VERTICAL DISTRIBUTION OF ZOOPLANKTON IN CENTRAL EQUATORIAL PACIFIC, JULY-AUGUST 1952

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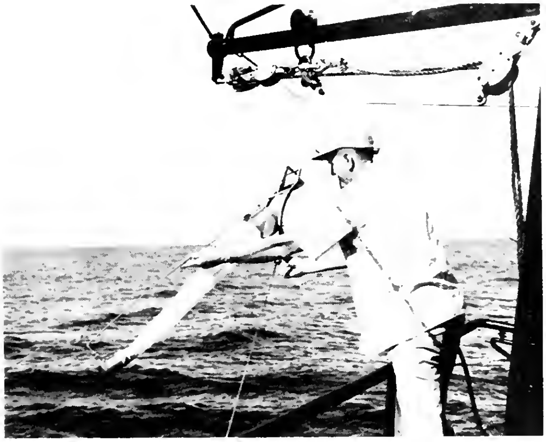

VERTICAL DISTRIBUTION OF ZOOPLANKTON IN THE CENTRAL EQUATORIAL PACIFIC, JULY-AUGUST 1952

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VERTICAL DISTRIBUTION OF ZOOPLANKTON IN THE CENTRAL EQUATORIAL PACIFIC, JULY-AUGUST 1952

Longline-fishing surveys by the Pacific Oceanic Fishery Investigations (POFI) have shown a concentration of deep-swimming yellowfin tuna between the Equator and 5°N. latitude from 140° to 160°W. longitude (Sette 1954). This area is also relatively high in zooplankton abundance (King and Demond 1953), and it is believed that the concentration of both zooplankton and tuna within these latitudes is influenced by the increased fertility of the surface layer resulting from the equatorial upwelling of nutrient-rich water (Cromwell 1951, Sette 1954, and King[1/]).

In longline fishing in this region there has been a tendency for the deeper hooks, fishing at depths of about 300 to possibly 500 feet, to catch more tuna[2/] than the shallower hooks fishing at 150 to 250 feet (Murphy and Shomura, 1953a, 1953b). In the area of best catch, the deeper hooks apparently fish at about the level of the thermocline. One hypothesis immediately suggests itself: that these deep-swimming tunas are concentrating at the level which provides the most available food. It is known that the sharp temperature gradient associated with the thermocline may have a concentrating effect on certain plankton forms (Sverdrup et al. 1942, p. 794) and may restrict the migration of others (Moore et al. 1953).

The food of the yellowfin tuna consists of a great variety of organisms, both fish and invertebrates, varying widely in size (Reintjes and King 1953). Although zooplankton comprises on the average a very small percentage of adult tuna food, it is essential food of the forage fish, squid, and shrimp which are utilized directly by the tuna. Therefore, in sampling the zooplankton we believe we are obtaining a reliable index to the basic fish-food present in an area whether utilized directly or indirectly by the tunas.

Since the vertical distribution of zooplankton cannot be determined by the 200-meter oblique tow which has been used by POFI in surveying the relative abundance of zooplankton, a series of horizontal closing-net hauls was made with Clarke-Bumpus samplers (Clarke and Bumpus 1940) to investigate the vertical distribution of zooplankton in relation to the thermocline. Townsend Cromwell was field party chief on cruise 16 of the Hugh M. Smith on which these collections were made, and Heeny Yuen, field party member, was largely responsible for making the hauls. The figures were prepared by Tamotsu Nakata. The oceanographic data resulting from cruise 16 have been published (Austin 1954).

AREA AND METHODS

The sampling was done at 30 stations along 150° W. longitude extending from 12°N. to 7°S. latitude in the 9-day period, July 27 to August 4, 1952, on cruise 16 of the Fish and Wildlife Service vessel Hugh M. Smith. The approximate position of each station is shown in figure 1 and given more exactly together with the date, hour, and depth of hauling in table 1. Of the 90 hauls made, 68 are quantitatively usable. Improper functioning of the gear vitiated the remaining 22 hauls.

At each station, horizontal hauls were made simultaneously at three levels with Clarke-Bumpus samplers equipped with nets of 56XXX grit gauze having mesh apertures averaging 0.31 mm. in width. These were clamped on 5/32-inch (diameter) wire cable at intervals intended to place one sampler at a depth of about 200 meters during the haul, one at about the 70°F.

1/ MS. Variations in zooplankton abundance in the central equatorial Pacific, 1950-52. To be published in Proceedings of the Fifth Meeting of the Indo-Pacific Fisheries Council.

2/ Yellowfin, *Neothunnus macropterus* (Temminck and Schlegel); bigeye, *Parathunnus sibi* (Temminck and Schlegel); and albacore, *Germo alalunga* (Bonnaterre).

isotherm (which occurs within the thermocline in this region), and one just below the surface. A bathythermograph (BT) cast was made at each station before the plankton haul to determine the depth of the 70° F. isotherm. A 150-pound streamlined weight was attached to the end of the towing cable. The hauls were of about 1 hour's duration with a ship's speed of approximately 2 knots. The samples were preserved in 8 to 10 percent formalin neutralized with borax. The samplers were calibrated before and after the cruise, and the average of these calibrations was used to compute the cubic meters of water strained for each haul.

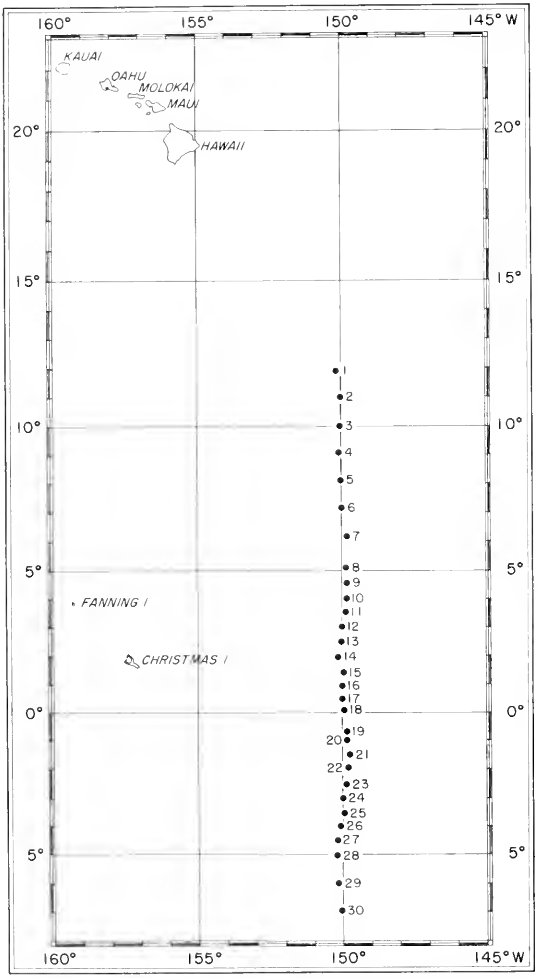

Figure 1.--Locations of stations 1-30 occupied by Hugh M. Smith, cruise 16, July-August 1952.

Estimating Sampling Depth

Throughout the cruise--for lack of exact information--the spacing of samplers on the towing wire was in accordance with the assumption that during the tow the wire described a straight line in the water; thus the cosine of the angle of stray of the towing wire from the vertical was used in calculating the amount of wire to pay-out to reach a desired depth. For example, anticipating a final wire angle of 60° and intending to have the middle sampler operate at the 70° isotherm located at 100 meters, the procedure would be: (1) attach the 150-pound weight to the end of the towing wire; (2) have the winch operator pay-out 10 meters of wire; (3) attach sampler No. 1; (4) pay-out 200 meters of wire; (5) attach sampler No. 2; (6) pay-out an additional 200 meters of wire; (7) attach sampler No. 3; (8) pay-out wire until the last sampler was just below the surface; (9) then begin the 1-hour tow, measuring the wire angle at 5-minute intervals and attempting to maintain a wire angle of about 60° by varying the vessel's speed.

In operating the samplers, however, it was found that the wire angle increased steadily with the increase in the amount of wire out and we doubted that the assumption of a straight wire provided a good estimate of the depth of the samplers. In order to obtain a closer approximation of the true sampling depth, four test hauls were made following the cruise essentially duplicating the procedure outlined above except

Table 1.--Estimated numbers and volumes of zooplankton collected on Hugh M. Smith cruise 16 using Clarke-Bumpus samplers (S = surface sample, I = intermediate sample, D = deep sample)

Sta-tion	Position		Date 1952	Time[1/]	Sample	Depth, meters	Water strained, m^3	Zooplankton		
	Latitude	Longitude						No. /m^3	Vol., cc/ $1000m^3$	Adj. sur. vol., cc/ $1000m^3$
1	11°56'N.	150°09'W.	7/27	0506-0606	S	11	45.4	85	31.3	30.2
					I	125	29.5	107	36.3	--
					D[2/]	--	--	--	--	--
2	11°00'N.	150°00'W.	7/27	1355-1500	S	10	38.2	221	43.5	58.3
					I	117	25.8	77	39.1	--
					D	260	28.5	29	7.7	--
3	10°01'N.	150°03'W.	7/27	2245-2345	S	6	42.7	172	74.9	52.6
					I	92	42.2	96	30.3	--
					D	185	38.9	50	8.5	--
4	09°05'N.	150°06'W.	7/28	0731-0831	S	8	39.8	167	43.2	51.8
					I	65	30.2	94	25.2	--
					D	223	36.3	43	12.7	--
5	08°06'N.	150°02'W.	7/28	1613-1714	S	10	25.0	394	81.9	92.5
					I	83	26.6	175	45.9	--
					D	257	41.1	24	12.9	--
6	07°08'N.	149°58'W.	7/29	0130-0212	S	8	19.5	329	98.3	72.3
					I	121	13.6	198	42.5	--
					D	223	35.2	57	20.2	--
7	06°10'N.	149°49'W.	7/29	1015-1115	S	8	34.1	368	62.8	87.9
					I	142	33.6	58	17.8	--
					D[2/]	--	--	--	--	--
8	05°06'N.	149°51'W.	7/29	1942-2042	S	9	34.5	367	77.3	63.0
					I[2/]	--	--	--	--	--
					D	225	42.2	45	12.3	--
9	04°34'N.	149°51'W.	7/30	0240-0340	S	9	29.6	353	85.5	66.4
					I	160	41.1	42	34.6	--
					D	230	41.0	36	14.6	--
10	04°02'N.	149°52'W.	7/30	0728-0828	S	9	29.2	313	52.3	62.5
					I	156	38.9	66	15.9	--
					D	233	50.4	84	25.2	--
11	03°32'N.	149°53'W.	7/30	1315-1415	S	10	32.7	221	28.1	38.9
					I[2/]	--	--	--	--	--
					D[2/]	--	--	--	--	--
12	03°02'N.	149°59'W.	7/30	1903-2003	S	9	27.0	584	89.5	76.9
					I	172	34.8	94	20.4	--
					D[2/]	--	--	--	--	--
13	02°30'N.	150°02'W.	7/31	0050-0150	S	9	25.2	644	133.8	95.5
					I	152	34.8	88	31.0	--
					D	232	39.9	52	12.5	--
14	01°57'N.	150°07'W.	7/31	0642-0742	S	8	30.7	538	72.6	82.0
					I[2/]	--	--	--	--	--
					D	215	42.0	65	24.5	--
15	01°24'N.	149°57'W.	7/31	1240-1340	S	8	27.7	344	50.9	72.0
					I	117	36.1	199	39.6	--
					D	215	47.2	92	25.4	--

1/ Zone time for 150° west longitude.
2/ No samples due to mechanical failure of samplers.

Table 1.--Estimated numbers and volumes of zooplankton collected on Hugh M. Smith cruise 16 using Clarke-Bumpus samplers (S = surface sample, I = intermediate sample, D = deep sample) (continued)

Station	Position		Date 1952	Time[1/]	Sample	Depth, meters	Water strained, m^3	Zooplankton		
	Latitude	Longitude						No. $/m^3$	Vol., cc/ $1000m^3$	Adj. sur. vol., cc/ $1000m^3$
16	00°57'N.	150°01'W.	7/31	1753-	S	9	26.1	515	93.1	90.2
				1853	I	132	33.8	164	39.4	--
					D	243	44.6	77	26.4	--
17	00°28'N.	150°01'W.	7/31-	2332-	S	8	28.4	403	85.1	59.6
			8/1	0032	I[2/]	--	--	--	--	--
					D[2/]	--	--	--	--	--
18	00°06'N.	149°55'W.	8/1	0519-	S[2/]	--	--	--	--	--
				0629	I[2/]	--	--	--	--	--
					D[2/]	--	--	--	--	--
19	00°39'S.	149°49'W.	8/1	1047-	S	8	21.6	273	51.9	73.8
				1147	I	127	38.8	258	44.3	--
					D	224	49.8	92	20.5	--
20	00°59'S.	149°50'W.	8/1	1509-	S	10	26.4	576	100.6	123.4
				1609	I[2/]	--	--	--	--	--
					D[2/]	--	--	--	--	--
21	01°28'S.	149°45'W.	8/1	2003-	S	9	18.7	722	121.2	96.4
				2103	I[2/]	--	--	--	--	--
					D[2/]	--	--	--	--	--
22	01°58'S.	149°48'W.	8/2	0133-	S	8	28.4	353	85.3	62.7
				0233	I[2/]	--	--	--	--	--
					D[2/]	--	--	--	--	--
23	02°29'S.	149°53'W.	8/2	0710-	S	7	30.0	266	47.4	55.2
				0810	I[2/]	--	--	--	--	--
					D	191	49.8	58	27.1	--
24	02°59'S.	149°59'W.	8/2	1230-	S	6	30.0	204	20.7	29.2
				1330	I	99	41.7	288	41.0	--
					D	176	40.5	84	14.8	--
25	03°29'S.	149°57'W.	8/2	1752-	S	8	29.2	228	41.7	40.4
				1852	I	132	35.7	113	25.5	--
					D	211	34.2	68	12.9	--
26	03°59'S.	150°05'W.	8/2-3	2305-	S	8	23.9	300	37.3	26.1
				0005	I	144	41.6	100	24.5	--
					D[2/]	--	--	--	--	--
27	04°29'S.	150°12'W.	8/3	0432-	S	6	28.2	285	36.2	33.0
				0532	I	116	46.3	126	22.3	--
					D[2/]	--	--	--	--	--
28	05°02'S.	150°12'W.	8/3	0949-	S	9	25.3	279	24.5	33.9
				1053	I	176	31.3	100	7.7	--
					D[2/]	--	--	--	--	--
29	06°00'S.	150°10'W.	8/3	1756-	S	6	29.1	239	49.9	48.3
				1856	I	147	53.5	94	20.6	--
					D	168	47.3	42	12.7	--
30	06°58'S.	150°05'W.	8/4	0209-	S	8	27.7	297	55.9	42.5
				0309	I	188	38.0	55	10.2	--
					D	225	37.4	31	7.0	--

1/ Zone time for 150° west longitude.

2/ No samples due to mechanical failure of samplers.

that a bathythermograph was attached just below the 150-pound weight to record depth and that the wire angle and wire out were measured at 1- to 2-minute intervals during each haul. From these measurements the approximate curvature of the towing wire on these four hauls has been reconstructed (fig. 2) by means of a series of triangles. If we assume that the wire maintains the same angle as it is lowered farther into the sea, then the sum of the vertical sides of the triangles should approximate the true depth attained under uniform current and ship speed. The pertinent data on the four test hauls are given in table 2. It is evident from this table that the method illustrated in figure 2 produces an estimate of the depth of hauling which is much closer to the depth recorded by the bathythermograph than the estimate based on the assumption that the towing wire conformed to a straight line.

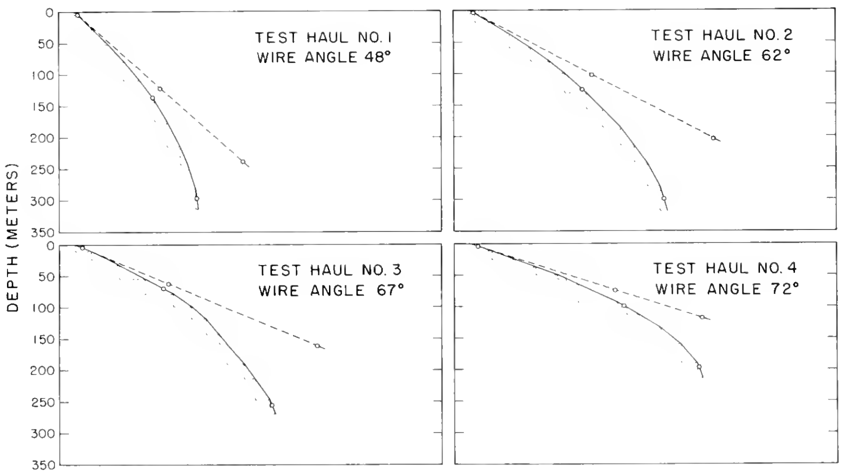

Figure 2. --Reconstruction of the curvature of the towing wire during four test hauls utilizing wire-angle and wire-out observations. Depths of the samplers assuming the towing wire to describe a straight line are shown for comparison.

The next step was to plot for the four test hauls the estimated depths calculated by the straight-line method against the estimated depths calculated by the curved-line method. On logarithmic graph paper the distribution appears to be rectilinear and a straight regression line was fitted as shown in figure 3. This line was then used to convert the straight-line estimated depths of cruise 16 to the equivalent curved-line estimated depths (given in table 1), using the maximum wire out and an average wire angle for the 1-hour haul. For example, if the estimated depth of the deep sampler on one of the hauls was 100 meters calculated by the straight-line method, the converted depth for that sampler would be 120 meters as derived from the graph in figure 3. When the converted depths are plotted in reference to the temperature structure, as in figure 4 and the selected bathythermographs of figure 5, it is apparent that the intermediate sampler was operating within the thermocline and usually between the 60° and 70° isotherms. The deep sampler was below 60° F.--with one exception (station 29)--and frequently below the 50° F. isotherm.

This method of estimation was necessary because wire out and wire angle were not recorded on cruise 16 while the samplers were being lowered but only during that portion of the haul when the samplers were open and fishing. This precludes direct estimation by the use of

Table 2.--Results of four test hauls showing differences in the estimated depth reached, employing three methods of determination

	Haul			
	1	2	3	4
Wire angle with full amount of wire out	48°	62°	67°	72°
Total wire out (meters)	370	450	427	431
Vertical height of work platform above sea surface (meters)	3	3	3	3
Length of wire between lead weight and deep sampler (meters)	10	10	10	10
Estimated depth of the deep sampler (meters):				
a. Assuming a straight wire	238	204	163	127
b. On curved-wire basis	294	300	257	197
c. As obtained from BT	293	301	239	204

triangles. However, it should be noted that in the waters traversed during this cruise there is marked horizontal shearing associated with differential current flows which undoubtedly exert a strong influence on the shape of the towing cable with its attached instruments. Under these conditions the actual depth of sampling will vary considerably from the estimated depth, especially when the latter has been derived from average relations. It is regretted that a continuous depth recorder was not available at the time of the cruise.

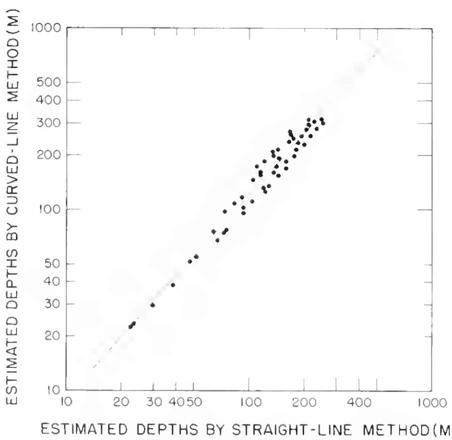

Figure 3.--Combined results of the four test hauls, plotted on a logarithmic scale, showing the relationship between estimated depths based on straight-wire and curved-wire calculations. The regression coefficient (b) = 1.1238.

Treatment of Samples in Laboratory

In the laboratory, displacement volume measurements were made on the 68 acceptable samples. First the few organisms with longest dimension greater than 2 cm. were removed from the sample, identified as precisely as possible, and their displacement volume measured. Then the volume of the remainder and bulk of the sample, i.e. those organisms with longest dimension less than 2 cm., was determined. In measuring the displacement volume, the plankton was poured into a draining sock of 56XXX grit gauze to filter off the preserving liquid. When the sample stopped dripping it was transferred to a graduated cylinder of appropriate size (usually 5 or 10 ml. capacity). By means of a burette a known volume of water was added to the drained plankton. The difference between the volume of the plankton plus the added liquid and the volume of added liquid was recorded as the displacement or net wet volume of that portion of the sample.

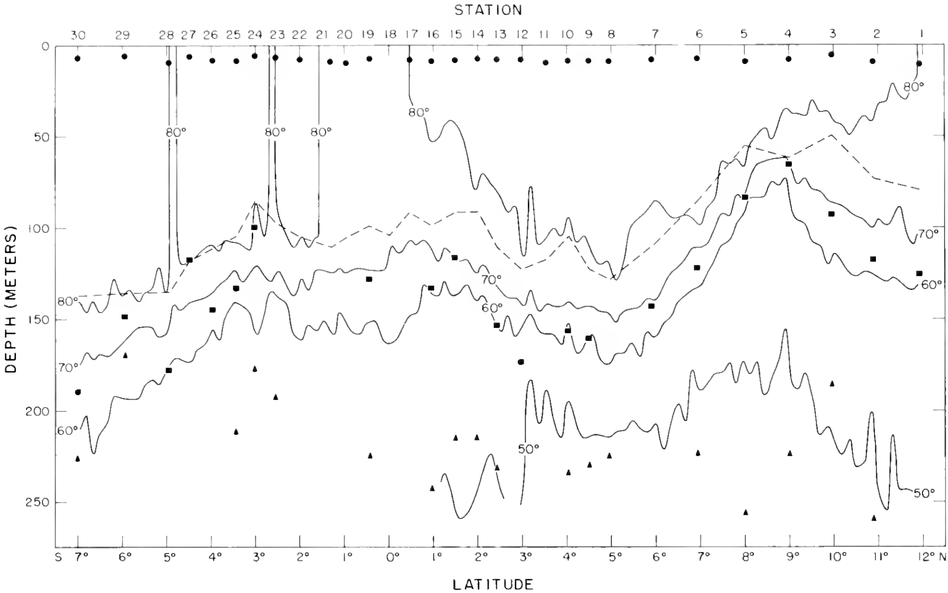

Figure 4.--Vertical temperature section along 150°W. longitude, showing the estimated hauling depths of the surface (●), intermediate (■), and deep samplers (▲) in relation to the temperature structure. The isotherms are derived from 900-ft. bathythermograph observations taken on stations 1 through 30 of Hugh M. Smith cruise 16, July-August 1952. The top of the thermocline is indicated by the dashed line.

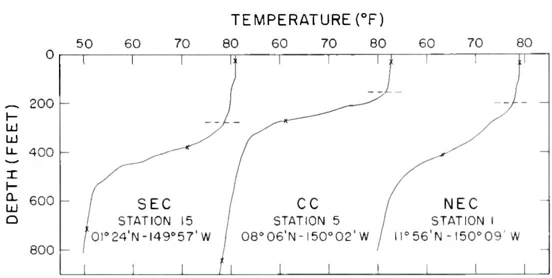

Figure 5.--Bathythermographs representative of the vertical temperature structure in the North Equatorial Current (NEC), the Countercurrent (CC), and the South Equatorial Current (SEC), at the station positions indicated. The hauling depths of the surface, intermediate, and deep plankton samplers are shown (X). A dashed line is drawn at the top of the thermocline.

Following the usual procedure at our laboratory, the volume of all organisms less than 2 cm. in length plus the volume of organisms 2 to 5 cm. in length that might be considered of significant nutritional value (such as the annelids, crustaceans, cephalopods and fish) were combined to give a single volume measurement for each sample. This figure was divided by the estimated amount of water passing through the net to give the volume of zooplankton per unit of water strained.

After the volume measurement the contents of each sample were spread out in a shallow rectangular dish (10 x 15 cm.). A Wolffhuegel counting plate was placed over the dish and all organisms greater than 0.2 mm.[3] in their longest dimension were counted in 10 fields, each 1 cm. square. Organisms larger than 2 cm. had been previously removed from the sample and were counted separately. The counts of 12 major groups of the zooplankton, together with a miscellaneous category, including such things as annelids, shrimps, and fish, are given in table 3. An identification to species level was made of most of the organisms appearing in the six samples collected at stations 3 and 13. These results are given in table 4 and discussed in a later section (p. 14).

DIURNAL VARIATION

The importance of diurnal variation in estimating zooplankton abundance in the central Pacific has been discussed by King and Demond (1953) and King and Hida (1954). It was evident from initial examination of the volumetric data on which this report is based that the hour of hauling provided an important source of variation. This is demonstrated by the ratios of the average volumes of night hauls to day hauls, which were 1.63 for the surface samples, 0.90 for the intermediate samples, and 0.66 for the deep samples (table 5). When the data[4] were examined by means of a "t" test, we found a highly significant ($P < 0.01$) difference between the volumes of day and night samples taken at the surface, a slight but nonsignificant ($P \cong 0.5$) difference at the intermediate level, and a considerable, and nearly significant ($P \cong 0.08$), difference at the deep level. Although the difference at the deep level may not be judged statistically significant, the fact that the observed volumes of the day hauls materially exceeded those of the night hauls at the deep level with just the reverse being true in the surface layer (table 5), suggests that there was some vertical migration taking place and that this marked day-night difference at the surface was not entirely the result of a simple dodging of the net. The lack of a strong day-night difference at the intermediate level suggests that this stratum received from layers below about as much plankton as it lost to layers above.

An adjustment to remove the effect of diurnal change in zooplankton volumes has been suggested by O. E. Sette, Director, Pacific Oceanic Fishery Investigations, and described by King and Hida (1954). The method is based upon the similarity between the diurnal variation in zooplankton abundance and the curve of the sine function with midnight equated to the angle whose sine is +1.0.

To examine the suitability of this method for correcting the day-night variation in the surface samples of cruise 16, the data were plotted as in figure 6, the abscissa being the sine function of the angle corresponding to the time of hauling. As the values have essentially a rectilinear distribution, a straight line was fitted as shown. The regression of the zooplankton volumes on the sine function is highly significant ($b = 0.1553$, $P < 0.01$). Following adjustment the night-day ratio is 0.98, as compared with 1.63 before adjustment, and the variance is reduced by one-third (table 6). From this evidence it appeared that the sine method of adjustment as devised for

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3/ It should be noted that this differs from the lower limit of 0.5 mm. used by King and Demond (1953) on plankton from hauls made by nets of coarser (30XXX grit gauze) mesh.

4/ Transformed by means of logarithms since the standard deviations of the untransformed data were proportional to the means.

Table 3.--Variations in numerical abundance (number[1/] of organisms per cubic meter of water strained) of 12 major groups of the zooplankton as sampled on cruise 16 of the Hugh M. Smith. (S = surface sample, I = intermediate sample, and D = deep sample)

Station	Sample	Foraminifera	Radiolaria	Siphonophora	Chaetognatha	Copepoda	Euphausiacea	Amphipoda	Ostracoda	Crustacean larvae	Gastropoda	Tunicata	Eggs	Miscellaneous
1	S	3	-	1	2	38	2	1	0	2	5	1	29	1
	I	-	-	1	4	76	2	0	6	2	1	6	6	2
2	S	3	0	1	16	184	0	3	0	1	3	3	4	4
	I	6	1	1	4	51	0	0	2	1	4	2	4	2
	D	5	0	0	0	19	1	0	0	0	0	0	2	3
3	S	12	0	3	5	132	5	3	1	0	6	1	2	1
	I	2	0	-	2	77	2	1	1	-	1	1	5	3
	D	2	1	-	2	38	-	0	-	-	1	-	5	-
4	S	19	0	2	8	120	-	1	0	1	8	3	1	2
	I	9	0	0	10	60	6	1	0	2	0	1	4	2
	D	0	1	0	1	31	1	0	3	-	0	1	3	2
5	S	14	0	0	6	330	0	0	0	4	4	23	11	2
	I	9	1	2	5	140	2	1	0	1	3	3	7	1
	D	-	-	0	-	17	2	0	2	0	0	0	2	1
6	S	27	0	2	7	234	2	1	1	4	18	22	9	3
	I	16	1	1	1	146	0	2	3	4	0	2	7	13
	D	4	-	-	1	36	-	0	6	0	-	-	4	6
7	S	29	5	-	7	249	2	-	0	5	4	21	41	4
	I	8	1	2	1	25	1	0	2	7	1	3	5	1
8	S	30	0	3	14	255	6	1	0	-	8	14	35	2
	D	6	2	-	1	17	0	-	5	0	4	-	8	1
9	S	36	0	5	8	217	2	-	0	2	15	9	57	-
	I	6	2	0	-	22	0	1	4	1	1	1	5	-
	D	2	6	0	2	16	0	-	2	2	0	0	6	0
10	S	57	1	0	8	164	7	0	0	4	10	9	53	-
	I	4	1	1	2	39	0	0	0	4	1	1	11	2
	D	3	2	-	1	59	2	0	4	0	3	1	7	2
11	S	32	1	0	4	119	-	-	0	2	6	7	49	0
12	S	32	0	2	16	434	13	1	0	3	13	19	50	1
	I	1	4	-	0	65	-	-	10	-	0	-	10	2
13	S	85	0	5	9	470	10	1	1	2	11	5	38	9
	I	13	-	-	1	49	1	0	7	0	-	2	6	7
	D	8	1	-	3	24	1	1	4	-	0	0	4	5
14	S	128	3	2	8	286	3	0	0	10	13	11	73	0
	D	2	-	-	2	31	12	1	5	1	1	0	9	1
15	S	101	2	0	3	195	0	-	0	0	-	13	27	1
	I	39	9	1	12	116	0	-	0	-	2	2	17	0
	D	6	13	-	3	56	1	-	7	1	-	-	4	-

1/ A zero indicates no organisms present; a hyphen indicates a count of less than 1 per cubic meter.

Table 3.--Variations in numerical abundance (number[1/] of organisms per cubic meter of water strained) of 12 major groups of the zooplankton as sampled on cruise 16 of the Hugh M. Smith. (S = surface sample, I = intermediate sample, and D = deep sample) (continued)

Station	Sample	Foraminifera	Radiolaria	Siphonophora	Chaetognatha	Copepoda	Euphausiacea	Amphipoda	Ostracoda	Crustacean larvae	Gastropoda	Tunicata	Eggs	Miscellaneous
16	S	41	2	2	6	372	3	-	0	3	10	23	49	3
	I	30	3	-	6	86	4	-	1	5	3	-	24	1
	D	4	7	0	1	45	1	0	8	3	1	-	5	-
17	S	48	-	3	7	263	10	-	0	0	17	23	31	0
19	S	76	6	1	4	136	2	0	1	1	0	33	11	1
	I	79	3	2	19	136	0	1	-	-	5	1	10	1
	D	8	9	1	-	39	6	-	2	0	2	0	24	1
20	S	32	15	4	4	319	6	0	0	8	1	50	136	0
21	S	117	5	4	14	415	2	2	0	23	30	40	69	2
22	S	32	9	2	8	176	2	1	0	5	15	12	90	1
23	S	63	2	2	2	126	3	0	-	4	2	6	56	-
	D	3	2	0	1	32	-	0	5	1	4	-	7	2
24	S	30	4	0	2	118	5	0	0	-	7	15	22	0
	I	29	5	0	6	172	0	0	-	2	44	3	24	1
	D	2	4	0	1	53	0	0	7	2	3	3	11	0
25	S	20	2	-	2	170	1	-	0	2	1	12	16	0
	I	8	2	0	3	80	2	0	6	1	1	-	9	-
	D	1	4	0	3	45	0	0	2	2	0	3	6	2
26	S	18	0	1	11	266	1	0	1	0	0	1	0	0
	I	9	-	0	6	72	-	0	9	0	1	-	2	-
27	S	22	-	-	6	230	1	0	1	0	9	3	12	0
	I	24	0	-	5	82	2	0	1	2	-	1	8	1
28	S	33	1	1	3	179	0	0	0	5	0	30	27	1
	I	10	1	-	2	62	0	-	2	1	0	1	19	-
29	S	21	0	1	4	157	-	0	0	1	15	13	25	-
	I	16	2	0	2	49	2	-	3	3	6	1	10	-
	D	2	-	-	0	27	1	0	7	0	0	-	3	1
30	S	14	-	1	7	201	1	0	-	4	44	11	14	-
	I	4	5	-	1	31	1	-	9	1	0	0	2	2
	D	-	2	0	-	21	0	0	4	1	1	-	1	0

1/ A zero indicates no organisms present; a hyphen indicates a count of less than 1 per cubic meter.

Table 4.--Partial list of organisms occurring in samples collected at stations 3 and 13 of Hugh M. Smith cruise 16, with the general estimated abundance classified as present (x), frequent (xx), very frequent (xxx), and conspicuously abundant (xxxx). Both stations were occupied at night

Organisms	Station 3 10°01'N.-150°03'W. N. Equatorial Current			Station 13 02°30'N.-150°02'W. S. Equatorial Current		
	Surface sample	Interm. sample	Deep sample	Surface sample	Interm. sample	Deep sample
Copepoda						
Calanoidea						
Euchaeta prestandreae (Philippi)	xxx	xxxx	xx	xx	xx	--
Pleuromamma abdominalis (Lubbock)	--	xx	--	xxxx	x	--
Pleuromamma robusta (Dahl)?	--	--	--	--	x	--
Pleuromamma xiphias (Giesbrecht)	x	--	--	x	--	--
Candacia pachydactyla (Dana)	x	x	--	xx	--	--
Neocalanus gracilis (Dana)	xxx	x	--	xxx	xxx	--
Rhincalanus cornutus (Dana)	--	x	--	--	x	xxxx
Calanus minor (Claus)?	--	xxxx	--	--	--	--
Eucalanus attenuatus (Dana)	x	x	x	xxx	xxxx	--
Heterorhabdus spinifrons (Claus)	--	--	xx	--	x	--
Phyllopus bidentatus (Brady)	--	--	--	--	--	xx
Metridia longa (Lubbock)	--	--	--	x	--	x
Scottocalanus securifrons (T. Scott)	--	--	--	--	x	--
Scolethrix danae (Lubbock)	--	--	x	x	--	--
Undeuchaeta sp.	--	x	--	--	--	--
Undeuchaeta major (Giesbrecht)	--	--	--	--	x	x
Bradyidius armatus (Brady)?	--	--	--	--	x	--
Undina vulgaris (Dana)	xx	--	--	--	--	--
Cyclopoidea						
Oncaea sp.	xx	xxx	x	xxx	x	xxx
Oithona sp.	xx	xx	--	--	x	--
Corycaeus sp.	x	xxx	x	xxx	x	xx
Saphirinella stylifera (Lubbock)	--	--	--	x	x	--
Copilia mirabilis (Dana)	--	--	--	x	x	--
Saphirina scarlata (Giesbrecht)	--	--	--	x	--	--
Saphirina metallina (Dana)	--	x	x	--	--	--
Harparticoidea						
Aegisthus mucronatus (Giesbrecht)	--	--	--	--	--	xx
Microsetella rosea (Dana)	--	x	x	--	--	--
Euphausiacea						
Euphausia sp.	--	--	x	--	--	--
Euphausia diomedeae (Ortmann)	xx	x	--	xx	x	--
Stylocheiron sp.	--	x	x	--	--	--
Amphipoda						
Primno latraillei (Gosse)?	--	--	x	--	--	--
Phronima sp.	--	x	--	--	--	--
Phronimella elongata (Claus)	x	--	--	x	--	--
Cyphocaris micronyx (Stebbing)	--	--	--	--	--	x
Hyperia luzoni (Stebbing)	--	--	--	x	--	--
Letocotis ambobus (Stebbing)	x	--	--	--	--	--
Anchylomera blossevillii (Milne-Edwards)	--	x	--	--	--	--
Decapoda						
Lucifer reynaudii (Milne-Edwards)	--	--	--	x	--	--

Table 4.--Partial list of organisms occurring in samples collected at stations 3 and 13 of Hugh M. Smith cruise 16, with the general estimated abundance classified as present (x), frequent (xx), very frequent (xxx), and conspicuously abundant (xxxx). Both stations were occupied at night (continued)

Organisms	Station 3 10°01'N.-150°03'W. N. Equatorial Current			Station 13 02°30'N.-150°02'W. S. Equatorial Current		
	Surface sample	Interm. sample	Deep sample	Surface sample	Interm. sample	Deep sample
Chaetognatha						
Sagitta sp.	--	x	x	xx	--	x
Pteropoda						
Cymbulliopsis sp.	--	x	--	--	--	--
Heteropoda						
Atlanta sp.	--	--	--	x	x	--
Fish						
Vinciguerria lucetia (Garman)	--	--	--	--	x	--

Table 5.--Average volumes and night/day ratios of zooplankton collected by Clarke-Bumpus samplers on cruise 16 for 3 depths of sampling (twilight hauls omitted)

Depth	Time of hauling	No. of samples	Ave. volume, cc/1000m^3	Ratio, N/D
Surface	Night	11	85.2	1.63
	Day	13	52.3	
Intermediate	Night	7	27.6	.90
	Day	9	30.7	
Deep	Night	6	12.5	.66
	Day	9	19.0	

Table 6.--Certain statistics showing the mean volumes and extent of variation for the surface, intermediate, and deep hauls

	Surface		Intermediate	Deep
	Adjusted	Unadjusted		
Number of samples (n)	29	29	21	18
Mean volume ($\bar{x}$)	62.7	64.7	29.2	16.6
Variance (s^2)	581.4	850.7	129.9	46.2
Standard deviation(s)	24.1	29.2	11.4	6.8
Coefficient of variation (C), as percent	38.5	45.1	39.0	41.0

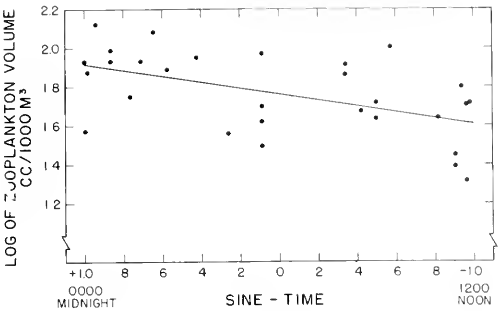

Figure 6.--Logarithms of zooplankton volumes of Hugh M. Smith cruise 16 plotted against the sine value corresponding to the hour of hauling, and showing the calculated regression line for the relationship.

the 200-meter oblique hauls provided a means for approximately removing the diurnal variation in this group of surface samples. This method of adjustment was not considered applicable to the intermediate samples where there was almost no day-night difference nor to the deep samples where there may be a difference but in a direction opposite to that at the surface.

The numerical data show essentially the same diurnal variation in zooplankton abundance as the volume data, although statistically the day-night difference must be considered nonsignificant (since $P > 0.05$) at all three levels. Table 7 gives the night-day ratios based on numbers of organisms for the total samples and for Copepoda, the major constituent. Although the differences are not significant, the ratios suggest that more zooplankton was captured at the surface at night than in the day time, with just the reverse being true for the intermediate and deep levels.

VARIATIONS WITH DEPTH AND LATITUDE

The average volumes for the three sample depths, surface (adjusted for hour of hauling), intermediate, and deep, were 62.7, 29.2, and 16.6 cc/1000m^3 respectively (table 6). The corresponding variances were 581.4, 129.9 and 46.2. Since most of the variation in the surface volumes related to hour of sampling had already been removed, the chief sources of variation remaining are those associated with latitude, depth, and sampling error.

When the zooplankton volumes (transformed by means of logarithms) are subjected to an analysis of variance with 2-way classification, we find significant differences ($P < 0.05$) among stations (latitudes) and highly significant differences ($P < 0.01$) related to the depth of sampling. In respect to latitude, the area of best catch, particularly for the surface samples, extended from approximately 2°S. to 8°N. (fig. 7A). About the same degree of variation with latitude is evident at all three depths. Although there was no marked indication of increased abundance immediately at the Equator, the largest single volume was taken at the surface at about 1°S. latitude.

Table 7.--Average numbers and night-day ratios of total zooplankton and of Copepoda as obtained in the Clarke-Bumpus hauls of cruise 16 for 3 depths of sampling (twilight hauls omitted)

Depth	Time of hauling	Number of samples	Total zooplankton: Ave. number per m^3	Total zooplankton: Ratio N/D	Copepoda: Ave. number per m^3	Copepoda: Ratio N/D
Surface	Night	11	411.1	1.28	278.3	1.43
	Day	13	320.2		194.2	
Intermediate	Night	7	96.0	0.66	66.0	0.74
	Day	9	146.0		89.1	
Deep	Night	6	45.1	0.71	25.3	0.68
	Day	9	63.4		37.4	

With only two exceptions (stations 1 and 24, at latitudes 12°N. and 3°S.) the largest volumes were found among the surface samples. There was no evidence of a concentration of zooplankton in the region of the thermocline. The apparent greater abundance of deep-swimming tuna at this depth cannot, therefore, be explained on this basis. Information on the abundance of the intermediary forage organisms, which have not as yet been sampled quantitatively, and their grazing effect on the zooplankton are needed if we are to fully understand the complex interrelationship that exists.

The plankton counts demonstrated the same general variation with latitude and depth as was found for the volumes (fig. 7B). Figure 8 illustrates the variation in numbers of organisms with latitude and depth for eight of the major zooplankton groups. Although there is considerable station-to-station variation--partly due to differences in the hour of sampling--the figure shows that, for most groups, the largest numbers were found at the surface and in the general region of the Equator. This is particularly well demonstrated by the Copepoda, Foraminifera, eggs (mostly invertebrate), and Tunicata. The other groups shown on figure 8 were present in relatively small numbers and do not provide as definite conclusions.

Another variation related to depth and hour of hauling is that of size of organism. A rough estimate of average size (volume) for the constituents of each sample was obtained by dividing the displacement volume of the sample by the estimated number of organisms. The results, summarized in figure 9, show an increase in average size with depth. Disregarding time of hauling, the means for the three sampling depths--surface, intermediate, and deep--were 2.0, 2.7, and 3.0×10^{-4}cc., respectively. These were found to be significantly different ($P < 0.05$) when examined by means of an analysis of variance.

When the data are segregated into day, night, and twilight hauls, we find some suggestions that the mean size of the zooplankton was greater at night than in the day at the surface and intermediate levels, but the opposite was true at the deep level (fig. 9). It is possible that the relatively large organisms captured in the day hauls at the deep level swam upward at night to be taken in the night hauls at the intermediate level, but most of this group, apparently, never reached the surface. The presence of larger organisms in the night hauls than in day hauls at the upper two levels is possibly the result of upward movement of larger organisms from deeper layers in the case of the intermediate depth, but dodging of the net in the daytime could also be involved, especially at the surface level.

COMPOSITION OF THE ZOOPLANKTON

The great variety of organisms making up the collections is characteristic of tropical zooplankton populations as contrasted with the larger volumes but relatively few species which are typical of temperate and boreal waters. The Copepoda were the most abundant group in actual numbers in all samples (table 3). The similar importance of copepods in 1-meter net collections from the central Pacific was previously noted by King and Demond (1953). Next in order of numerical abundance were the Foraminifera (mostly Globigerina and Globorotalia), eggs (mostly invertebrate), Tunicata (mostly Appendicularia), Gastropoda (mostly Pteropoda and Heteropoda), Chaetognatha, Radiolaria, crustacean larvae, Ostracoda, Euphausiacea, Siphonophora, and Amphipoda. Average numbers per cubic meter and percentage composition, by major constituents, of the zooplankton are summarized by depth for the entire cruise in table 8. While most groups decreased in absolute number with depth of sampling, the Ostracoda showed a small but consistent increase with depth. The Radiolaria also averaged greater in number in the deep samples than at the surface and intermediate levels. With respect to percentage composition, the Copepoda and Tunicata became relatively less important with increased depth of sampling, while Ostracoda, Euphausiacea, and Amphipoda consistently gained in relative importance with depth. The percentages for the remainder of the groups varied in irregular manner or were approximately the same at all three depths.

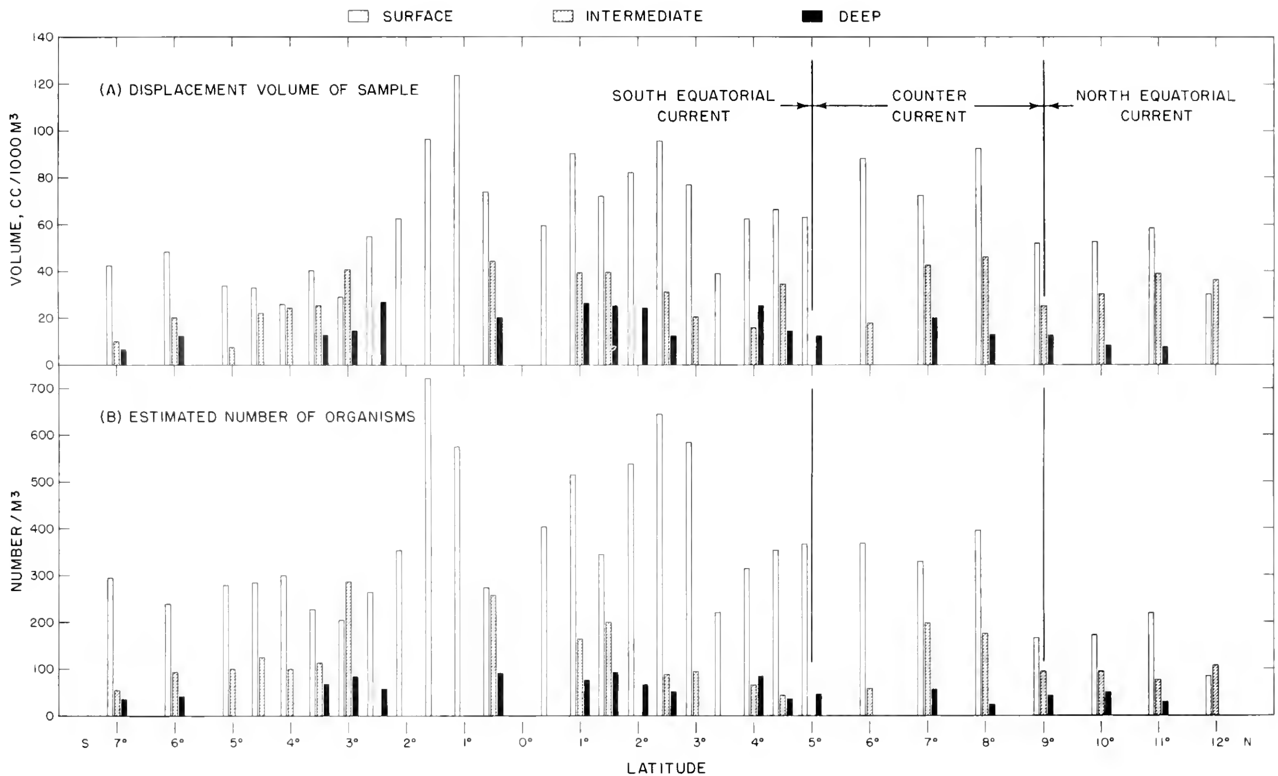

Figure 7.--Variations in the horizontal and vertical distribution of zooplankton as measured on Hugh M. Smith cruise 16.
A.--Displacement volumes of samples. The surface volumes have been adjusted for differences related to the hour of hauling.
B.--Estimated numbers of organisms.

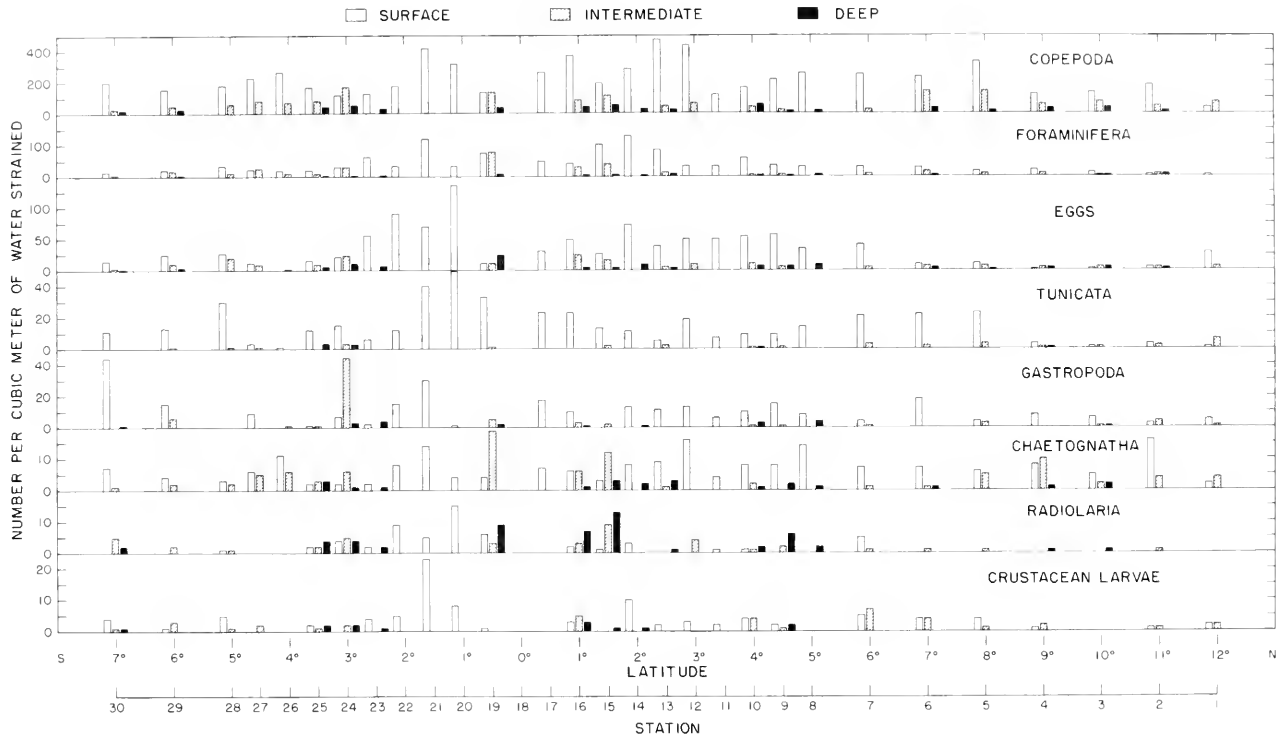

Figure 8. -- Horizontal and vertical distribution of eight major groups of the zooplankton sampled on Hugh M. Smith cruise 16.

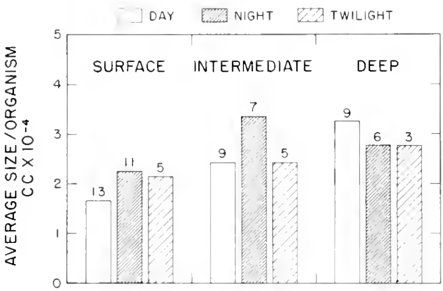

Figure 9. -- Variations in average size of the organisms in the collections of cruise 16 calculated by dividing the displacement volume of the sample by the estimated number of constituents. (Number of samples is indicated above each block.)

A comparison of the zooplankton populations in the North Equatorial and South Equatorial currents was made by a detailed examination of the composition of the zooplankton at two typical night stations, station 3 on latitude 10°N. in the North Equatorial Current and station 13 on latitude 2°30'N. in the South Equatorial Current. The list of organisms (table 4) is not complete for any of the samples but does include the dominant forms as well as certain of the less abundant species. Of the 28 kinds of copepods identified or partially identified from the six collections, only 13 were noted at both stations. The species occurring in greatest abundance at station 3 in the North Equatorial Current were Euchaeta prestandreae and Calanus minor while Pleuromamma abdominalis, Rhincalanus cornutus, and Eucalanus attenuatus were the most abundant species at station 13 in the South Equatorial Current.

There are a few notable similarities in the distribution of species recorded at both stations: e.g., Pleuromamma ziphias and Phronimella elongata were found only in the surface samples at the two stations; Euphausia diomedeae was obtained in the intermediate and surface samples at both stations but not at the deep level. Among the remainder of the organisms there appeared to be no pattern of vertical stratification. According to references in the available literature, all of the 23 identified species of copepods have been collected at the surface or at shallow depths, and most are considered to be cosmopolitan in distribution. It would require much more extensive study to determine whether or not there exist groups of organisms with preponderant tendencies to inhabit certain portions of the equatorial current system or certain levels within these portions.

COMPARISON WITH OTHER SAMPLING METHODS

This series of collections obtained with Clarke-Bumpus samplers, with finer meshed nets and with a smaller (5-inch) mouth opening than the 1-meter nets which have been regularly employed in POFI's plankton surveys, might be expected to sample a somewhat different element of the zooplankton community. Tables 9 and 10 have been compiled to provide a comparison.

Two series of hauls employing 1-meter nets of 30XXX grit gauze and oblique tows to 200 meters depth were made on Hugh M. Smith cruises 5 and 11 and were taken at approximately the same time of year and in about the same area as the Clarke-Bumpus hauls of cruise 16. The average zooplankton volumes of 37.9 and 36.0 cc/1000m^3 obtained on these two sections are considerably less than the average volume (64.7 cc/1000m^3) of the Clarke-Bumpus surface hauls, and greater than the average volumes for the intermediate (29.2 cc/1000m^3) and deep (16.6 cc/1000m^3) levels of hauling (table 9). The standard deviations of these different lots of data vary in about the same manner. When we examine the coefficients of variation, which provide a measure of average variation independent of the mean, we find the largest value (61.3 percent) for the 1-meter net hauls of cruise 5; the coefficient of 47.8 percent for cruise 11 does not differ greatly from 45.1, 39.0, and 41.0 percent, the coefficients obtained for the surface, intermediate, and deep hauls of the Clarke-Bumpus samples. Thus neither the average volume nor the variance differed appreciably between the two types of gear.

The composition of the catches (table 10) obtained by these two methods indicates that the 56XXX mesh retains a much larger number of Copepoda, particularly the microcalanid and cyclopoid copepods of length less than 1 mm., which may be important constituents of tropical

Table 8.--Summary of average numbers and percentage composition of the major groups of zooplankton collected on Hugh M. Smith cruise 16

Organisms	Surface		Intermediate		Deep	
	Average number/m^3	Percentage comp.	Average number/m^3	Percentage comp.	Average number/m^3	Percentage comp.
Copepoda	226.0	65.3	78.0	63.2	33.6	59.0
Foraminifera	40.6	11.7	15.4	12.5	3.2	5.6
Eggs	35.8	10.3	9.3	7.5	6.1	10.7
Tunicata	15.0	4.3	1.5	1.2	0.5	0.9
Gastropoda	9.5	2.7	3.5	2.8	1.1	1.9
Chaetognatha	7.0	2.0	4.4	3.6	1.3	2.3
Radiolaria	2.1	0.6	2.0	1.6	3.0	5.3
Crustacean larvae	3.3	1.0	1.9	1.5	0.7	1.2
Ostracoda	0.2	0.1	3.2	2.6	4.1	7.2
Euphausiacea	3.1	0.9	1.2	1.0	1.5	2.6
Siphonophora	1.6	0.5	0.6	0.5	0.2	0.4
Amphipoda	0.5	0.1	0.4	0.3	0.2	0.4
Miscellaneous	1.3	0.4	2.0	1.6	1.4	2.5

Table 9.--Comparison of average volume of catch and degree of variance in results obtained with Clarke-Bumpus samplers and 1-meter (mouth diameter) nets

	Hugh M. Smith 16			Hugh M. Smith 5	Hugh M. Smith 11
Longitude sampled	150°W.			158°W.	150°W.
Range of latitude	7°S.-12°.N			5°S.-21°N.	5°S.-19°N.
Month and year	July-August 1952			July-August 1950	Sept.-Oct. 1951
Sampling device	Clarke-Bumpus sampler			1-meter nets	1-meter nets
Net material	56XXX grit gauze			30XXX grit gauze	30XXX grit gauze
Mesh aperture width	0.31 mm.			0.65 mm.	0.65 mm.
Type of haul	Horizontal			Oblique	Oblique
Depth of haul	Surface	Interm.	Deep	200 m. to surface	200 m. to surface
Number of observations	29	21	18	24	23
Average sample volume ($\bar{x}$), cc/1000m^3	64.7	29.2	16.6	37.9	36.0
Variance (s^2)	850.7	129.9	46.2	474.3	296.7
Standard deviation(s)	29.2	11.4	6.8	23.2	17.2
Coefficient of variation ($^s/\bar{x}$), as percent	45.1	39.0	41.0	61.3	47.8

Table 10. --Comparison of differences in composition of zooplankton catches obtained with Clarke-Bumpus samplers using 56XXX grit gauze nets (Hugh M. Smith cruise 16, horizontal hauls) and those obtained with 1-meter (mouth diameter) 30XXX grit gauze nets (Hugh M. Smith cruise 5, oblique hauls)

	Cruise 16						Cruise 5	
	Surface		Intermediate		Deep		200 m. oblique	
	Average number per m^3	Per-cent comp.	Average number per m^3	Per-cent comp.	Average number per m^3	Per-cent comp.	Average number per m^3	Per-cent comp.
Copepoda	226.0	65.3	78.0	63.2	33.6	59.0	21.8	53.0
Foraminifera	40.6	11.7	15.4	12.5	3.2	5.6	4.1	9.9
Eggs (mostly invertebrate)	35.8	10.3	9.3	7.5	6.1	10.7	1.7	4.0
Tunicata	15.0	4.3	1.5	1.2	0.5	0.9	2.3	5.6
Chaetognatha	7.0	2.0	4.4	3.6	1.3	2.3	4.1	10.0
Euphausiacea	3.1	0.9	1.2	1.0	1.5	2.6	1.4	3.5
Siphonophora	1.6	0.5	0.6	0.5	0.2	0.4	1.4	3.4
Miscellaneous	16.9	4.9	13.0	10.4	10.5	18.5	6.1	10.6

plankton. The greater retention of Foraminifera, small invertebrate eggs, and Appendicularia (Tunicata) is also evident. The other major groups of the zooplankton are apparently captured in about equal proportions by the two methods.

The tendency for the capture of smaller organisms with the finer meshed, smaller mouthed Clarke-Bumpus gear, noted qualitatively above, can be expressed quantitatively by comparison of average size of organisms taken on cruises 5 and 16, from which both volumes and counts are available (table 11). In most of the hauls of cruise 16, employing the Clarke-Bumpus gear, the average size of organisms was between 1 and 3 x 10^{-4} cc., while in most of the hauls of cruise 5 the average size was between 6 and 14 x 10^{-4} cc. The mean size of organism in the samples (each sample given equal weight) was about five times as large for the coarse-meshed meter net of cruise 5 as for the fine-meshed nets of cruise 16. It is quite obvious that the gear of the two cruises exercised a strong size selection in sampling the plankton community. The volume of catch was not greatly different however, indicating that with the larger net of coarse mesh the loss in small organisms was compensated by the less successful dodging of the larger organisms.

Table 11.--Average size of individuals in zooplankton hauls of cruise 16, employing Clarke-Bumpus samplers equipped with 56XXX grit gauze nets, and in hauls obtained on the eastern leg (158° W. longitude) of cruise 5 employing 1-meter nets of 30XXX grit gauze

Average size at center of class interval, in cc. x 10^{-4}	Number of hauls				
	Cruise 16				Cruise 5
	Surface	Inter-mediate	Deep	Total	
1	7	2	-	9	-
2	18	11	6	35	-
3	2	5	7	14	-
4	2	1	3	6	1
5	-	1	2	3	1
6	-	-	-	-	5
7	-	-	-	-	1
8	-	1	-	1	4
9	-	-	-	-	2
10	-	-	-	-	4
11	-	-	-	-	1
12	-	-	-	-	2
13	-	-	-	-	2
14	-	-	-	-	1
Mean (x 10^{-4} cc)				1.9	9.2

SUMMARY AND CONCLUSIONS

1. At 30 stations in a series along 150°W. longitude from 12°N. to 7°S. latitude, 68 samples were obtained at three depths--the surface, the level of the 70°F. isotherm, and at approximately 200 meters--by means of horizontal closing-net hauls with Clarke-Bumpus samplers.

2. According to an analysis of variance, for surface hauls the volumes of the night samples were significantly greater ($P < 0.01$) than the volumes of the day samples. For intermediate and deep levels the volumes of the day hauls exceeded those of the night hauls, but the differences were not statistically significant.

3. Within the range of latitudes sampled, the area 2°S. to 8°N. contained the greatest amount of zooplankton, with a peak in abundance near 1°S. latitude.

4. The surface samples ranked considerably above the intermediate and deep samples in volume and number of organisms. There was no evidence of a concentration of zooplankton in the region of the thermocline.

5. The average size of organisms in the collections increased with depth of sampling, and was greater in the night hauls than in the day hauls except at the deep level, where the opposite was true.

6. The copepods were by far the most abundant group present in the samples, followed by foraminifers, eggs, tunicates, gastropods, chaetognaths, radiolarians, crustacean larvae, ostracods, euphausiids, siphonophores, and amphipods in that order.

7. A detailed examination of collections obtained at two stations, one in the North Equatorial Current and the other in the South Equatorial Current, provided little evidence of major differences in species composition between these two current sytems.

8. Clarke-Bumpus samplers equipped with 56XXX grit gauze nets retained large numbers of small Copepoda, Foraminifera, and Appendicularia which passed through the coarser meshes of 1-meter nets of 30XXX grit gauze. The volume of catch per unit of water strained was not greatly different, however, for the two types of gear, indicating that with the larger net the loss in small organisms was compensated by the less successful dodging of the larger organisms.

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