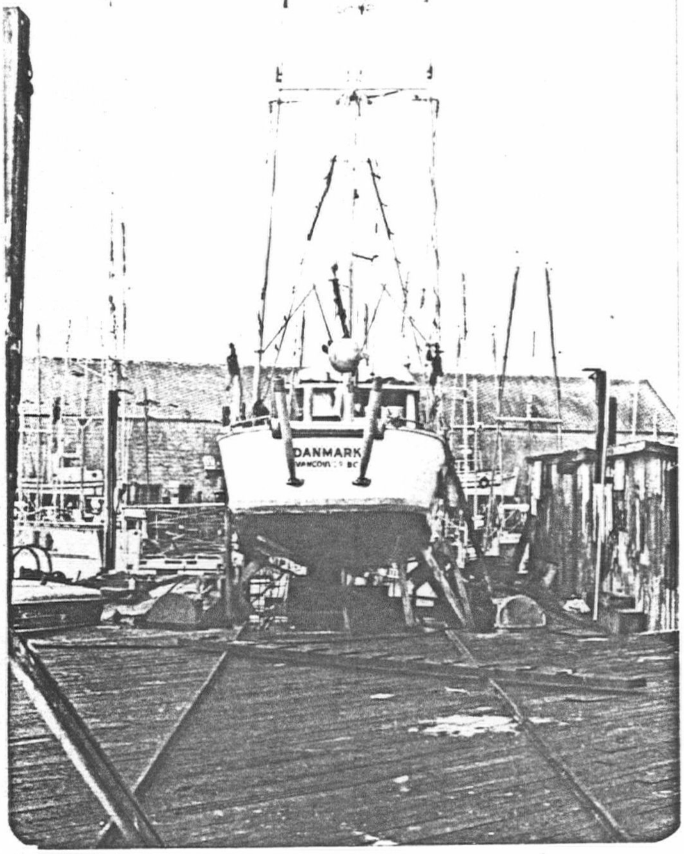
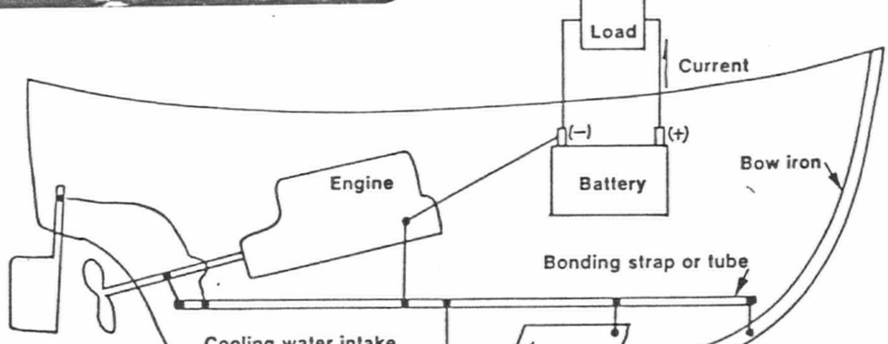


Figure 2: The commercial troller was drydocked and all potential underwater electrodes were bonded. The schematic diagram is from Russell (1977) (in Western Fisheries).





I. Data Collection and Sampling

The troll catch was recorded by species and total length(to the nearest millimeter). Round weights(to the nearest 2 ounces) and sex data were taken whenever possible.

Fishing data including capture time, relative depth of terminal gear(for example, depth 1 was the terminal gear nearest to the surface) and trolling line(for example, port pig line) were recorded together with the catch data.

Scale samples were all taken from the left side of the fish along the lateral line in a section midway between the dorsal and adipose fins(Koo, 1962). Four scales per target fish were cleaned and mounted. Data including total length, round weight, sex(whenever possible), time and date of capture were recorded for each scale sample.

Under a permit issued by the Federal Fisheries Department the experimental fishing was conducted during periods when commercial trolling was closed.

Ia. First Experimental Period

The first experimental period took place from 20 March to 22 May, 1978. The fishing was done in the general area of lower Georgia Strait, Canadian statistical fishing Areas 29A and 17(see Figure 3). The local areas fished within Areas 29A and 17 were the North and South Flats of the Fraser River for Area 29A, and Porlier Pass, Sylva Bay and Five Fingers Island for Area 17(see Figure 4).

The target species for the first experimental period was *O. tschawytscha* but *O. kisutch* was caught incidentally.

The effect of polarity(+,-) for the claimed optimum voltage of positive 0.5 ± 0.1 volts(Russell, 1977; Scientific Fishing Systems(personal communications)) was tested first. A second set of experiments was then done using a range of different treatment conditions, including positive 1.0, positive 0.5 and negative 0.5 volts. These treatments were tested at the same time with a control condition of 0 volts potential between the control set of troll gear and the vessel. A schedule of the treatment conditions is included in Appendix IV.

Ib. Second Experimental Period

The second experimental period was scheduled according to the available use of the commercial troller as well as the arrival time and milling period for the Adams River sockeye in the lower Georgia Strait(Area 29A). Experimental fishing was conducted from 2 September to 24 September, 1978. Local areas fished within Area 29A were areas just outside the dropoff zones along the North and South Flats of the Fraser River(see Figure 4).

The target species was *O. nerka* (sockeye salmon) but incidental target species included *O. tschawytscha* and *O. kisutch* .

Troll success during the second experimental period was tested using treatment conditions of positive 1.0, positive 0.5, negative 0.5, negative 1.0, negative 2.0 volts.

Figure 3. Aerial photo showing general location of experimental fishing areas (scale 1:1,000,000).

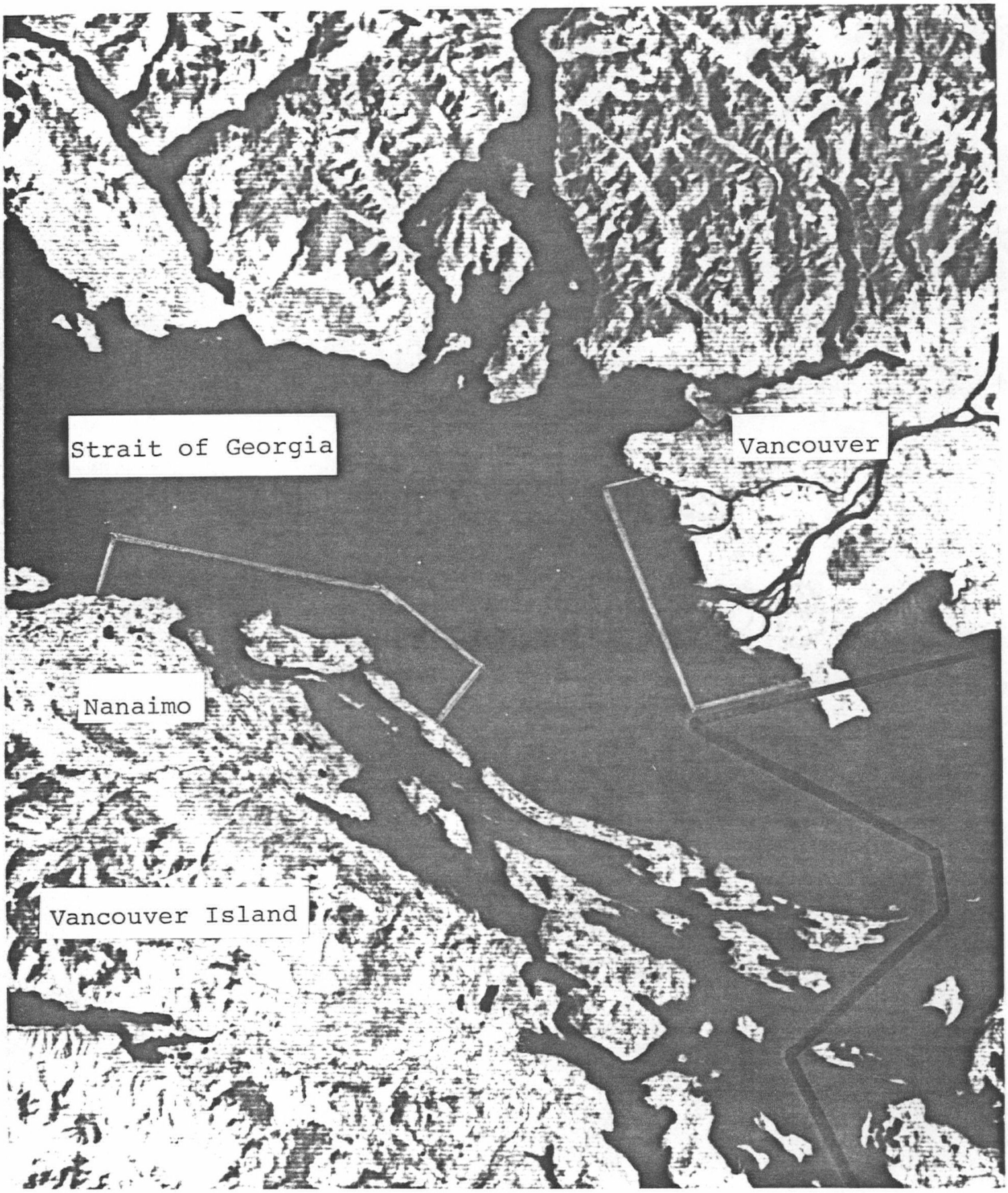
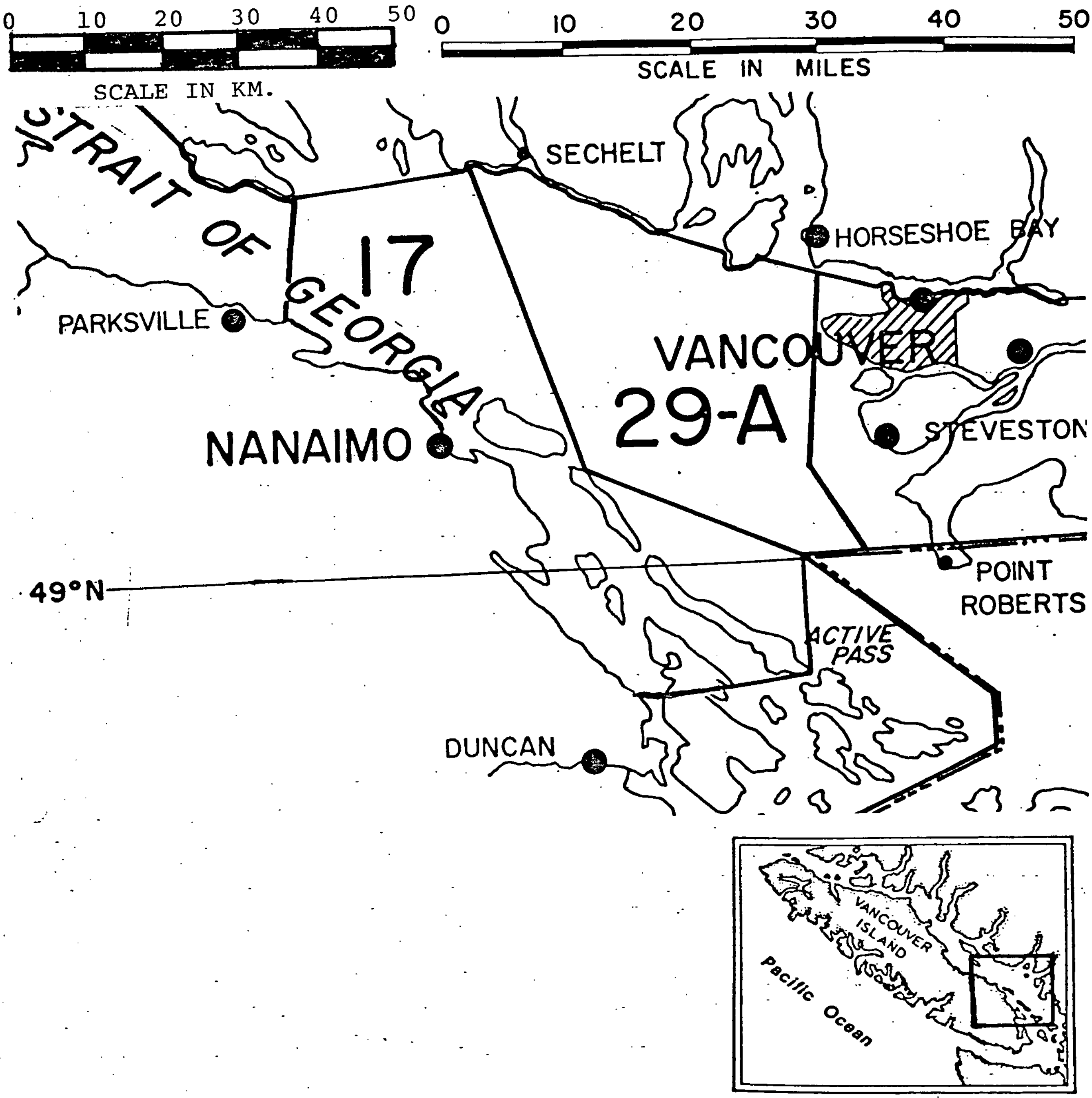


Figure 4. Map outlining Canadian statistical fishing areas 17 and 29A, Department of the Environment Fisheries Service Statistical Map.



The greater range of voltages for the sockeye trolling experiment was made possible by a re-designed voltage unit(Russell Electronics Ltd). The control condition was 0 volts difference between the control set of troll gear and the vessel, and was effective at the same time as the treatment condition. The schedule for the test conditions during the second experimental period is summarized in Appendix IV.

II. Experimental Design

An experiment was designed to investigate the effects of applied electrical fields on commercial troll success in the most efficient manner.

There are three possible types of experimental designs; a single-vessel design testing alternating control and treatment conditions, a two-vessel design pairing control and treatment conditions, and a single-vessel split-gear design testing control and treatment conditions at the same time.

IIa. Alternate Designs (Single-vessel Alternating Gear, Two-vessel)

Salmon troll catch has been found to vary greatly with different environmental conditions(time of day, tide, climate)(Argue, 1970). A single-vessel experiment, using replicated trials of control and treatment conditions, would be highly susceptibe to these conditions. Each trial would be affected by different environmental conditions so that no standard reference catch could be set for a proper control. A proper control condition should be affected by the same factors which affect treatment condition, except for the treatment itself.

A two-vessel design using one vessel as a control condition and the other vessel as a treatment condition is a second possible type of experimental design. Unfortunately, the fishing efficiency of two vessels varies extensively even with replicated trolling gear. An experiment with two vessels would require two commercial trollers with similar troll riggings, trolling speeds and any other vessel characteristics which would affect their troll success. One troller would probably fish in a normal manner while the second troller may have to accordingly change his fishing technique to permit the experiment to be effective. The change in the second troller's fishing technique may cause his catch success to significantly decrease since his trolling gear probably operates most efficiently with his own unique fishing technique (Argue, 1970; Browning, 1974). Argue's salmon troll study showed that even under rigid control, charter vessels differed somewhat even in species selection and he suggested that this was due to either vessel differences or variations between fishermen. Argue suggested factors such as handling of gear(retrieval of lines, care of gear) and fishing speed as possible sources of this variation.

A second disadvantage of a two-vessel experimental design is the difference in fishing conditions between the two vessels. Target fish such as salmon are not uniformly distributed across the water column and therefore, variance in troll catch due to area differences may be significant where the fishing areas for the control and treatment sets of troll gear are distantly separate. This factor could become very important since the trollers must maintain significant individual vessel distances for practical operation. Therefore, it seems reasonable to assume that the catch successes for the two troll vessels would be affected by dissimilar fishing conditions.

IIb. Single-vessel Split-gear Design

A third type of experimental design is a single-vessel split-gear experiment(Stewart, 1978). Each commercial troller has a set of troll gear on either side of the vessel which may be used as replicates so that one set of fishing gear may be used as the control gear and the other set as the treatment gear.

This type of design has the advantage of reducing all factors other than the applied voltages from varying the troll success between the control and experimental troll gear. Both sets of gear will fish in an area as similar as can be possibly achieved. The troll rigging will be the same for both control and experimental conditions since the rigging on one side of a vessel is essentially the mirror image of the other side. The variance in capture rates for control and treatment conditions due to environmental factors will be reduced since both control and treatment sets of gear will be trolled at the same time and within the same fishing area. Therefore, by using this experimental design with treatments of different troll line voltages, differences in troll success between control and experimental conditions should be due to the different line voltages.

IIc. Control and Treatment Sets of Fishing Gear

The three potential electrodes in the single-vessel split-gear design are the two sets of troll gear and a common vessel electrode. The control is the set of troll gear grounded to the bonded system of the vessel and represents the condition which has no voltage difference between the control fishing gear and the bonded system. The treatment is the other set of troll gear which is controlled by a variable voltage source which applies a known voltage difference between the troll gear and the bonded system. An electronic device which outputted and monitored the voltage potentials between the fishing gear and the vessel is manufactured by Russell Electronics Limited. The electronic device basically inputted a 12 volt direct current source and outputted, using a variable potentiometer, a desired voltage between the trolling gear and the bonded system which was also measured by the device's voltmeter.

The control and treatment sets of fishing conditions are assumed to be independent of each other on the basis of electrical field principles for aqueous media. The sea water medium, which contains the three potential electrodes, represents a large number of interlinking circuits between the effective surface areas of each electrode. The larger area of the vessel's bonded system electrode will create a larger number of interlinking circuits to each trolling gear electrode, more than from one trolling gear electrode to the other trolling gear electrode. Dickson (1954) states that the resistance between two electrodes in sea water is determined by the dimensions and shapes of the electrodes, conductivity of the medium as well as the distance between the electrodes. Therefore, when the distance between the electrodes becomes much greater than the dimension of each electrode, the resistance becomes independent of the separation distance and is only determined by the medium's conductivity and the shapes and dimensions of the electrodes such that:

$$(1) \quad R \propto \frac{1}{g(S_1 + S_2)}$$

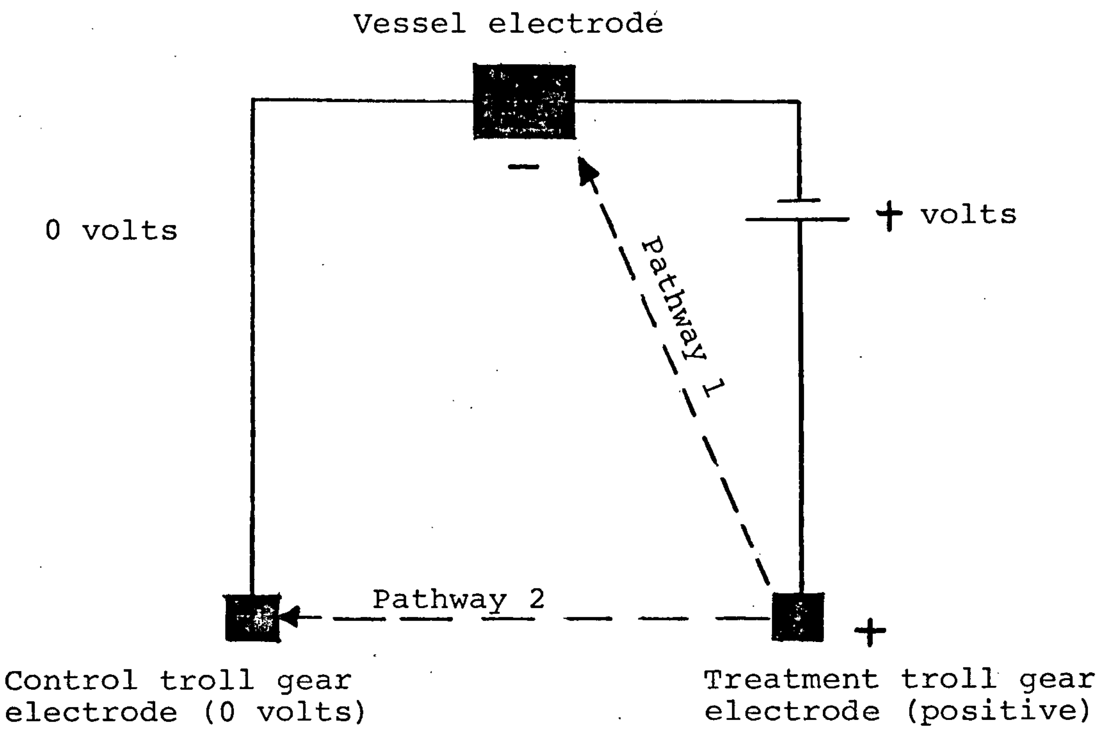
- where R is the resistance
  S_1 and S_2 are the dimensions of electrodes 1 and 2
  g is the conductivity of the medium (sea water)

In the study under investigation, the two polarity conditions for the treatment troll gear are shown in Figure 5. When the voltage difference between the troll gear and the vessel is positive (Figure 5a), there are two possible pathways through which the applied current will flow. However, according to basic electrical circuit theory, the current tends to flow in the pathway with the least resistance. The total dimensions of the vessel electrode and troll gear electrode is much greater than the total dimensions of the two troll gear electrodes. Since the resistance is inversely proportional to the dimensions of the electrodes, the current will tend to flow through pathway one rather than pathway two. Since the ratio of vessel electrode radius to troll gear radius is very large, it was assumed that comparatively negligible current would flow through pathway two.

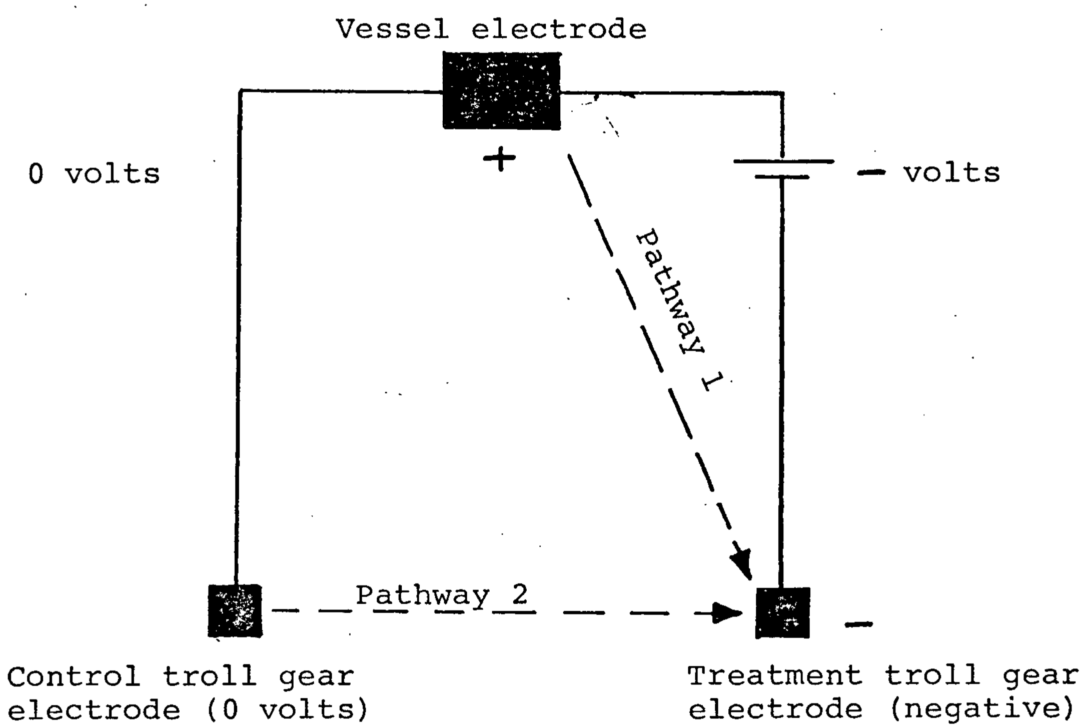
In a treatment condition with a reversed current flow(shown in Figure 5b), the voltage difference between the troll gear electrode and the vessel electrode is negative(negative troll gear relative to the vessel), the current should also tend to flow through pathway one because of lesser resistance.

Figure 5: Schematic diagrams showing the two polarity conditions which the troll gear may be tested. Figure 5a shows the voltage difference between the troll gear being positive with respect to the vessel. Figure 5b shows the troll gear being negative with respect to the vessel.

(5a)



(5b)



IId. Control condition as ground condition

The 'zero volts' ground condition was chosen as a control because a natural voltage of positive 0.3 volts ± 0.1 volts was present between the vessel electrode and the troll gear electrode in a non-ground condition. This voltage was due to electrolytic reactions(Burgess, 1966; Amos, 1977) between the dissimilar metals of the vessels and fishing gear immersed in sea water. The voltage potential may vary with different environmental conditions and since this study attempts to investigate the change in troll success between different electrical fields(varying in polarity and voltage), it would seem unreasonable to use a troll gear electrode with a varying electrical field as a control condition. However, by grounding one set of troll gear to the bonded system of the vessel, the voltage difference between these two potential electrodes will be zero volts. Varying voltages will be applied between the treatment set of troll gear and the bonded system and, since the control set of troll gear is grounded to the bonded system, the same voltage differences will be effective between the treatment and control sets of troll gear.

It seemed reasonable that the effects of electrical fields would be best investigated by using a reference troll catch affected by a zero volts potential(ground condition) and by comparing all other troll catches affected by different applied voltages and polarities to the reference troll catches.

RESULTS

I. Preliminary Field Experiments

The commercial salmon troller was prepared for the field experiments during the period from 16 February to 26 February, 1978. Preliminary fishing experiments were done for five days during this period, including 16,21,22,25 and 26 February. The troll catch data was collected and analyzed for possible differences between port and starboard sets of gear, particularly on the effect of side.

As described in Materials and Methods, the fishing gear was standardized for both port and starboard sets of gear, using replicated sets of terminal gear and also similar troll gear rigging and arrangement. However, it was necessary to investigate whether the effect of side would cause differences in troll catch. The effect of side was tested using a potential condition of zero volts between each set of troll gear and the common bonding system. This condition was established by grounding both port and starboard sets of gurdies to the vessel's common bonding system.

Table 1 summarizes the catch data between the port and starboard sets of troll gear. Total lengths were measured for each fish captured and it was possible to group the target spring salmon into ocean ages. The ocean age groupings were estimated from a functional equation regressing total length data and corresponding ocean age data derived from scale samples(discussed in Section Va).

Table 1. A summary of catches (by numbers of fish) during preliminary experiments, grouped by ocean age, for spring salmon trolling.

		PORT CATCH						STARBOARD CATCH					
	Fishing	Spring Salmon						Spring Salmon					
Date	Time (hook hours)	.+	.1+	.2+	.3+	All Ages	Coho Salmon	.+	.1+	.2+	.3+	All Ages	Coho Salmon
16/02	49.5	4	3	7	2	16	4	4	3	6	0	13	5
21/02	45.0	4	4	3	1	12	1	2	0	5	1	8	1
22/02	49.5	8	1	7	0	16	6	11	1	3	1	16	9
25/02	45.0	8	2	4	0	14	3	10	0	3	1	14	0
26/02	76.5	11	3	5	1	20	4	12	3	4	0	19	9
Total	265.5	35	13	26	4	78	18	39	7	21	3	70	24

Troll catch data for incidental target species *O. kisutch* were also recorded and are included in Table 1.

Interpretations

The troll catch data for each side, in both individual and all age groupings, seem to suggest that there are no differences in spring salmon troll catch. Incidental troll catches of coho salmon also do not seem to vary between port and starboard sides. No significant differences in troll catch between port and starboard sets of troll gear were verified by using statistical Chi-square analyses.

Thus, it seems reasonable to assume that no differences in troll catch exist between the port and starboard sets of troll gear under the same fishing conditions, including a potential of zero volts between each set of troll gear and the common bonding system.

II. *Characteristics of Variates Estimating Trolling Success*

Troll success was estimated by both catch data(by numbers of fish) and catch rate data. It was assumed, in collecting catch data, that each test was one continuous sampling period. The total number of target fish caught at the end of the test period for each condition , control and treatment, was taken to be the observed catches for those conditions.

The catch data were also transformed into catch rate data to provide a second measurement of troll success. The catch rate measurement also provided the required level of measurement for statistical analyses using the paired t-test. A second reason for catch data transformation was to provide appropriate data for correlation and regression analyses between the available fish density and the effect of voltage potentials on catch success.

Data analyses on differences in troll success between treatment and control voltage conditions were done for both catch data and catch rate data. A section was written for each type of data analysis for both spring and sockeye salmon trolling.

The catch data were analyzed using the Chi-square test (Seigel, 1956; Larkin, 1977) and the Paired T-test (Rohlf and Sokal, 1969; Summers and Peters, 1973) was used to analyze the catch rate data.

III. Troll Catch Data and Chi-square Analyses

The null hypothesis proposed by this study is that there are no changes in troll success with different voltage conditions. Therefore, the ratio between the total treatment and control troll catches is expected to be 1.00 such that:

(2) H_O: Total Treatment Catch = Total Control Catch

Chi-square statistics were calculated by using the conventional equation for two-tailed tests:

$$(3)\quad \chi_{df=1\ 2\text{-}t} = \left[\frac{((|\text{Observed Catch} - \text{Expected Catch}|) - 0.5)^2}{\text{Expected Catch}} \right] 2$$

- where the Observed Catch can be either the treatment or control catch since the Expected Catch is equal to one half the summed catches for the treatment and control conditions, as indicated in equation (4).

$$(4)\quad \text{Expected Catch} = \frac{(\text{Treatment Catch} + \text{Control Catch})}{2}$$

Table 2 and 3 summarizes the Chi-square statistics and probabilities for both spring and sockeye salmon troll catches, respectively.

Troll capture of incidental target species O. kisutch occurred during the spring salmon trolling experiments. No statistical analyses were done on the catch data for coho salmon because of the small catches involved. Table 4 summarizes the incidental coho catches during the spring salmon trolling experiments.

O. tschawytscha were incidentally caught during the sockeye trolling experiments. Jack(precocious males) spring salmon were captured as well as the resident spring salmon. No analyses were done because the numbers of spring salmon captured incidentally during the sockeye trolling experiments were very low. Table 4b summarizes the catches of incidentally caught spring salmon during the sockeye salmon trolling experiments.

Interpretations

The resultant Chi-square statistics and probabilities, summarized in Table 2, show that certain voltage conditions change catches(by numbers of fish) of troll-caught spring salmon. All voltage tests except Test 3(+1.0 vs 0.0) show significant differences(probability <0.05) between treatment and control conditions.

Results for the polarity test(Test 4) between positive 0.5 volts and negative 0.5 volts suggest that the spring salmon troll catch for a positive 0.5 volts condition is significantly greater(probability <0.05) than the catch for a negative condition of the same voltage.

Table 2. A summary of Chi-square statistics and probabilities for different voltage conditions tested during spring salmon trolling.

Test	Fishing Time (hook hours)	Treatment Catch	Control Catch	Total Catch	Chi-square Statistic	Chi-square Probability
1. +0.5 vs 0.0	502.2	81	49	130	7.39*	<0.05
2. -0.5 vs 0.0	534.6	65	94	159	4.93*	<0.05
3. +1.0 vs 0.0	633.6	59	65	124	0.20	>0.05
4. +0.5 vs -0.5	505.8	147	109	256	5.35*	<0.05

* Significant at a 0.05 probability level

Table 3. A summary of catches (by numbers of fish) and the Chi-square statistics and probabilities for the voltage tests done during sockeye salmon trolling.

Test	Fishing Time (hook hours)	Treatment Catch	Control Catch	Total Catch	Chi-square Statistic	Chi-square Probability
1. -0.5 vs 0.0	465.0	78	72	150	0.17	>0.65
2. +1.0 vs 0.0	312.0	74	51	125	3.87*	<0.05
3. -1.0 vs 0.0	678.0	81	125	206	8.98*	<0.05
4. -2.0 vs 0.0	267.0	81	50	131	6.87*	<0.05
5. +0.5 vs 0.0	420.0	82	62	144	2.51	>0.10

* Significant at a 0.05 probability level

Table 4. Catches (by numbers of fish) of incidental troll-caught coho salmon during spring salmon trolling.

Test	Fishing Time (hook hours)	Treatment Catch	Control Catch	Total Catch
+0.5 vs - 0.5	505.8	57 (+0.5)	58 (-0.5)	115
-0.5 vs 0.0	534.6	17	22	39
+0.5 vs 0.0	502.2	1	2	3
+1.0 vs 0.0	633.6	0	2	2

It is interesting to note that, although the catch for positive 0.5 volts is greater than negative 0.5 volts, results from Test 1(+0.5 vs 0.0) indicate that the positive 0.5 volts condition has a higher troll catch than the control condition(0.0 volts) and Test 2(-0.5 vs 0.0)'s results suggest that the treatment condition of negative 0.5 volts has a lower troll catch than its paired control condition.

Results from the Chi-square analyses for target species _O. nerka_ were different than those results for _O. tschawytscha_ (Table 3). The range of voltages tested during sockeye salmon trolling was greater than that for spring salmon trolling. Voltage tests done during sockeye salmon trolling included both polarities of low voltages(+0.5,-0.5 volts), both polarities of higher voltages(+1.0,-1.0 volts) and an extreme high negative voltage(-2.0 volts).

The low voltage tests, Test 1(-0.5 vs 0.0) and Test 5(+0.5 vs 0.0), showed no significant differences(probability >0.05) in catches between treatment and control conditions. However, the high voltage tests, including Test 2(+1.0 vs 0.0), Test 3(-1.0 vs 0.0) and Test 4(-2.0 vs 0.0), suggest significant differences(probability <0.05) between paired treatment and control conditions. In contrast to the results for Test 3(-1.0 vs 0.0) during spring salmon trolling, the treatment condition of positive 1.0 volts(Test 2) showed a larger catch of sockeye salmon than the paired control condition. The treatment troll catch in Test 3(-1.0 vs 0.0) was significantly smaller than its paired control condition's catch. It was also interesting that the extreme negative voltage condition, negative 2.0 volts, showed a larger total catch than its corresponding zero volts control condition(Test 4).

A total of 159 coho salmon were captured during the spring salmon trolling experiments. The coho salmon usually ranged from 45 to 50 centimeters in total length and were found to be mostly age 3_2 fish (Milne, 1964b). The majority of the incidental target fish were captured during the two early spring salmon troll experiments. These experiments included positive 0.5 vs negative 0.5 volts being tested on 20 March to 24 March and negative 0.5 vs zero volts being tested on 6 April to 10 April. There seems to be no apparent differences in the incidental catches of coho salmon for paired conditions in the early experiments done. The later two experiments did not show any significant catches of incidental target species *O. kisutch*.

IV. Catch Rate Data and Paired T-test Analyses

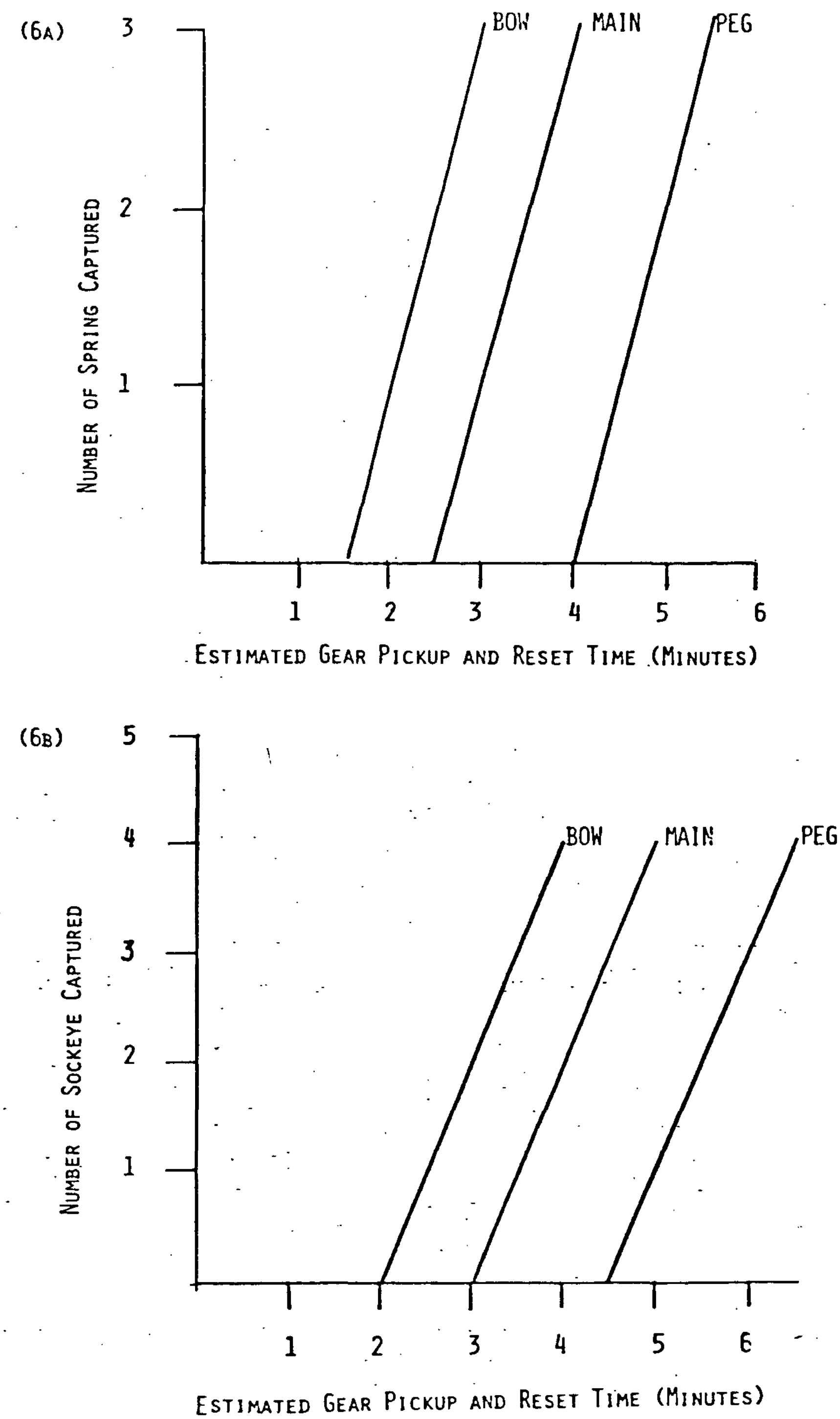
Catch success may be also estimated by troll catch rate. The problem investigated by this study may be presented as whether different voltage conditions affect the troll catch rate of target species *O. tschawytscha* and *O. nerka*. The null hypothesis for this type of analytical approach would state that no differences exist between troll catch rates for paired treatment and control voltage conditions such that:

$$(5) \quad H_0 : \mu\,(\text{Treatment}) = \mu\,(\text{Control})$$
$$\text{and} \quad \mu\,(\text{Difference}) = 0.0$$

IVa. Estimation of Troll Catch Rates

The salmon troll catch data were recorded by time and it was possible to group the catch data into approximate one-hour fishing trials. The control and treatment conditions for each fishing trial were then represented by a pair of actual catch rates. The actual catch rate is the number of target fish caught divided by the actual fishing time for the particular fishing trial. The actual fishing time is the difference between the total time of the fishing trial(approximately one hour) and the time when the fishing gear is not fully effective. The fishing gear is not fully effective when part of the gear is retrieved and reset during apparent fish captures. The time spent retrieving and resetting gear depends on several factors; the number of terminal gear used, the particular line involved(bow, main, peg) and the number of fish caught at any one retrieval(single or multiple captures). The terminal gear arrangement and the number of terminal gear used for spring and sockeye salmon are different. Retrieval and reset times for different numbers of fish caught per line, for different lines, for both target species were measured. Average time measurements were then estimated for different types and numbers of captures. Figure 6 includes graphs describing the estimated retrieval and reset times for target spring and sockeye salmon.

FIGURE 6. ESTIMATED TIME TAKEN TO RETRIEVE AND RESET THE GEAR FOR CAPTURE(S) OF SPRING SALMON (FIGURE 6A) AND SOCKEYE SALMON (FIGURE 6B) FOR DIFFERENT FISHING LINES.



Since the original catch data were recorded by time and line, the non-effective fishing time could be estimated using Figure 6a for spring salmon trolling and Figure 6b for sockeye salmon trolling. The non-effective fishing time is the length of time period when only one-third of the gear is not effective because each gurdy system can only retrieve one line at a time(the total number of gurdy spools used is three per side). Thus, each gear retrieval and re-set causes one-third of the entire gear for that condition(control or treatment) to be ineffective.

The fishing effort unit was standardized to one hook hour. One hook hour is the product of one hook(one set of terminal gear) and one hour of continuous fishing. In spring salmon trolling each condition has three lines each bearing three sets of terminal gear, therefore, the total fishing effort is nine hook hours after one hour of continuous fishing. In contrast, the total fishing effort is fifteen hook hours after one hour of continuous fishing in sockeye salmon trolling because each condition has three lines, each bearing five sets of terminal gear.

In spring salmon trolling, since the total number of hooks is nine and during an apparent capture three hooks are retrieved and reset such that:

(6) Actual Spring catch rate =

$$\frac{\text{(Number of Spring caught during the fishing trial)}}{\text{(9 hooks x total length of trial)} - \text{(3 hooks x gear pickup time)}}$$

In contrast, sockeye salmon trolling uses a total of fifteen sets of terminal gear, each line dragging five sets of gear such that:

(7) Actual Sockeye catch rate =

$$\frac{\text{(Number of Sockeye caught during the fishing trial)}}{\text{(15 hooks x total length of trial)-(5 hooks x gear pickup time)}}$$

Appendix V includes a set of equations which summarizes the estimation of actual catch rates for each condition (control and treatment) during a fishing trial.

Each fishing trial was represented by a pair of actual catch rates, one for the treatment condition and the other for the control condition. Acceptance as a valid set of observations required the fishing trial to meet two conditions. Firstly, a trial which had zero catch rates for both conditions was rejected as a valid set of observations. It was assumed that trials with zero catch rates were trials during which no available target fish were within the range of the trolling gear. The second condition required that the fishing trial be no less than fifty minutes in total duration. The fishing trials were grouped into times of day ranging from 0700-0759 to 1400-1459. It was often not possible to begin and finish fishing trials at desired times of the day and some trials were rejected as valid sets of observations. A total of 10 trials were rejected as invalid sets of observations during the spring salmon trolling experiments, including Test 1(5), Test 2(2), Test 3(2) and Test 4(1). In sockeye salmon trolling a total of 19 trials were rejected, including Test 1(3), Test 2(2), Test 3(6), Test 4(2) and Test 5(6).

IVb. Goodness of Fit for Various Types of Distributions

Goodness of fit tests(G-tests) were done on the distribution of catch rate differences which were transformed to logarithms base 10. A library computer program was used to test for five different types of distributions; the Normal Distribution, the Poisson Distribution, the Binomial Distribution, the Negative Binomial Distribution and the Gamma Distribution. The goodness of fit for each distribution was calculated by the Chi-Square and Kolmogorov-Smirnov tests. The calculated Chi-Square and Kolmogorov-Smirnov statistics and their appropriate probabilities for the different tests in the spring and sockeye salmon experiments are included in Tables 5 and 6, respectively.

Interpretations

The calculated G-statistics for the distributions of logarithmic transformed catch rate differences of all the voltage potential conditions tested in both the spring and sockeye salmon experiments suggest that the distributions closely follow the Normal Distribution rather than the other types of distribution tested.

The G-test statistics for the distributions of the catch rate differences for tests done during the sockeye salmon experiment (Table 6) shows a number of tests where the sample sizes are small. In such cases, the Chi-Square test was regarded as invalid because of the adjusted degrees of freedom being less than zero. A Kolmorgorov-Smirnov test was done together with the Chi-Square test and has the advantage of providing a goodness of fit statistic when the sample size is small.

Table 5. A summary of Chi-square statistics and probabilities calculated by the goodness of fit tests. The G-tests were done to determine whether differences in spring salmon troll catch rates were normally distributed.

Test	Number of Valid Differences	Chi-square Statistics	Chi-square Probabilities
1. +0.5 vs 0.0	29	1.87	0.60
2. -0.5 vs 0.0	26	1.37	0.51
3. +1.0 vs 0.0	26	2.69	0.44
4. +0.5 vs -0.5	26	2.24	0.33

Table 6. A summary of the Chi-square and Kilmogorov-Smirnov statistics and probabilities used to determine the goodness of fit with the normal distribution for differences in sockeye troll catch rates.

Test	Number of Valid Differences	CHI-SQUARE Statistic	CHI-SQUARE Probability	KOLMOGOROV-SMIRNOV Statistic	KOLMOGOROV-SMIRNOV Probability
1. -0.5 vs 0.0	13	1.91	0.17	0.13	>0.20
2. +1.0 vs 0.0	10	--	--	0.13	>0.20
3. -1.0 vs 0.0	21	0.79	0.67	0.07	>0.20
4. -2.0 vs 0.0	8	2.18	0.14	0.12	>0.20
5. +0.5 vs 0.0	11	--	--	0.14	>0.20

By analyzing the Kolmorgorov-Smirnov statistics it seemed reasonable to assume that the distribution of catch rate differences for sockeye salmon was normally distributed.

IVc. Statistical Analyses for Differences in Catch Rates Between Treatment and Control Conditions

The paired t-test was used to test for significant differences in catch rates between treatment and control conditions for different types of voltage potentials. The fishing trials were assumed to be independent of each other and differences in control and treatment catch rates were found to closely follow the normal distribution (probability 0.01) after logarithmic transformation ($\log(x+c)$, $c=1.00$).

Tables 7 and 8 summarizes the t-statistics and t-probabilities for the differences between actual catch rates for the treatment and control conditions for the different voltage potentials tested during the spring and sockeye salmon trolling experiments, respectively.

Interpretations

The paired t-test analyses using differences in catch rates, during both the spring and sockeye salmon trolling experiments, seem to suggest similar results as those derived from the catch data (Section III). It is important to note that, although catch (by numbers of fish) analyses utilizes all the catch data, analyses using catch rate data disqualifies a number of observation sets as being valid, as discussed in Section IV.

Table 7. A summary of t-statistics and t-probabilities for voltage tests done during spring salmon trolling.

Test	Number of Valid Observations	$t_{statistic}$	$t_{probability}$
1. +0.5 vs 0.0	29	2.89*	0.01
2. -0.5 vs 0.0	26	-1.91**	0.07
3. +1.0 vs 0.0	26	-0.04	0.97
4. +0.5 vs -0.5	26	2.73*	0.01

Table 8. A summary of t-statistics and t-probabilities for voltage tests done during sockeye salmon trolling.

Test	Number of Valid Observations	$t_{statistic}$	$t_{probability}$
1. -0.5 vs 0.0	13	0.28	0.78
2. +1.0 vs 0.0	10	2.48*	0.04
3. -1.0 vs 0.0	21	-3.16*	0.01
4. -2.0 vs 0.0	8	1.77	0.12
5. +0.5 vs 0.0	11	0.30	0.77

*Significant at a 0.05 probability level
**Significant at a 0.10 probability level

Results for voltage tests done during spring salmon trolling suggest that positive 0.5 volts has significantly higher (probability <0.05) catch rates than the control condition. It is also suggested that the negative 0.5 volts condition has lower catch rates than the control condition (probability <0.10). The high positive condition of 1.0 volts and its paired control condition show no significant difference (probability >0.05) in catch rates.

Similar results were found using catch rates instead of catch for voltage tests done on target sockeye salmon. It is, however, interesting that results for Test 4 (-2.0 vs 0.0) indicate a >0.05 probability that the catch rates for treatment and control conditions are significantly different whereas the results for the catch data suggest significant differences at a probability <0.05.

V. The Effect of Voltage Conditions on Troll Success for Different Ocean Age Groupings.

Va. Target Species (*O. tschawytscha*)

1. Ocean Age Classes

Target spring salmon captured during the trolling experiment ranged in total length from 30 to 80 centimeters. It has been shown that trolling gear captures spring salmon from a range of different ages (Argue, Marshall, Coursley, 1977). Further statistical analyses were done on catch rates for different ages of spring salmon to determine whether the effects of voltage conditions on spring salmon troll success are age-selective.

An ocean age-total length regression was calculated by using total length measurements and corresponding scale readings. Only ocean ages were read from the scales because most chinook salmon in the Strait of Georgia spend only one year in freshwater(Milne and Ball, 1958; Argue, Marshall, Coursley, 1977) and the ocean age may be an index to the extent of 'experience' gained by the fish on encountering troll gear. Reactions towards different fishing conditions may be a form of learned behaviour and, therefore, ocean age was assumed to be an index of the extent of the target fish's experience.

A total of 238 sets of spring salmon scales were used for establishing a functional ocean age-total length regression(Koo, 1962; Bilton and Shepard, 1964). Twenty-two sets of scales were rejected as valid observations for age-length data because of either being regenerated, unreadable or because of lack of agreement on the same age.

Regression analyses were done on each sex separately and equations 9 and 10 describe the functional regressions for male and female spring salmon, respectively(see Figure 7). Logarithmic transformation to the base 10 was made to both the ocean age and total length data. The calculated regressions for both male and female spring salmon were significant(probability <0.05).

$$\text{(9)} \quad \text{LOG } Y = 1.522 + 0.5268 \times \text{LOG } X \quad \text{(MALE)}$$

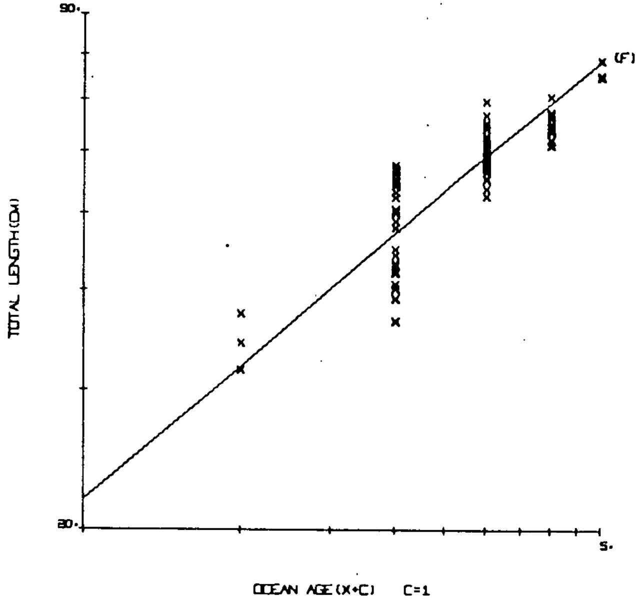
$$\text{(10)} \quad \text{LOG } Y = 1.507 + 0.5548 \times \text{LOG } X \quad \text{(FEMALE)}$$

A covariance analysis was done to determine whether or not the functional regressions for male and female spring salmon were significantly different. The results of the covariance analysis are summarized in Table 9.

Figure 7: Functional regressions for ocean age-total length relationship in troll-caught spring salmon (male, female, combined).

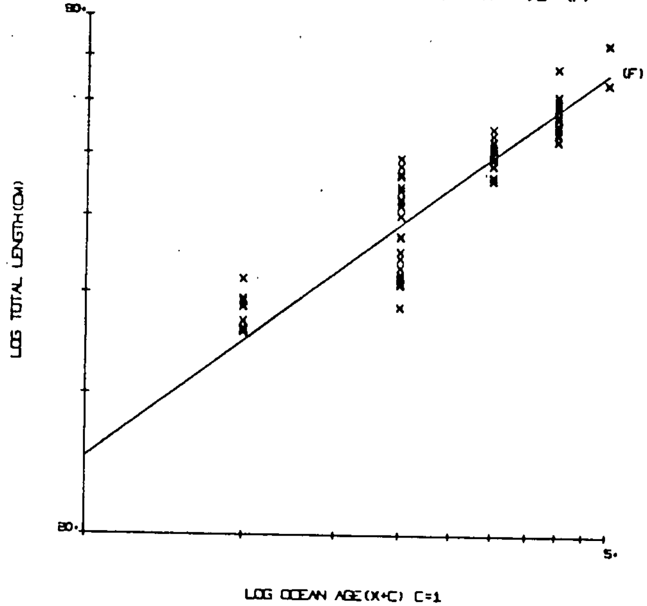
OCEAN AGE - TOTAL LENGTH RELATIONSHIP FOR SPRING SALMON (FEMALE ONLY)

LOG Y = 1.507 + 0.5548 * LOGX N = 119 (F)



OCEAN AGE - TOTAL LENGTH RELATIONSHIP FOR SPRING SALMON (MALE ONLY)

LOG Y = 1.543 + 0.4888 * LOGX N = 79 (F)



OCEAN AGE - TOTAL LENGTH RELATIONSHIP FOR SPRING SALMON (MALE AND FEMALE)

LOG Y = 1.530 + 0.5096 * LOGX N = 238 (F)

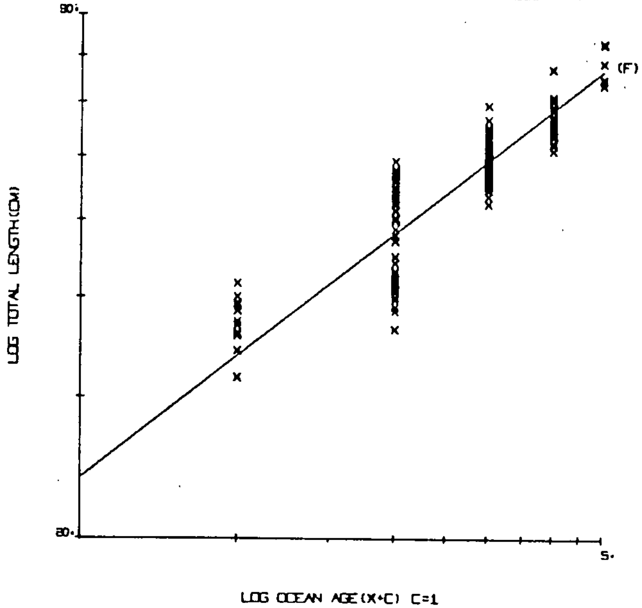


Table 9a. A summary of ocean age-total length regression statistics for troll-caught O. tschawytscha

Log x vs Log y: $y = a + b(x - \bar{x})$

Sex	a	b	$\bar{x}$	N	s.e. of b	F-statistics	F-probability
Male	1.75	0.53	0.43	98	0.026	307.4	>0.05
Female	1.75	0.55	0.45	119	0.026	343.8	>0.05
Combined	1.75	0.51	0.43	238	0.016	797.8	>0.05

Table 9b. A summary of the covariance statistics for male and female regression lines.

Source of Variation	Variance (male)	Variance (female)	F-statistic	F-probability
Difference in Slopes (b)	6.68×10^{-3}	6.68×10^{-3}	1.00	>0.05
Difference in Intercepts (a)	0.145×10^{-4}	0.103×10^{-4}	1.41	>0.05

No significant differences were found between the two functional regressions in slopes or intercepts. The ocean age-total length data for both sexes were then combined to form a common functional regression(Equation 11) which was also significant(probability <0.05).

(11) $\text{LOG } Y = 1.530 + 0.5096 \times \text{LOG } x$ (COMBINED)

Regression equation 11 was used to calculate the ranges of total length for the different ocean ages, and are included in Table 10.

The ocean age is designated by a European method where the dot specifies marine age only and the Arabic numeral indicates the number of winters which the fish has spent in the ocean(Koo, 1962).

The catch data for ocean ages of spring salmon, varying from .+ to .4+ years old, for different voltage tests are summarized in Table 11. The calculated Chi-square statistics and probabilities for the different ocean age classes are also included in Table 11.

The results of the paired t-tests for testing differences in catch rates for troll-caught spring salmon, grouped by ocean age, are summarized in Table 12.

Interpretations

Analyses on differences in troll success for individual ocean age classes of spring salmon, between treatment and control conditions, were done using both catch data and catch rate data. However, analyses were restricted to only certain ocean age classes because of small sample sizes(see Tables 11 and 12).

Table 10. A summary of the estimated ranges of total body length for ocean ages .+ to .4+ in troll-caught spring salmon (Georgia Strait).

Ocean Age Class	Total body Length (cm.)
.+	<41.7
.1+	41.7 - 54.0
.2+	54.1 - 64.1
.3+	64.2 - 72.9
.4+	73.0 - 83.0

Table 11. A summary of Chi-square statistics and probabilities for different voltage conditions tested during spring salmon trolling, catches (by numbers of fish) are grouped into ocean ages.

Test	Ocean Age Class	Fishing Time (hook hours)	Treatment Catch	Control Catch	Total Catch	Chi-square Statistic	Chi-square Probability
	.+		26	21	47	0.34	>0.50
	.1+		13	7	20	--	--
1.	.2+		32	15	47	5.45*	<0.02
+0.5 vs 0.0	.3+	502.2	9	5	14	--	--
	.4+		1	1	2	--	--
	ALL		81	49	130	7.39*	<0.01
	.+		28	31	59	0.02	>0.80
	.1+		9	8	17	--	--
2.	.2+		21	41	62	5.82*	<0.02
-0.5 vs 0.0	.3+	534.6	6	13	19	--	--
	.4+		1	1	2	--	--
	ALL		65	94	159	4.93*	<0.05
	.+		28	24	52	0.01	>0.80
	.1+		9	7	16	--	--
3.	.2+		19	25	44	0.03	>0.80
+1.0 vs 0.0	.3+	633.6	3	8	11	--	--
	.4+		0	1	1	--	--
	ALL		59	65	124	0.20	>0.50
	.+		13	17	30	0.30	>0.50
	.1+		25	15	40	2.03	>0.10
4.	.2+		102	67	169	6.84*	<0.01
+0.5 vs -0.5	.3+	505.8	7	9	16	--	--
	.4+		0	1	1	--	--
	ALL		147	109	256	5.35*	<0.05

*Significant at a 0.05 probability level

Table 11a. A summary of Chi-square statistics and probabilities from Table 11 for those ocean age groups with adequate sample sizes during spring salmon trolling.

Test	Ocean Age Class	Chi-square Statistic	Chi-square Probability
1.	.+	0.34	>0.50
+0.5 vs 0.0	.2+	5.45*	<0.02
	ALL	7.39*	<0.01
2.	.+	0.02	>0.80
-0.5 vs 0.0	.2+	5.82*	<0.02
	ALL	4.93*	<0.05
3.	.+	0.01	>0.80
+1.0 vs 0.0	.2+	0.03	>0.80
	ALL	0.20	>0.50
4.	.+	0.30	>0.50
+0.5 vs -0.5	.1+	2.03	<0.20
	.2+	6.84*	<0.01
	ALL	5.35*	<0.05

*Significant at a 0.05 probability level

Table 12. A summary of t-statistics and t-probabilities for different voltage conditions tested during spring salmon trolling, catch data were based on actual catch rates.

Test	Ocean Age Class	$t_{statistic}$	$t_{probability}$	Number of Valid Observations
	.+	0.75	0.46	20
	.1+	0.88	0.40	11
1.	.2+	5.06*	0.0001	18
+0.5 vs 0.0	.3+	0.36	0.74	6
	.4+	0.04	0.97	2
	ALL	2.89*	0.01	29
	.+	0.48	0.64	19
	.1+	-0.11	0.92	11
2.	.2+	-2.08*	0.05	19
-0.5 vs 0.0	.3+	-1.53	0.15	12
	.4+	0.04	0.97	2
	ALL	-1.91**	0.07	26
	.+	-1.35	0.19	20
	.1+	-0.46	0.66	10
3.	.2+	-0.78	0.45	20
+1.0 vs 0.0	.3+	-1.44	0.19	8
	.4+	--	--	1
	ALL	-0.04	0.97	26
	.+	-0.24	0.81	16
	.1+	1.04	0.31	20
4.	.2+	2.37*	0.03	26
+0.5 vs -0.5	.3+	-0.74	0.49	8
	.4+	--	--	1
	ALL	2.73*	0.01	26

*Significant at a 0.05 probability level

**Significant at a 0.10 probability level

The restriction was mainly on the catch data because, when df=1, the total number of observations should be at least 25 and the expected number in each category ≥ 5 for Chi-square analyses(Larkin, 1977).

A common observation in all voltage tests is that the .+ ocean age class, or target fish which have not yet spent one full year in the ocean, show no significant difference in troll success between treatment and control conditions(Chi-probability >0.05 and t-probability >0.05).

Low troll catches of .1+ year old spring salmon restricted Chi-square analyses to only one voltage test, Test 4(+0.5 vs -0.5). The results for Test 4(+0.5 vs -0.5) show that troll successes due to different polarities of 0.5 volts show no significant difference (Chi-probability >0.05). The paired t-test analyses for the .1+ ocean age class show no significant differences(probability >0.05) in all voltage tests, including Test 4(+0.5 vs -0.5). However, small sample sizes for Test 1(+0.5 vs 0.0),Test 2(-0.5 vs 0.0) and Test 3(+1.0 vs 0.0) may be an important factor in the t-test results.

The results for the .2+ ocean age class, in both the catch data and catch rate data analyses, show significant differences(Chi-probability <0.05 and t-probability ≤ 0.05) between paired treatment and control conditions in all voltage tests except Test 3(+1.0 vs 0.0). The positive 0.5 volts condition had a significantly higher troll success for .2+ year olds than the negative 0.5 volts condition. The results for Test 3(+1.0 vs 0.0) suggest no significant differences in troll success(Chi-probability >0.05 and t-probability >0.05).

Very low troll catches of older spring salmon, .3+ and .4+ years old, were made. The low catches provided only small numbers of observations for the catch data and small sample sizes for the catch rate data. Chi-square analyses were not done on the .3+ and .4+ ocean age classes for any of the voltage tests, as indicated in Table 11. It should be noted that only small sample sizes for .3+ and .4+ year olds were available for the paired T-test analyses.

2. Combined Ocean Age Groupings

Sample sizes for several individual ocean age classes were inadequate in each voltage test done during the spring salmon trolling experiments. This can be observed in Table 11 which shows the number of captured target fish for each particular ocean age class. Low numbers of .1+, .3+, and .4+ year old spring salmon were caught whereas high numbers of .+ and .2+ year olds were caught during the voltage tests. Therefore, it seemed reasonable to combine individual ocean age classes to provide age groupings with larger sample sizes(Larkin, 1977). By analyzing the ocean age composition of the troll catch, it seemed reasonable to combine the individual ocean ages into two groups. Group I consists of younger fish which were .+ and .1+ ocean years old, and Group II includes older fish from .2+ to .4+ years old. Table 13 shows that this particular combination of ocean age classes divided the total troll catch into approximately two equal groups for all tests except for Test 4(+0.5 vs -0.5) where the younger fish(Group I) made up 28.5 % of the total troll catch and the older fish(Group II) represented 71.5 % of the total troll catch.

Chi-square tests were repeated on the catch data for the combined ocean age classes and the calculated Chi-statistics and probabilities are summarized in Table 14.

Inadequate numbers of valid sets of observations, due to low catches of target fish for several ocean age classes, made it desireable to also combine ocean age classes for the catch rate data. Table 12 shows the small numbers of valid observations for several of the individual ocean age classes. Therefore, the catch rate data was also divided into two ocean age groupings, each with a larger sample size.

Analyses using the paired t-test were done on the combined age groupings, and Table 15 summarizes the resultant t-statistics and t-probabilities.

Table 13. A summary of percentages of troll catches for two combined age groups (Group I and Group II) and catch data (by numbers of fish) for each age group during spring salmon trolling.

Test	Ocean Age Group (combined)[1]	Treatment Catch	Control Catch	Summed Group Catch	% of Total Catch
1.	I	39	28	67	51.5
+0.5 vs 0.0	II	42	21	63	48.5
2.	I	37	39	76	47.8
-0.5 vs 0.0	II	28	55	83	52.2
3.	I	37	31	68	54.8
+1.0 vs 0.0	II	22	34	56	45.2
4.	I	38	32	70	27.3
+0.5 vs -0.5	II	109	77	186	72.7

[1] Note: Group I includes .+, .1+ year olds and Group II includes .2+, .3+, .4+ year olds.

Table 14. A summary of Chi-square statistics and probabilities for combined ocean age groups for spring salmon troll catches (by numbers of fish).

Test	Ocean Age Group (combined)	Chi-square Statistic	Chi-square Probability
1.	I	1.49	>0.20
+0.5 vs 0.0	II	6.35*	<0.02
2.	I	0.01	>0.90
-0.5 vs 0.0	II	8.14*	<0.01
3.	I	0.37	>0.50
+1.0 vs 0.0	II	2.16	>0.10
4.	I	0.36	>0.50
+0.5 vs -0.5	II	5.17*	<0.05

*Significant at a 0.05 probability level

Table 15. A summary of t-statistics and t-probabilities for combined ocean age groups for spring salmon catch rate data. Group I includes .+ and .1+ ocean year olds and Group II includes .2+, .3+, .4+ year olds.

Test	Ocean Age Group (combined)	Number of Valid Observations	$t_{statistic}$	$t_{probability}$
1.	I	26	1.35	0.19
+0.5 vs 0.0	II	18	4.13*	0.001
2.	I	21	0.24	0.81
-0.5 vs 0.0	II	21	-2.37*	0.03
3.	I	22	-1.32	0.20
+1.0 vs 0.0	II	22	-1.33	0.20
4.	I	24	0.81	0.43
+0.5 vs -0.5	II	26	1.97**	0.06

*Significant at a 0.05 probability level

**Significant at a 0.10 probability level

Interpretations

The catch data and catch rate data for combined ocean age groupings, Group I and Group II, seem to suggest that troll success for the younger half of the troll spring salmon catch(.+,.1+ years old) does not differ significantly(Chi-square probability >0.05 and t-probability >0.05) between treatment and control voltage conditions in Test 1(+0.5 vs 0.0), Test 2(-0.5 vs 0.0) and Test 4(+0.5 vs -0.5). However, in contrast, the older half of the catch(.2+,.3+ and .4+) for the forementioned tests show significant differences in troll success(Chi-square probability <0.05 and t-probability <0.10). Higher catches of older target fish were observed in the positive 0.5 volts condition and lower catches in the negative 0.5 volts condition relative to their paired control conditions.

Test 3(+1.0 vs 0.0) shows no significant difference in troll success between treatment and control conditions for ocean age group I(Chi-square probability >0.05 and t-probability >0.05) and ocean age group II(Chi-square probability >0.05 and t-probability >0.05).

Vb. Target Species (*O. nerka*)

The troll-caught sockeye were mainly from the Adams River stock, verified by the Federal Fisheries Department. These sockeye were assumed to be four years in total age(cycle year). Therefore, similar age analyses done on spring salmon were not done on the troll-caught sockeye salmon.

VI. The Effect of Voltage Conditions on the Size Frequency Distributions of Spring Salmon

VIa. Comparison of Central Tendencies using the Median

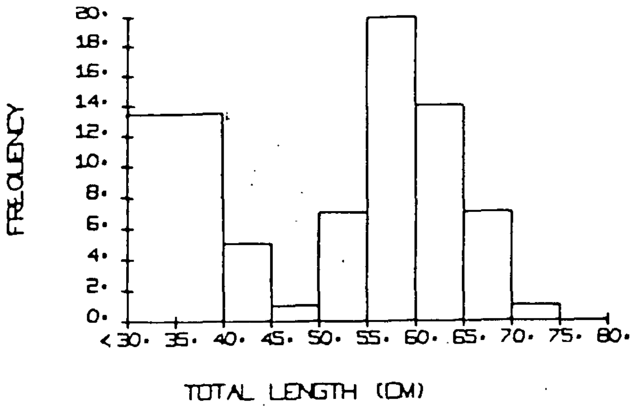
Analyses were also done to determine whether the effects of weak electrical fields on troll success are size-selective, such as in strong electrical fields used for electro-fishing(Meyer-Waarden, 1957, Vibert, 1967). Size frequency distributions for each voltage test's treatment and control troll catches were statistically tested for differences.

Normally symmetric size frequency distributions are commonly characterized by their mean sizes and variances. However, by observing Figure 8, this study's size frequencies show asymmetrical distributions which tend to be skewed to the left. In such cases of asymmetric distributions, the median rather than the mean is a more representative measurement of central tendency(Rohl and Sokal, 1973). Stray high or low points tend to over-estimate or under-estimate the central tendency when the mean is used.

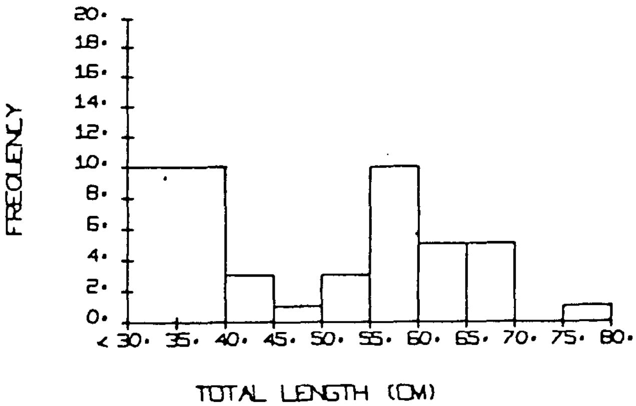
Therefore, the common medians for the control and treatment conditions for the voltage tests were calculated. The number of observations with total lengths above and below each respective common median were counted for each voltage test. The Median Test was then used to test whether the distributions for each set of conditions, treatment and control, differed in central tendency(Seigel, 1956).

Figure 8: Size frequency distributions for treatment and control catches in Test 1 to 4 during the spring troll experiments.

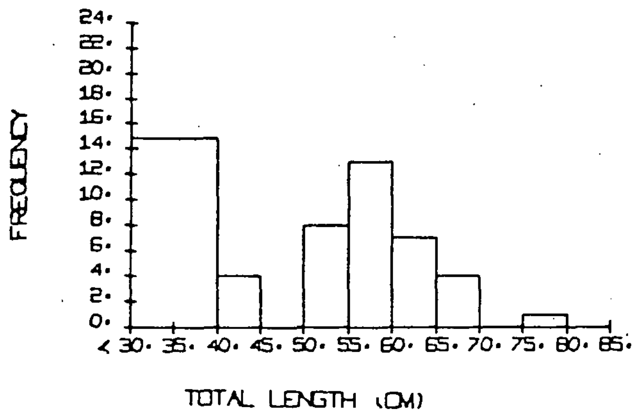
TEST 1 TREATMENT (+0.5 VOLTS) CATCH



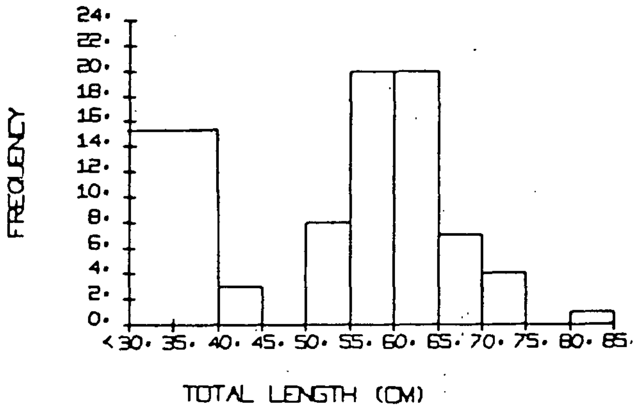
CONTROL (0.0 VOLTS) CATCH



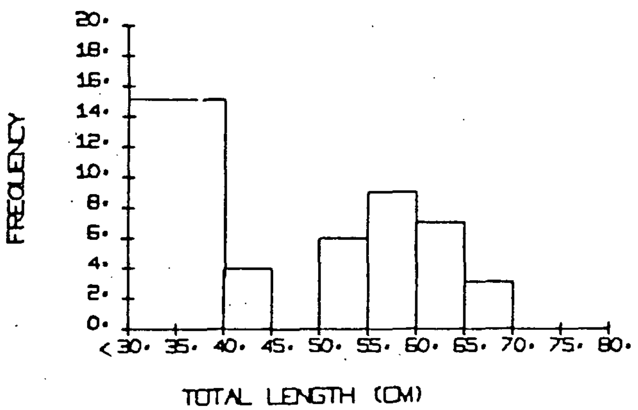
TEST 2 TREATMENT (-0.5 VOLTS) CATCH



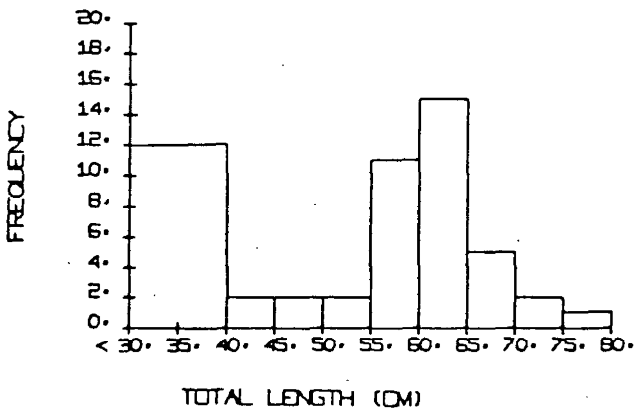
CONTROL (0.0 VOLTS) CATCH



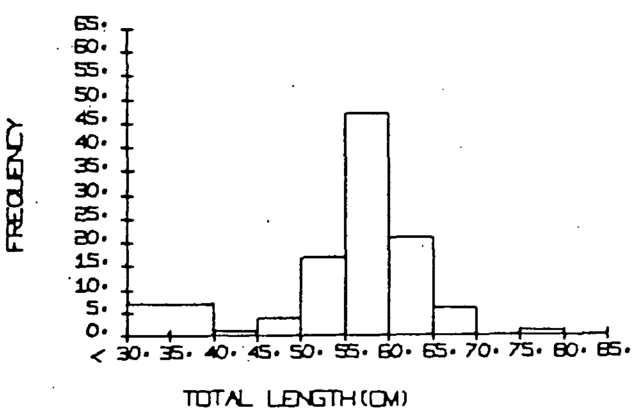
TEST 3 TREATMENT (+1.0 VOLTS) CATCH



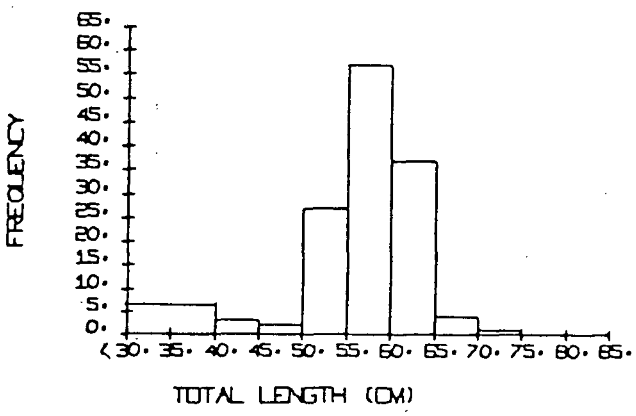
CONTROL (0.0 VOLTS) CATCH



TEST 4 TREATMENT (-0.5 VOLTS) CATCH



TREATMENT (+0.5 VOLTS) CATCH



The median is also more appropriate than the mean for this particular study because troll-caught spring salmon less than 40 centimeters were mostly categorized as grilse. Therefore, since all the voltage tests have common medians greater than 40 cm, the entire troll catch data can be used with the spring salmon grilse ranking as the first part of the range of total lengths.

Table 16 summarizes the calculated medians for each voltage condition and the common median for each voltage test. Table 17 includes the calculated Chi-square statistics and probabilities for the Median Tests done on each voltage test.

Interpretations

A commmon observation is that the larger total length median occurs with the higher troll success. However, the Chi-statistics calculated for the Median Test(Table 17) suggest that the medians for the paired conditions do not differ(Chi-probability >0.10) in all the voltage tests done.

VIb. Analyses using Means and Variances for Spring Salmon at Least One Ocean Years Old

It was also decided that analyses on comparing mean sizes of troll catches would be done on spring salmon at least one ocean years old(≥ 47.1 centimeters in total length). These analyses would exclude the spring salmon grilse and also provide normally symmetric size frequencies for all the voltage tests done.

The mean sizes between treatment and control conditions for each voltage test were analyzed statistically by the t-test. The variances were also calculated and tested for significant differences using a F-test.

Table 16. A summary of the statistics used in the Median Tests for the Total Length Size Distributions of each voltage test.

Test	Condition	Number of Observations	Median (cm)	Common Median (cm)	Above Common Median	Below Common Median
1. +0.5 vs 0.0	Treatment	81	55.2	53.1	43	38
	Control	49	45.2		21	27
2. -0.5 vs 0.0	Treatment	65	47.6	54.3	25	39
	Control	94	56.1		39	52
3. +1.0 vs 0.0	Treatment	59	40.8	46.1	38	27
	Control	64	55.8		34	25
4. +0.5 vs -0.5	Treatment (+0.5)	147	57.1	57.0	72	70
	Treatment (-0.5)	109	56.7		55	53

Table 17. A summary of calculated Chi-square statistics and probabilities for Median tests done on spring salmon catch (by numbers of fish). The number of valid observations does not include those observations with total lengths equalling the median.

Test	Number of Valid Observations	Chi-square Statistic	Chi-square Probability
1. +0.5 vs 0.0	129	0.50	0.49
2. -0.5 vs 0.0	155	0.09	0.75
3. +1.0 vs 0.0	124	0.01	0.89
4. +0.5 vs -0.5	250	0.01	0.89

Table 18. A summary of mean total lengths and variances for each condition's troll catch. The mean total lengths were calculated on spring salmon at least 1 ocean years old ($\geq$ 47.1 cm).

Test	Condition	Number of Observations	Mean Total Length (cm)	t statistic	t probability	Variance	F-Statistic	F-Probability
1. +0.5 vs 0.0	Treatment	56	57.0	0.38	>0.05	108.0	1.71	>0.05
	Control	29	56.0			185.1		
2. -0.5 vs 0.0	Treatment	31	54.4	-1.55	>0.05	153.8	1.09	>0.05
	Control	40	58.9			141.7		
3. +1.0 vs 0.0	Treatment	38	55.7	-1.42	>0.05	139.3	1.36	>0.05
	Control	64	58.9			102.3		
4. +0.5 vs -0.5	Treatment (+0.5)	131	57.2	0.20	>0.05	45.1	1.30	>0.05
	Treatment (-0.5)	98	57.0			58.8		

Table 18 summarizes each condition's mean size and variance. The t-statistics and F-statistics with their respective probabilities are also included in Table 18.

Interpretations

Results from Table 18 suggest troll-caught spring salmon at least one ocean years old show no significant difference in mean total length(t-probability >0.05). The calculated F-statistics also suggest that the variability of total length for troll catches of the paired conditions are not significantly different(F-probability >0.05) for spring salmon at least one ocean years old.

VII. Correlation Analyses Between Effect of Voltage Conditions and Available Fish Density

Many commercial trollers claim that the density of available target fish affects the change in catch success, caused by the electrical phenomenon investigated in this study. Russell (1977) states that a trolling wire having a positive voltage will catch more fish than one with a neutral or negative voltage, especially during "scratch" fishing conditions. He does not clearly state whether or not this density effect is common among all troll-caught salmon species.

Data taken during this study were used to analyze whether the density of available target fish affects the difference in catch rate caused by different voltage conditions for troll-caught spring and sockeye salmon.

The available fish density was assumed to be the number of fish within the fishing range of the troll gear and catch per unit effort(CPUE) was assumed to be a valid index of available fish density. Independence between CPUE and effort was established for both spring and sockeye trolling, based on correlation and regression analyses done on sample spring and sockeye troll data.

The troll catch rates for the hourly fishing trials were used for the correlation analyses between the effect of voltage conditions and available fish density. The difference in the paired catch rates for treatment and control conditions was used as an index for the effect of a particular voltage condition. The same pair of catch rates was also summed to provide an index for available fish density. Scatter diagrams for troll-caught spring salmon were done for each voltage test, including separate diagrams for all Ages, Group I and Group II target fish(Figures 9,10,11,12). Scatter diagrams for troll-caught sockeye were also done for all voltage tests and are included in Figure 13.

Correlation analyses were done on troll-caught spring(all ages) and sockeye salmon for all voltage tests and the results are summarized in Tables 19 and 20, respectively. Regression analyses were also done and summaries of the probabilities for the calculated regression lines are included in Tables 21 and 22.

Table 19. A summary of r-statistics and r-probabilities for analyses correlating Effect and Fish density using the catch rate data for spring salmon trolling

Test	Number of Sets of Observations	^{r}statistic	^{r}probabilities
1. +0.5 vs 0.0	29	0.22	>0.05
2. -0.5 vs 0.0	26	0.38	>0.05
3. +1.0 vs 0.0	26	0.05	>0.05
4. +0.5 vs -0.5	26 (25)	0.03 (0.42*)	>0.05 (0.04)

Table 20. A summary of r-statistics and r-probabilities for analyses correlating Effect and Fish density using the catch rate data for sockeye salmon trolling.

Test	Number of Sets of Observations	^{r}statistic	^{r}probability
1. -0.5 vs 0.0	13	0.66*	0.02
2. +1.0 vs 0.0	10	0.43	>0.10
3. -1.0 vs 0.0	21	0.26	>0.10
4. -2.0 vs 0.0	8	0.43	>0.10
5. +0.5 vs 0.0	11	0.40	>0.10

*Significant at a 0.05 probability level

Table 21. A summary of probabilities for the regression analysis done using the spring salmon catch rate data.

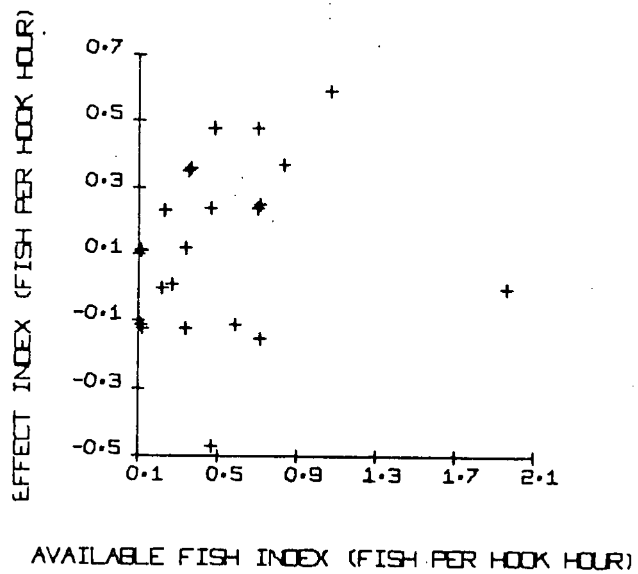
Test	Number of Observations	Probability (H_o: b = 0)
1. +0.5 vs 0.0	29	>0.05
2. -0.5 vs 0.0	26	>0.05
3. +1.0 vs 0.0	26	>0.05
4. +0.5 vs -0.5	26	>0.05

Table 22. A summary of probabilities for the regression analyses done using the sockeye salmon catch rate data.

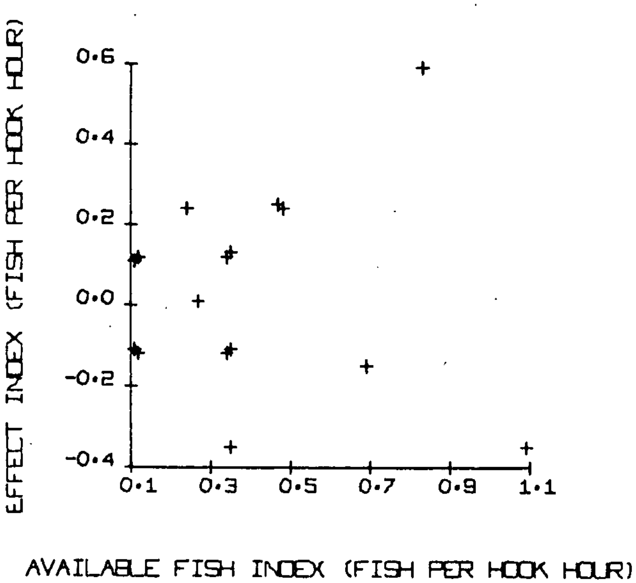
Test	Number of Observations	Probability (H_o: b = 0)
1. -0.5 vs 0.0	13	0.02
2. +1.0 vs 0.0	10	>0.05
3. -1.0 vs 0.0	21	>0.05
4. -2.0 vs 0.0	7	0.04
5. +0.5 vs 0.0	11	>0.05

Figure 9: Scatter diagrams showing the relationship between the Effect Index and Available Fish Index for Test 1 (+0.5 vs 0.0 volts). Functional equations are included in cases where regressions were found to be significant (probability 0.05).

+0.5 VS 0.0 VOLTS (ALL AGES)



+0.5 VS 0.0 VOLTS (.+ .1+)



+0.5 VS 0.0 VOLTS (.2+ .3+ .4+)

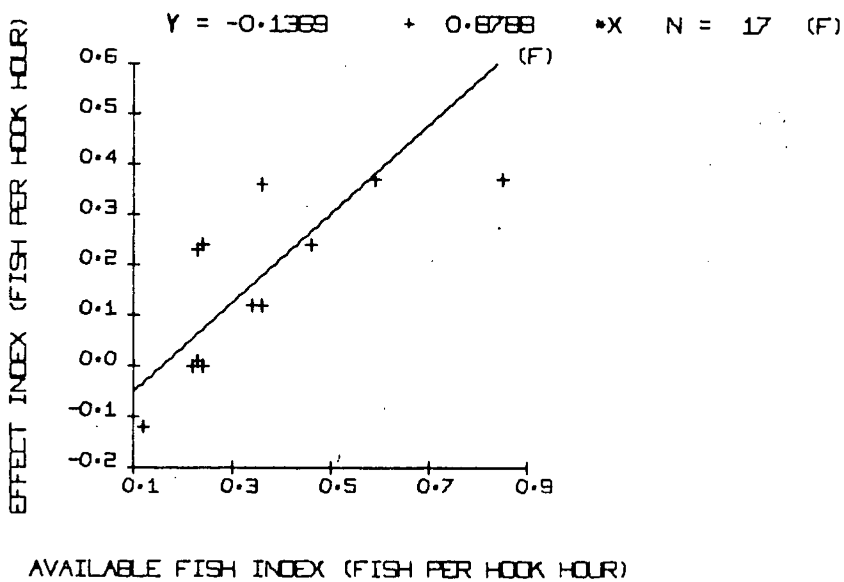
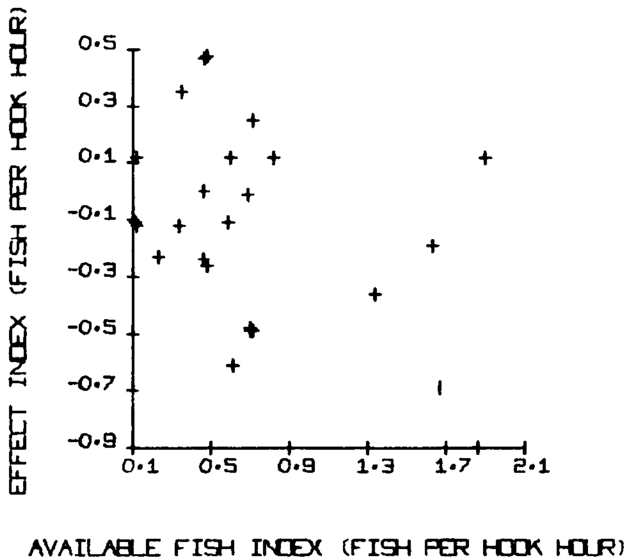
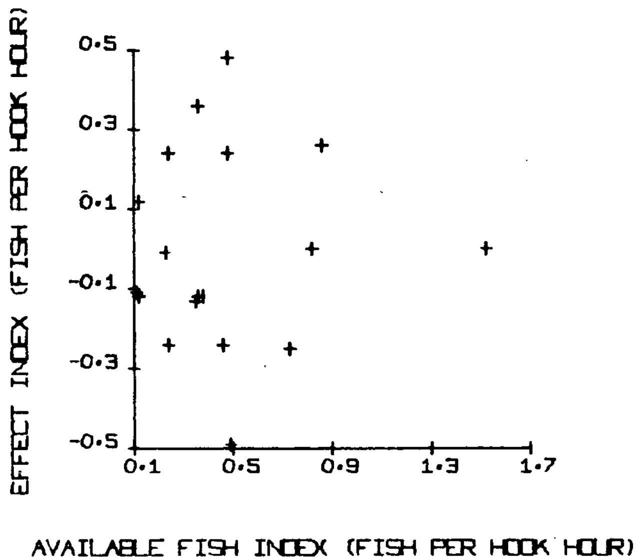


Figure 10: Scatter diagrams showing the relationship between the Effect Index and Available Fish Index for Test 2 (-0.5 vs 0.0 volts). Functional equations are included in cases where regressions were found to be significant (probability 0.05).

-0·5 VS 0·0 VOLTS (ALL AGES)



-0·5 VS 0·0 VOLTS (·+ ·1+)



-0·5 VS 0·0 VOLTS (·2+ ·3+ ·4+)

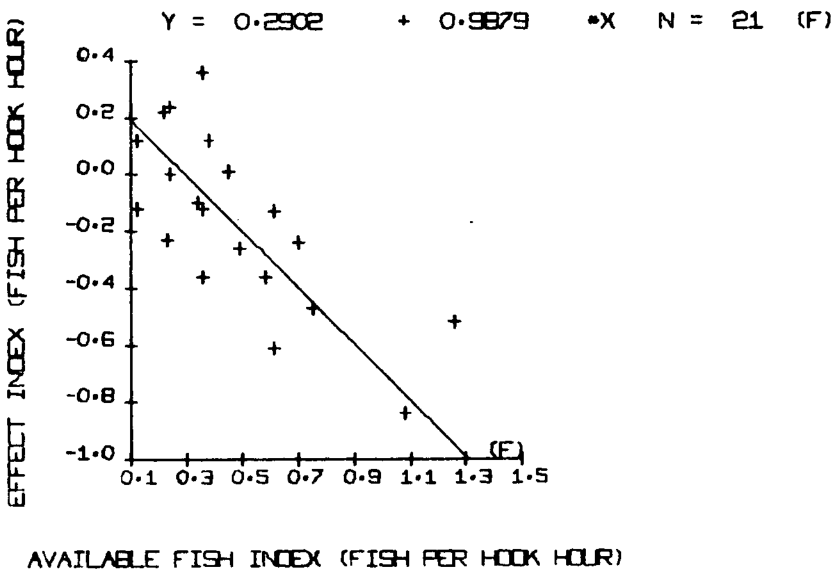
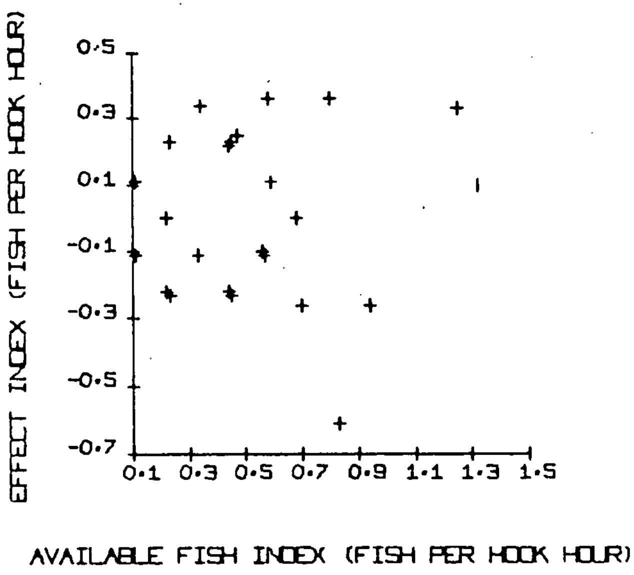
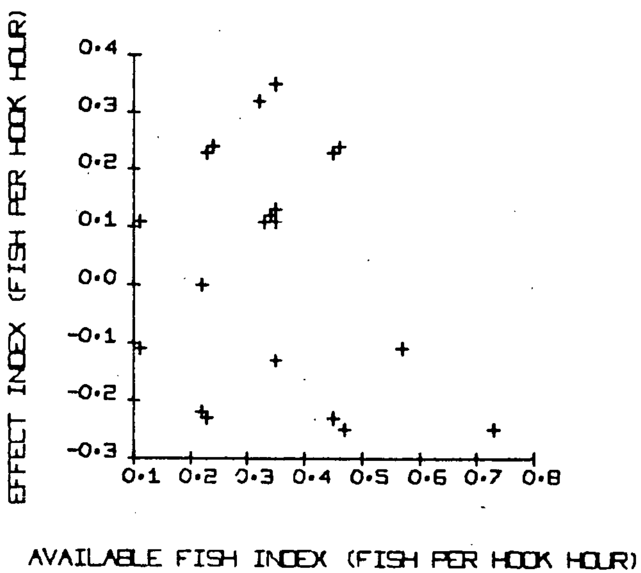


Figure 11: Scatter diagrams showing the relationship between the Effect Index and Available Fish Index for Test 3 (+1.0 vs 0.0 volts). Functional equations are included in cases where regressions were found to be significant (probability 0.05).

+1·0 VS 0·0 VOLTS (ALL AGES)



+1·0 VS 0·0 VOLTS (·+ ·1+)



+1·0 VS 0·0 VOLTS (·2+ ·3+ ·4+)

Y = 0·1865 + -0·8967 *X N = 22 (F)

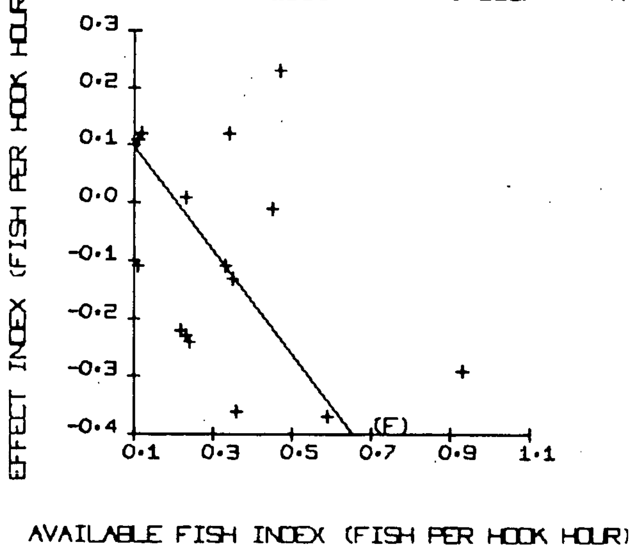
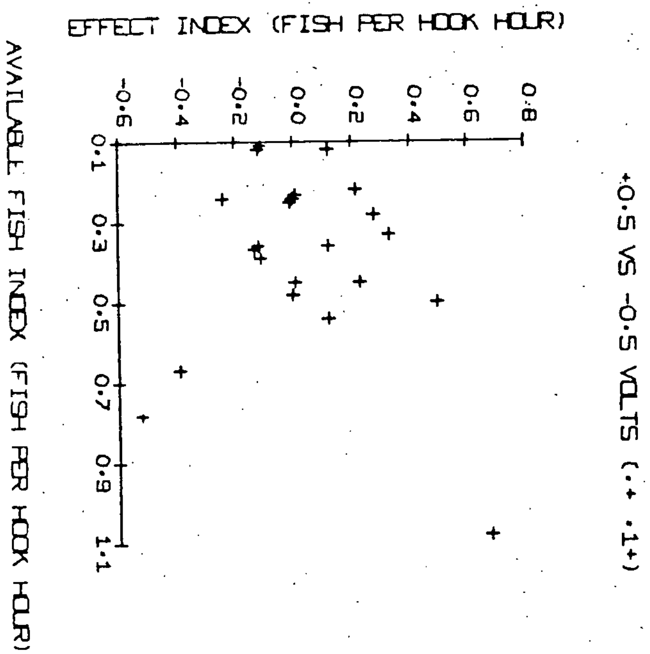
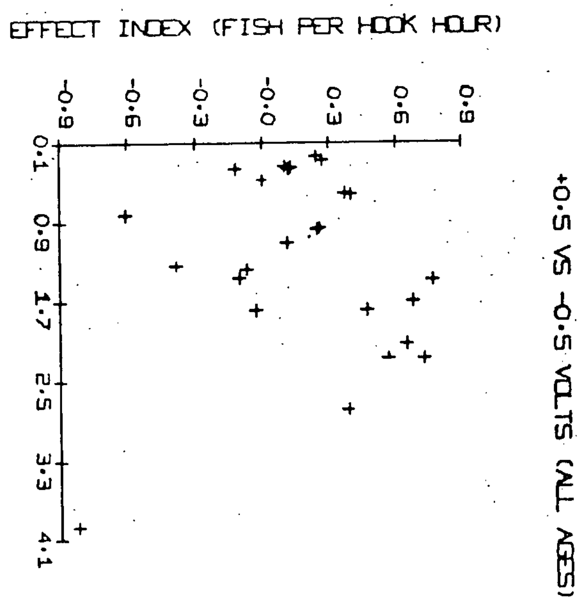


Figure 12: Scatter diagrams showing the relationship between the Effect Index and Available Fish Index for Test 4 (+0.5 vs -0.5 volts). Functional equations are included in cases where regressions were found to be significant (probability 0.05).


+0.5 VS -0.5 VOLTS (.+ .1+)
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)


+0.5 VS -0.5 VOLTS (ALL AGES)
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)

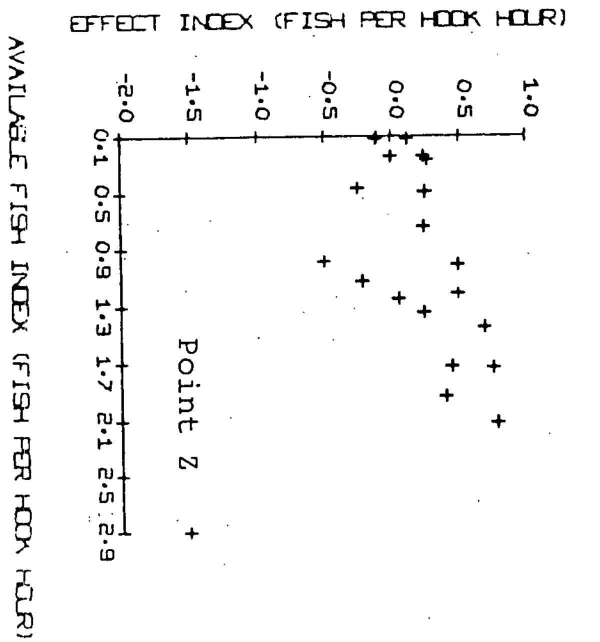
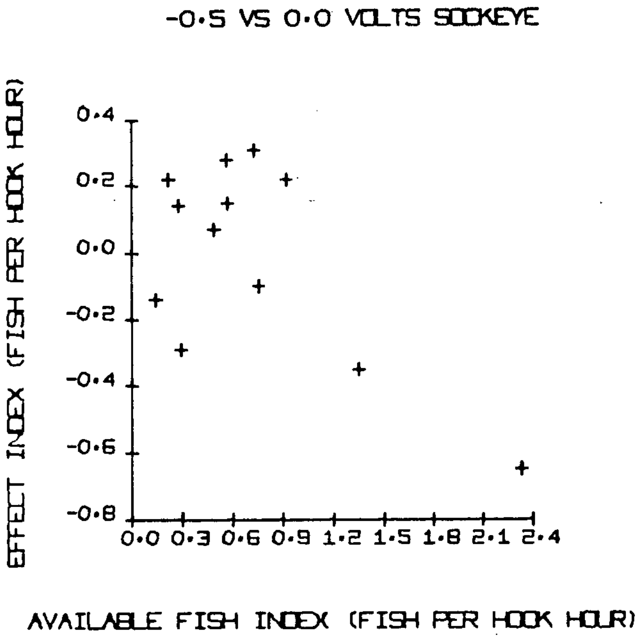
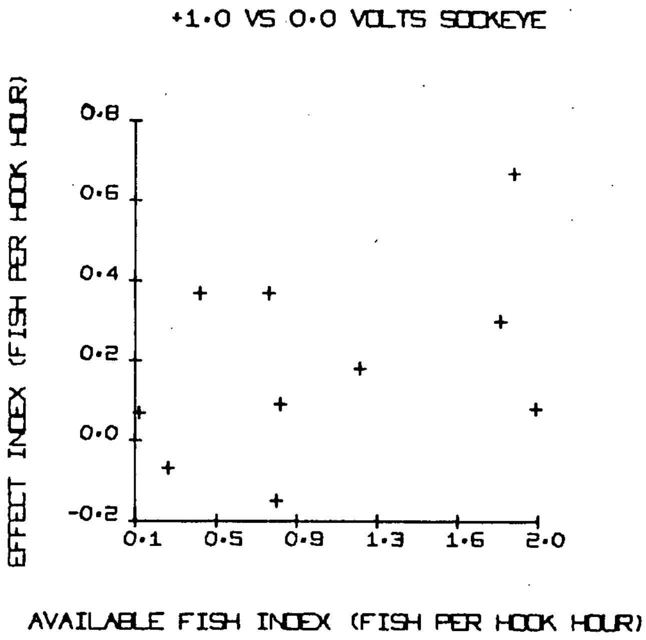
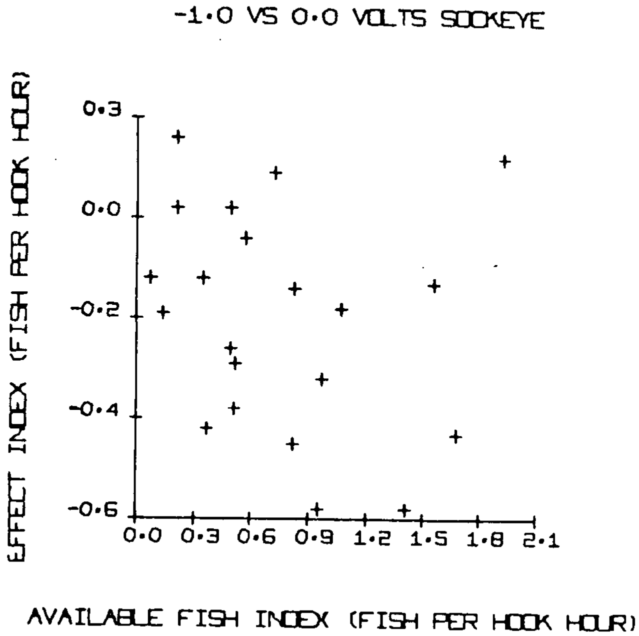
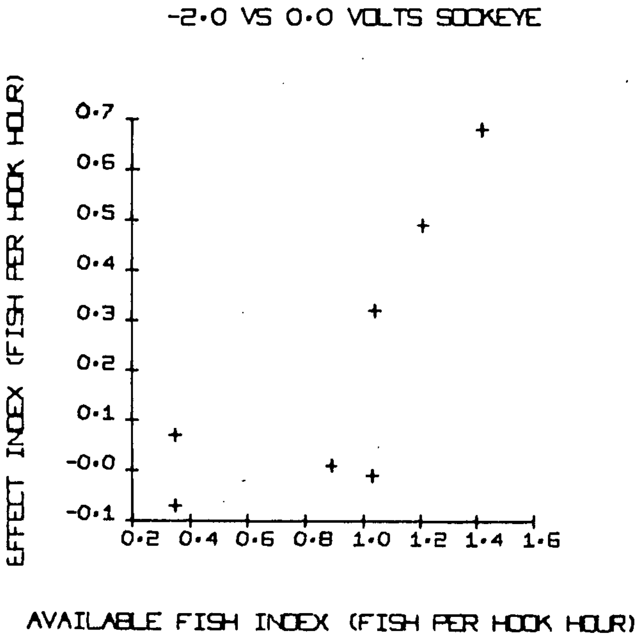

+0.5 VS -0.5 VOLTS (.2+ .3+ .4+)
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)
Point Z

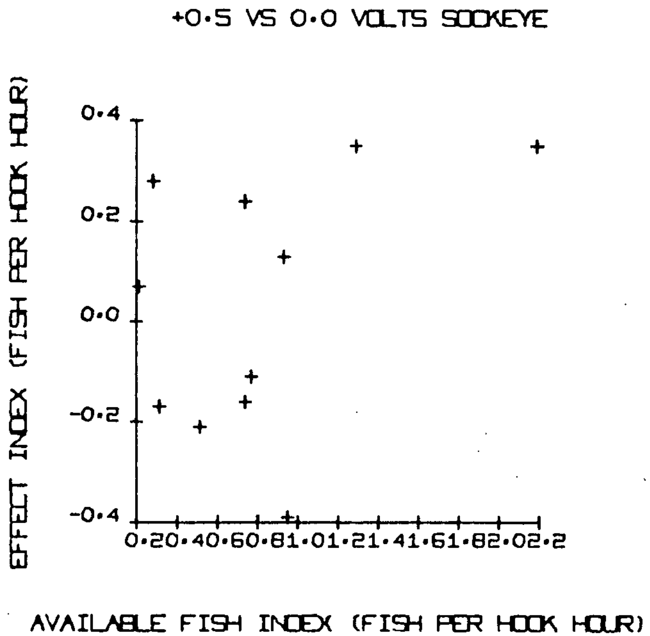
Figure 13: Scatter diagrams showing the relationship between the Effect Index and Available Fish Index for all voltage tests (Tests 1 to 5) done during the sockeye troll experiments.


-0.5 VS 0.0 VOLTS SOCKEYE
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)


+1.0 VS 0.0 VOLTS SOCKEYE
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)


-1.0 VS 0.0 VOLTS SOCKEYE
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)


-2.0 VS 0.0 VOLTS SOCKEYE
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)


+0.5 VS 0.0 VOLTS SOCKEYE
EFFECT INDEX (FISH PER HOOK HOUR)
AVAILABLE FISH INDEX (FISH PER HOOK HOUR)

Interpretations

Young and Veldman (1972) state that the significance of a correlation can be tested on the basis of its r-probability, which in this study was set at 0.05. The null hypothesis is that the correlation coefficient(r-statistic) is equal to 0.00, indicating no significant correlation to exist.

The calculated correlation statistics and probabilities for target species O. tschawytscha (all ages) suggest that there are no signifcant correlations(r-probability >0.05) between the index for the effect of the voltage condition and the index for available target fish in all tests done.

Similar results were obtained for sockeye salmon, indicating that all voltage tests except Test 1(-0.5 vs 0.0) show no significant correlations(probability >0.05). Test 1(-0.5 vs 0.0)'s results show the r-probability to be <0.05. However, Figure 13 shows the higher available fish levels to be represented by only two points, and the elimination of these two points gives an r-probability >0.05. No regression analyses were done for spring(all ages) and sockeye salmon as no significant correlations were observed.

VIIa. Combined Ocean Age Groupings for Troll-Caught Spring Salmon

Correlations analyses were also done on the data collected for the combined ocean age groupings. Functional linear regression analyses(Ricker, 1973) were done for cases where correlations were found to be significant. Table 23 summarizes the r-statistics and r-probabilities for younger(Group I) and older(Group II) troll-caught spring salmon. The calculated probabilities for the regressed lines are included in Table 24.

Interpretations

The results from the correlation analyses done on the combined age groupings suggest that there are no significant correlations in Group I fish for all voltages tested. The r-probabilities were greater than 0.05 for the younger fish group. However, significant correlations were suggested in the older fish, the r-probabilities were less than 0.05 for all the voltage tests. A consistently large difference was observed in the r-statistics between the younger and older fish group.

Significant regression lines(probability <0.05) were calculated only for the older fish group(Group II), as expected from the calculated correlation coefficients. It should be noted that Point Z was eliminated to calculate a significant regression(probability <0.05) for Test 4(+0.5 vs -0.5) (see Figure 12).

Table 23. A summary of r-statistics and r-probabilities for analyses correlating Effect and Fish density for spring salmon catch rate data for combined age groupings.

Test	Ocean Age Grouping	Number of Observations	r statistic	r probability
1. +0.5 vs 0.0	I	26	0.06	>0.10
	II	17	0.69*	0.002
2. -0.5 vs 0.0	I	21	0.04	>0.10
	II	21	0.72*	0.0003
3. +1.0 vs 0.0	I	22	0.23	>0.10
	II	22	0.46*	0.03
4. +0.5 vs -0.5	I	24	0.15	>0.10
	II	24 (23)	0.09 (0.56*)	>0.10 (0.01)

*Significant at a 0.05 probability level

Table 24. A summary of probabilities for regression analyses for the combined age groupings using the spring salmon catch rate data.

Test	Age Grouping	Number of Observations	Probability (H_o : b = 0)
1.	I	26	1.00
+0.5 vs 0.0	II	17	0.002*
2.	I	21	1.00
-0.5 vs 0.0	II	22(21)	0.06(0.0003*)
3.	I	22	0.31
+1.0 vs 0.0	II	22	0.03*
4.	I	24	1.00
+0.5 vs -0.5	II	24(23)	1.00(0.005*)

*Significant at a 0.05 probability level

GENERAL DISCUSSION

The electrical phenomenon investigated by this study was previously recognized by commercial salmon trollers. For years many commercial trollers have claimed that different voltage conditions on the troll lines change the troll success for target salmon. In the early 1960's an electronics specialist, Mr. William Russell, from Victoria, British Columbia began to investigate the problem of electrolysis associated with commercial fishing vessels. Russell was able to reduce the corrosive action of electrolysis by electrically connecting all potential underwater electrodes and using sacrificial zinc anodes. A number of trollers, who had their vessels re-wired by Russell's bonding technique, claimed that their troll success had increased. The increase was based on their success relative to other trollers and in many cases, was based on a number of fishing seasons. Russell (1977), in co-operation with the Oregon State University's Sea Grant Program, described the technical aspects of the electrical phenomenon.

This study investigated whether different troll line voltages do change the troll success for two salmon target species, Oncorhynchus tschawytscha and O. nerka. Troll success was measured by both troll catch (by numbers of fish) and troll catch rate data. Commercial trollers and fishery researchers usually describe troll success in terms of numbers of fish. However, a more accurate estimation of troll success is given by the actual catch rate where non-effective fishing time during gear retrieval is included in the calculation. The catch rate data were also used for analyzing the effect of available fish density on the extent to which voltage conditions changed troll success.

The catch (by numbers) data were analyzed using the non-parametric Chi-square test and the results were verified by analyzing the catch rate data using the parametric paired t-test. Both types of statistical analyses used a two-tailed, 0.05 probability level to test for significant differences.

Certain voltage conditions tested do affect the troll successes for target species O. tschawytscha and O. nerka . One of the obvious observations from the fishing experiments is that the changes in troll success due to similar voltage conditions were different for the two target salmon.

Four voltage tests were done during the spring salmon trolling experiments, including Test 1(+0.5 vs 0.0), Test 2(-0.5 vs 0.0), Test 3(+1.0 vs 0.0) and Test 4(+0.5 vs -0.5). The results show the positive voltage conditions(+0.5,+1.0 volts) to have higher troll successes than that for the negative voltage(-0.5 volts) condition. A difference was observed between changes in troll success for a low positive(+0.5) voltage and a high positive(+1.0) voltage tested. The high positive voltage and its control voltage(0.0 volts) showed no significant difference in troll success whereas the low positive voltage does show a higher troll success than its paired 0.0 volts condition, suggesting an optimum voltage condition at positive 0.5 volts.

The sockeye salmon trolling experiments tested a greater range of voltage conditions than the spring salmon troll experiments. Results for the low voltage tests, Test1(-0.5 vs 0.0) and Test 5(+0.5 vs 0.0), showed no affect on troll success.

However, the higher voltage conditions did affect the fishing success in sockeye trolling. Results from Test 2(+1.0 vs 0.0) demonstrated that positive 1.0 volts had a higher troll success than its paired control voltage(0.0 volts) whereas, negative 1.0 volts had a lower success than its paired control voltage as shown from Test 3(-1.0 vs 0.0)'s results. A higher negative voltage condition done during sockeye salmon trolling, Test 4(-2.0 vs 0.0), showed a larger catch than its control condition. However, similar analyses done on the troll catch rates showed no significant differences between the negative 2.0 volts condition and its control condition due to the small sample size for that particular test. As noted in the schedule of voltage tests(Appendix III), Test 4(-2.0 vs 0.0) was done for three fishing days, involving only 267.0 hook hours.

The results obtained from the trolling experiments are similar to the assertions of Russell (1977) and commercial salmon trollers. Many commercial salmon trollers, including some of the top B. C. salmon producers, agree that troll lines with positive voltages are more successful in catching target salmon than lines with negative voltages. However, commercial trollers do not agree on the specific voltage most effective for increasing the troll success for any one salmon species. This disagreement may be due to differences in vessels, electrical bonding systems or fishing techniques. Russell (1977) suggests that about positive 0.5 volts is the optimum voltage condition for all target salmon species. Unfortunately, he does not give any evidence for this particular voltage. The results obtained from this study supports Russell's view for target species O.

tschawytscha but not *O. nerka*. Results from the spring salmon trolling experiments show that positive 0.5 volts was the optimum condition for the voltages tested. In contrast, the greatest troll success for sockeye salmon was during the positive 1.0 volts condition.

There are very few papers on the effect of weak electrical fields on non-electric fishes , such as salmon. Researchers have suggested that salmon are capable of detecting ultraweak electric fields (Harden Jones, 1968; Royce, Smith and Hart, 1968; MacCleave, Rommel and Cathcart, 1971; Stasko, Sutterlin, Rommel and Elson, 1972; Rommel and MacCleave, 1973a, 1973b). MacCleave, Rommel and Cathcart (1971) and Rommel and MacCleave (1973b) have demonstrated that Atlantic salmon are capable of detecting electrical fields of the intensities found in major ocean current systems. The mechanism by which non-electric fish are able to detect weak electrical fields is not clearly understood. It has been suggested that sensory structures in the lateral line organs may be capable of detecting the weak electrical fields (Royce, Smith and Hartt, 1968).

Responses to weak electrical fields are different than those responses associated with strong electrical fields. Electrotactic responses require high voltage gradient fields, many times more intense than those used in this study. It is, however, interesting that the sensory responses to the weak electrical fields observed in this study show similar behaviour patterns as those caused by the muscular reactions to strong electrical fields. In electrofishing techniques, anodic reactions cause target fish to move towards the positive electrode and an avoidance away from the negative electrode. The results from this study's experiments showed an increase in fishing success when the troll lines were positive with respect to the vessel's bonding system but a decrease when the troll lines were negative. However, the high voltage intensity required for electrotactic reactions makes it an improbable explanation for the results obtained by this study.

A number of papers have been written on the ability of fishes which have been previously considered non-electric to emit weak electric discharges (Kleerekoper and Sibakin, 1956, 1957; Lissmann, 1958; Minto and Khadson, 1967; Ostroumov, 1968; Barham, Huckabay, Growdy and Burns, 1969; Protasov, Basov, Krumin and Orlov, 1970, 1971; Protasov, 1973). Protasov *et al.* (1970) studied two salmon species, *Oncornynchus kisutch* and *O. nerka*, and detected electric discharges from the salmon under natural conditions. They concluded that the electric discharges are the results of change in field potential generated in the water by electric processes in the neuromuscular apparatus of the fishes. Protasov *et al.* also concluded that the species specificity of the electric discharges depends on the morphology of the species' neuromuscular complex. Protasov (1973) further concluded, through observations on the behaviour of non-electric fishes in laboratories and under natural conditions, that electric discharges are emitted at the moment a fish is stimulated such as by response to fright, during lunges of a predator at its catch, during sharp lunges of a school and during acts of food gathering. Therefore, the responses to the weak electrical fields observed in this salmon troll investigation may be related to Protasov's conclusions on non-electric fish behaviour.

Different troll successes for different target salmon species under similar voltage conditions were observed. It is important to note the different physiological states of each target species during the experimental fishing periods. The spring salmon were actively feeding as indicated by the contents of the stomach samples but almost all the stomachs of the sockeye salmon were devoid of any food items. The Adams River sockeye captured during this study were in a pre-spawning condition. Halsband (1959) and Vibert (1967) state that the physiological state of a fish is of great importance in its reaction to electric current. Halsband proposes that the intensity of metabolism and activity of the fish are important factors influencing the behaviour of the fish in an electrical field. Therefore, different changes in troll successes, relative to the paired control conditions, under similar electrical field conditions for the two target salmon species may be due to differences in their physiological states.

Results from further analyses done on spring salmon of different ocean ages suggest that the voltages tested may affect the troll success for only older troll-caught spring salmon. The small sample sizes for each individual ocean age class, from .+ to .4+ year olds, limited the analyses to two combined age groupings which included the younger spring salmon(.+,.1+ year olds) and the older spring salmon(.2+,.3+,.4+ year olds). It was also more reasonable to combine ocean age classes into two larger age groups because of the overlapping size ranges found in spring salmon of different ocean ages in the Georgia Strait(Argue, Marshall and Coursley, 1977).

Results from the analyses done on combined age groupings show the troll success for older spring salmon to be significantly different(probability <0.05) between treatment and control conditions in Test 1(+0.5 vs 0.0), Test 2(-0.5 vs 0.0) and Test 4(+0.5 vs -0.5). Troll success was greater for positive voltage conditions than for negative voltage conditions. The troll success for younger spring salmon during the forementioned voltage tests were not significantly different(probability >0.05) between treatment and control conditions. Results for Test 3(+1.0 vs 0.0) indicated no significant differences in troll successes for neither the young nor older spring salmon. Age may be an important factor in the target spring salmon's response to different troll line voltages. Fishermen propose that younger spring salmon show non-selective attack behaviour towards trolling lures. It is apparently common to observe a young spring salmon attacking terminal gear which are dragged on the water surface during gear retrieval, a situation which rarely causes an older spring salmon to attack the lure. Therefore, some form of learned behaviour may be associated with the attack of target spring salmon on troll gear. Younger spring salmon may tend to be naive towards the electric fields around the troll gear because, although these less than two ocean year olds include spring salmon which may have encountered trolling gear one time before, most of the fish in this age group have encountered the massive confusion of commercial trolling gear for the first time. A second possible explanation to why only the older spring salmon responded to the voltage conditions on the troll lines may be due to the physiological development of possible sensory structures capable of detecting the ultra-weak voltages.

Similar age analyses were not done for the effect of voltage conditions on troll success in sockeye salmon because all troll-caught sockeye were assumed to be four years old spawners from the Adams River stock.

Size distribution analyses were done on the spring salmon troll catches to determine whether the effects of weak electrical fields on troll success are size-selective. There were no apparent differences between the size distributions for the paired treatment and control troll catches in all the voltage tests done during spring salmon trolling. The medians of each paired distributions were tested for differences using the entire spring salmon troll catch and no significant differences were found. Further analyses showed the means and variances of each size distribution to be similar between paired conditions for troll-caught spring salmon at least one ocean years old.

The results from the size distribution analyses suggest that this electrical phenomenon does not act as a size selective mechanism during spring salmon trolling. Strong electrical fields, such as those utilized in electric fishing techniques, are known to be size selective(Vibert, 1963,1967) since the voltage drop along the fish is determined by the length of the fish. Weak electrical fields have been found to affect salmon only when the voltage is applied perpendicular to the body axis not parallel to it(Rommel and MacCleave, 1973b). Rommel and

MacCleave's findings further suggest that the response mechanism associated with weak electrical fields is different than the electrotactic responses associated with strong electrical fields.

It has been previously suggested by Russell (1977) that the effect of the electrical phenomenon on troll success is greatest when the density of available target fish is low. The catch rate data collected during the spring and sockeye trolling experiments were used to provide indices to estimate voltage effect and available fish density. Correlation and regression analyses were done and the results suggest that the effect of voltage conditions does vary with different available fish densities for the older (Group II) troll-caught spring salmon. Group I, younger fish, showed non-significant r-probabilities (>0.05) and their respective linear regressions were non-significant (probability >0.05). Similar correlation analyses were done for the troll-caught sockeye salmon. The results show that the effect of voltage conditions does not vary significantly with different available fish densities in all the voltage tests done during sockeye trolling. Therefore, the results obtained from the correlation and regression analyses do not support Russell's suggestion that the effect of voltage conditions is greatest with low numbers of available fish. Varying numbers of available sockeye salmon do not change the effect of the voltage conditions. Younger spring salmon, Group I, also do not show any changes in voltage effect with different numbers of available spring salmon. However, older spring salmon (Group II) do show changes in effect with varying available spring salmon but contrary to Russell's suggestion, was found to be the greatest with high available fish densities in all cases studied.

Characteristic differences in available fish densitites for spring and sockeye salmon may be a factor for the differences found in the correlation analyses. Sockeye salmon tend to be available to the troll gear in a higher density than spring salmon.

Although a significant number of commercial salmon trollers utilize this electrical phenomenon, there are many trollers who believe that the electrical phenomenon does not increase their troll success. It is interesting to note that in a number of these cases, even though the fishermen do not utilize a controlled voltage source such as Russell's electronic unit, many of them unknowingly have a bonded system with a natural voltage of positive 0.5 existing on their troll lines.

Commercial trollers do not regard the troll line voltage to be the primary fishing factor such as trolling speed, depth and gear arrangement but estimate that an optimum line voltage may increase their salmon troll catch by 5% to over 50%. Fishermen suggest that the magnitude of increase in troll catch depends on the target species, availability of the target fish and the skill of the fisherman. This study showed changes in troll catch ranging from -40% to +65% for both target species captured. It should be noted that the changes in troll catches observed by this study include the commercially worthless troll-caught spring salmon shakers(less than three pounds in round weight).

This investigation shows that troll fishing effort can be made more efficient in harvesting at least two species of salmon by using weak positive voltages on the troll lines. Any slight increase in troll success, which depends on a number of factors including the skill of the fisherman, target species and availability of target fish, gives significant economic returns because of the high price paid to commercial trollers for their salmon catch. The market price for troll-caught spring salmon is especially high. This price factor and the fact that spring salmon can not be troll-caught on a quantity basis, such as pinks and sockeye, makes the use of troll lines with positive voltages especially desireable during spring salmon trolling.

FUTURE STUDIES

The effects of voltage conditions on troll success were investigated only for two target species, *O. tschawytscha* and *O. nerka*, encountered in the lower Strait of Georgia during the Spring and Fall of 1978. Further investigation should be done on other salmon species, and also on other stocks of spring and sockeye salmon, successfully captured by the commercial trollers.

The range of voltages investigated was limited to only two or three relatively low positive and negative voltages because of two reasons. Firstly, most commercial trollers seem to have a voltage condition within the voltage range investigated by this study. Secondly, the proposed study was to be done within a limited time period because of vessel availability. Any new study should investigate a larger range of voltages.

A fiber-glass hulled vessel was used in the fishing experiments to reduce complications in electrical leakages found in vessel hulls made of conductive material. The present commercial trolling vessels have hulls made of wood, aluminum, steel and cement, as well as fiber-glass. Older wooden trollers have hulls with conductive properties because of the water-saturated wood planks. Vessels made of metal hulls may have complicated electrical leakages because of dissimilar metal characteristics (including different metal grades) immersed in electrolytic sea water. Therefore, it would be desireable to investigate whether the type of construction material used for vessel hull affects the extent to which the voltage condition changes troll success.

CONCLUSIONS

Certain weak electrical fields were found to affect troll success for the target species *O. tschawytscha* and *O. nerka*, encountered in the Strait of Georgia during the Spring and Fall of 1978. Troll successes for both target species were higher for the positive voltage conditions than for the negative voltage conditions.

The two target species showed different changes in troll success affected by common voltage conditions tested, including the treatment conditions positive 0.5, positive 1.0 and negative 0.5 volts. Troll success for spring salmon trolling was higher for the positive 0.5 volts condition, lower for the negative 0.5 volts condition and not significantly different for the positive 1.0 volts condition, with respect to the paired control conditions of zero volts. In contrast, troll success for sockeye salmon trolling was not significantly different for the low voltage conditions(positive 0.5 and negative 0.5 volts) but was higher for the positive 1.0 volts conditon, with respect to the paired control conditions of zero volts. Additional voltage conditions tested during sockeye salmon trolling showed a negative 1.0 volts condition to have a lower troll success than its paired control condition. No conclusive results were obtained for the negative 2.0 volts test.

Incidental troll catches of coho salmon(mostly age 3_2) were low and no significant differences were apparent between treatment and control conditions for all the voltages tested during spring salmon trolling.

There were no apparent differences in size distributions between treatment and control spring salmon troll catches. In contrast to the strong electrical fields used in electro-fishing techniques, weak electrical fields do not seem to be effectively size selective.

It is interesting to note that the spring salmon's response to troll line voltages may depend on the age of the target fish. Factors such as the physiological development of possible electrically-sensitive structures and the development of attack behaviour towards troll lures may cause different responses between the younger(less than one and one ocean years old) and older(two to four ocean years old) troll-caught spring salmon. All troll-caught sockeye were assumed to be four-year old Adams River spawners and, therefore, similar age and size distribution analyses were not done.

The density of target fish within the range of the troll gear may vary the extent to which the voltage condition affects troll success. However, contrary to previous assertions, the effect of the voltage condition on troll success for older spring salmon seems to be greatest when encountering high numbers of available target spring salmon. The voltage effect for troll catches of sockeye and younger spring salmon does not significantly change with the density of available fish.

LITERATURE CITED

Amos, B.

1977. Electrolysis. Cruising World, Newport, April, pg. 76-84.

Andrew, F. J., Kersey, L. R. and P. C. Johnson.

1955. An investigation of the problem of guiding downstream-migrant salmon at dams. Intern. Pac. Salm. Fish. Comm., Bull. No. 8, 65 pp.

Andrew, F. J., Kersey, L. R. and P. C. Johnson.

1956a. Electric screens for adult salmon. Intern. Pac. Salm. Fish. Comm., Progress Rept., 43 pp.

Andrew, F. J., Kersey, L. R. and P. C. Johnson.

1956b. Further experiments with an electric screen for downstream-migrant salmon at Baker Dam. Intern. Pac. Salm. Fish. Comm., Progress Rept., 29 pp.

Anonymous.

1976. Acoustic testing suggests noise limits troll catch. Western Fisheries, Vancouver, Vol. 93, No. 1, pg. 14.

Applegate, V. C., Macy, P. T. and V. E. Harris.

1954. Selected bibliography on the applications of electricity in fishery science. U. S. Fish and Wildlife Service, Spec. Scien. Rept.: Fisheries , No. 126, 54 pp.

Argue, A. W.

1970. A study of factors affecting exploitation of Pacific salmon in the Canadian gantlet fishery of Juan de Fuca Strait. Technical Report(1970-71), Dept. Fish. Forest., Fisheries Service, Pacific Region, December, 259 pp.

Argue, A. W., Marshall, D. E. and J. Coursley.

1977. Size and age of chinook and coho salmon for subdivisions of the Strait of Georgia troll fishery, 1967. Technical Report Series, PAC/T-77-20, 44 pp.

Balayev, L. A., Fedorenko, G. S. and A. G. Gusar.

1971. Reaction of some Black sea fishes in uniform D. C. fields(from 'Problems of Fish Physiology'). Journ. Fish. Res. Bd. Can., Translation Series, No. 1642, 24 pp.

Barham, E. G., Huckabay, W. B., Gowdy, R. and B. Burns.

1969. Microvolt signals from fishes and the environment. Science, Vol. 164, New York, pg. 965-968.

Bary, B. M.

1956. The effect of electrical fields on marine fishes. Marine Research, Scotland, Vol. 1, 32 pp.

Bilton, H. T., Jenkinson, D. W. and M. P. Shepard.

1964. A key to five species of Pacific salmon(Genus Oncorhynchus) based on scale characters. Journ. Fish. Res. Bd. Can., Vol. 21(5), pg. 1267-1283.

Browning, R. J.

1974. Fisheries of the north Pacific - history, species, gear and process(pg. 200-224), Alaska Northwest Publish., Anchorage, 408 pp.

Burgess, J.

1966. Fishing boats and equipment. Fishing News(Books)

Ltd., London, 216 pp.

Butler, J. A. and K. E. Loeffel.

1972. Experimental use of barbless hooks in Oregon's troll salmon fishery. Pacific Marine Fish. Commission Bulletin, Oregon, Vol. 8, pg. 24-30.

Cattley, J. G.

1955. Your guide to electrical fishing (1) (2) (3). World Fishing, Vol. 4, No. 3, pg. 125-127, 166-169, 202-205.

Cobb, J. N.

1930. Pacific salmon fisheries. U. S. Depart. Comm. Bur. Fish. Fisheries Document No. 1092, pg. 487-491.

Deelder, C. L.

1952. On the migration of the elver(*Anguilla vulgaris*) of the sea. Journ. Cons. Perm. Int. Explor. Mer., Vol. 18, No. 2, pg. 187-218.

Dethloff, J.

1964. Problems of electro-fishing and their solution. Modern Fishing Gear of the World I, F. A. O.,pg. 551-556.

Dickson, W.

1954. Marine electrical fishing. World fishing, April, pg. 148-151.

Dijkgraaf, S.

1962. The functioning and significance of the lateral line organs. Biological Reviews, Cambridge, Vol. 38, pg. 51-105.

Erickson, G.

1978. Albacore troll boat acoustic study. Oregon State University Sea Grant Program, 46 pp.

Forester, J. E. and A. D. Forester.

1975. Fishing - British Columbia's commercial fishing history. Hancock House Publishers, Saanichton, B. C., 224 pp.

Fridman, A. L.

1973. Theory and design of commercial fishing gear. Isreal Program for Scientific Translations, Jerusalem, 489 pp.

Groody, T., Loukashkin, A. and N. Grant.

1950. Electrical stimulation of fish in sea water. California Co-op. Sardine Research Program, Progress Report, pg. 46-47.

Groody, T., Loukashkin, A. and N. Grant.

1952. A preliminary report on the behaviour of the Pacific sardine in an electrical field. Proc. Cal. Acad. Sci., Fourth Series, Vol. 27, No. 8, pg. 311-323.

Hanson, H. C.

1955. Pacific trollers. In: Fishing boats of the world I. Edited by Jan-Olof Traung. F. A. O. Fishing News, London, pg. 107-112.

Harden Jones, F. R.

1968. Fish migrations(pp. 195-197). London, 325 pg.

Harreveld, Van A.

1937. On galvanotropism and oscillotaxis in fish. Journ. Exp. Biol., Vol. 15, pg. 197-208.

Hermann, L.

1885. Eine Wirkung galvanische strome auf organismen. Pflugers Arch. f. die Gesam. Physiol., Vol. 37, pg. 457-460.

Kleerekoper, H. and K. Sibakin.

1956. An investigation of the electrical 'spike' potentials produced by the sea lamprey(Petromyzon marinus) in the water surrounding the head region. Journ. Fish. Res. Bd., Canada, Vol. 13(3), pg. 375-383.

Kleerekoper, H. and K. Sibakin.

1957. An investigation of the electrical 'spike' potentials produced by the sea lamprey(Petromyzon marinus) in the water surrounding the head region. Journ. Fish. Res. Bd., Canada, Vol. 14(2), pg. 145-151.

Klima, E. F.

1972. Voltage and pulse rates for inducing electrotaxis in twelve coastal pelagic and bottom fishes. Journ. Fish. Res. Bd., Canada, Vol. 29, pg. 1605-1614.

Kolbe, E., Mate, B. and R. Jacobson.

1975. Bonding of boats and adjustment of trolling wire voltages. Oregon State University Sea Grant Program(notes), 12 pp.

Koo, Ted S. Y.

1962. Age designation in salmon. In: Studies of Alaska Red Salmon(pg. 37-48). Univ. Wash. Press, Seattle, 449 pp.

Krayukhin, B. V.

1938. The electric shock of the Black Sea ray(_Raja clavata_). Medichniy Ahurnal AN USSR , Vol. 8, No. 3.

Larkin, P. A.

1977. A handbook of elementary statistical tests(Biometrics). University of British Columbia, 161 pp.

Lissmann, H. W.

1958. On the function and evolution of electric organs in fish. Journ. Exp. Biol., Edinburgh, Vol. 35, No. 1, pg. 156-191.

Lissmann, H. W. and K. E. Machin.

1963. Electric receptors in a non-electric fish(_Clarias_). Nature, London, Vol. 199, pg. 88-89.

Loeb, J.

1918. Forced movements, tropisms, and animal conduct(pg. 32-46). Philadelphia and London, 201 pp.

MacCleave, J. D., Rommel, S. A. and C. L. Cathcart.

1971. Weak electric and magnetic fields in fish orientation. Ann. N. Y. Acad. Sci., Vol. 188, pg. 270-282.

Meyer-Waarden, P. F.

1957. Electrical fishing. F. A. O. Fisheries Study No. 7, 78 pp.

Milne, D. J.

1953. The troll fishery of British Columbia. Canada Dept.

Fish., Trade News, Vol. 5(10), pg. 3-5.

Milne, D. J.

1955. Selectivity of trolling lures. Fish. Res. Bd. Can., Pac. Biol. Stn., Prog. Rept., No. 103, pg. 3-5.

Milne, D. J.

1964a. The chinook and coho salmon fisheries of British Columbia. Fish. Res. Bd. Canada, Bulletin No. 142, 46 pp.

Milne, D. J.

1964b. Sizes and ages of chinook (Oncorhynchus tschawytscha) and coho (O. kisutch) salmon in the British Columbia troll fisheries(1952-1959) and the Fraser River gillnet fishery (1956-1959). Fish. Res. Bd. Canada, MS Report Series, Biol. Stn., Nanaimo, B. C., No. 776, 42 pp.

Milne, D. J. and E. A. R. Ball.

1958. The tagging of spring and coho salmon in the Strait of Georgia in 1956. Progress Reports of the Pacific Coast Station, No. 111, pg. 14-17.

Minto, U. and D. Khadson.

1967. Hydronic signals from fishes. Abstract of a report presented at the 31st Annual Conference, State of Florida, University of Florida, Tampa.

Mironov, A. T.

1948. Electric currents in the sea and the effect of current on fishes. Trudy Morsk. Gidrografish. In - ta ANSSSR , Vol. 1.

Murray, R. W.

1962. The response of the ampullae of Lorenzini of elasmobranchs to electrical stimulation. Journ. Exp. Biology, Edinburgh, Vol. 39, pg. 119-128.

Okada, M.

1929a. On the action of electric current on fishes I. Excitation and narcosis. Journ. Imperial Fish. Inst., Tokyo, Vol. 24, No. 2, pg. 64-72.

Okada, M.

1929b. On the action of electric current on fishes II. Electrophobotaxis of fishes in a group. Journ. Imperial Fish. Inst., Tokyo, Vol. 25, No. 1.

Okada, M.

1929c. Notes on leading the movement of fish-groups by electric current. Journ. Imperial Fish. Inst., Tokyo, Vol. 24, No. 5, pg. 124-128.

Ostroumov, G. A.

1968. At what distance might marine animals communicate by electric waves? Problemy Differentsiatsii I Rasprostraneniya Radiovoln, Leningrad State University, No. 8.

Protasov, V. R.

1973. Electric and acoustic fields of fishes. Joint Publications Res. Serv., Arlington, N. T. I. S., 276 pp.

Protasov, V. R., Basov, B. M., Krumin, V. M. and A. A. Orlov.

1970. Electric discharges of the so-called nonelectric fishes and their possible biological importance(English summary). Zoologicheskii Zhurnal, Vol. 49, No. 5, pg. 754-766.

Protasov, V. R., Basov, B. M., Krumin, V. M. and A. A. Orlov.

1971. Low-frequency discharges of nonelectric fishes. Zoologicheskii Zhurnal, Vol. 50, No.5, pg. 779-782.

Regnart, H. C.

1931. The lower limits of perception of electrical currents by fish. Journ. Mar. Biol. Ass. U. K., Vol. 17, pg. 415-420.

Ricker, W. E.

1973. Linear regressions in fishery research. Journ. Fish. Res. Bd. Can., Vol. 30, pp. 409-434.

Rohlf, F. J. and R. R. Sokal.

1969. Biometry. W. H. Freeman, San Francisco, 776 pp.

Rommel, S. A. and J. D. MacCleave.

1973a. Prediction of oceanic electrical fields in relation to fish migration. Journ. Cons. int. Explor. Mer., Vol. 35(1), pg. 27-31.

Rommel, S. A. and J. D. MacCleave.

1973b. Sensitivity of American eels(Anguilla rostrata) and Atlantic salmon(Salmo salar) to weak electric and magnetic fields. Journ. Fish. Res. Bd. Can., Vol. 30, No. 5, pg. 657-663.

Roth, A.

1969. Elektrische sinnesorgane beim Zwergwels Ictalurus nebulosus (Amiurus nebulosus) (Electroreceptors in the catfish Ictalurus nebulosus (Amiurus nebulosus). Zeitschrift fur vergleichende physiologie, Vol. 65, pg. 368-388(English summary).

Royce, W. F., L. S. Smith And A. C. Hartt.

1968. Models of oceanic migrations of Pacific salmon and comments on guidance mechanisms. U . S. Bur. Comm. Fish. Bull., No. 66(3), pg. 441-462.

Russell, W.

1977. Positive approach to catch salmon with trolling gear. Western Fisheries, Vancouver, Vol. 94, No. 2, pg. 94.

Scofield, W. L.

1921. Gear used for salmon trolling in California in 1920. California Div. Fish and Game, Vol. 7, No. 1, pg. 22-38.

Scofield, W. L.

1956. Trolling gear in California. Dept. of Fish and Game, State of California, Fish Bulletin, No. 103, 45 pp.

Siegel, S.

1956. Nonparametric statistics for the behavioral sciences. MacGraw-Hill, Toronto, 312 pp.

Stasko, A. B., Sutterlin, A. M., Rommel, S. A. and P. F. Elson.

1972. Migration-orientation of Atlantic salmon(Salmon salar L.). In International Atlantic Salmon Symposium(edited by Smith, M. W. and W. M. Carter (1972)), pg. 119-141, New Brunswick, 504 pp.

Stewart, Peter, A. M.

1978. Comparative fishing for flatfish using a beam trawl fitted with electric ticklers. Department of Agriculture and Fisheries for Scotland, Scottish Fisheries Research Report No. 11, 10 pp.

Summers, G. W. and W. S. Peters.

1973. Basic statistics in business and economics. Wadsworth Publishing Co., Belmont, California, 445 pp.

Sundstrom, G. T.

1957. Commercial fishing vessels and gear. U. S. Dept. Inter., Fish and Wildlife, Washington, pg. 7, 44-48.

Tully, J. P.

1954. Conditions for troll fishing. Fish. Res. Bd. Canada, Progress Reports of the Pacific Coast Stations, No. 101, pg. 12-16.

Vibert, R.

1963. Neurophysiology of electric fishing. Trans. Amer. Fish. Soc., Vol. 92, No. 3, pg. 265-275.

Vibert, R.

1967. Fishing with electricity its application to biology and mangement. F. A. O. Fishing News (Books) Ltd., 276 pp.

Yoshida, H. O.

1966. Tuna fishing vessels, gear and, techniques in the Pacific ocean. In Proceedings of the Governor's Conference on Central Pacific Fishery Resources (edited by Manar, T. A.), pg. 87-89.

Young, R. K. and D. J. Veldman.

1972. Introductory statistics for the behavioural sciences. Holt, Rinehart and Winston, Toronto, 559 pp.

APPENDICES

APPENDIX I: COMMERCIAL SALMON TROLLING IN BRITISH COLUMBIA

History of B. C. Salmon Trolling

Trolling is one of the oldest methods of capturing salmon in British Columbia. Although the Haida Indians started trolling from dugout canoes with primitive bone hooks and twisted bark lines off Masset and other North Island ports prior to 1890, trolling became part of commercial fishing in British Columbia around 1899(Milne, 1953, 1964a; Forester and Forester, 1975). Commercial trolling only reached a quantity production in the early 1900's when the industry began to use the mildcuring process(Scofield, 1956). It was then possible to store large quantities of salmon by this packing process, which greatly stimulated commercial salmon trolling. The history of trolling has been described in a number of papers(Scofield, 1921; Cobb, 1930; Milne, 1953, 1964a; Scofield, 1956; Forester and Forester, 1975).

Trolling Effort in British Columbia

Trolling was not regulated until 1917, when 1370 commercial fishing licenses were purchased. In 1954, the number of licenses had increased to over 4580. The number of licenses dropped during 1955-1957 due to a change in license qualification, to 4373. In 1962, there were over 6000 licenses issued to commercial trollers, making up about 50% of the total commercial salmon fleet in British Columbia(Milne, 1964a).

The commercial trollers' catch in B. C. for spring salmon was about 100,000 fish annually, or approximately 20% of the total spring salmon catch in 1920, to more than 470,000 fish annually, or 65% of the total commercial spring salmon catch in 1962. The annual troll catch of coho salmon in B. C. during the 1920's was about 400,000 coho, or about 25% of the total commercial coho salmon catch, to more than 2,000,000 coho in 1962, or about 65% of the total commercial coho catch(Milne, 1964a). In 1967, according to Fisheries Statistics, commercial salmon trollers caught over 1,200,000 spring salmon, or about 81% of the annual commercial spring salmon catch and 2,800,000 coho salmon, or about 74.3% of the annual commercial coho catch.

Trolling Vessels and Equipment

Vessel Design

Trollers vary from 16-foot(4.9 m) skiffs to vessels as long as 60 feet(18.3 m), normally with a forward wheelhouse arrangement and a working aft deck, they are the most abundant type of fishing vessel on the Pacific coast of North America(Hanson, 1955, Scofield, 1956). B. C. salmon trollers are usually between 30 and 40 feet(9.1-12.2 m) long(Milne,1964). Vessels under 30 feet could be classified as small trollers and the proportional number of these small trollers has been decreasing through recent years. There has been a general trend toward larger trollers, particularly in beam and depth, to accomodate larger engines and permit larger storage space below deck for iced or even frozen fish. Hanson(1955) and Forester and Forester(1975) give vessel specifications for a 42-foot(12.8 m) and a 28-foot(8.5 m) troller, respectively.

A large number of trollers are equipped with a second or even third type of fishing gear such as longlines, prawn traps, shrimp trawl or gillnet. The most common type of combination vessel is the troller-gillnetter, in 1976 there were 1,000 combination vessels, making up 30% of the troll fleet, and 15% of the entire salmon fishing fleet(Federal Fisheries Statistics, 1977).

Although many wooden vessels are still used in trolling, many steel, aluminum and fibre-glass vessels are replacing the wooden vessels. The increasingly high maintenance costs for wooden vessels has attracted the use of these alternate construction materials.

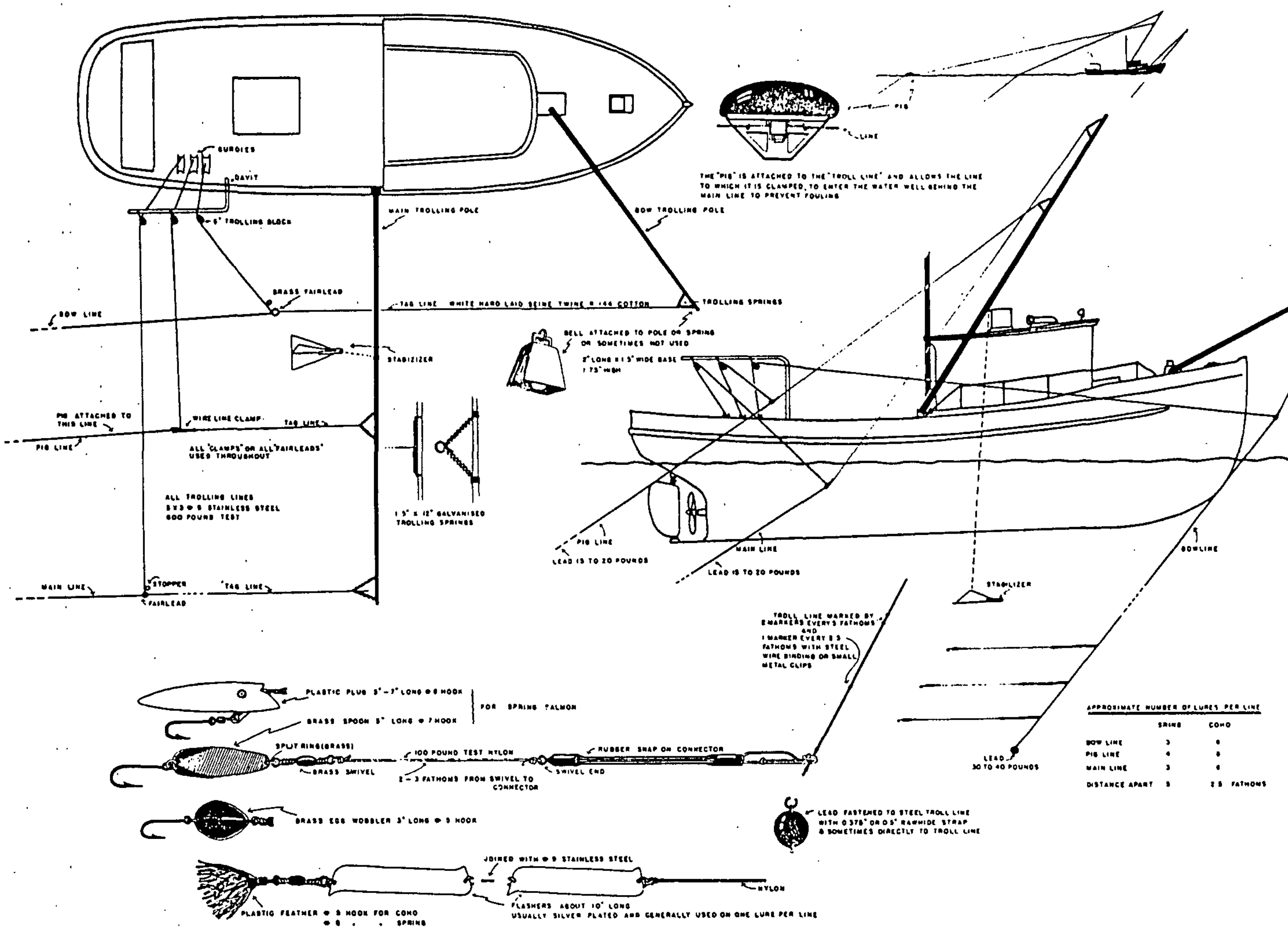
Trolling Equipment

Figure 14 shows the details of a typical B. C. salmon troller(Milne, 1964a).

1. Outrigger Poles

The most distinct feature of a troller is the tall outrigger poles, these poles are usually as long as the vessel. The outrigger poles separate the troll lines so that up to twelve lines may be fished at the same time without interference from each other. Outrigger poles taper from 5 inches(12.7 cm) in diameter at the base to 2 inches(5.1 cm) at the tip(Yoshida, 1966). The bases of the poles are secured in brackets set amid ship and abeam of the mast. The poles are guyed forward and aft by a set of galvanized steel wires. Only wood poles were used prior to World War Two.

Figure 14: Typical B.C. salmon troller and its rigging, from Milne (1964a).



However, due to the relatively modest cost, high strength to weight ratio and high resistance to sea water corrosion, aluminum poles have become increasingly popular. When not trolling, the outrigger poles are stowed in the forks of a cross tree below the masthead. When fishing, the poles are lowered to an angle of 20 to 45 degrees to the water surface.

Some trollers use two sets of outrigger poles, the second set of poles are usually 10 feet(3.0 m) shorter than the main poles and are set at the bow of the vessel. Figure 18 shows the rigging for a troller with these bow poles in addition to its main outrigger poles.

A stabilizing vane, attached to each outrigger pole, is dragged through the water to reduce the vessel's pitch and roll in rough seas. Some trollers also use steadying sails, attached from the main mast to the boom, in heavy weather.

2. Trigger Poles

Trigger poles(also called jigger, spring, gaff and sucker poles) are attached at slight angles along different positions of the outrigger pole. The common six-line troll system uses six trigger poles, three on each outrigger pole. The trigger poles are held towards the outrigger pole usually by a set of heavy springs and each pole has a cow bell attached to its tip. Each trigger pole supports one main fishing line by using a tag line(also called brail line, shock line, drag line and standing line). A device called a donut is attached to the extreme end of the tag line. The donut, together with a stopper, control the depth at which the trolling gear is fished. The stopper is knotted at the desired depth marking and prevents any more main line from passing through the donut. Additional main line being payed out pulls the main line away from the vessel and then transfers the weight of the troll gear onto the trigger pole. The trigger pole acts both as a shock absorbing device and as a signalling device. The lead weights hitting the sea bottom is the most common type of shock and damage will occur unless the energy is dissipated. Salmon, hooked on a lure, will be more likely to be lost unless this type of shock absorbing system is utilized. Fishermen claim that different types of bell signals due to differences in the struggling behaviour of different salmon permit species to be recognized. Since trollers use different techniques to retrieve troll gear for different target species, knowledge of the species captured prior to gear retrieval may increase catch success.

3. Gurdy System

The main lines are reeled in and payed out on separate metal spools called gurdies. Each gurdy is individually controlled by a clutch and brake. The clutch is near the gurdies for the fisherman to have easy control. The most common type of gurdy system uses three spools on each side of the vessel but there are systems using up to five spools for each side. The gurdies may be powered by a takeoff from the main engine, by hydraulics or by electricity. The hydraulic system is the most popular and is the system mostly used on new vessels and those that have been remodelled.

A set of pulleys, mounted on both the port and starboard stern quarter davits, feeds the line to and from the gurdies. This system prevents the main lines from jumping outside the gurdy spools and causing tangles.

4. Main Fishing Lines

The main fishing lines are made of braided stainless steel wire and range from 3/64 to 5/64 inches(1.2 to 2.0 mm) in diameter, giving a strength of 600 to 900 pound test. Each main line may be as long as 600 feet(188 m) and are marked with wire wrapping(usually brass wire) at at measured intervals(usually 3 to 5 fathoms(5.5 to 9.1 m). Therefore, the fisherman knows how much line is payed out or reeled in and is able to estimate the fishing depth. The main lines are each weighted by lead cannonballs to keep the lines at a reasonable angle to the vertical. Plastic or styrofoam floats, often called pigs, are used to buoy and steady outside lines in order to keep the gear spread and prevent fouling of lines.

5. Terminal Gear and its Arrangement

There is a significant variation in the troll vessels' rigging and terminal gear arrangement and it depends on the target species and the conditions of the fishing area(Milne, 1966). However, each main line basically has several sets of terminal gear clipped to it. Each set of terminal gear consists of a snap, leader and lure. All three components are connected by stainless steel or chromed snap swivels and heavy duty swivels(Sundstrom, 1957). The snap is clipped on the main line at the appropriate depth markings and may have a rubber nylon bumper attached to it. The bumper absorbs the shock when the fish has taken the lure. The entire assembly of trolling gear from the outrigger pole to the terminal gear is designed to absorb shock. A nylon leader, usually 100 to 150 pound test, connects the terminal lure to the snap. Although there are numerous types of lures which may be used, the most common types are combinations of flasher and either artificial or bait lures, spoons and plugs. Again, depending on the target species and size, different types and combinations of lures are used. Very few papers have been written on the selectivity of trolling lures(Tully, 1954; Milne, 1955; Milne and Ball, 1958; Argue, 1970).

Lure hooks are described by Scofield(1956), Sundstrom(1957) and Forester and Forester(1975). Hooks used in salmon trolling range in size from Nos. 5/0 to 11/0(Sundstrom(1957)). There has been very little investigation done on the effect of hook size on target species and size selection. Another significant difference in hooks is whether or not they are barbed. Fisherman claim that slow moving fish like salmon are more likely to shake the barbless hook(Scofield, 1956), Butler and Loeffel(1972) have also suggested that catch success does decrease using barbless hooks in salmon trolling.

Scofield(1956) states that to avoid tangling between sets of terminal gear on each main line the distance separating them is usually somewhat greater than the length of each gear. However, fishermen seem to determine terminal gear spacing and the number of gear sets per main line by the target species sought. Trolling for coho, sockeye and pink salmon commonly use up to nine sets of terminal gear per main line whereas spring salmon trolling usually has a maximum of three or four sets of terminal gear on each main line.

5. Trolling Operation

The vessel steams at a slow speed, towing the main lines each with a number of clipped trolling lures. Two of the most important factors in trolling are fishing speed and fishing depth. Fishing speed is different for different target species, commonly two knots for spring salmon, one knot for sockeye and pink salmon and three knots for coho salmon (Scofield, 1956). In general, spring salmon are taken deep while sockeye, pink and coho salmon are taken near the water surface.

A signal from the bell on the trigger pole denotes the hooking of a fish. The fish is retrieved by reeling in the appropriate main line with the gurdy spool containing it. As the main line is reeled in, the tag line is pulled towards the vessel. The weight of the gear is now transferred onto the davit's pulley and gurdy spool. The sets of terminal gear with no hooked fish are unclipped as the main line is reeled in until a terminal gear with a hooked fish is encountered. The gurdy spool is stopped and the fish is brought aboard. When all the sets of terminal gear have been checked for hooked fish, the main line is payed back out from the gurdy spool with the leaders being clipped back on to the appropriate depth markings.

APPENDIX II: ELECTRICAL FIELDS AND NON-ELECTRIC FISH BEHAVIOUR

Introduction

Although the first studies on the reactions of aquatic organisms to the passage of an electric current through water surrounding them have been done over ninety years ago(Hermann, 1885), the literature on non-electric fish or fish without any special receptors is scarce. The studies which have been done on electrical fields and non-electric fish behaviour are almost wholly concerned with muscular reactions caused by strong electrical fields (Loeb (1918); Okada (1929a, 1929b, 1929c); van Harreveld (1937); Groody, Loukashkin and Grant (1950,1952); Applegate, Macy and Harris (1954); Bary (1956); Balayev, Federenko and Gusar (1971), Klima (1972)). Cattley j(1955); Meyer-Waarden (1957); Vibert (1963,1967); Dethloff (1964) and Fridman (1973) have demonstrated the role of muscular reactions in electrical fishing techniques. These studies deal with three types of muscular reflex reactions; first reaction, galvanotaxis and galvanonarcosis and are described in detail by the forementioned authors.

The effects of electrical fields on salmon(*Oncorhynchus* sp. has not been well studied, the studies which have been done are mainly those involving moderate voltage electric screens for upstream and downstream migrant salmon(Andrew, Kersey and Johnson (1955, 1956a, 1956b). Andrew, Johnson and Kersey conducted a number of field experiments investigating the effects of electric screens on the direction and movement of migrating salmon. They recorded the threshold voltage gradients for galvanotropic reactions in adult sockeye salmon. The threshold value was considered to be the minimum voltage gradient required to produce a pronounced muscular contraction, all minor reactions such as slight fin movements were disregarded.

Sensitivity of Electrical Fields by Non-electric Fishes

The sensitivity of non-electric fish species toward electrical fields has not been studied extensively(Regnart, 1931; Lissmann and Machin, 1963; Protasov,1973). Regnart(1931) states that experiments have been made to determine the magnitude of the currents which are sufficient to paralyze fish which may enter the electrical but in such strong fields, the perception of the mechanism by which fish respond to electric currents is masked by the paralysis produced. Regnart emphasizes that experiments performed upon fish which were exposed to unnatural environmental conditions such as light, confinement and diet could not be comparable in vigour and sensitiveness with those in a natural environment. However, even under such unfavourable conditions, Regnart found fish to be extremely sensitive to electric currents. He found that goldfish(*Carassius auratus*) have a lower sensitivity threshold at about five microamperes per centimeter squared direct current, and cod(*Gadus callarias*) have a threshold of about fifteen microamperes per centimeter squared direct current.

MacCleave, Rommel and Cathcart (1971) and Rommel and MacCleave (1973b) have done experiments to determine the sensitivity of the American eel(*Anguilla rostrata*) and the Atlantic salmon(*Salmo salar*) to weak electrical fields. They used conditioned cardiac deceleration techniques to show that both these species are capable of detecting electrical fields of the intensities found in major ocean current systems. They found that neither the eels nor salmon appeared to sense electrical fields applied parallel to their bodies. However, with application of weak electrical fields perpendicular to the body axes of the fishes the American eel and Atlantic salmon can detect fields of approximately 0.167 microamperes per centimeter squared. A current density of 0.167 microamperes per centimeter squared represents a voltage gradient of about 670 microvolts per centimeter in freshwater and a voltage gradient of about 5 microvolts per centimeter in sea water.

Rommel and MacCleave (1973 a, b) propose that the American eel and the Atlantic salmon do have sufficient electrosensitivity to detect naturally occurring electrical fields. They suggest that the electrical fields generated in ocean water currents moving through the geomagnetic field are perpendicular to the direction of water motion and may act as a cue in orientation of a fish in a moving water current without fixed references. A number of other researchers have hypothesized that naturally occurring geoelectrical fields may serve as orientational cues for long-distance migrating fishes (Deelder (1952); Murray (1962); Harden Jones (1968); Royce, Smith and Hartt (1968); Stasko, Sutterlin, Rommel and Elson (1972)). Royce, Smith and Hartt suggested that Pacific salmon detect geoelectrical fields and use them as an orientation cue but they recognized an absence of electrical sensitivity measurements on migrating fishes such as salmon.

Rommel and MacCleave's experiments did not distinguish between sensitivity to a direct current field itself or to the change in the field at its onset. However, since the fish moves from side to side as it is swimming, a rapid change in the electric field relative to the fish will occur. Roth (1969) demonstrated in the brown bullhead that such motion of a direct current field with respect to the fish's body is emough to stimulate the phasic receptors.

Protasov (1973) states that the sensitivity threshold of non-electric fish species which do not possess special electric receptors is normally a few millivolts per centimeter. Protasov (1973) criticizes the recording of the so-called 'initial reaction'(shuddering of fish when the current is turned on) as the threshold sensitivity levels. Protasov points out the groundlessness of such determinations by giving an example of an electric fish which has electroreceptors and possesses high electrical sensitivity yet shows low sensitivity in experiments determining 'initial reaction'; the thornback ray(Raja clavata) has a sensitivity of 0.01 microvolt per centimeter(Dijkgraaf,1962) but manifests an initial motor reaction only at a potential of 0.1 volts(Krayukhin, 1938(in Protasov,1973). This seems to indicate that an initial motor reaction does not seem to coincide with the threshold for reception of electrical fields by fish. Mironov (1948)(in Protasov, 1973) and Balayev, Fedorenko and Gusar (1971) also suggest that non-electric fish can sense external electrical fields of very weak potential. Mironov showed that non-electric fish perceive currents at sea and that a recalculation of the voltages of these perceived fields produces values comparable to the sensitivity of weak electrical fields.

Electric Discharges from Non-electric Fishes

The first recordings of electrical fields among non-electric fishes were done by Kleerekoper and Sibakin (1956, 1957). They detected rhythmically arising spike potentials, synchronized with external breathing motions. Kleerekoper and Sibakin found that the source of potential generation was two muscles of the gill structure. Lissmann (1958) also detected electric discharges emitted from the eel(*Anguilla anguilla*).

It has been suggested that it is technically impossible to record the external electrical field of non-electric fishes since external electrical fields arise only as a result of the operation of specialized electric cells(electroplaxes).

Minto and Khadson (1967) recorded the electrical field emissions from 130 species of marine fishes. Minto found that these fish were capable of producing high-frequency electrical fields(hydronic radiations) and he was able to record them at a distance of 100 meters away from the fish. Minto and Khadson recorded these species-specific emissions with dipole antennae in aquarium tanks and, in some cases, the fishes' natural environment.

Barham, Huckabay, Growdy and Burns (1969) repeated Minto's experiments. They recorded pulses in the 0.01 to 40 microvolt range from five fishes and one amphibian in aquarium tanks. The generation of such pulsed signals was suggested to be from white fibre muscle action potentials. However, Barham et al did not detect any biologically generated signals in natural environments. Instead, they observed a multitude of similar signals but suggested their source as being 'atmospheric'. The question of whether these ultraweak fields could be technically recorded was presented by Ostroumov (1968) (in Protasov, 1973), who suggests that the low power of these fields would theoretically restrict the recording to no more than several meters away.

There is a number of other papers confirming the ability of fishes which have been previously considered non-electric to emit weak electric discharges (Protasov, Basov, Krumin and Orlov, 1970, 1971; Protasov, 1973). Protasov et al (1970) studied commercial fish species of the U.S.S.R. with the purpose of obtaining new data on the diversity and species specificity of electric discharges inherent to non-electric fishes. Two species of salmonids were used as test specimens, O. kisutch and O. nerka. The electric discharges of the salmon were recorded under natural conditions. The potentials measured were 220 ± 20 microvolts for the coho salmon and 160 ± 20 microvolts for the sockeye salmon when the electrodes were about one meter away. The characteristic electric discharges of the O. kisutch and O. nerka have long duration periods of 10 ± 3 and 41 ± 3 milliseconds, respectively.

Protasov et al (1970) concluded, firstly, electric discharges recorded for non-electric fishes are the result of change in potential of the field generated in the water by fishes through electric processes occurring in the neuromuscular apparatus of the fishes. Secondly, the species specificity of the discharges depends on the morphology of the neuromuscular complex for the species and is most clearly pronounced by the discharge duration.

It was also concluded, through observations on the behaviour of non-electric fishes in laboratories and under natural conditions, that electric discharges are emitted at the moment a fish is stimulated such as by mechanical stimulation, response to fright, response in an aggressive or defensive state, during lunges of a predator at its catch, during sharp lunges of a school, during acts of food gathering and sometimes even spontaneously.

Appendix III: Typical sets of terminal gear used during troll fishing experiments. Hoochie-flasher combinations were only used during spring salmon trolling (Photo 1) and sockeye salmon trolling (Photo 2).

Photo 1

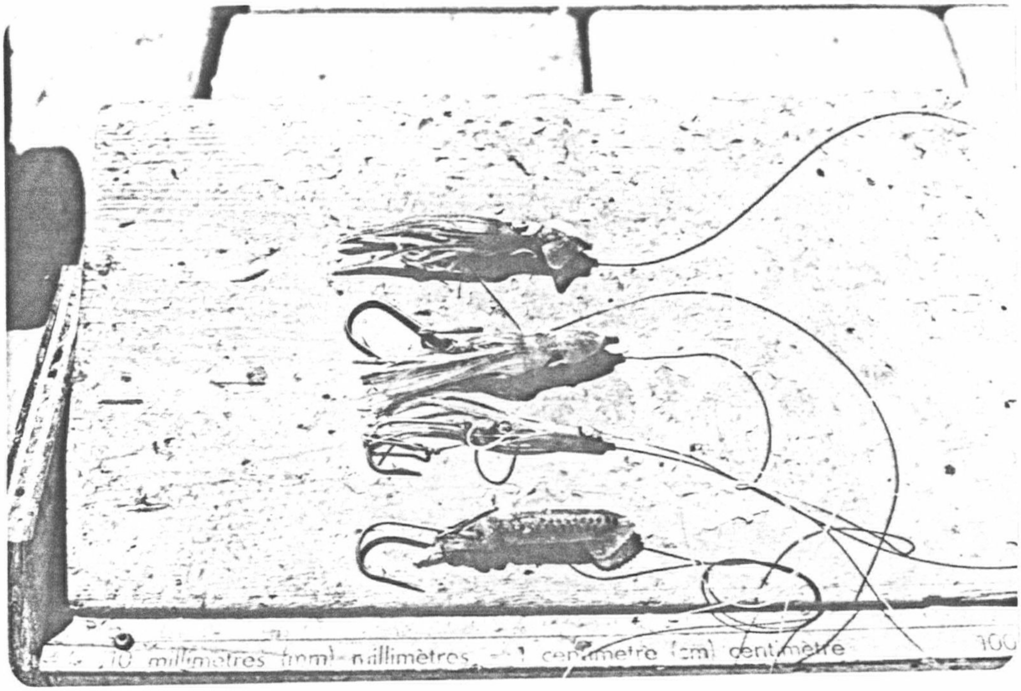
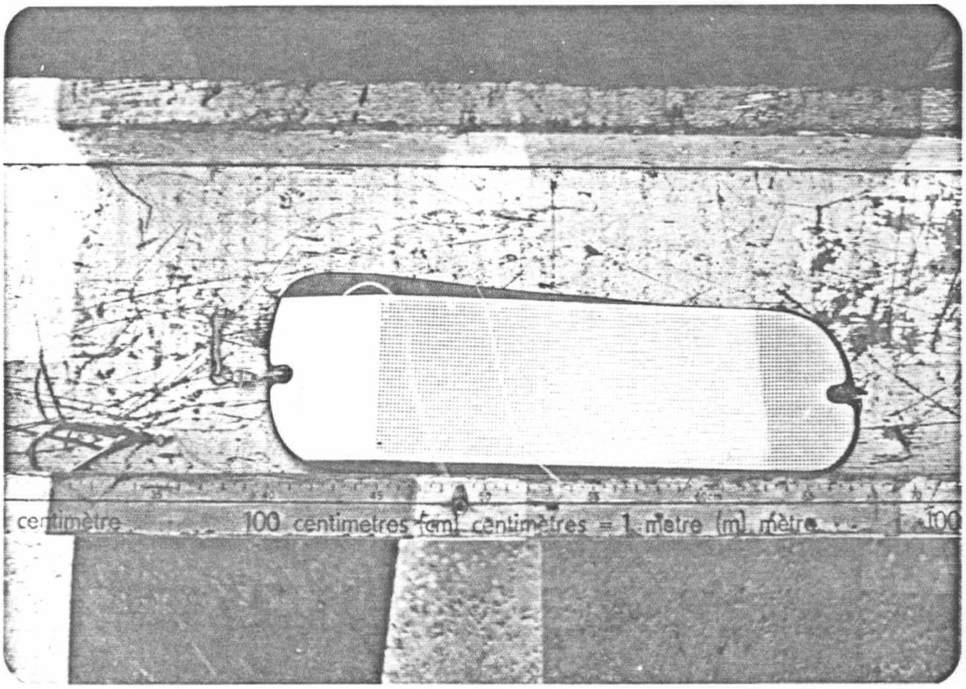


Photo 2



Appendix III. A summary of the time schedules for voltage tests done during the spring and sockeye salmon trolling experiments.

	Test	Days Fished	Fishing Time (hook hours)
I. Target Species (<u>O. tschawytscha</u>)	+0.5 vs -0.5	20/03, 21/03, 22/03, 23/03, 24/03	505.8
	-0.5 vs 0.0	06/04, 07/04, 09/04, 10/04	534.6
	+0.5 vs 0.0	05/05, 06/05, 07/05, 08/05, 09/05, 12/05	502.2
	+1.0 vs 0.0	15/05, 16/05, 18/05, 20/05, 22/05	633.6
II. Target Species (<u>O. nerka</u>)	-0.5 vs 0.0	02/09, 03/09, 04/09, 24/09	465.0
	+1.0 vs 0.0	05/09, 06/09, 08/09, 09/09	312.0
	-1.0 vs 0.0	08/09, 09/09, 11/09, 12/09, 13/09, 16/09, 18/09	678.0
	-2.0 vs 0.0	16/09, 17/09, 18/09	267.0
	+0.5 vs 0.0	19/09, 20/09, 21/09, 26/09	420.0

APPENDIX V. A set of equations summarizing the calculations of actual troll catch rates for each trial's treatment and control conditions.

1. Total Hooking Time = (number of terminal gear sets x total length of a trial)
(hook hours)

2. Non-Effective Hooking Time = (number of terminal gear sets x time spent retrieving and resetting the gear)
(hook hours)

3. Actual Fishing Time = (total hooking time - non-effective hooking time)
(hook hours)

4. Actual Catch Rate = $\dfrac{\text{(number of target fish caught during the trial)}}{\text{(actual fishing time)}}$
(fish/hook hours)