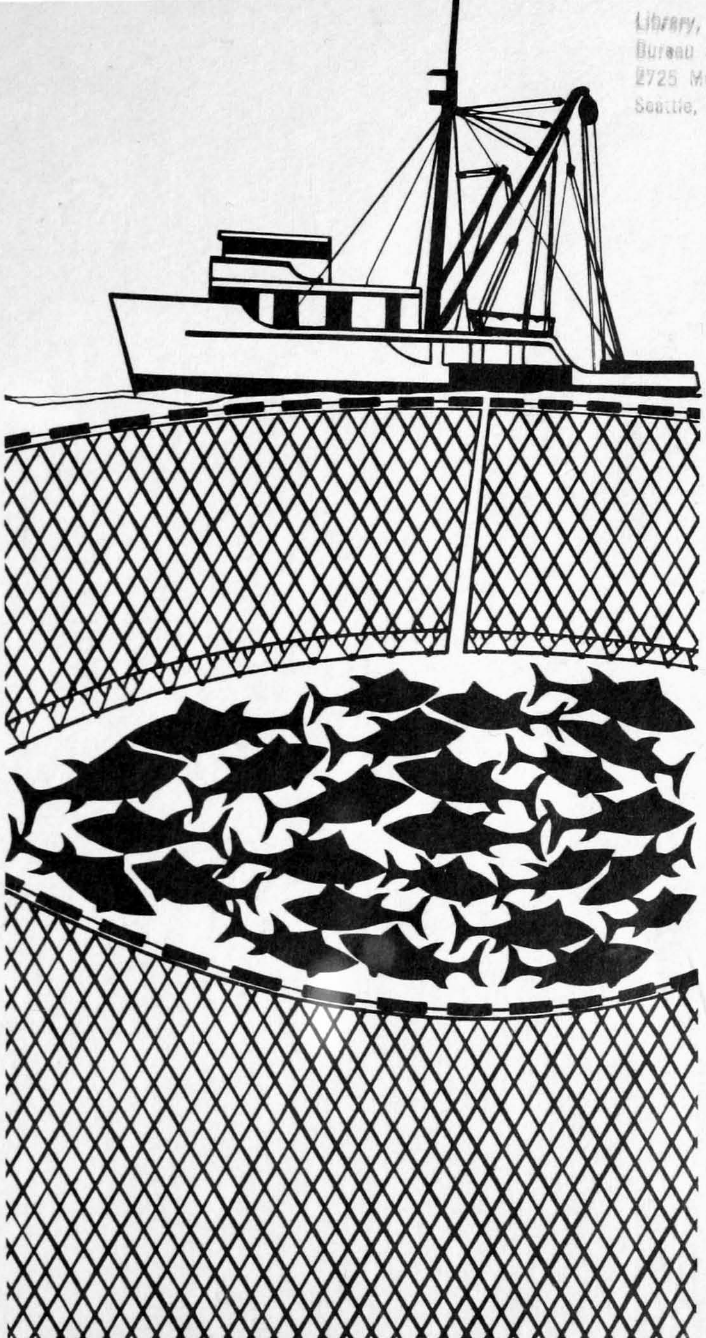

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SHRIMP-BEHAVIOR STUDIES UNDERLYING THE DEVELOPMENT OF THE ELECTRIC SHRIMP-TRAWL SYSTEM

by

Edward F. Klima

ABSTRACT

Observation of how shrimp react to different amounts of electrical energy and repetition rates of pulsating direct current in the laboratory and the field provided information on the electric characteristics needed for an effective electric shrimp trawl.

The laboratory studies showed the electric threshold voltage of shrimp oriented at different positions to the electrodes and the effect of different voltages on the shrimp's responses. Threshold voltages were affected by the animal's position relative to the electric field, and the shrimp's reaction increased with an increase in voltage.

The field studies provided information on the electrical output needed to force burrowed shrimp out of the substrate. Capacitor-discharge pulses of 4 per second with a potential of 3.0 volts or more across 100 millimeters parallel to the electric field were best for forcing shrimp out of the types of bottom on some of the commercial shrimping grounds in the Eastern Gulf of Mexico.

CONTENTS

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INTRODUCTION

Commercial fishing for brown and pink shrimp, *Penaeus aztecus* and *P. duorarum*, is now restricted to trawling at night because these species stay in their burrows during the day. This restriction causes the fleet to remain idle during daylight, or roughly one-half of the time. If shrimp could be caught during the daytime, manpower, vessels, and equipment could be used more efficiently.

Higman (1956) found that pulsating direct current caused a pink shrimp to hop at each pulse. A sharp vertical jump was caused by an involuntary contraction of the shrimp's abdominal muscle. In laboratory studies, Kessler (1965) found that shrimp could be effectively stimulated with pulsating direct current of low voltage. Because of the low-energy drain of pulsating direct current in sea water, as compared with that of alternating current, the use of an electric trawl system to harvest burrowed shrimp appeared possible.

Before a practical electric shrimp-trawl system could be designed and developed, however, information was needed on the optimum electric characteristics required to force shrimp out of the substratum to a height suitable for capture with trawls. The purpose of the studies reported in this paper, therefore, was to determine the optimum electrical requirements necessary for the development of an electric shrimp-trawl system. To achieve this purpose, I carried out two studies: one in the laboratory; the other in the field.

I. LABORATORY STUDIES

The laboratory studies were concerned with determining threshold voltages and the effect of high- and low-voltage stimulation.

A. DETERMINING THRESHOLD VOLTAGES

Kessler (1965) studied the minimum voltage necessary to produce a hopping response in pink shrimp positioned parallel or perpendicular to the electric field. His findings indicated that threshold voltage varied according to the temperature of the water, size of the shrimp, width of the pulse, and position of the experimental animal relative to the electric field.

1. Procedure

Experimental animals were caught by trawling in St. Andrews Bay, Florida. The trawl tows were about 10 minutes long to minimize injury to the shrimp. After capture, the shrimp were held in tanks of circulating sea water before being transported to the laboratory. At the laboratory, they were held in live cages for at least 24 hours prior to experimentation to allow for detection and elimination of injured animals. Random samples of shrimp in "good physical condition" (that is, not injured; not obviously infected with protozoan microsporidians; and not confused or disoriented) were used in each experiment. These animals ranged from 73 to 110 millimeters total length.

The laboratory studies were carried out in 190-liter plexiglass aquariums containing water at 20° C. and at salinities ranging from 28 to 30 parts per thousand.

An electric system similar to that described by Kessler (1965) was used because this type of system provided a uniform electric field in the aquariums. This system has a capacitor-discharge stimulation pulse that can be monitored from the center of the aquarium. A pulse generator produced electric pulses that were applied through two Monel-metal electrodes[1], 46 centimeters square by 1 millimeter thick, mounted at opposite ends of the aquarium. Pulse characteristics were tested by means of a pair of pickup probes made from two 3-millimeter-diameter bronze rods, spaced 5 centimeters apart and insulated so that only

[1] Trade names are mentioned merely to simplify the description of the experimental equipment; no endorsement is implied.

the bottom 10 millimeters of each rod was exposed. These pulse characteristics were displayed on an oscilloscope showing a graph of voltage versus time.

To determine threshold voltages, I held the shrimp immobile in a predetermined position relative to the electric field. Each shrimp was placed in a nylon-mesh tube in the center of the aquarium, and the tube was positioned at 0°, 15°, 30°, 45°, 60°, or 75° in relation to the electrodes. The voltage was increased slowly until the shrimp hopped. The voltage at the time of the hop was called the threshold voltage — it was read from the oscilloscope and recorded.

2. Results

Figure 1 shows the relation between length of shrimp at various angles of theta and lines of equal potential or, in other words, the voltage drop across the length of the animal's body perpendicular to the equal potential surfaces. These findings indicate a direct relation between threshold voltages or lines of equal potential and positions of the shrimp in the electric field (Table 1). Slightly more voltage is required to produce a response in shrimp facing the negative electrode as compared with that required to produce a response in shrimp facing the positive electrode. This polarity effect was observed for all angles of theta tested.

Threshold voltages are lowest when shrimp are parallel to the electric field (theta equals zero) and are facing the positive electrode. As the angle of the animal increases from 0° to 75°, the threshold voltage increases. Average response voltages for shrimp oriented at

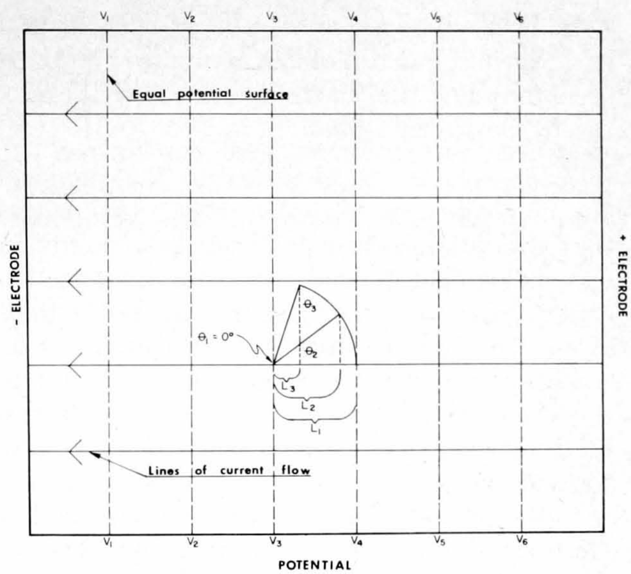

Figure 1.—Uniform electric field showing hashed lines of equal potential surfaces, solid lines of current flow, angle of theta, and the relation between L length of an object at various angles of theta and lines of equal potential (V = voltage).

various angles to the field are up to four times greater than are threshold voltages for shrimp parallel to the field. Shrimp at 45° to the field require only 1.4 times as much voltage to elicit a hopping response as those parallel to the field, whereas those at 75° to the field require about four times as much voltage to be stimulated. This relation can be expressed as:

$$\text{Threshold voltage at angle } \theta = \frac{\text{threshold voltage at } 0°}{\text{cosine } \theta}$$

where 0° is an angle parallel to the electric field and perpendicular to the electrodes.

The theoretical voltages for shrimp oriented at angles of 0°, 15°, 30°, 45°, 60°, and 75° were calculated by the above formula

Table 1.—Threshold voltage for pink shrimp

Orientation of shrimp in relation to electrodes	Data for shrimp facing positive electrode				Data for shrimp facing negative electrode			
	Shrimp in sample	Potential difference			Shrimp in sample	Potential difference		
		Mean	Standard deviation	Theoretical		Mean	Standard deviation	Theoretical
Degrees	*Number*	*Voltage drop per 5 cm. sea water*			*Number*	*Voltage drop per 5 cm. sea water*		
0	30	0.16	0.04	0.16	20	0.20	0.04	0.29
15	30	0.17	0.04	0.17	20	0.31	0.05	0.30
30	30	0.18	0.04	0.18	20	0.35	0.06	0.33
45	30	0.23	0.06	0.23	20	0.42	0.09	0.41
60	30	0.34	0.09	0.32	20	0.60	0.13	0.58
75	30	0.56	0.15	0.61	19	0.96	0.24	1.12

(Table 1). The agreement between the actual and theoretical threshold voltages justified acceptance of the above relation for the different positions tested.

This relation is identical to the physical law of electricity (Brophy, 1966) that states that the voltage drop between two points in an electric field depends upon the distance between these points as measured along the lines of current flow (Figure 1). In this instance, the lines of current flow are perpendicular to the electrodes. As the angle of the shrimp relative to the lines of equal potential increases, the voltage drop across the animal decreases with the cosine of the angle, which implies that electric stimulation occurs from one end of the shrimp's body to the other. We can, therefore, conclude that the voltage felt by shrimp varies not only with its orientation but also with its total length. Hence, as the length of the animal increases, the amount of voltage felt also increases, according to the following:

$$L \cos \theta = \Delta V$$

where L = total length of the animal and ΔV = voltage drop across the animal.

B. DETERMINING EFFECT OF HIGH- AND LOW-VOLTAGE STIMULATION

Further laboratory studies were made to ascertain how different voltages would affect the reactions of shrimp.

1. Procedure

Experimental animals were caught and handled in the same manner as was described in the preceding experiment on the determination of threshold voltages.

To determine the effect of different voltages on the hopping response of electrically stimulated shrimp, I first applied the threshold voltage and then applied 7.0 volts to each experimental animal. The height each shrimp jumped was measured with a ruler and recorded.

2. Results

This laboratory study to ascertain the effect of voltage on the response of shrimp indicates that the height jumped above the bottom is greater when the shrimp are stimulated at 7.0 volts than when they are stimulated at the threshold voltages (Table 2).

Table 2.—Relation between length of shrimp and their response to electric potential

Length of shrimp	Shrimp in sample	Average height shrimp jumped when stimulated at:	
		0.16 volt	7 volts
Millimeters	*Number*	*Centimeters*	*Centimeters*
70- 79	20	6.0	8.1
80- 89	45	8.9	12.2
90- 99	24	7.9	11.4
100-109	11	7.6	14.1
Total	100	---	----
Average	---	7.9	11.4

Also a direct relation appears to exist between shrimp size and height jumped for animals stimulated with high voltage — the larger the animal, the higher it jumps. At threshold voltage, however, no such relation appears to exist; the height jumped does not increase with an increase in the length of the shrimp.

II. FIELD STUDIES

In the field studies, which were to provide the engineering staff at the Base with sufficient data to enable them to design an electric shrimp-trawl system, it was desirable to determine the optimum electric stimulus necessary to "deburrow" (to evacuate the burrow) shrimp from the major kinds of bottom found on commercial shrimp grounds in the Eastern Gulf of Mexico. These studies were divided into two parts: The first determined the optimum pulse rate and voltage needed to force brown and pink shrimps out of white sand. The second evaluated the efficacy of the optimum combination of electric characteristics necessary for deburrowing shrimp from substrata found on the Cape San Blas, Florida;

St. Andrews Bay, Florida; Dry Tortugas, Florida, grounds; and fishing grounds of the State of Mississippi.

A. RESPONSES OF ELECTRICALLY STIMULATED SHRIMP BURROWED IN SAND

Part A of the field studies was carried out at Panama City, Florida.

1. Procedure

Shrimp used in the experiments were caught with trawls towed for less than 10 minutes. The shrimp were measured, placed in a tank of circulating sea water, and held for at least 24 hours. Shrimp in "good physical condition," ranging from 90 to 200 millimeters total length, were transferred from the tank to a wire cage on the floor of the sea, where they were held until needed.

SCUBA divers placed individual shrimp in the bottomless cages in which the shrimp could burrow into the sea bottom. The burrowed shrimp were then covered with an electrode array that was powered by a surface pulse generator through a No. 14-gage wire covered with neoprene. This generator provided pulses of the capacitor-discharge type. The array had a pair of bronze electrodes, 10 centimeters long by 1.9 centimeters wide, spaced 28 centimeters apart. Attached to the electrodes was a timing-event light, which came on simultaneously with the electric current. A pair of adjustable pickup probes, which were made of 3-millimeter-diameter bronze rods insulated except for the center 10 millimeters of each, was located between the electrodes. The probes were placed at the head and tail of each animal to check the pulse characteristics. Pulse rate, pulse width, and voltage applied to the shrimp were displayed on an oscilloscope on the vessel that was being used. Because Kessler (1965) found that a pulse width of 140-microseconds was satisfactory for stimulating shrimp, this pulse width was used in all the field experiments. Pulse rate was held constant during each experiment. Since the voltage for each shrimp is a function of its length, each animal could not be subjected to an exact predetermined voltage. Thus, an average voltage is given for each experimental group (Table 3).

Table 3.—Summary of experiments in which burrowed shrimp were stimulated electrically

Group	Shrimp tested		Location of test	Type of sediment	Electrical stimulation data		
					Electrode toward which shrimp faced	Pulse rate	Average potential across shrimp's body
No.	*No.*	*Species*				*Pulses/sec.*	*Volts*
1	52	Pink	Panama City	Sand[1]	+	3	0.7
2	55	Pink	Panama City	Sand	+	3	3.8
3	54	Pink	Panama City	Sand	+	4	5.8
4	50	Pink	Panama City	Sand	+	5	3.2
5	49	Pink	Panama City	Sand	+	4	3.2
6	50	Brown	Panama City	Sand	–	4	5.2
7	47	Brown	Panama City	Sand	–	4	3.3
8	64	Brown	Panama City	Sand	–	6	3.7
9	21	Brown	Panama City	Sand	–	3	0.9
10	59	Brown	Panama City	Sand	–	4	1.1
11	34	Brown	Panama City	Sand	–	5	1.1
12	27	Brown	Panama City	Sand	+	5	1.1
13	48	Brown	Panama City	Sand	+	6	0.9
14	52	Brown	Panama City	Sand	+	5	1.6
15	62	Brown	Cape San Blas	Sand[2]	+	4	3.6
16	63	Brown	Cape San Blas	Sand[3]	+	4	3.6
17	10	Brown	Cape San Blas	Sand[3]	+	5	3.2
18	59	Brown	St. Andrews Bay	Silty sand	+	4	3.6
19	24	Pink	Dry Tortugas	Sand	+	3	4.4
20	20	Pink	Dry Tortugas	Sand	+	3	0.8
21	89	Pink	Dry Tortugas	Sandy silt	+	4	3.3
22	34	Pink	Off the State of Mississippi	Sand-silt-clay	+	4	3.3

[1] 98 percent sand and 2 percent silt and clay.
[2] 99 percent sand and 1 percent silt.
[3] 83 percent sand, 11 percent silt, and 6 percent clay.

Owing to the difficulty in obtaining accurate measurements under water, motion picture photography was used to record the escape reactions of stimulated shrimp. A SCUBA diver operated a hand-held 16-millimeter movie camera in a watertight housing to record the action (Figure 2). The timing-event light provided the time base for each observation. When used in combination with the motion-picture film speed of 32 frames per second, the data obtained by means of the timing-event light permitted the escape reactions of stimulated shrimp to be measured with an accuracy of 0.03 second. The checkered grid shown in Figure 2 was used for measuring the lateral and vertical escape movements of the shrimp. Film analyses of the escape sequences provided data on the time required for shrimp to evacuate

Figure 2.—SCUBA diver filming electrically stimulated shrimp for time and motion studies.

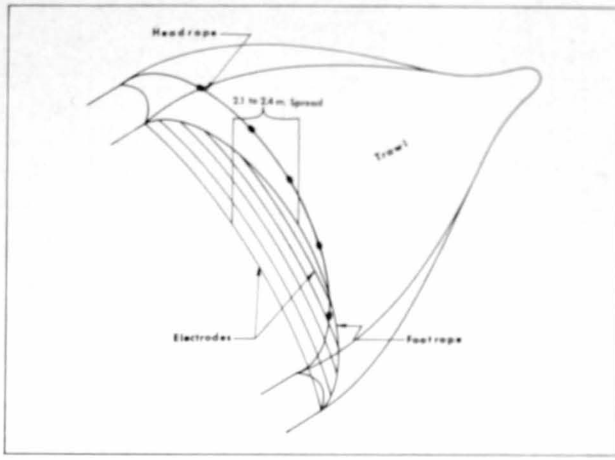

Figure 3.—Diagram of shrimp trawl rigged with the electric system, showing terms used.

their burrows and jump to heights of 75, 150, 225, or 300 millimeters above the bottom.

Before the optimal stimulation pulse rates and voltages for use with an electric trawl could be determined, knowledge on specific characteristics of the trawl design and performance was needed. The width of the electric field at the center of the net opening, as shown in Figure 3, and the speed at which the net travels over the bottom will determine the minimum time required to force shrimp out of the substratum, whereas the height of the footrope above the bottom will be the minimum height the shrimp must jump to be captured by the trawl. I anticipated that the electric field of the prototype trawl would range in width from 2.1 to 2.4 meters, at the center of the trawl, and that the footrope would not be higher than 75 millimeters above the bottom when traveling at a speed of 4.6 kilometers per hour. Between 1.66 and 1.90 seconds is needed for a trawl with a 2.1- to 2.4-meter wide electric field to pass a given point when traveling at this speed. Thus, if shrimp could be forced out and off the bottom to a height of 75 millimeters within 1.66 or 1.90 seconds, they would probably be captured by the trawl.

To evaluate the effectiveness of the pulse characteristics tested, I measured, by means of film sequences, the reaction times for the shrimp to deburrow and jump heights of 75 and 150 millimeters. I compared pulse characteristics with the following responses: (1) proportion of shrimp deburrowing; (2) proportion of shrimp jumping heights of 75 and 150 millimeters, respectively, within 1.66 and 1.90 seconds; (3) average height shrimp jumped within 1.90 seconds; and (4) rate at which shrimp jumped a height of 75 millimeters.

Optimum pulse characteristics for shrimp burrowed in sand were determined by combinations of pulse rates and voltages inducing the greatest percentage of shrimp to perform the above-mentioned escape reactions in the shortest time.

Also determined were the physical characteristics of the various sea bottoms on which the studies were made. Soil from various substrata was sampled and analyzed for particle size composition, by use of sieves and soil hydrometers (Krumbein and Pettijohn, 1938). The Wentworth scale of particle type and Shepard's (1954) sand-silt-clay terminology were followed. Bottom salinities and temperatures were taken with a portable salinometer at each station.

2. Results

Analysis of the escape reactions of the study animals provided information on the optimum electric characteristics necessary to deburrow shrimp from a bottom classified as sand (that is, 98-percent sand) near Panama City (Table 3). The time-frequency distributions of specific escape reactions for Groups 1 to 14 in Tables 4, 5, and 6 yielded data on the optimum pulse rate and voltage for forcing brown and pink shrimps out of white sand.

The escape reactions of brown and pink shrimps from a sand substratum were compared to determine whether or not these species behaved differently when stimulated electrically. By the chi-square contingency test, analyses were made of the proportion of animals of each species that deburrowed within 1.66 seconds and the numbers of brown and pink shrimps that jumped 75 millimeters high within the same time limit. The results showed that the responses of the two species were essentially the same (Table 7). Therefore, I concluded that the escape responses for these

Table 4.—Time-frequency distribution of burrowed shrimp deburrowing when stimulated electrically

Response time	Shrimp that deburrowed in Group:																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	1	4	3	4	3	11	4	11	1	4	1	2	4	5	17	3	1	53	1	--	82	21
0.31-0.59	5	8	23	11	12	16	6	23	1	10	4	2	5	6	37	10	--	4	5	--	5	11
0.62-0.90	9	8	7	23	16	11	14	15	5	18	10	5	4	9	6	16	2	1	4	1	--	2
0.94-1.22	5	10	12	6	11	7	7	5	6	9	3	3	6	9	1	7	1	--	2	3	--	--
1.25-1.53	7	7	4	6	3	1	7	3	1	6	3	4	7	1	--	6	4	--	3	2	--	--
1.56-1.84	6	2	2	--	3	4	3	1	1	3	3	--	1	3	--	5	2	--	3	1	1	--
1.87-2.15	5	4	2	--	1	--	1	1	3	1	3	2	2	3	--	7	--	--	3	2	--	--
2.18-2.46	2	1	--	--	--	--	3	1	--	1	--	3	3	3	--	5	--	--	2	1	1	--
2.50-2.78	1	5	--	--	--	--	--	1	1	1	--	3	2	1	--	--	--	--	--	3	--	--
2.81-3.09	1	--	--	--	--	--	--	--	--	1	--	--	3	1	--	--	--	--	1	2	--	--
3.12-3.40	--	--	--	--	--	--	--	--	--	--	--	2	1	--	--	--	--	--	--	--	--	--
3.43-3.71	--	1	--	--	--	--	--	--	1	2	1	--	3	--	--	--	--	--	--	1	--	--
3.74-4.02	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--
4.06-4.34	2	1	--	--	--	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	--
4.37-4.65	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
>4.96	1	1	--	--	--	--	--	2	--	--	1	--	2	1	--	--	--	--	--	--	--	--
Number responding	45	52	54	50	49	50	45	63	20	56	29	26	44	44	61	59	10	58	24	16	89	34
Number not responding	7	3	0	0	0	0	2	1	1	3	5	1	4	8	1	4	0	0	0	4	0	0
Total shrimp	52	55	54	50	49	50	47	64	21	59	34	27	48	52	62	63	10	58	24	20	89	34
Percent responding within 1.66 seconds	56	69	91	100	92	96	85	91	71	80	65	59	56	60	98	70	90	100	71	30	98	100
Percent responding within 1.90 seconds	67	71	96	100	98	100	89	91	81	86	71	59	63	63	98	78	100	100	79	35	99	100

Table 5.—Time-frequency distribution of burrowed shrimp jumping 75 millimeters high when stimulated electrically

Response time	Shrimp that jumped 75 millimeters in Group:																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	1	2	2	2	2	7	2	10	1	2	--	1	3	3	10	2	1	43	1	--	71	12
0.31-0.59	3	6	23	7	10	19	6	18	1	8	2	2	3	7	40	5	--	14	3	--	17	15
0.62-0.90	8	7	5	25	11	11	9	17	2	12	9	1	2	7	9	16	1	1	4	1	--	6
0.94-1.22	3	9	10	7	10	6	12	7	2	15	2	3	3	6	--	10	2	--	2	2	--	--
1.25-1.53	4	6	7	5	7	2	7	2	1	4	4	5	3	2	1	5	3	--	1	3	--	--
1.56-1.84	2	5	3	1	3	3	5	--	4	5	2	--	3	5	--	7	2	--	3	1	--	1
1.87-2.15	7	2	1	--	3	1	1	--	3	4	1	1	2	6	--	5	1	--	6	2	1	--
2.18-2.46	4	1	--	--	--	--	3	1	1	1	--	1	3	--	--	8	--	--	--	1	--	--
2.50-2.78	1	1	--	--	--	1	--	--	--	--	1	--	2	--	--	1	--	--	2	1	--	--
2.81-3.09	--	2	--	--	--	--	--	--	1	1	--	1	--	1	--	--	--	--	--	1	--	--
3.12-3.40	--	--	--	--	--	--	--	--	1	--	--	1	2	--	--	--	--	--	1	1	--	--
3.43-3.71	--	--	--	--	--	--	--	--	1	1	--	1	2	--	--	--	--	--	--	--	--	--
3.74-4.02	1	1	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 5—Continued

Response time	Shrimp that jumper 75 millimeters in Group:																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
4.06-4.34	1	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4.37-4.65	1	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	1	--	--
>4.96	--	2	1	--	--	--	--	1	--	--	--	--	1	--	--	--	--	--	--	--	--	--
Number responding	36	46	52	47	46	50	45	57	18	53	22	17	29	38	60	59	10	58	23	14	89	34
Number not responding	16	9	2	3	3	0	2	7	3	6	12	10	19	14	2	4	0	0	1	6	0	0
Total shrimp	52	55	54	50	49	50	47	64	21	59	34	27	48	52	62	63	10	58	24	20	89	34
Percent responding within 1.66 seconds	38	60	87	94	86	92	79	84	52	71	50	44	31	54	97	70	90	100	63	40	99	100
Percent responding within 1.90 seconds	50	64	89	94	90	98	87	84	52	79	55	44	35	60	97	75	100	100	71	45	99	100

Table 6.—Time-frequency distribution of burrowed shrimp jumping 150 millimeters high when stimulated electrically

Response time	Shrimp that jumped 150 millimeters in Group:																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	--	--	--	1	--	4	1	5	--	--	--	--	1	--	3	1	--	16	1	--	29	--
0.31-0.59	1	1	15	2	8	12	5	14	--	2	1	--	--	3	31	4	--	21	2	--	23	19
0.62-0.90	1	6	6	13	1	10	3	10	1	7	--	2	4	1	7	3	1	5	2	--	5	4
0.94-1.22	1	5	6	7	6	9	6	5	1	5	1	--	--	5	5	4	1	2	3	1	2	3
1.25-1.53	--	5	5	2	6	3	6	1	1	5	3	--	--	2	1	7	1	--	2	1	2	2
1.56-1.84	1	3	2	1	2	1	1	--	--	1	--	--	3	2	1	8	--	--	3	2	--	--
1.87-2.15	1	5	3	1	2	2	--	--	3	2	--	--	--	4	--	4	2	--	5	2	--	1
2.18-2.46	4	--	--	--	1	--	2	--	2	4	1	--	--	--	--	2	--	--	--	--	--	--
2.50-2.78	--	2	--	--	--	1	--	1	--	--	--	--	1	1	--	1	--	--	3	--	1	--
2.81-3.09	--	1	--	--	--	--	--	--	--	--	--	1	--	--	--	1	--	--	--	--	--	--
3.12-3.40	2	1	--	--	--	--	--	--	--	--	--	--	--	3	--	--	--	--	--	--	--	--
3.43-3.71	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
3.74-4.02	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	--
4.06-4.34	1	--	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--
4.37-4.65	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
>4.96	--	--	1	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	1	--	--
Number responding	12	30	38	27	26	42	24	37	8	27	6	3	10	22	48	35	5	44	21	9	62	29
Number not responding	40	25	16	23	23	8	23	27	13	32	28	24	38	30	14	28	5	14	3	11	27	5
Total shrimp	52	55	54	50	49	50	47	64	21	59	34	27	48	52	62	63	10	58	24	20	89	34
Percent responding within 1.66 seconds	6	33	63	50	45	76	45	55	14	32	15	7	13	23	77	40	30	76	50	10	69	82
Percent responding within 1.90 seconds	8	38	63	52	47	76	45	55	14	36	15	7	17	25	77	43	30	76	54	20	69	82

Table 7.—Comparison between responses of brown and pink shrimps when stimulated with more than 5 volts at 4 pulses per second

Shrimp response	Shrimp that:			
	Evacuated burrow within 1.66 seconds		Jumped 75 millimeters high within 1.66 seconds	
	Pink	Brown	Pink	Brown
	No.	*No.*	*No.*	*No.*
Responded	49	48	47	46
Did not respond	5	2	7	4
Total shrimp	54	50	54	50
Chi-square	1.143		0.676	
Degree of freedom	1		1	
Probability	0.25-0.10		0.50-0.25	

Note: These data are from Groups 3 and 6 (Table 3).

two species were sufficiently similar so that such information could be pooled.

A comparison was made of the escape reactions of shrimp burrowed in sand facing either pole, because Kessler (1965) found that threshold voltages for shrimp facing the anode were different from those for shrimp facing the cathode. Analysis by the chi-square contingency test showed no significant difference at the 5-percent level of probability in the escape responses (Table 8). This finding

Table 8.—Comparison between responses of shrimp facing positive or negative electrode when stimulated with 1.1 volts at 5 pulses per second

Shrimp response	Shrimp that:			
	Evacuated burrow within 1.66 seconds when they faced the:		Jumped 75 millimeters high within 1.66 seconds when they faced the:	
	+ electrode	—electrode	+ electrode	—electrode
	No.	*No.*	*No.*	*No.*
Responded	16	22	12	17
Did not respond	11	12	15	17
Total shrimp	27	34	27	34
Chi-square	0.273		0.186	
Degree of freedom	1		1	
Probability	0.75-0.50		0.75-0.50	

Note: These data are from Groups 11 and 12 (Table 3).

permitted combining experimental groups facing either electrode. The animal's position relative to either pole was not considered important in altering the behavior of the experimental shrimp.

To facilitate analyses, I combined Groups 1 and 9; 3 and 6; 5 and 7; and 11, 12, and 14 because of their similarity in the stimulation pulse rates and voltages. Time-frequency distributions of the three escape criteria for these combined experimental groups are listed in Table 9.

Analysis of the escape responses from the first 14 groups indicates that pulse rate and voltage affect the time required for shrimp burrowed in white sand to deburrow and jump heights of 75 and 150 millimeters. The percent activity (that is the proportion of animals deburrowing within 1.90 seconds) is greater for groups exposed to high-voltage stimulation (more than 3.0 volts) than for those exposed to low-voltage stimulation (Figure 4). With high-voltage stimulation, activ-

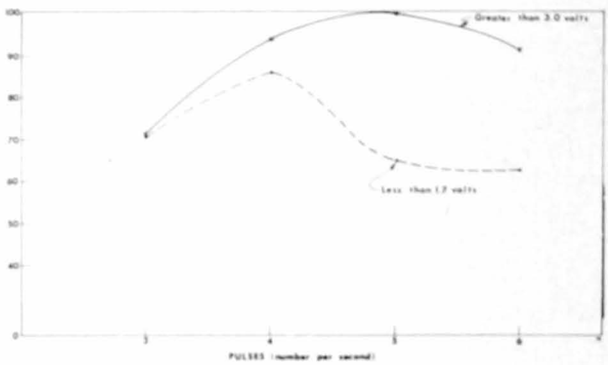

Figure 4.—Relation between pulse rate and percentage of shrimp deburrowing from white sand within 1.90 seconds.

ity was highest at 5 pulses per second, slightly less at 4 and 6 pulses per second, and lowest at 3 pulses per second. With low-voltage stimulation, the best pulse rate was 4 pulses per second because activity was much more depressed at repetition rates of 3, 5, and 6.

The proportion of shrimp jumping 75 millimeters high within 1.90 seconds indicates the optimal characteristic to be high voltage at 4 or 5 pulses per second (Figure 5). The percent activity was more than 80 percent for these pulse characteristics but was less than 80 percent for other stimulation pulse rates and voltages.

A similar relation can be seen for the proportion of shrimp jumping 150 millimeters high within 1.90 seconds (Figure 6). The

Table 9.—Time-frequency distribution of combined groups depicting rate of deburrowing and jumping 75 and 150 millimeters high

Response time	Shrimp that: Deburrowed in: Groups 1 & 9	Groups 3 & 6	Groups 5 & 7	Groups 11, 12, & 14	Jumped 75 millimeters in: Groups 1 & 9	Groups 3 & 6	Groups 5 & 7	Groups 11, 12, & 14	Jumped 150 millimeters in: Groups 1 & 9	Groups 3 & 6	Groups 5 & 7	Groups 11, 12, & 14
Seconds	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
0.00-0.28	2	14	7	8	2	9	4	4	--	4	1	--
0.31-0.49	6	39	18	12	4	42	16	11	1	27	13	4
0.62-0.90	14	18	30	24	10	16	20	17	2	16	4	1
0.94-1.22	11	19	18	15	5	16	22	11	2	15	12	6
1.25-1.53	8	5	10	8	5	9	14	11	1	8	12	5
1.56-1.84	7	6	6	6	6	6	8	7	1	3	3	2
1.87-2.15	8	2	2	8	10	2	4	8	4	5	2	4
2.18-2.46	2	--	3	6	5	--	3	1	6	--	3	1
2.50-2.78	2	--	--	4	1	1	--	1	--	1	--	1
2.81-3.09	1	--	--	1	1	--	--	2	--	--	--	1
3.12-3.40	--	--	--	2	1	--	--	1	2	--	--	3
3.43-3.71	1	--	--	1	1	--	--	1	--	--	--	--
3.74-4.02	--	--	--	--	1	--	--	--	--	--	--	--
4.06-4.34	2	--	--	2	1	--	--	--	1	--	--	--
4.37-4.65	--	1	--	--	1	--	--	1	--	--	--	--
4.68-4.96	--	--	--	--	--	--	--	--	--	--	--	--
>4.96	1	--	--	2	--	--	--	--	--	--	--	--
Number responding	65	104	94	99	54	102	91	77	20	80	50	31
Number not responding	8	0	2	14	19	2	5	36	53	24	46	82
Total shrimp	73	104	96	113	73	104	96	113	73	104	96	113
Percent responding within 1.66 seconds	60	93	89	61	42	89	82	50	8	69	45	9
Percent responding within 1.90 seconds	71	98	94	65	51	93	86	55	10	69	46	9

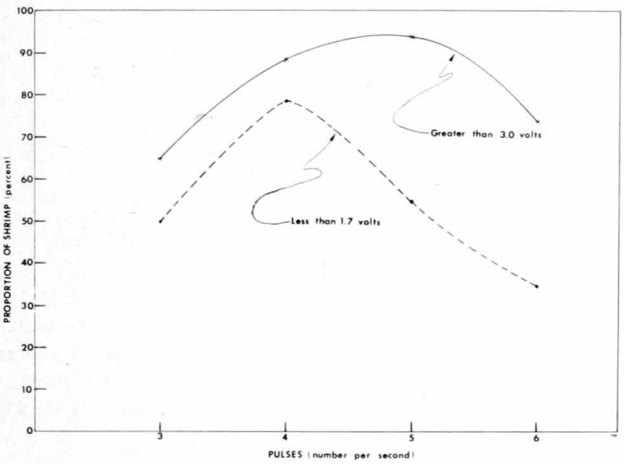

Figure 5.—Relation between pulse rate and percentage of shrimp jumping 75 millimeters high within 1.90 seconds.

highest activity is again at a high voltage combined with repetition rates between 4 and 6 pulses per second. The activity level was reduced at low-voltage stimulation.

The relation between percentage activity and the three escape criteria for various pulse characteristics is shown in Figures 7, 8, 9, and 10. Percentage activity and the three escape criteria show a curvilinear relation between the percent deburrowing and the percent jumping 75 and 150 millimeters high within 1.90 seconds. As would be expected, the proportion of shrimp that deburrow within 1.90 seconds is greater than the proportion that

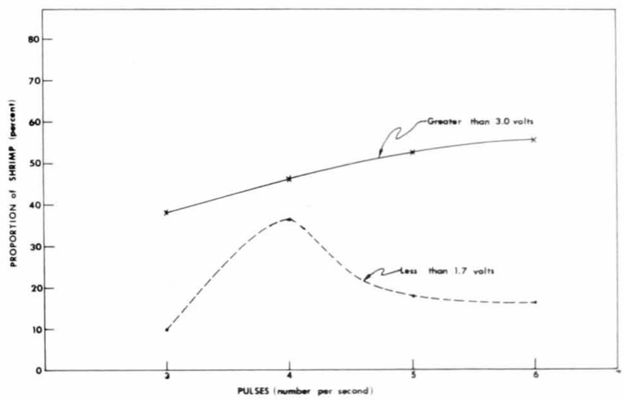

Figure 6.—Relation between pulse rate and percentage of shrimp jumping 150 millimeters high within 1.90 seconds.

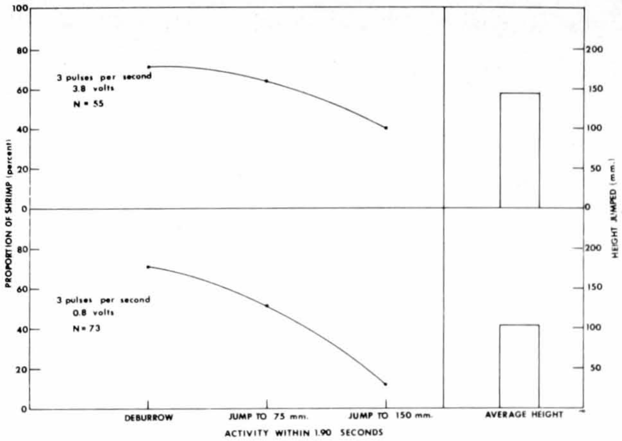

Figure 7.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 3 pulses per second at 0.8 and 3.8 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

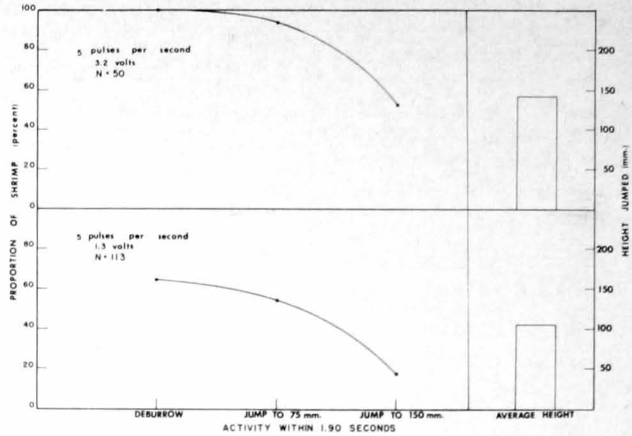

Figure 9.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 5 pulses per second at 1.3 and 3.2 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

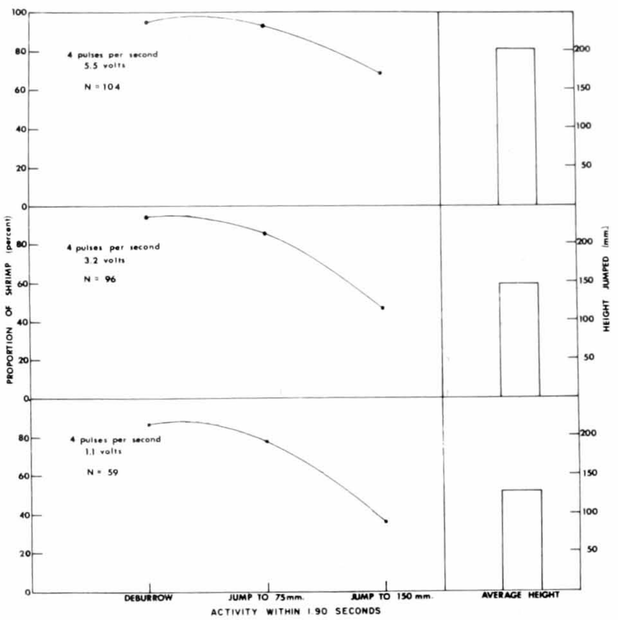

Figure 8.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 4 pulses per second at 1.1, 3.2, and 5.5 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

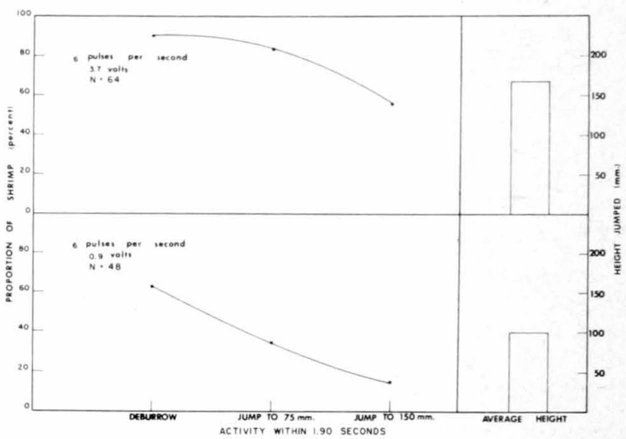

Figure 10.—Percentage of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds when stimulated with 6 pulses per second at 0.9 and 3.7 volts. The average height jumped within 1.90 seconds is shown on the right side of the figure.

jumped a height of 75 or 150 millimeters. Further, the proportion is higher for those that jumped 75 millimeters than for those that jumped 150 millimeters. Comparison of the curvilinear relation between groups shows that the overall activity increases with an increase in voltage. This trend in activity is evident generally for all the repetition rates tested.

As voltage increases, the average height of the jump also increases (Figures 7, 8, 9, and 10). At 4 pulses per second and 1.1 volts, the shrimp averaged a height of 132 millimeters, whereas when stimulated with 3.2 and 5.5 volts, they averaged heights of 152 and 206 millimeters, respectively.

Comparison of activity levels between pulse rates shows the highest levels of activity for the curvilinear graph at pulse rates between 4 and 6 (Figures 8, 9, and 10). Shrimp stimulated with more than 3.0 volts at 5 pulses per second have the highest activity level, whereas those stimulated with high voltage at 4 and 6 pulses per second have similar activity levels. At 5 and 6 pulses per second, at low voltage, however, the level of activity is considerably more depressed than is the level at 4 pulses per second at a similar voltage. This observation indicates that the optimal pulse rate for a given range of voltage would be 4 pulses per second.

The rate at which shrimp jump 75 millimeters high (Figure 11) is remarkably similar for animals stimulated with pulse rates of 4, 5, and 6 per second at high voltage. At these pulse rates, the rate of reaction increases exponentially from 0 to about 1.70 seconds; thereafter, no appreciable change is noticeable. At 4 pulses per second, shrimp stimulated at more than 5.0 volts appear to have a slightly faster rate than do those stimulated at 3.0 volts.

As voltage increases, the reaction time decreases. This relation is evident when the reactions of shrimp stimulated at low and high voltages are compared within a range of pulse rates. Figure 12 depicts the reaction rate at low voltage at pulse rates of 4, 5, and 6 per second. These reaction rates are slower than are those for similar groups exposed to high voltage (Figure 11). Because the reaction time is slower at less than 1.3 volts, the optimum voltage appears to be in excess of 3.0 volts.

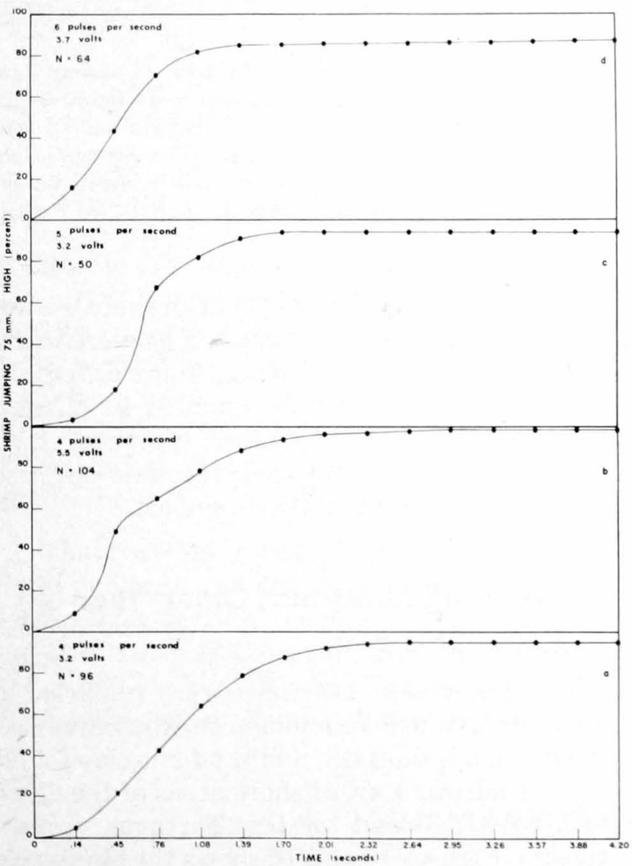

Figure 11.—Reaction rate of shrimp jumping 75 millimeters high when stimulated with (a) 4 pulses per second at 3.2 volts, (b) 4 pulses per second at 5.5 volts, (c) 5 pulses per second at 3.2 volts, and (d) 6 pulses per second at 3.7 volts.

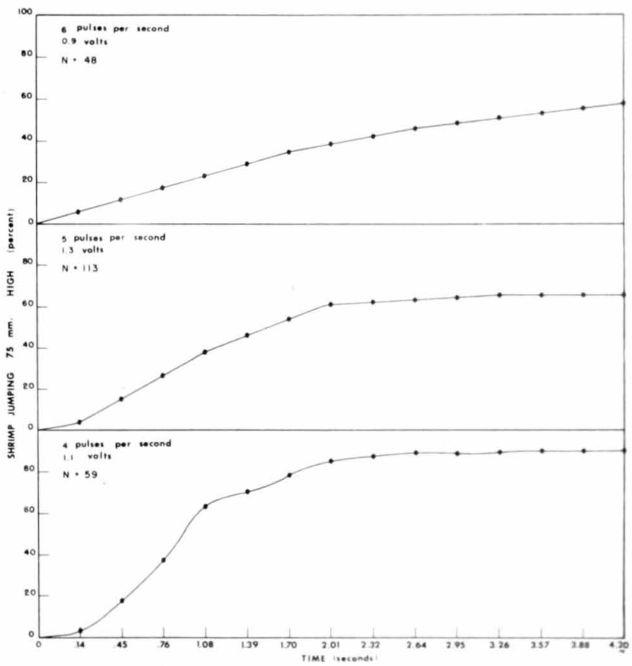

Figure 12.—Reaction rate of shrimp jumping 75 millimeters high when stimulated with 4, 5, and 6 pulses per second at 1.3 volts or less.

B. RESPONSES OF ELECTRICALLY STIMULATED SHRIMP BURROWED IN SUBSTRATA FOUND IN COMMERCIAL SHRIMP GROUNDS

Shrimp were tested in the substrata found on Cape San Blas, St. Andrews Bay, Dry Tortugas, and Mississippi shrimp grounds.

1. Cape San Blas Substrata

Two types of sediments were encountered on the Cape San Blas shrimp grounds (Table 3). The first was similar to the sand found off Panama City and contained about the same proportion of sand (99 percent). The other was also classified as sand, although it contained 83 percent sand, 11 percent silt, and 6 percent clay.

The rate of the escape reactions of Group 15 stimulated from the latter substratum was generally slower than was that of Group 16 stimulated from the pure sand substratum (Figure 13). In Group 15, about 80 percent of the shrimp jumped a height of 75 millimeters within 0.59 second; over 94 percent attained this height within 1.22 seconds. In Group 16, however, 80 percent of the shrimp took 2.15 seconds to jump a height of 75 millimeters, and 94 percent reached this height in 2.46 seconds.

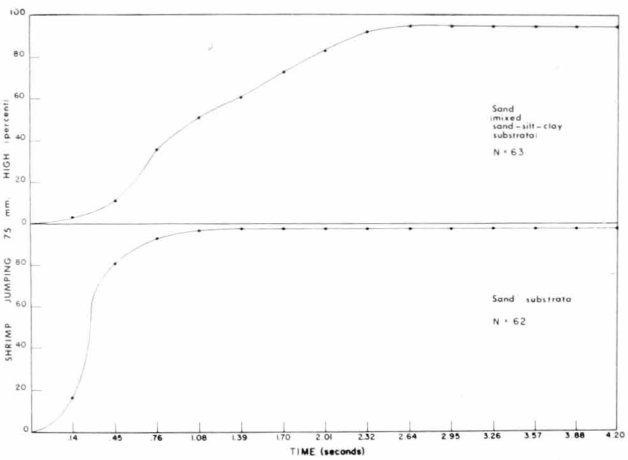

Figure 13.—Relation between reaction rate of shrimp jumping 75 millimeters high and the two bottom types found in the Cape San Blas area (stimulation was 3.6 volts at 4 pulses per second).

The proportion of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds was much lower for Group 16 than for Group 15 (Figure 14). Figure 14 also shows that shrimp burrowed in pure sand jumped slightly higher than those burrowed in mixed sand.

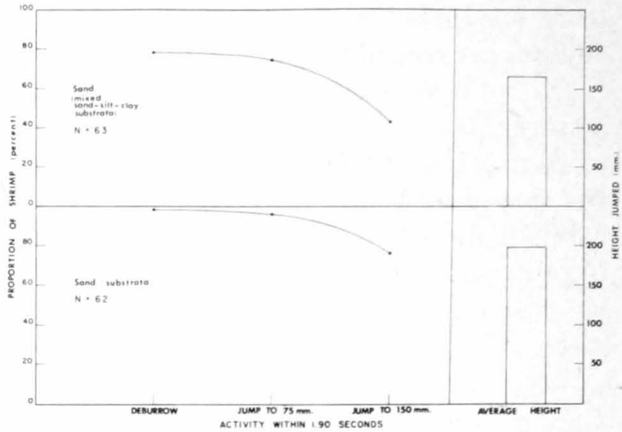

Figure 14.—Comparison of activity level of shrimp burrowed in the two bottom types found in the Cape San Blas area (stimulation was 3.6 volts at 4 pulses per second). The average height jumped within 1.90 seconds is shown on the right side of the figure.

These results indicated that the substratum does affect the escape reactions of electrically stimulated shrimp. Although some difference was noted in the escape reaction of shrimp from the two types of bottom, the pulse characteristics tested appeared adequate for use in an electric shrimp-trawl system.

2. Types of Substrata Other Than Cape San Blas

The escape reactions were remarkably alike for similarly stimulated shrimp burrowed in silty sand, sand silt, and sand-silt-clay found in St. Andrews Bay, offshore areas of the State of Mississippi, and the Dry Tortugas, respectively. Figures 15 and 16 shows the similarity in escape reactions among Groups 18, 21, and 22 burrowed in three different types of bottom. The curves showing the proportion of shrimp deburrowing and jumping heights of 75 and 150 millimeters within 1.90 seconds are very

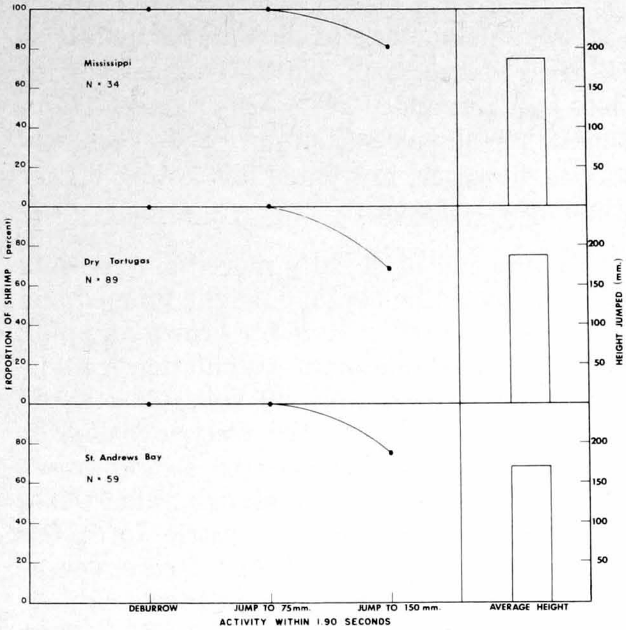

Figure 15.—Comparison of activity level of shrimp burrowed in substrata found in St. Andrews Bay, off Dry Tortugas, and off Mississippi (stimulation was 3.3 to 3.6 volts at 4 pulses per second). The average height jumped within 1.90 seconds is shown on the right side of the figure.

similar (Figure 15). In addition, the groups differ but little in the average height jumped.

Rates of jumping 75 millimeters high among the three groups indicate that the escape rate was slightly slower for shrimp stimulated from a sand-silt-clay bottom than for those stimulated from the two other types of sediments. More than 96 percent of the shrimp in each of the three groups jumped 75 millimeters high within 0.90 second.

The reaction rates of shrimp stimulated from substrata on the shrimp grounds were faster than those of shrimp stimulated from the substrata off Cape San Blas and Panama City. These high levels of activity and the rapid rates of reaction indicate that an electric stimulus with pulse characteristics of 4 pulses per second and more than 3.0 volts was optimum for the substrata tested.

The optimum pulse characteristics for stimulating shrimp from a sand substratum were also effective on commercial shrimp grounds in the Eastern Gulf of Mexico. Groups 15 to 22 provided information on the efficacy of these pulse characteristics for various substrata. The shrimp exhibited no great difference in the rate of escape from the different types of substratum found on the commercial shrimp grounds. The shrimp burrowed in the mud bottom substrata on the shrimp grounds generally had more rapid escape reactions than those burrowed in the sand substratum off Panama City.

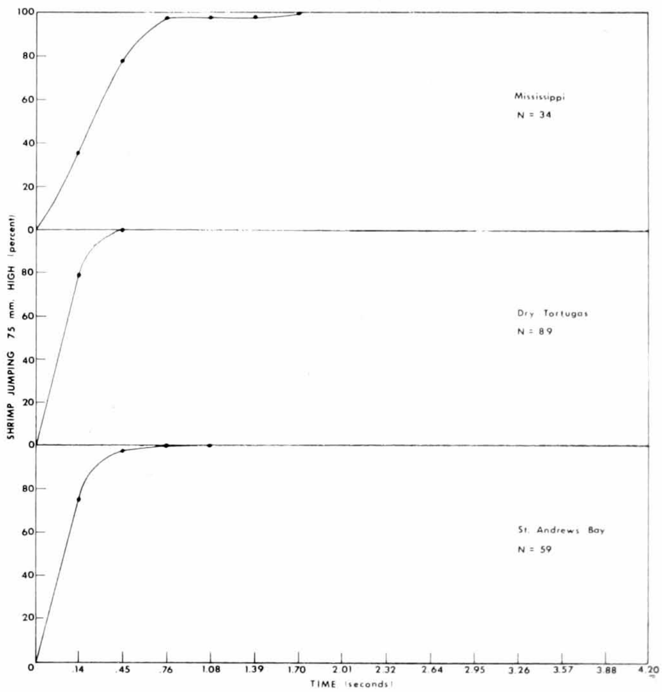

Figure 16.—Relation between reaction rate of jumping 75 millimeters high and substrata found in St. Andrews Bay, off Dry Tortugas, and off Mississippi.

SUMMARY AND CONCLUSIONS

Laboratory studies showed that the voltage to which a shrimp was subjected was a function of its orientation in relation to the electric field as well as the size of the shrimp. This relation was described as $L \cos \Theta = \Delta V$. The height the animal jumped was a function of the voltage applied. As the stimulation voltage increased, the height to which the shrimp jumped also increased.

Field studies indicated that shrimp burrowed in sand were most effectively forced from the substratum with a voltage greater than 3.0 volts at pulse rates of 4 or 5 per second. When these voltages and pulse rates were used, the reaction rates were faster, and a larger proportion of the shrimp jumped heights of 75 and 150 millimeters above the bottom within 1.90 seconds.

Bottom type affected the escape reactions of similarly stimulated shrimp. Generally, shrimp escaped from mixtures of sand, silt, and clay faster than they did from sand. Shrimp jumped higher from substrata found off Mississippi, Dry Tortugas, Cape San Blas, and in St. Andrews Bay than they did from the sand found off Panama City. At 3.0 volts and 4 pulses per second, 100 percent of the shrimp burrowed in mixtures of sand, silt, and clay jumped 75 millimeters high within 1.90 seconds, whereas between 78 and 98 percent of the shrimp burrowed in substrata classified as sand jumped 75 millimeters high within 1.90 seconds.

Pulse characteristics of either 4 or 5 pulses per second, at more than 3.0 volts across 100 millimeters parallel to the field, appear to be satisfactory for use in an electric shrimp-trawl system. These pulse chracteristics caused the greatest percentage of burrowed shrimp, in the substrata tested, to jump 75 millimeters high within the time a trawl would take to cover the distance from the front of a 2.4-meter wide electric field to the footrope.

However, the optimum stimulation voltage appears to be greater than 3.0 volts because a greater percentage of shrimp responded at voltages in excess of 3.0 as compared with those that responded at lower voltages. (Limitations in the pulse generator used in the field studies, however, prevented my testing higher stimulation voltages.)

Application of slightly more voltage could likely increase the average height jumped and decrease the reaction time for brown and pink shrimps. The minimum stimulation voltage should not be less than 3.0 volts, across 100 millimeters parallel to the electric field, for effective utilization of an electric shrimp trawl. Two to three times this minimum value would be preferable because the electric force felt by the shrimp is related to its size as well as to its position relative to the anode and cathode ($L \cos \theta = \Delta V$). Fuss and Ogren (1966) showed that orientation of burrowed shrimp appeared generally to be random. Consequently an electric trawl would encounter shrimp positioned at varying angles relative to the electric field. A minimum 3.0 volts across 100 millimeters in the electric field of a trawl would mean that a 100-millimeter shrimp positioned perpendicular to the electrodes would receive 3.0 volts, positioned at 45° would receive 2.1 volts, and at 75° would receive only 0.6 volt. If the minimum voltages were raised to 9.0 volts across 100 millimeters parallel to the field, a 100-millimeter shrimp positioned at 45° would receive 6.4 volts, and those at 75° would receive 2.3 volts. As the size of the shrimp increases, the voltage it received would also increase. I believe that an increase to 9.0 volts in the electric field would cause the shrimp to jump higher and to jump to a height of 75 millimeters faster.

LITERATURE CITED

Brophy, James J.
1966. Basic electronics for scientists. McGraw-Hill Book Company, New York, 471 pages.

Fuss, Charles M., Jr., and Larry H. Ogren,
1966. Factors affecting activity and burrowing habits of the pink shrimp, *Penaeus duorarum* Burkenroad. Biological Bulletin (Woods Hole) 130: 170-191.

Higman, James B.
1956. The behavior of pink grooved shrimp, *Penaeus duorarum* Burkenroad, in a direct current electrical field. Florida State Board of Conservation Technical Series No. 16, 23 pages.

Kessler, Doyne W.
1965. Electrical threshold responses of pink shrimp *Penaeus duorarum*, Burkenroad. Bulletin of Marine Science 15: 885-895.

Krumbein, W. C., and F. J. Pettijohn.
1938. Manual of sedimentary petrography. Appleton-Century-Crofts, Inc., New York, 549 pages.

Shepard, Francis P.
1954. Nomenclature based on sand-silt-clay ratios. Journal of Sedimentary Petrology 24: 151-158.

MS #1752

DESIGNING AN IMPROVED CALIFORNIA TUNA PURSE SEINE

by

M'nakhem Ben Yami and Roger E. Green

ABSTRACT

In the Eastern Tropical Pacific Ocean, about 50 percent of the purse seine sets for tuna are unsuccessful, owing mostly to the fish's escaping the net during setting and pursing operations. Described here is the design of a proposed purse seine that will largely retain the desirable features of the presently used seine but that will sink faster and use the webbing with greater economy. In comparative tests with scale models (1:25), the model built according to the proposed design sank nearly three times as fast as did the model of the presently used seine.

CONTENTS

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INTRODUCTION

Purse seining is one of the most aggressive methods of fishing. It aims mostly at catching mobile, dense schools of pelagic fish and contains all the elements of searching, hunting down, and capture. Its instrument of capture, the purse seine, is a large encircling net with a closable bottom.

The last decade witnessed a great expansion of purse seining both in old and new fisheries. In the United States, purse seines now capture most of the tuna landed (McNeely, 1961); in Iceland and Norway, purse seines capture huge amounts of herring (Jakobsson, 1964), capelin, and mackerel. Purse seines also catch mammoth quantities of anchovetas off the west coast of South America and pilchards off South West Africa.

The world over, purse seines catch fish that range from diminutive anchovies and sprats to huge bluefin and yellowfin tunas. Purse seines take about one half of the world's over 50 million metric tons whole fish. In the United States alone, about 1 million metric tons of fish worth about 77 million dollars were caught with purse seines in 1965 (Table 1).

Despite the growing importance of purse seining, researchers have made little attempt to improve the basic means of capture — namely, the purse seine. In this respect, purse seining lags far behind trawling, for which the techniques and the design of gear have been thoroughly studied in many countries during the last decade.

About 50 percent of the purse seine sets for tuna are unsuccessful in the Eastern Tropical Pacific Ocean, owing mostly to the escape of fish from the net during setting and pursing operations (Schaefer, 1962). The proportion of unsuccessful sets increases with the depth of thermocline[1] (Green, 1967). If tuna purse seines could sink faster to fish deeper, the efficiency of fishing probably could be increased. Only a 10-percent improvement in the rate of success would reduce operating costs for the U. S. tuna fleet to maintain the same catch by more than 1 million dollars annually (Green and Broadhead, 1966).

Another problem of research on purse seines is that of reducing the amount of netting without impairing the catching ability of the net. The price of a tuna purse seine ranges from $50,000 to $70,000. Most of this cost is in the webbing.

Comparison of sinking rates of California and Norwegian tuna purse seines (Green, 1964; Hamre, 1963) and of an anchovy purse seine in Peru (Kristjonsson, private communication) revealed great variations in the performances of purse seines of different construction. Thus, the performance of a seine can vary markedly, depending upon its design. The purpose of this paper is to report on a proposed improved California tuna purse seine, the design of which was based both on theoretical considerations and on observation and study of numerous other purse seines from several countries. Our principal aims in the design of this new version of the California

[1] The relatively sharp temperature gradient separating the layer of warmer water above from the colder water below.

Table 1.—U. S. landings of fish in 1965, by fishing method

Fishing method	Catch				Fishing units operating	Value of catch per fishing unit
	Amount		Value			
	Weight	Amount relative to total amount	Money value of catch	Value relative to total value		
	Metric tons	*Percent*	*Dollars*	*Percent*	*Number*	*Dollars*
Purse seining	996,830	46.0	76,545,000	17.2	2,034	37,633
Trawling	543,483	25.1	137,844,000	30.9	13,678	10,078
Other methods	626,427	28.9	231,150,000	51.9	[1]	[1]
Total	2,166,740	100.0	445,539,000	100.0	--	--

[1] Not applicable because of noncomparability of "other methods."
Source: Lyles, 1967.

tuna purse seine was to improve its sinking and pursing performance using a minimum of webbing.

After we had completed our design of the proposed improved purse seine, we would have liked to have built one immediately so as to test it out. Experimenting with a full-size purse seine, however, is inordinately expensive. We therefore had to do our testing with scale models rather than with full-size seines. In the following report of our work, we describe first our studies with the models and then apply the results of the model studies and theoretical considerations to the design of a new version of the California tuna purse seine.

I. MODEL STUDY

A. CONSTRUCTION OF MODELS

1. Modeling Rules Followed

As was just indicated, the experimental phase of the present study consisted of testing, underwater, a large model of a purse seine in use and comparing its behavior with that of an improved version of the same model. This experimental approach was based on the assumption that if different nets are scaled down in a uniform manner, the main differences in performance between the models also will hold in the performance of the full-scale nets.

In scaling down the original net, we followed the modeling rules of Dickson (1959) as closely as practicable within the limitations imposed by the materials available. Our suggested full-scale version of the improved model, reported elsewhere in this paper, was designed along the same modeling rules. In ascertaining the hydrodynamic rules applicable to scaling down fishing nets and in constructing the model nets, we consulted Baranov (1948), Dickson (1959), Fridman (1964a), and Kawakami (1959, 1964).

2. Descriptions of Model Purse Seines

a. Model I.—Model I was a model of the California tuna purse seine (McNeely, 1961; FAO, 1965a) scaled down at a ratio of 1:25. The details of its construction are given in Figure 1 and Table 2.

b. Model II.—After we had measured Model I and observed its action, we took it apart and constructed Model II, from about the same amount of netting and auxiliaries. The new net, Model II, is symmetrical and is deeper in the central half than in the side quarters. Its wings were baited — 4 strips to 3; 3 strips to 2; 2 strips to 1, respectively, from the center toward the sides. The tips are tapered by diagonal taper (bar cut) of the lower corners. The wing tips end in gavels (vertical lines at the net ends, which can be pursed separately) instead of the corkline, leadline, and all the webbing between being gathered onto single end rings as usual. Figure 2 and Table 3 give the details of the construction of Model II.

3. Comparison of Constructions of Models

In the comparison of the models, we must remember that both were intended to simulate purse seines made of horizontal strips. The seven horizontal strips of body netting in the California tuna purse seine were simulated in Model I by a single panel, 220 meshes deep.

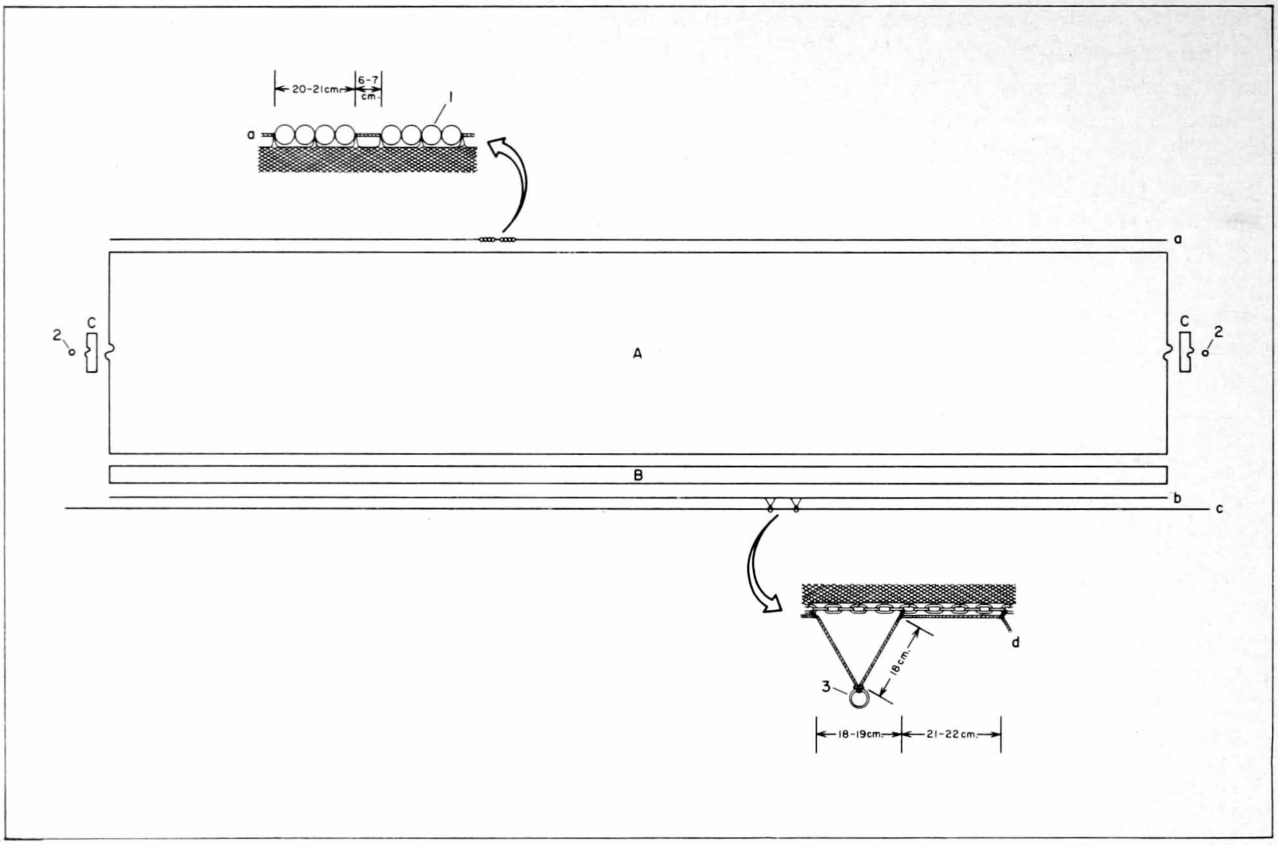


Figure 1.—Model I — construction diagram (see Table 2).

Table 2.—Specifications for Model I (see Figure 1)

Webbing sections	Data on webbing									
	Material	Twine size		Mesh size (stretched mesh)		Length (stretched)		Depth (stretched)		Hanging coefficients (k_h)
		Tex	American							
				Mm.	*Inches*	*Meters*	*Meshes*	*Cm.*	*Meshes*	
A	Marlon	175	2	13.7	0.54	**34.4**		301	220	$\frac{a}{A} = 0.9$
B	Marlon	400	6	25.4	1	34.4		38	15	$\frac{A}{B} = 1.0$
C	Marlon	400	6	25.4	1		7		25	$\frac{b}{B} = 0.9$

Items	Data on lines and bridles		
	Material	Diameter	Length
		Millimeters	*Meters*
a (corkline)	Braided nylon	5.5	31
b (leadline)	Galvanized chain	2.7 (wire) (36 links per meter chain)	31
c (purse line)	Braided nylon	5.5	31
d (bridles)	Nylon parachute cord	4	(See Figure 1)

Items	Data on floats, brackets, and rings			
	Material	Shape	Diameter	
			Mm.	*Inches*
1 (floats)	Expanded polystyrene	Spherical	50.8	2
2 (end brackets)	Galvanized iron	Ring	50.8	2
3 (purse rings)	Galvanized iron	Ring	36.0	1.4

This use of a single panel in place of seven should be satisfactory, since there is no horizontal takeup between the seven strips in the full-size net. The eighth strip, the lower guarding or selvage, as well as the end-pieces, gathered at the rings, were simulated in both models by a 15-mesh strip of heavier, larger mesh webbing. The upper, narrow selvage was not incorporated in the model seines; nor was the thicker netting used in the bunts of the full-size net incorporated in the models, the main netting being uniform all along the seine. We felt that the effects of the selvage strip and bunts on sinking rate and other performance criteria would not be marked and that they accordingly could be neglected.

In Model II, the three top strips were of equal length and therefore presented one sheet of netting 126 meshes deep. The lengths of the remaining four bottom strips varied, and we used different hanging coefficients[2] when we laced them together (Table 2).

The amount of webbing used in each model was the same: 104 square meters, fictitious area (stretched length times stretched depth, summed over all net panels).

One of the main features of Model II was the hanging coefficient between the horizontal strips, which increased downwards, starting with the fourth strip (between D and I, Figure 2) so that each strip was shorter than the next higher one. Thus, although the hanging coefficient at the corkline was 0.70 and that at the chain was 0.90, the corkline and the chain had practically equal lengths. The reasons for this design and the difference in the performance achieved are discussed in detail later in this report.

[2] Hanging coefficient (k_h): ratio of stretched lengths of adjacent sections of webbing or ratio of length of line to stretched length of adjacent webbing (Baranov, 1948; Ben-Yami, 1959; Lusyne, 1959).

B. USE OF MODELS AS AIDS IN DESIGN

In this section we give the methods we used in observing the performance of the seine models and then discuss how their performances compared.

1. Methods of Observing Depths, Sinking Rates, and Net Configuration

The working depths and the sinking speeds of the models were measured by the use of colored, spherical, plastic floats attached to the leadline with sections of nylon twine. Each float was ballasted so that it sank easily when the depth of the leadline exceeded the length of the twine attached to the float. For measuring the working depth of the leadline, a number of floats, each with a twine slightly longer than that of the preceding one, were attached to the leadline along a relatively short section of midnet. The working depth was estimated to be the mean of the depth of the last float that submerged and the adjacent one that did not sink. Depths in the wings were determined with weighted strings attached to the corkline. A diver marked the strings at the leadline and measured the distances from the corkline to the marks.

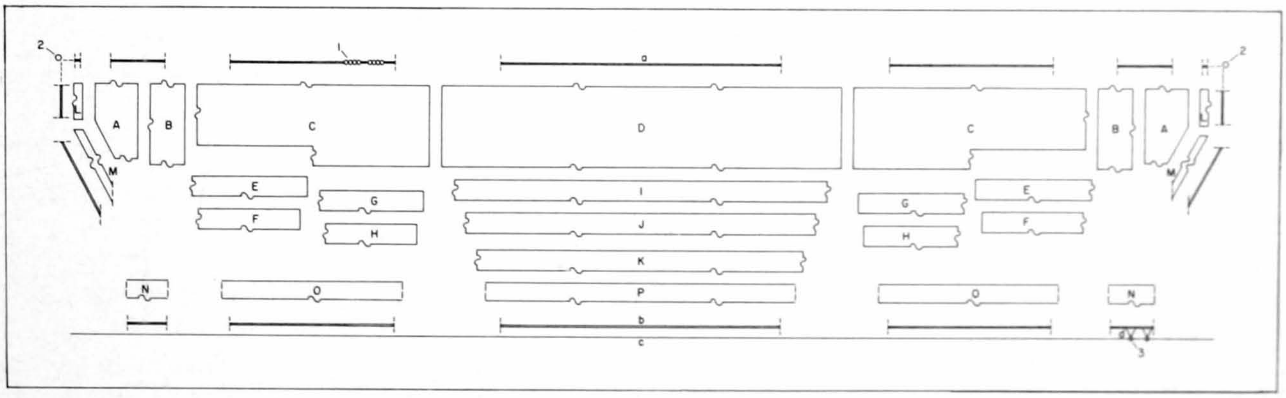


Figure 2.—Model II—construction diagram (see Table 3).

Table 3.—Specifications for Model II (see Figure 2)

Webbing sections	Data on webbing							
	Material	Twine size		Stretched mesh		Length[1] (stretched)	Depth[2] (stretched)	Hanging coefficients (k_h)[3] (top edge/bottom edge)
		Tex	American	*Mm.*	*Inches*	*Cm.*	*Cm.*	
A	Marlon	175	2	13.7	0.54	184/104	160/80	0.7/0.8
B	Marlon	175	2	13.7	0.54	150	172	0.7/0.8
C	Marlon	175	2	13.7	0.54	990/495	172/129	0.7/1.0
D	Marlon	175	2	13.7	0.54	1700	172	0.7/0.935
E	Marlon	175	2	13.7	0.54	495	43	1.0/0.9
F	Marlon	175	2	13.7	0.54	445	43	(—)[4]/0.91
G	Marlon	175	2	13.7	0.54	445	43	(—)/0.9
H	Marlon	175	2	13.7	0.54	400	43	(—)/0.91
I	Marlon	175	2	13.7	0.54	1590	43	(—)/0.935
J	Marlon	175	2	13.7	0.54	1490	43	(—)/0.935
K	Marlon	175	2	13.7	0.54	1390	43	(—)/0.95
L	Marlon	400	6	25.4	1.0	38	80	0.7/1.0
M	Marlon	400	6	25.4	1.0	38	161/237	0.7/0.7
N	Marlon	400	6	25.4	1.0	204	38	(—)/0.9
O	Marlon	400	6	25.4	1.0	770	38	(—)/0.9
P	Marlon	400	6	25.4	1.0	1320	38	(—)/0.9

Items	Data on lines and bridles		
	Material	Diameter	Length
		Millimeters	*Meters*
a (corkline)	Braided nylon	5.5	31
b (leadline)	Galvanized chain	2.7 (wire) (36 links per meter of chain)	33.8
c (purse line)	Braided nylon	5.5	>33.8
d (bridles)	Nylon parachute cord	4	(See Figure 1)

Items	Data on floats, brackets, and rings			
	Material	Shape	Diameter	
			Mm.	*Inches*
1 (floats)	Expanded polystyrene	Spherical	50.8	2
2 (end brackets)	Galvanized iron	Ring	50.8	2
3 (purse rings)	Galvanized iron	Ring	36.0	1.438

[1] Double entries indicate top edge/bottom edge.

[2] Double entries indicate left edge/right edge.

[3] $k_h = \frac{\text{shorter section}}{\text{longer section}}$; it is specified only where the length of an edge represents the denominator of the respective k_h.

[4] (—) denotes that the edge concerned is laced to another, longer section at a k_h specified for respective edge of the latter. Thus: the top edge of F, denoted (—), is laced to the lower edge of E at $k_h = \frac{E}{F} = 0.9$ (see E - bottom edge and Figure 2).

An outboard skiff and a rowboat were used on a lake in the measurement of the sinking speed and working depths. The model net was stacked on a net-board described by Hunter, Aasted, and Mitchell (1966). A drogue-chute (small parachute) attached to a buoy served to create the necessary drag to aid in pulling the net off from the net-board at the start of the set. Because of the difficulty of setting a closed circle with a net of this small size, we made each set in a semicircle.

We measured the speed of sinking by attaching three floats to the leadline, with lengths of twine slightly less than the working depth (190-195 centimeters). As the net was set, three observers with stop watches recorded the time intervals between entry of each float in the water and the submergence of that float.

Divers observed the performance and configuration of the model net during setting and pursing. They also observed the net when it was pursed in a large swimming pool. The high transparency of the water in the pool permitted them to make detailed visual observations as well as to take motion and still pictures both from above the surface of the water and underwater.

2. Comparisons of Performances

In our studies, we compared Model I not only with Model II but also with the full-size commercial seine to see how faithfully Model I simulated the full-size seine that it was supposed to represent.

a. Comparison of the performances of Model I and the full - size commercial seine. — Sinking rates and depths of the full-size purse seine were determined from BKG (bathykymograph) data (Hester, 1961; Hester, Aasted, and Gilkey, 1963). These data were obtained on cruises aboard the purse seiners *Westpoint* and *Conte Bianco*, 1961 and 1966.

The sinking performance of the full-scale tuna purse seine and of its scaled-down counterpart, Model I, are illustrated in Figure 3. The time and depth rates for the model are superimposed on the time and depth scale for the full-size seine. The model depth scale is 25:1, and the time scale is 5:1 in accord with net modeling rules (Dickson, 1959).

The model was not ideal. Its leadline sank too fast for exact simulation of the sinking speed of the original seine, and the model fished slightly deeper than did the original. These differences were due to the excess weight of the chain on the model. Nevertheless, the sinking performances of the original and the model were otherwise closely similar.

If the leadline were lighter and the leadline kept close to the maximum working depth, however, the allowable maximum pursing speed of the model would decrease. This decrease may be seen from Figure 5, where if the magnitude of Vector P is increased or

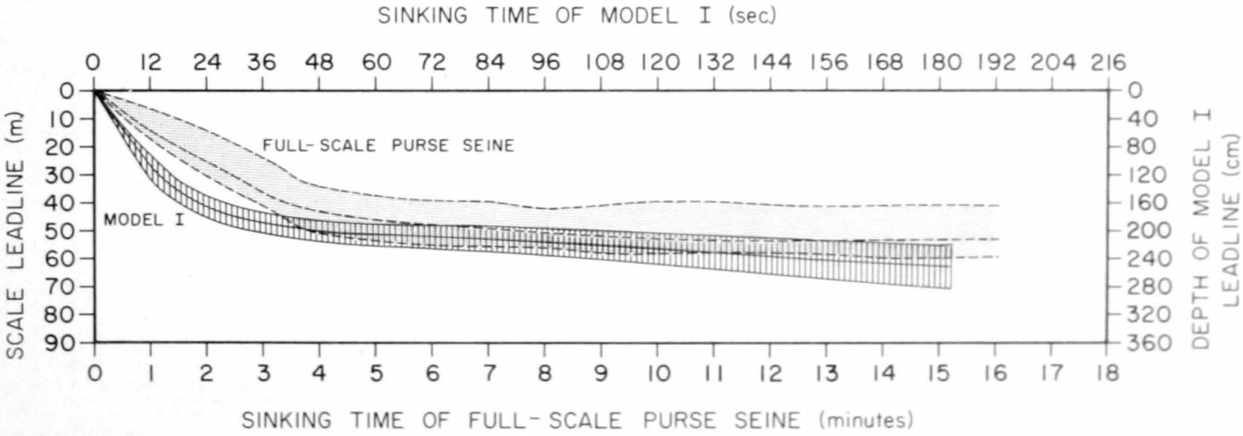


Figure 3.—Comparison of sinking performances at center net of full-scale purse seine and Model I.

Vector W decreased, the effect would be to elevate the direction of Resultant M.

The pursing time for a purse seine 775 to 800 meters long was 12 to 22 minutes from the start of pursing until the moment when the bunched purse rings started to rise. The variation depended upon the conditions of the set. On the assumption that Model I approximated the conditions stated for a 25:1 model of a fishing net (Dickson, 1959), the pursing time of the model, t_{mod}, should relate to the pursing time of the full-scale net, t_f, as follows:[3]

$$t_{mod} = \frac{t_f}{S_m} \qquad (1)$$

where: S_m is the model scale or, in this particular case, 25.

The pursing times of the model were, therefore, kept within the range of 2.4 to 4.4 minutes to simulate the pursing operation of a full-scale net 25 times its size.

[3] The same formula may be applied to the sinking time and, with the substitution of t by v, to the setting speed of the seiner.

The ideal weight of the model chain would be $1{:}25^3$, or $\frac{1}{15{,}625}$ of the original ballast (Dickson, 1959). In Model I, the weight of the chain and the ring was $\frac{1}{885}$ of that of the full-size net ballast.

Neither the pursing performance nor the sinking speed of Model I can, therefore, represent exactly the full-size net performance, but they can be used as a basis for comparison with Model II. If our aim had been to create a model that would faithfully simulate the original in all respects, we could have made additional tests with lighter leadlines, until the sinking time for the model was correct.

b. Comparison of performances of Model I and Model II. — In comparing the two models, we investigated sinking rate, pursing time, and net shape.

(1) Sinking rate.—Figure 4 shows the times required for the two models to sink to 190-195 centimeters. The faster sinking of

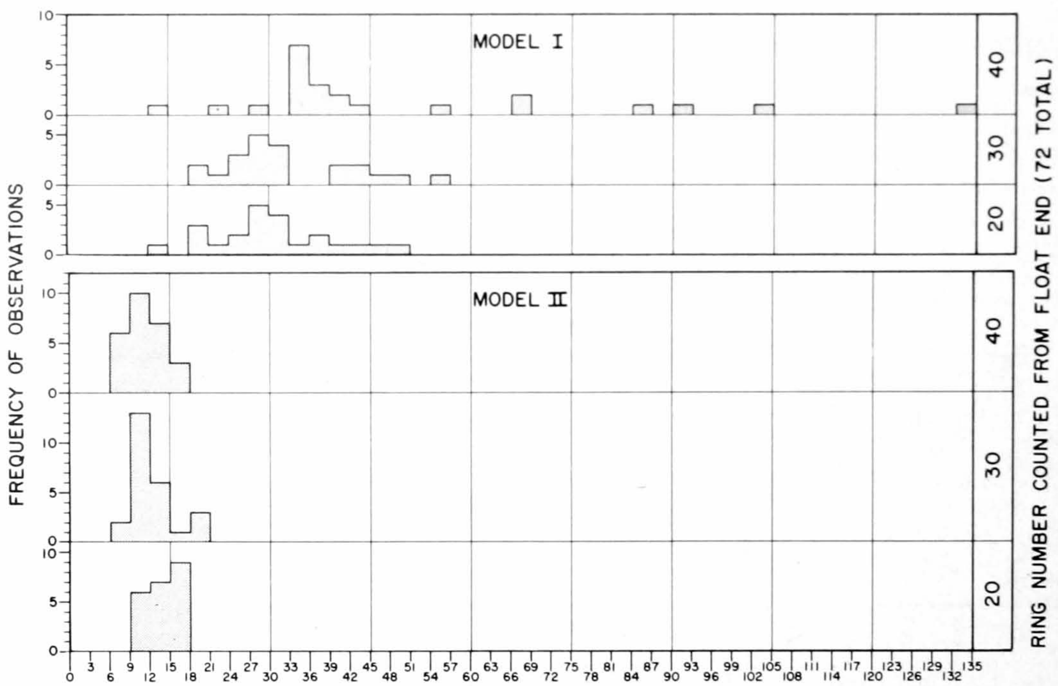


Figure 4.—Sinking time of models.

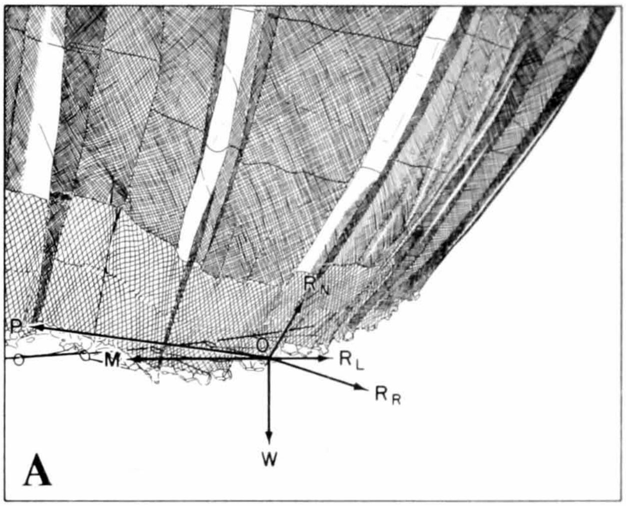
Model II is obvious: the median sinking time for all observations of Model I was 32 seconds; that for Model II, 12 seconds.

Comparing standard deviations of the sinking times of the two models is instructive. Standard deviations — as estimated from the ranges (Tate and Clelland, 1957, page 12) at rings 20, 30, and 40 — were 9.7, 9.7, and 32.4 seconds with Model I and 2.1, 3.2, and 2.4 seconds with Model II. The most obvious reason for this dissimilarity is the different hanging coefficients of the two nets. The large hanging coefficient of Model I makes its working depth much more sensitive to horizontal strains on the end of the net at the completion of the set. The net had to be shortened by loosening and bunching at the corks to reach depths exceeding 150 centimeters in Model I and 215 centimeters in Model II.[4] It is also reasonable to expect that the working depth would be more sensitive at Ring Number 40 than at the other locations in this respect because it was nearer to the skiff end. Another factor contributing to the depth variations in Model I was the common attachment points for leadline and corkline at each end of the net. This commonality of attachment resulted in an upward force component being transmitted to the leadline through a horizontal force at the ends. When each measurement of sinking time was ended, we observed that the submerged floats of Model I would bob to the surface, beginning at Ring Number 40, at the start of net hauling, whereas with Model II, a considerable amount of webbing was pulled aboard before any floats reappeared.

Although the setting time was varied from 15 to 103 seconds, the setting speed was not related to the sinking time in either model. Nor was such a relation found for the full-sized purse seine. We concluded that variations in setting speed have little or no effect on how tightly the net is set.

(2) Pursing time.—The maximum working depth was maintained by Model II during all pursing stages when pursing took 2½ minutes or longer. When Model II was pursed faster — that is, in 1½ minutes — the leadline tended to rise.

Figure 5A and B show estimated vector analyses, drawn on tracings of underwater photographs of Model II, at two different



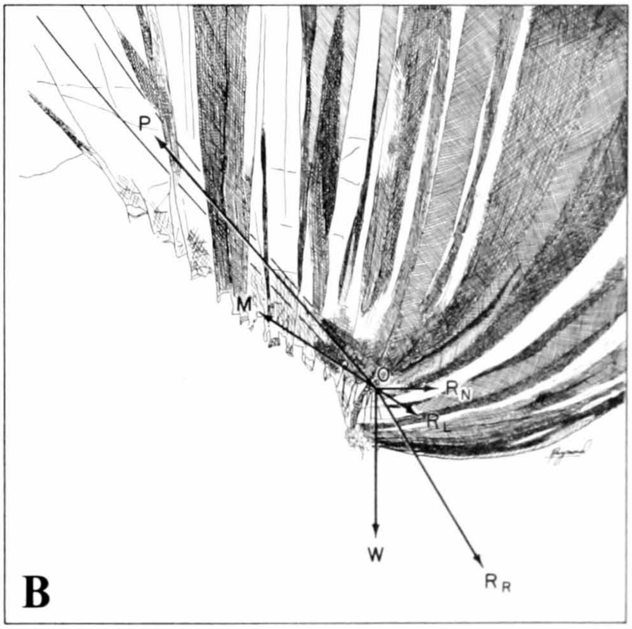


Figure 5.—Pursing forces acting on leadline of Model II: (A) at start of pursing and (B) near completion of pursing. Symbols: O = point of leadline at which forces act. Force vectors: P = pull in purse line, R_N = pull in netting, R_L = water resistance on leadline, W = force of gravity. Resultants: R_R = resultant of R_N, R_L, and W, M = resultant of all forces.

[4] These are the designed depths of the two models. Designed depth depends solely on hanging coefficient and is the maximum depth attainable before mesh deformation and consequent horizontal shortening (puckering) allow the net to sink deeper. Working depth (DW) is usually more than the designed depth, depending on such factors as sinking time, net construction, and horizontal forces.

stages in pursing. These analyses indicate the forces that acted upon the leadline. The upward motion of the leadline was caused by the pull in the purse line and was opposed by the combined effect of ballast, net resistance, and leadline drag.

Model I (for which no vector analyses were made) achieved its maximum working depth only at the end of the pursing operation — that is, when the corkline was bunched to a considerable extent. The leadline, however, tended less to rise with exaggerated pursing speed.

(3) Net shape.—The wing shapes of the two models differed markedly (Figure 6). The wing ends of Model II quickly reached their maximum working depth — that is, they reached at least 71 percent of their stretch depth and remained at this depth notwithstanding the pursing operation. The wings of Model I were canoe-shaped when under tension because their shortest components, the chain and the corkline, had almost the same length, so the netting overhung between them (Figure 7). When the three end purse rings at each wing of Model I were released from the purse line, the wing tips fished deeper, thus decreasing the size of the "escape gate." Nevertheless, the wing tips of Model II provided the smaller gate.

Figure 8 shows schematically the approximate shapes and areas of half the model's netting in a two-dimensional plane at three different stages in the sets. Under actual conditions, particularly under pursing tension, the working depth (D_W) is generally not vertical but is measured along the concavity of the scooping net wall.

The shape of Model I changed much more rapidly during the set than did that of Model II. The working length (L_W), the actual length of the net in the water, of Model I decreased rapidly, whereas the working depth (D_W) increased. Model I reached the working depth of Model II only in the final stages of the pursing operation and at the cost of an extensive reduction in the area enclosed by the net. The L_W, or circumference, of each model is plotted against D_W in Figure 9.

During pursing, both models gradually acquired a bowl shape, which turned more and more cuplike towards the final stages of pursing. The leadlines moved in a scooping motion following the bridles and the purse lines. The cupping and scooping actions were more pronounced with Model II (Figures 10, 11, and 12), where the central half of the seine, being deeper than both side quarters, was more concave (Figure 5B) than were the latter sections. During pursing of both models, the

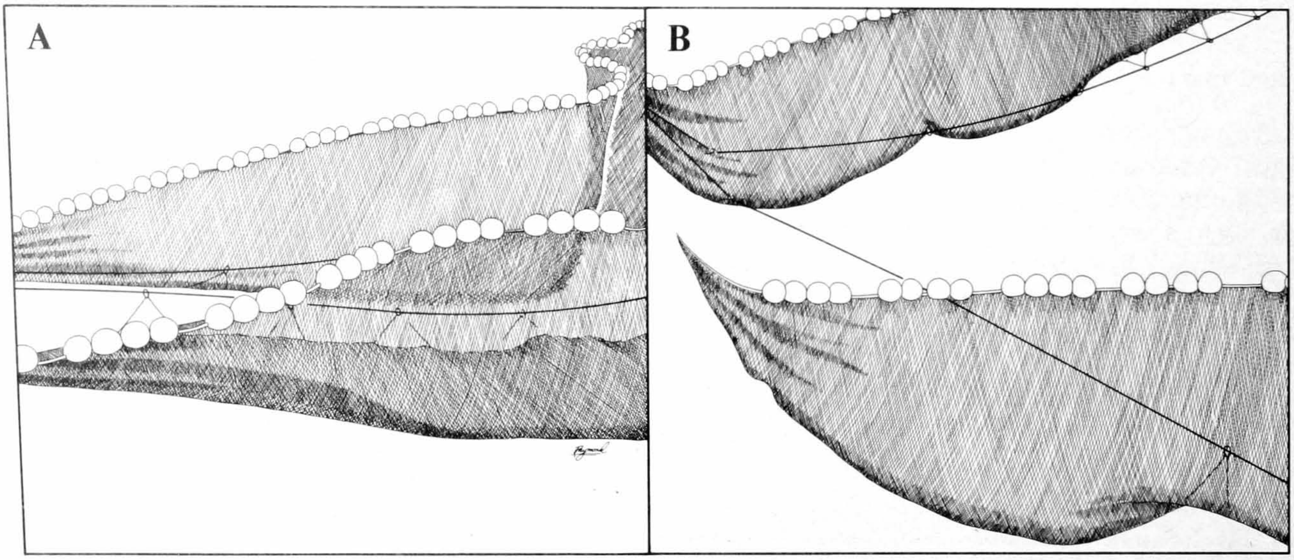


Figure 6.—Wing ends of both models (traced from projected photo transparencies): (A) Model I and (B) Model II.

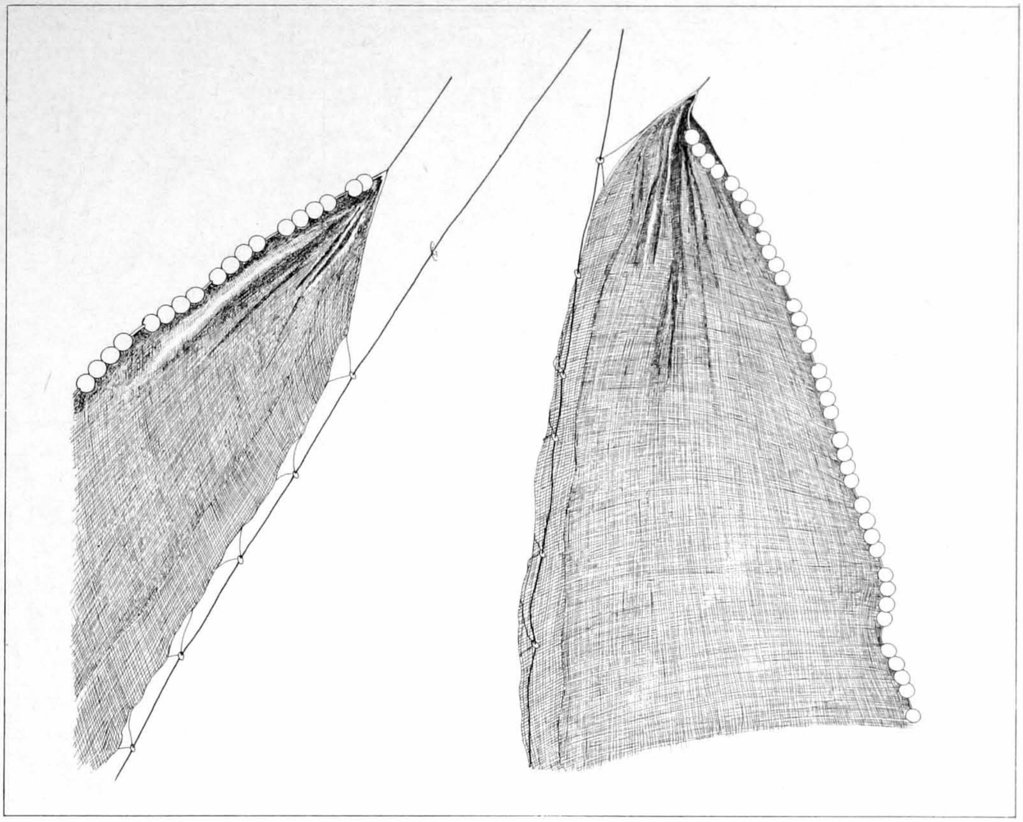


Figure 7.—Top view of wing ends of Model I (traced from projected photo transparency).

netting wall scooped under toward the center of the enclosed area, and the central section of the seine gathered in heavier folds than did the rest of the seine.

The enclosed area was much more elongated in Model II (Figures 10 and 11) than in Model I. This elongation was due to the increased drag of the central part of Model II resulting from its tapered design (Baranov, 1948). Elongation was exaggerated in both models because we pursed from a stationary point instead of a boat or float which would have been drawn toward the center of the net during pursing.

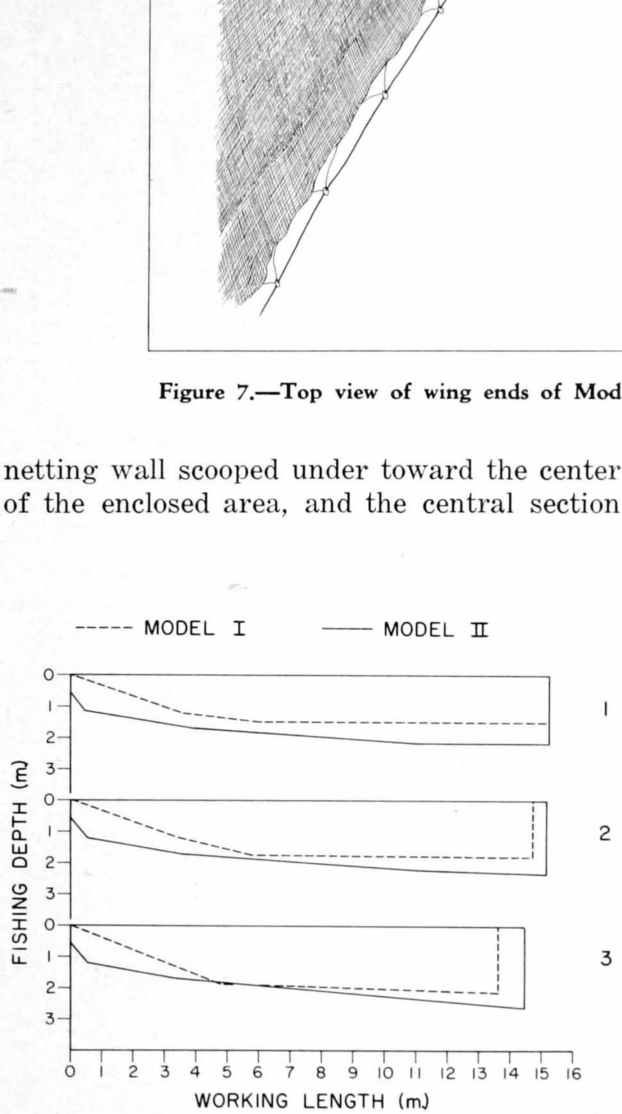


Figure 8.—Approximate shape of one-half the netting of Models I and II at three stages during set: (1) just after completion of circle, (2) just after start of pursing, and (3) pursing one-third completed.

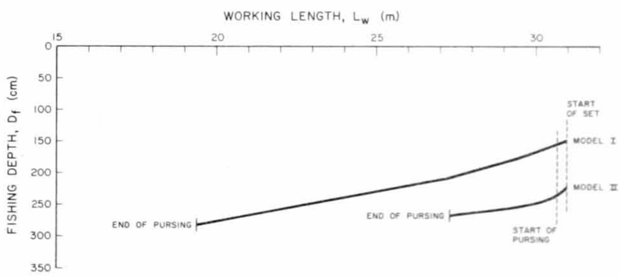


Figure 9.—Relation between working length (L_W) and working depth (D_W) of each model.

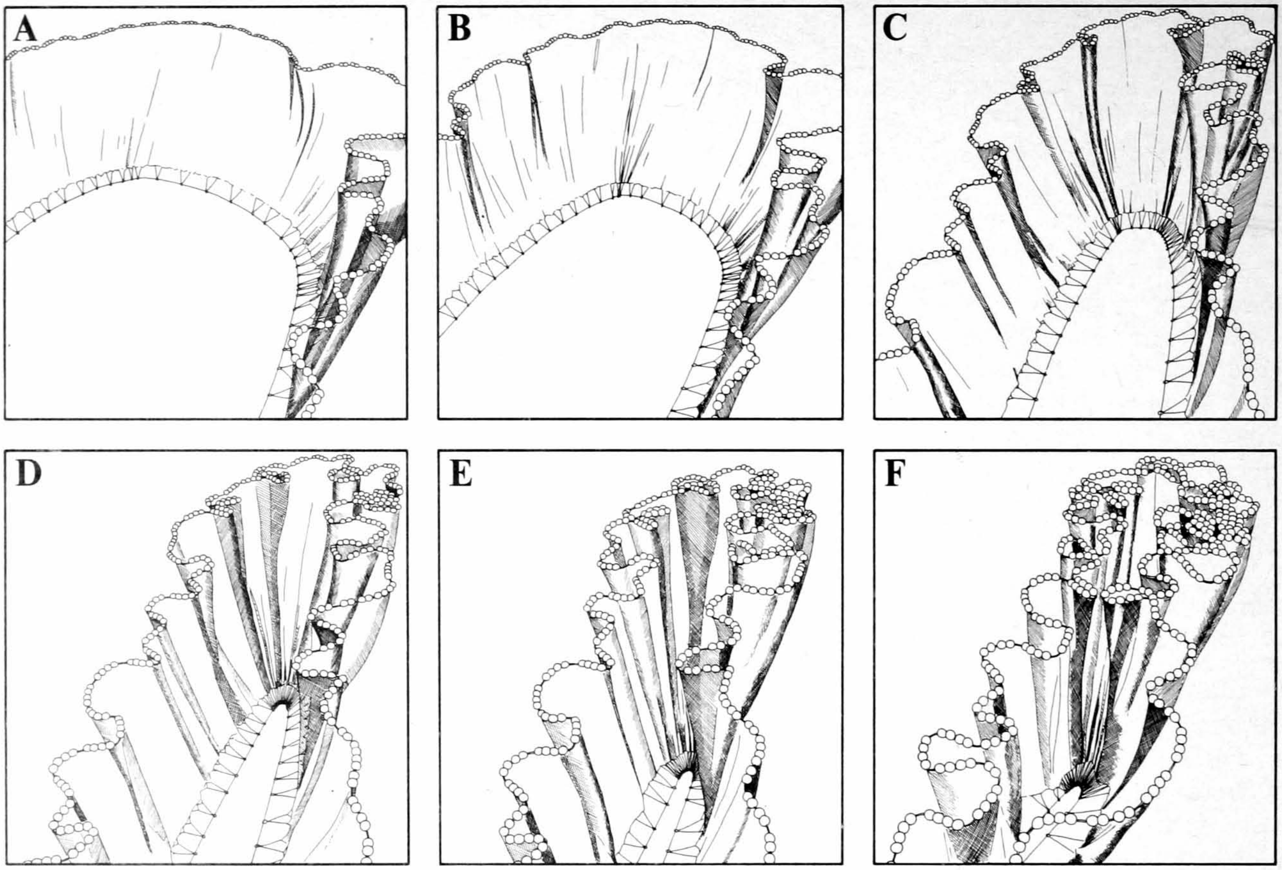


Figure 10.—Successive net configurations assumed by Model II during pursing. (Elongate form assumed as pursing progresses is due to pursing from stationary edge of pool. In practice, drawing of the purse seiner toward center of net during pursing, gives a more circular shape.)

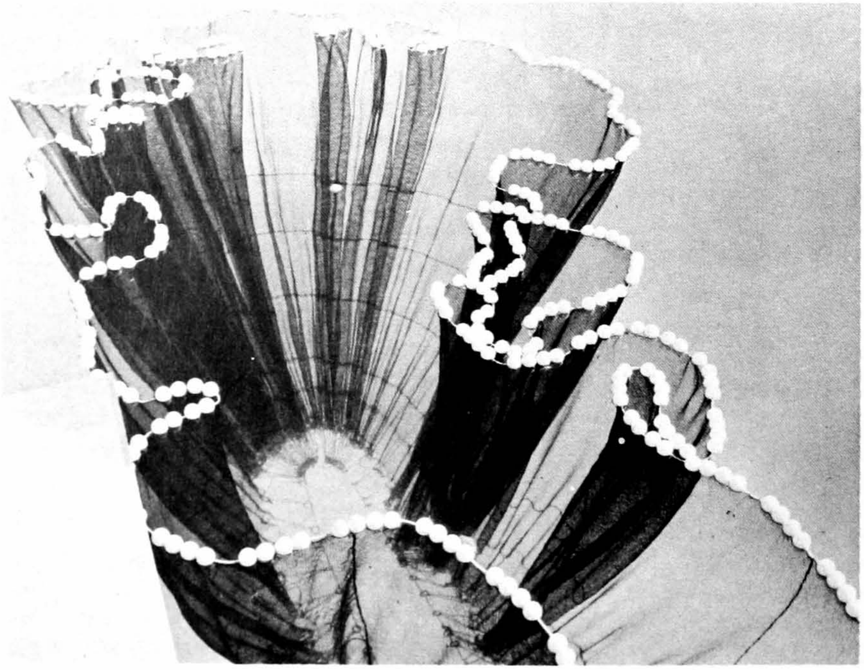


Figure 11.—"Cuplike" configuration in final stage of pursing Model II.

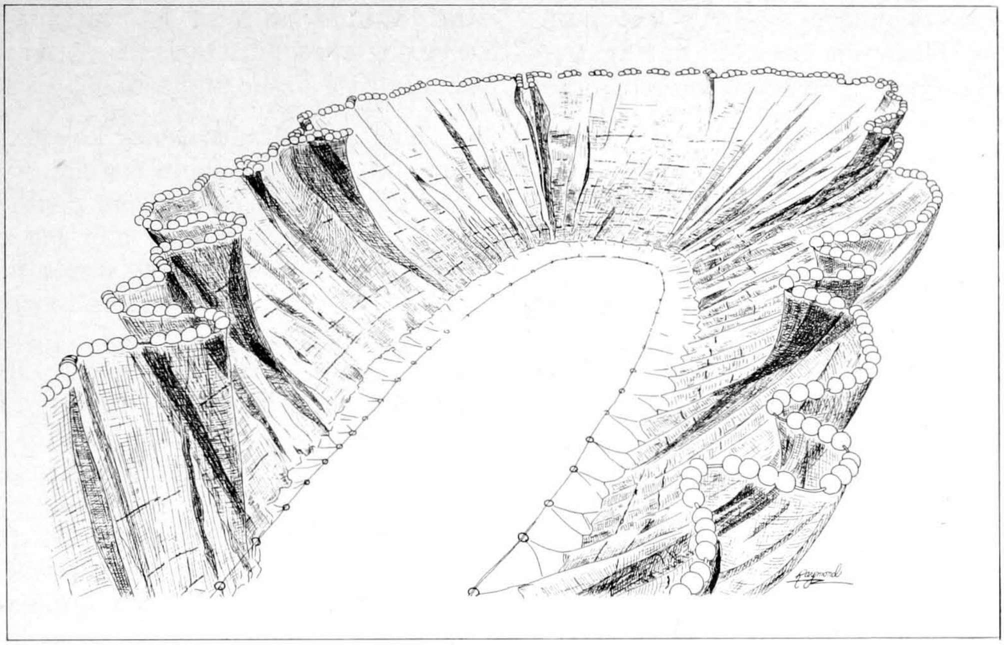


Figure 12.—Scooping action of Model II's leadline (traced from projected photo transparency).

II. NEW DESIGN SUGGESTED BY MODEL STUDY

Having obtained a picture of the comparative design of Models II and I and having seen how the performance compares with that of the full-size commercial seine in present use and how that of Model II, in turn, compares with that of Model I, we turn now to a detailed consideration of the proposed full-size improved seine. In so doing, we consider first the essential elements of purse seine design and then the main features of our hybrid purse seine, which incorporates certain desirable features from a number of other seines.

A. ESSENTIAL ELEMENTS OF PURSE SEINE DESIGN

What are the general requirements related to school behavior? We asked this question and then looked into a number of other important factors — principally, variations in purse seine design, effect of design variations on performance of tuna purse seine models, sinking speed, and pursing.

1. General Requirements Related to School Behavior

To capture a school of fish, a purse seine has to provide for the following three conditions:

i. The school must be encircled in a horizontal plane.

ii. The school must be "fenced off" vertically from the surface to a level below which the fish will not swim.

iii. The school must be enclosed beneath by the pursed seine — that is, the bottom edge of the purse seine, during the pursing operation, must pass below the greatest depth at which the fish school swims in the encircling net.

Condition i is provided by the length of the purse seine, Condition ii by its width (depth), and Condition iii by the ballast, hanging coefficient, and closable bottom.

When a purse seine is set, the school of fish may (1) retain its position during the setting operation or (2) attempt to escape the purse seine.

The first situation may occur in purse seining with lights,[5] in fishing of the "Kannizzati"-type,[6] and in purse seining with chumming.[7] Theoretically, in such situations, provided that the net is long and deep enough and its leadline is heavy enough, the catch is sufficiently secure that time is of little importance. The attention of the school remains directed to the source of attraction, so that the speed at which the net is set around the school and at which the leadline sinks to its working depth and even the speed at which the net is pursed may be of little or no importance.[8]

[5] Most common in the Mediterranean (Grubisic, 1961; Ben Tuvia, 1961; Dieuzeide and Novella, 1953).

[6] A commercial fishing method used in Malta for concentrating fish under floating objects (Galea, 1961).

[7] French fishermen purse seining in the East Atlantic Ocean use live bait to concentrate scattered tuna to keep them in a feeding frenzy until the set is completed. Iberian fishermen use hake eggs to chum sardines before setting their purse seines. American fishermen sometimes set around a baitboat which is holding the school of tuna with live bait.

The second situation, however, is most common in purse seine fishing. Even if the net has sufficient length and depth to encircle the fish, the school may slip out of the net. It may escape before the circle is completed because the setting speed is too slow or the direction in which the school is moving has not been judged correctly (Figure 13A). Also the school may dive and escape under the leadline before the leadline descends to its working depth (Figure 13B); or it may escape through the still open part of the partially pursed net, often beneath the boat (Figure 14). These hypotheses concerning how the fish react are subjective, however, in the absence of direct evidence of how fish actually escape a net.

[8] Under certain conditions, the fishermen try to avoid noise, so the net is set slowly.

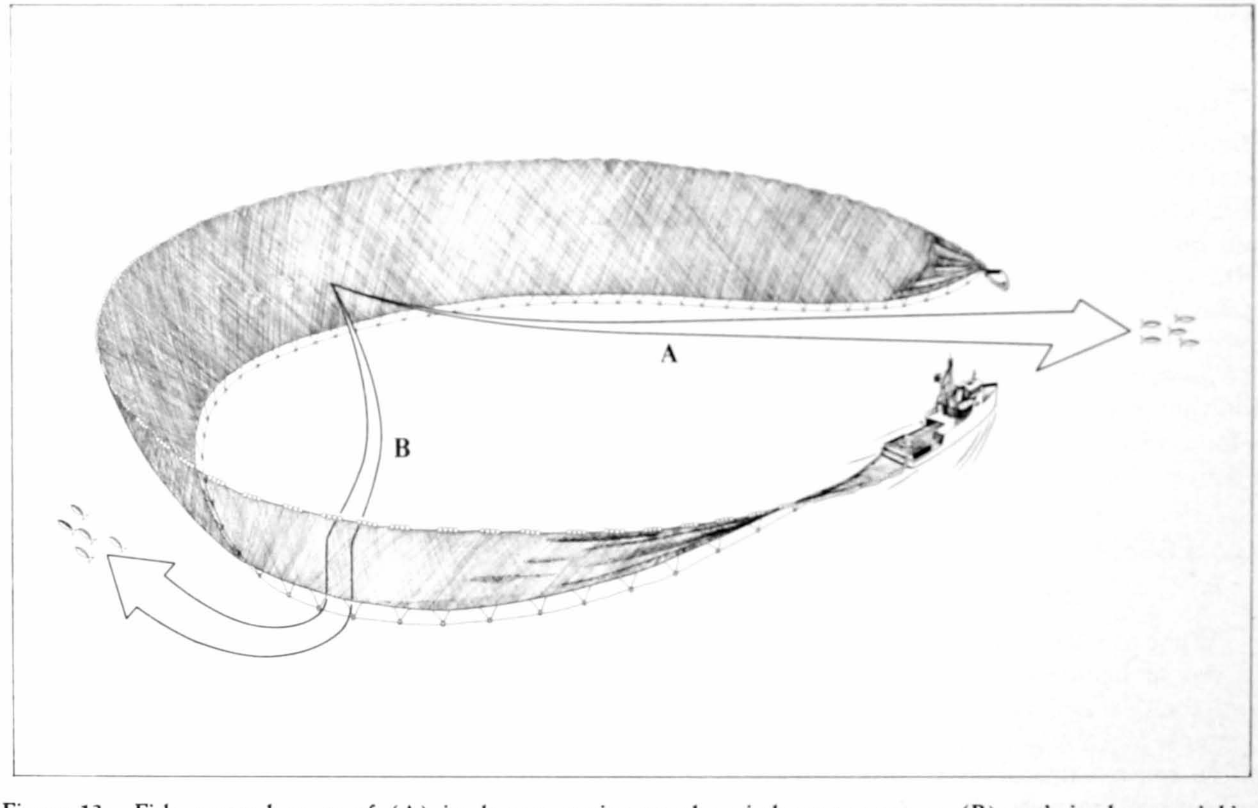


Figure 13.—Fish escape because of (A) inadequate setting speed or judgment errors or (B) net's inadequate sinking speed.

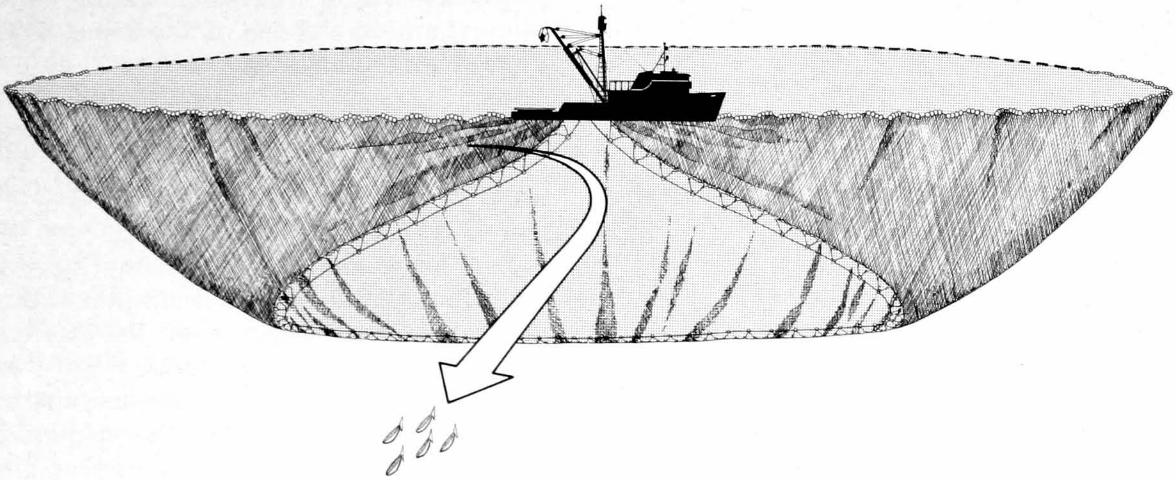


Figure 14.—Fish escape because of unfavorable configuration of partially pursed net.

2. Variations in Purse Seine Design

The basic pattern of a purse seine is the same the world over. It consists of an elongated sheet of netting hung between a corkline and a leadline. The leadline is fitted with rings through which the purse line passes. The construction and the design (Table 4) that govern the performance of the purse seine, however, vary greatly (Andreev, 1959; FAO, 1965a; Ben Tuvia, 1961; Brandt, 1964; Grubisic, 1961; Dieuzeide and Novella, 1953; Fry, 1931; Iitaka, 1955; Nakamura and Igarashi, 1964; DuPlessis, 1959; Robas, 1959; Schmidt, 1959; Scofield, 1951).

Although different species and different fishing methods require variations in the design of purse seines, we wonder whether this large proliferation of purse seine types came about through knowledge of what actually was needed or whether it came about through haphazard evolution, stabilizing in types of purse seines which seemed to offer their users fairly reasonable combinations of ease of handling and acceptable catches of fish. We believe that many types of purse seines could be improved by objective analyses of their design and performance in relation to the behavior of the fish they are used to catch.

3. Effect of Design Variations on Performance of the Tuna Purse Seine Models

The present study does not deal with those elements of purse seining that are not influenced by, or do not influence, the design of the net itself — for example, the element of setting speed dealt with in detail by Andreev (1959) or the method of handling the net on board the seiner, deck arrangement.... Several elements of the operation depend upon the design of the net — namely, the sinking speed of the leadline, the shape of the net in water before and during pursing, the volume enclosed by the net during each stage of pursing, and the working depth and the working circumference of the enclosed area.

Table 4.—Comparative table of design variables in different purse seines

Main species caught	Country	Ratios					Shape of net body	Construction of wing ends		Leadline weight (in air)		FAO Reference No.
		L_s/D_s	L_{cork}/D_s	L_{cork}/L_{lead}	k_h (corkline)	k_h (leadline)		Shape	Terminating of webbing	Per unit length of leadline	Per unit fictitious net area	
										Kg./m.	*Kg./m.*	
Coal fish and cod	Norway	13.4	6.3	0.91	0.47	0.51	Rectangular	Rectangular	Laced to gravels	1.64	0.014	306
Herring	Canada	7.6	5.9	1.03	0.78	0.76	Tapered toward bunt	Rectangular	Laced to gravels	1.93	0.016	301
Herring	United Kingdom	6.3	4.0	1.00	0.60	0.61	Rectangular	Rectangular	Laced to gravels	0.51	0.007	302
Herring	Norway	9.5	3.9	0.91	0.41	0.45	Slightly tapered	Rectangular	Laced to gravels	1.45	0.007	304
Herring	Iceland	5.5	3.0	0.88	0.55	0.63	Tapered	Tapered in bunt	Free hanging between cork and leadline	2.79	0.015	308
Salmon	Canada	11.0	7.7	1.11	0.70	0.63	Tapered toward bunt	Rectangular	Laced to gravels	1.73	0.017	312
Tuna	Norway	16.3	6.7	0.96	0.41	0.43	Tapered toward bunt	Rectangular	Laced to gravels	1.84	0.008	305
Tuna	United States	9.9	9.2	1.01	0.93	0.92	Rectangular	Rectangular	Gathered to end brackets	4.60	0.050	310

Key: L_s = stretched length of webbing.
D_s = stretched depth of webbing.
L_{cork} = length of corkline.
L_{lead} = length of leadline.
k_h = hanging coefficient (L_s/L_{cork} or L_s/L_{lead}).
Fictitious area = $L_s \times D_s$.

Source: Calculated from FAO (1965a).

We found that variations in design influenced the performance of the model purse seines as follows:

1. When the ratio of the length of corkline to length of leadline was equal to or greater than 1, speed of sinking was slower, and the shape of the seine ends was adversely affected.

2. Changing the k_h at the corkline from 0.90 to 0.70 and adding to the length of the leadline more than doubled the speed of sinking.

3. A lower hanging coefficient (k_h = 0.70) allowed the seine to maintain the maximum circumference of the surrounded area for a longer time. This longer maintenance of the maximum circumference resulted because the leadline could reach deeper before its further sinking caused the floats to bunch.

4. The speed of sinking and the shape of the wing ends while pursing were improved and the gap or "gate" between them was reduced by the addition of gavels between the corkline and the leadline at the wing tips. The hanging of the netting to the gavels was at the side k_h corresponding to the top and bottom hanging coefficients.

5. Tapering the net from the center towards both ends saved substantial amounts of netting without impairing the working depth. The deepened center of the net provided more scooping action during the pursing operation.

Thus, a faster sinking net with the desired underwater configuration was produced for possible use in the Eastern Pacific tuna fishery. Whether or not these features will bring higher catches of tuna can be determined only by experiments with a full-scale net. Details of handling the net and analysis of its catching efficiency must also be the subject of further experiments.

4. Sinking Speed

Hamre (1963) stated that "the most obvious reason for the fast sinking of the Norwegian net [as compared with the American tuna purse seine] is the small resistance of the light webbing used in that net." The sinking speed of the Norwegian tuna purse seine tested by Hamre was about four times that of the American net. Hamre's statement was based on an equation of net resistance to the flow of water. The present study, however, used two different nets with the same webbing and ballast. In this experiment, sinking speed was more than doubled. This finding indicates that the lower k_h (0.40) as well as longer leadline used with the Norwegian net may have been more important than the size of webbing in producing its higher rate of sinking. Although Hamre did not mention gavels in his paper, his net was probably fitted in the usual Scandinavian manner with gavels at both sides. The effect of all of these features improved its sinking speed markedly.

Netting material plays a secondary role in speed of sinking as long as the specific gravity — ballast ratio remains unchanged. (Today, lighter-than-water, as well as heavier-than-water, synthetic net materials are available). The main factor affecting a net's rate of sinking is its hanging coefficient. When the actual depth of the seine starts to exceed the designed depth, the actual length of the net (the circumference of the encircled area) starts to decrease (Figure 8). This decrease occurs only when the whole puckering wall of the netting moves through the water towards the center of the encircled area. The netting therefore has to overcome the resistance of water. The higher the k_h, the greater the lateral movement of the netting required for the leadline to descend to the same working depth; this lateral movement of the netting takes more time than longitudinal movement.

When Vinogradov (1950), cited by Andreev (1959), increased k_h from 0.5 to 0.8, his leadline sank 100 percent faster. Andreev attempted to explain this greater rate of sinking by "increased deformation of netting" at higher k_h. The present study indicates that Vinogradov's results and Andreev's explanation cannot both be correct. Vinogradov's net was probably set in a straight line, so that the netting and the corkline could pucker without any lateral motion through the water. With less water resistance, the D_W could increase faster.

If all other conditions are equal, an increase in weight of leadline increases the speed of sinking (as well as the working depth). Figure 4 illustrates the importance of the weight of leadline in keeping the leadline deep during pursing. Weight of leadline alone, however, is not sufficient to provide a fast rate of sinking if the hanging coefficient and the ratio of the length of corkline to the length of leadline are too high. This influence of the hanging coefficient and the ratio of length of corkline to leadline is illustrated by the Norwegian purse seine, which, with a much lighter leadline, sinks much faster than does the heavily ballasted American purse seine (Hamre, 1963; Green, 1964).

5. Pursing

What is the importance of the shape of the seine during pursing? Baranov (1948) emphasized the importance of the increase of the D_W during pursing and stated that fish usually move downwards to escape the net. Since a leadline with high k_h had less tendency to rise during pursing, he recommended the use of a high k_h, though one not higher than 0.87-0.90. Hamre (1963) stated that, "Apart from size, the catching capacity of a purse seine is mainly determined by the operational speed and the sinking velocity."

The present study indicates that the best sinking velocity could be had by using a low k_h. On the other hand, the use of a low k_h caused the leadline to rise earlier during pursing. This early rise was due to changes in the true c_1 at the upper edge of the seine (c_1 = ratio of actual length to stretched length of netting) when the corkline bunches. At k_h = 0.90, as long as c_1 was near to k_h or equal to it, the initial working depth of the seine was about 0.44 of its stretched length — that is, c_2 = 0.44 (c_2 = ratio of actual depth to stretched depth of netting) — Ben-Yami, 1959. The relation of c_1 to c_2 is given by

$$c_1 = \cos \alpha$$

$$c_2 = \sin \alpha, \qquad (2)$$

where $\alpha = \frac{1}{2}$ the mesh angle formed by upper and lower mesh bars at either side. Derivations of Equation (2) and other pertinent net equations are given by Hamre (1963).

When k_h equals 0.60, for example, the initial D_W is twice as great, for when $c_1 = 0.60$, then $c_2 = 0.80$. During pursing, however, the c_2 of the former more tightly hung net can more than double with the bunching of the leadline, whereas the c_2 of the latter loosely hung net cannot increase much.

Another performance factor affected by k_h is the actual area surrounded by the purse seine during pursing. When k_h is large, this area decreases rapidly with an increase of D_W, whereas when k_h is small, the original size of the encircled area is maintained for a longer time, because the corkline has less tendency to bunch during the first part of the pursing operation. Thus, we have another problem — deciding whether greater pursing depth, or larger encircled area and volume is more important to keep the fish in the seine. In other words, which is the more important — the depth of the bowl's bottom or the size of the bowl and the speed with which it is created?

In our opinion, the relative importance of sinking speed and pursing depth on the one hand and size of the encircled area during pursing on the other depends on the species of fish, their particular behavior under the circumstances,[9] and the other fishing conditions, such as depth of thermocline (Green, 1967), depth of bottom at the fishing location, and underwater visibility of the net (Hester and Taylor, 1965). When a school of fish is not moving, the pursing performance and D_W seems to be more important than the speed of pursing, setting, and sinking. When a school is in motion trying to escape the net, the elements of setting and sinking speed seem to be the more important. Mediterranean fishermen are aware of this difference. For example, whereas their purse seines used for sardine fishing during daylight, when sardine schools are in motion, are loosely hung (low k_h) and long, their purse seines used for fishing the same fish at night with lights, are shorter, deeper, and more tightly hung.

Until new technologies are applied in research on fish behavior in relation to purse seines, the fishermen's experience should be relied upon. Thus, where fishermen believe that a fast-sinking net is less important than is a deep pursing one, high k_h is to be recommended and vice versa.

B. THE HYBRID PURSE SEINE

Presented in this section is the design of the hybrid purse seine that we are proposing as an improvement over the seine currently used and a prediction of its sinking performance.

1. Design

The design of Model II was based on a combination of elements of the California and the North European designs to combine the fast sinking of the latter with the deep pursing of the former. Thus:

1. The ballast of the California seine was maintained.
2. The high k_h at the leadline of the California seine was maintained.
3. The k_h at the corkline was lowered to 0.70 (Scandinavian).
4. Gavels were introduced (Scandinavian, Russian, Canadian).
5. Netting of tapered shape (deep center and shallower wings) was introduced (Scandinavian).
6. Separate side (breast) purse rings and lines were introduced (Norwegian, Russian).
7. The horizontal net sections were gradually shortened, from the midsections downward to give equal lengths of lead-

[9] Mullet sometimes escape a seine by jumping over the corkline (Leslie Scattergood, personal communication) as do the Red Sea milkfish *(Chanos chanos)*. Of two species of tuna simultaneously encircled in the same purse seine set, the one — long-tail tuna *(Thunnus tonggol)* — was observed diving under the leadline while the other — little tuna *(Euthynnus affinis)* — stayed in the net (Ben-Yami, 1966).

line and corkline between the end perpendiculars. This equality is made possible by the use of incremental hanging coefficients varying from $k_h = 0.7$ at the top to $k_h = 0.9$ at the bottom. When the breast purse lines have been hauled and the wing ends gathered, the nearly equal lengths of cork and leadline should facilitate the hauling operation where power blocks are used. The gradual decrease toward the bottom in the length of webbing strips is designed for the better attainment of the bowllike shape of the net with minimum waste of netting.

A design of a tuna purse seine for a larger seiner, based on the results of the present study and the described design of the Model II, is shown in Figure 15 and Table 5. We expect this seine to sink faster and to a greater depth than the present California purse seine without losing its superior pursing performance at depth. The table presents only the linear dimensions of the different sections of the seine. It therefore gives no specifications for the mesh size and rope and twine size or the other components of the net, these items being left to individual preference.

Following a general trend toward larger nets, the proposed design is for a net scaled up at a ratio of about 31:1 from Model II. Thus, the full-scale seine will be comparable with a 960-meter (525-fathom) California purse seine rather than the 777-meter (425-fathom net) described by McNeely (1961) and FAO (1965a).

2. Prediction of Sinking Performance

The difference in sinking speed between the Model I and the full-size net was taken into consideration in the prediction of the sinking performance for the scaled up Model II, using the equation

$$\frac{t_{A_f}}{t_{A_{mod}}} = \frac{t_{B_f}}{t_{B_{mod}}}\text{; and } \frac{D_{A_f}}{D_{A_{mod}}} = \frac{D_{B_f}}{D_{B_{mod}}} \quad (3)$$

where: t_{A_f} = sinking time of full-scale California tuna purse seine at midnet

$t_{A_{mod}}$ = sinking time of Model I, at midnet

t_{B_f} = sinking time of scaled up Model II, at midnet

$t_{B_{mod}}$ = sinking time of Model II, at midnet

D_{A_f} = depth reached by full-scale seine leadline at the time t

$D_{A_{mod}}$ = depth reached by the Model I leadline at the time t

D_{B_f} = depth reached by the scaled up Model II leadline at the time t

$D_{B_{mod}}$ = depth reached by the Model II leadline at time t.

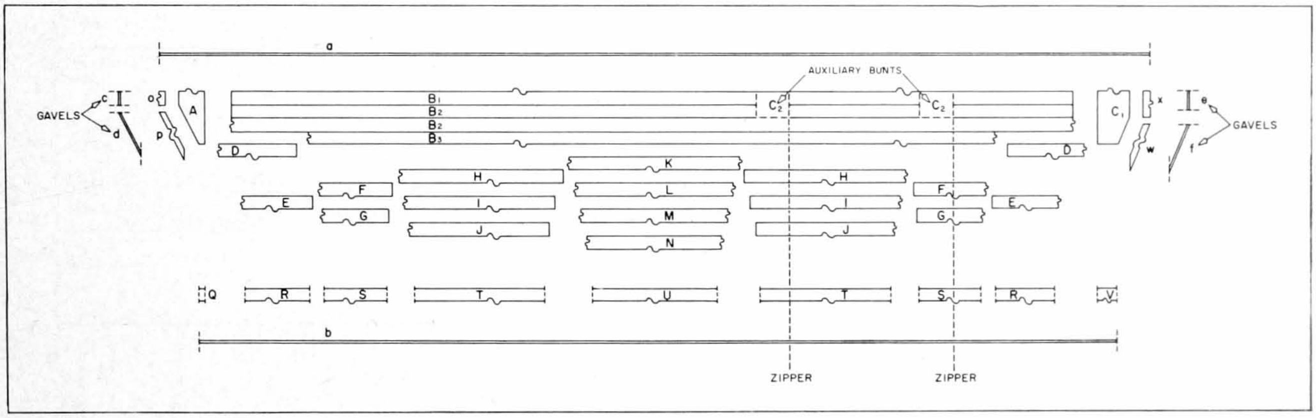


Figure 15.—Construction diagram of hybrid purse seine.

Table 5.—Construction specifications of hybrid net (see Figure 15).

Webbing sections	Data on webbing			Webbing sections	Data on webbing		
	L_s	D_s	k_h		L_s	D_s	k_h
	Meters	*Meters*			*Meters*	*Meters*	
A	40/10	10/40	0.7/1.0	L	240	10.5	(—)/0.93
B_1	1283	10.5	0.7/1.0	M	224	10.5	(—)/0.93
B_2	1283	10.5	1.0/1.0	N	208	10.5	(—)/0.93
B_3	1047	10.5	1.0/0.93	O	10.2	10	0.7/0.7 0.7/10.
C_1	40/20	40/20	0.7/1.0	P	42.8/58.1	7.1	0.7/0.7
C_2	40	21	0.7/1.0	Q	10	10.2	(—)/0.90
D	118	10.5	1.0/0.93	R	102	10.2	(—)/0.90
E	110	10.5	(—)/0.93	S	94	10.2	(—)/0.90
F	109	10.5	(—)/0.93	T	200	10.2	(—)/0.90
G	101	10.5	(—)/0.93	U	193	10.2	(—)/0.90
H	248	10.5	(—)/0.93	V	20	10.2	(—)/0.90
I	231	10.5	(—)/0.93	W	28.6/42.8	7.1	0.7/0.7
J	215	10.5	(—)/0.93	X	10.2	20	0.7/0.7 1.0/0.7
K	259	10.5	(—)/0.93				

Lines	Data on lines	Lines	Data on lines
	Length		Length
	Meters		*Meters*
a	968	d	41
b	914	e	14
c	7	f	30

Key: L_s = stretched length of webbing.
D_s = stretched depth of webbing.
k_h = hanging coefficient (L_s/L_{cork} or L_s/L_{lead}).
(—) = denotes that the edge concerned is laced to another, longer section at a k_h specified for respective edge of the latter.

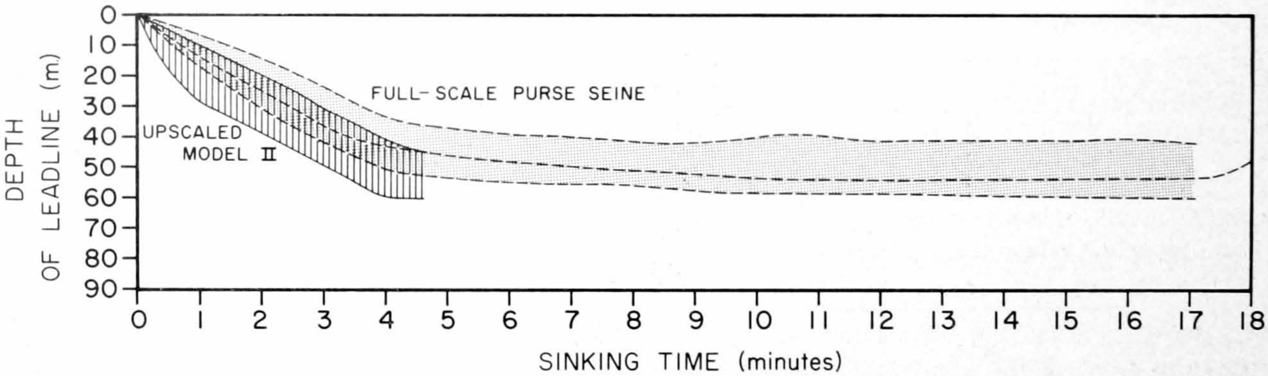


Figure 16.—Predicted sinking performance of scaled up Model II.

The predicted range of the sinking performance of the scaled up Model II is shown in Figure 16, where it is superimposed over the measured sinking performance range of a conventional American tuna purse seine.

The sinking performance is predicted for only the time before the start of the pursing operation. It can be seen that a scaled up Model II would sink faster and to greater depth than would the conventional seine. The sinking range of the conventional seine, as plotted, covers 17 sets made under different wind and current conditions. BKG recordings (Hester, 1961) show that when the wind and current tend to pull the boat and the net apart (a "tight" set) the leadline sinks to a lesser depth than when these conditions do not occur and the boat drifts into the net (a "loose" set). The working depth at midnet may be up to 43 percent deeper in a loose set than that in a tight set.

During the model trials, however, almost all sets were tight. Thus, the predicted range of the upscaled Model II is based more upon the upper part of the range of the sinking performance of the conventional net than the lower. The predicted sinking curve of the updated Model II, therefore, is on the conservative side.

CONCLUSIONS AND RECOMMENDATIONS

1. The use of models in the study of purse seines may serve as a good method for designing nets rationally for different fishing conditions and for improving the commercial nets now used.
2. This method rationally calls for emphasizing the comparative performance of different models rather than for attempting to duplicate exactly scaled-down nets.
3. The main conditions for increasing the sinking speed of tightly hung purse seines is to decrease their k_h, but this decrease may cause the pursing depth to become shallower.
4. A suggested hybrid purse seine for tuna fishing, incorporating certain characteristics of several types of nets, promises, on the basis of model tests, to produce a compromise performance — that is, a higher sinking speed and yet a satisfactory pursing depth.
5. Further research into purse seining operations should be carried on along the following lines:
   a. Model tests of various net designs accompanied by collection of data from BKG and other measuring instruments (for example, from recording dynamometers and inclinometers) during actual fishing of full-size nets.
   b. Research into the behavior of fish in the immediate vicinity of, or encircled by purse seines, by means of direct observations by SCUBA divers and submarine vehicles, aircraft, echo sounding and echo ranging, and underwater photography and television.
   c. Experiments with net-handling equipment and techniques, such as bow-situated pursing davit aimed at increased safety of gear and efficiency of pursing, arrangement for hauling breast purse lines, and use of snatch purse rings to eliminate the ring-hauling stage during pursing and hauling.
   d. Construction of lower strips of purse seines of netting lighter-than-water as suggested by Kristjonsson (private communication) — Thomson, 1967.

SUMMARY

Purse seines have been the object of comparatively little technological research, despite the fact that they take increasingly large portions of the world's catch of fish. This fact and observed differences in performance and construction of existing purse seines led to the present study. The study inquired into the varying performance factors of purse seines and resulted in an experimental purse seine design intended to improve on the design of the purse seine now used in the tuna fishery of the Eastern Tropical Pacific.

Two model purse seines were constructed. The first, Model I, was a 1:25 scale model of the California tuna purse seine. After being tested, this model was reworked to form Model II in an effort to produce a better combination of performance characteristics. Major alterations consisted of varying hanging coefficients (k_h) from 0.7 at the top to 0.9 at the bottom, introducing gavels, and tapering the body. Total size, ballast, and materials of construction were not changed.

Comparative tests indicated that Model II sank more than twice as fast as Model I did and offered a smaller escape opening at its ends while maintaining the acceptable pursing performance of Model I. Also, the working depth was less sensitive to horizontal strains on the net in Model II than in Model I.

Scale comparisons of the performances of Model I and its full-size counterpart indicated that sinking speed for Model I was faster than it should have been. We attributed this excessive speed of sinking to the excessive weight of ballast on Model I, for the ballast was greater than the scale required. We assumed, however, that comparisons between models were valid, because both used the same leadline and were otherwise scaled down along the same modeling rules. We used correction factors to compare the results of models and full-scale purse seines.

We concluded that k_h is probably the most important design variable affecting sinking speed, area encircled, and pursing performance. Low k_h gives greater sinking speed and greater area of encirclement during later stages in the set but allows the leadline to rise earlier during pursing. The converse is also true. Other important factors affecting these and other performance characteristics are weight of ballast, size of mesh, and size of twine.

The optimal combination of performance characteristics for any purse seine depends on the species of fish, school behavior before and during the set, fishing methods that modify behavior including use of adjuncts such as lights and noise, and oceanographic conditions. These factors were considered in the design of a hybrid purse seine, which essentially is a scaled-up Model II with a combination of design elements from various other types of purse seines.

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REFERENCES

[* = not cited in text]

Andreev, N. N.
1959. Teoriya lova ryby koshel 'kovymi nevodami (The theory of purse seining). Trudy Vsesoyuznogo Nauchno-Issledovatel 'skogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii (Trudy VNIRO) 41: 114-123. In Russian.

Baranov, F. I.
1948. Teoriya i raschet orudii rybolovsta (Theory and design of fishing gear). Pishchepromizdat, Moscow, 436 pages. In Russian.

Ben Tuvia, A.
1961. Catch per unit of effort of *Sardinella aurita* along the coast of Israel during the years 1950-59. General Fisheries Council for the Mediterranean, Proceedings and Technical Papers No. 6, pages 271-278.

Ben-Yami, Menachem.
1959. Study of the Mediterranean trawl net. *In* Modern fishing gear of the world, edited by Hilmar Kristjonsson, pages 213-221. Fishing News (Books) Ltd., London.

1966. Observations on the distribution and behaviour of pelagic fish in the southern Red Sea. Ministry of Agriculture, Department of Fisheries, Haifa, Israel, 16 pages [Processed.] Also: Sea Fisheries Research Station, Haifa, Bulletin (in press).

Brandt, Andres von.
1964. Fish catching methods of the world. Fishing News (Books) Ltd., London, 191 pages.

Dickson, W.
1959. The use of model nets as a method of developing trawling gear. *In* Modern fishing gear of the world, edited by Hilmar Kristjonnson, pages 166-174. Fishing News (Books) Ltd., London.

Dieuzeide, R., and M. Novella.
1953. Le materiel de peche maritime utilise en Algerie. Documents et Renseignments Agricoles 179, Alger: 1-274.

DuPlessis, C. G.
1959. Fishing with South African pursed lampara. *In* Modern fishing gear of the world, edited by Hilmar Kristjonsson, pages 391-393. Fishing News (Books) Ltd., London.

Food and Agriculture Organization of the United Nations.
1965a. Catalogue of fishing gear designs. Food and Agriculture Organization of the United Nations, Rome, Italy, 24 pages plus appendix of data sheets and plans (irregular pagination).

* 1965b. Yearbook of fishery statistics, volume 18. Catch and landings, 1964. Food and Agriculture Organization of the United Nations (irregular pagination).

Fridman, A. S.
1964a. Opredelenie uslovii podobiya rybolovnykh orudii i osnovnye napravleniya dal 'neishikh issledovanii dlya obosnovaniya metodiki modelirovaniya (Determination of the conditions of similarity of fishing gear and main trends in the further studies in devising methods of models construction). Trudy Kaliningradskogo Tekhnicheskogo Instituta Rybnoi Promyshlennosti i Khoziaistva (17): 129-146.

* 1964b. Proektirovanie orudii promyshlennogo rybolovsta metodami teorii podobiya (The theory of similarity as a means of designing commercial fishing gear). Trudy Kaliningradskogo Tekhnicheskogo Instituta Rybnoi Promyshlennosti i Khoziaistva (17): 147-159.

Fridman—Continued
* 1964c. Usloviya podobiya rybolovnykh orudii (Conditions of similarity of fishing gear). Trudy Kaliningradskogo Teknicheskogo Instituta Rybnoi Promyshlennosti i Khoziaistva (18): 181-199.

Fry, Donald H., Jr.
1931. The ring net, half ring net, or purse lampara in the fisheries of California. California Division of Fish and Game, Fish Bulletin 27, 67 pages.

Galea, J. A.
1961. The "Kannizzati" fishery. General Fisheries Council for the Mediterranean, Proceedings and Technical Papers No. 6, pages 85-91.

Green, Roger E.
1964. Norwegian bluefin tuna seines. Faster sinking, faster hauling than U. S. nets. Pacific Fisherman 62(1): 10-11.

1967. Relationship of the thermocline to success of purse seining for tuna. Transactions of the American Fisheries Society 96(2): 126-130.

Green, Roger E., and Gordon C. Broadhead.
1966. Costs and earnings of tropical tuna vessels based in California. U. S. Fish and Wildlife Service, Fishery Industrial Research 3(1): 29-45.

Grubisic, F.
1961. Length of purse-seine and size of sardine schools. General Fisheries Council for the Mediterranean, Proceedings and Technical Papers No. 6, pages 233-235.

Hamre, J.
1963. Some technological aspects of the Norwegian tuna purse seine fishery. Fiskeridirektoratets skrifter Serie Havunderskelser 13(6): 106-119.

Hester, F. J.
1961. Tuna seines: how deep? Pacific Fisherman 59(12): 19-20.

Hester, Frank J., Donald C. Aasted, and Robert W. Gilkey.
1963. The bathykymograph, a depth-time recorder. U. S. Fish and Wildlife Service, Special Scientific Report — Fisheries, 441, 5 pages.

Hester, Frank, and John H. Taylor.
1965. How tuna see a net. Commercial Fisheries Review 27(3): 11-16.

Hunter, John R., Donald C. Aasted, and Charles T. Mitchell.
1966. Design and use of a miniature purse seine. Progressive Fish-Culturist 28(3): 175-179.

Iitaka, Yunosuke.
1955. Model experiments on the sardine purse seine operating in Hyuganada — III. Bulletin of the Japanese Society of Scientific Fisheries 21(7): 459-462.

Jakobsson, J.
1964. Recent developments in Icelandic herring purse seining. *In* Modern fishing gear of the world 2, "arranged by the Technical Staffs of Fishing News International and Fishing News from the papers and discussions at the Second FAO World Fishing Gear Congress, London, 1963," pages 303-304. Fishing News (Books) Ltd., London.

Kawakami, T[usae].
1959. Development of mechanical studies of fishing gear. *In* Modern fishing gear of the world, edited by Hilmar Kristjonsson, pages 175-184. Fishing News (Books) Ltd., London.

1964. The theory of designing and testing fishing nets in model. *In* Modern fishing gear of the world 2, "arranged by the Technical Staffs of Fishing News International and Fishing News from the papers and discussions at the Second FAO World Fishing Gear Congress, London, 1963, "pages 471-481. Fishing News (Books) Ltd., London.

Lusyne, P. A.
1959. Some considerations on netmaking. *In* Modern fishing gear of the world, edited by Hilmar Kristjonsson, pages 102-106. Fishing News (Books) Ltd., London.

Lyles, Charles H.
1967. Fishery statistics of the United States, 1965. U. S. Fish and Wildlife Service, Statistical Digest 59, 756 pages.

McNeely, Richard L.
1961. Purse seine revolution in tuna fishing. Pacific Fisherman 59(7): 27-58.

Nakamura, Hideo, and Shuzo Igarashi.
1964. Studies on the fishery of mackerel by purse seines on the sea off southwest Hokkaido. 4. Statistical investigation about the structures of two-boat type purse seine on Ishikari Bay, and a preliminary experiment on the representative model net. Bulletin of the Faculty of Fisheries, Hokkaido University 15(3): 157-168. In Japapenes with English abstract.

Robas, John S.
1959. Menhaden purse seining. *In* Modern fishing gear of the world, edited by Hilmar Kristjonsson, pages 394-399. Fishing News (Books) Ltd., London.

Schaefer, Milner B.
1962. Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1961. Inter-American Tropical Tuna Commission Annual Report for the year 1961, Appendix A: 44-103 (in English), 104-171 (in Spanish).

Schmidt, Peter G.
1959. The puretic power block and its effect on modern purse seining. *In* Modern fishing gear of the world, edited by Hilmar Kristjonsson, pages 400-413 (see page 404 and Figure 4). Fishing News (Books) Ltd., London.

Scofield, W. L.
1951. Purse seines and other roundhaul nets in California. California Department of Fish and Game, Fish Bulletin 81, 83 pages.

Tate, Merle W., and Richard C. Clelland.
1957. Nonparametric and shortcut statistics in the social, biological, and medical sciences. Interstate Printers and Publishers, Inc., Danville, Illinois, 171 pages (see page 12).

Thomson, D. B.
1967. The N. American and European purse seine types compared. World Fishing 16(6): 78-79.

Vinogradov, N. N.
1950. Skorost' pogruzheniya nizhnei podbory koshel 'kovykh nevodov (The sinking speed of purse seines' leadlines). Trudy Azovo-Chernomorskogo Nauchno-Issledovatel 'skogo Instituta Morskogo Rybnogo Khozyaistva i Okeanografii (Trudy AzCherNIRO) 14, pages 23-28. (Not seen by the authors.)

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by F. Bruce Sanford, Lena Baldwin, and Mary S. Fukuyama

A. APPROACH

Write your paper for a reader who has had advanced scientific training. Organize and write it in such a way that he can read it rapidly, yet understand it the first time through.

B. COMPONENTS OF THE PAPER

1. Title

Select a title that reveals the overall purpose of your research. When appropriate, include scientific names of species.

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In the introduction, (1) orient the reader to your overall purpose, (2) state the purpose explicitly, (3) orient the reader to the subpurposes, and (4) end with a listing of the subpurposes.

Include in each orienting discussion all the important words that will occur in the subsequent statement of purpose. Avoid unnecessary reviews and economic data.

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a. **Materials and methods.**—Describe in detail the materials and the methods used in your first experiment. If the materials and methods used in succeeding experiments are similar to those in the first, merely describe the differences when you report the succeeding experiments.

If a method includes several closely consecutive steps, number them and write out the steps; use the active voice —for example, "In the separation of acids from the aqueous phase, the analyst:

1. Neutralized a 1-milliliter portion of the aqueous layer to a pH of 10 with 0.1 N NaOH.
2. Transferred the neutralized solution to Flask A.
3. Placed Flask A in a bath . . . ."

b. Results.—Report all numerical data in tables and graphs—avoid cluttering the text with numbers. In the discussion of results, do not repeat the data that are contained in the tables and graphs. Instead, analyze the data by pointing out significances and implications. Use summary tables; do not overwhelm the reader with unnecessary tables of raw data.

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Draw conclusions from your results. Make sure that the overall conclusion and the subconclusions correspond with your overall purpose and subpurposes. Present the conclusions in logical sequence.

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