Variable Factors Affecting the Apparent Range and Estimated Concentration of Euphausiids in the North Pacific

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THE QUANTITATIVE and qualitative contents of a zooplankton sample are influenced by two kinds of variables: (1) natural variables such as temperature of the water, currents, latitudinal and seasonal variations in sunlight intensity, water transparency, amount of food or nutrients, oxygen content of the water, which may modify or maintain the horizontal and vertical distribution of species and condition their breeding and growth cycles; (2) artificial variables associated with (a) the method used to present the data, (b) the method used to take aliquots and count the plankton, and (c) the collecting method—type of net, depth of tow, hour of day of sampling.

This discussion deals with the artificial variables in the study of euphausiid distribution. Before ecological relationships can be considered, apparent variability in number and kind of organisms due to artificial circumstances must be distinguished where possible.

The standard net, 1 m in mouth diameter, used by the California Cooperative Oceanic Fisheries Investigations, or CCOFI (Ahlstrom, 1948), and the Pacific Oceanic Fisheries Investigations, or POFI (King and Demond, 1953), is now widely used in the Pacific area. This paper examines the hypothesis that the net is a reliable sampler of euphausiids and considers density estimates in relation to other variables in sampling and data processing procedures.

This paper represents one of the results of research conducted under the Marine Life Research Program, the Scripps Institution's component of CCOFI. The suggestions of Professor M. W. Johnson are gratefully acknowledged. I want to thank Dr. E. W. Fager for planning the test of the counting method and for many important suggestions. I am grateful to Professor C. L. Hubbs for critical review of much of the original manuscript.

METHODS OF COLLECTION AND ANALYSIS

The euphausiids here considered were taken from plankton collected during oceanographic surveys carried out by the Scripps Institution of Oceanography, 1950–57, and from surveys in the region of the California Current by CCOFI, 1949–59. Data from seven cruises are considered (Table 1).

The standard 1-m net is conical, 5 m long, and made of heavy-duty grit gauze, 0.65 mm between threads.

Quantitative estimates of flow through the net were obtained by means of an Atlas Flow Meter. An analysis of the performance and calibration of the flow meter is given by Ahlstrom (1948). Readings were made of meters placed at the center and at the periphery of the mouth of the net. The standard deviation of the paired readings was 6.5%.

The counts of euphausiids are standardized on the basis of 1000 m^3 of water strained. Most samples were obtained by oblique hauls, while the ship moved at a speed of 1–2 knots. In such hauls the net strained 400–1000 m^3 of water. Individual samples consisted of elements of plankton populations integrated across a horizontal distance of 0.3–2.0 miles and depths of 0–70, 0–140, or 0–280 m. (Tows made by the "E. W. Scripps" off Monterey, Oct 1950, were vertical. The ship was anchored during the 7-day period.)

Subsurface layers were sampled by nets which were opened and closed at desired depths, using a device described by Leavitt (1938).

During the 1956 cruise to the mid-Equatorial Pacific ("Equapac"), a smaller net, 45-cm mouth diameter and 0.33-mm mesh width, was used in conjunction with the standard 1-m net. Both nets, the smaller attached to the wire above the

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TABLE 1

CRUISES ON WHICH PLANKTON WAS COLLECTED

CRUISE	AREA SAMPLED	NET USED	DEPTHS SAMPLED
1939 "E. W. Scripps" Cruise VIII	California Current; Cascade Head, Ore., to Viscaino Bay, Baja California	1.0 m, #24XXX grit gauze; open and opening-closing nets	0–40, 40–80, 80–120 m; oblique hauls
Oct 1950 CCOFI Cruise 19	sta. 72.60: 35° 35.5′ N, 122° 07.5′ W	1.0 m, #30XXX grit gauze; open net	0–140 m, vert.
	sta. 70.90: 34° 51′ N, 124° 33′ W	1.0 m, #30XXX grit gauze; open net	0–140 m, oblique
	sta. 70.130: 33° 33′ N, 127° 16.5′ W	1.0 m, #30XXX grit gauze; open net	0–140 m, oblique
Apr 1952 CCOFI Cruise 36	California Current; San Francisco to Magdalena Bay; grid-buoy survey off Punta Eugenia	1.0 m, #30XXX grit gauze; open net	0–140 m, oblique
Aug–Dec 1953 "Transpacific" Exped.	San Diego–Bering Sea, Japan, Hawaii	1.0 m, #30XXX grit gauze; open and opening-closing nets	0–150 m, oblique 150–300 m, oblique 300–450 m, oblique 450–600 m, oblique 0–700 m, oblique
Apr–May 1954 Pelagic Area Cruise	Offshore Baja California	1.0 m, #30XXX grit gauze; open and opening-closing nets	surface net 0–25 m, oblique 25–50 m, oblique 50–75 m, oblique 75–100 m, oblique 100–300 m, oblique 300–500 m, oblique 500–700 m, oblique
Aug–Sep 1955 Norpac Survey (CCOFI Cruise 5508)	North Pacific east of 150° W, 20–48° N	1.0 m, #30XXX grit gauze; open and opening-closing nets	0–140 m, oblique 140–280 m, oblique 0–700 m, oblique
Aug–Sep 1956 Equapac Survey; sta. occupied by "Stranger"	mid-Equatorial Pacific	1.0 m, #30XXX grit gauze; 45 cm, 0.33 mm between meshes	0–140 m, oblique

other, were towed obliquely. Standardized counts of samples obtained from the two nets are compared.

PRESENTATION OF ZOOGEOGRAPHICAL DATA

Estimated concentration and geographical distribution of zooplankton are usually plotted by indicating the volume, weight, or number of organisms on a map of the collecting pattern of the survey. The quantity at a given locality may be indicated as (1) a number, often used when numbers of organisms at the localities are small; (2) a symbol (Glover, 1952; Johnson, 1956; Bary, 1959; Baker, 1959), the size or shape of which is related to the observed concentration; (3) a straight line bearing a linear relationship to the concentration, drawn through the position of the station (Johnson, 1953); (4) a numerical range which is an interval between selected sequences of contour levels (Thrailkill, 1957; Glover, 1957; David, 1958; Bieri, 1959).

The contour method may best be used to describe a distribution when the local patchiness is less than the geographical variation in concentration shown by the contours. Use of this method implies that the plankton net has strained enough water to average out the local patchiness.

Charts using contour levels to show species concentration combine presentation and interpretation of the data. The contoured distribution of a species visually relates the similar concentrations sampled. The resulting geographical patterns of presence and absence, abundance and scarcity, become discrete with respect to the sampling pattern. Intervals must be wide enough to minimize sampling and counting variables, but small enough to reflect significant geographical variations in population size.

Intervals between contour levels might have been selected according to a graphical method described by Cushing (1953). This method, not used in the present analysis, has the advantage that confidence limits can be attached to single observations. Confidence limits of some values will, of course, overlap two contour intervals.

Levels derived by Cushing for *Calanus* differed from one another by a factor of 7. Those used here differ by a factor of 10, arrived at by trial after the ranges of concentration were determined for all species in the several surveys.

The effects of artificial variables, such as diurnal discrepancies in the availability of euphausiids to the nets, and sampling and counting errors, are reduced when the contour intervals have a wider range than the variables. It will be seen that some details of the distributions would be altered if the hour of day of sampling and depth of tow were standardized. In most zoogeographical studies attention focuses on the general character of the distribution, or on features of boundary and concentration based upon a number of records. Less reliability can be attached to details, which may be influenced locally by transient hydrographic anomalies, cloudiness, or the swarming habits of certain nearshore or cold-water species.

REPLICATE COUNT ANALYSIS

In our treatment of the many plankton samples it was necessary to use aliquots, while retaining as far as possible the quantitative and qualitative worth of the large sample. The procedure included (1) counting and measuring all specimens in an aliquot of the sample, and (2) scanning the remainder of the sample under the microscope for species that appeared not to have been represented properly in the aliquot, or that were entirely lacking in it. In general, the fraction served for counts of the dominant species, while for the rarer species all individuals were counted.

When the sample was seen to contain few euphausiids, an aliquot of ¼ or ⅕ the sample was taken. One-tenth of the sample was usually counted when the sample was rich, that is, when it contained more than 700–1,000 euphausiids. Two methods have been used for taking aliquots. The Folsom plankton sample splitter has been shown to be statistically reliable for fractioning and for the euphausiid component of the plankton (McEwen, Johnson, and Folsom, 1954), but a quicker method proved adequate. The sample was gently agitated. When the plankton was in suspension it was poured into a 500-ml graduate cylinder. The combined volume of plankton and fluid, usually about 400 ml, was measured, and all but the intended aliquot (approximately the lower 1/10 or 1/5) was quickly poured back into the original container. Since the larger euphausiids settle to the bottom of the cylinder in 20–40 sec, it was important to keep the material in a state of agitation while fractionating except when the volumetric readings were made. The majority of the euphausiid specimens in the samples were larvae or immature individuals. These remained longer in suspension than did the adults.

The reliability of the aliquot and counting procedure was examined in a test in which replicate counts were made of 1/10 aliquots of three samples. Quantities of plankton containing up to three test species were, one at a time, provided the author, who was not informed of the number of samples prepared, or of the number of specimens of the test species, if any, added to them. This plankton contained many euphausiid species, but had previously lacked those which were added for the purpose of the test counts. The three samples were then presented, one at a time, in random sequence until a total of five counts had been made of each. Two "nuisance samples," not counted in replicate, were inserted in the sequence.

Counts of the 1/10 aliquots are given in Table 2.

Analysis of the counts for each of the densities (15 counts each) indicated that in this range of densities the present fractionating method yields effectively random aliquots of the plankton samples (agreement with Poisson, all probabilities over 0.10). The square root of the count on a single sample may, therefore, be considered an estimate of the variation due to sampling, and, for counts over 10, 95% confidence intervals may be estimated by the count ± two times its square root. Although the three test species differed considerably in size, there was no evidence that this factor influenced the counts. The greatest apparent difference, *P. latifrons* vs. *N. simplex* at density 19, was not significant (p = 0.40). Mean estimates of density based on 15 aliquots each were 15.27, 2.00, and 1.13; true values were 19.00, 2.60, and 0.90. The distributions of observed counts above and below the true mean values were not significantly different from the expected 7.5/7.5 for the two lower densities; for density 19.00, there were 12.5 below and only 2.5 above (p = about .01). This suggests that higher densities may be consistently somewhat underestimated. No reason for this is apparent.

The importance of scanning the entire sample for the rarer species is indicated by the fact that in random aliquots, a species with a mean density of one individual per aliquot would be absent in about 37% of all aliquots, and a species with a mean density of 0.5 individual per aliquot would be absent in about 61% of all aliquots.

DEPTH OF TOW

Sampling at more than one depth using opening-closing nets, carried out on "E. W. Scripps" Cruise VIII, 1939, the "Transpacific" expedition, and the "Norpac" survey, has made it possible to consider the extent to which change in depth of tow can alter the apparent range and estimated density of a species.

"E. W. Scripps" Cruise VIII surveyed an area off Oregon, California, and Baja California. At 50 stations between the latitude of San Diego (32° N) and the Columbia River, Oregon (46° N), samples were collected from three strata of water. Only two of these strata were sampled on station lines off Baja California (Fig. 1).

The upper net sampled obliquely between the surface and a depth of approximately 40 m; the intermediate net sampled the layer between

TABLE 2

REPLICATE COUNTS OF $\frac{1}{10}$ ALIQUOTS OF THREE SAMPLES
(Number in parenthesis is $\frac{1}{10}$ of actual number present in sample)

REPLICATE COUNT NO.	SAMPLE I			
	E. pacifica (19)	*N. simplex* (2.6)	*P. latifrons* (0.9)	Total (22.5)
1	19	3	1	23
2	13	2	1	16
3	11	3	0	14
4	15	2	0	17
5	9	1	2	12
	SAMPLE II			
	P. latifrons (19)	*E. pacifica* (2.6)	*N. simplex* (0.9)	Total (22.5)
1	24	4	1	29
2	10	1	0	11
3	22	1	3	26
4	18	3	3	24
5	15	1	1	17
	SAMPLE III			
	N. simplex (19)	*P. latifrons* (2.6)	*E. pacifica* (0.9)	Total (22.5)
1	12	3	0	15
2	16	3	1	20
3	16	1	1	18
4	17	2	0	19
5	12	0	3	15

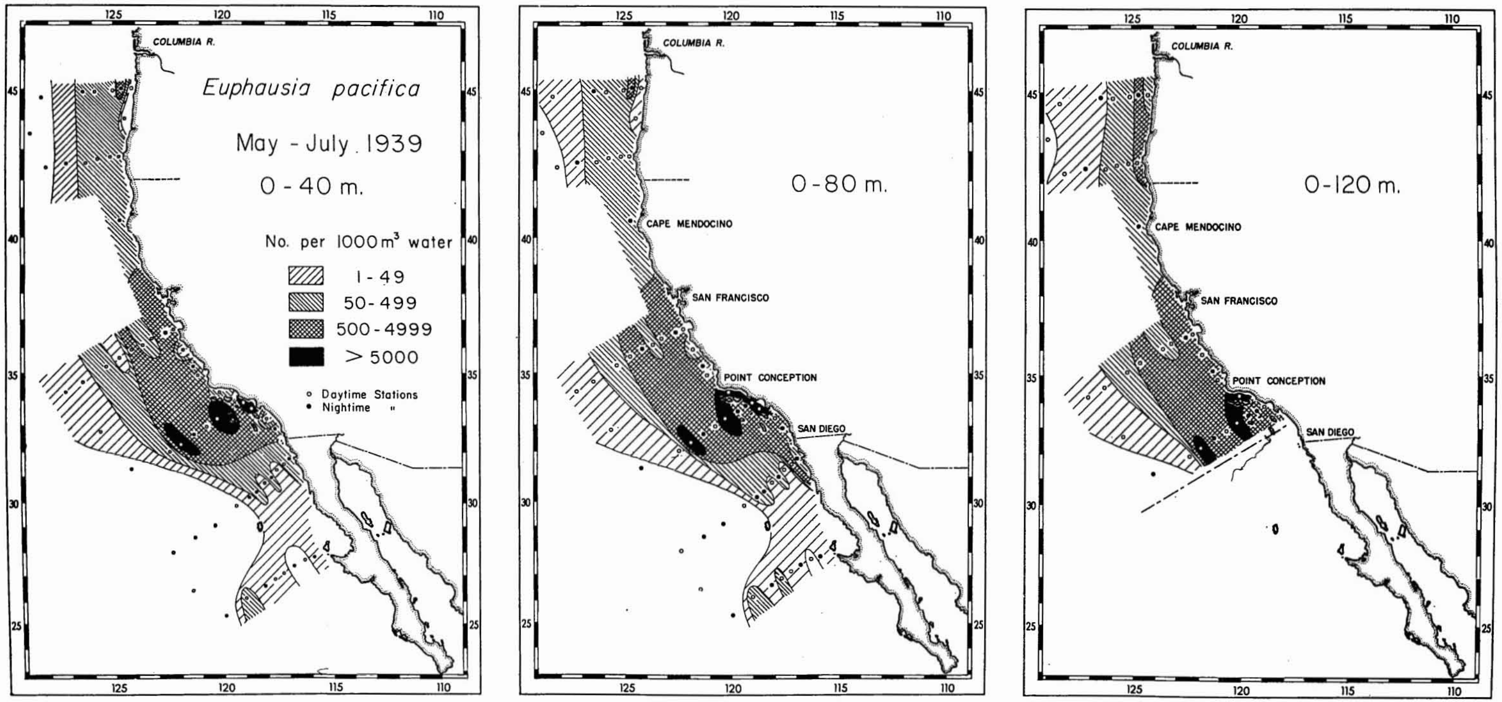


FIG. 1. Distribution of *Euphausia pacifica,* based upon sampling to 0–40 m, 0–80 m, and 0–120 m. "E. W. Scripps" Cruise VIII, May 10–July 10, 1939. Stations off Baja California, south of 32° N, were sampled only to 40 m and 80 m.

TABLE 3

"E. W. SCRIPPS" CRUISE VIII, 1939:
EFFECT OF ALTERING DEPTH OF TOW ON ABUNDANCE INTERVAL (CONTOUR)
(Intervals: 0, 1–49, 50–499, 500–4,999, > 5,000, per 1000 m³; only those stations are considered at which tows were made to three depths)

SPECIES	CHANGE OF DEPTH OF TOW (m)	NO. STATIONS WHERE ABUNDANCE INTERVAL WAS UNCHANGED BY INCREASING DEPTH OF TOW	NO. STATIONS WHERE ABUNDANCE INTERVAL WAS CHANGED BY INCREASING DEPTH OF TOW			NO. NEGATIVE STATIONS MADE POSITIVE BY INCREASING DEPTH OF TOW
				To Higher Interval	To Lower Interval	
Euphausia pacifica	0–40 to 0–80	27	10	6	4	2
	0–40 to 0–120	27	10	6	4	3
	0–80 to 0–120	33	4	2	2	1
Thysanoessa gregaria	0–40 to 0–80	15	7	7	0	6
	0–40 to 0–120	9	13	12	1	11
	0–80 to 0–120	14	8	6	2	6
T. spinifera	0–40 to 0–80	9	9	7	2	5
	0–40 to 0–120	11	7	5	2	5
	0–80 to 0–120	16	2	0	2	0
Nematoscelis difficilis	0–40 to 0–80	20	10	8	2	5
	0–40 to 0–120	14	16	12	4	8
	0–80 to 0–120	24	6	4	2	3
Tessarabrachion oculatus	0–40 to 0–80	5	7	7	0	7
	0–40 to 0–120	4	8	8	0	7
	0–80 to 0–120	11	1	1	0	0
Thysanopoda aequalis	0–40 to 0–80	3	1	0	1	0
	0–40 to 0–120	3	1	0	1	0
	0–80 to 0–120	4	0	0	0	0
Stylocheiron carinatum	0–40 to 0–80	2	2	1	1	1
	0–40 to 0–120	2	2	1	1	1
	0–80 to 0–120	4	0	0	0	0
Nyctiphanes simplex	0–40 to 0–80	1	3	2	1	1
	0–40 to 0–120	0	4	2	2	2
	0–80 to 0–120	1	3	1	2	1

40 and 80 m; the lowest net sampled the layer between 80 and 120 m. The summed catch of the two upper tows (0–80 m) is thus comparable to samples taken during the 1949–50 cruises of CCOFI, which made single oblique hauls from depths of 0 to ca. 70 m. After 1950, the depth of sampling on CCOFI cruises was changed from 0–70 m to 0–140 m. Using data from the 1939 "E. W. Scripps" cruise it is possible to compare the numbers of euphausiids caught in the 0–80-m stratum with those collected in the 0–120-m layer.

The question arises: Are the qualitative or quantitative determinations of the distribution of euphausiid species significantly changed by changing the depth of tow? If a map is plotted (on the basis of 0–40-m tows) showing the qualitative aspects of the distribution of a species in the region of the California Current, the character of the distribution is somewhat altered if a different depth of tow (0–80 m or 0–120 m) is used.

Species of four faunal groups are considered (Table 3). They are: *Euphausia pacifica* and *Thysanoessa spinifera,* which have an affinity with cold northern waters; *Nyctiphanes simplex,* with upwelled areas marginal to the equatorial zone; *Thysanoessa gregaria,* with a transitional belt which lies at 35–45° N in mid-ocean; and *Stylocheiron carinatum* and *Thysanopoda aequalis,* with offshore central waters. All occur in part of the California Current. The apparent concentration of each species was most changed if the depth of tow was altered from 0–40 m to 0–120 m; it was not changed at all for *Thysanopoda aequalis* and *Stylocheiron carinatum,* and only at one station for *Thysanoessa spinifera* when the depth of tow was changed from 0–80 to 0–120 m—the same order of change in depth of tow that was made in the CCOFI sampling program in 1950. *Nyctiphanes* was little affected by altering the depth from 0–40 m to 0–80 m but, where *Nyctiphanes* was present, the concentration interval was changed at each of the four stations when the depth of tow was increased from 40 m to 120 m.

Changes in depth of tow had comparable effects on records of the presence of species: increasing the depth from 40 m to 80 m considerably increased the number of positive stations; the increase from 80 m to 120 m had less effect.

Inasmuch as oceanwide distribution charts of

TABLE 4

"NORPAC" CRUISE, 1955:
EFFECT OF ALTERING DEPTH OF TOW ON ABUNDANCE INTERVAL (CONTOUR)
(Intervals: 0, 1–49, 50–499, 500–4,999, > 5,000, per 1000 m^3; only those stations are considered at which tows were made to three depths)

SPECIES	CHANGE OF DEPTH OF TOW (m)	NO. STATIONS WHERE ABUNDANCE INTERVAL WAS UNCHANGED BY INCREASING DEPTH OF TOW	NO. STATIONS WHERE ABUNDANCE INTERVAL WAS CHANGED BY INCREASING DEPTH OF TOW			NO. NEGATIVE STATIONS MADE POSITIVE BY INCREASING DEPTH OF TOW
				To Higher Interval	To Lower Interval	
Euphausia pacifica	0–140 to 0–280	9	6	5	1	2
	0–140 to 0–700	4	11	9	2	6
	0–280 to 0–700	9	6	5	1	4
Thysanoessa gregaria	0–140 to 0–280	10	3	0	3	0
	0–140 to 0–700	6	7	0	7	0
	0–280 to 0–700	9	4	0	4	0
T. spinifera	0–140 to 0–280	4	0	0	0	0
	0–140 to 0–700	2	2	1	1	1
	0–280 to 0–700	2	2	1	1	1
Nematoscelis difficilis	0–140 to 0–280	9	5	1	4	1
	0–140 to 0–700	2	12	3	9	2
	0–280 to 0–700	6	8	2	6	2
Tessarabrachion oculatus	0–140 to 0–280	2	3	3	0	3
	0–140 to 0–700	1	4	4	4	4
	0–280 to 0–700	4	1	1	1	1
Thysanopoda aequalis	0–140 to 0–280	16	4	1	3	1
	0–140 to 0–700	7	13	4	9	3
	0–280 to 0–700	11	9	3	6	2
Stylocheiron carinatum	0–140 to 0–280	17	1	0	1	0
	0–140 to 0–700	11	7	3	4	3
	0–280 to 0–700	12	6	3	3	3
Euphausia brevis	0–140 to 0–280	7	8	7	1	5
	0–140 to 0–700	3	12	7	5	5
	0–280 to 0–700	11	4	0	4	0
E. tenera	0–140 to 0–280	8	0	0	0	0
	0–140 to 0–700	5	3	3	0	2
	0–280 to 0–700	5	3	3	0	2

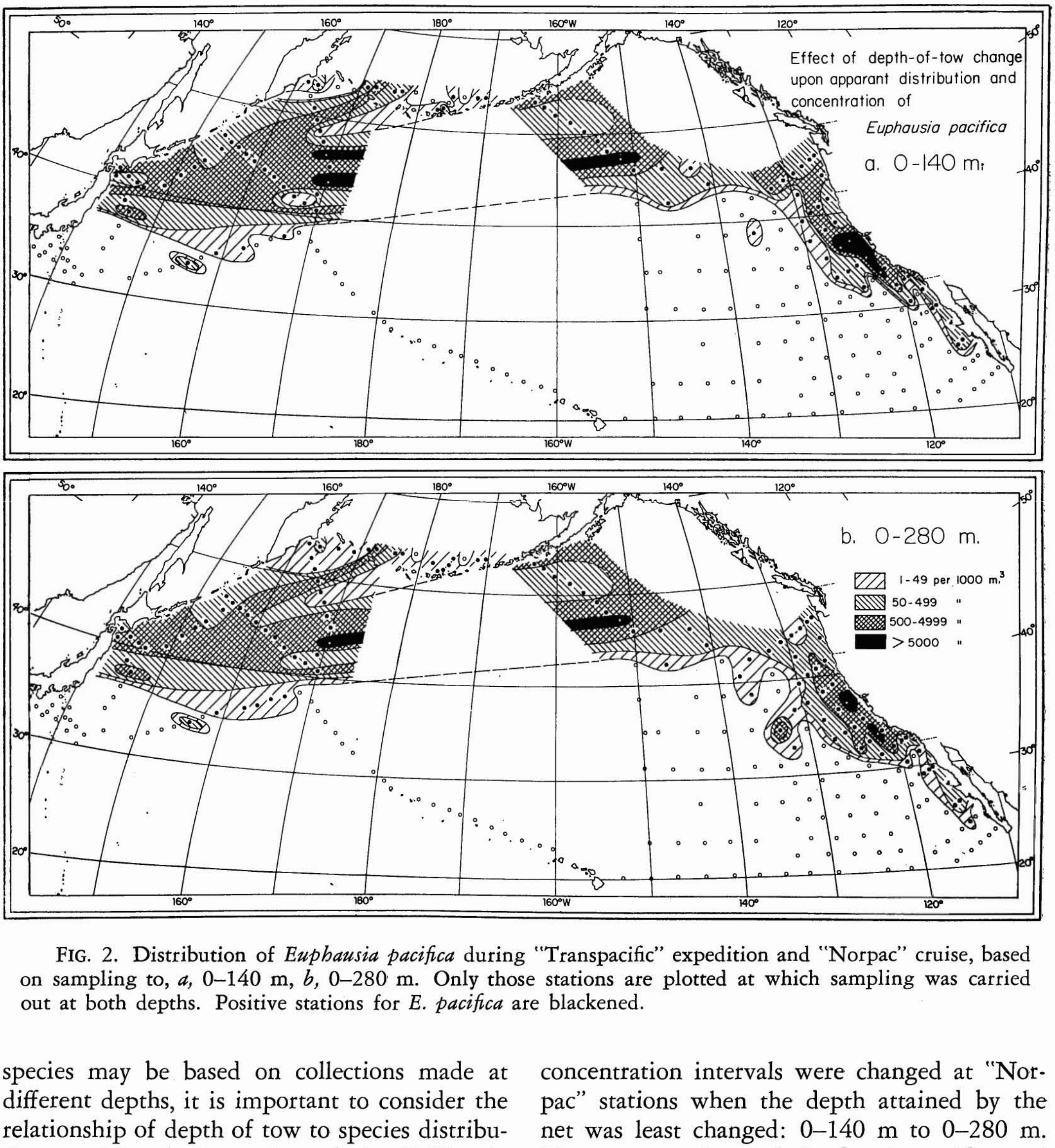


FIG. 2. Distribution of *Euphausia pacifica* during "Transpacific" expedition and "Norpac" cruise, based on sampling to, *a,* 0–140 m, *b,* 0–280 m. Only those stations are plotted at which sampling was carried out at both depths. Positive stations for *E. pacifica* are blackened.

species may be based on collections made at different depths, it is important to consider the relationship of depth of tow to species distribution outside of the region of the California Current. The multiple-depth sampling carried out by the "Transpacific" expedition, 1953, and the "Norpac" cruise, 1955, makes it possible to consider the effect over a much larger area on apparent euphausiid distribution. Table 4 shows the extent to which concentration intervals were altered in the area of the "Norpac" cruise in the eastern North Pacific when the depth of tow was increased from 0–140 m to 0–280 m or to 0–700 m.

As in the "E. W. Scripps" Cruise VIII, fewer concentration intervals were changed at "Norpac" stations when the depth attained by the net was least changed: 0–140 m to 0–280 m. The concentrations of *Euphausia pacifica* and *E. brevis* were altered at about 50% of the "Norpac" stations by sampling to 280 m instead of to 140 m, but the general features of the distributions of these two species were little changed (Figs. 2, 3). This was true despite the fact that *E. pacifica* occurred at only 44 "Norpac" stations, based on sampling to a depth of 140 m, but at 53 stations when sampling reached a depth of 280 m. The number of positive records of *E. brevis* was similarly increased from 32 to 45 by this change in the depth of sampling. The other species listed in Table 4 were only slightly affected by it. The increase to 700 m frequently altered the apparent concentrations of species, but few negative stations were made positive, even by this largest increase in depth of tow.

HOUR OF DAY OF SAMPLING

The diurnal vertical migrations performed by euphausiids bring certain species and stages of development near to the surface of the sea at night, where they can be taken by plankton nets sampling the upper 200–300 m. In many species, the adults descend to depths in excess of 300 m during the daylight hours, and consequently become unavailable to the nets sampling above that depth. The vertical ranges of the larvae and immature individuals of many species do not extend to depths beneath the stratum sampled. Thus, certain categories of size are more effectively sampled by the routine techniques than others.

The patterns of survey grids do not permit emphasis upon nighttime sampling to the exclusion of daytime sampling. The stations, situated 20–60 miles apart, are ordinarily occupied in sequence without regard for the time of day. It is therefore necessary to consider the diurnal changes in numbers in the sampled layers, as

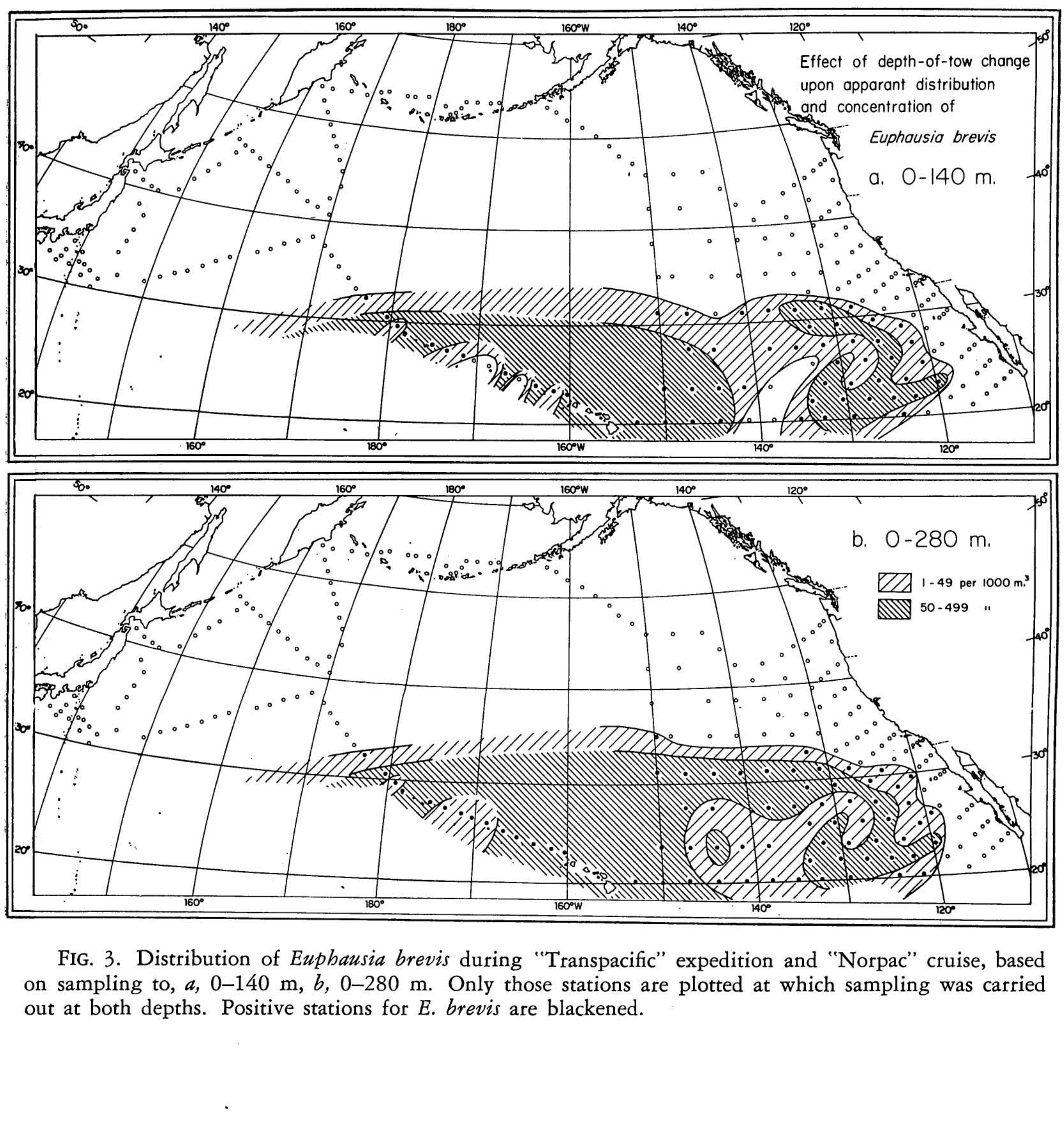


FIG. 3. Distribution of *Euphausia brevis* during "Transpacific" expedition and "Norpac" cruise, based on sampling to, *a*, 0–140 m, *b*, 0–280 m. Only those stations are plotted at which sampling was carried out at both depths. Positive stations for *E. brevis* are blackened.

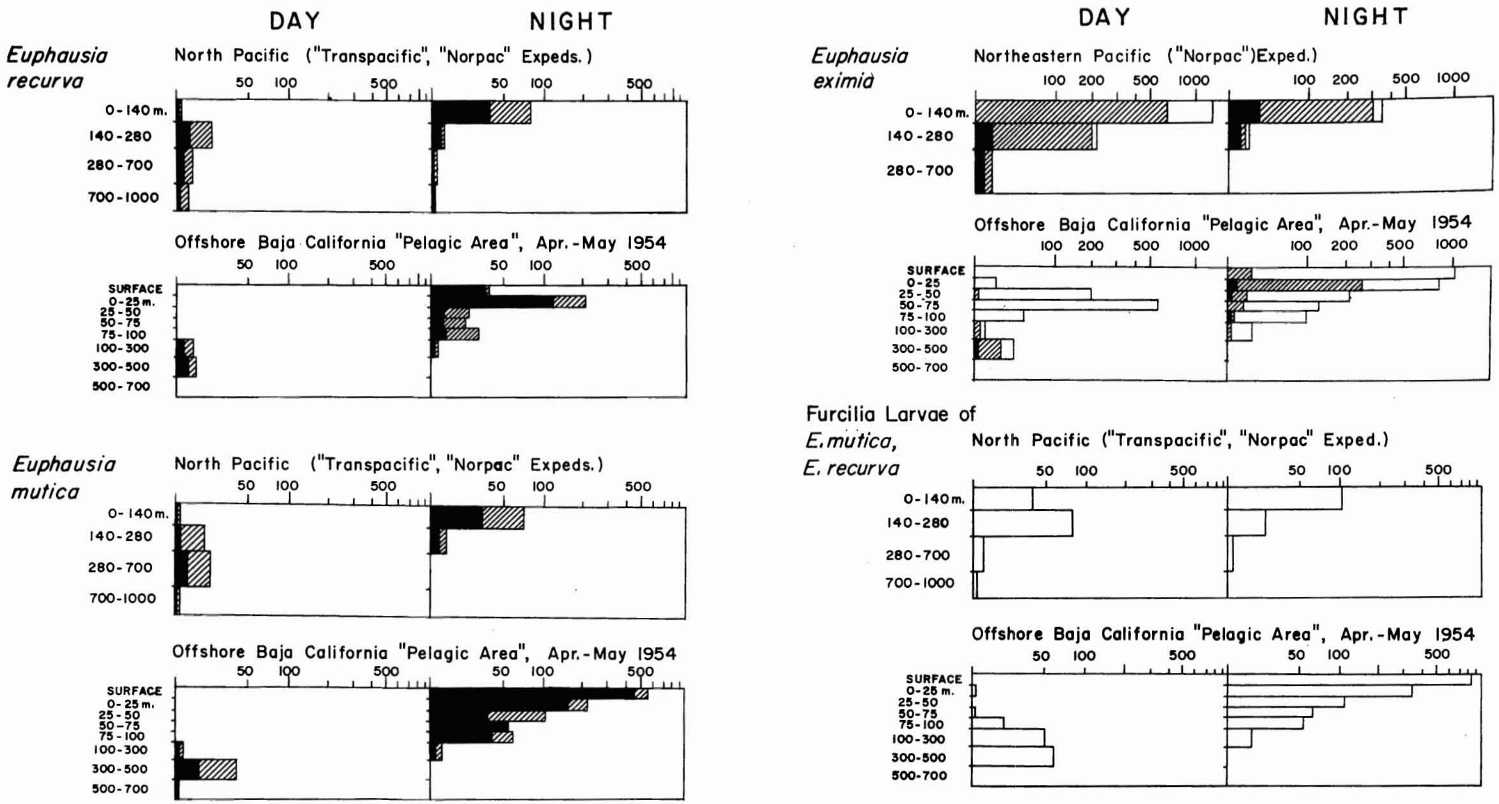


FIG. 4. Vertical distributions of certain euphausiid species in the North Pacific, from cruises listed in Table 1. Positions of stations are plotted in Figs. 2, 3, and 5. In each histogram, adults are indicated by the solid black bars, juvenile specimens by the cross-hatched bars, and furcilia larvae by the open bars. The number of specimens at each depth is the average collected at all stations within the ranges of the species, determined for each of the survey cruises.

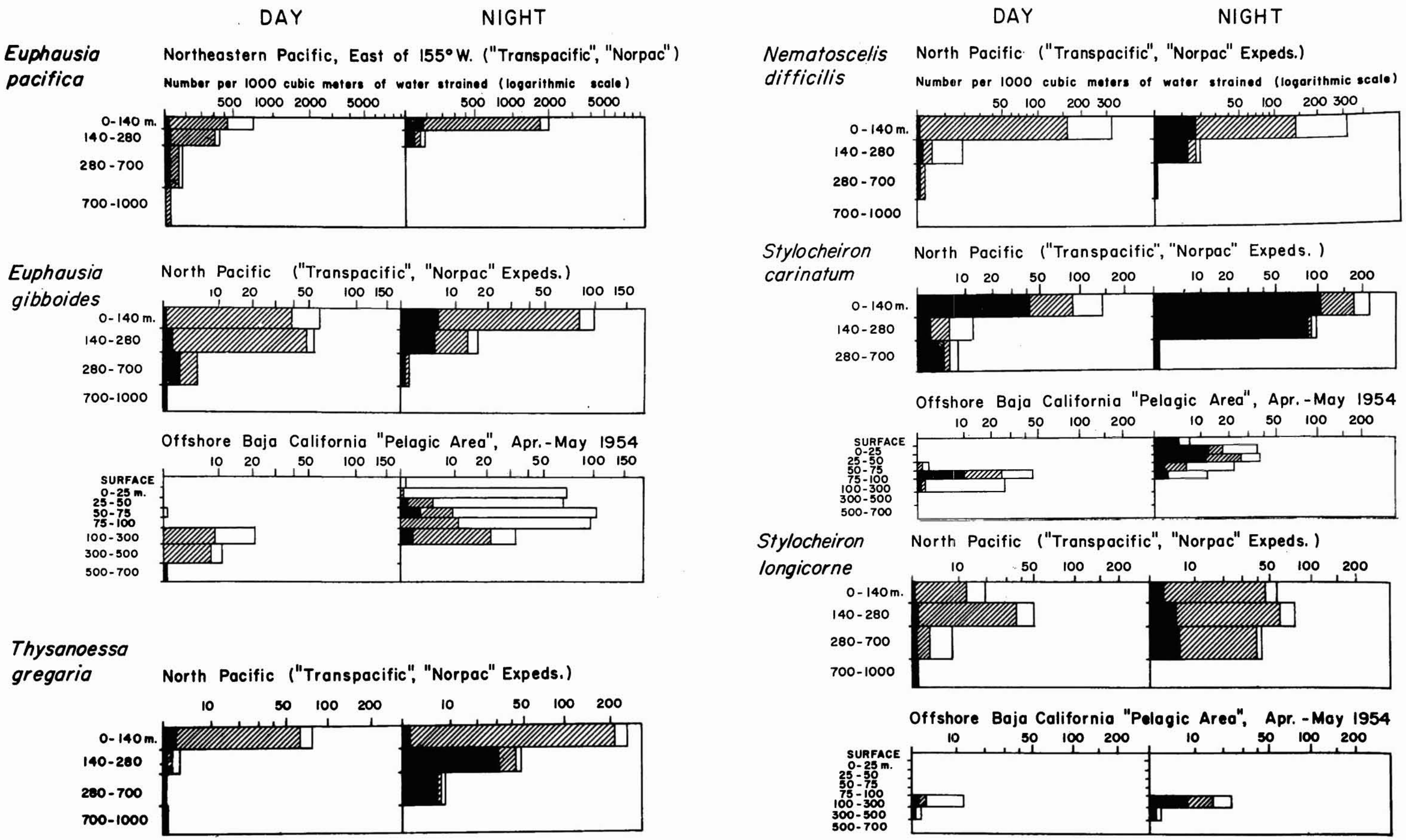


FIG. 5. Vertical distributions of certain euphausiid species in the North Pacific. (See caption for Fig. 4.)

these relate to coastal regions, mixed waters, and the open sea.

Daytime levels of occurrence of nine California Current species are compared with nighttime levels (Figs. 4, 5). These euphausiids, with the exception of *Stylocheiron longicorne,* are more abundant in the upper (0–140 m) layer by night than by day. The histograms indicate average day and night values for the indicated depths, based upon those stations of "Transpacific," "Norpac," and "Pelagic Area" surveys located within the known distributional ranges of the particular species.

Diurnal changes in the concentration of several euphausiid species were observed during an 8-day period at three stations (Fig. 6) off central California, Oct 11–19, 1950, on CCOFI "Anchor Station" Cruise 5010. The near-shore locality, station 72.60, was 75 miles south of Monterey and 50 miles offshore. Station 70.90 was 200 miles offshore, while station 70.130 was 400 miles west of Point Conception. The near-shore ship was at anchor during the 8-day period of observations. The two offshore ships maintained fairly constant positions by steaming to compensate for drift.

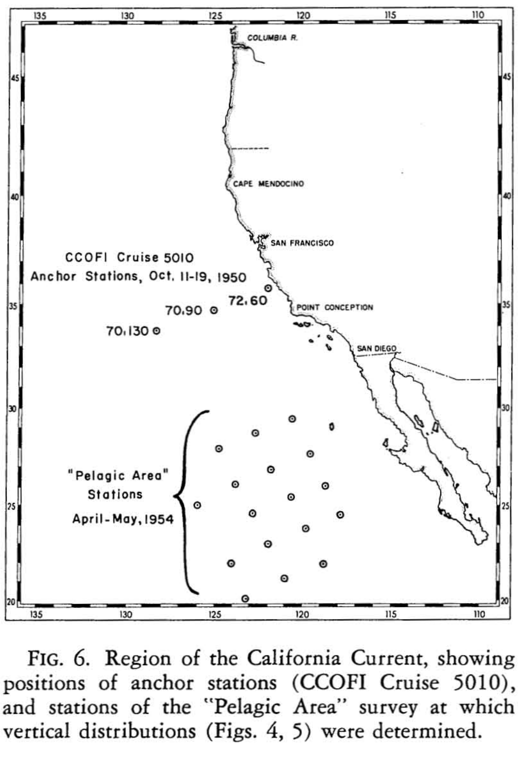


FIG. 6. Region of the California Current, showing positions of anchor stations (CCOFI Cruise 5010), and stations of the "Pelagic Area" survey at which vertical distributions (Figs. 4, 5) were determined.

The three stations were situated across the California Current. They were midway between the northern region, where this current arises in the southeastward flow of the Aleutian Current and the North Pacific Drift, and the region off the northern part of Baja California, where the current bends offshore and Equatorial water appears. The stations provided an opportunity to observe time changes in local populations, including day-night changes in the available euphausiid component of the plankton in the 0–140-m layer.

Anchor Station 72.60. The biological and physical changes which occurred at station 72.60 illustrate the manner in which the coastal environment may change. The numbers of the several euphausiid species occurring at this station are plotted in Figure 7, as a function of time. Vertical net hauls were made from the anchored "E. W. Scripps" at 3-hr intervals during the 8-day period.

No flow meter was used in the mouth of the vertically hauled net; 500 m^3 of water strained per net-haul was estimated for the hauls, based upon their elapsed time compared with a mean value for water strained by quantitative hauls of the same duration. This value is probably significantly in error for some hauls, owing to changes in current velocity. Nevertheless, the repetitive nature of the sampling provided a general picture of variability in the numbers of plankton organisms in the near-shore environment.

The sampling carried out at station 72.60 may be separated into three periods:

1) From Oct 11 (haul K-2) to 14 (haul K-21) *Thysanoessa gregaria* and *Stylocheiron longicorne* were relatively abundant, *Euphausia pacifica* larvae were few, and *Nyctiphanes simplex* was present in 6 of the 19 hauls. This indicated the presence of plankton with southern (*N. simplex*) and non-coastal (*T. gregaria* and *S. longicorne*) affinities. Haul K-15, within this period, had more northern characteristics. *T. gregaria, S. longicorne,* and *N. simplex* dropped off sharply at the time of this haul; while a characteristic subarctic species, *Tessarabrachion oculatus,* was present in small numbers, its only recorded appearance during the 8-day period.

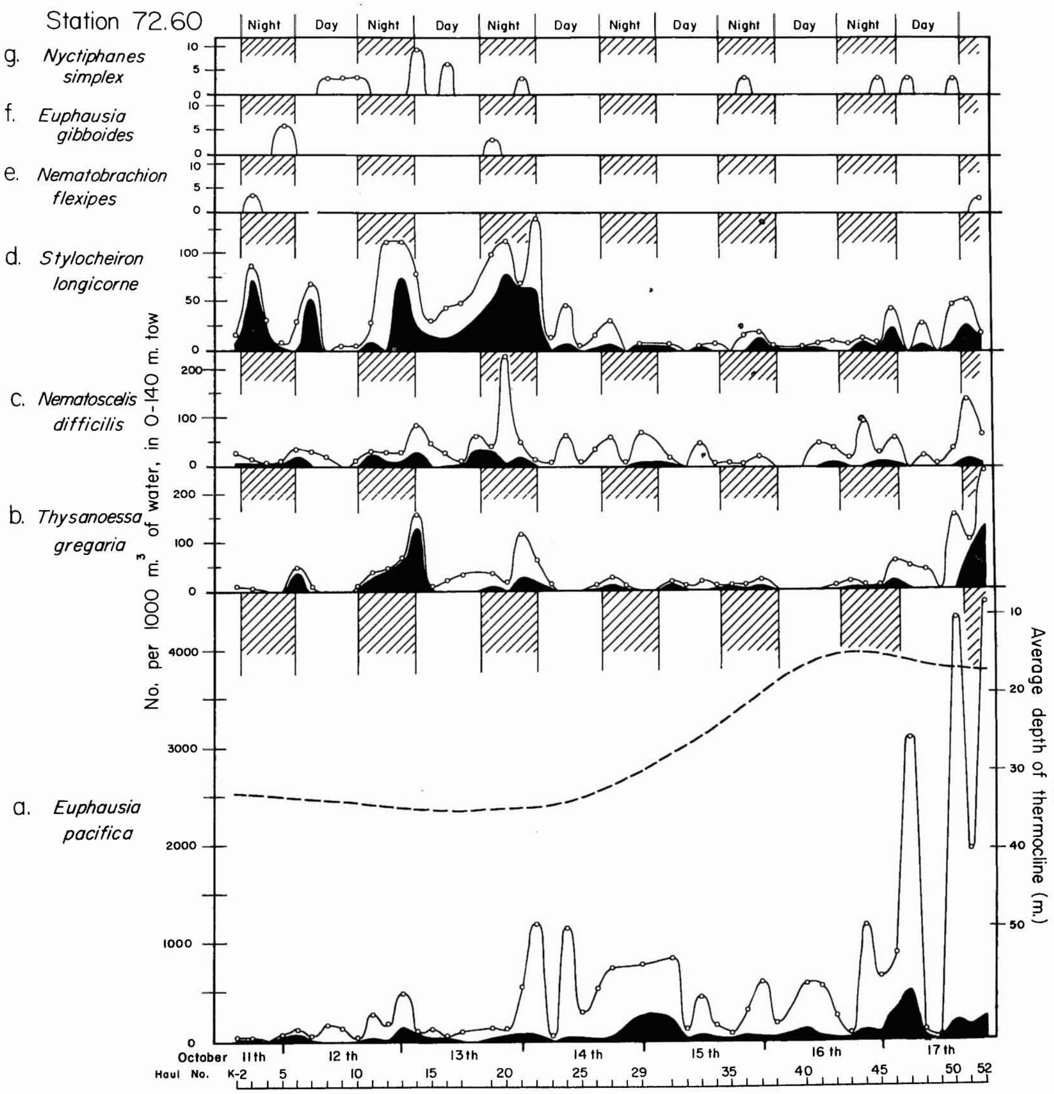


FIG. 7. Time variation in concentration of euphausiids at anchor station 72.60. Sampling was by vertical hauls to 140 m, at 3-hr intervals over an 8-day period. Blackened areas indicate concentrations of adults. Upper curves indicate total concentration of each species, including furcilia and juvenile individuals.

The adjacent hauls, K-14 and K-16, were characteristic of this first 3-day period, Oct 11–14.

2) From Oct 14 (haul K-22) to 16 (haul K-45) *Euphausia pacifica* larvae were more consistently abundant, while *Thysanoessa gregaria, Stylocheiron longicorne,* and *Nyctiphanes simplex* were few. This suggests a nearer-shore, coastal plankton, coincident with a shoaling thermocline and cooling surface temperatures.

3) From midnight Oct 16 (haul K-45) to the end of observations at midnight Oct 17, *Euphausia pacifica* larvae were numerous, *Thysanoessa gregaria* and *Stylocheiron longicorne* were more numerous than during Oct 14–16, and *Nyctiphanes simplex* was present in 3 of 8 hauls. These populations differed from the first group in the greater numbers of *E. pacifica,* but they clearly have southern, possibly more offshore

affinities as presumed from the prevalence of *T. gregaria.*

The species composition of the euphausiids at station 72.60 was nearly constant, and the subsurface physical characteristics of the water (Fig. 8), were rather uniform. Changes in the numbers of individuals of the species appear to be caused by changes occurring within the upper 100 m of the sea. These are apparently related to inconstant direction of surface flow, more characteristic of the near-shore region than of the open ocean. Day-night changes in the surface plankton due to the vertical migrations of euphausiids seem here to be limited to maximum concentrations of *Thysanoessa gregaria, Nematoscelis difficilis,* and *Stylocheiron longicorne* met with during hours of darkness. The numerically dominant species, *E. pacifica,* showed no significant day-night periodicity.

Anchor Station 70.90. The species present at

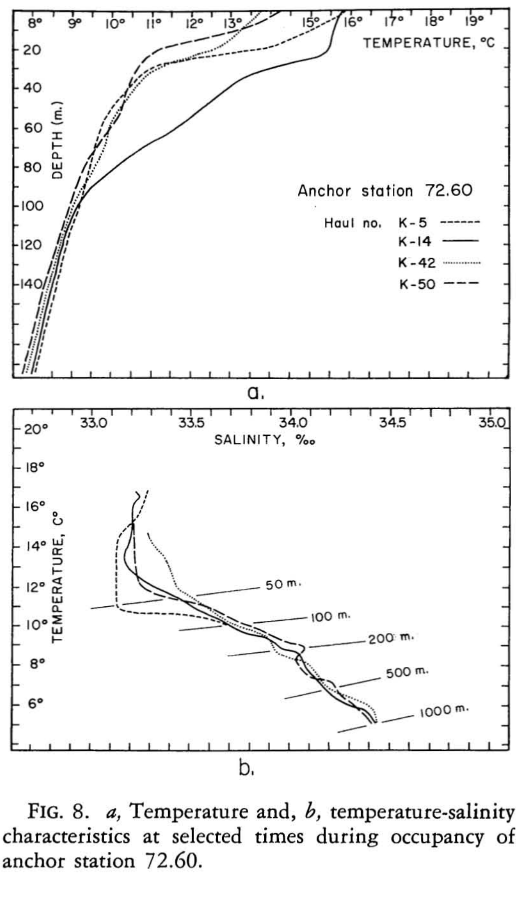


FIG. 8. *a,* Temperature and, *b,* temperature-salinity characteristics at selected times during occupancy of anchor station 72.60.

the inshore anchor station 72.60 also occurred at station 70.90, occupied midway across the California Current.

A warm-water species, *Euphausia recurva* (Fig. 9*f*), was found in one to three samples during each of the 8 nights. Nearly all individuals of this species were fully grown; one furcilia larva was present in haul K-19. The average depth of daytime occurrence of the adult *E. recurva* is below 140 m, though the larvae may be present at lesser depths (Fig. 4). Thus, in this region located near the eastern margin of the range of the species where few larvae and immature individuals are present, the population of *E. recurva* was not sampled by 0–140-m daytime hauls. It was sampled elsewhere, however, by the 0–280-m daytime hauls made by the Scripps oceanic expeditions. This is true also of the cold-water species, *Euphausia pacifica,* at this station and at anchor station 70.130, both situated near the western limit of the range of the species (Figs. 2, 6). Here, young individuals are few, and in the daytime the bulk of the adult population migrates deeper than the 140-m sampling depth.

Nighttime sampling of *Euphausia pacifica* indicated consistent concentrations in the range of 500–4,999 per 1000 m^3, except on the final night of sampling, Oct 18, when numbers fell off sharply.

Of the daytime samples, 13 were negative for *Euphausia pacifica,* 13 fell in the 1–49 per 1000 m^3 interval, while 3 were in the 50–499 range.

An unusually high concentration (3,110 per 1000 m^3) of half-grown specimens of *Euphausia pacifica* was recorded during daylight hours (1330 PST) on Oct 15, haul K-33. No other species occurred in unusual numbers at that time. It was partially overcast throughout the day. The peculiar near-surface appearance of these euphausiids cannot be attributed, then, to a sudden change in the intensity of light. It may be remarked, however, that the thermocline was relatively shoal, near 25–30 m of depth, during the first 12 hr of Oct 15 (hauls K-29 to K-33, Figs. 9*b*, 10).

A second factor possibly related to the large catch of *Euphausia pacifica* in haul K-33, is that few individuals of this species were in the sampled layer during the previous night, Oct 14–15. If migration toward the surface was in-

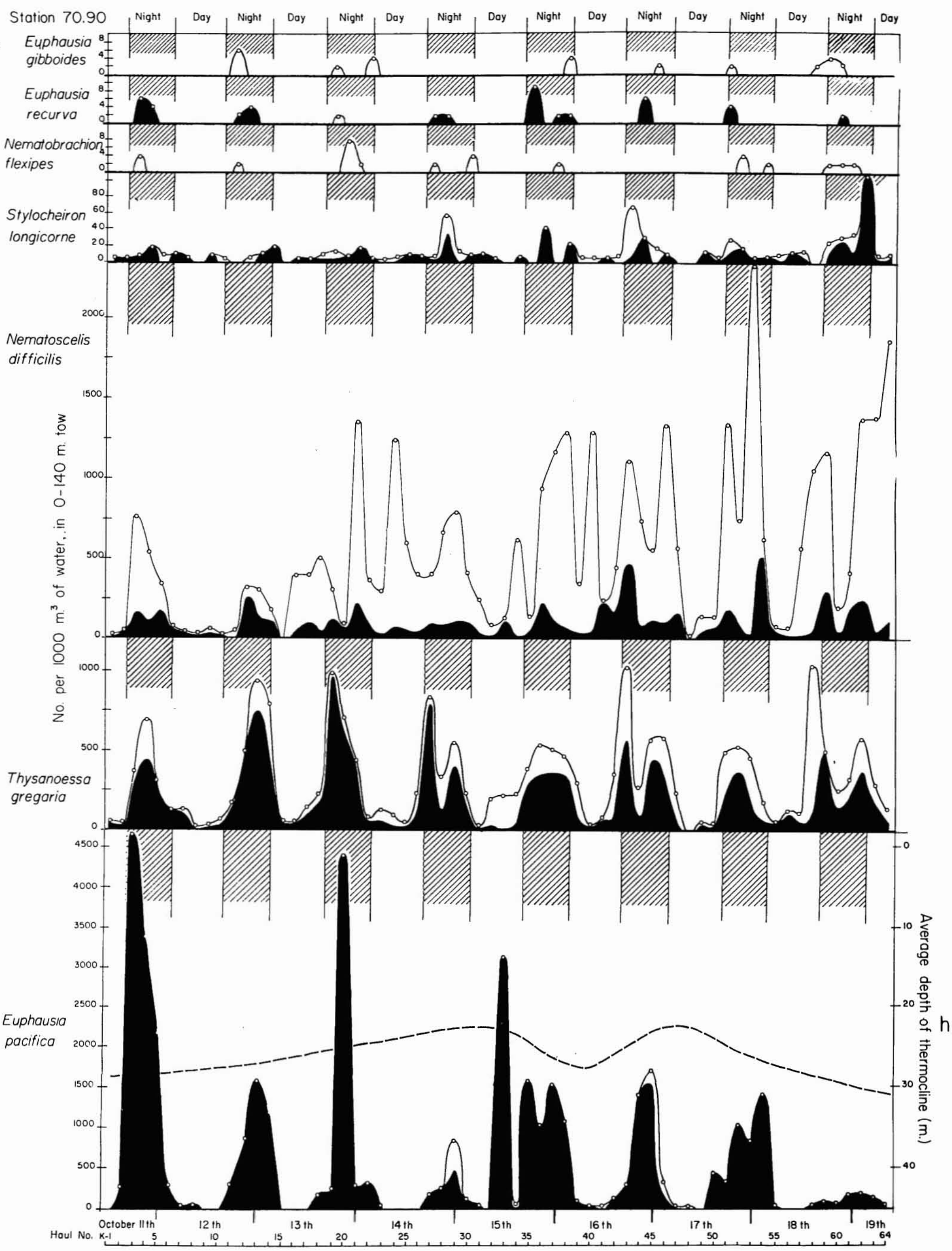


FIG. 9. Time variation in concentration of euphausiids at anchor station 70.90. Sampling was by standard oblique hauls to 140 m at 3-hr intervals over an 8-day period. Blackened areas under curves indicate concentrations of adults. Upper curves indicate total concentrations of each species, including furcilia and juvenile individuals.

hibited during the night of Oct 14–15, interruption of the diurnal periodicity of migration during the succeeding day-night interval may have resulted.

Thysanoessa gregaria also showed a constant day-night periodicity. Its population was made up largely of strongly migrating juvenile and adult euphausiids.

The combined juvenile-adult size group of the third prevalent species at station 70.90, *Nematoscelis difficilis,* showed less conspicuous nighttime peaks in numbers. Data for this species included in Figure 5 indicates that it is a less active vertical migrant than the species discussed above. The larvae, which made up the bulk of this species, were present in the 0–140-m layer without regard to time of day. Daytime populations of *Euphausia gibboides* (Fig. 9*g*) and *Nematobrachion flexipes* (Fig. 9*e*) were not sampled by the 0–140-m tows at station 70.90. Remarkable consistency in the catch of these two species is evident in the repeated presence of one, two, or three specimens of each species in nighttime samples: two nights were negative for *E. gibboides* and one night was negative for *N. flexipes.* Concentrations of *Stylocheiron longicorne* (Fig. 8*d*) exceeded 50 per 1000 m^3 on only three occasions. Otherwise numbers were within the 1–49 interval, with 7 negative samples in the series of 64.

Anchor Station 70.130. This station was situated far out at sea, in an environment which showed little variation in temperature during the period of observations (Fig. 13). The numbers of individuals of the colder-water species (Fig. 11) showed marked night-day maxima and minima. The offshore warm-water species (Fig. 12), allied to the central pelagic province, were less regular in this respect, being consistently within the 1–49 per 1000 m^3 numerical range during night and day.

The water layer above 150 m was warmer than at station 70.90 (by 2.5° at the surface, by 4° at 100 m). The thermocline at station 70.130 was close to 50 m, as compared with an average depth of about 30 m at station 70.90, and was less abrupt.

At station 70.130, *Euphausia pacifica* (Fig. 11*a*) was found in the 0–140-m stratum at night, usually in the 1–49 per 1000 m^3 range of density. At station 70.90, where it was caught

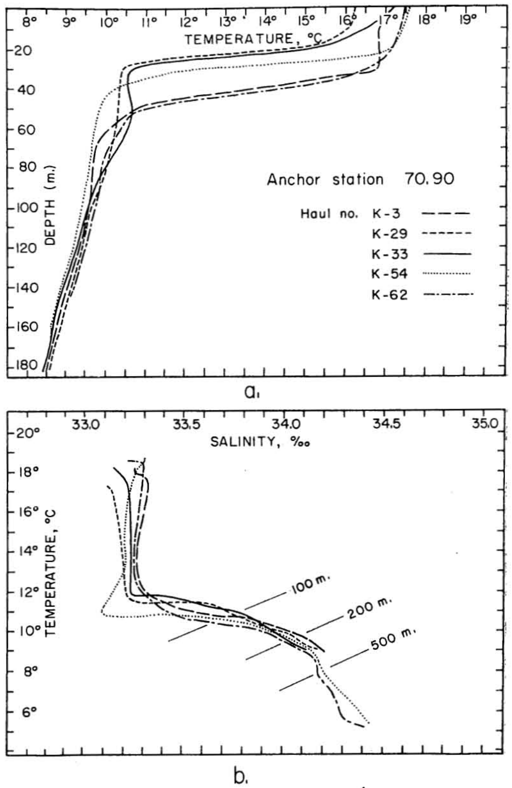


FIG. 10. *a,* Temperature and, *b,* temperature-salinity characteristics at selected times during occupancy of anchor station 70.90.

during the day as well as at night, *E. pacifica* was most often in the 50–499 interval. On the other hand, the environment at station 70.130 was somewhat more favorable for *Thysanoessa gregaria* (Fig. 11*b*) than the environment at station 70.90 (Fig. 9*b*). Both species showed two nocturnal peaks of abundance, the first after sunset and the second after midnight on all eight nights. Similar twin peaks were observed for these species on only two to three of the eight nights at station 70.90.

Nematoscelis difficilis (Fig. 11*d*), a species allied in distribution to *Thysanoessa gregaria,* appeared in all samples. Compared with station 70.90, few larvae were present, and there was a nocturnal maximum in the numbers of adults. The concentration of this species was 50–499 per 1000 m^3 until dawn, Oct 14. (One count was greater than 500, and one was less than 50.) After haul K-22, 23 of the 39 hauls sampled

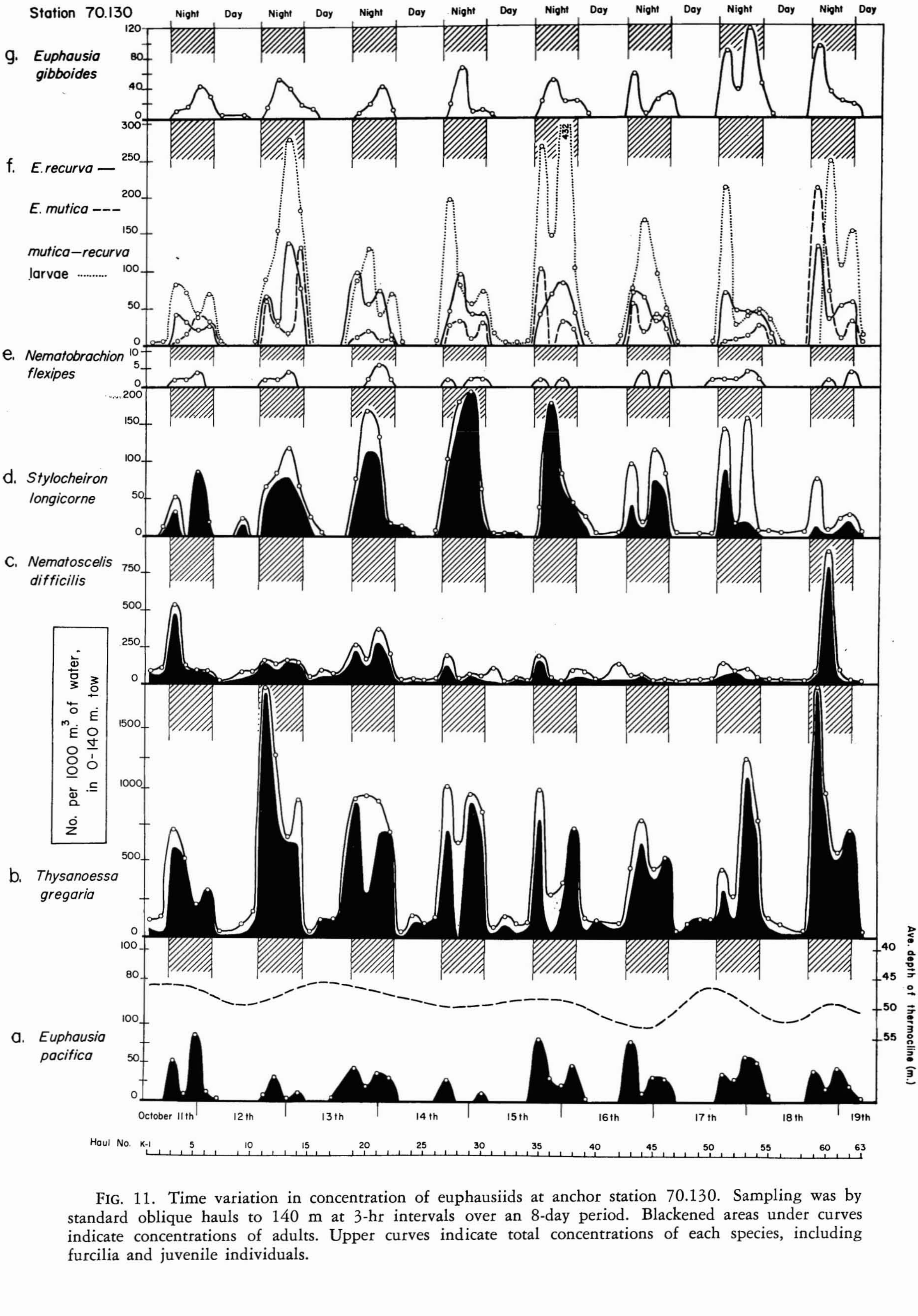


FIG. 11. Time variation in concentration of euphausiids at anchor station 70.130. Sampling was by standard oblique hauls to 140 m at 3-hr intervals over an 8-day period. Blackened areas under curves indicate concentrations of adults. Upper curves indicate total concentrations of each species, including furcilia and juvenile individuals.

concentrations in the 1–49 range, suggesting that a different population of *N. difficilis* had entered the area, or that the depth distribution of the species had changed.

Stylocheiron longicorne (Fig. 11*c*) was present in greater numbers than at the two previous stations. It showed greater diurnal periodicity in the 0–140-m layer than at the anchor stations nearer shore. This indicates a deeper average habitat for the species. Its daytime migration carried it entirely below the sampled layer, whereas at stations 70.90 and 72.60 some young individuals remained within the 0–140-m stratum throughout the 24-hr period.

Individuals of *Nematobrachion flexipes* (Fig. 11*e*) and *Euphausia gibboides* (Fig. 11*g*) appeared at station 70.130 with the same regularity shown at station 70.90. A few individuals were present in the samples each night.

The temperate character of the water at station 70.130 is reflected in the fact that the adults and larvae of *Euphausia recurva* and *E. mutica* begin to form a significant part of the night population sampled (Fig. 11*f*). These larvae were also present in small numbers in seven daytime hauls, but the station is still shoreward of the optimal environment of these *Euphausia* species. Westward of this station larvae were consistently taken in 0–140-m daytime hauls by "Transpacific" and "Norpac" expeditions.

The counts of five warm-water species are shown in Figure 12. At station 70.130, these species are near the eastern limits of their ranges. The numbers are largely made up of larval and immature individuals. Larvae of *Stylocheiron abbreviatum* (Fig. 12*a*) consistently appeared in greatest numbers at night. Immature and adult individuals of *Nematoscelis tenella, Nematoscelis atlantica,* and *Thysanopoda aequalis* (Fig. 12*c–e*) were not often caught except at night, but the total concentrations of these species did not always peak at night.

Counts of the euphausiids from the three anchor stations showed that the number of individuals of each species within the 0–140-m stratum varied from hour to hour at each locality. Variation in the numbers of the *Euphausia* species and *Thysanoessa gregaria* were most extensive and regular in respect to time. All size groups of the several *Euphausia* species showed

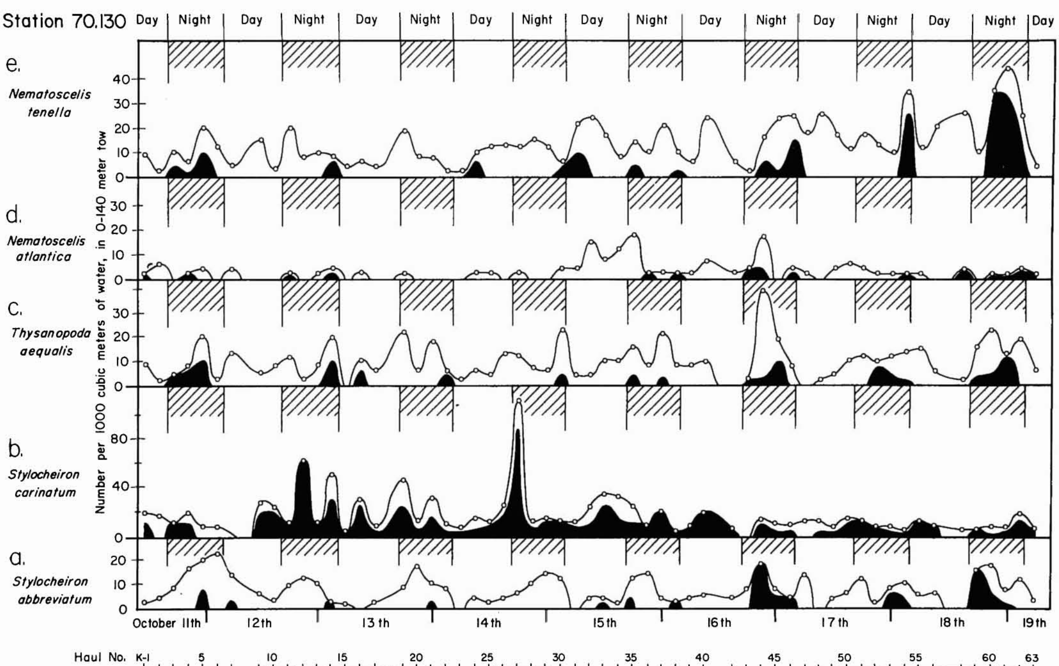


FIG. 12. Time variation in concentration of euphausiids at CCOFI anchor station 70.130; a continuation of Fig. 10, showing the central (warm-water) species.

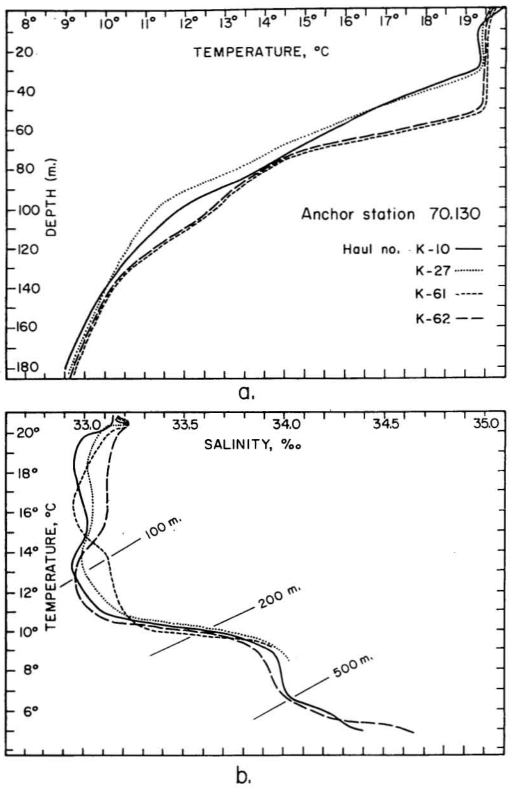


FIG. 13. *a,* Temperature and, *b,* temperature-salinity characteristics at selected times during occupancy of anchor station 70.130.

a consistent tendency to migrate into and out of the 0–140-m layer. The several species of *Nematoscelis* showed less diurnal variability in numbers, apparently owing to the near-surface habitat of the larvae and the fact that they are less inclined to migrate to depths below 140 m. The warm-water species at station 70.130 showed the least variability within the 24-hr period. Here, near the northeastern limits of their range, these species live in the thin peripheral part of the central Pacific warm-water lens.

LOCAL SEQUENCE COMPARED WITH INDIVIDUAL POPULATION SUCCESSION

The series of changes taking place with time in a plankton population occupying a moving or stationary mass of water has been called an "individual population succession" (Sverdrup, Johnson, and Fleming, 1942). The series of changes observed at a locality because different populations and masses of water are passing is called a "local sequence."

The examples in the preceding section show changes in estimated concentrations observed at three fixed localities off central California in the cool northern part of the California Current. If, during the 8-day sampling period, the plankton was carried southward at a mean current velocity of 0.3 knots, measured between the surface and 500 decibars (U. of Calif., Scripps Inst. Ref.

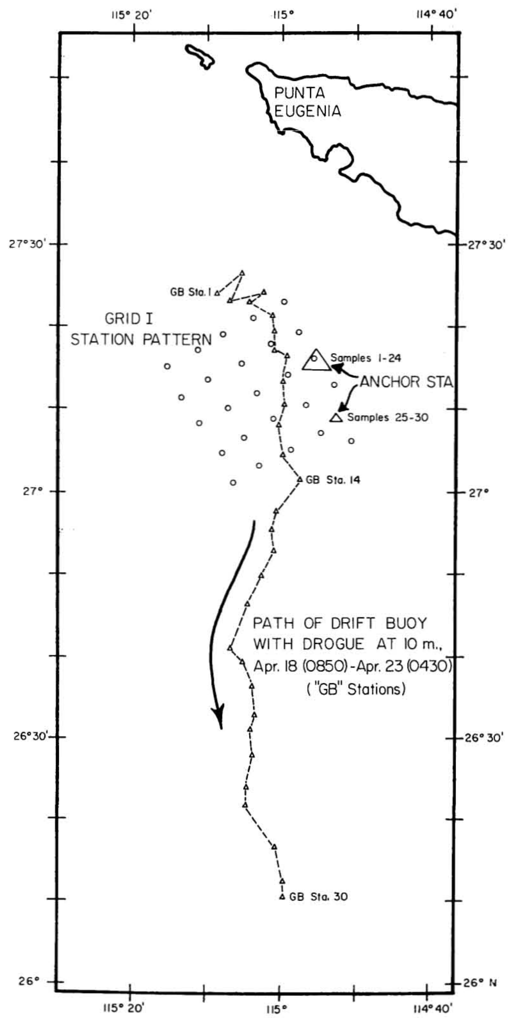


FIG. 14. Region off Punta Eugenia, Baja California, showing locations of anchor stations, drift-buoy stations, and close-grid survey carried out Apr 18–23, 1952.

52-37), these samples of euphausiids represented local sequences. It is known, however, that in the course of 24 hr vertically migrating plankton populations may occupy currents that move in different directions. In the region of the California Current these currents may be opposite in direction at the extremes of the vertical range of the adult euphausiids (0 and 300–500 m). In general, this will tend to keep the adult component of the population, which migrates through a 300–500-m span, at a given locality, while furcilia larvae living near the surface will be carried by the superficial currents through a horizontally distributed sequence of adult populations. Local sequence and individual population succession, therefore, could not be certainly differentiated at the central California anchor stations. However, most of the variability in estimated species concentrations can be interpreted as a measure of population replacement at the anchor station localities, because the trends in concentration-change extended for periods of several days.

A three-ship study, carried out in Baja California waters as part of the CCOFI survey cruise of Apr 1952 provided material for a comparison of local and time change in population composition and concentration. Simultaneous observations were made at (1) an anchor station located 30 miles offshore, south of Punta Eugenia, mid-Baja California; (2) a drifting buoy to which a metal drogue was attached at a depth of 10 m; (3) 25 stations forming a 20-mile square grid (Fig. 14). The entire grid was occupied on each of 5 consecutive days. Only the first 2 days of grid samples were analyzed for euphausiids. Sampling at the buoy and anchor stations was carried out at 4-hr intervals for a 5-day period. All plankton hauls were oblique to a depth of 140 m. Hydrographic measurements were made at the buoy and anchor stations, in conjunction with the plankton hauls.

Samples from the anchor station measured change at a fixed locality. The sampling program at the buoy station was designed to measure time change in the plankton populations inhabiting the superficial layers. Although it cannot be assumed that the flow of the current at a depth of 10 m approximates the average flow of the current in the 0–140-m layer sampled by the plankton net, euphausiid populations in the area were composed mainly of young individuals (larvae and juveniles) whose habitat is known to be the upper part of the vertical range of the species as a whole.

Six species were present throughout the sampling period at the anchor and buoy stations. These were *Euphausia gibboides, E. eximia, Thysanoessa gregaria, T. spinifera, Nematoscelis difficilis,* and *Nyctiphanes simplex* (Fig. 15). *Euphausia recurva* and *Stylocheiron affine* were sometimes present but were numerous only to the east of the buoy and anchor stations, as shown by the grid survey distributions (Figs. 16, 17). The distributions of *E. recurva* and *S. affine* were to some extent determined by the proportion of nighttime sampling stations, (cf grid distribution, and Apr 1952, CCOFI cruise). Records for *Euphausia pacifica* were also not consistent; the study was carried out near the southern limit of the Apr 1952 range of this species (Fig. 18).

The anchor station did not represent a fixed point. The area in which samples 1–24 were taken (the large triangle, Fig. 14) and in which samples 25–30 were taken (the small triangle, 10 miles farther south) were approximately 4 and 1 sq miles, respectively. The southward shift of the position of the anchor station did not appear to affect the composition of the euphausiid population which was sampled.

Counts of the most abundant species, *Nyctiphanes simplex,* varied a good deal (Fig. 15): the first six hauls (Apr 18) fell in the 50–499 range; hauls 7–29 (Apr 19–23), with three exceptions, fell in the 500–4,999 range; hauls 24 and 30 contained more than 5,000 *Nyctiphanes,* per 1000 m^3. It was thought that if these differences meant that different populations were being sampled, this might be indicated by differences in the mean size of the furcilia larvae which made up the bulk of the population. The average sizes of *N. simplex* for each 24-hr period (dawn to dawn), determined from all individuals caught in all anchor station samples, were as follows:

APR	ANCHOR STATION HAULS	MM
18–19	1–6	3.99
19–20	7–12	3.87
20–21	13–18	3.45
21–22	19–24	3.17
22–23	25–30	3.84

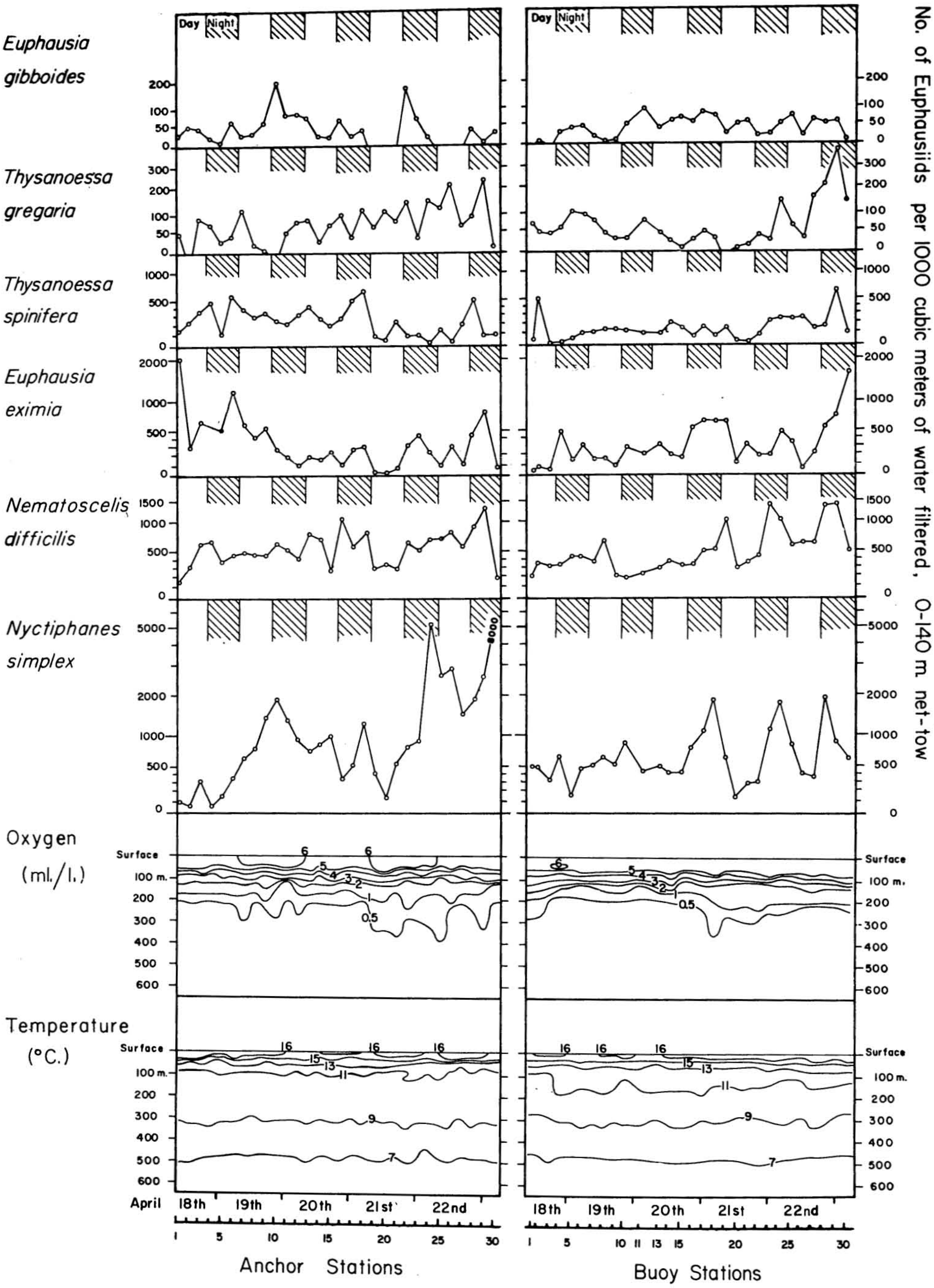


FIG. 15. Time changes in concentrations of euphausiids sampled at anchor and buoy stations off Baja California, Apr 18–23, 1952. Sampling was by standard oblique hauls, 0–140 m, at 4-hr intervals. Oxygen and temperature profiles for the two series of observations are plotted to a depth of 600 m.

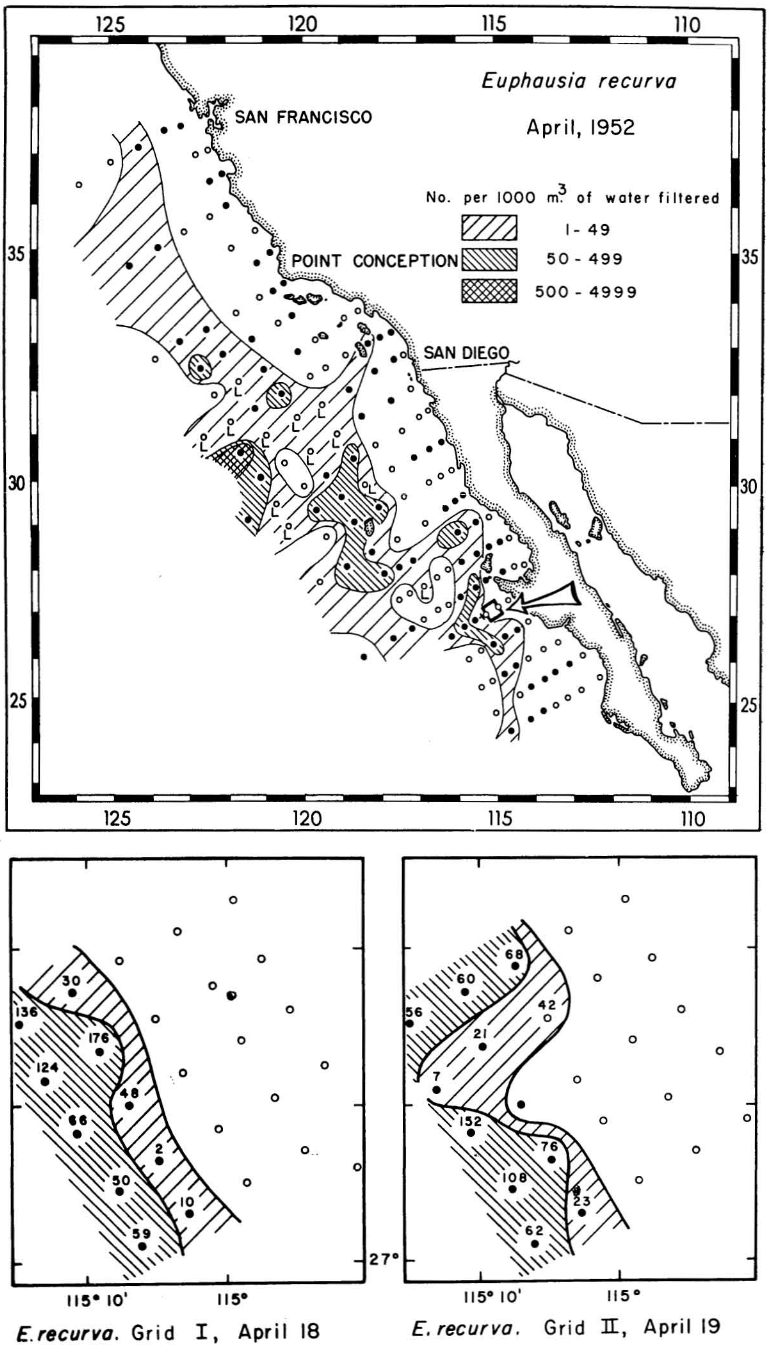


FIG. 16. *Euphausia recurva,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close grid survey. The letter *L* indicates occurrence of larvae *probably* belonging to *E. recurva.*

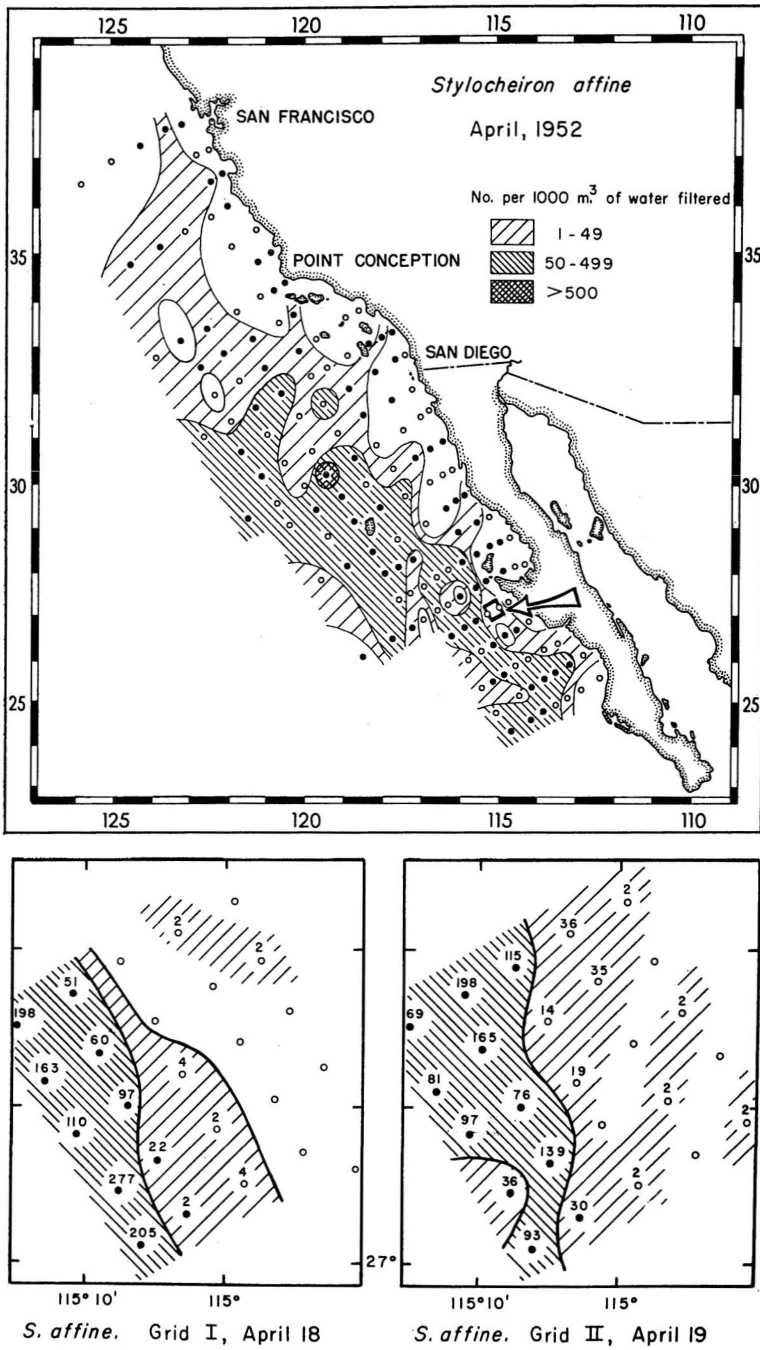


FIG. 17. *Stylocheiron affine,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.

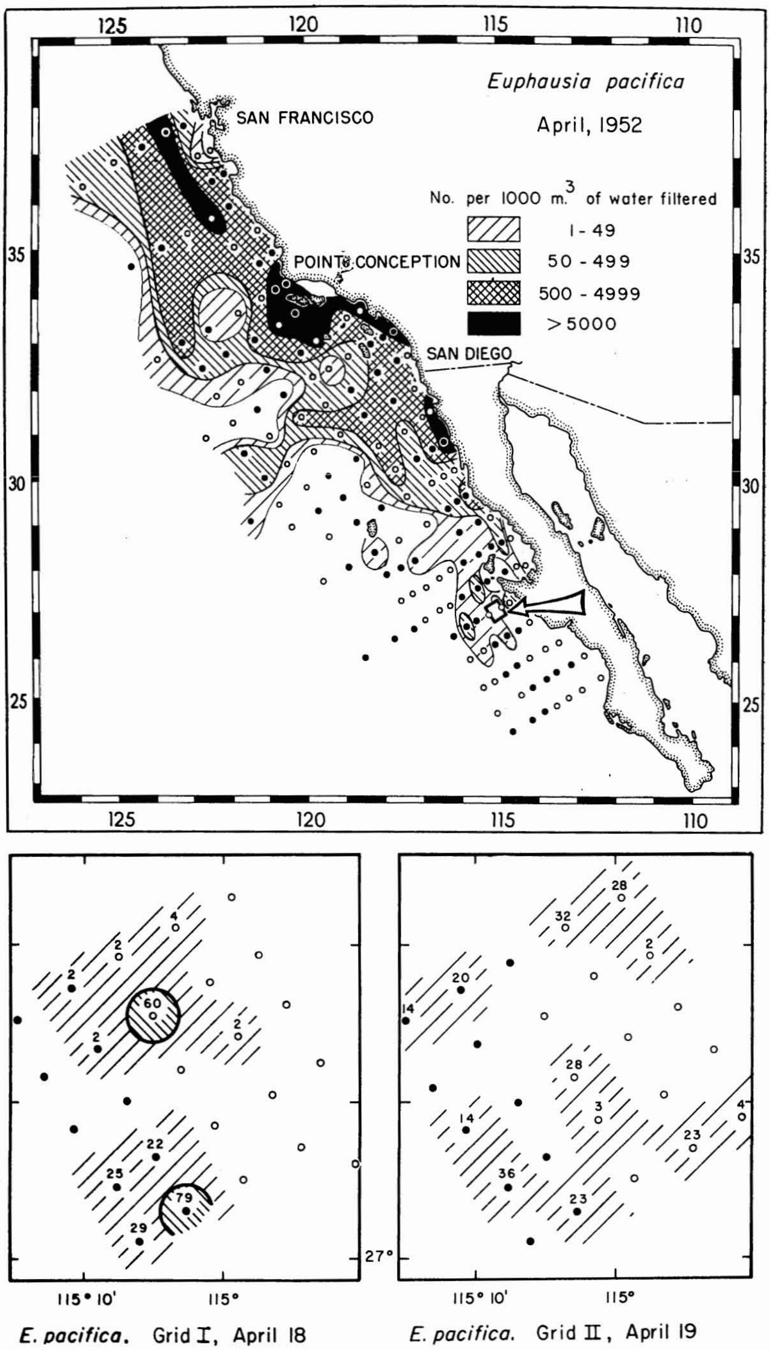


FIG. 18. *Euphausia pacifica,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.

As single *Nyctiphanes* furcilia stages of development may include individuals that differ from each other in length by 1.0–1.5 mm, the differences in average length are not sufficient to suggest that populations of different age or size were sampled at the anchor station. A comparison of the distribution of *N. simplex* in grids I and II (Fig. 19) suggests that from Apr 18 to 19 the water containing high concentrations of this species moved in a southeast or eastward direction. According to the grid samples, the numbers of this species near the anchor station were in the 50–499 per 1000 m^3 interval on Apr 18, and in the 500–4,999 interval on Apr 19; the concentrations actually sampled at the anchor station (Fig. 14) on these 2 days were within this range.

Of the other species occurring at the anchor station, *Euphausia eximia* had a high amplitude of variation, while *Thysanoessa gregaria* had the most up-down sequences in abundance, during the 5-day period. Concentrations of *Nematoscelis difficilis* were near 250–750 per 1000 m^3, except in the first sample (156 per 1000 m^3) and the last two samples (1,291 and 190, per 1000 m^3, respectively).

The concentration of *Euphausia eximia* fell in the 500–4,999 per 1000 m^3 interval in six of the first nine anchor station hauls (Fig. 15). This was in agreement with the grid sampling (Fig. 20). After anchor station haul no. 9, Apr 19, *E. eximia* numbers were in the 50–499 interval, except for three hauls, until the end of the sampling period.

Thysanoessa spinifera was in the 50–499 range, with the exception of four samples, during the anchor station sampling (Figs. 15, 21). *T. gregaria* was consistently in the 50–499 range after Apr 19, the second day at the anchor station. During the first 2 days it was often less numerous, agreeing with the grid concentrations shown in Figure 22.

The anchor station counts of *Euphausia gibboides* were erratic. As in the grid distributions (Fig. 23), the numbers of this species were most often in the 1–49 per 1000 m^3 interval during the first day and a half of sampling at the anchor station.

Samples were taken at the drift-buoy at the same times as those at the anchor station. The two series of observations can be compared in Figure 15. The path of the buoy (Fig. 14) indicates that, until haul no. 14, the current at a depth of 10 m traveled in a direction that was east of south. According to J. L. Reid (personal communication), who conducted operations on the R/V "Black Douglas" which followed the buoy, the apparently erratic path of the buoy during the first day may have been due to early difficulties in ascertaining the ship's position. After buoy haul no. 14, the buoy moved in a direction west of south. At haul no. 20 the buoy appeared to resume its original course.

At the buoy stations five species were evidently in a favorable environment, judging from their numbers. Thus, *Nyctiphanes simplex, Nematoscelis difficilis, Thysanoessa spinifera, T. gregaria,* and *Euphausia eximia* were most regular in hauls 1–14. After haul no. 14, the course of the buoy changed, and diurnal periodicity of these species was observed. *Nyctiphanes simplex, Nematoscelis difficilis,* and *Euphausia eximia* were most extreme in this respect. (However, the apparent density of *Nyctiphanes* did not change as extremely at the buoy stations as at the anchor stations).

Daytime concentrations of the above five species were compared (Table 5) with nighttime concentrations for the two parts of the buoy stations series, hauls 1–14 and hauls 15–30. Levels of significance of the differences between the two series of hauls were determined according to the distribution of the rank sum T'.

Daytime concentrations for hauls 1–14 did not differ significantly from concentrations in hauls 15–30, except in the case of *Euphausia eximia* which was more numerous after haul 14. Nighttime concentrations of *Nematoscelis difficilis* and *Nyctiphanes simplex,* two species showing conspicuous nocturnal peaks in abundance after haul 14, were significantly higher after the course of the buoy changed. *Euphausia eximia* also became more numerous (as stated above for the daytime hauls), though the nighttime values for hauls 15–30 were greater than those for hauls 1–14 only at the level p—.06. Nighttime means for *Thysanoessa spinifera* and *T. gregaria* were higher after haul 14, but the ranked values of the hauls did not differ significantly from the haul 1–14 series.

The euphausiid assemblage remained the same after haul 14. The character of the water

TABLE 5

DRIFT BUOY STATION HAULS 1–14 COMPARED WITH HAULS 15–30

SPECIES	HAULS	MEAN DAY DENSITY	LEVEL OF SIG. OF DIFFERENCE	MEAN NIGHT DENSITY	LEVEL OF SIG. OF DIFFERENCE
Nyctiphanes simplex	1–14 15–30	494 446	.280	529 1146	.028
Nematoscelis difficilis	1–14 15–30	356 565	.152	326 841	.006
Euphausia eximia	1–14 15–30	102 251	.040	265 609	.060
Thysanoessa spinifera	1–14 15–30	152 139	.612	70 189	.112
T. gregaria	1–14 15–30	44 38	.190	72 114	1.000

mass also remained stable, according to the temperature and oxygen profiles plotted in Figure 15. However, temperature at a depth of 9 m was at all times colder than 16 C before haul 14 (15.71–15.98 C), and warmer than 16 C after haul 14 (16.02–16.26 C). This could not be interpreted as a gradual time increase in temperature accompanying southward movement of the water, but probably reflected replacement of surface water. The changed abundance and behavior of euphausiids therefore probably indicates a more dense population brought in with this surface water. *E. eximia, N. difficilis,* and *N. simplex* then exhibited diurnal vertical migration.

The behavior of *N. simplex* changed conspicuously at haul no. 14. However, the mean sizes of individuals, determined for each of the 5 days of sampling, did not differ significantly from one another or from the mean sizes of *N. simplex* measured at the anchor station, listed above:

APR	BUOY STATION HAULS	MM
18–19	1–6	3.91
19–20	7–12	4.32
20–21	13–18	3.99
21–22	19–24	3.86
22–23	25–30	3.48

SAMPLES FROM 45-CM NET AND 1-M NET COMPARED

During the Aug–Sep 1956 cruise of the R/V "Stranger," transects were made of the mid-equatorial Pacific using two types of net. A net, 45 cm in mouth diameter and 0.33 mm in mesh width,[2] was attached to the wire at a distance of 10 m above a 1-m net of the standard 0.65-mm mesh width. The nets were towed obliquely to a depth of 140 m.

The paired samples were counted for 10 of the "Equapac" stations. These were standardized for 1000 m^3 of water, assuming that the large net strained 4.94 times as much water as the small net (that is, in the ratio of the areas of the mouths of the two nets). The large nets strained 325–463 m^3 of water, the small nets 66–94 m^3.

The relative catching ability of the two nets is summarized in Table 6. Furcilia larvae (2.5–4.5 mm long) of the most abundant species, *Euphausia tenera,* were sampled in greater numbers by the 45-cm net than by the 1-m net at 9 of the 10 stations. Furcilia of *E. diomediae* and *Stylocheiron abbreviatum* were better sampled by the small net at all stations where they were present, furcilia of *Thysanopoda aequalis* at all but 1 station, and those of *Nematoscelis gracilis, Thysanopoda tricuspidata,* and *S. affine* at all but 2 stations. In the most extreme case, larvae in a 45-cm net sample outnumbered by a factor of

[2] At a meeting in Hawaii, Apr 1956, the 45-cm net was adopted as one of the standard plankton nets for sampling in the Pacific. The meeting was attended by oceanographers from Canada, Japan, and the United States for the purpose of coordinating publication of "Norpac" expedition data. It was agreed that the 45-cm net was to be used to supplement other standard nets.

TABLE 6

EUPHAUSIID CATCHING ABILITY OF 45-CM NET COMPARED WITH 1-M NET, AT 10 "EQUAPAC" EXPEDITION STATIONS, 12° N–3° S, 166.5°–175° W

SPECIES	STAGE	DENSITY MEASURED BY 45-CM NET EXCEEDED DENSITY MEASURED BY 1-M NET (no. of hauls)	DENSITY MEASURED BY 1-M NET EXCEEDED DENSITY MEASURED BY 45-CM NET (no. of hauls)	DENSITY MEASURED BY 45-CM NET EQUAL TO DENSITY MEASURED BY 1-M NET (no. of hauls)
Euphausia tenera	adults	2	3	6
	juvs.	2	6	2
	furcilia	9	1	0
E. diomediae	adults	0	5	5
	juvs.	2	4	4
	furcilia	6	0	4
E. paragibba	adults	1	3	6
	juvs.	1	4	5
	furcilia	1	1	8
Nematoscelis gracilis	adults	0	1	9
	juvs.	4	5	1
	furcilia	8	2	0
N. tenella	adults	0	0	10
	juvs.	1	3	6
	furcilia	6	2	2
N. microps	adults	0	0	10
	juvs.	1	1	8
	furcilia	6	3	1
Stylocheiron affine	adults	4	6	0
	juvs.	4	5	1
	furcilia	8	2	0
S. carinatum	adults	4	4	2
	juvs.	6	4	0
	furcilia	5	5	0
S. microphthalma	adults	4	4	2
	juvs.	4	5	1
	furcilia	3	4	3
S. abbreviatum	adults	0	0	10
	juvs.	2	2	6
	furcilia	8	0	2
S. suhmii	adults	1	0	9
	juvs.	1	1	8
	furcilia	0	1	9
S. longicorne	adults	0	1	9
	juvs.	0	1	9
	furcilia	1	0	9
Thysanopoda aequalis	adults	2	0	8
	juvs.	4	3	3
	furcilia	4	1	5
T. tricuspidata	adults	0	0	10
	juvs.	4	4	2
	furcilia	8	2	0
T. monacantha	adults	0	1	9
	juvs.	2	1	7
	furcilia	1	4	5
Totals (all species)	adults	18	28	($p = .18$)
	juvs.	38	49	($p = .28$)
	furcilia	74	28	($p < .01$)

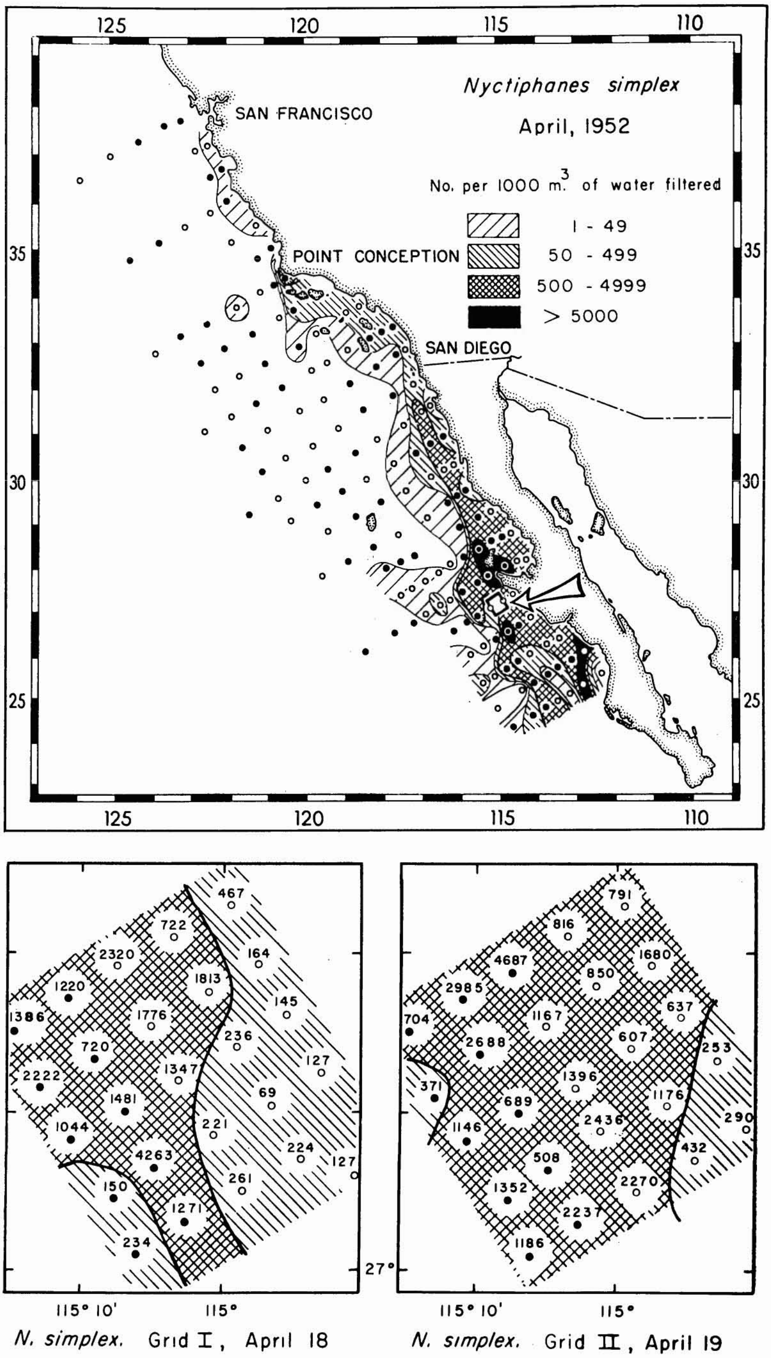


FIG. 19. *Nyctiphanes simplex,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.

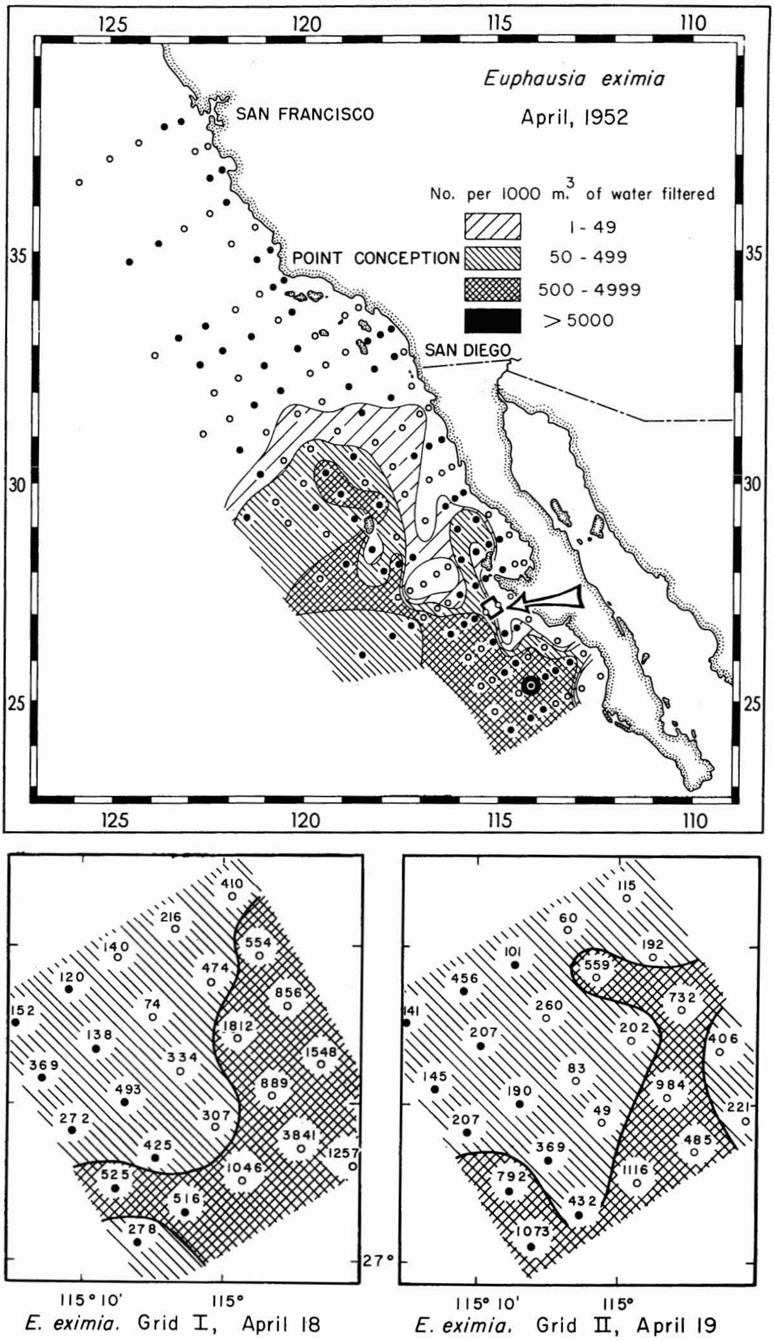
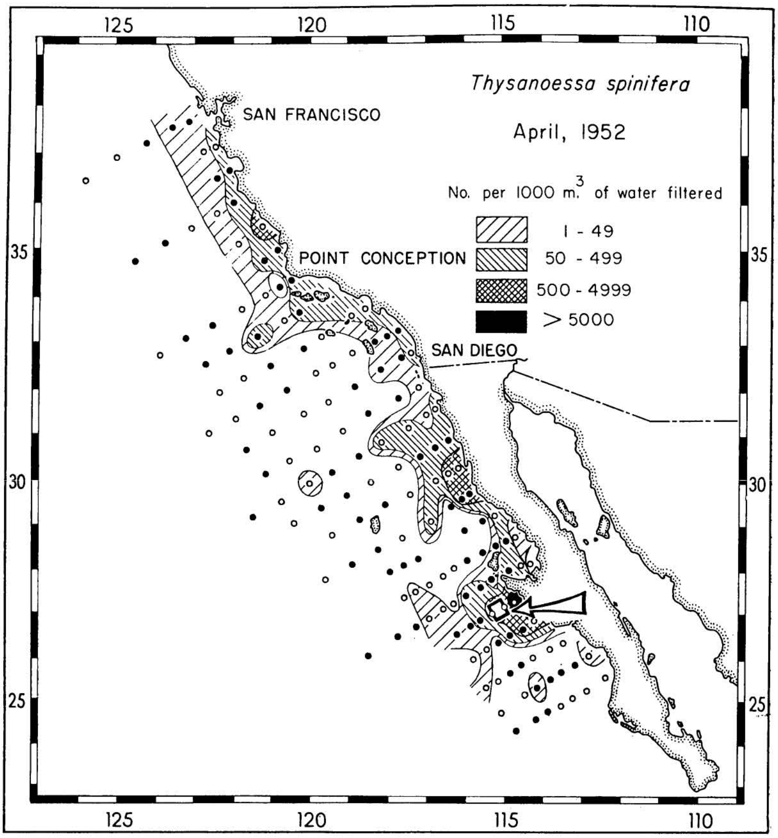
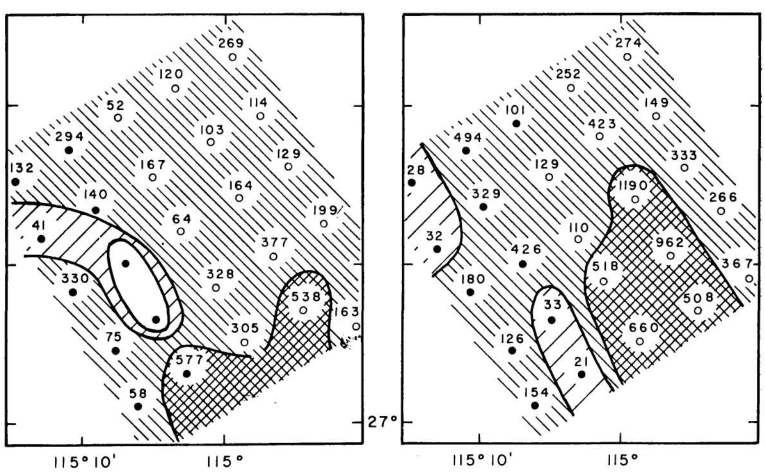


FIG. 20. *Euphausia eximia,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.





T. spinifera. Grid I, April 18

T. spinifera. Grid II, April 19

FIG. 21. *Thysanoessa spinifera,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.

4.1 larvae in a 1-m net sample. More often the values differed by factors smaller than 3.0.

Adults of the large *Euphausia* species, *E. diomediae,* appeared to be more numerous when sampled by the 1-m net than by the 45-cm net. Adults of the other species, generally low in concentration, were not consistently better sampled by either type of net.

In 21 instances the estimated concentration interval for the total count of a species differed between the two samples (using intervals of 1–49, 50–499, 500–4,999, > 5,000 per 1000 m^3). In 86 instances the interval was the same.

On 41 occasions both samples were negative for a species listed in Table 6 (these accounted for all but 4 of the instances in which the density of a species measured by the 45-cm net was equal to the density measured by the 1-m net); on 98 occasions both samples were positive (Table 7).

Eight stations were positive for a species on the basis of the 1-m net sample and negative on the basis of the 45-cm net sample: *Euphausia diomediae* (1 sta.), *E. paragibba* (1 sta.), *Nematoscelis microps* (1 sta.), *N. tenella* (1 sta.), *Thysanopoda monacantha* (4 sta.). *T. monacantha* was present only in the 45-cm net sample at two stations and *Stylocheiron abbreviatum* at one station. It is evident, therefore, that in terms of presence and absence the two nets did not clearly differ in sampling.

The total euphausiid concentrations at each station (all species summed), determined by the two samples, differed by maximum factors of 1.89 and 1.94. At 8 of the 10 stations the total euphausiid concentration based upon the 45-cm net sample was larger. This was related to the greater number of furcilia larvae retained by the fine-mesh net.

The numbers of adults, juveniles, and furcilia larvae, totalled for all of the euphausiid species caught by each type of net, were as follows:

	45-CM NET	1-M NET	RATIO
Adults	6,716	6,682	1.01 : 1.00
Juveniles	11,780	16,086	0.73 : 1.00
Furcilia larvae	23,362	11,706	2.00 : 1.00
Total	41,858	34,474	1.21 : 1.00

Only the furcilia larvae were sampled in very different concentrations: the 45-cm net with a mesh size of 0.33 mm retained on the average twice as many as the 1-m net. The larger net evidently allowed some furcilia to pass through the meshes, 0.65 mm apart. Though the over-all length of the larva is greater than the mesh width of both nets, larvae with a height or width of 0.33–0.65 mm were more often retained by the small net.

CONCLUSIONS AND SUMMARY

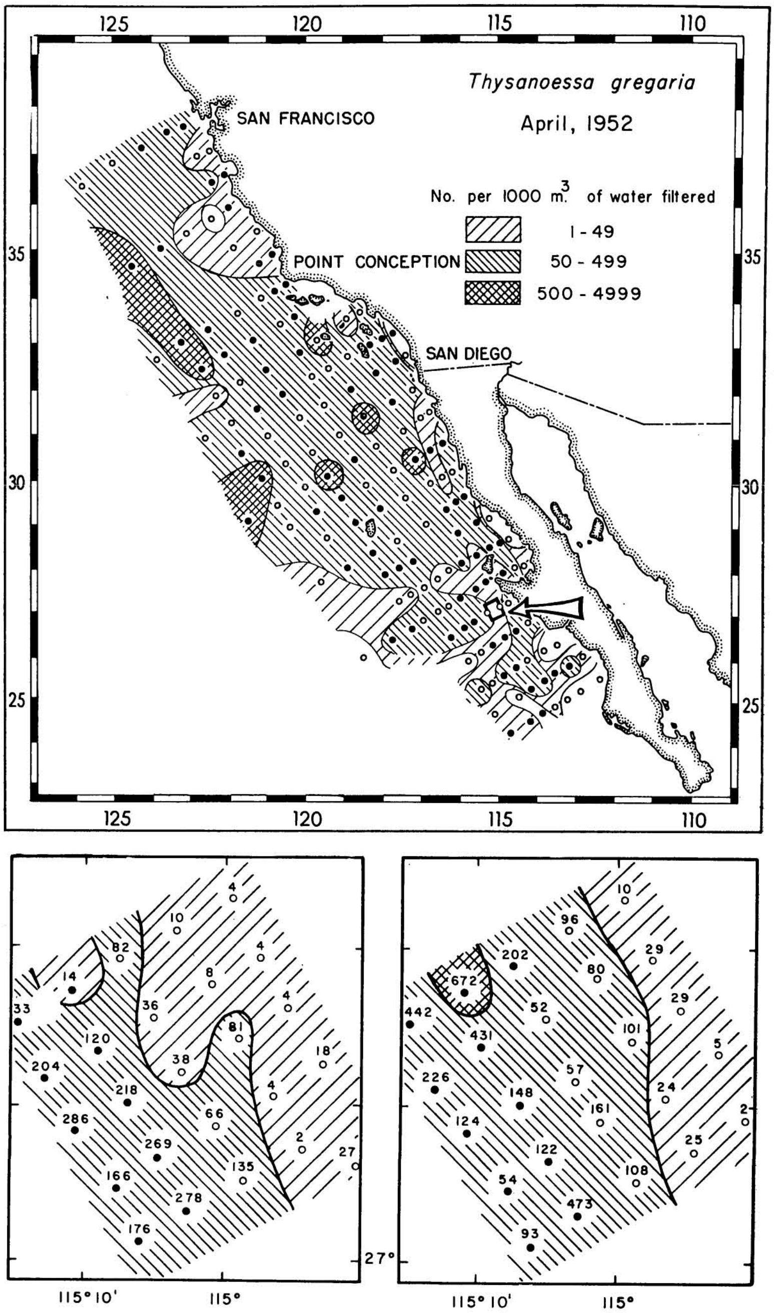
A precise picture of the concentrations of the euphausiid species, with attention to geographical distribution and time variation, can be established only if the effective artificial variables are recognized, and the estimated concentrations corrected. The data included here suggest that a standard basis for such corrections would be difficult to establish.

The qualitative aspect of the counting procedure is accurate. All euphausiid species present in a sample are recorded. An aliquot is counted so that the concentrations of the plentiful species (more than about 25 specimens per 1000 m^3) can be determined. The method of taking aliquots using a graduated cylinder to measure a fraction of the total volume of plankton and fluid was tested for reliability. Replicate counts of three samples indicated that the ali-

TABLE 7

PRESENCE AND ABSENCE OF SPECIES; 1-M NET SAMPLES COMPARED WITH 45-CM NET SAMPLES

		1-M NET		
		Present	Absent	
45-cm net	Present	98	3	101
	Absent	8	41	49
		106	44	150



T. gregaria. Grid I, April 18   *T. gregaria*. Grid II, April 19

FIG. 22. *Thysanoessa gregaria*, Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.

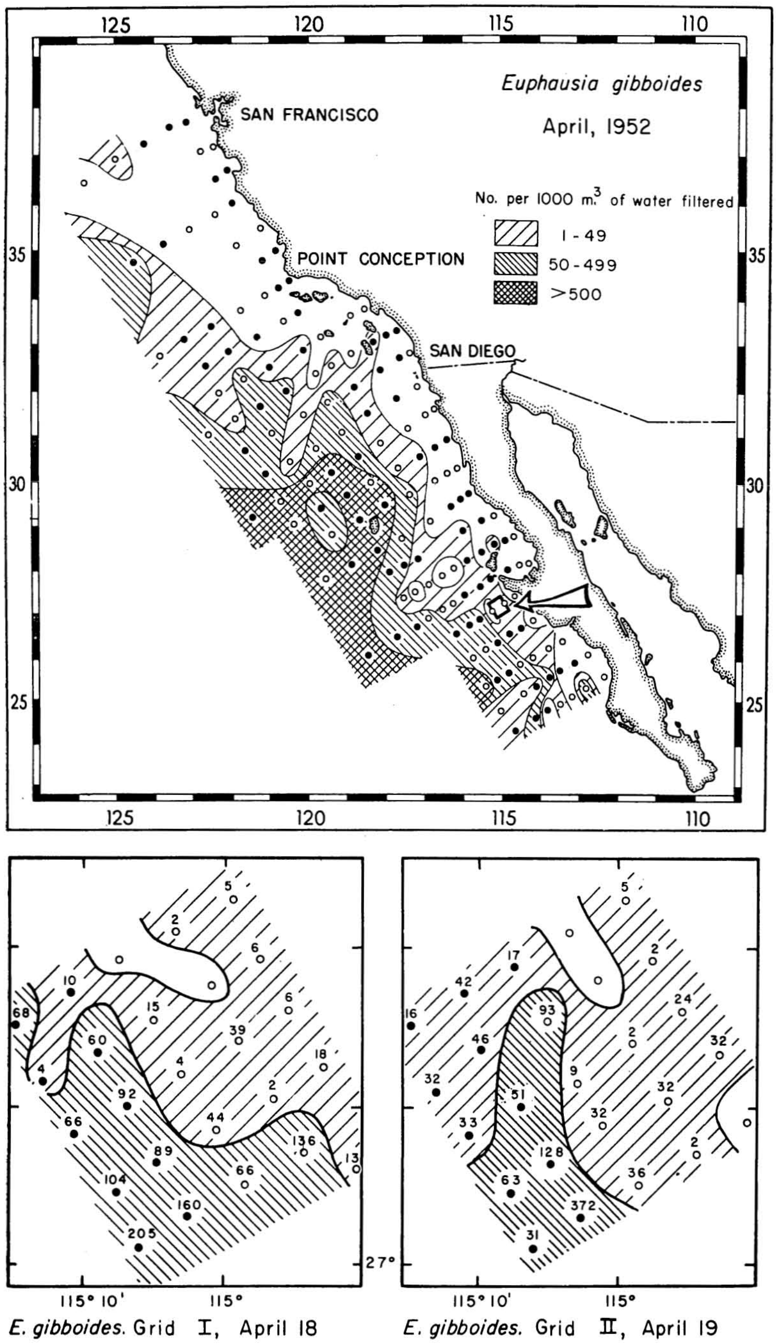


FIG. 23. *Euphausia gibboides,* Apr 1952 (CCOFI Cruise 5204), and two close-grid surveys carried out at the conclusion of the CCOFI cruise. Nighttime station dots are blackened. Daytime stations are open circles. The arrow on the upper chart indicates the area of the close-grid survey.

quots were obtained in a random manner and provided reliable estimates of species composition and concentration.

The catching ability of the standard 1-m net (mesh width of 0.65 mm) did not differ greatly from that of a smaller net, constructed of material with a mesh width of 0.33 mm. As great or greater numbers of adult and juvenile euphausiids were taken by the larger net of coarser mesh, but about twice as many furcilia larvae, which made up a large proportion of the total population, were obtained by the 45-cm net.

The "Equapac" collections established that the 45-cm net samples, filtering 66–99 m^3 of water, were almost as complete with respect to the number of species present as those taken by the 1-m net. The latter filtered a volume of water five times as great. Both nets sampled obliquely to a depth of 140 m, integrating the catch across a horizontal distance of about 1 mile.

Populations that are patchy between the horizontal extremes of the oblique towing distance will not be sampled as adequately by single vertical hauls as by single oblique tows. Numbers fluctuated in an erratic way in the samples taken at anchor station 72.60 by vertical hauls. Diurnal periodicity in numbers of the cool-water species was observed at the offshore anchor stations 70.90 and 70.130 (Figs. 9, 11). The warm-water species (Fig. 12) were consistent within the 1–49 concentration interval and, except for *Stylocheiron abbreviatum,* did not show diurnal peaks. The difference between stations may be due to (1) the relatively smaller amount of water filtered by the vertical hauls at station 72.60, and (2) irregular fluctuations in current speed and direction at the near-shore locality. The time-concentration series at anchor stations 70.90, 70.130, and at the Baja California anchor and buoy stations (Fig. 15) indicated that most concentrations were constant and were representatively sampled.

All species at station 70.130 were uniform in estimated numbers or in their diurnal period of availability during the 8-day sampling period. Similarly, at station 70.90, only *Nematoscelis difficilis* and *Euphausia pacifica* underwent real changes in concentration during the 8-day sampling period. The former species replaced the latter in dominance.

Euphausiid species showing no significant density change, or showing a regular change with a diurnal period, were either (1) homogeneously distributed in a segment of the current stream, at least 50–100 miles long, that passed the ship during the time the station was occupied, or (2) relatively stationary at the anchor station locality. Species that underwent gradual concentration changes of nondiurnal period were either carried from different parts of their distributional ranges, across which there were concentration gradients, or were changed locally in apparent numbers as the mean depth of the population changed. A mechanism for replacement can be seen in the differential lateral movement of species in relation to each other, owing to differences in their vertical ranges. Species having similar vertical ranges remain longer in association with each other than those having dissimilar vertical ranges. The latter may be transported in different directions horizontally. For example, *Thysanoessa gregaria* and *Nematobrachion flexipes* at station 70.90 remained in association with each other, but not with *Nematoscelis difficilis* and *Euphausia pacifica,* the numbers of which increased and decreased respectively.

Data from the grid–buoy–anchor station survey off Baja California agreed with the data from the central California anchor station 72.60, in that the 24-hr periodicity in concentration was *least* where larval euphausiids were dominant, and *most* where juveniles and adults were numerous. The central populations found at anchor station 70.130, composed mainly of larvae and postlarvae, showed little 24-hr fluctuation in the 0–140-m layer.

Populations of larvae and postlarvae sampled from a vessel following a drogue which drifted with the current at a depth of 10 m, were little, if at all, more constant in numbers during the 5-day period than those sampled at the anchor station, a fixed geographical locality. Only *Nyctiphanes simplex* changed extremely in concentration at the anchor station but not at the drift buoy. Diurnal periodicity, not evident at the anchor station, was found for the three most numerous species in the samples taken at the drift buoy after the second day, when the course of the buoy changed.

Concentrations of species sampled by the grid surveys showed agreement with concentrations at the concurrent anchor station. Species boundaries and concentration intervals were in close agreement with the generalized boundaries and concentration intervals determined from the Apr 1952, CCOFI Cruise, which was followed by the Punta Eugenia survey. The determination of the distributions of some species, notably *Euphausia recurva* and *Stylocheiron affine,* was to a considerable extent dependent at their southern limits upon the presence of night stations.

Distribution patterns plotted on the scale of the California Current or the entire North Pacific appeared discrete, notwithstanding the inconsistency in the time of day of sampling. Distributions based upon sampling to a depth of 280 m (Figs. 2, 3) were less patchy than those based on sampling to 140 m.

Nevertheless, the species distributions plotted for the CCOFI survey region on the basis of the 0–140-m samples show some regions of high density that are based on day stations, and some regions of low density based on night stations. Of the stations shown (Figs. 1, 16–23) at which the concentration of a species was greater than 50 per 1000 m^3, only 346 out of a total of 603 (57.4%) were occupied at night (twilight to dawn).

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