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HIGH-SPEED PLANKTON SAMPLER

By Elbert H. Ahlstrom, John D. Isaacs, James R. Thrailkill, and Lewis W. Kidd

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ABSTRACT

A high-speed plankton sampler is described, and performance tests are discussed in this paper. The sampler was designed to supplement, and, in certain cases, to supersede standard plankton nets. The sampler is so constructed that it can be fastened to the towing cable at any point, hence samplers can be used in series to sample different depth levels simultaneously. The samplers are towed at normal ship's speed between hydrographic stations; each sampler obtains a horizontal strip sample of the plankton at the level at which it is hauled. The usual length of haul has been 10 miles. The depth sampled and the amount of water filtered by a sampler during a haul are recorded on a strip of 35-millimeter acetate film. Tests were made to determine the comparative effectiveness of high-speed samplers and standard 1-meter plankton nets in delimiting the distribution and abundance of fish eggs and larvae. Both types of gear seem to be equally effective in delimiting the horizontal distribution of eggs and larvae. Standard nets are more versatile in depth sampling, as they can be operated to any desired depth; high-speed samplers have been operated only between about 60 meters deep and the surface, when hauled at normal ship's speed. The most marked advantage of high-speed samplers over conventional gear is that samples obtained with the former are far more representative of the mean density of plankton organisms.

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Because of the diversity in size, motility, and distribution of plankton, there is no one type of plankton sampler yet devised that can obtain a fully representative sample of all organisms in the water. Every type of plankton collector is selective in one way or another. Samples obtained with plankton-collecting gear may be classified, on the basis of distance covered in obtaining the samples, into two principal categories: spot samples and strip samples. Each has its limitations and its advantages. The conventional 1-meter plankton net used in a standard oblique tow is hauled only a short distance, seldom more than ¼ mile; hence it is regarded as a spot sampler.

The Isaacs high-speed sampler, to be described in this paper, was designed to supplement the information obtained with conventional 1-meter nets. At the time of its development, the California Cooperative Oceanic Fisheries Investigations (then the California Cooperative Sardine Research Program) was just getting under way. The plan of operation under the program was to cover a widespread grid of hydrographic stations approximately 40 miles apart. It was desired to construct a collecting device that could obtain information on plankton distribution by taking a strip sample while the ship was running full speed ahead between stations.

HISTORICAL REVIEW

A pioneer in the development of high-speed plankton sampling gear is A. C. Hardy. He has devised two instruments, one known as the Hardy Plankton Recorder, the other as the Hardy Plankton Indicator. The latter is a simple, non-quantitative instrument designed for on-the-spot assays of plankton samples. It has been widely used by fishermen in the North Sea herring fishery and by scientists (Hardy 1936a; Barnes 1951).

The Hardy Plankton Recorder (Hardy 1936b, 1939) has proved to be a successful high-speed plankton sampler. It was first used during the Discovery Expedition to the Antarctic in 1925–27. It was designed to take a continuous sample over distances as great as several hundred miles. It has been operated from both research and commercial vessels. Only one recorder is towed at a time, ordinarily at a depth of about 10 meters and a vessel speed of 8 to 16 knots. The forward end of this collector is provided with a small opening, about 1¼ inches square, which may be reduced to ½ inch square or even less. The water, after entering the instrument, flows through a wide tunnel across which is stretched a band of silk or nylon gauze. The gauze band is slowly wound across the water tunnel into a chamber where it is stored in a bath of formalin. The spooling mechanism is geared to an external propeller that is actuated by the passing water, hence the spooling is in direct relation to the distance traveled. The recorder gives a continuous line of ecological observations across an area being investigated; furthermore, since the straining band is graduated into numbered divisions, it is possible to identify any portion of the sample as to approximate location of collection. This unique feature of the Hardy Plankton Recorder makes it particularly useful for certain kinds of ecological studies. Hardy Recorders are being used by us in a study of the relation between the distribution of plankton organisms and adult sardines. The most serious disadvantages of the instrument are (1) its lack of versatility in operation, since it is designed for towing at a single depth near the surface, and (2) the difficulty of identifying the organisms caught, since they are crushed when rolled up in the filtering band.

[1] Contribution from the Scripps Institution of Oceanography, New Series, No. 982. This work represents in part work carried out for the Marine Research Committee of the State of California and in part work carried out by the Office of Naval Research and the Bureau of Ships under contract with the University of California.

Note.—Approved for publication April 23, 1957. Fishery Bulletin 132.

A simple type of high-speed collector was employed by personnel of the South Pacific Fishery Investigations of the U. S. Fish and Wildlife Service from the purse seiner *Pearl Harbor*, during April to June, 1946 (Smith and Ahlstrom, 1948). The idea for the collector was suggested by the work of Hardy. The cruises were made off central California, primarily to explore for sardines with echo-ranging equipment. The collector consisted of three parts: a brass towing head, a cylindrical net, and a plankton bucket (ibid., fig. 11). The towing head, shaped somewhat like an inverted funnel, was 1 inch in diameter at the mouth, expanding to 2 inches before the point of attachment of the net; the cylindrical net was 2 inches in diameter by 10 inches long, and was constructed of No. 56xxx grit gauze; the plankton bucket was the more or less standard type used for limnological work.

Most samples were obtained by towing the net at 9 knots, for a period of 20 minutes. Not only did the collector tow well at this speed, but plankton organisms were taken in fair numbers and were in excellent condition. In all, 54 samples were obtained. The analyses of the samples, including the percentage composition (by volume) of the major constituents and the distribution of fish eggs and larvae, are discussed by Smith and Ahlstrom (1948).

The results from this initial high-speed collector were so encouraging that an experimental model of a high-speed volumetric plankton sampler was built (Ahlstrom and Smith, MS.). The collector consisted of four detachable parts: a weighted forward section, a metering device, a cylindrical net, and a metal plankton bucket. The forward section, constructed of bronze, was cylindrical except for a slight taper at the forward nose: the mouth opening was 1 inch in diameter with the inner bore widening gradually to 2 inches; this section provided weight (15 lbs.) and was equipped with diving vanes and multiple attachment points. The metering section, about 1 foot long, contained an impeller and worm gear in the main tube, with the gear train of the current meter underneath. It was provided with three tail fins, with the streamlined meter box acting as a fourth. All parts were made of bronze. The cylindrical net was fastened to the "metering" section of the sampler. Nets of several lengths (10 to 24 inches) and of several mesh sizes (No. 24xxx, 40xxx and 56xxx silk grit gauze) were tried and all worked effectively. The plankton bucket was of the type used with the Clarke-Bumpus net (1950). The device was used to collect more than 150 samples during two cruises off Baja California in 1948 (Ahlstrom and McHugh, MS.).

The Ahlstrom-Smith sampler had a number of good qualities. It was easy to operate, since it could be launched or retrieved with the same ease as a bathythermograph, and was towed on the bathythermograph cable. It had good towing qualities, keeping a steady course without yawing. The plankton was recovered in excellent condition. The metering device could be accurately calibrated, and gave consistent readings when in use at sea. The mouth opening preceded the cable. This is not difficult to arrange if the sampler is attached to the end of the cable. The disadvantages of the sampler were as follows: (1) at normal vessel cruising speed it could be towed only at shallow depths, perhaps not greater than 10 meters, (2) no record was obtained of the actual depth traversed by the sampler, and (3) it was not possible to use several samplers on the same cable at one time. This type of high-speed sampler is excellent for reconnaissance work.

To overcome these disadvantages, while retaining desirable features, Isaacs and associates developed the high-speed collectors described in this paper. The qualities that the investigators sought to incorporate in the high-speed sampler described in this paper are the following:

Good towing characteristics: The sampler has been so designed that bridles are not necessary, and the mouth opening precedes the towing wire, thus eliminating water disturbance in front of the sampler; the sampler keeps a steady horizontal position without yawing while being towed at 8 to 10 knots.

Simple method of attachment: A method of fastening to the towing cable has been devised that permits attachment at any desired position on the cable, and also permits the use of any desired number of samplers at one time (in order to sample several depth layers simultaneously).

Suitable depressing force: A suitable depressing force is needed to get samplers down to desired depths; an excellent depressor has been designed, that has proven useful with many types of oceanographic gear.

Quantitative measurement of water strained: A measure of amount of water strained by each sampler has been accomplished by incorporating an impeller, gear train and recording device into the design of the sampler.

Record of depth sampled: A record of the depth traversed by a sampler has been made possible by incorporating a pressure-sensitive bellows with attached stylus. A permanent record of depth against flow is obtained on acetate film.

Plankton material should be recoverable in good condition: The high-speed sampler meets this requirement.

Rugged construction: High-speed gear must be ruggedly constructed to withstand the continuous vibration of the towing cable when hauled at high speed. A well designed sampler should operate for 100 hours or more before adjustments are needed. Ruggedness was a major consideration in the design of the Isaacs high-speed sampler.

Low cost: It is highly desirable that high-speed samplers be inexpensive, both in initial cost and maintenance. Our sampler is a fairly expensive instrument. However, the cost of the sampler could be considerably reduced if made in larger quantities. Also it is not necessary that every instrument be equipped with a depth-flow meter.

One desirable feature of the Hardy Plankton Recorder that we have not been able to incorporate into our high-speed sampler is a continuous record of plankton. Our sampler obtains an integrated sample over the distance hauled rather than a continuous line of observations.

DESCRIPTION OF HIGH-SPEED SAMPLER

The high-speed sampler is a streamlined metal tube containing a plankton filter and depth-flow meter (fig. 1). When assembled for operation, the sampler has an over-all length of 130 centimeters, a basic diameter of 7.6 cm. and a weight of 17.3 pounds (7.7 kg.). It is attached to a towing cable by means of a spherical brass clamp and socket.

The sampler is composed of three parts: an outer casing, a plankton filter, and a depth-flow meter.

The outer casing tapers from its basic diameter of 7.6 cm. to a mouth opening of approximately 2.5 cm. The anterior half of the casing is divided longitudinally to accommodate attachment to the towing cable some distance behind the mouth of the sampler. Three radially arranged stabilizing fins are attached to the rear section of the casing. A protective bumper at the back edge of the divided section protects both the towing cable and the tube. An experimental sampler which was not provided with the bumper almost severed the cable during a trial run, whereas samplers with the bumper have not injured the cable after many tows.

The plankton filter consists of two sections, the body or straining section, and a cod-end cup. The detachable straining section is made of Monel metal mesh having about 23 mesh openings to the centimeter (each opening 0.24 mm. across and 0.33 mm. on the diagonal). The straining section

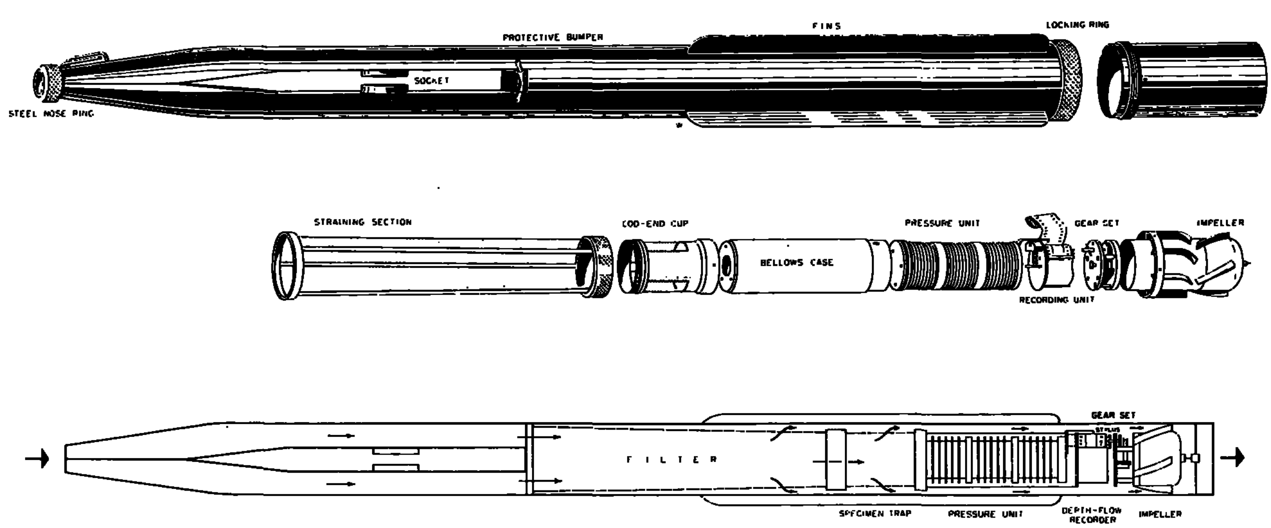

FIGURE 1.—Exploded schematic drawing of high-speed plankton sampler.

has an over-all length of approximately 36 cm.; it is supported by a brass ring at either end, and by three strengthening ribs. The cylindrical brass cod-end cup (specimen trap) is 10.5 cm. long by 5.2 cm. in diameter; two windows, approximately 5.0 cm. square, are cut out of the sides of the cup, and fitted with fine Monel metal screens (39 mesh openings to the centimeter). The cod-end cup is attached to the bellows case.

The plankton filter retains the plankton organisms in the water column entering the sampler. In present models, water is filtered at a rate of ⅛ to ¼ cubic meter per minute at 8 to 10 knots towing speed. The actual filtering rate is dependent, to some degree, on the extent of clogging of the filter by plankton organisms.

The depth-flow meter consists of three sections: a pressure unit with attached stylus, a metering unit (impeller and gear set), and a recording unit. The pressure unit makes use of bellows originally designed for the bathythermograph, which are available in different depth ranges. One type is effective to depths of 180 feet (approximately 55 meters), another to 450 feet (137 m.), and a third to depths of 900 feet (274 m.). The latter has not been used as yet with the present high-speed samplers. The bellows is housed in a brass tube. An L-shaped brass stylus is attached to the back end of the bellows.

The metering unit consists of an impeller and gear set enclosed in a brass housing. The impeller has a coaxially attached shaft which is supported at the ends in low friction bearings. Incorporated in the forward end of the shaft is a worm gear, which meshes with a gear in the gear set. The gear set is contained in a brass cylinder immediately forward of the impeller.

The recording unit is housed between the pressure unit and the gear set. It consists of a sprocket geared to the metering unit which advances a roll of 35-mm. clear acetate film. The stylus atached to the bellows produces a scratch on the 35-mm. film, recording depth of operation against quantity of water filtered. The film supply is sufficient for a one-hour tow at 10 knots when using one gear ratio, six hours when using another. After calibration, towing depths and quantity of water strained may be readily estimated by simple analysis of the record (calibration procedures are discussed in appendix II.).

TESTS

In May 1950, five high-speed samplers were tested during a regular cruise of the California Cooperative Oceanic Fisheries Investigations (cruise 5005, formerly numbered cruise 14). The tests took place in an area between Point Conception, Calif., and Point Descanso, Baja California. Standard 1-meter net hauls were made at 46 stations (Ahlstrom 1952). The high-speed samplers were towed between stations, most of which were spaced at 40-mile intervals.

Net hauls on station were taken with a standard plankton net of 1.0 meter in diameter at the mouth by approximately 5 meters in length, constructed of No. 30xxx grit gauze, a sturdy grade of Swiss bolting silk. The hauls were made obliquely from approximately 70 meters deep to the surface; a distance of approximately ½ mile was covered while making each tow.

Two series of high-speed hauls, each utilizing four samplers, were made when traveling between most stations. Locations of high-speed sampler hauls are shown in figure 2. The first series was begun immediately upon leaving a station. A depressor and three of the four samplers were attached and lowered at approximately half speed; after attachment of the fourth sampler the ship's speed was increased to normal cruising speed (approximately 10 knots), and an additional 150 to 180 meters of cable was payed out. The samplers were then towed for one hour, and retrieved.

SPACING OF SAMPLERS ON TOWING WIRE

The amount of towing cable that must be payed out to establish a sampler at a desired depth depends upon several factors, among which the following are probably the more important: amount and kind of depressing force; type and weight of the towing cable; speed of hauling; height of the boom above the water; number of samplers being hauled simultaneously.

It was possible to maintain three factors constant throughout the test operations. A ¼-inch rope-laid stainless steel towing cable was used for each test; the boom was maintained at a constant height (approximately 20 ft.) above the water; and four samplers in a series were used per tow. Only the remaining two factors could not be kept constant: (1) vessel speed of 10 knots was usually

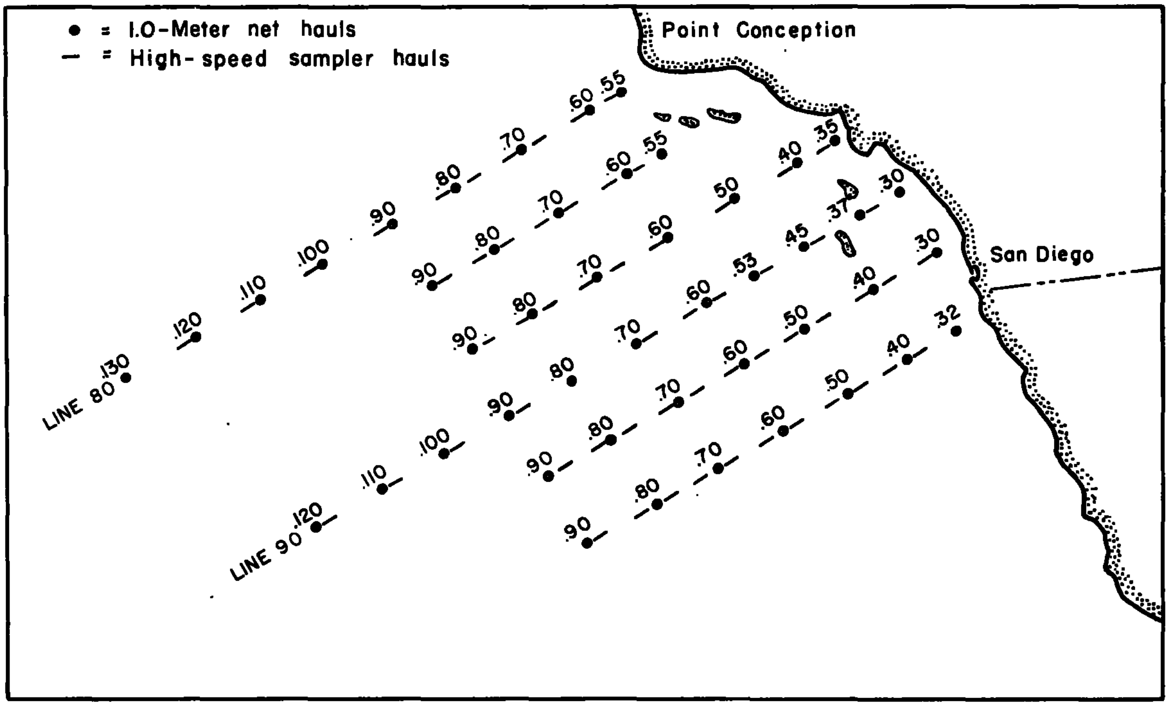

FIGURE 2.—Location of plankton hauls on cruise 5005.

maintained, but the speed varied somewhat with changing sea conditions and could not be considered constant; (2) owing to the loss of a depressor midway through the cruise, it was necessary to substitute a depressor with somewhat different depressing characteristics.

To determine the length of towing cable required to place a sampler at given depths, a single sampler was towed at normal cruising speed (10 knots) on the following lengths of towing cable: 15, 30, 50, 80, 130, 200, 300, and 450 meters. The sampler was placed approximately 6 meters above depressor. The data are summarized in table 1, and graphically presented in figure 3.

TABLE 1.—*Depths fished by a single high-speed sampler towed at a constant speed (10 knots) with selected lengths of towing cable*

Length of towing cable (meters)	Depth fished by sampler	Wire angle at vessel from vertical
	Meters	*Degrees*
15	6	
30	11	65
50	16	72
80	19	76
130	25	78
200	33	80
300	39	81
450	48	82

The use of several samplers instead of one changed the curve slightly; the exact spacing of samplers on the cable to obtain desired towing depths of 10, 20, 30, and 40 meters below the surface was determined by trial and error. As shown in table 2 and figure 4, the spacing that placed the four samplers at desired depths of 10, 20, 30, and 40 meters was as follows: 10 m. of cable between the depressor and the first sampler, 15 m. between the first and second samplers, 45 m. between the second and third, 80 m. between the third and fourth, and 150 m. between the fourth sampler and the ship. These trials were made with the first depressor at regular vessel speed of 10 knots.

To sample the same depths, when using the second depressor, it was necessary to change the spacing, as shown in table 3, to the following: 5 meters between the depressor and first sampler, 20 m. between the first and second samplers, 45 m. between the second and third samplers, 80 m. between the third and fourth samplers, and 180 m. between the fourth sampler and the ship. A fairly constant angle of 82° (from the vertical) was obtained with both depressors when the samplers were fishing at the desired depths and the ship was traveling at 10 knots (fig. 5).

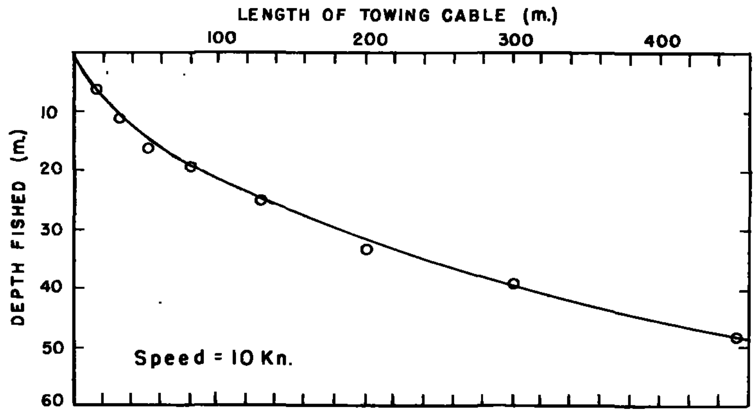

FIGURE 3.—Depths fished by a high-speed sampler with selected lengths of towing cable.

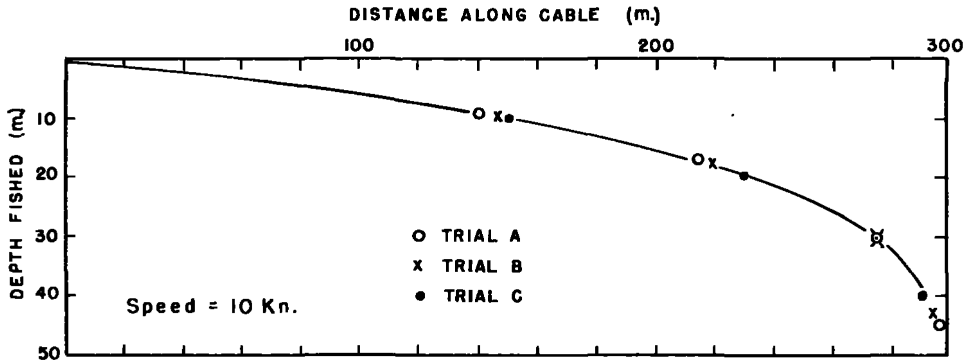

FIGURE 4.—Depths fished by four samplers at different spacings along towing cable.

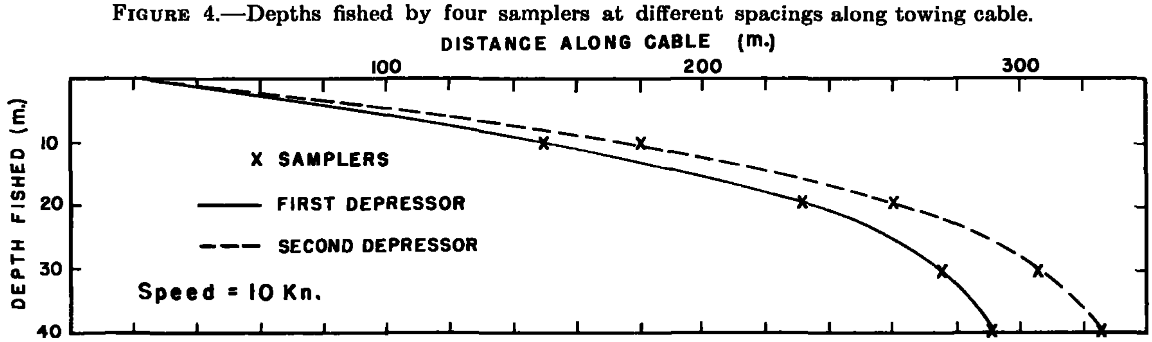

FIGURE 5.—Spacings required to place four samplers at depths of 10, 20, 30, and 40 meters when two different depressors were used.

TABLE 2.—*Depths fished by four samplers at different spacings along towing cable*

Sampler number	Trial A			Trial B			Trial C		
	Spacing between samplers	Length of towing cable	Depth fished	Spacing between samplers	Length of towing cable	Depth fished	Spacing between samplers	Length of towing cable	Depth fished
	Meters	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*	*Meters*
		300			300			300	
	3			6			10		
1		297	45		294	43		290	40
	22			19			15		
2		275	30		275	30		275	30
	60			55			45		
3		215	17		220	18		230	20
	75			73			80		
4		140	9		147	9		150	10
	140			147			150		

TABLE 3.—*Spacing required to place four samplers at depths of 10, 20, 30, and 40 meters when two different depressors were used at cruising speed of 10 knots*

Sampler number	First depressor			Second depressor		
	Spacing between samplers	Length of towing cable	Depth fished	Spacing between samplers	Length of towing cable	Depth fished
	Meters	*Meters* 300	*Meters*	*Meters*	*Meters* 330	*Meters*
	10			5		
1		290	40		325	40
	15			20		
2		275	30		305	30
	45			45		
3		230	20		260	20
	80			80		
4		150	10		180	10
	150			180		

The three deeper samplers, as pointed out previously, were lowered and retrieved at half speed (5 knots). From an average of ten trials, using the first depressor, the following results were obtained: the total wire out was 150 m., the first sampler spaced 10 m. from the depressor, fished at 43 m.; the second sampler, 15 m. from the first, fished at 33 m.; and the third sampler, 45 m. from the second, fished at 13 m. (fig. 6). This shows the greater depth that can be attained at reduced vessel speed.

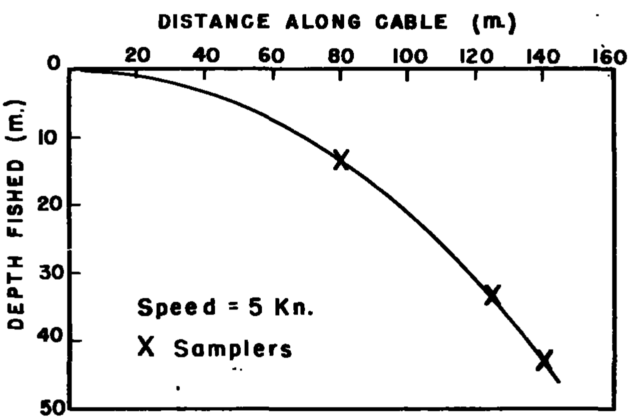

FIGURE 6.—Depths fished by three samplers towed on 150 meters of wire at ship's speed of 5 knots.

PLANKTON VOLUMES

Wet plankton volumes were determined for all samples obtained on cruise 5005. The plankton material obtained in 1-meter net hauls was standardized to the quantity in 1,000 cubic meters of water strained. This standard has been used in reporting all plankton volumes obtained on CCOFI cruises (Staff, South Pacific Fishery Investigations, 1952–56, Thrailkill, 1956).

The wet plankton volumes were determined for the individual catches obtained in high-speed samplers and standardized to the amount in 1,000 cubic meters of water strained. For comparability with standard net tows, the four plankton volumes of a series were averaged, and standardized to the amount in 1,000 cubic meters of water strained. The volumes of plankton in different parts of the area surveyed on cruise 5005, as determined by the two methods of collection, are shown in figure 7. Both methods revealed a similar outline of plankton distribution within the area. The largest individual volumes were taken by the standard 1-meter net; but a somewhat higher concentration of plankton throughout the entire area is shown in the catches of high-speed samplers. It should be noted that the two types of samplers are not entirely comparable for these reasons: (1) the standard net sampled a stratum from approximately 70 meters deep to the surface, while the high-speed samplers fished at four selected depths between 40 meters and the surface; (2) the mesh of the high-speed samplers was finer and hence retained a larger proportion of the smaller plankton material than the standard net.

The four levels sampled by high-speed samplers were found to differ in plankton density between day and night, as is shown in table 4. A similar volume of plankton was taken at all four levels during the night, but rather sharp stratification of plankton was noted during the daylight hauls, the density of plankton increasing with depth. Night hauls at 10 meters obtained a plankton volume three times greater than daylight hauls; at 20 meters twice as much plankton was taken; at 30 meters 1½ times; and at 40 meters 1¼ times as much was collected. At no level was as large a volume taken during daylight as at night. For all levels combined, the ratio of night to day was 1.75. The difference between night and day

TABLE 4.—*Comparison of plankton volumes taken at four selected depths by high-speed samplers (average plankton volume, in cc. per 1,000 m.*[3]*)*

Depth of sampler (meters)	All hauls	Day hauls	Night hauls	Night/day ratio
10	653	356	1,086	3
20	735	514	1,057	2
30	837	695	1,044	1.5
40	1,016	913	1,166	1.3
Average	810	619	1,088	1.75

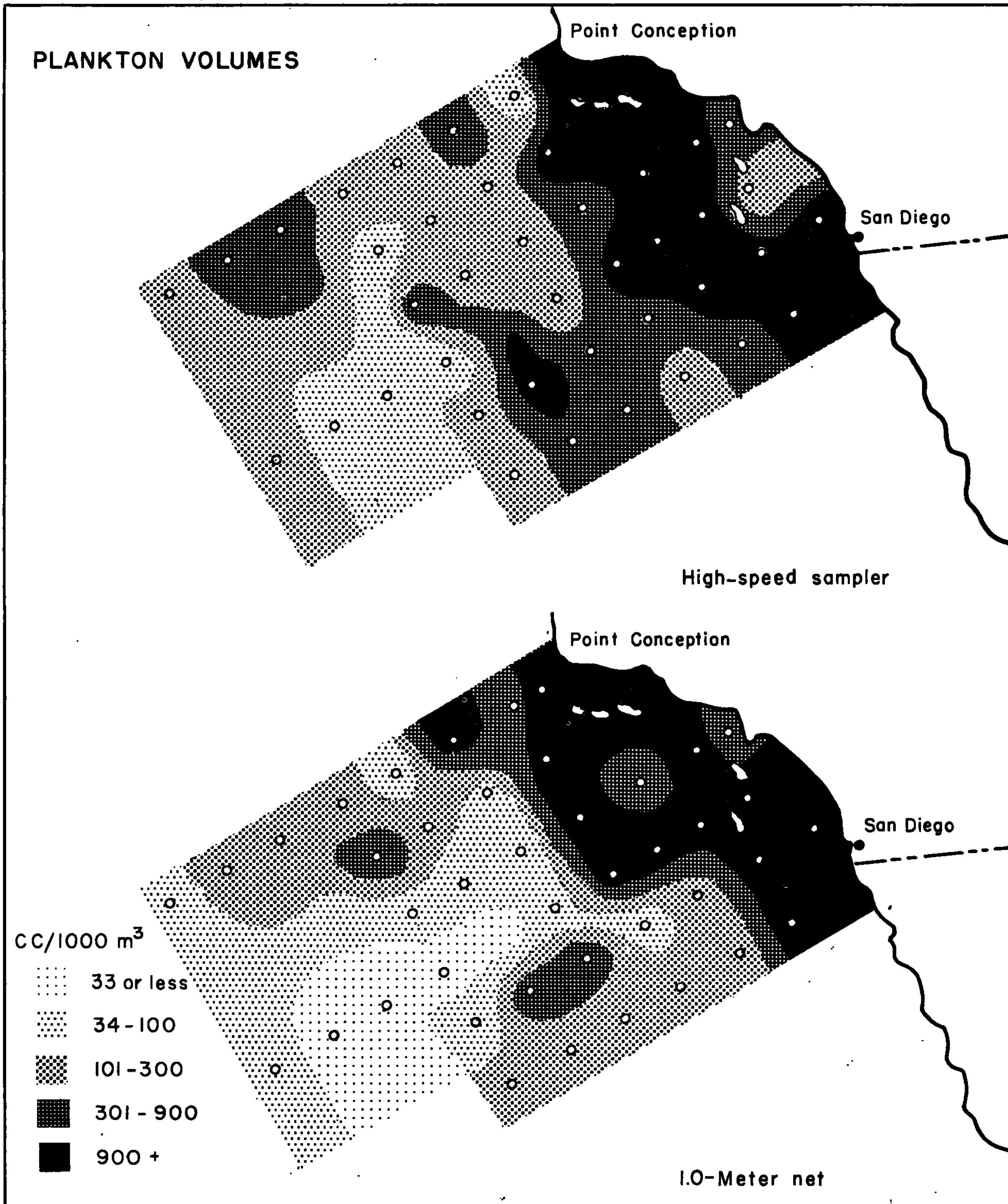

FIGURE 7.—Distribution of plankton volumes based on hauls made with high-speed samplers and with 1-meter net.

hauls in the levels sampled (0–40 m.) may be due to a downward migration of plankters out of the level by day, and an upward migration by night. Information of this type is not ordinarily obtained from routine hauls made with conventional nets.

Many plankton organisms tend to occur in swarms or patches. High-speed samplers obtain an average density relevant to greater distances (10 mi.) than is possible with conventional gear which samples a limited area only.

Because of the greater distance covered with high-speed samplers, it is possible to define average plankton abundance more precisely than has been possible in the past with conventional gear on similar cruise tracks.

SARDINE CATCHES

As has been indicated, the high-speed sampler facilitates the quantitative sampling of various eggs and larvae. The spawning and survival of the sardine in particular, in relation to oceanographic conditions, has been a major concern of the California Cooperative Oceanic Fisheries Investigations and is being studied on an extensive scale. The distribution and abundance of the eggs and larvae of the sardine, as well as those of the northern anchovy, jack mackerel, and lantern fish, found during cruise 5005, will be compared for the two types of gear.

Eggs.—A somewhat more extensive distribution of sardine eggs was obtained with the high-speed samplers than with conventional plankton nets, as shown in figure 8. Sardine eggs were taken at 10 stations with conventional plankton gear. They were present in one or both high-speed sampler hauls taken adjacent to these stations and, in addition, at four other stations.

The abundance of sardine eggs taken in the high-speed samplers was 3½ times greater than in the standard net hauls. Based on the high-speed samples, the estimated average number of sardine eggs spawned per day in this survey area was 642 billion eggs, as compared to 180 billion based on the standard net hauls.

Of particular interest is the sampling at and adjacent to station 97.40. At this station no sardine eggs were taken in the conventional net haul, but large numbers were taken in the high-speed sampler series made on either side of it. There can be little doubt that the sampling of sardine eggs with high-speed samplers was much more effective than with conventional gear when used to estimate the average density of eggs along cruise tracks.

Inasmuch as the high-speed samplers fished four different levels, the samples can be used to determine the level of occurrence of the largest concentrations of sardine eggs. The number of eggs (standard haul totals) taken at the different depth levels in 20 high-speed tows is shown in table 5.

TABLE 5.—*Depth distribution of sardine eggs as determined from high-speed sampler hauls*

Depth of sampler (meters)	Number of occurrences	Number of sardine eggs (standard haul totals)	Percent of total
10	16	2,741	39.9
20	13	1,541	22.4
30	14	1,350	19.6
40	13	1,246	18.1
Total		6,878	100.0

The largest number of sardine eggs collected, approximately 40 percent, were taken at the 10-meter level. The numbers taken at the 20-, 30-, and 40-meter levels were about equal. However, the depth distribution of the eggs varied greatly from series to series. The distribution between the samplers is shown in table 6 for the ten high-speed series in which most of the sardine eggs were taken.

TABLE 6.—*Depth distribution of sardine eggs in 10 high-speed sampler series*

Series taken adjacent to station numbered	Number of eggs taken (standard haul total)	Percentage of total taken at each level			
		10 meters	20 meters	30 meters	40 meters
		Percent	*Percent*	*Percent*	*Percent*
97.40a [1]	2,416	52	27	19	2
97.40b [1]	1,265	47	37	10	6
93.60	845	1	1	7	91
93.40a	676	33	16	37	14
87.60	312	32	36	29	3
90.60a	224	45	0	55	0
83.70	209	73	8	9	10
97.50	193	56	18	4	22
93.40b	161	27	0	40	33
90.60b	139	8	0	49	43

[1] When both high-speed sampler series taken adjacent to a station appear in this table, one of the series is designated a, the other b.

Larvae.—Sardine larvae, taken only in the lower half of the area surveyed, occurred mostly on the lines centering off San Diego. A somewhat wider distribution was indicated by collections taken with conventional gear than with high-speed samplers. Sardine larvae were taken at 12 sta-

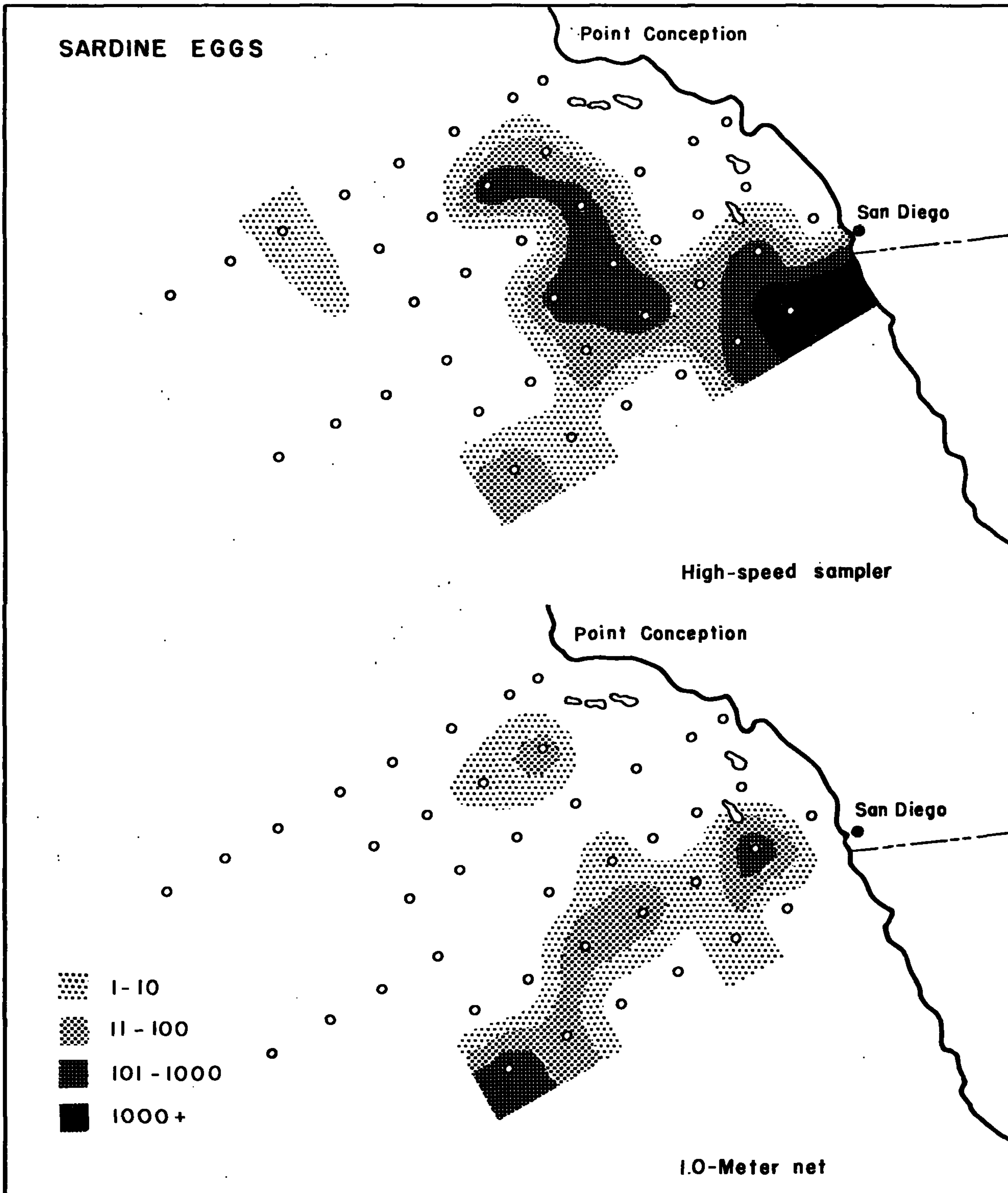

FIGURE 8.—Distribution of sardine eggs based on hauls made with high-speed samplers and with 1-meter net. The legend represents numbers per standard haul.

tions using conventional gear and adjacent to only 9 stations using high-speed samplers. The distributions obtained by both types of gear are shown in figure 9.

Census estimates of all sizes of sardine larvae in this area at the time of survey were similar for both types of gear: 477 billion for conventional gear as compared to 502 billion for the high-speed samplers. A comparison of the size of larvae taken by the two types of gear is shown in figure 10 and summarized in table 7. The smallest group size (2.5–5.0 mm.) and the largest group size (10.5 mm. and longer) were taken in slightly greater numbers by conventional gear, while larvae between 5.5 and 10.0 mm. long were taken in greater abundance by high-speed samplers.

TABLE 7.—*Abundance of sardine larvae, in billions, (census estimates) summarized by size group for 1-meter net hauls and high-speed sampler hauls*

Size of larvae (mm.)	High-speed sampler hauls	1-meter net hauls	Ratio, sampler/net
2.5–5.0	366	394	0.93
5.5–7.5	101	53	1.91
8.0–10.0	20	12	1.67
10.5 and larger	15	18	.83
Total	502	477	

These findings are, in part, contrary to expectation. It is known that the 1-meter net does not fully retain the smaller larvae, hence we would expect larger numbers of these sizes to be taken by the sampler. A possible explanation is that the 1-meter net hauls are influenced by local clumping of small sardine larvae, while the sampler catches are more representative of the mean density of these sizes.

The series of high-speed sampler hauls can be used to determine that depth within the 40-meter stratum at which sardine larvae occurred in greatest abundance. Numbers of larvae (standard haul totals) taken at the four depths sampled are tabulated in table 8. The largest number of larvae was taken at the 20-meter level. The concentration was 1.5 times as great as at the 10-meter level and nearly four times as great as at 30- and 40-meter depths. Approximately four-fifths of the larvae 8.0 mm. and longer were taken at the 20-meter level.

TABLE 8.—*Sardine larvae concentrations at four selected depths*

Depth of sampler (meters)	Number of larvae taken (standard haul totals)	Percent of total
10	274	29.8
20	422	45.9
30	116	12.6
40	107	11.7
Total	919	100.0

ANCHOVY CATCHES

Eggs.—Measuring only about 0.5 millimeters in their narrowest dimensions, anchovy eggs are not fully retained by our standard nets. In fact, a test conducted with a somewhat coarser mesh net than that now in use (No. 24xxx grit gauze with 0.9-mm. openings between threads when new, and shrinking to approximately 0.7 mm. after use) gave only about 1.5 percent as much retention as No. 40xxx grit gauze with pores of 0.40 mm. The net employed on cruise 5005 was constructed of No. 30xxx grit gauze, with 0.7-millimeter mesh openings when new, and approximately 0.55 mm. openings after use; this mesh retains only a small percentage of anchovy eggs. With the finer mesh used in high-speed samplers (openings 0.24 mm. across and 0.33 mm. on the diagonal) anchovy eggs were completely retained.

A census estimate of the abundance of anchovy eggs in the survey area gave 7,065 billion eggs, based on high-speed sampler hauls. The estimate based on net hauls was only 3.3 percent as large. Hence, the high-speed samplers proved effective in sampling anchovy spawning, while the conventional gear now in use is not effective for this purpose.

The depth distribution (within the upper 40-m. stratum) of anchovy eggs for hauls in which 100 or more eggs were obtained (standard number) is given in table 9. In the three hauls containing the largest number of eggs, the majority were taken below 20 meters. A portion of the eggs must have occurred below the levels fished by the high-speed samplers.

Larvae.—Anchovy larvae were taken at 10 stations with conventional gear, and adjacent to 13 stations with high-speed gear. The distribution obtained with the two types of equipment was similar; anchovy larvae occurred in a coastwise band about 125 miles wide.

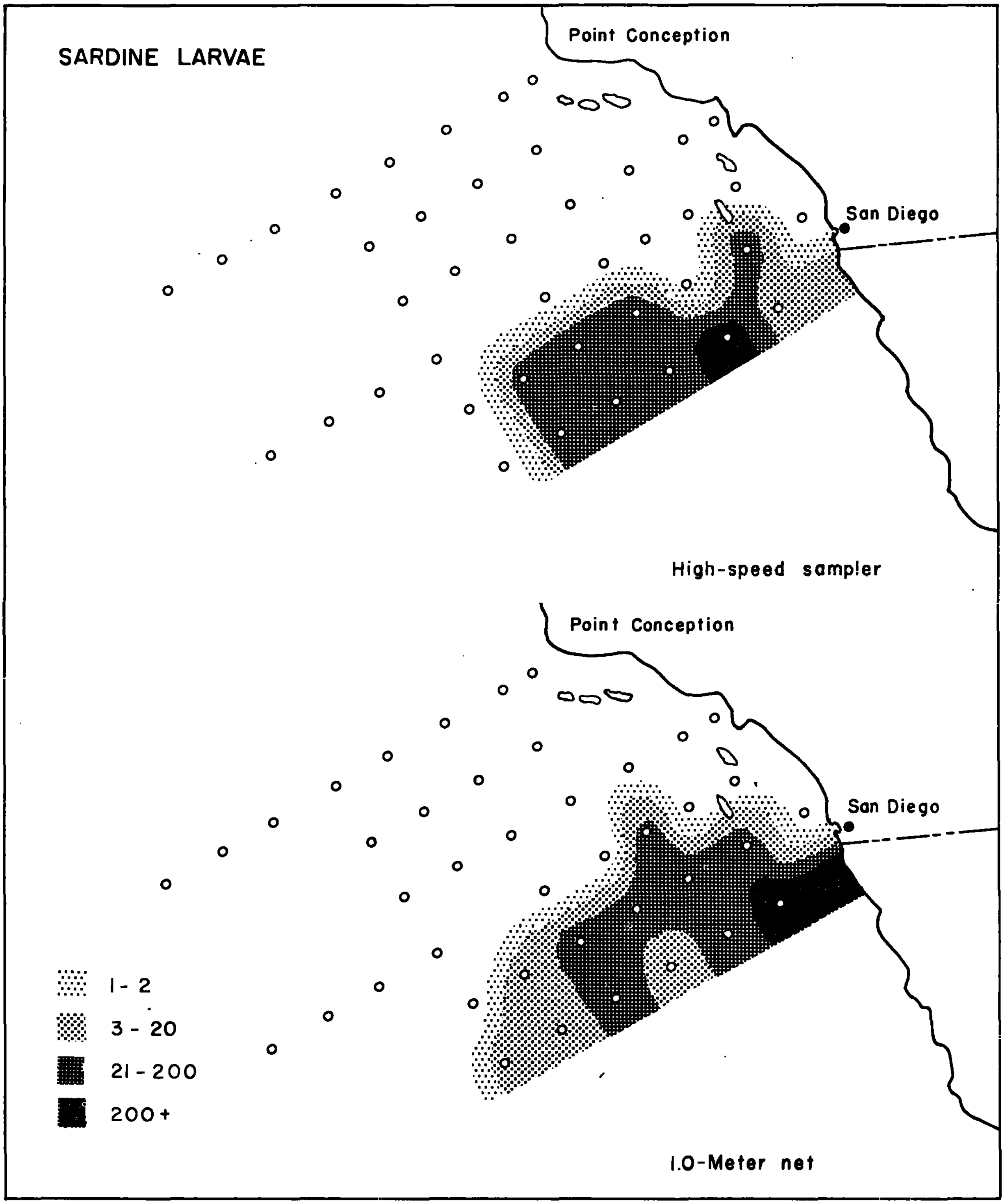

FIGURE 9.—Distribution of sardine larvae based on hauls made with high-speed samplers, and with 1-meter net. The legend represents numbers per standard haul.

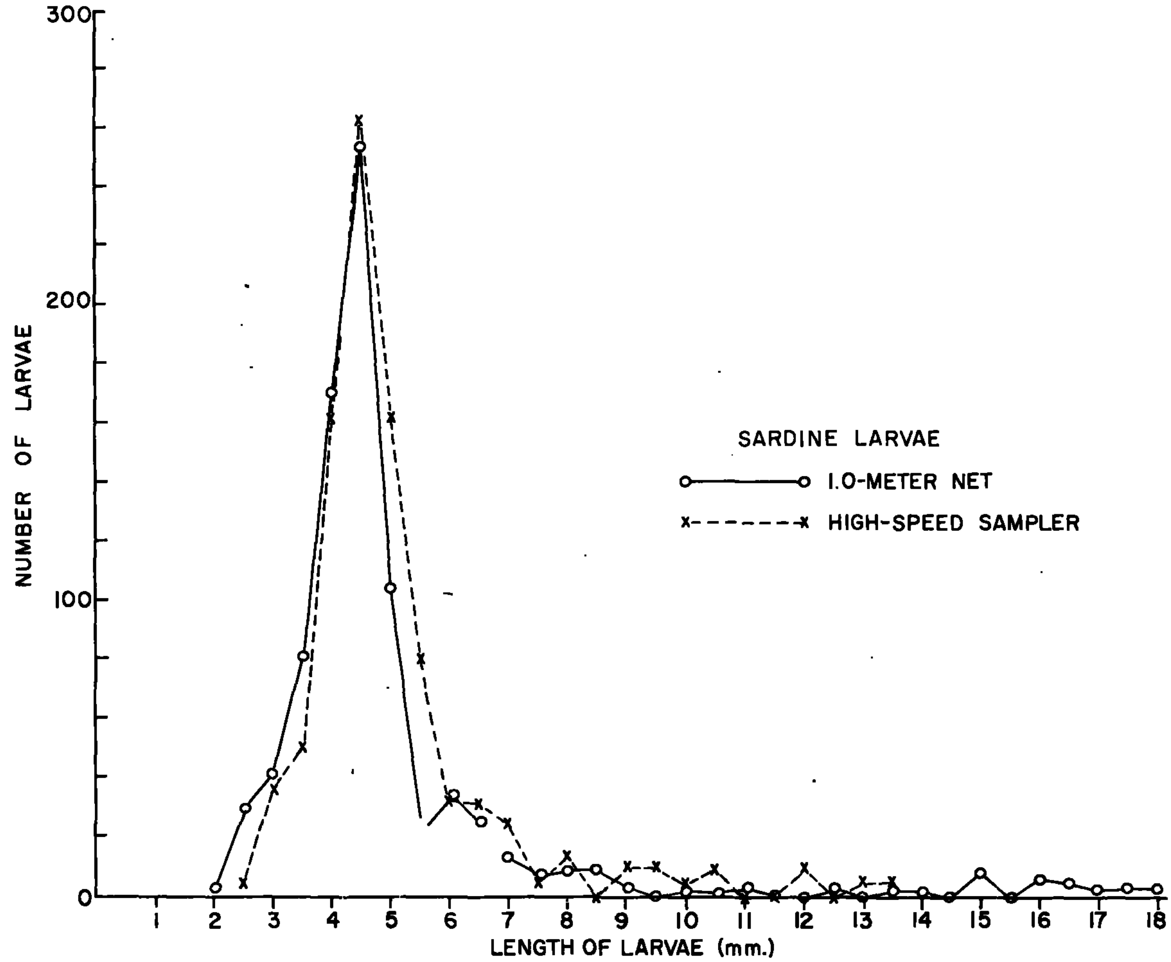

FIGURE 10.—Comparison of size composition of sardine larvae taken by high-speed sampler and 1-meter net.

TABLE 9.—*Depth distribution of anchovy eggs in 6 high-speed sampler series*

Series taken adjacent to station numbered	Number of eggs taken (standard haul total)	Percentage of total taken at each level			
		10 meters	20 meters	30 meters	40 meters
		Percent	*Percent*	*Percent*	*Percent*
93.50a [1]	15,200	2.1	2.4	56.7	38.8
93.50b [1]	8,432	3.3	2.5	8.7	85.5
93.40	1,076	3	3.3	37.1	56.5
93.30	201	60.7	39.3	0	0
90.37	183	91.8	0	8.2	0
97.50	113	8.8	37.2	35.4	18.6

[1] When both high-speed sampler series taken adjacent to a station appear in this table, one of the series is designated a, the other b.

Greater numbers of anchovy larvae were taken with high-speed samplers than with conventional gear. Census estimates of the number of anchovy larvae of all sizes in the area were more than three times as large when based on high-speed sampler collections as when based on standard net hauls: 2,156 billion as compared to 625 billion larvae. This reflects the larger numbers taken in individual hauls: nearly 2,900 anchovy larvae (standard number) were taken in one series of high-speed sampler hauls, while the largest number taken in a haul using conventional gear was 679. The size distribution of anchovy larvae taken by the two types of gear is shown in figure 11 and summarized in table 10.

TABLE 10.—*Abundance of anchovy larvae, in billions (census estimates), summarized by size group for 1-meter net hauls and high-speed sampler hauls*

Size of larvae (mm.)	High-speed sampler hauls	1-meter net hauls	Ratio, sampler/net
2.0–5.0	3,674	715	5.13
5.5–7.5	155	95	1.63
8.0–10.0	102	90	1.13
10.5–17.5	29	25	1.16
Total	3,960	925	

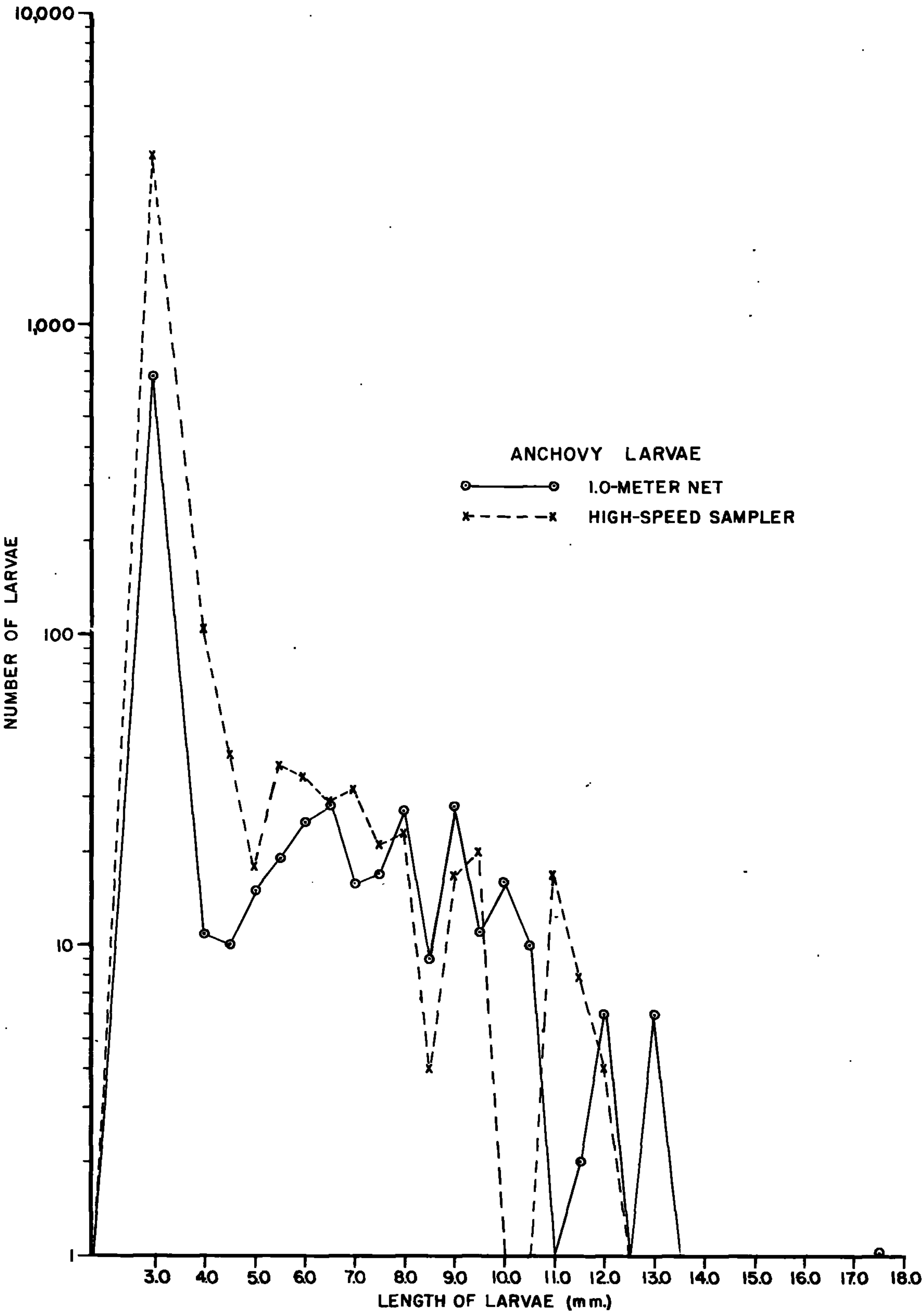

FIGURE 11.—Comparison of size composition of anchovy larvae taken by high-speed sampler and 1-meter net.

It is interesting to compare the numbers of larvae of different sizes taken by the two types of gear. More than five times as many of the smaller larvae, 2.0–5.0 mm. long, were taken in the high-speed sampler collections as in the net hauls. For larvae 5.5–7.5 mm. long, the ratio decreased to 1.63, and for larvae larger than 7.5 mm., the ratio was only slightly greater than 1. The much larger ratio of small larvae taken in high-speed sampler collections reflects, at least in part, the more complete retention of these sizes by the high-speed samplers. The Monel screen used in the high-speed samplers had pore openings of slightly less than one-fourth mm. wide, while the openings between meshes of 30xxx grit gauze used in the nets were slightly larger than one-half millimeter.

The largest concentrations of both anchovy eggs and larvae were taken at the 40-meter level in two adjacent hauls at station 93.50 representing the depth distribution at a particular locality under a specific set of conditions. In other studies of the depth distribution of anchovy eggs and larvae, eggs had not been taken in abundance as deep as 40 meters. However, at these stations there were probably many anchovy eggs and larvae below the depths reached by the lower sampler. The average depth distributions of anchovy eggs and larvae as determined from high-speed sampler hauls are summarized in table 11.

TABLE 11.—*Depth distribution of anchovy eggs and larvae as determined from high-speed sampler hauls*

Depth of sampler (meters)	Anchovy eggs		Anchovy larvae	
	Standard haul totals	Percent of total	Standard haul totals	Percent of total
10	941	3.7	210	2.7
20	741	2.9	2,393	30.7
30	9,845	39.0	1,820	23.3
40	13,742	54.4	3,377	43.3
Total	25,269	100.0	7,800	100.0

JACK-MACKEREL CATCHES

Eggs and larvae.—The eggs and larvae of the jack mackerel were more widely distributed than those of the sardine or anchovy, occurring throughout the area surveyed except near shore. The center of abundance was between 125 and 250 miles offshore. The distribution determined from high-speed samplers gives a more detailed picture than the distribution determined from net hauls (fig. 12).

Census estimates of the number of jack-mackerel larvae in the survey area at the time of the cruise gave 6,600 billion when based on high-speed sampler hauls, compared to 4,800 billion when based on standard net hauls. The difference may have resulted from better retention of larvae (3.0 mm. and smaller) by the high-speed sampler. Larvae more than 3.0 mm. in length are retained fully by both types of sampling gear.

Information on depth distribution of jack-mackerel eggs and larvae as determined from high-speed sampler series is summarized in table 12. Some material was probably below the nets in these series.

TABLE 12.—*Depth distribution of jack-mackerel eggs and larvae, based on high-speed sampler hauls*

Depth of sampler (meter)	Jack-mackerel eggs		Jack-mackerel larvae	
	Standard haul totals	Percent of total	Standard haul totals	Percent of total
10	16,580	42.5	3,471	20.2
20	9,060	23.2	6,227	36.2
30	6,900	17.7	4,297	25.0
40	6,510	16.7	3,205	18.6
Total	39,050	100.1	17,200	100.0

LANTERN FISH CATCHES

Larvae.—Larvae of the lantern fish *Lampanyctus leucopsarus* were taken throughout the survey area. They were obtained in all but two of the hauls made with conventional nets, and in 50 of the 59 series of hauls made with high-speed samplers. The distribution and abundance based on hauls made with high-speed samplers and with a 1-meter net is shown in figure 13.

Census estimates of the number of larvae of *L. leucopsarus* in the area at the time of cruise 5005 was 1,313 billion, based on high-speed sampler hauls, and 856 billion, based on 1-meter net hauls. Here again the difference may have been due to more complete retention of smaller larvae by the high-speed samplers.

There was an increase in abundance with depth, at least to the 40-meter level (table 13). Other studies made by the senior author have shown 40 meters to be the usual depth of greatest concentration, and some *Lampanyctus leucopsarus* larvae have been taken as deep as 100 meters. Hence, we may assume that larvae occurred below the level sampled by the high-speed nets.

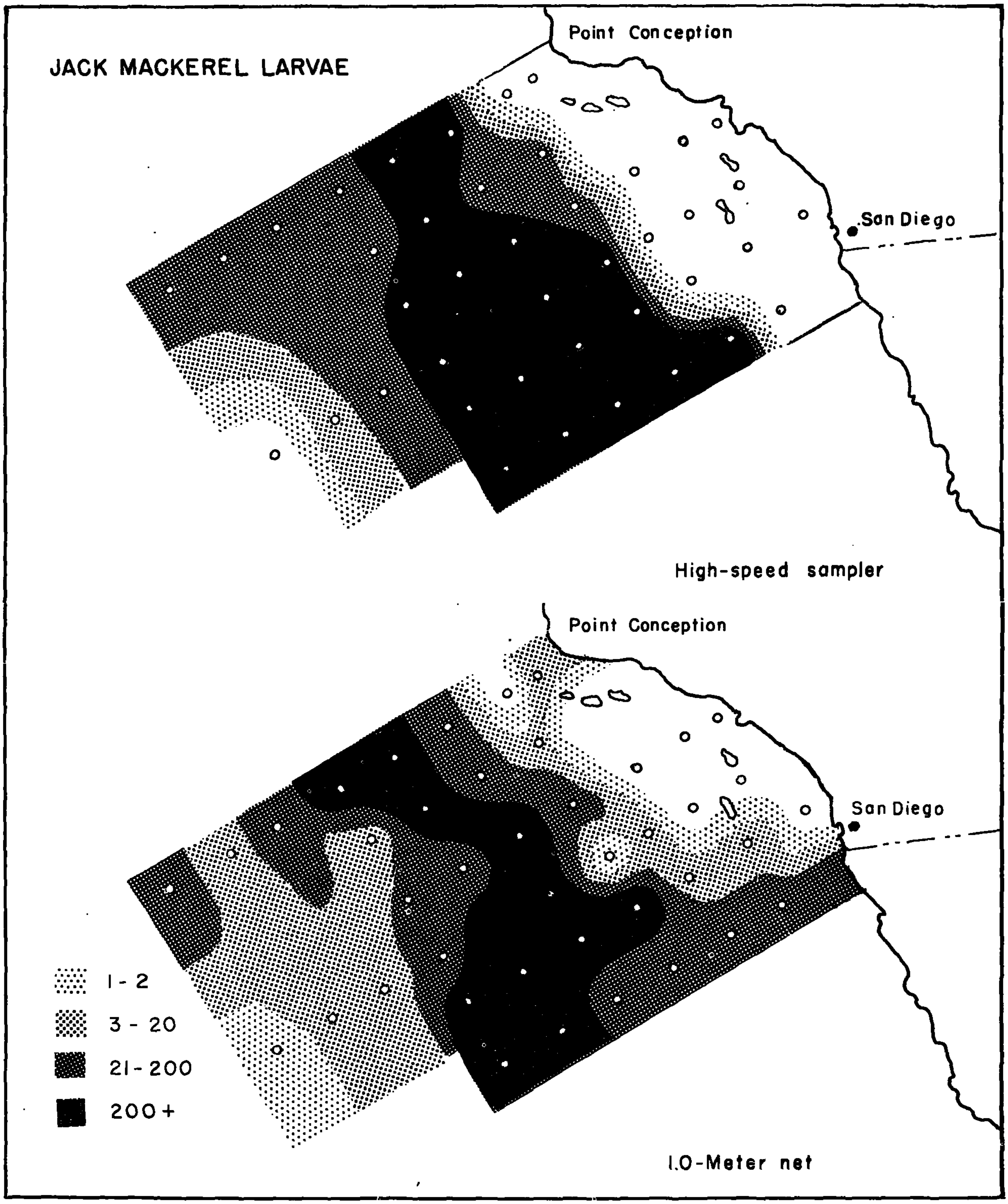

FIGURE 12.—Distribution of jack-mackerel larvae based on hauls made with high-speed samplers, and with 1-meter net. The legend represents numbers per standard haul.

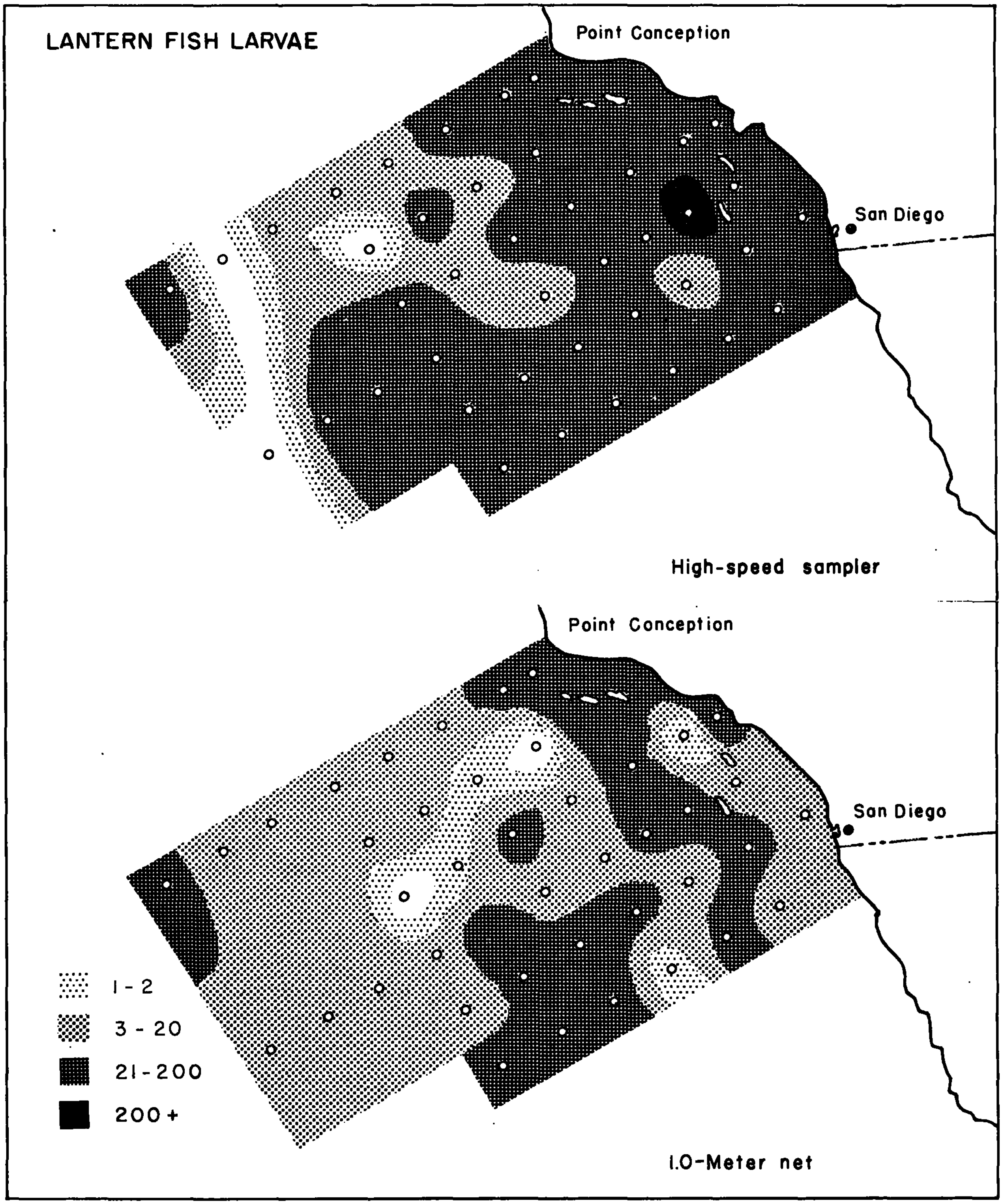

FIGURE 13.—Distribution of larvae of the lantern fish (*Lampanyctus leucopsarus*) based on hauls made with high-speed samplers and with 1-meter net. The legend is based on numbers per standard haul.

TABLE 13.—*Depth distribution of lantern fish larvae* (Lampanyctus leucopsarus), *based on high-speed sampler hauls*

Depth of sampler (meter)	Number of larvae taken (standard haul totals)	Percent of total
10	154	5.1
20	392	13.1
30	1,058	35.3
40	1,400	46.6
Total	3,004	100.1

OTHER FISH CATCHES

Small pelagic fish are occasionally taken at night in net hauls. Among those commonly caught are a number of species of lantern fish and some deep-sea smelts. Only a small fraction of the fish in the path of the net are caught, since most fish could easily avoid capture by the slow-moving standard gear. However, they have less chance of getting out of the path of the high-speed gear. This is clearly demonstrated by the fish taken during cruise 5005. Based on comparable volumes of water strained, approximately 30 times as many fish were taken in high-speed sampler hauls as with standard gear. This is a clear-cut demonstration of the greater efficiency of high-speed samplers as compared to standard nets in capturing the more agile organisms.

All fish taken with both types of gear were obtained between 8:00 p. m. and 4:00 a. m. probably as a result of the fish migrating upward for night feeding in the levels being sampled by our gear. The largest numbers were taken at 20 and 30 meters depth with high-speed samplers (table 14).

TABLE 14.—*Depths at which fish were taken in high-speed sampler hauls*

Depth of sampler (meter)	Number of fish taken (standard haul totals)	Percent of total
10	30	17.1
20	63	35.8
30	68	38.6
40	15	8.5
Total	176	100.0

The species of fish taken as juveniles or adults in both types of gear on cruise 5005 were as follows:

Myctophidae:
- *Ceratoscopelus townsendi*
- *Diaphus theta*
- *Diogenichthys atlanticus*
- *Hygophum reinhardti*
- *Lampanyctus leucopsarus*
- *Lampanyctus mexicanus*
- *Notolychnus valdiviae*

Gonostomatidae:
- *Vinciquerria lucetia*

Bathylagidae:
- *Bathylagus wesethi*
- *Leuroglossus stilbius*

EVALUATION

To sample organisms adequately, such as the larval stage of a fish, it is necessary to (1) delimit the range both horizontally and vertically; (2) obtain enough samples to estimate variation in density and (3) employ an instrument capable of quantitative measurement of water strained, retention of desired sizes (no loss of organisms through openings between meshes), capture of larger individuals in their relative proportion in the population, and in sufficient numbers for abundance and mortality estimates. The relative merits of high-speed samplers and of standard 1-meter plankton nets in fulfilling these requirements are evaluated in the following discussion.

Horizontal range.—Both types of gear seem to be equally effective in delimiting the horizontal distribution of plankton organisms. This was brought out in the discussion of the distribution of various fish eggs and larvae, as well as in figures and tables. These data are summarized in table 15. The high-speed sampler gave more information on the distribution of eggs, in the two species cited, than did the 1-meter net. The total occurrences for both eggs and larvae, however, are extremely close.

Vertical range.—High-speed samplers, used in a series, automatically give information on the distribution of organisms at the several depth zones sampled by the gear. Results of the previously discussed tests are summarized in table 16. From this information, it is obvious that the entire depth distribution of most species was not encompassed during cruise 5005 by these samplers. Hence, a somewhat deeper stratum should be sampled. It might be possible to sample as deeply as 60 meters using present equipment, but to exceed this would require changes in the depressing force and in the wire used. However, for the sardine and many other fish species, 60 meters probably would be deep enough for adequate quantitative sampling. For some species, such as hake, this depth is not adequate.[2]

TABLE 15.—*Occurrences of fish eggs and larvae in 1-meter net hauls at stations as compared to occurrences in high-speed sampler hauls taken adjacent to stations*

Organism	1-meter net	High-speed sampler
Sardine eggs	10	14
Sardine larvae	12	9
Anchovy eggs	4	7
Anchovy larvae	10	13
Jack-mackerel larvae	34	28
Lampanyctus leucopsarus larvae	39	37
Total	109	108

TABLE 16.—*A summary of the depth distribution of eggs and larvae taken with high-speed samplers*

Organism	Percentage at each level				Total
	10 meters	20 meters	30 meters	40 meters	
Sardine eggs	39.9	22.4	19.6	18.1	100.0
Sardine larvae	29.8	45.9	12.6	11.7	100
Anchovy eggs	3.7	2.9	39	54.4	100
Anchovy larvae	2.7	30.7	23.3	43.3	100
Jack-mackerel eggs	42.5	23.2	17.7	16.7	100.1
Jack-mackerel larvae	20.2	36.2	25	18.6	100
Lampanyctus leucopsarus larvae	5.1	13.1	35.3	46.6	100.1

Conventional gear definitely has the advantage in this phase of sampling, since it is exceedingly versatile in depth sampling. Nets can be lowered to any desired depth, even to the deepest layers of the ocean; conventional gear can also be used in series to furnish data on depth distribution of organisms. However, with nets as large as 1.0 meter in diameter, as were used on cruise 5005, such series have been taken to establish depth distribution rather than for routine sampling. Once the depth distribution of an organism has been established, then oblique hauls can be made deep enough to encompass routinely this distribution.

Variation in density.—Obtaining enough samples of organisms to determine the variation in density with range is important because organisms are seldom found to be uniformly distributed. Usually there is considerable variation in abundance in various parts of their range. Because of these variations, it is difficult to sample an organism adequately with standard plankton gear. Strip samples, covering miles at a time, are far more representative of mean density; such samples automatically average-out much of the variation in abundance. This capability of the high-speed sampler, lacking in the spot sampler, is an important advantage and was the primary consideration prompting the development of this type of gear. The results obtained on cruise 5005 point up these advantages. Very large concentrations of sardine eggs, for example, that were missed entirely by standard net hauls were picked up by means of strip sampling.

Instrument requirements.—The performance of sampling gear can seriously limit the value of plankton collections. Four aspects of gear performance will be compared for the two types of plankton samplers.

An adequate means of measuring the quantity of water strained in making a haul is an essential requirement of an instrument used for quantitative sampling. The depth-flow mechanism of the high-speed sampler automatically records both water flow and depth; the Atlas current meter used with 1-meter nets gives a reliable record of water flow.

The high-speed sampler was constructed of finer meshed netting material than the 1-meter net now being employed on cruises of the California Cooperative Oceanic Fisheries Investigations. We did not have any serious clogging of the Monel screen of the high-speed samplers (on one test, clogging retarded flow by about 10 percent after 4 hours of continuous towing), yet retention of smaller-sized fish eggs and larvae was much better than with conventional gear. However, we are now experimenting with finer-meshed synthetic netting in 1-meter nets in order to increase retention without impairing the flow of water through the nets.

Large plankton organisms are often agile enough to dodge relatively slow-moving plankton nets. The high-speed sampler was designed to prevent dodging through its speed of operation and mode of attachment to the towing wire. The mouth opening of the sampler precedes the towing wire, consequently no part of the gear can act as a scare as do both the towing wire and the bridle of our standard plankton gear. Organisms capable of moving out of the path of a conventional net being hauled at 1 to 1½ knots may have little chance of dodging the high-speed sampler moving at 10 knots. The taking of approximately 30 times as many small pelagic fishes with high-speed gear as with conventional plankton nets (based on comparable volumes of water

[2] A newly designed depressor, given the model number 3x, permits operation to 300 meters with ⅜" and ½" towing cable (J. D. I.).

strained) accents the effectiveness of high-speed samplers in this field.

A limitation of high-speed samplers for certain purposes results from the rather small quantity of plankton collected. A group of 4 samplers hauled for 10 miles would collectively strain only about 40 cubic meters of water. This is less than one-tenth the quantity of water strained during a routine 1-meter net haul. The smaller quantity is adequate for measuring mean density of many plankton organisms, including fish eggs, but not for obtaining sufficient numbers of larvae, particularly of older stages, for mortality estimates.

The cost of constructing the Isaacs high-speed sampler may place a limitation on its widespread use. As one way of reducing the cost of equipment, it is practicable to use only one instrument with a depth-flow meter in a string of 4 or 5 samplers towed simultaneously. On cruise 5005, the three upper high-speed samplers were equipped with plankton filters of the same mesh size. Due to the time required for attaching and retrieving the samplers, the upper sampler was hauled only 83.6 percent as long, on the average, as the sampler at 30 meters, while the sampler at 20 meters was hauled 94.1 percent as long. A comparison of the volumes of water strained by the three samplers showed that the upper one strained on the average 83.2 percent as much as the sampler at 30 meters, and the 20-meter sampler strained 93.5 percent as much. We conclude from these comparisons that a fairly accurate estimate of volume of water strained by either of the upper samplers could have been obtained by using the volume of water strained by the net at 30 meters, adjusted for difference in time of hauling.

APPENDIX I: OPERATING INSTRUCTIONS

Preparing film.—Film used in the high-speed sampler is 35 mm. perforated clear No. 3 Safety Leader film. The film which is obtained in bulk must be cut into appropriate lengths (approximately 2½ ft.). To prepare the film for use, roll on a slotted brass rod (⅛'' in diameter) just tight enough that the roll will come off the rod without difficulty. Wrap with a rubber band, applying sufficient tension to prevent unrolling, but not enough for tension lines to bake into the film. After the film is properly banded, remove from the rod.

The film is baked in order to set it in a tight roll, which assures that the film will automatically rewind during use. It should be baked for 4 hours at a temperature of 220° F. in a thermostatically-controlled oven.

After baking, the film is cooled to room temperature, and then rerolled. This is done so that the point of maximum tension will be on the outside of the roll, ensuring that the film will rewind on itself when in use.

Handling of samplers.—We have found from experience that careful instructions for assembling the samplers, and attaching and removing them from the towing cable may prevent costly repairs or even loss of the equipment.

Assembling.—Load the sampler with film starting the film around the film sprocket and marking the zero trace. Attach the straining section of the plankton filter to the cod-end cup. Attach the metering unit and tighten the stylus screw. Insert complete unit in the outer casing and secure.

Placing samplers on towing cable.—Attach and lower the depressor (illustrated in fig. 14) into the water with ship at half speed. Place the ball clamp on the towing cable and tighten (fig. 15). Remove the nose ring from the sampler and push the slotted nose over the wire, above or below the cable clamp. Pull the cable clamp into the cable-clamp seat and replace the nose ring. Lower the sampler the desired amount and attach (fig. 16) the second sampler in the same manner, and so on.

Removing samplers from towing cable.—The procedure for removing samplers from the towing cable is just the reverse of the preceding description. When samplers break water, they assume the mouth-up vertical position of pre-lowering, thus preventing loss of any part of the sample.

Disassembling.—Remove outer casing while keeping sampler upright to prevent loss of sample. Play a jet of salt water along the outside of the plankton filter to dislodge any adhering plankton. Detach the straining section of the filter and concentrate sample further by patting salt water on the outside of the mesh of the cod-end cup. Pour sample into a suitable container, label, and add preservative. Detach the metering unit. Remove film by slicing down through the film with a knife blade, and label (fig. 17). Wash plankton filter and metering unit with fresh water. Reload film, and reassemble sampler.

At no time during assembling or disassembling should force be used on the high-speed sampler. Gentle tapping or rocking motions will dislodge any stubborn sections without damaging the instrument. Should any section consistently stick, silicone stopcock grease can be used to overcome the tendency.

APPENDIX II: CALIBRATION

The method of standardizing hauls would require a lengthy explanation and hence would be out of place in this paper which is concerned with performance and not the technical aspects of quantitative sampling. The method of standardizing regular plankton hauls is discussed by Ahlstrom (1948), and a modification of this method was used in standardizing the high-speed sampler hauls.

The following procedures were used for obtaining depth flow calibrations:

Depth calibration.—The depth calibration was done at sea during calm weather. Instead of a

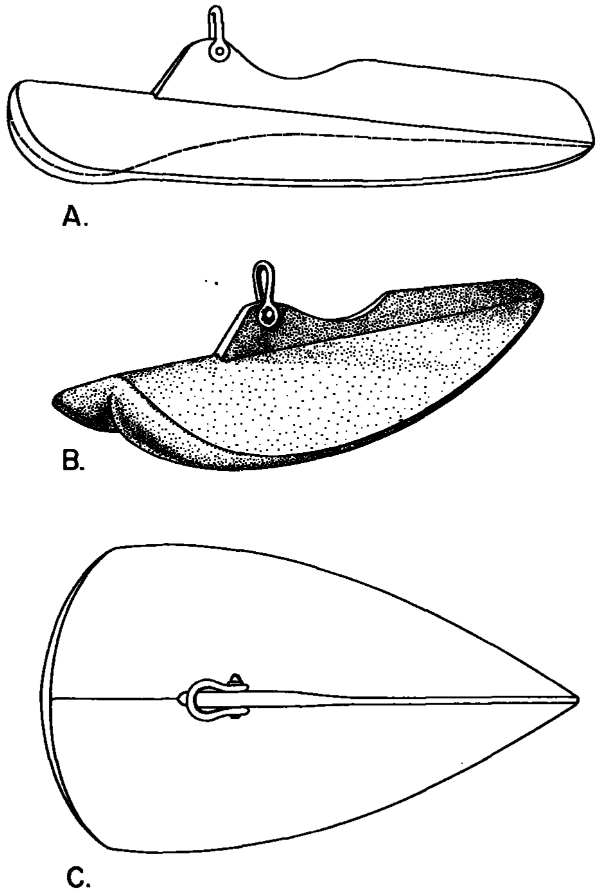

FIGURE 14.—Three views of depressor.

depressor, an ordinary 100-lb. weight was attached to the end of the towing cable. The sampler being calibrated for depth was attached about 10 meters above the weight. It was properly loaded with film and lowered to the water surface, at which time the meter wheel of the winch was set at zero. The sampler was then successively lowered to a number of depths. After each lowering the metering unit was removed, the depth scratched above the trace on the film, the sprocket turned about one-half a revolution, and the unit reassembled for the next lowering. Two kinds of pressure elements have been used, one type effective to approximately 55 meters, the other to approximately 137 meters. For the shallower element, lowerings were made to 10, 20, 30, 40, 50, and 60 meters, respectively. For the deeper element, lowerings were made to 10, 20, 30, 40, 50, 60, 70, 80, 100, 120, 130, and 140 meters. At the completion of a calibration the traces were measured and graphed against depth as determined by wire out, and a line was fitted to the points. Typical depth calibration graphs for the two types of pressure elements are shown in figure 18.

Flow calibration.—Flow calibration presented more of a problem. Several methods were tried before a satisfactory one was found. The most difficult problem was to find a suitable method for measuring the volume of water that passed through the sampler during the tests. Several preliminary methods did not achieve a desirable degree of either accuracy or consistency (repeatability) of results. These included rough and ready methods of either weighing or collecting and measuring the water passing through the sampler. Finally, a water meter was installed in front of the sampler in the calibration system. By this means it was possible to measure accurately the quantity and rate of flow of water passing through the sampler during each trial.

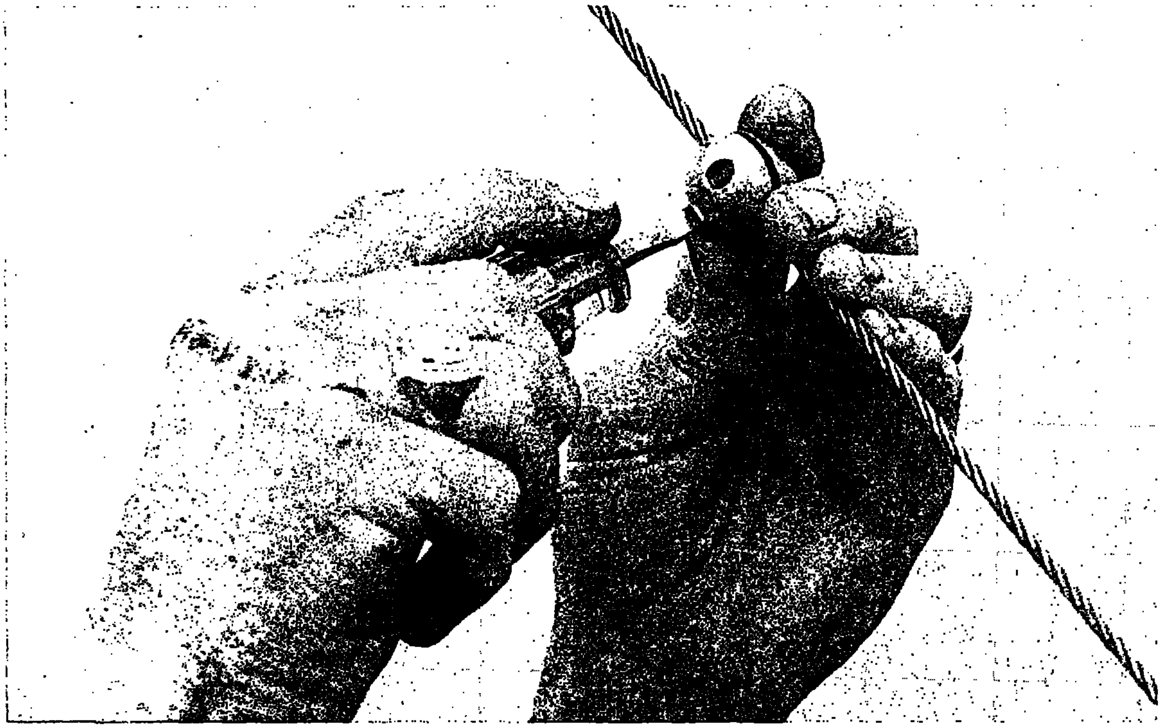

FIGURE 15.—Fastening ball clamp to towing cable.

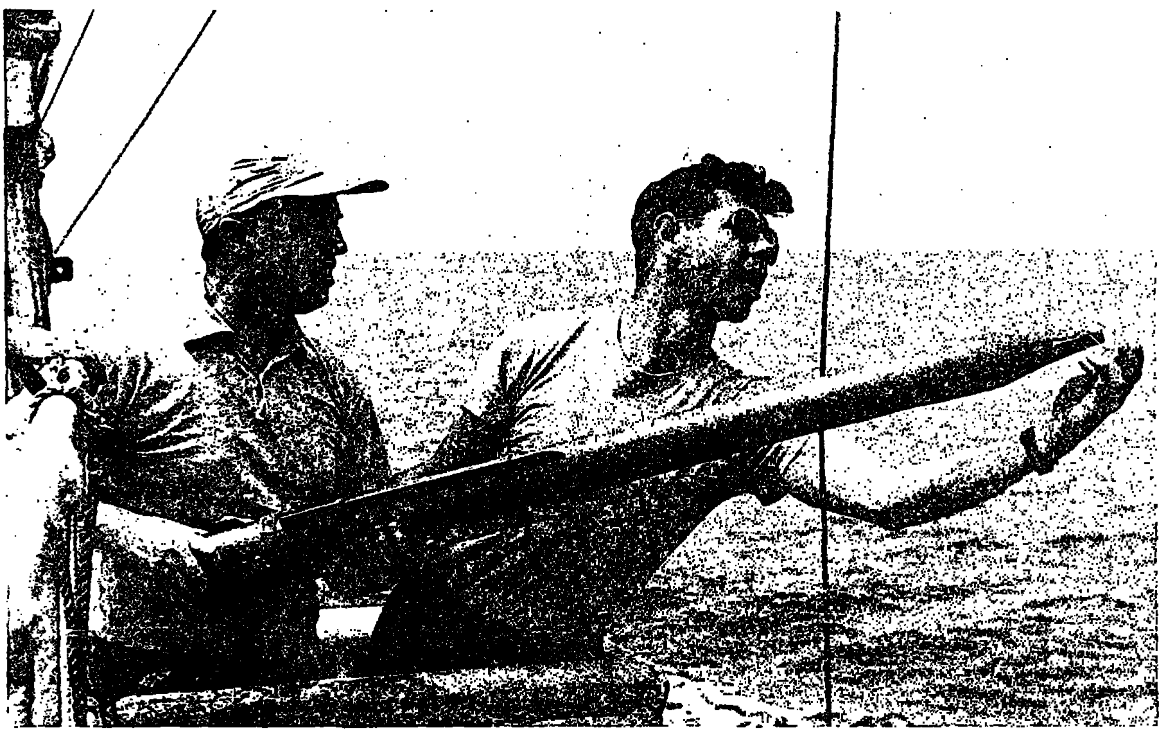

FIGURE 16.—Fastening sampler to towing cable.

NOTE:—The samplers after attachment to the towing cable, hang vertically with the mouth up. When lowered into the water, they orient themselves and assume a horizontal fishing position.

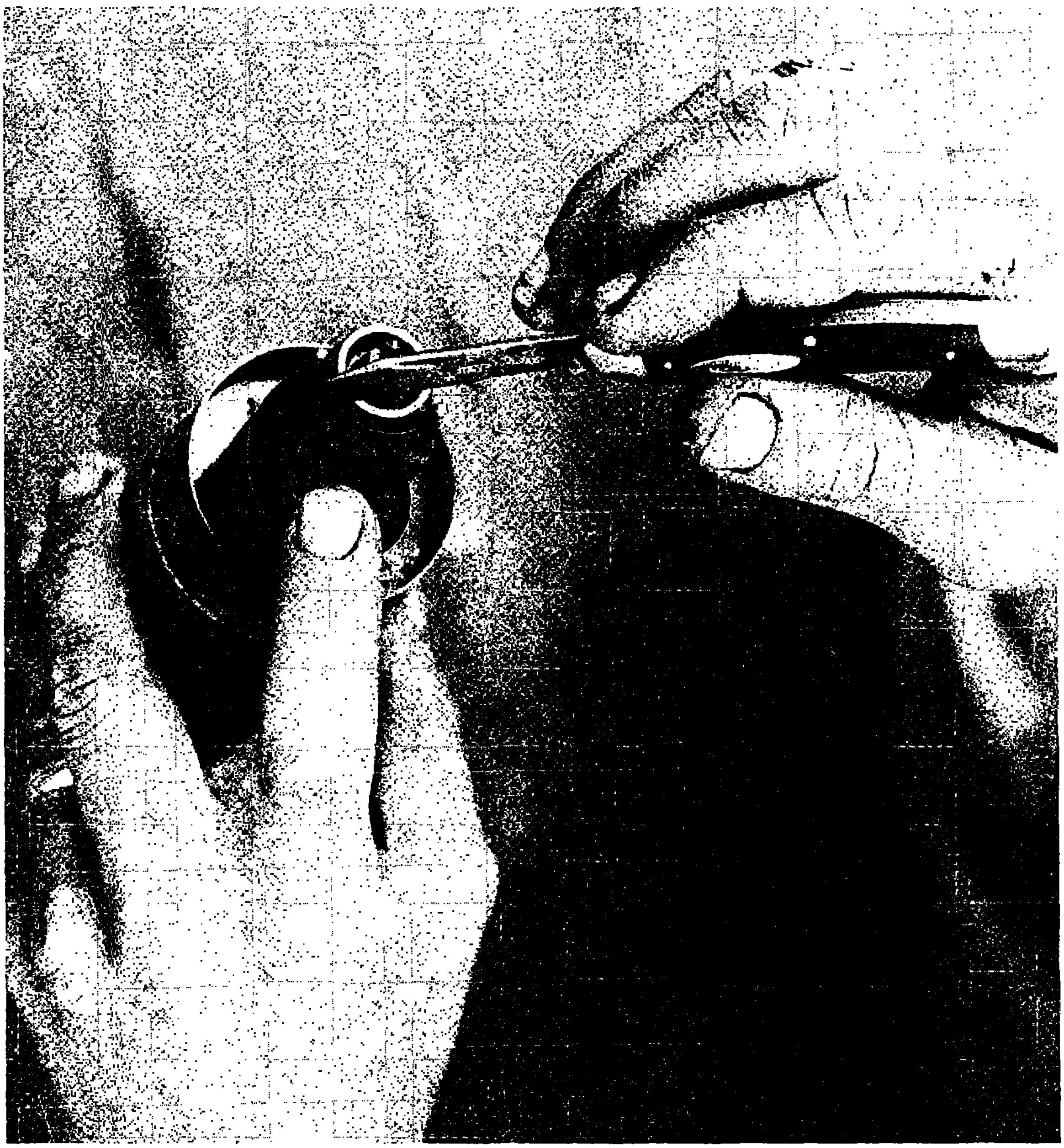

FIGURE 17.—Removal of film from sampler.

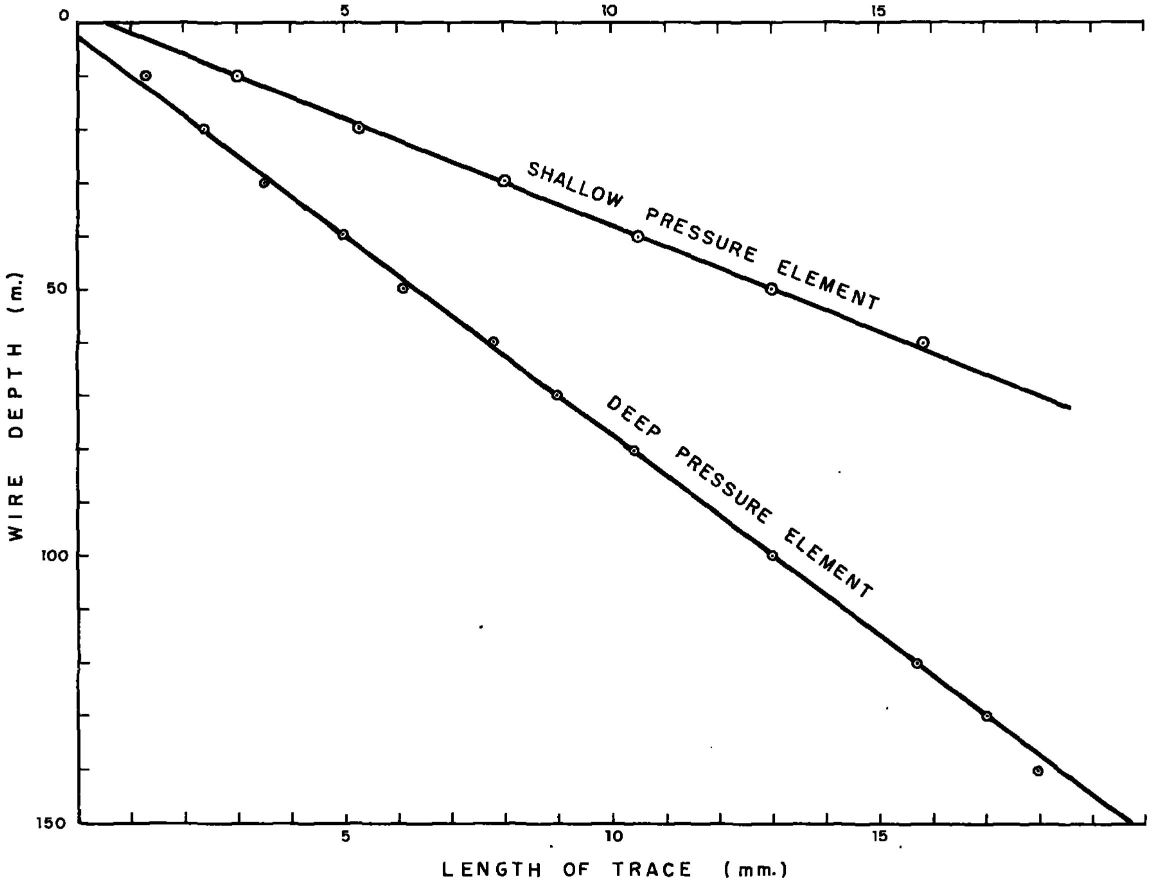

FIGURE 18.—Typical depth-calibration curves for the two types of pressure elements used.

The calibration tests were conducted in a pool. There are four important elements in the calibration system: (1) Housing for attaching essential portion of high-speed sampler to the calibration system; (2) metering device (a calibrated water meter) measuring flow; (3) water source; and (4) flow rate valve (for controlling volume of water entering system per unit of time).

Housing.—Inasmuch as the casings used with high-speed samplers at sea could not be employed conveniently during calibration tests, a cylindrical casing was substituted (fig. 19). It had a bonnet at its forward end for convenient attachment to a water meter.

Water meter.—The water meter employed had openings of 1½ inches diameter (3.8 cm.) at attachment points. It was calibrated, before use, by the Engineering Department of the San Diego Municipal Water Company (fig. 19).

Water source.—The water source was a submersible pump that drew water from the pool in which the calibration tests were made. A 1½-inch hose connected the pump to the calibration setup. The submersible pump used with this operation gave an even, steady flow of water through the calibration tube.

Valve.—A manually operated valve was used to control the rate of flow of water entering the system. In calibrating the flow-meter, it was desirable to obtain rates of flow that would bracket those obtained when in use at sea. The flow-meter being calibrated is shown in figure 20.

Because the flow-meter is directly geared to a sprocket over which is led the clear acetate film, when the flow-meter is actuated by water passing through the sampler, a trace is obtained on the film. The length of the trace is determined by two factors, the volume of water and rate of flow. In calibrating the flow unit, identical volumes of water were used on all trials, but the rate of flow was varied. A range of flow rates from 3.1 to 10.0 cubic feet per minute (0.088 to 0.283

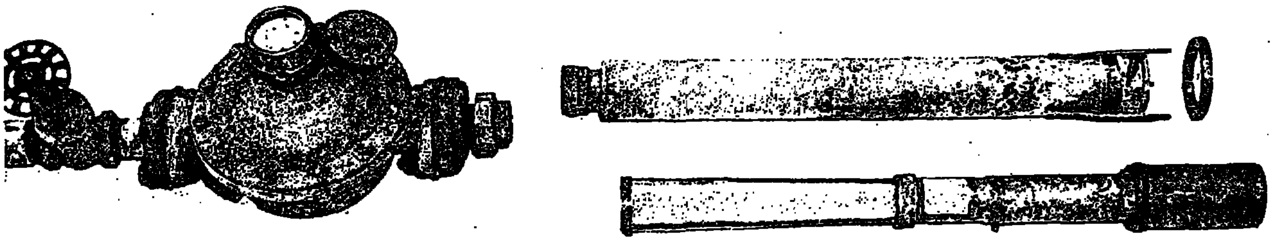

FIGURE 19.—Disassembled flow calibration units.

FIGURE 20.—Flow calibration setup in pool.

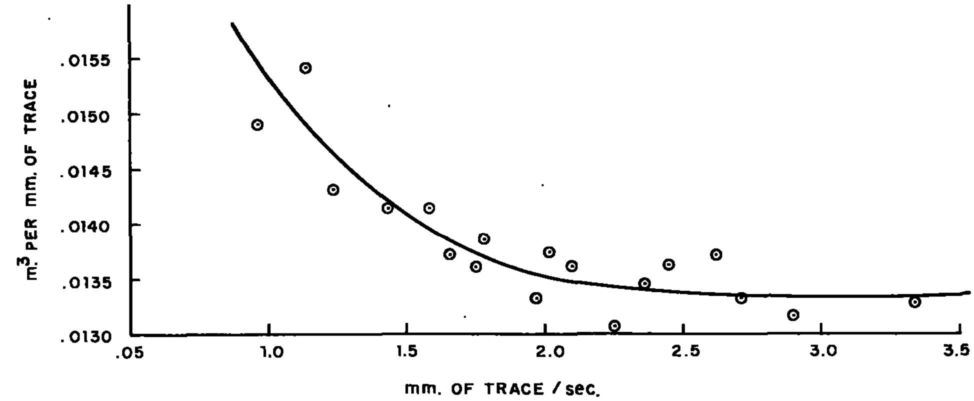

FIGURE 21.—A typical flow calibration.

m.³/min.) was used. (The water meter used in the calibration tests recorded in ft.³). The data obtained during calibration tests of one of the flow-meters are given in table 17 and graphically illustrated in figure 21.

TABLE 17.—*Typical flow calibration using a constant volume of water (40 ft.³ or 1.133 m.³) and various rates of flow*

Time in seconds	Length of trace (mm.)	Millimeters trace per seconds	Cubic meters per millimeter trace
255	85.1	0.334	0.0133
297	86.0	.290	.0132
313	84.9	.271	.0133
315	82.5	.262	.0137
340	83.2	.245	.0136
356	84.1	.236	.0135
386	86.7	.225	.0131
395	83.2	.210	.0136
409	82.4	.202	.0137
430	84.9	.197	.0133
456	81.7	.179	.0139
475	83.1	.175	.0136
496	82.5	.166	.0137
503	80.0	.159	.0142
555	80.0	.144	.0142
638	79.1	.124	.0143
643	73.5	.114	.0154
780	76.0	.097	.0149

Note on flow calibration.—The following considerations were helpful in choosing the range of 3.1 to 10.0 cubic feet per minute:

The normal cruising speed of the survey vessels was 10 knots; hence the vessel would cover 1 nautical mile in 6 minutes. Assuming that the high-speed samples strained while being towed 1 nautical mile, a cylinder of water 1 mile long by 2.54 centimeters in diameter (diameter at mouth opening), it would strain 0.94 cubic meters of water or 0.157 cubic meters per minute. (This is equivalent to 5.5 ft.³/min.).

Inasmuch as the collector has a 1-inch or 2.54-centimeter opening at the inlet and a 3-inch or 7.62-centimeter opening at the outlet, it was anticipated (and preliminary tests had confirmed) that the sampler would strain a somewhat greater quantity of water than the above-calculated cylinder.

However, it was also anticipated that there would be considerable variation in the volume of water strained from haul to haul, due to varying degrees of clogging of the fine-meshed net.

The flow rates at sea, measured by length of film trace per second of hauling, fell within the anticipated range of flow rates used in calibration.

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