TABLE 3.—Statistics of length-weight relations for all data used in study.

Species	Number of fish	a	[1]b	Mean square error	Minimum fork length (cm)	Maximum fork length (cm)
Yellowfin tuna	3,689	0.000021804	2.96989	0.003265	40	170
Skipjack tuna	2,554	0.000005611	3.31497	0.005193	36	64
Bigeye tuna	190	0.000012494	3.12082	0.003405	41	132
Little tunny	753	0.000012000	3.08340	0.006935	41	57
Auxis sp.	50	0.000000280	4.13514	0.030871	30	45

[1]All estimates are significantly different than 0 at the 1% level.

where a' = unbiased estimate of a

$(s^2_{W \cdot L})$ = mean square error about the regression line.

The mean square errors for this study are low (Table 3). Thus the bias should be negligible. The results of this study were examined by comparing average weights of yellowfin used in the study against predicted weights. Differences were negligible as expected.

The significant differences found among samples and categories indicate that the variance of estimated numbers of fish caught, estimated from length frequency samples, could be reduced by a sophisticated sampling scheme which is stratified by category if not sample. Obviously it would be simpler to weigh fish from each sample rather than measure lengths, if one desired to stratify by sample. Logistics rule out this possibility. A formal cost-benefit analysis of the effort required to develop an adequate sampling scheme stratified by category probably would rule out this scheme. The significant differences among samples do point out the desirability of obtaining large numbers of samples rather than large sample sizes in further study of length-weight relations.

Acknowledgments

E. Scott of the Southeast Fisheries Center, National Marine Fisheries Service, NOAA, Miami, Fla., measured fish under the supervision of J. Wise of the same laboratory. I thank both of these individuals for their helpful suggestions on this paper. E. Holzapfel and M. Kimura of the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, Calif., also deserve thanks for performing most of the data compilations and calculations used in the study. I also thank D. Kramer of the Southwest Fisheries Center for his technical editing of the paper.

Literature Cited

BATTS, B. S.
1972. Age and growth of the skipjack tuna, *Katsuwonus pelamis* (Linnaeus), in North Carolina waters. Chesapeake Sci. 13:237-244.

BEARDSLEY, G. L., JR., AND W. J. RICHARDS.
1970. Size, seasonal abundance, and length-weight relation of some scombrid fishes from southeast Florida. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 595, 6 p.

CHATWIN, B. M.
1959. The relationships between length and weight of yellowfin tuna (*Neothunnus macropterus*) and skipjack tuna (*Katsuwonus pelamis*) from the Eastern Tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Comm. 3:307-352.

PIENAAR, L. V., AND J. A. THOMSON.
1969. Allometric weight-length regression model. J. Fish. Res. Board Can. 26:123-131.

POINSARD, F.
1969. Relations entre longueur prédorsale, longueur à la fourche et poids des albacores *Thunnus albacares* (Bonnaterre) pêchés dans le sud du Golfe de Guinée. Cah. ORSTOM. (Off. Rech. Sci. Tech. Outre-Mer), Sér Océanogr. 7(2):89-94.

WILLIAM H. LENARZ

Southwest Fisheries Center
National Marine Fisheries Service, NOAA
La Jolla, CA 92037

ELECTRICAL THRESHOLD RESPONSE OF SOME GULF OF MEXICO FISHES

Threshold voltage is the minimum electrical potential to which an animal responds (Vibert, 1967). Usually threshold measurements are inexpensive and easy to obtain, and they provide guidelines for designing electrical fishing systems. Bary (1956) and Kessler (1965) showed that threshold voltage varied according to water temperature, size of animal, and width of the pulse. Earlier workers clearly demonstrated that threshold voltages are affected by the position of the animal in the electrical field. Klima (1968) documented experimentally the mathematical relationship between the angle of the animal in the electrical field and its threshold voltage. These authors have defined the basic physical and biological factors which affect the response of selected marine animals to electricity.

To understand more clearly the basic characteristics of electrical fields which control marine fishes, threshold response of selected Gulf of Mexico species was investigated. I determined the minimum threshold voltage (in a field with other specific characteristics) for Atlantic croaker, *Micropogon undulatus*; spot, *Leiostomus xanthurus*; longspine porgy, *Stenotomus caprinus*; chub mackerel, *Scomber japonicus*; and scaled sardine, *Harengula pensacolae*. I further attempted to determine the minimal effective pulse width by estimating the threshold voltage at selected pulse widths.

Procedure

Spot, Atlantic croaker, and longspine porgy were trawled in Mississippi Sound; minimizing injury to fish was accomplished by towing for only 10 min. Chub mackerel and scaled sardines were caught by night-lighting off the Mississippi Coast (Wickham, 1970). The experimental animals were held in shipboard tanks of circulating seawater while being transported to the Laboratory. Only fish acclimated for more than 3 days and in good physical condition were used. Threshold voltages were determined for 140 individuals. Each specimen was subjected to only one test and discarded.

Studies were conducted in a 72 × 45 × 45 cm, 190-liter plexiglass aquarium at temperatures between 15° and 17.5°C; salinities ranged from 19.6 to 26.4‰.

An electrical system providing a uniform electrical field was used. It had a capacitor-discharge stimulation pulse that could be monitored from the center of the aquarium. Pulse shapes which exhibit a rapid rise in amplitude and slow rate of decay, such as capacitor-discharge pulses, are the most effective for controlling fish (Taylor, Cole, and Sigler, 1956; Vibert, 1967; Klima, 1972).

A pulse generator was used for the stimulation pulses. Pulses were applied to two monel electrodes mounted at opposite ends of the aquarium. Pulse characteristics were measured with a pair of pickup probes. These were constructed from two 3-mm diameter bronze rods 10 cm apart and insulated so that only the bottom 10 mm of each rod was exposed. Pulse characteristics were displayed on an oscilloscope as a graph of voltage against time.

Threshold voltages were determined with the fish held immobile parallel to the electric field in a plastic mesh tube in the center of the aquarium facing either the positive or negative electrode. Voltage was slowly increased until the fish responded by fluttering of the body. This value was then recorded from the oscilloscope and assumed to be the threshold voltage.

Results and Discussion

Kessler (1965) found that variations in pulse width alter the threshold voltage for shrimp. Pulse widths longer than 150 μs are satisfactory for stimulating shrimp, whereas below that width the power required for stimulation would be significantly greater. Longspine porgies stimulated with less than 100 μs pulse widths required at least four times more voltage to respond than fish stimulated with a wider pulse (Table 1). At narrow pulse widths threshold voltage was high; at the longer widths it was low, forming an inverse relationship.

Scaled sardine required higher voltages to elicit a response at narrower pulse widths than at wider pulse widths. At 45 μs it took almost 1.9 V/10 cm to elicit a minimum response, but at 100 μs it took only 1.3 V/10 cm, and at 250 and 1,000 μs it took only 1.0 and 0.9 V across 10 cm. A comparison of threshold voltages of scaled sardines at different pulse widths shows a significant difference between the threshold values at pulse widths tested (Table 1). Student's *t*-test was used in making these comparisons:

$$(t = 6.316,\ t_{0.975\,(18)} = 2.101)\ \text{45 and 100}\ \mu\text{s},$$

$$(t = 3.815,\ t_{0.975\,(18)} = 2.101)\ \text{100 and 250}\ \mu\text{s},$$

$$(t = 5.000,\ t_{0.975\,(18)} = 2.101)\ \text{250 and 1,000}\ \mu\text{s}.$$

Although there was a difference in the minimum voltage within the 250 μs to 1.0 ms range, as shown by the reactions of scaled sardine, the difference in actual voltage was minimal. For scaled sardine the most efficient pulse width in terms of electrical power would be not less than 250 μs. Generally, threshold voltages at pulse

TABLE 1.—A summay of threshold voltages.

Species	Average V/10 cm	Variance	Pulse width (ms)	Electrode which fish faces	Sample size	Range fish length (mm)
Atlantic croaker	0.39	0.006	2.500	+	10	130-150
Atlantic croaker	0.30	0.001	2.500	−	10	120-150
Spot	0.38	0.048	2.300	+	10	102-132
Chub mackerel	0.31	0.005	2.300	+	15	175-189
Longspine porgy	2.90	0.004	0.045	+	10	90-106
Longspine porgy	1.82	0.004	0.100	+	10	91-106
Longspine porgy	0.35	0.001	0.250	+	10	93-111
Longspine porgy	0.35	0.001	2.500	+	10	92-110
Scaled sardines	1.89	0.331	0.045	+	10	85-98
Scaled sardines	1.00	0.010	0.045	−	5	78-93
Scaled sardines	1.29	0.056	0.100	+	10	80-101
Scaled sardines	0.83	0.003	0.100	−	5	84-91
Scaled sardines	1.00	0.020	0.250	+	10	79-94
Scaled sardines	0.80	0.300	0.250	−	5	88-98
Scaled sardines	0.90	0.020	1.000	+	10	80-99

widths greater than 2,000 μs were similar between species.

Atlantic croaker were used to test the hypothesis that fish require more voltage to show a threshold reaction when facing the positive electrode. Analysis of the average threshold voltages of croakers facing the positive and negative electrode by Student's t-test shows a significant difference between the values

$$(t = 3.60 \text{ and } t_{0.975\,(18)} = 2.101).$$

Scaled sardines showed a similar response (Table 1). These results confirm those of Bary (1956) where he showed that mullet required more voltage to respond when facing the anode than the cathode.

The cost of producing a useful electrical field in seawater is dependent upon the power required to elicit specific responses in the desired species. Pulse width obviously is a major factor which affects the power requirements along with voltage and pulse rate (Klima, 1972). Narrow pulse widths require proportionately less power than wider ones. Engineering design criteria for pulse generators are usually based on the minimum pulse width electronically possible. These results, however, indicate that pulse width should not be less than 250 μs and probably should range between 250 and 1,000 μs.

Literature Cited

BARY, B. M.

1956. The effect of electric fields on marine fishes. Scotl. Home Dep. 1, 32 p.

KESSLER, D. W.

1965. Electrical threshold responses of pink shrimp *Penaeus duorarum*, Burkenroad. Bull. Mar. Sci. 15:885-895.

KLIMA, E. F.

1968. Shrimp-behavior studies underlying the development of the electric shrimp-trawl system. U.S. Fish Wildl. Serv., Fish. Ind. Res. 4:165-181.

1972. Voltage and pulse rates for inducing electrotaxis in twelve coastal pelagic and bottom fishes. J. Fish. Res. Board Can. 29:1605-1614.

TAYLOR, G. N., L. S. COLE, AND W. F. SIGLER.

1957. Galvanotoxic response of fish to pulsating direct current. J. Wildl. Manag. 21:201-213

VIBERT, R.

1967. Part I — General report of the working party on the applications of electricity to inland fishery biology and management. *In* R. Vibert (editor), Fishing with electricity — Its applications to biology and management, p. 31-73. Fishing News (Books) Ltd., Lond.

WICKHAM, D. A.

1970. Collecting coastal pelagic fishes with artificial light and a 5-meter lift net. Commer. Fish. Rev. 32(12):52-57.

EDWARD F. KLIMA

Southeast Fisheries Center
National Marine Fisheries Service, NOAA
Pascagoula, MS 39567
Present address:
Office of Living Resources, NOAA
6010 Executive Boulevard
Rockville, MD 20852