# MESH RETENTION OF LARVAE OF *SARDINOPS CAERULEA* AND *ENGRAULIS MORDAX* BY PLANKTON NETS

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## ABSTRACT

Mesh retention of the standard plankton sampling gear used by the California Cooperative Oceanic Fisheries Investigations between 1949 and 1968 for larvae of the Pacific sardine (*Sardinops caerulea*) and northern anchovy (*Engraulis mordax*) was estimated by comparing catches made by the standard gear with a gear that retains larvae of all sizes. The results indicate that 67% of sardine larvae and 60% of anchovy larvae are retained by the meshes of the standard gear. The standard gear was replaced by a similar gear in 1969. Apparently all anchovy larvae are retained by the new gear. The new gear is the same as the old gear except for the netting. The netting of the new gear is constructed from 0.505-mm mesh width nylon while the netting of the standard gear was constructed from 0.55-mm mesh width silk. Catch curves of anchovy and sardine larvae corrected for escape through meshes revealed no evidence of a critical period.

Although fisheries literature contains numerous examples of estimates of mesh retention of fish by commercial fishing gear, there is little quantitative work on mesh retention of fish larvae by plankton gear. A review of such studies by Vannucci (1968) revealed only three papers containing quantitative estimates of mesh retention by plankton gear. The lack of knowledge on this subject can cause serious errors when comparing the estimates of abundance of fish larvae made from samples taken by different sampling gears or of two or more species of fish larvae by the same gear.

This paper presents estimates of mesh retention of larvae of the Pacific sardine (*Sardinops caerulea*) and northern anchovy (*Engraulis mordax*) by plankton nets that have been used by the CalCOFI (California Cooperative Oceanic Fisheries Investigations). Estimates are made of the errors that result because mesh retention is ignored when the relative abundance of the two species is calculated and when abundance of the anchovy is computed using data from two quite similar types of sampling gear. Finally the catch curves of the two species are examined for evidence of the critical period proposed by Hjort (1926).

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Several authors have noted that small larvae of the Pacific sardine and northern anchovy are not completely retained by the meshes of the plankton nets used by the CalCOFI, but did not have the necessary data to make quantitative estimates of the retention rates. Ahlstrom (1954) noted that small sardine larvae were not fully retained by the meshes of the net in use at that time. Ahlstrom (personal communication) attempted to obtain a measure of the retention rates with a series of paired plankton samples made with a regular CalCOFI net and a net with a finer mesh, but failed to capture an adequate number of sardine larvae. Isaacs (1965) concluded that anchovies up to 7.75 mm were not fully retained by the meshes. He attributed differences in the form of catch curves of anchovy larvae in different years to changes in the minimum size of complete retention. Murphy (1966) stated that anchovy larvae are undersampled ". . . by a factor of about 2, relative to sardines, i.e., they tend to pass through the mesh of the net to a marked extent." He did not describe his method of obtaining the estimate but later informed me (Murphy, personal communication) that he based his conclusion on comparison of catch curves with hypothetical curves based on the assumption of exponential mortality. Lenarz (in press) estimated that

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northern anchovy larvae were undersampled by a factor of 3.4 relative to sardine larvae because of differences in retention rate and rate of decline in catch with increase in size. His estimates of retention rates also were based on differences between observed catch curves and hypothetical curves based on a constant rate of decline.

## METHODS

The data for this study on fish larvae were taken from CalCOFI plankton tows. From 1949 to 1968, CalCOFI used a single silk net (type 1) of 0.55-mm mesh with a 1-m diameter mouth opening. During 1966-68 this net was paired with one of nylon of 0.333-mm mesh (type 2) with a ½-m diameter mouth opening. In 1969 the netting of the larger net was replaced with monofilament nylon netting of 0.505-mm (type 3). The variance of mesh width of the type 3 net is considerably less than that of the type 1 net. Other details of the net characteristics are available from Smith[2]. The nets were lowered and raised obliquely at a rate of 1.5 knots to a depth of 140 m in 1966-1968 and to 210 m during 1969. Since very few anchovy or sardine larvae occur below a depth of 140 m, the change in depth should make no difference in the results of this study. Other details of sampling are described by Ahlstrom (1966).

All sardine and anchovy larvae in each sample were identified and measured to the nearest 0.5 mm, standard length. The data revealed evidence of varying degrees of personal bias towards favoring measurements of whole millimeter rather than half millimeter. Sette (1950) was aware of the potential for this type of bias in measuring adult fish and stated: "... to avoid personal bias in favor of whole or half centimeter marks, the measuring scale had uniform graduation marks and they were serially numbered. In addition to avoiding bias, this had the advantage of giving two digit numbers for all listings and computations, the data being divided by two for conversion to centimeters at the final stage of work." Perhaps it would be prudent to follow the advice of Sette, if 0.5 mm accuracy is desired. Evidence of personal bias in measuring the smallest sizes of larvae was also noted. Since the smallest larvae are often distorted, it is difficult to make objective measurements. Because of the above described biases, measurements of the larvae are grouped into the intervals shown in Tables 1 and 2. Larvae captured by the type 2 net were multiplied by the ratio of volume of water sampled by the type 1 net to the volume of water sampled by the type 2 net to adjust for the smaller size of the type 2 net. The samples were chosen on the basis of the presence of sardine larvae or moderate numbers of anchovy larvae.

The following equations, using the notation of Regier and Robson (1966), were used to estimate mesh retention of the type 1 net

$$n_{1jk} = S_{1j} n_{2jk} + e_{jk} \qquad (1)$$

where $n_{ijk}$ = number of larvae of size $L_j$ caught by type $i$ net in $k$th sample.

$s_{ij}$ = mesh retention of type $i$ net to larvae of size $L_j$, i.e., $s_{ij} = n_{ij}/N_j$

where $N_j$ = either absolute or relative number of larvae of size $L_j$ in the population.

$e_{jk}$ = error term that is assumed to be normally distributed and independent of $n_{2jk}$.

The use of equation (1) to estimate mesh retention of the type 1 net implies the assumption that $s_{2j}$ is 1 for all $j$, i.e., $N_j \approx n_{2j}$. Preliminary analysis of data obtained from a series of paired samples of the type 2 net and a finer meshed net indicates that this assumption is valid for northern anchovy and Pacific sardine (P. E. Smith, personal communication). This method of estimating $S_{1j}$ from a known or estimated $N_j$ is noted as the "direct approach" in the terminology of Regier and Robson (1966).

The least squares estimate of $s_{1j}$ is given by Cochran (1963) as

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TABLE 1.—Catches of northern anchovy larvae by type 1 (0.55-mm mesh) and type 2 (0.333-mm mesh) nets for each sample.

| Cruise | Station | Net type | Standard length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5 | 3.75 | 4.75 | 5.75 | 6.75 | 7.75 | 8.75 | 9.75 |
| 6601 | 93.35 | 1 | 141 | 175 | 38 | 18 | 17 | 14 | 4 | 0 |
| | | 2 | 994.950 | 55.275 | 22.110 | 25.795 | 14.740 | 0.000 | 0.000 | 0.000 |
| 6601 | 103.29 | 1 | 95 | 121 | 291 | 145 | 45 | 23 | 10 | 5 |
| | | 2 | 164.250 | 141.255 | 351.495 | 128.115 | 42.705 | 22.995 | 13.140 | 3.285 |
| 6601 | 120.24 | 1 | 22 | 51 | 66 | 62 | 30 | 21 | 15 | 4 |
| | | 2 | 32.330 | 54.961 | 109.922 | 42.029 | 42.029 | 32.330 | 22.631 | 12.932 |
| 6601 | 120.35 | 1 | 25 | 59 | 37 | 17 | 11 | 0 | 0 | 0 |
| | | 2 | 36.113 | 68.943 | 36.113 | 16.415 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 113.50 | 1 | 3 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| | | 2 | 9.716 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 117.45 | 1 | 0 | 11 | 23 | 22 | 13 | 6 | 6 | 5 |
| | | 2 | 4.448 | 84.512 | 44.480 | 26.688 | 12.344 | 4.448 | 8.896 | 0.000 |
| 6607 | 118.39 | 1 | 17 | 64 | 22 | 9 | 8 | 10 | 14 | 0 |
| | | 2 | 208.518 | 117.858 | 13.599 | 13.599 | 9.066 | 4.533 | 4.533 | 4.533 |
| 6607 | 119.33 | 1 | 96 | 72 | 109 | 126 | 90 | 56 | 33 | 9 |
| | | 2 | 32.508 | 102.168 | 130.032 | 130.032 | 116.100 | 55.728 | 32.508 | 9.288 |
| 6607 | 120.25 | 1 | 8 | 11 | 2 | 2 | 0 | 0 | 0 | 0 |
| | | 2 | 97.196 | 128.122 | 26.508 | 8.836 | 4.418 | 0.000 | 0.000 | 0.000 |
| 6607 | 133.23 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 137.22 | 1 | 3 | 58 | 217 | 133 | 91 | 45 | 25 | 3 |
| | | 2 | 8.212 | 143.710 | 316.162 | 176.558 | 90.332 | 86.226 | 36.954 | 16.424 |
| 6607 | 137.23 | 1 | 6 | 29 | 41 | 80 | 45 | 27 | 13 | 2 |
| | | 2 | 66.195 | 61.782 | 105.912 | 52.956 | 26.478 | 30.891 | 8.826 | 13.239 |
| 6608 | 87.35 | 1 | 360 | 11 | 13 | 6 | 6 | 8 | 2 | 0 |
| | | 2 | 877.150 | 162.190 | 122.470 | 33.100 | 39.720 | 26.480 | 6.620 | 3.310 |
| 6608 | 130.28 | 1 | 23 | 43 | 21 | 10 | 1 | 1 | 1 | 0 |
| | | 2 | 29.552 | 51.716 | 18.470 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6608 | 130.30 | 1 | 13 | 29 | 29 | 15 | 7 | 1 | 0 | 0 |
| | | 2 | 47.879 | 66.294 | 22.098 | 11.049 | 11.049 | 7.366 | 0.000 | 0.000 |
| 6608 | 133.25 | 1 | 32 | 19 | 7 | 8 | 2 | 0 | 1 | 0 |
| | | 2 | 151.578 | 79.398 | 21.654 | 25.263 | 7.218 | 0.000 | 0.000 | 0.000 |
| 6610 | 120.40 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6610 | 130.28 | 1 | 0 | 5 | 6 | 9 | 2 | 3 | 0 | 1 |
| | | 2 | 0.000 | 7.128 | 10.692 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6611 | 120.25 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6611 | 137.23 | 1 | 32 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 127.575 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6706 | 83.55 | 1 | 9 | 17 | 36 | 53 | 35 | 33 | 23 | 25 |
| | | 2 | 41.808 | 62.712 | 70.551 | 39.195 | 44.421 | 23.517 | 15.678 | 33.969 |
| 6706 | 110.40 | 1 | 21 | 6 | 30 | 57 | 56 | 52 | 48 | 58 |
| | | 2 | 3.074 | 3.074 | 24.592 | 18.444 | 36.888 | 12.296 | 15.370 | 3.074 |
| 6706 | 120.24 | 1 | 1 | 0 | 0 | 4 | 4 | 1 | 0 | 0 |
| | | 2 | 6.278 | 0.000 | 0.000 | 0.000 | 3.139 | 0.000 | 0.000 | 0.000 |
| 6706 | 120.40 | 1 | 2 | 4 | 14 | 31 | 19 | 26 | 12 | 7 |
| | | 2 | 0.000 | 0.000 | 17.550 | 14.625 | 14.625 | 20.475 | 5.850 | 5.850 |
| 6712 | 107.45 | 1 | 123 | 106 | 18 | 10 | 13 | 1 | 5 | 0 |
| | | 2 | 287.586 | 114.297 | 11.061 | 14.748 | 14.748 | 0.000 | 0.000 | 0.000 |
| 6712 | 120.50 | 1 | 333 | 23 | 9 | 11 | 7 | 6 | 1 | 0 |
| | | 2 | 496.110 | 14.380 | 0.000 | 7.190 | 17.975 | 0.000 | 3.595 | 3.595 |

$$\tilde{s}_{1j} = \frac{\sum_{k=1}^{m} n_{1jk} n_{2jk}}{\sum_{k=1}^{m} n_{2jk}}, \qquad (2)$$

where $m$ = number of samples.

However, if the assumption of independence of $e_{jk}$ is violated, (2) is not the least squares estimate of $s_{1j}$. A form of violation of the assumption which is common in plankton sampling is that the error term is proportional to $\sqrt{n_{2jk}}$. In this case the least squares estimate of $s_{1j}$ is given by Cochran (1963) as

TABLE 2.—Catch of Pacific sardine larvae by type 1 (0.55-mm mesh) and type 2 (0.333-mm mesh) nets for each sample.

| Cruise | Station | Net type | Standard length | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2.5 | 3.75 | 4.75 | 5.75 | 6.75 | 7.75 | 8.75 | 9.75 |
| 6601 | 93.35 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6601 | 103.29 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 |
| | | 2 | 0.000 | 3.285 | 3.285 | 0.000 | 0.000 | 0.000 | 3.285 | 0.000 |
| 6601 | 120.24 | 1 | 1 | 2 | 7 | 8 | 4 | 3 | 0 | 1 |
| | | 2 | 0.000 | 3.233 | 16.165 | 6.466 | 12.932 | 0.000 | 0.000 | 0.000 |
| 6601 | 120.35 | 1 | 0 | 1 | 38 | 4 | 0 | 0 | 0 | 0 |
| | | 2 | 0.000 | 3.283 | 42.679 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 113.50 | 1 | 0 | 0 | 2 | 8 | 0 | 0 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 4.858 | 4.858 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 117.45 | 1 | 0 | 0 | 0 | 2 | 8 | 5 | 5 | 3 |
| | | 2 | 0.000 | 0.000 | 0.000 | 13.344 | 8.896 | 8.896 | 17.792 | 13.344 |
| 6607 | 118.39 | 1 | 0 | 3 | 16 | 17 | 4 | 2 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 31.731 | 18.132 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 119.33 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 120.25 | 1 | 4 | 3 | 4 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 13.254 | 8.836 | 17.672 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6607 | 133.23 | 1 | 10 | 28 | 8 | 6 | 2 | 0 | 0 | 0 |
| | | 2 | 43.030 | 51.636 | 12.909 | 21.515 | 8.606 | 0.000 | 4.303 | 4.303 |
| 6607 | 137.22 | 1 | 60 | 15 | 8 | 11 | 14 | 6 | 3 | 3 |
| | | 2 | 147.816 | 24.636 | 24.636 | 32.848 | 12.318 | 4.106 | 8.212 | 8.212 |
| 6607 | 137.23 | 1 | 5 | 0 | 1 | 0 | 1 | 1 | 0 | 1 |
| | | 2 | 0.000 | 4.413 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6608 | 130.28 | 1 | 8 | 33 | 29 | 27 | 9 | 5 | 1 | 1 |
| | | 2 | 36.940 | 70.186 | 33.246 | 33.246 | 3.694 | 7.388 | 3.694 | 0.000 |
| 6608 | 130.30 | 1 | 83 | 56 | 15 | 8 | 1 | 0 | 2 | 1 |
| | | 2 | 99.441 | 77.343 | 7.366 | 11.049 | 7.366 | 0.000 | 3.683 | 0.000 |
| 6608 | 133.25 | 1 | 11 | 63 | 13 | 3 | 6 | 0 | 1 | 0 |
| | | 2 | 43.308 | 198.495 | 14.436 | 10.827 | 3.609 | 0.000 | 0.000 | 0.000 |
| 6610 | 120.40 | 1 | 2 | 14 | 9 | 4 | 5 | 8 | 6 | 8 |
| | | 2 | 0.000 | 10.761 | 7.174 | 3.587 | 14.348 | 17.935 | 10.761 | 3.587 |
| 6610 | 130.28 | 1 | 2 | 32 | 2 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 7.128 | 46.332 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6611 | 120.25 | 1 | 1 | 13 | 263 | 294 | 111 | 75 | 40 | 33 |
| | | 2 | 3.621 | 28.968 | 318.648 | 152.082 | 83.283 | 83.283 | 65.178 | 32.589 |
| 6611 | 137.23 | 1 | 1 | 23 | 2 | 1 | 0 | 0 | 0 | 0 |
| | | 2 | 10.935 | 54.675 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6706 | 110.40 | 1 | 0 | 1 | 9 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0.000 | 0.000 | 3.074 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6706 | 120.24 | 1 | 5 | 30 | 57 | 13 | 4 | 1 | 0 | 0 |
| | | 2 | 113.004 | 194.618 | 116.143 | 12.556 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6706 | 120.40 | 1 | 4 | 118 | 175 | 65 | 25 | 11 | 5 | 2 |
| | | 2 | 32.175 | 216.450 | 187.200 | 35.100 | 8.775 | 5.850 | 2.925 | 0.000 |

$$\tilde{s}_{1j} = \frac{\sum_{k=1}^{m} n_{1jk}}{\sum_{k=1}^{m} n_{2jk}}. \qquad (3)$$

Plots of $n_{1jk}$ and $n_{2jk}$ did not clearly indicate the relation between $e_{jk}$ and $n_{2jk}$. Thus both methods of estimating $s_{1j}$ were used.

Examination of the data revealed that a linear equation is appropriate to describe the relation between $s_{1j}$ and $L_j$ when $L_j \leqslant 5.75$ mm.

$$\tilde{s}_{1j} = a + bL_j. \qquad (4)$$

Linear regression techniques were used to estimate the parameters, $a$ and $b$, of the equation.

## RESULTS

Table 1 presents catches of anchovy larvae by the type 1 and type 2 nets for each sample. The first two digits of the cruise refer to year and the second two by month. Station notation is explained by Ahlstrom (1966). Larvae greater than 9.75 mm were captured, but the numbers involved were too small to be useful for the study. Estimates by (2) and (3) of $s_{1j}$ are as follows:

| $L_j$(mm) | $\tilde{s}_{1j}(2)$ | $\tilde{s}_{1j}(3)$ |
|---|---|---|
| 2.50 | 0.312 | 0.367 |
| 3.75 | 0.512 | 0.603 |
| 4.75 | 0.711 | 0.699 |
| 5.75 | 0.946 | 1.057 |
| 6.75 | 0.875 | 0.916 |
| 7.75 | 0.753 | 1.021 |
| 8.75 | 1.007 | 1.226 |
| 9.75 | 0.664 | 1.087 |

Plots, Figure 1, of the estimates show that there is a very good linear relation between the estimates and $L_j$ when 2.50 mm $\leqslant L_j \leqslant$ 5.75 mm. When $L_j >$ 5.75 mm $\tilde{s}_{1j}(2)$ decreases while $\tilde{s}_{1j}(3)$ fluctuates about 1. Thus it appears that a linear relation (4) provides an adequate description of the relation between $\tilde{s}_{1j}$ and $L_j$ when 2.50 mm $\leqslant L_j \leqslant$ 5.75 mm. When $L_j >$ 5.75 mm it is assumed that $\tilde{s}_{1j} = 1$. Vannucci (1968) reviewed papers that used the logistic and normal distribution functions which have $s_{ij}$ approaching 1 as an asymptote rather than the discontinuous equation used in this study. The data used in this study are not accurate enough when $L_j >$ 5.75 mm to warrant use of an asymptotic relation. The very good linear relation between $L_j$ and $\tilde{s}_{1j}$ when $L_j \leqslant$ 5.75 mm and the high values of $\tilde{s}_{1j}$ when $L_j$ = 5.75 mm indicate that any deviation from the equation used in this study would cause minor errors when $\tilde{s}_{1j}$ are used to correct catches of anchovy larvae for loss through meshes.

The estimate of $a$ from (2) and (4) is —0.1942, $b$ is 0.1945, and the correlation coefficient, $r$, is 0.9961. When (3) was used $a$ is —0.1075, $b$ is 0.1850, and $r$ is 0.9814.

Table 2 contains catches of sardine larvae used in the study. Estimates by (2) and (3) of $s_{1j}$ are as follows:

| $L_j$(mm) | $\tilde{s}_{1j}(2)$ | $\tilde{s}_{1j}(3)$ |
|---|---|---|
| 2.50 | 0.375 | 0.358 |
| 3.75 | 0.385 | 0.436 |
| 4.75 | 0.817 | 0.782 |
| 5.75 | 1.754 | 1.330 |
| 6.75 | 1.275 | 1.203 |
| 7.75 | 0.881 | 0.926 |
| 8.75 | 0.584 | 0.526 |
| 9.75 | 0.873 | 0.854 |

The estimates of $s_{1j}$ for sardine larvae are similar to those for anchovy larvae. Thus the same discontinuous function is assumed. The estimate of $a$ from (2) and (4) is —0.2382, $b$ is 0.2107, and $r$ is 0.9320. Estimates obtained when (3) was used are $a$, —0.2286, $b$, 0.2084, and $r$, 0.9639. The resulting curves for both anchovy and sardine larvae are shown in Figure 2. The curves differ little either within or between species. Since the highest value of $r$, 0.9961, was estimated for anchovy larvae using equation (2), the somewhat arbitrary decision was made to use the results obtained from equation (2).

## ESTIMATION OF PORTION OF LARVAE PASSED THROUGH MESHES OF TYPE 1 (0.55-MM MESH) NET

The type 1 net has been the major plankton sampler of the CalCOFI. Estimates of spawning biomass of the northern anchovy population have been based on the ratio of total catches of sardine larvae to total catches of anchovy larvae (Ahlstrom, 1968). If there are major differences in the percentages of sardine and anchovy larvae retained by the net, then the estimates of anchovy spawning biomass may be seriously in error. Ahlstrom (personal communication) believed that his assumption that the two species were sampled equally well was valid because of the similar forms of larvae of the two species and his interpretations of catch curves of larvae of the two species.

Catch (average) curves of anchovy and sardine larvae were calculated from a series of CalCOFI samples taken during the months of January through July during the decade 1951-1960. More than 10,000 samples are involved. Catch curves were calculated for day and night samples separately because of marked differences between the two. The curves were then corrected for nonretention of larvae as follows:

$$n'_{1jko} = n_{1jko}(1/s_{1j}) \qquad (5)$$

where $n'_{1jko}$ = the corrected catch of larvae of size $L_j$ by net type 1 in the $k$th time of day, and $o$th species.

$$k = \begin{cases} 1 \text{ for night samples} \\ 2 \text{ for day samples} \end{cases}$$

$$o = \begin{cases} 1 \text{ for anchovy} \\ 2 \text{ for sardine} \end{cases}$$

The corrected and uncorrected curves plotted on a semilogarithmic scale are shown with $n_{1jko}$ and $n'_{1jko}$ expressed in percent of total in Figures 3-6. The corrected curve for anchovy larvae caught at night shows a slight increase in the rate of decline with size. The corrected curve for anchovy caught during the day is essentially linear as is the corrected catch curve for sardine larvae caught during the night. The corrected catch curve for sardine larvae caught during the day shows a decreasing rate of decline with size. In all cases the corrected curves show little indication of undersampling of small larvae.

The following equation was used to estimate the portion of larvae not collected by the type 1 net because of passage through the mesh:

$$P_{1o} = \frac{\sum\limits_{jk}\sum n_{1jko}}{\sum\limits_{jk}\sum n'_{1jko}} \qquad (6)$$

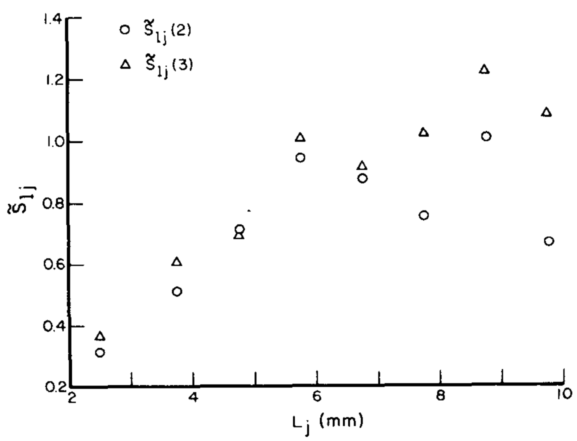


FIGURE 1.—Scatter diagram of estimates of mesh retention by type 1 (0.55-mm mesh) net using equation (2) ($S_{1j}(2)$), mesh retention using equation (3) ($s_{1j}(3)$), and standard length ($L_j$) for northern anchovy larvae.

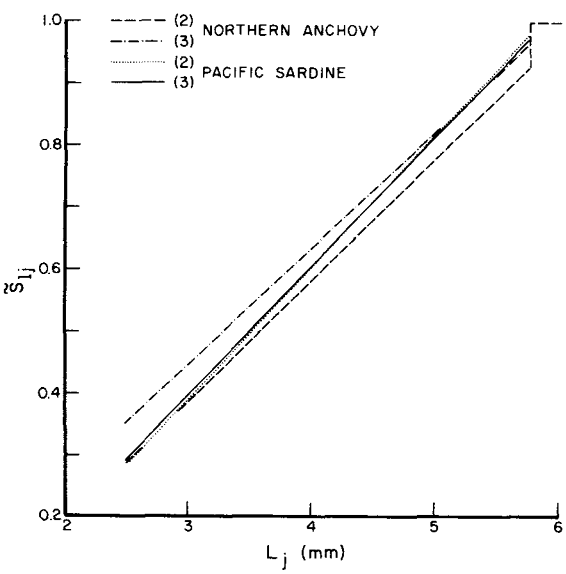


FIGURE 2.—Estimates of mesh retention by type 1 (0.55-mm mesh) net ($s_{1j}$) against standard length ($L_j$) for larvae of northern anchovy and Pacific sardine using equations (2) and (3).

where $1—P_{io}$ = portion of larvae of species $o$ not sampled by type $i$ net because of passage through meshes.

Equation (6) implies that an equal number of night and day samples are taken. This is approximately correct. The estimate of $P_{1o}$ for anchovy is 0.60. The estimate of $P_{1o}$ for sardine is 0.67. Thus anchovy larvae are undersampled by about 12% relative to sardine larvae because of differences in mesh retention and size composition.

## CATCH CURVE OF TYPE 3 (0.505-MM MESH) NET

Figure 7 shows the catch curve plotted on a semilogarithmic scale of anchovy larvae caught by the type 3 net during 1969 by the CalCOFI. This data is preliminary (P. E. Smith, personal communication) and catches have not been separated by day and night. The interesting feature of this curve is that it is essentially linear

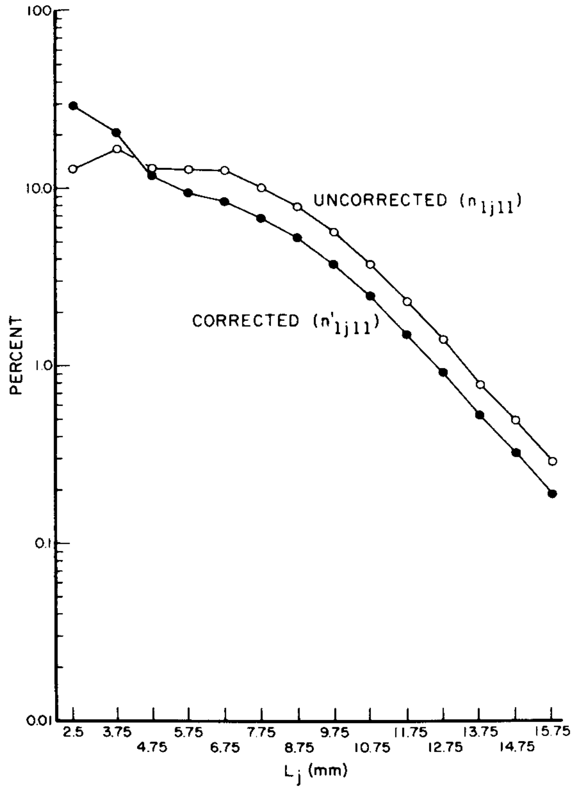


FIGURE 3.—Corrected ($n'_{1j11}$) and uncorrected ($n_{1j11}$) catches by standard length ($L_j$) of northern anchovy taken at night with type 1 (0.55-mm mesh) net. Catches are expressed in percent of total.

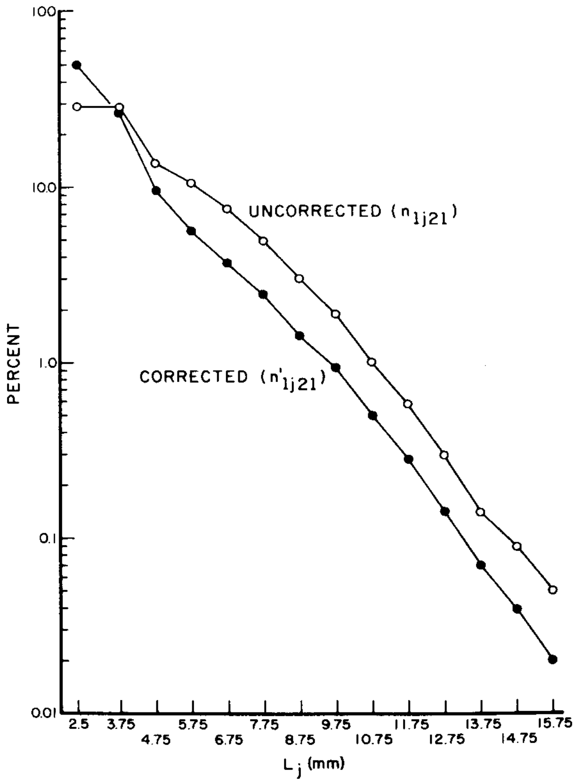


FIGURE 4.—Corrected ($n'_{1j21}$) and uncorrected ($n_{1j21}$) catches by standard length ($L_j$) of northern anchovy taken during day with type 1 (0.55-mm mesh) net. Catches are expressed in percent of total.

with size. This indicates that few if any small anchovy larvae escape capture by passing through the meshes. Thus a 10% decrease in mesh size and a large decrease in the variance of mesh size changed $P_{i1}$ from 0.60 to about 1. The difference in $P_{i1}$ between the type 1 and type 3 nets means that total catches of anchovy larvae by the type 1 net should be multiplied by 1.7 to be comparable to catches of anchovy larvae by the type 3 net.

## DISCUSSION

The similarity of the catch curves of anchovy larvae caught by the type 3 net and the corrected catch curve for the type 1 net suggests that the estimates of $s_{1j}$ are reasonably accurate. It would be a remarkable coincidence otherwise as the data are independent.

It is interesting that the type 3 (0.505-mm mesh width) net apparently retains most if not all anchovy larvae, for the body depth at the insertion of the pectoral fin of 3.75-mm anchovy larvae is about 0.35 mm (P. E. Smith, personal communication) which is considerably less than the mesh width. Smith, Counts, and Clutter (1968) summarized the results of Saville (1958) by concluding that an organism must be wider than the mesh diagonal to be completely retained. A conclusion of this study is that the "diagonal rule" is too conservative for slowly towed nylon nets. Heron (1968) concluded that mesh variability is a very important factor in-

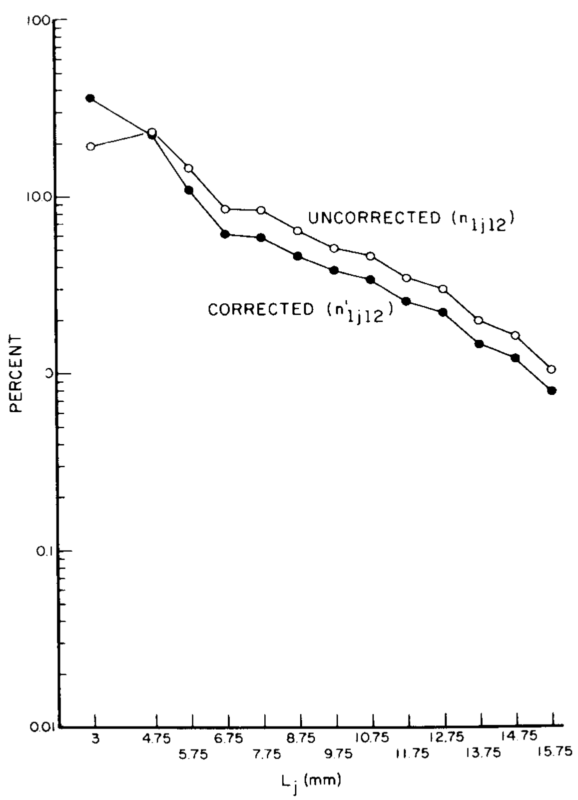


FIGURE 5.—Corrected ($n'_{1j12}$) and uncorrected ($n_{1j12}$) catches by standard length ($L_j$) of Pacific sardine taken at night with type 1 (0.55-mm mesh) net. Catches are expressed in percent of total.

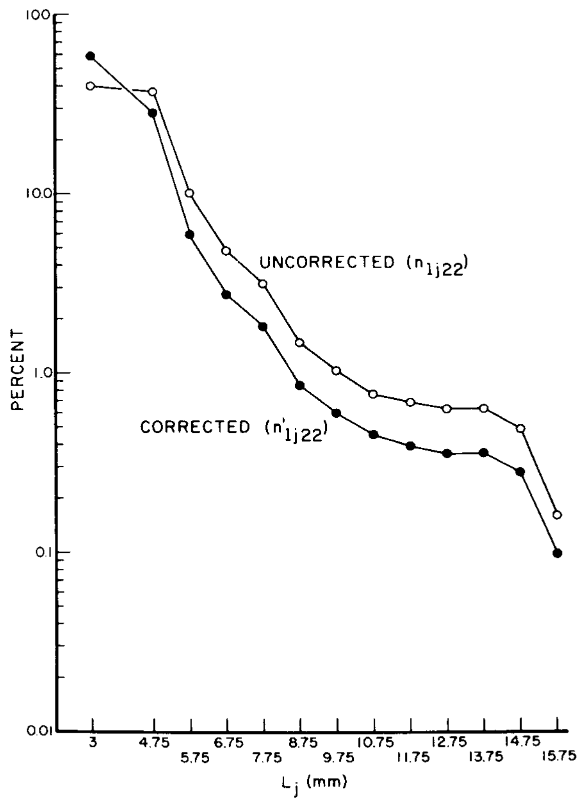


FIGURE 6.—Corrected ($n'_{1j22}$) and uncorrected ($n_{1j22}$) catches by standard length ($L_j$) of northern anchovy taken during day with type 1 (0.55-mm mesh) net. Catches are expressed in percent of total.

fluencing escapement and implied that the coefficient of variation of mesh width is greater for silk than nylon nets. The results of this study agree with Heron's conclusions.

The results indicate that two similar types of sampling gear have greatly different mesh retention properties for anchovy larvae. This implies that considerable care should be taken in the selection of sampling gear if quantitative estimates of the abundance of fish larvae are desired. The similarity in mesh retention shown for anchovy and sardine larvae may be due to the fact that the larval forms are very similar. However the diversity of forms found in fish larvae is tremendous. Mesh retention should be estimated before quantitative estimates of the relative abundance of larvae of different species of fish are attempted. The results indicate that adequate estimates of mesh retention can be made from less than 30 samples containing the desired species of fish larvae. If the mesh retention curve is curvilinear in the region of fish larvae of minimum size, more samples may be necessary.

The reasoning of Hjort (1926) in expecting a critical period in the early life of fish larvae is intuitively pleasing. Hunter (1972) showed experimentally that a much higher density of food organisms is necessary for survival of 4- to 6-mm anchovy than for larger larvae. However, there is no indication of a critical period at the 4- to 6-mm sizes in this study, i.e., there are no major

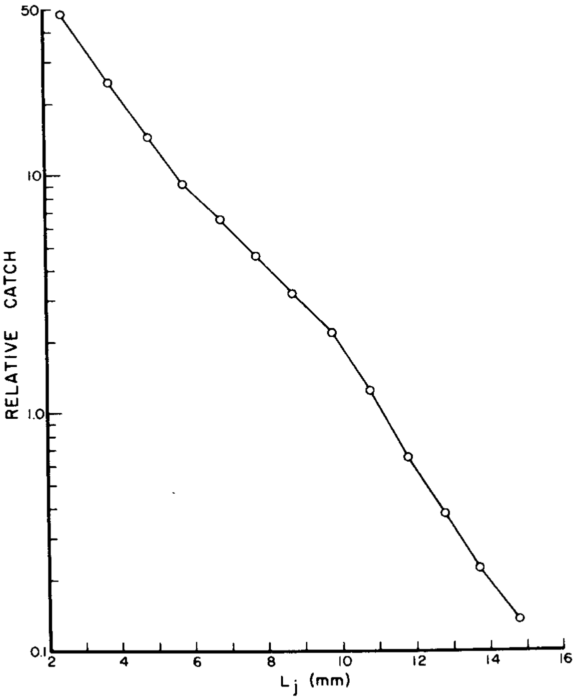


FIGURE 7.—Catches of northern anchovy by standard length ($L_j$) taken by type 3 (0.505-mm mesh) net.

changes in the slopes of the catch curves. However, since the catches are plotted with size rather than age, a faster rate of growth at small sizes relative to large sizes could cause small size larvae to be relatively undersampled. If this were the case, a critical period could occur but not be indicated by catches plotted with size. Kramer and Zweifel (1970) indicated that the growth rate of anchovy larvae increases rather than decreases with size during the first few millimeters of growth. Another factor that could influence the catch rate of larvae differently with size is avoidance of the net. However, experience indicates that avoidance increases with size (Lenarz, in press). Thus, the large larvae should be relatively undersampled. I conclude, therefore, that available data does not provide any evidence of the critical period for sardine or anchovy larvae. This conclusion is in agreement with other authors that have examined catch curves of fish larvae, e.g., Marr (1956).

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