

# SAMPLING ANCHOVY LARVAE WITH A PLANKTON PURSE SEINE<sup>1</sup>

GARTH I. MURPHY<sup>2</sup> AND ROBERT I. CLUTTER<sup>3</sup>

## ABSTRACT

A miniature purse seine (100 ft by 21 ft) was constructed of 333  $\mu$  Nitex. It was used in Kaneohe Bay, Hawaii, together with a 1-m plankton net constructed of the same material in order to evaluate the sampling efficiency of the towed plankton net on anchovy larvae (*Stolephorus purpureus*). The results show that during the day, the purse seine is at least an order of magnitude more efficient for larvae over 5.5 mm in length. The largest larva caught by the plankton net was 14.5 mm and by the purse seine 29.5 mm. At night the plankton net was relatively more effective than during the day, catching about 60% as many larvae as the purse seine over the interval 3.5-19.5 mm. The maximum size taken increased to 21.5 mm, but the maximum taken by the purse seine increased to 50 mm. An attempt was made to rationalize the difference between the day plankton net and purse seine catches by a geometric model involving alarm distance and larval swimming speed. The results are moderately satisfactory.

More limited data on anchovy larvae catches by a 10-ft Isaacs-Kidd trawl, 1/4-m, 1/2-m, and 1-m plankton nets are presented and discussed in the framework of the meter net-purse seine data. These analyses suggest one or more paradoxes in the larval escape problem, or that the data are inadequate.

The classical approach to sampling zooplankton is the towed net. This has two disadvantages: an unknown fraction of the organisms in the path of the net escape by dodging and the net integrates the organisms living along a transect of considerable length—making it difficult to consider the catch from a tow as representing an assemblage of coexisting organisms. The dodging problem has been considered by (among others) Fleminger and Clutter (1965) with respect to planktonic crustacea, Ahlstrom (1954) and Isaacs (1965) with respect to fish larvae, and McGowan and Fraundorf (1966) with respect to zooplankton. A general review of the problem is given in UNESCO (1968).

In recent years there have been attempts to apply community theory to the pelagic realms, e.g., Fager and McGowan (1963) and Venrick

(1971). Such attempts should involve samples that represent organisms likely to be coexisting. Grab sampling such as used by Venrick (1971) for diatoms is the obvious method of choice as the scale of coexistence can be specified with precision, but existing grab samplers engulf so little water that they are not likely to afford meaningful information on the medium and large zooplankton. The probability that a towed net will integrate several communities has also been recognized and several solutions developed with respect to subdividing a tow, e.g., Longhurst et al. (1966). But if the tow is subdivided small enough for the dimensions to be meaningful, it will not likely strain enough water to sample the less abundant forms.

The purse seine (and other nets of similar design) is an extremely effective large volume grab sampler in wide use by commercial fishermen. Essentially, a wall of net is set in a circle and the bottom closed (pursed) by drawing on the purse lines. This kind of grab sampler can only be effective at the surface and, therefore, is of general application only in shallow water or under circumstances where the surface fauna is of interest.

<sup>1</sup> Contribution No. 390, Hawaii Institute of Marine Biology, University of Hawaii. Supported in part by NSF Grant GB 5698 and the Marine Life Research Program, Scripps Institution of Oceanography.

<sup>2</sup> Department of Oceanography, University of Hawaii, Honolulu, HI 96822.

<sup>3</sup> Formerly Department of Oceanography, University of Hawaii.

The primary purpose of the present study is to evaluate the extent that a large grab sampler (miniature purse seine) can generate samples of fish larvae that are less biased than towed nets with respect to avoidance. The catches of an anchovy larva (*Stolephorus purpureus*) were enumerated from the samples. These were thought to be the most informative of the organisms captured by the net in part because they were present consistently in the samples, in part because they provide a spectrum of small to large zooplankton essentially constant in body form, and in part because there is a wealth of literature on the sampling of fish larvae, in particular, anchovy larvae.

### DESIGN AND OPERATION OF THE NET

The net employed was patterned exactly, insofar as operational considerations are concerned, after that described in Hunter, Aasted, and Mitchell (1966), excepting that the body of the net was constructed of 333  $\mu$  Nitex.<sup>4</sup> The length of the Nitex section was 100 ft and the depth 21 ft. A small cod end was placed near the bitter end of the net.

The net was usually set in the form of an incomplete circle from a platform mounted on a 16-ft Boston Whaler, so that the net set off the port side. Closure of the circle was effected during the first stages of hauling. The operation from starting the set to pursing generally took less than 5 min. Hauling up the net required 15 to 20 min with two men at work. Figure 1 shows the net in the water at the start of pursing.

All of the data considered in this report were taken in Kaneohe Bay, Oahu, where swell is negligible and seas are generally less than 1 ft. It was tested in open ocean swell and in seas up to 4 ft. The operation was not affected by swell and seemed to be effective in seas of short period waves, although the effect of waves splashing over the float line of the net was not evaluated.

<sup>4</sup> Reference to trade names in the publication does not imply endorsement of commercial products by the National Marine Fisheries Service.

One operational problem that we anticipated never materialized. We had feared that significant amounts of zooplankton would catch on the net as it was being hauled up. This did not happen even in the instance of chaetognaths, apparently because the plankton, being alive, avoided the mesh. During the final stages, it was necessary to carefully wash the catch toward, and finally into, the cod end.

### FIELD AND LABORATORY METHODS

The primary objective of the study, comparison of the catches by the purse seine with catches by a meter net, dictated the field sampling pattern. Two skiffs were employed, one with the seine and the other with the meter net. As soon as the seine was set, the second skiff began towing the meter net as close to the seine as possible. The meter net was raised and lowered so as to proportionally sample the same water column fished by the seine. The plankton net was fitted with a Rigosha flow meter. Tows were generally 10 min in duration, but sometimes they were reduced to 5 min when clogging was a problem.

In the laboratory the total wet volume of the samples was measured. The entire sample was scanned for fish larger than 10 mm. Then either the entire sample or an appropriate aliquot was examined in detail, enumerating and measuring all anchovy larvae (*Stolephorus purpureus*), and enumerating anchovy eggs. The entire sample was then reconstructed by appropriate linear adjustments. Finally, all results were adjusted to numbers per 300 m<sup>3</sup>. This value was selected because it was intermediate between the actual typical volumes of water strained by the two samplers, giving the advantage that the numbers to be dealt with are roughly the same as the actual numbers of organisms captured.

In all, there were 44 day stations and 10 night stations from Kaneohe Bay. The exact locations of the stations are not relevant to this study and so are not given. Most were made at Tester's stations 1, 2, 5, and 10 (Tester, 1951). Samples were roughly evenly spaced from November 29, 1966, to August 25, 1967.



FIGURE 1.—Underwater view of the plankton purse seine just as pursing was initiated. Photograph by Robert R. Harvey.

### CALIBRATION OF SEINE

Although, as will be seen later, it is not absolutely necessary for some analyses to know exactly how much water was sampled by the seine, it is desirable to have a reasonably accurate estimate. The size of the net and idealized geometry of a perfect set suggest the net could surround about  $500 \text{ m}^3$  of water.

Actual sets are not perfect, and an attempt was made to standardize for obvious imperfec-

tions by noting visually estimated percent efficiency during each set. These ranged from 60 to 100% with six from 60 to 65%, nine from 80 to 85%, and the balance (40) from 90 to 100%. All numerical data generated by the samples were adjusted to 100% efficiency.

Since metered plankton net samples were available from presumably the same water as the purse seine, it should have been possible, ideally, to calibrate each set by comparing the catches of some nonmotile component of the plankton, e.g., fish eggs. This was not possible because such items were not consistently present and, more importantly, because high amplitude, short-period patchiness was obviously generating high variability, even between such closely spaced samples.

The final decision was to use total sample volume as a measure of the water strained by the seine, i.e., the volume of water strained by the seine was estimated by comparing the total volume of wet plankton with the total volume of wet plankton taken by the metered plankton net. This was based on the hindsight fact that the volume of non-escapers, e.g., ctenophores, was very large compared with the volume of escapers, e.g., fish larvae, and therefore, the total volume was essentially independent of escapers. Several analytical techniques, e.g., regression, were considered and applied. These yielded estimates of the purse seine volume at 100% efficiency from  $305 \text{ m}^3$  to  $441 \text{ m}^3$ . Finally adopted was a simple comparison of the geometric means (because the volumes were logarithmically distributed) of the two series after raising the meter net catches to  $300 \text{ m}^3$  of water strained, and the purse seine catches to 100% efficiency. This yielded a value of  $356 \text{ m}^3$  of water strained for the purse seine at 100% efficiency. The procedure was: geometric mean of 54 purse seine catches divided by the geometric mean of 54  $300\text{-m}^3$  plankton net catches multiplied by 300 equals mean purse seine volume of 356. This value, of course, remains an approximation. Any error has no effect on the analytical portions of this paper as the slopes of the length frequency curves are of primary concern. As indicated earlier, the primary purpose of the adjustments is to deal with reasonably real world numbers.

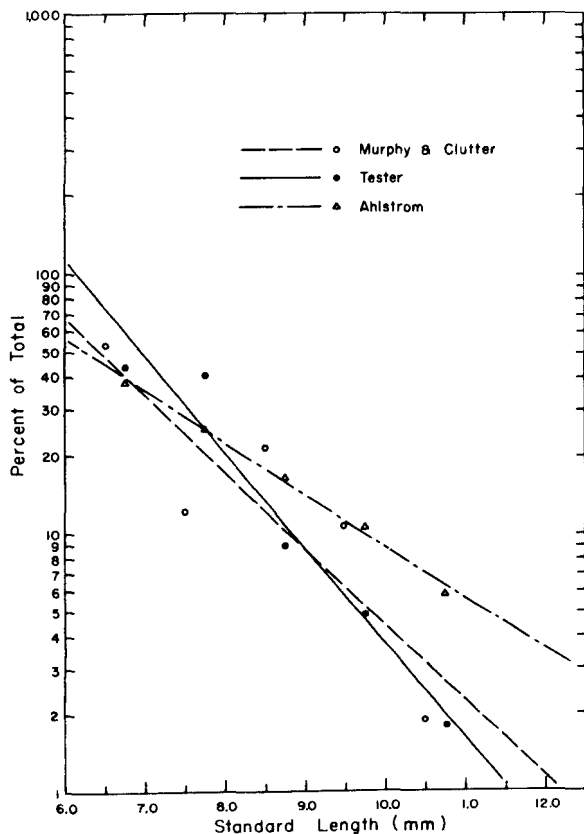


FIGURE 2.—Anchovy larvae catches reported by Ahlstrom (1965) on *Engraulis*, Tester (1951) on *Stolephorus*, and Murphy and Clutter (present paper) on *Stolephorus*. The lines are least square regressions.

## RESULTS

### DAY SAMPLES

As indicated earlier, the bulk of the sampling was done in the daytime. We used a meter plankton net as our measure of normal sampling efficiency. Because of this, it is of considerable interest to establish how the sampling efficiency of our meter net system compared with the experience of other investigators using the same equipment and towing speeds. This was done by comparing the slopes of our anchovy size-frequency curve with the results of an earlier study in Kaneohe Bay (Tester, 1951) and with the re-

sults of a massive program in the eastern Pacific on the northern anchovy (*Engraulis mordax*) (Ahlstrom, 1965).

The results of the three programs (Figure 2) are remarkably similar, and although the *Engraulis* data have a somewhat flatter slope, the difference is not significant, at least for the present purpose. This was not entirely unexpected since the eggs and larvae of *Stolephorus* are almost identical in size and appearance to those of *Engraulis*. We assume that our comparison of purse seine and plankton net catches of anchovy larvae is applicable to all anchovy larvae.

Our day purse seine and meter net data are compared in Figure 3 and Table 1. They indicate remarkable undersampling by the meter net. The break in the slope at 20 mm in the purse seine curve coincides approximately with the transformation from larva to juvenile. This may

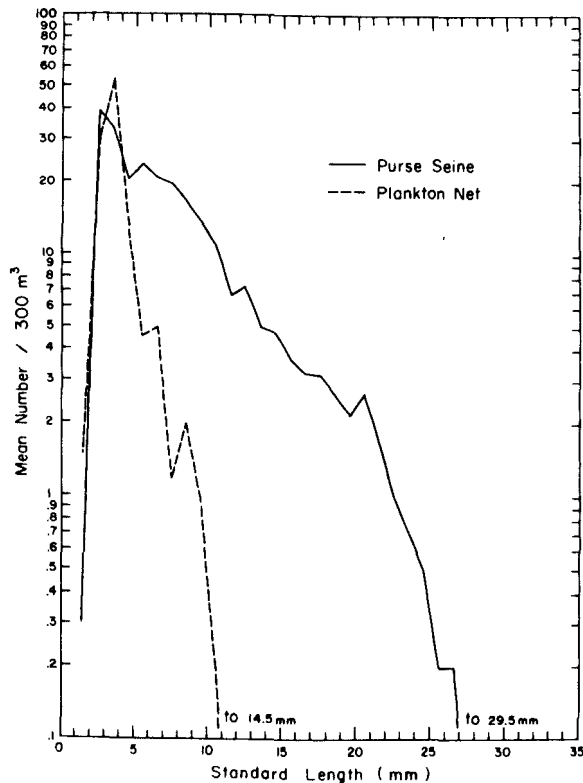


FIGURE 3.—Day catches of the purse seine and plankton net.

TABLE 1.—Results of paired purse seine and 1-m plankton net samples expressed as numbers per 300 m<sup>3</sup>. Lengths are preserved lengths. There were 44 paired samples.

Standard length (mm)	Day		Night	
	Purse seine	Meter net	Purse seine	Meter net
1.5	0.3	1.5		
2.5	39.3	30.7	13.3	
3.5	33.1	53.9	9.6	6.4
4.5	20.4	13.0	4.6	7.5
5.5	23.6	4.6	10.4	13.3
6.5	20.8	5.0	10.6	6.2
7.5	19.5	1.2	16.4	5.4
8.9	16.6	2.0	18.0	10.8
9.5	13.5	1.0	10.4	14.2
10.5	10.9	0.2	14.0	10.2
11.5	6.9	0.02	17.4	4.2
12.5	7.4	0.05	16.5	6.2
13.5	5.1	0.08	9.0	6.3
14.9	4.8	0.05	5.2	11.0
15.5	3.8		6.1	7.3
16.9	3.3		7.9	4.6
17.5	3.2		2.6	3.5
18.5	2.7		2.6	1.7
19.9	2.2		1.9	1.7
20.9	2.7		2.5	0.3
21.5	1.7		3.4	0.2
22.5	1.0		1.5	
23.5	0.7		1.7	
24.9	0.5		2.0	
25.9	0.2		3.8	
26.9	0.2		5.2	
27.9	0.02		5.6	
28.5	0.03		4.1	
29.5	0.02		2.3	
30.5			4.5	
31.5			1.1	
32.5			1.2	
33.5			1.2	
34.5			0.7	
35.5			1.7	
36.5			0.6	
37.5			0.8	
38.5			0.2	
39.5			0.2	
40.5			0.1	
41.5			0.1	
45.5			0.1	
Total	244.47	113.30	219.9	121.0

be accompanied by behavioral changes, e.g., onset of schooling, as well as more efficient swimming—all of which might increase their ability to escape the purse seine. The low numbers in the 1.0 to 2.0 mm (preserved lengths) are, at least in part, a function of the newly hatched larvae being able to pass through the 333  $\mu$  Nitex. The seeming differences in the next two larger intervals are not statistically significant ( $P = 0.216$  and  $0.141$ , respectively). The remainder, involving larvae greater than 4.0 mm, are all significant at the 0.01 level or greater.

## NIGHT SAMPLES

The night samples (Table 1, Figure 4) were fewer in number (10) and, therefore, exhibit greater variance. They also suffer from poor stratification as evidenced by the near lack of a negative slope below 12 mm in length, in spite of what must be a very high mortality rate (see Figure 3). These data clearly indicate that the purse seine is superior at night too, even with respect to the smaller sizes, supporting Ahlstrom's (1954) contention that larvae probably dodge nets at night as well as day. For example, over the interval 3.5 to 11.5 mm, inclusive, the purse seine took 127.9 per 300 m<sup>3</sup>, and the meter net took only 69.8. Over a larger interval (3.5-19.5 mm), the purse seine took 163.2 larvae and the meter net 99.6. For this interval the  $F$  ratio is 6.19 with 1 and 32 df ( $P < 0.025$ ). Never-

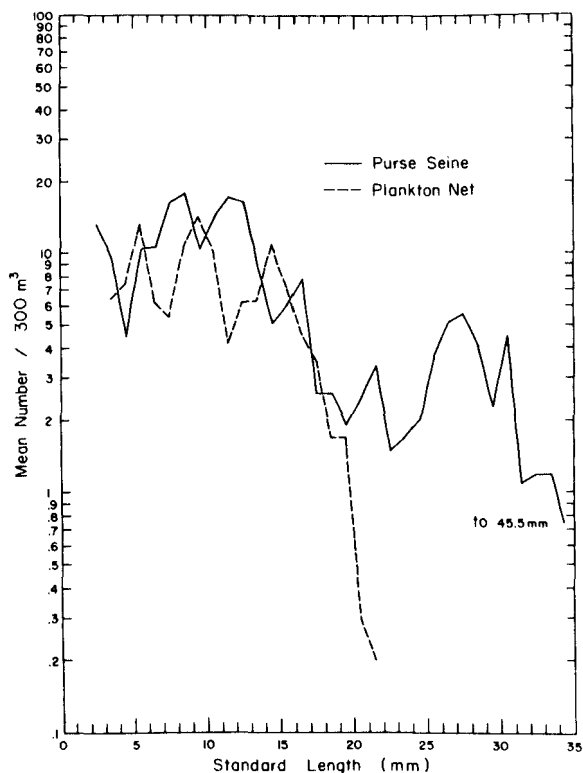


FIGURE 4.—Night catches of the purse seine and plankton net.

theless, the plankton net appears to be more efficient at night than during the day. The catches of the smaller larvae are closer to the purse seine catches than during the day, and much larger larvae were taken at night—21.5 mm maximum versus 14.5 mm by day. This suggests that vision plays an important role in dodging.

It is interesting to note that the maximum size taken by the plankton net at night (21.5 mm) coincides with a change of slope of the day purse seine catches. The plankton observation taken by itself might be interpreted as a size beyond which all larvae can swim out of the net even if they blunder into it. A length of 21.5 mm is approximately the size of metamorphosis and the onset of schooling. This social trait might also adversely affect the day purse seine catches to the extent that a school is more effective than the sum of the individuals in detecting and responding appropriately. It does not seem to have affected the night catches. This may be evidence that schools tend to disperse at night.

Each night station was paired with a day station. These latter were taken late in the afternoon at the same geographical point, but of necessity, several hours before the night station. Examination of the data shows that this degree of control was inadequate to allow meaningful comparisons, at least on the basis of only 10 sets of data.

## A DODGING MODEL

In this section an attempt is made to rationalize the difference between the day plankton net catches and the day purse seine catches on the basis of the geometry of the towed net situation, the swimming speed of the larvae, and the alarm distance, i.e., the distance in front of the net that a larva would have to begin evasive action in order to avoid capture.

The algebra of the model is an extension of the results of Barkley (1964). We start with his equation (7) (our 1) which defines the escape velocity, i.e., swimming speed, necessary to escape a net assuming the larva is mathematically inclined and rational and, therefore, selects

the shortest possible escape path. We follow Barkley's notation.

$$u_e = U \left[ 1 + \frac{x_0^2}{(R - r_0)^2} \right]^{-1} \quad (1)$$

where:  $u_e$  = escape velocity (swimming speed) (cm/sec)  
 $U$  = towing speed of net (cm/sec)  
 $x_0$  = reaction distance of the larva (cm)  
 $r_0$  = initial offset of larva (from dead center of the net) (cm)  
 $R$  = radius of net (cm).

Equation (1) can be rearranged to provide the minimum  $r_0$  from which escape is possible given a swimming speed  $u_e$  yielding:

$$r_0 = R - [x_0 u_e (U^2 - u_e^2)^{-1}]. \quad (2)$$

Of course, escape is possible from all larger  $r_0$ 's.

Now the proportion that escapes ( $P$ ) is from elementary principles:

$$P = (\pi R^2 - \pi r_0^2) (\pi R^2)^{-1} \quad (3)$$

Substituting the right hand side of (2) into (3) and rearranging yields the desired equation, i.e., an expression relating the proportion escaping to swimming speed and alarm distance as follows:

$$P = \left[ R - \left( \frac{x_0 u_e}{U^2 - u_e^2} \right) \right]^2 R^{-2}. \quad (4)$$

From (4) we can define the proportion caught ( $P'$ ) as simply  $1 - P$ . Assuming that the purse seine catches all larvae up to 10.5 mm by day, the proportion caught (or escaping) can be estimated as a function of size. The towing speed of the net was about 1.5 knots (76 cm sec<sup>-1</sup>). This leaves two unknowns, alarm distance ( $x_0$ ) and swimming speed ( $u_e$ ). Our approach in testing the model is to estimate swimming speed as a function of size based on values in the literature, and solve for alarm distance—also as a function of size. As will be seen, the derived alarm distances seem intuitively reasonable and, anticipating a later section, may explain the relatively small increase in sampling power of larger towed nets.

Appropriate measurements on the swimming speed of larval anchovies are not available. What

are required are maximum sustainable speeds over distances ranging from 0 to 100 cm or so. Houde (1969) found that yellow perch larvae larger than 9.5 mm could sustain speeds up to 4 body lengths per sec for 1 hr. Larimore and Duever (1968) observed swimming speeds over 10 body lengths per sec for over 3 min for small-mouth bass 20-25 mm in length. Hunter and Zweifel (1971), Figure 4, present data for sustained swimming of jack mackerel 4.5-27.0 cm for short periods. These data fitted to the expression  $y = ax^b$  yielded an  $a$  of 18.06,  $b$  of 0.829, and  $r$  of 0.997,  $y$  being speed in centimeters per second, and  $x$  body length ( $L$ ) in centimeters. This gives an extrapolated speed of 10 cm per sec for a 5-mm nehu larva. More recently, Hunter (1972) observed burst speeds of very short duration as high as 28 lengths per sec for a 4.2-mm larva and 25 lengths per sec for a 12.1-mm larva. Whether such speeds can be sustained long enough to explain plankton net avoidance is not known. In the computations to follow, we assume that they can be sustained as follows. One trial ( $u_e'$ ) assumes that the backward extrapolation of the data by Hunter and Zweifel (1971) holds ( $\text{cm/sec} = 18.06 L_{\text{cm}}^{0.829}$ ), and the second trial ( $u_e''$ ) assumes that cm/sec equals body length in centimeters times 10.

The catch data were processed as follows. The raw data (second and third columns in Table 2) were fitted to exponential expressions (fourth and fifth columns). The purse seine data were then multiplied by 46.883/29.685 to adjust the data to the point of assumed 100% meter net

efficiency (see Figure 2).  $P'$ , the fraction retained, was then calculated as  $1 - P$ .  $u_e'$  and  $u_e''$  were then calculated from the expressions in the preceding paragraph. Minimum alarm distance,  $x_0$ , was then calculated from:

$$x_0 = \frac{R(U^2 - u_e'^2)^{1/2} [1 - (P')^{1/2}]}{u_e'} \quad (5)$$

which is a straightforward rearrangement of equation (4). The resulting minimum alarm distances (last two columns in Table 2) do not seem unreasonable. For example, it seems reasonable that a 7.5-mm larva could detect a meter net 200-400 cm away and begin to take meaningful evasive action. The greater effectiveness of towed nets at night might be caused by a reduction in detection distance as well as reduced ability to take early, well-directed evasive action.

## OTHER TOWED NETS

Two additional sets of data will be considered here. The first is a comparison between a 10-ft Isaacs-Kidd trawl and a standard meter net. The ratio of mesh area-to-mouth opening was the same for both nets in order to ensure comparability of hydrodynamic and clogging characteristics. The trawl was meshed throughout with Nitex having an opening of 0.505 mm. This is nearly the same as that used in the standard CalCOFI (California Cooperative Oceanic Fisheries Investigations) meter net which, according to Smith, Counts, and Clutter (1968), had silk gauze with a mesh width of 0.55 mm as its main

TABLE 2.—Calculation of escape parameters for meter net and purse seine data.

Standard length (mm)	Purse seine observed	Meter net observed	Purse seine calculated <sup>1</sup>	Meter net calculated <sup>2</sup>	Purse seine adjusted <sup>3</sup>	$P'$	$u_e'^*$	$x_0'^{\dagger}$	$x_0''^{\dagger}$
3.5	33.082	53.905	29.685	46.883	46.883	1.000	7.564	0	0
4.5	20.366	12.984	26.063	19.754	41.163	.4799	9.316	134.7	288.7
5.5	23.575	4.627	22.883	8.323	36.140	.2303	11.002	190.6	397.0
6.5	20.807	5.048	20.091	3.507	31.731	.1105	12.637	210.3	428.1
7.5	19.507	1.157	17.639	1.478	27.858	.0531	14.228	212.6	424.6
8.5	16.616	2.048	15.847	.623	25.028	.0249	15.7837	207.0	407.0
9.5	13.457	1.034	13.597	.262	21.474	.0122	17.3082	196.9	381.8
10.5	10.941	0.018	11.938	.111	18.854	.0059	18.8054	185.6	355.8

<sup>1</sup> P.S.  $Y = arbx$   $r = -.93779$   $b = -.13013$   $a = 46.81074$   $x = \text{length (mm)}$ .

<sup>2</sup> M.N.  $Y = arbx$   $r = -.90039$   $b = -.86431$   $a = 965.5874$   $x = \text{length (mm)}$ .

<sup>3</sup> P.S. calculated  $\times 46.883/29.685$ .

\*  $u_e' = 18.06 L$  (cm)<sup>0.828888</sup>;  $u_e'' = 10 L$  (cm).

$\dagger x_0 = \frac{R(U^2 - u_e'^2)^{1/2} [1 - (P')^{1/2}]}{u_e'}$ .

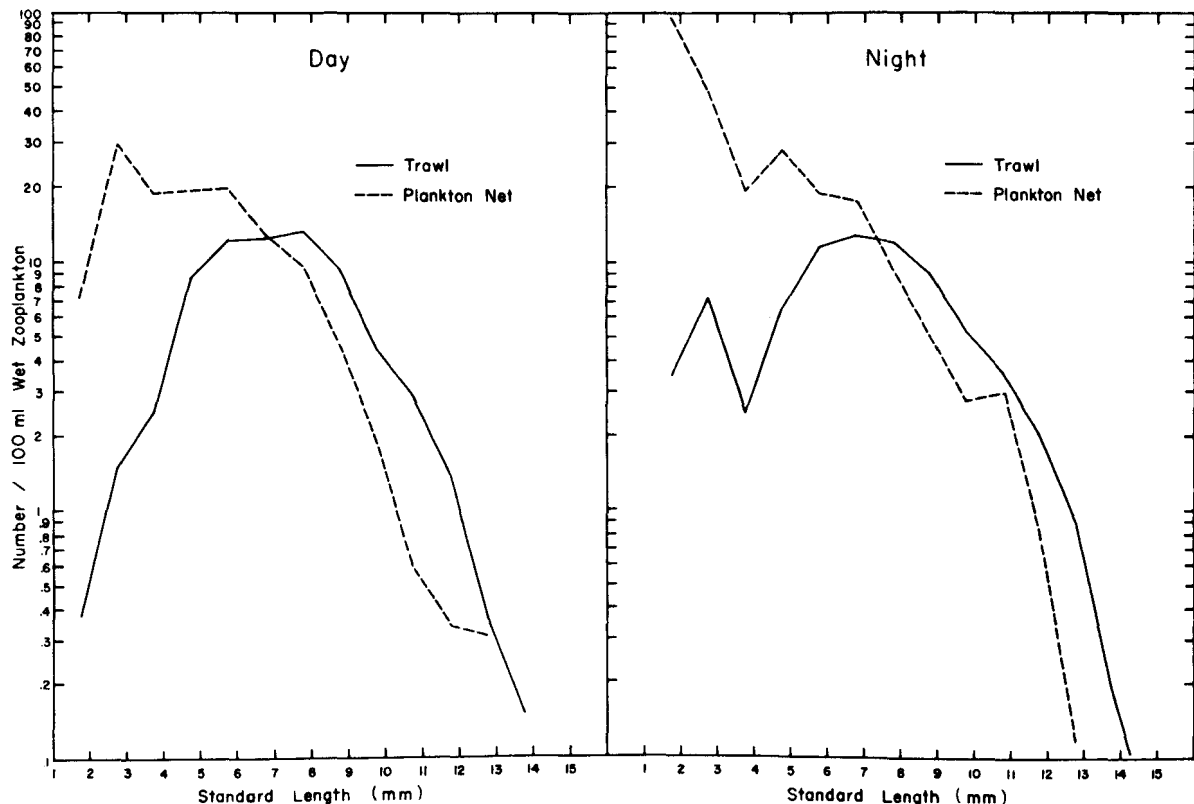


FIGURE 5.—Day and night catches of the Isaacs-Kidd trawl and the standard CalCOFI meter net.

body. It had a porosity of 36% after use compared to 51% for the Nitex. For this reason, the trawl, though preserving the geometry of the meter net, has a slightly better filtering capacity. These two nets were alternated over replicate courses off southern California during the period May 6 to May 8, 1964. In all, there were 22 paired day samples ( $\frac{1}{2}$ -hr tows) and 10 paired night samples.

The trawl-plankton net series are compared in Table 3 and Figure 5. The results are expressed as numbers per 100 ml of wet plankton taken. This was thought to be the best way to control the catches between the unmetered trawl and the metered plankton net. The severe undersampling of the small larvae by the trawl has no ready explanation, but could have been caused by our inadvertently having to tow at a faster

speed in order to maintain the vaned trawl at proper towing depths or by the greater transparency of the Nitex, which would reduce the effect of partial clogging on effective mesh size. The trawl is about twice as effective as the plankton net (Table 3) in the capture of larvae over 8.75 mm in length by day, but only slightly more efficient at night. With respect to both day and night, the trawl falls far short of the purse seine both with respect to the increased catches of larger larvae and the extension of upper limit of capture. The latter, of course, might be ascribable to the absence of larger larvae at the California sampling stations, but this seems unlikely.

The mean escape radius for the trawl is 3.4 times that of the meter net and led us, a priori, to expect a much greater enhancement of the



TABLE 3.—Summary of the meter net and trawl catches of anchovy larvae off southern California, May 6-8, 1964. The data are in numbers per 100 ml of wet volume zooplankton taken.

Length (mm)	Day		Night	
	Meter net	Trawl	Meter net	Trawl
1.75	7.332	0.382	96.160	3.490
2.75	28.746	1.491	48.030	7.110
3.75	18.869	2.473	19.360	2.430
4.75	19.320	8.619	28.060	6.410
5.75	19.927	12.222	18.880	11.200
6.75	12.860	12.578	17.130	12.480
7.75	9.646	13.168	9.070	11.890
8.75	4.650	9.432	5.020	8.880
9.75	1.959	4.537	2.760	5.260
10.75	0.604	2.887	2.960	3.590
11.75	0.345	1.428	0.840	2.020
12.75	0.313	0.368	0.120	0.900
13.75	--	0.150	--	.190
14.75	--	--	--	.060

TABLE 4.—Catches of four replicates of the purse seine and three simultaneously towed nets. Numbers are per 300 m<sup>3</sup> of water strained.

Length (mm)	Purse seine	1-m net	1/2-m net	1/4-m net
2.5	1,289.8	689.3	278.6	95.7
3.5	296.6	1,122.7	686.2	217.9
4.5	156.8	152.0	67.9	35.8
5.5	81.0	20.6	26.7	8.2
6.5	135.4			
7.5	89.5			
8.5	129.5			
9.5	49.3			
10.5	31.1			
11.5	29.6			
12.5	25.3			
13.5	41.4			
14.5	9.3			
15.5	10.1			
16.5	17.4			
17.5	2.6			
18.5	1.7			
19.5	6.9			
20.5	10.9			
21.5	7.8			
22.5	10.1			
23.5	8.3			
24.5	4.9			
25.5	0.9			

catches. Perhaps the larger size is detected farther away (increased  $x_0$ ), cancelling most of the advantage. This suggests that a towed net has to be large enough not to be perceived as a meaningful whole in order to significantly increase the catches of efficient escapers such as the anchovy.

The final set of data to be considered is four sets of stratified (in the same way as the purse seine-meter net data) samples taken by purse

seine, 1-m net, 1/2-m net, and 1/4-m net. All four sets were obtained on August 25, 1967, during daylight. The results (Table 4), apart from again demonstrating the superiority of the purse seine, are somewhat ambiguous. The towed nets clearly show a dramatic decrease in efficiency with decreasing size in terms of numbers caught, but the also-to-be-expected increase in slope (negative) with decreasing net size is not apparent.

The total numbers caught by the three towed nets are approximately proportional to the mean escape distance, but this observation is at variance with the slight improvement associated with the 10-ft trawl compared to the meter net discussed earlier. Very possibly the inconsistencies are a function of the limited sampling, especially with respect to this last set of data.

## DISCUSSION

Clutter and Anraku (1968) thoroughly reviewed the dodging problem on the basis of evidence and literature then available. Many of the data they reviewed were contradictory, and to some extent, we have extended the library of contradictions in this paper. We have, however, clearly shown from our purse seine data that towed nets are rather inefficient as samplers of at least one kind of fish larvae (anchovy)—especially by day. Likely, this conclusion can be extended to other pelagic larvae, as there must surely be strong selective pressure for avoidance of predation.

The algebraic model developed to reconcile the difference between our day purse seine and meter net catches involved two parameters, escape speed and alarm distance. It may be that future experimental work will not sustain the assumed escape velocities. If not, either a new model must be invoked or the alarm distance must be increased. The transparency of the water in Kaneohe Bay is low, so a very great extension of alarm distance on the basis of vision is not intuitively attractive.

A great deal of work has been directed at the design of towed nets in order to clean them up with respect to their disturbance in the water

and, hence, the vigor with which they telegraph their arrival. Yet, the dramatic improvement in the efficiency of towed nets at night suggests that vision is the most important avoidance cue. But, the optical characteristics of sea water are such that objects become invisible through contrast attenuation rather than resolution attenuation. This being so, large nets such as the Isaacs-Kidd trawl should be sighted at nearly the same distance as smaller nets such as the meter net. There should, then, be a dramatic increase in effectiveness with size. This is not evident in our data or anyone else's.

Short of resolving these contradictions, it appears that the development of towed sampling devices should proceed, as suggested by Clutter and Anraku (1968), in the direction of larger size, greater speed, and invisibility. The large scale "grab" sample, of which our purse seine is a rather specialized example, appears to be a possible definitive solution, or at least a practical means of calibrating towed nets.

## LITERATURE CITED

- AHLSTROM, E. H.  
1954. Distribution and abundance of egg and larval populations of the Pacific sardine. U.S. Fish and Wildl. Serv., Fish. Bull. 56:83-140.  
1965. A review of the effects of the environment of the Pacific sardine. Int. Comm. Northwest Atl. Fish., Spec. Publ. 6:53-74.
- BARKLEY, R. A.  
1964. The theoretical effectiveness of towed-net samplers as related to sampler size and to swimming speed of organisms. J. Cons. 29:146-157.
- CLUTTER, R. I., AND M. ANRAKU.  
1968. Avoidance of samplers. In D. J. Tranter (editor), Part I. Reviews on zooplankton sampling methods, p. 57-76. UNESCO, Monogr. Oceanogr. Methodol. 2, Zooplankton sampling.
- FAGER, E. W., AND J. A. MCGOWAN.  
1963. Zooplankton species groups in the North Pacific. Science (Wash., D.C.) 140:453-460.
- FLEMINGER, A., AND R. I. CLUTTER.  
1965. Avoidance of towed nets by zooplankton. Limnol. Oceanogr. 10:96-104.
- HOUDE, E. D.  
1969. Sustained swimming ability of larvae of wall-eye (*Stizostedion vitreum vitreum*) and yellow perch (*Perca flavescens*). J. Fish. Res. Board Can. 26:1647-1659.
- HUNTER, J. R.  
1972. Swimming and feeding behavior of larval anchovy, *Engraulis mordax*. Fish. Bull., U.S. 70: 821-838.
- HUNTER, J. R., D. C. AASTED, AND C. T. MITCHELL.  
1966. Design and use of a miniature purse seine. Prog. Fish-Cult. 28:175-179.
- HUNTER, J. R., AND J. R. ZWEIFEL.  
1971. Swimming speed, tail beat frequency, tail beat amplitude, and size in jack mackerel, *Trachurus symmetricus*, and other fishes. Fish. Bull., U.S. 69:253-266.
- ISAACS, J. D.  
1965. Larval sardine and anchovy interrelationships. Calif. Coop. Oceanic Fish. Invest., Rep. 10:102-140.
- LARIMORE, R. W., AND M. J. DUEVER.  
1968. Effects of temperature acclimation on the swimming ability of smallmouth bass fry. Trans. Am. Fish. Soc. 97:175-184.
- LONGHURST, A. R., A. D. REITH, R. E. BOWER, AND D. L. R. SEIBERT.  
1966. A new system for the collection of multiple serial plankton samples. Deep-sea Res. 13:213-222.
- MCGOWAN, J. A., AND V. J. FRAUNDORF.  
1966. The relationship between size of net used and estimates of zooplankton diversity. Limnol. Oceanogr. 11:456-469.
- SMITH, P. E., R. C. COUNTS, AND R. I. CLUTTER.  
1968. Changes in filtering efficiency of plankton nets due to clogging under tow. J. Cons. 32:232-248.
- TESTER, A. L.  
1951. The distribution of eggs and larvae of the anchovy, *Stolephorus purpureus* Fowler, in Kaneohe Bay, Oahu, with a consideration of the sampling problem. Pac. Sci. 5:321-346.
- UNESCO  
1968. Zooplankton sampling. UNESCO, Monogr. Oceanogr. Methodol. 2, 174 p.
- VENRICK, E. L.  
1971. Recurrent groups of diatom species in the North Pacific. Ecology 52:614-625.