ELECTRICAL THRESHOLD RESPONSES OF PINK SHRIMP *PENAEUS DUORARUM*, BURKENROAD

DOYNE W. KESSLER[1]
U. S. Bureau of Commercial Fisheries Gear Research Station, Panama City, Florida

ABSTRACT

Threshold voltages needed to produce a hopping response in pink shrimp *(Penaeus duorarum)* were determined. Single capacitor discharge pulses, 50 to 500 microseconds long were used to stimulate shrimp in an aquarium. Threshold voltages were measured across a pair of field strength probes 5 cm apart. Voltages ranged from .06 to .39 for shrimp held parallel to the field. Shrimp required about twice as much voltage to respond when facing the negative electrode as when facing the positive electrode. Electrical threshold levels were affected by animal size, position relative to the direction of the electrical field, pulse width, and water temperature; but were not affected appreciably by salinity, or by long periods of activity.

INTRODUCTION

Electrical threshold responses of pink shrimp (*Penaeus duorarum*, Burkenroad) are being studied as part of a program on shrimp behavior related to fishing gear research and development. The final objective of this program is to improve the efficiency of commercial shrimping operations.

Studies on the burrowing activity of pink shrimp indicate the presence of a diurnal activity cycle. Pink shrimp are active at night but tend to burrow into the bottom during daylight hours, where they are not available for capture by conventional trawling equipment (Fuss & Ogren, MS). Preliminary work indicates that electricity could be used to force shrimp out of their burrows, thus greatly increasing the efficiency of commercial shrimp trawling by enabling day time operations (Fuss & Wathne, 1964).

Reactions of pink shrimp to d-c electricity were first described by Higman (1956) who found that a "blocking response" or "scare hop" reaction occurred for each pulse of electricity at low power levels. This hopping response consists of a sharp vertical jump caused by an involuntary contraction of the shrimp's abdominal muscle. It is not known whether this response is caused by stimulation of the central nervous system or by direct stimulation of the shrimp's abdominal muscle. However, the important facts are that this response does occur at low power levels and that several of these responses will cause pink shrimp to leave their burrows.

The objective of the experiments was to determine the approximate electrical voltages needed to produce a hopping response in pink shrimp. These

[1]Present address: U.S. Bureau of Commercial Fisheries, Exploratory Fishing and Gear Research Base, Juneau, Alaska.

voltages were determined for various pulse widths, shrimp sizes, temperatures and salinities, and after long periods of shrimp activity.

Materials and Methods

Shrimp used for the experiments were obtained from St. Joseph Bay and St. Andrew Bay, Florida. St. Joseph Bay shrimp of 56 to 135 mm total length, with a mean length of 82 mm, were captured by bait fisherman in 1 to 2 m of water using small roller rig shrimp trawls. St. Andrew Bay shrimp ranged in size from 60 to 140 mm with a mean length of 114 mm. These shrimp were captured by night trawling with the R/V George M. Bowers in 6 to 15 m of water using a standard 12 m shrimp trawl, or with the R/V Observer using a 6 m shrimp trawl.

Standardized procedures were used to select and handle shrimp to insure uniform physical condition of the experimental animals. Shrimp were held overnight in a live cage on the bay bottom adjacent to the behavior laboratory to allow for detection and elimination of injured individuals. Twenty shrimp were taken at random for each experiment. These shrimp were removed from the live cage and placed in a large plastic container of aerated bay water inside the laboratory. In cold weather, shrimp were held overnight in the container which slowly reached room temperature. Temperature in this container was kept near that of the shocking aquarium to avoid sudden temperature changes that might disturb the shrimp. Constant aeration maintained the oxygen levels well above the minimum requirements. Salinity was controlled by the addition of dechlorinated tap water or commercial rock salt.

For experiments at salinity extremes, shrimp were held in a small aquarium for several days while the salinity was slowly changed to the desired level. All salinity measurements were made with precision grade sea water hydrometers.

The electrical system was designed to provide a capacitor discharge stimulation pulse which could be monitored from the center of the aquarium. A pulse generator, manufactured by Sea Technology Corporation, was used to generate the stimulation pulses. Pulses were applied to two monel metal electrodes, 45.7 cm square by 1 mm thick, which were mounted at each end of a 76.2 by 45.7 by 45.7 cm plexiglass aquarium filled to a depth of 30.5 cm with bay water. Electrical energy from the pulser existed in the aquarium as a uniform field. Pulse characteristics were sensed with a pair of pickup probes made from 3 mm diameter bronze rods spaced 5 cm and insulated so only the bottom 10 mm of each rod was exposed. The signal was displayed on an oscilloscope as a graph of voltage against time. Figure 1 shows the circuitry used in these experiments.

The wave form which appeared on the oscilloscope is not a true capacitor discharge shaped pulse because of the inductance of the external circuit. For this reason I decided to disregard rise time and to consider the peak of the pulse as zero time. The remaining portion of the pulse closely approximates a theoretical capacitor discharge shape. Pulse width is defined here as the time in microseconds it takes a pulse to decay to one-third of its peak value. This approximates the value of one time constant, a standard engineering method for describing capacitor discharges (International Telephone & Telegraph Corporation, 1956; Hammond, 1961).

Experimental animals were held immobile in a predetermined position relative to the electrical field so that threshold voltages could be accurately measured. Each shrimp was placed in a nylon mesh tube which was then positioned in the center of the aquarium. Pulser voltage was slowly increased until a hopping response was obtained. Reaction voltage was read from the oscilloscope. Initially each shrimp was tested once in each of three positions (see below). The perpendicular position, however, was subsequently eliminated due to large variations in response caused by the difficulty of positioning the animals exactly perpendicular to the electrical field.

1. (+) position - shrimp parallel to electrical field, facing positive electrode
2. (−) position - shrimp parallel to electrical field, facing negative electrode

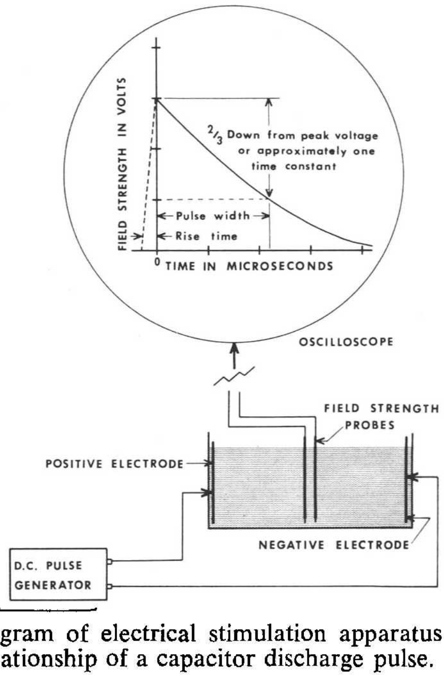

FIGURE 1. Block diagram of electrical stimulation apparatus and voltage-time relationship of a capacitor discharge pulse.

3. (⊥) position - shrimp perpendicular to electrical field, facing observer

In order to determine the effect of long periods of activity on electrical threshold voltages, pink shrimp were placed in a slowly revolving cylinder. Because of the rotation of the cylinder the shrimp were continually forced to move. A constant state of activity could be maintained for any desired length of time, after which the shrimp could be removed for electrical threshold determinations.

Results

Preliminary testing.—Data acquired during preliminary testing indicated the following general conclusions:

1. Threshold voltages are not affected by three successive shocks.
2. Threshold voltages are about equal for shrimp burrowed in the aquarium and shrimp held in nylon tubes.
3. A uniform electrical field was present in the experimental aquarium.

Parallel position.—Threshold voltages depended upon the position of the experimental animals relative to direction of the electrical field. Shrimp placed parallel to the electrical field responded to lower voltages than when placed perpendicular to the field. Shrimp orientated parallel to the field required about twice as much voltage for response when facing the negative electrode (d-c −) as when facing the positive electrode (d-c +). This polarity effect was observed for all conditions tested.

Perpendicular position.—A hopping response was not obtained when shrimp were perpendicular to the electrical field. Responses were variable, and usually consisted of a slight movement or jerk of a single appendage or some portion of the body; (e.g.) a flick of a uropod, pereiopod, antennal scale, eye stalk, or in one instance by the opening and closing of a single chela. Response voltages were also highly variable, ranging from 1½ to over 5 times the positive position threshold voltage. Many shrimp did not respond to maximum pulser voltage. Reactions became more violent as the voltage was increased but a hopping response was not obtained. A hopping response could be obtained, however, if the shrimp were shifted 2 or 3 degrees from the perpendicular position.

Pulse width.—An inverse relation existed between pulse width and threshold voltages. Threshold voltages decreased as pulse width was increased from 50 to 500 microseconds (Fig. 2).

Size.—Threshold voltages needed to produce a hopping response in pink shrimp depended upon the size of the shrimp. In general, larger shrimp responded to lower voltages than smaller shrimp. A group of 10 shrimp, 60 to 80 mm in total length, had a higher mean threshold voltage than a group of 10 shrimp of 110 to 137 mm in total length (Fig. 3).

Temperature.—Threshold voltages were affected by changes in water temperature, with higher voltages needed at high and low temperature extremes. Shrimp tested at 14°and 36° C had higher mean threshold voltages than shrimp tested at 20° and 28° C (Fig. 4).

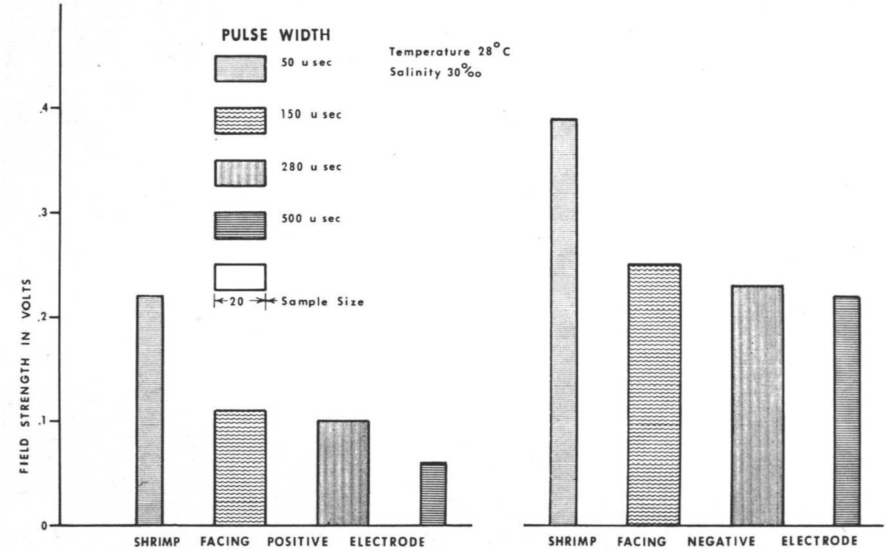

FIGURE 2. The effect of pulse widths on threshold voltages.

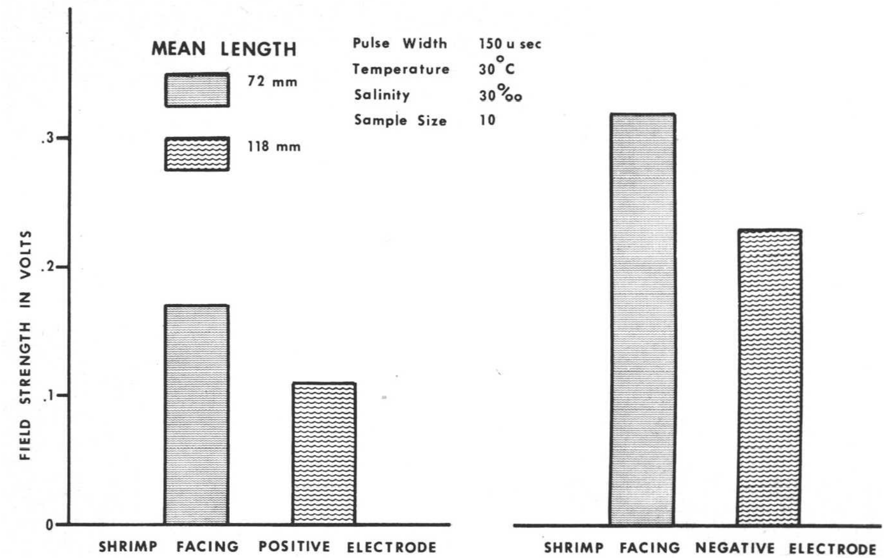

FIGURE 3. The effect of shrimp length on threshold voltages.

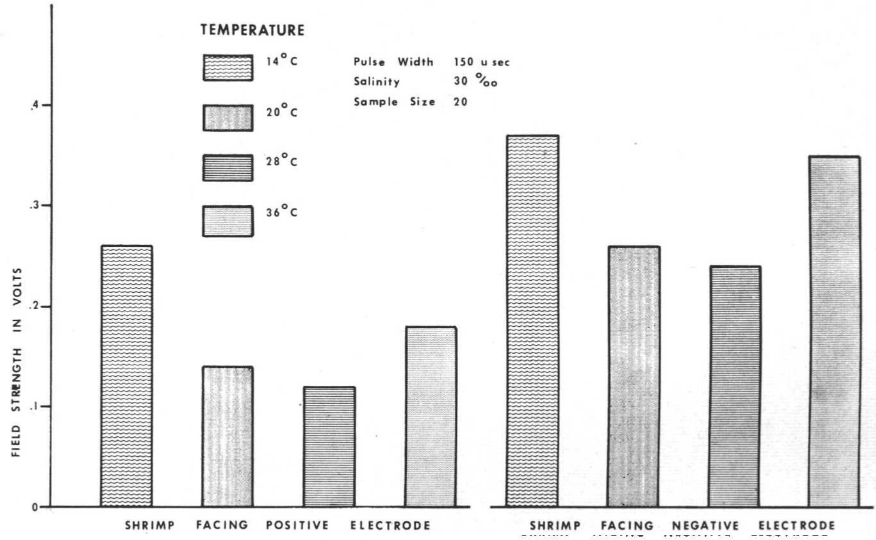

FIGURE 4. The effect of temperature on threshold voltages.

Salinity.—Threshold voltages were determined for several salinities. There was little difference in threshold voltages for salinities of 20, 30, and 40 parts per thousand (Fig. 5).

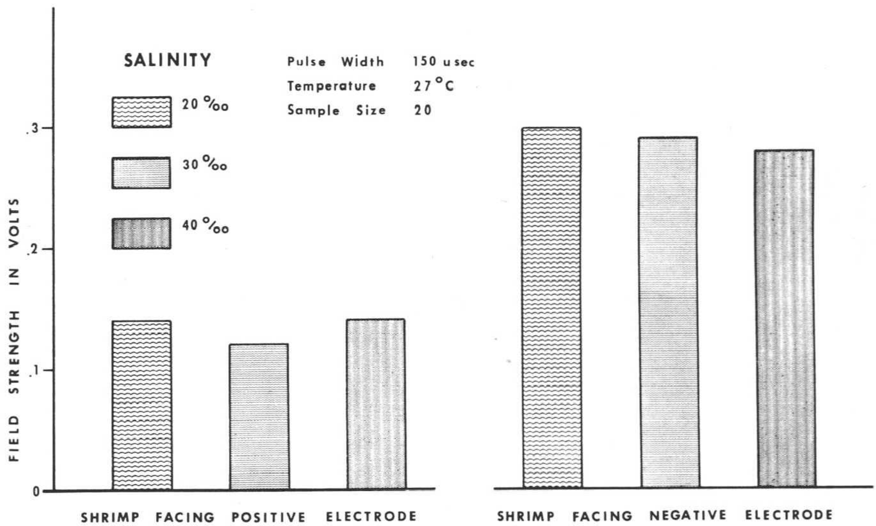

FIGURE 5. The effect of salinity on threshold voltages.

Activity.—Threshold voltages needed to produce a hopping response in shrimp which were active for 16 hours were compared with voltages obtained from shrimp which were burrowed (or inactive) the same length of time. Prolonged activity has little effect on threshold voltages of pink shrimp (Fig. 6).

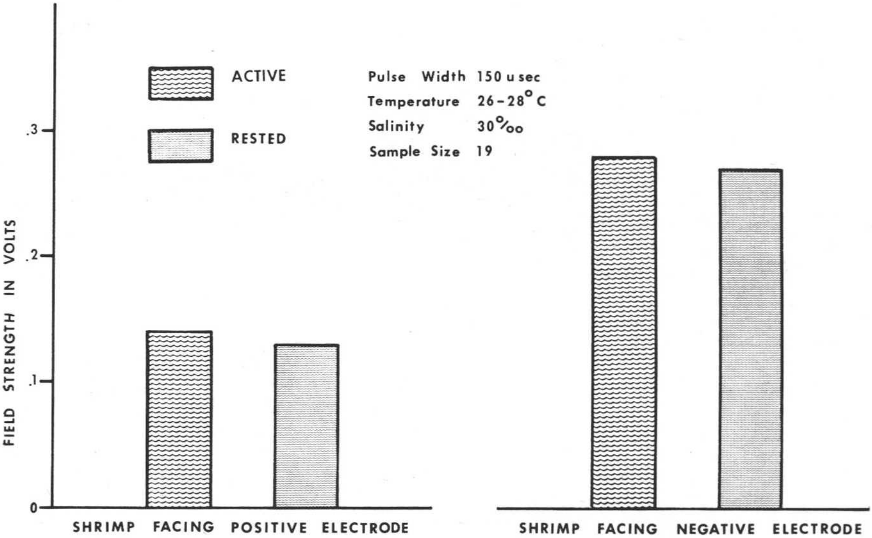

FIGURE 6. The effect of prolonged activity on threshold voltages.

Statistical data.—Ranges, standard deviations, and sample sizes for all experiments are summarized in Table 1.

DISCUSSION

Bary (1956) demonstrated that mullet require twice as much voltage to show a threshold reaction when a positive pulse is used instead of a negative pulse, however, shrimp respond in an opposite manner. All shrimp tested required about twice as much voltage to respond to a negative pulse as to a positive pulse. The reason for the apparent reversal of the affect of polarity on the threshold voltages of mullet and shrimp is not understood. More work is needed to determine the cause of this phenomena, and to determine if this difference exists between other fish and crustacea.

Calculations from data presented in this paper indicate that it takes a current density of 8.9 milliamperes per square inch to produce a hopping response with a negative capacitor discharge pulse of 500 microseconds on

TABLE 1
A SUMMARY OF THRESHOLD VOLTAGES FOR PINK SHRIMP
Potential Difference in Volts Between 5 cm of Sea Water

	Shrimp Facing Positive Electrode			Sample Size	Shrimp Facing Negative Electrode		
	$\overline{X}$	SD	Range		$\overline{X}$	SD	Range
Pulse Width							
500 μ sec	.06	.01	.04 - .09	10	.22	.04	.16 - .27
280 μ sec	.10	.02	.08 - .14	20	.23	.04	.17 - .37
150 μ sec	.11	.02	.06 - .14	20	.25	.04	.20 - .33
50 μ sec	.20	.02	.18 - .23	10	.39	.06	.28 - .48
Size							
118 mm	.11	.02	.09 - .14	10	.23	.03	.19 - .28
72 mm	.17	.02	.15 - .21	10	.32	.02	.29 - .35
Temperature							
36°C	.17	.05	.09 - .27	20	.35	.08	.25 - .64
28°C	.12	.02	.07 - .15	20	.24	.03	.19 - .30
20°C	.14	.03	.08 - .19	20	.26	.06	.16 - .44
14°C	.26	.04	.18 - .32	20	.37	.04	.27 - .44
Salinity							
40 ‰	.14	.02	.09 - .17	20	.28	.04	.20 - .36
30 ‰	.12	.02	.09 - .16	20	.29	.04	.22 - .35
20 ‰	.14	.02	.10 - .19	20	.30	.05	.23 - .42
Active	.14	.02	.10 - .20	19	.28	.04	.22 - .32
Rested	.13	.02	.10 - .18	19	.27	.03	.20 - .33

shrimp orientated parrallel to the electrical field. These calculations are shown below:

$$I = \frac{.63E \times 6.4516}{R}$$

$$I = \frac{.63(.22) \times 6.4516}{100}$$

$I = .00894$ amps or 8.9 milliamperes

where, I = Effective current density
E = Threshold voltage obtained in experiment
.63 = Conversion factor to change peak voltage to effective voltage
6.4516 = Conversion factor to change current density per square cm to current density per square inch

R = Total resistance in ohms between field strength probes calculated from the following formula:

$R = 5\ (1/c)$

$R = 5\ (1/.05)$

$R = 100$ ohms

where 5 = Distance in cm between probes
c = Conductivity of sea water in mohs per cm (from, Electrical Conductivity of Sea Water [table], Industrial Instruments, Inc., Cedar Grove, New Jersey)

As would be expected, this is considerably less than the current density of 15 milliamperes per square inch obtained by Higman (1956) to produce a galvanotaxis reaction in pink shrimp. Valid comparisons with Higman's results, however, are difficult because of differences in stimulation pulse characteristics.

Earlier workers (McMillan, 1928; Groody *et al.,* 1952) found that the reactions of fish to electrical stimulations vary inversely with length. Bary (1956) demonstrated this effect on mullet in salt water and Higman (1956) found that galvanotaxis reactions of shrimp depend on the size of the animal. Results presented here indicate that the voltage necessary to produce a hopping response in pink shrimp also depends on the animal size, i.e., larger shrimp respond to lower voltages than smaller shrimp.

Higman (1956) found that changes in temperatures had no significant effect on the galvanotaxis reactions of pink shrimp. He was interested primarily in demonstrating that temperature changes did not affect his experimental results, hence the effects of extreme temperatures were not tested.

The results of my study show that an increase in electrical threshold voltages does occur at extreme temperatures. Shrimp tested at 14° C had higher thresholds than those tested at 20° or 28° C. This increased threshold could be due to a general lowering of body metabolism as evidenced by a 50 per cent decrease in activity of pink shrimp below about 15° C (Fuss & Ogren MS). Shrimp that were stimulated at 36° C also had higher threshold voltages than those stimulated at 20° or 28° C, possibly because they were being held at conditions approaching the maximum limit of their temperature range.

No previous data are available on the effects of sea water salinities on electrical thresholds of penaeid shrimp. Since the electrical conductivity of sea water at a given temperature depends on salinity, one would assume that threshold voltages would be affected by salinity changes. Data from these experiments, however, indicate threshold voltages are not influenced by salinity changes. Although salinity regulates the power needed to produce a given field strength, changes in salinity do not affect the field strength voltage required to elicit a hopping response in pink shrimp.

According to Bary (1956), threshold voltages needed to produce a minimum response in mullet were increased after 15 minute periods of vigorous enforced swimming. My results, however, indicate that threshold voltages needed to produce a hopping response in pink shrimp were not affected by long periods of slowly enforced activity. This difference in results could be because Bary was measuring threshold voltages of animals which were physically fatigued. The present experiment was done to determine if differences in threshold voltages existed between rested shrimp and shrimp which had been active for long periods of time.

My primary objective was to determine the approximate electrical voltage required to produce a hopping response in pink shrimp. The objective was accomplished for laboratory conditions. However, recent field experiments indicate that wild shrimp may react differently from shrimp which have been held in captivity. Hence, differences in threshold voltages between wild and captured shrimp may also exist. Experiments are now being conducted to determine the threshold voltages for wild shrimp in their natural habitat.

SUMMARY

1. Shrimp orientated parallel to the electrical field responded to lower voltages than shrimp perpendicular to the field.
2. Threshold voltages obtained for shrimp facing the positive electrode were doubled when they were stimulated facing the negative electrode.
3. Threshold voltages decreased as pulse widths were increased from 50 to 500 microseconds.
4. Threshold voltages of pink shrimp were affected by size; larger shrimp had lower thresholds than smaller shrimp.
5. Shrimp had higher threshold voltages at extreme temperatures.
6. Threshold voltages obtained for shrimp at 20, 30, and 40 parts per thousand salinity were about equal.
7. Threshold voltages for active and rested shrimp were about equal.

SUMARIO

RESPUESTA DEL CAMARÓN ROSADO *Penaeus duorarum,* BURKENROAD AL MÍNIMO ESTÍMULO ELÉCTRICO

1. El camarón orientado paralelo al campo eléctrico respondió a voltajes más bajos que el camarón perpendicular al campo.
2. Los voltajes mínimos obtenidos para camarones frente al electrodo positivo fueron el doble que cuando fueron estimulados frente al electrodo negativo.
3. Los voltajes mínimos decrecieron a medida que las amplitudes de las pulsaciones fueron aumentadas de 50 a 500 microsegundos.
4. Los voltajes mínimos del camarón rosado estuvieron afectados por el tamaño; los camarones mayores tuvieron un mínimo más bajo que los camarones menores.
5. El camarón tuvo más alto voltaje mínimo a temperaturas extremas.
6. Los voltajes mínimos obtenidos para el camarón a salinidades de 20, 30 y 40 partes por mil fueron casi iguales.
7. Los voltajes mínimos para camarón activo y en reposo fueron casi iguales.

REFERENCES

BARY, B. M.
1956. The effect of electrical fields on marine fish. Marine Research No. 1, Scottish Home Department, Her Majesty's Stationery Office, Edinburgh, 32 p.

FUSS, C. M., JR. AND F. WATHNE
1964. Shrimp behavior as related to gear research and development *in* Kristjonsson, Hilman, Ed., Modern Fishing Gear of the World, 2. Fishing News Ltd., London, pp. 563-569.

GROODY, T., A. LOUKASHKIN, AND N. GRANT
1952. A preliminary report on the behavior of the Pacific sardine *(Sardinops caerulea)* in an electrical field. Proc. Calif. Acad. Sci., *27* (8): 311-323.

HAMMOND, S. B.
1961. Electrical engineering. McGraw-Hill. Inc., New York, New York, 77 p.

HIGMAN, J. B.
1956. The behavior of pink grooved shrimp, *Penaeus duorarum,* Burkenroad, in a direct current electrical field. Fla. St. Bd. Conserv. Tech. Ser. No. 16: 1-23.

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION
1956. Reference data for radio engineers. American Book, Stratford Press, Inc., New York, New York, pp. 152-153.

MCMILLAN, F. O.
1928. Electric fish screen. Fish. Bull., U. S., 44: 97-128.