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FISH AND WILDLIFE SERVICE

ZOOPLANKTON ABUNDANCE IN THE CENTRAL PACIFIC

PART II

By JOSEPH E. KING and THOMAS S. HIDA

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ABSTRACT

During the period May 1951 to April 1954, 270 quantitative zooplankton hauls were made on 8 cruises to the central equatorial Pacific. The purpose was to obtain a measure of abundance of the standing crop of zooplankton as basic fish food, which measure might be used as an index to the relative productivity of different areas of the sea.

Night hauls yielded volumes averaging 1.57 times that of day hauls; this ratio varied considerably in different subdivisions of the current system. Differences related to the hour of hauling were reduced by an adjustment method based on the similarity of the sine curve and the diurnal variation in zooplankton catch.

The highest concentration of zooplankton was found at the Equator which, under the influence of the trade winds, is a region of divergence and upwelling. Although the greatest abundance of yellowfin tuna occurred just to the north in the convergent zone, there was a high degree of covariation in yellowfin and zooplankton in respect to the current system.

In the east-central Pacific, high concentrations of zooplankton were found along the northern boundary of the Countercurrent. As this is an area of shallow thermocline, high-phosphate water occurs within the photosynthetic zone and within the reach of wind-induced turbulence; conditions are therefore more favorable for plankton production than to the westward where the thermocline deepens.

Within the equatorial region there was a west-to-east gradient of increasing zooplankton abundance from 180° to 150° W. longitude, which varied directly with the yellowfin catch and the average wind velocity, and inversely with thermocline depth. East of 140° W. longitude the catch remained high, but varied irregularly.

Largest zooplankton volumes were taken in the quarter, July, August, and September, the lowest in January, February, and March. Catches were smaller in 1951, 1952, and 1953 than in 1950. There was some evidence of an increase in 1954.

It appears that the zooplankton was quick to respond to physical changes in the environment by dispersal or concentration following changes in the water mass. With an increase in breadth of the mixing zone at the equatorial divergence, there was a broadening of the zooplankton-rich zone; an increase in velocity of the Countercurrent was accompanied by a marked change in zooplankton distribution.

On long north-south sections, there were highly significant positive correlations between zooplankton volume and surface inorganic phosphate. Although the highest concentration of phosphate was found in the divergent zone at the Equator, agreeing in this respect with zooplankton, longitudinally and seasonally there was some evidence of an inverse relationship with zooplankton and yellowfin; this may have resulted from differences in the rate of utilization.

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ZOOPLANKTON ABUNDANCE IN THE CENTRAL PACIFIC, Part II

By JOSEPH E. KING, *Fishery Research Biologist*, and THOMAS S. HIDA, *Fishery Aid*

As a result of the last cruise of the *Carnegie* in 1929 and the recent surveys of the Swedish Deep-Sea Expedition, Scripps Institution of Oceanography, and the Pacific Oceanic Fishery Investigations (POFI) of the United States Fish and Wildlife Service, there has developed a general understanding of the vertical and horizontal currents in the equatorial Pacific and their relation to marine life (Graham, 1941; Cromwell, 1953; Jerlov, 1953; Sette and others, 1954, Sette, 1955.[1] In brief, the moderate to strong east and southeast winds which prevail throughout most of the year in the eastern and central equatorial Pacific, together with the Coriolis force of the earth's rotation, produce a divergence of the surface waters at the Equator. Upwelling associated with this equatorial divergence replenishes the supply of nutrients in the surface water and provides a suitable environment for the growth of phytoplankton and consequently for zooplankton. Convergence and sinking of the surface waters, occurring between the Equator and the southern boundary of the Countercurrent, may physically tend to concentrate the zooplankton into a rich pasturage for small fish, squid, and other forage organisms. These in turn serve as food for the larger fishes such as the tunas, the group of fish presently under study in these investigations. Many aspects of this complex succession of events, such as the actual rates of production at the different eutrophic levels and the causes of variation in the system, are still to be determined.

This is the second POFI report concerned with zooplankton abundance in the central equatorial Pacific. The first report (King and Demond, 1953) was based on four cruises in 1950 and 1951; the present paper contains an analysis of plankton data resulting from eight cruises in the period 1951 to 1954 and utilizes some of the observations from the earlier publication. With these extensive observations, we are now able to show more clearly how the abundance of zooplankton is a function of such environmental factors as the equatorial divergence, convergence, depth of the isothermal layer, and other features of the surface waters of the equatorial current system. Variations in the zooplankton are also shown to be related to hour of hauling, season, area (longitude), and direction and velocity of the tradewinds.

The chief purpose of these studies has been to obtain a quantitative measure of the standing crop of zooplankton, or basic fish food, which may be used as an index to the relative productivity of different areas of the sea. It is hoped that this information together with other oceanographic observations made simultaneously by these investigations will help explain variations in the distribution and abundance of tunas as determined by experimental and commercial fishing.

AREA AND METHODS

This study is based primarily on 270 collections obtained on 7 cruises (cruises 9, 11, 14, 15, 16, 18, and 19) of the motor vessel *Hugh M. Smith* and one cruise (cruise 15) of the motor vessel *Charles H. Gilbert* during the years 1951 to 1954. The approximate locations of the plankton stations are shown in figures 1 to 4. More exact positions together with date and hour of hauling, amount of water strained, and the zooplankton volumes for each cruise are given in appendix B, tables 6 to 13. Data collected on 4 earlier cruises in 1950 and 1951 (*Hugh M. Smith* cruises 2, 5, 7, and 8), and published in an earlier report (King and Demond, 1953), are also utilized in this study. Appendix A presents the results of a special study on variations in zooplankton abundance about an oceanic island. Hydrographic data collected on certain of these cruises have appeared in other POFI reports (Cromwell, 1951, 1954; Austin, 1954a,

[1] Also paper by O. E. Sette entitled, Nourishment of Central Pacific Stocks of Tuna by the Equatorial Current System, to be published in the Proceedings of the Eighth Pacific Science Congress (Manila): and unpublished manuscript of T. S. Austin entitled, Review of Central Equatorial Pacific Oceanography, 1950-52.

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1954b; Stroup, 1954; Murphy and Shomura, 1955; and Iversen and Yoshida, 1956).

For the most part, sampling was done along north-south lines since in this portion of the central Pacific the current flow is zonal, i. e., tends to be parallel to the Equator. With this type of circulation, it was believed that maximum information from hydrographic and plankton observations would be obtained with station lines normal to the flow. The northernmost station was located at 31°54′ N. latitude, 119°46′ W. longitude and the southernmost station at 8°58′ S. latitude, 121°28′ W. longitude. In an east-west direction the sampling extended from 110° W. to the 180th meridian, a distance of 4,200 miles.

The majority of the collections were taken with 1-meter (mouth diameter) nets with body (front and middle sections) of 30XXX silk grit gauze (apertures averaging 0.65 mm. in width), rear section and bag of 56XXX silk grit gauze (apertures averaging 0.31 mm. in width). For comparative purposes 6 hauls were made on cruise 15, *Hugh M. Smith*, with a 1-meter net of 56XXX grit gauze body and 72XXX grit gauze (apertures averaging 0.21 mm. in width) rear section and bag.

Oblique hauls of approximately 30 minutes'

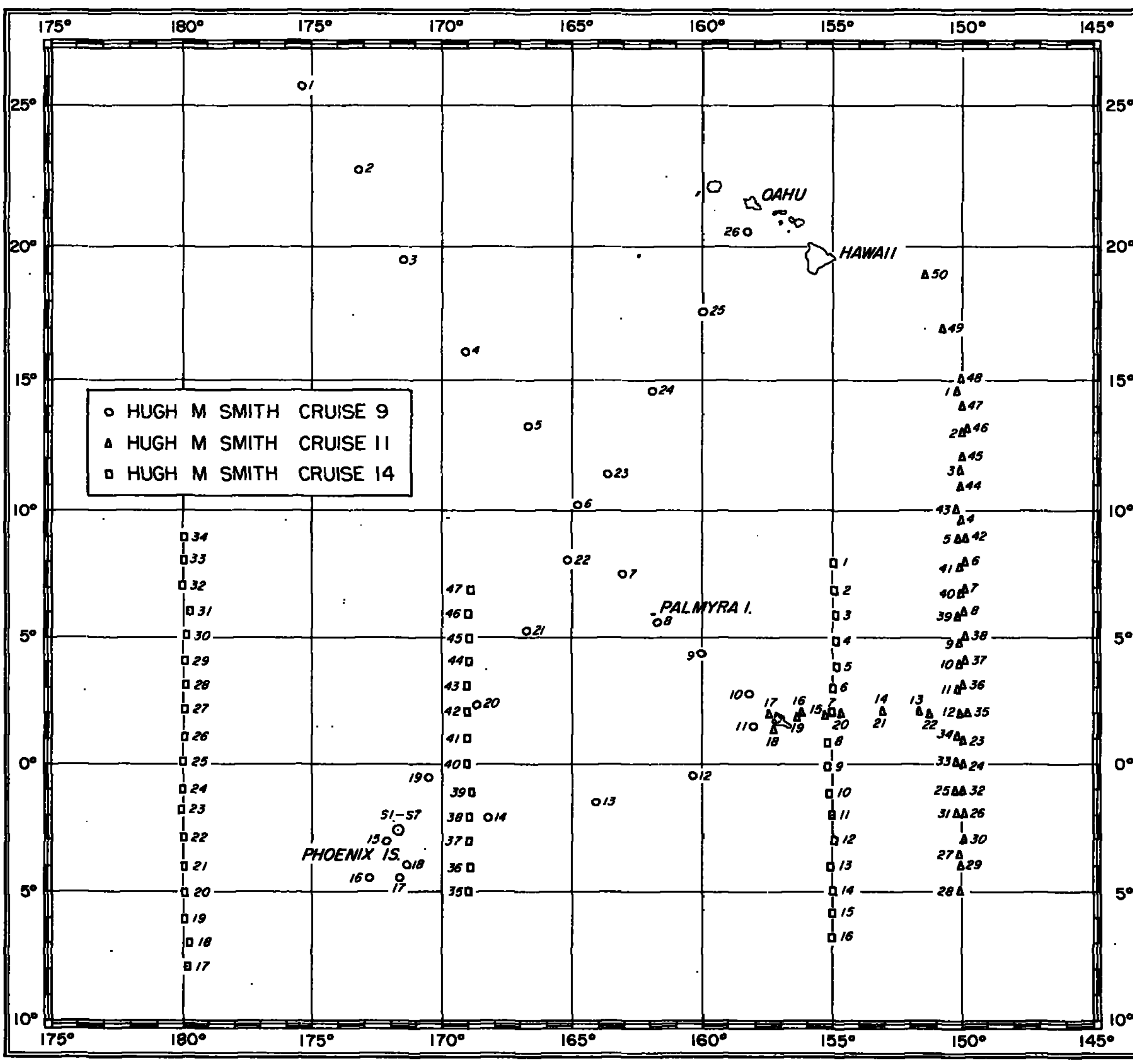

FIGURE 1.—Plankton-station positions of *Hugh M. Smith* cruises 9 (May–July 1951), 11 (August–October 1951), and 14 (January–March 1952).

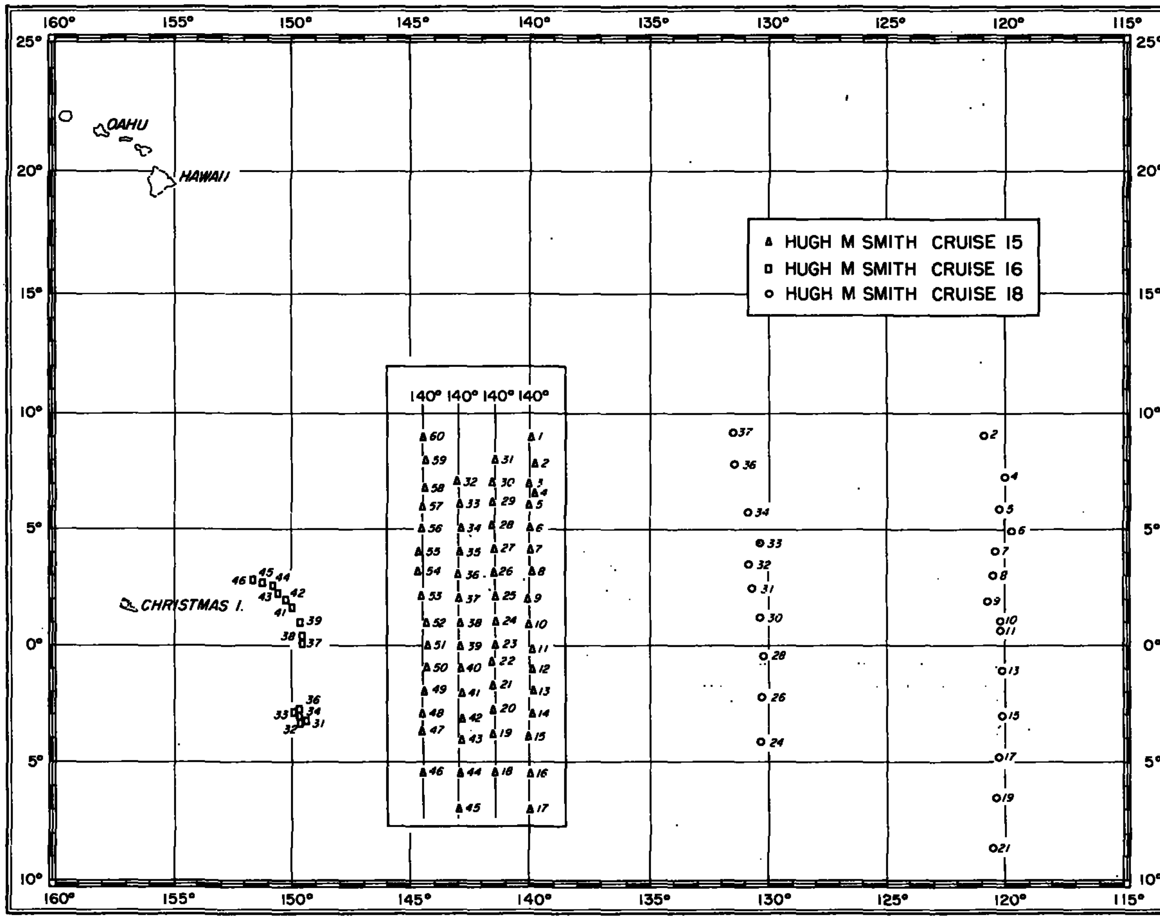

FIGURE 2.—Plankton-station positions of *Hugh M. Smith* cruises 15 (May–June 1952), 16 (August 1952), and 18 (October–November 1952).

duration to a depth of about 200 meters were employed on most cruises. On the *Hugh M. Smith* cruise 14, multiple-net horizontal hauls were made at 7 stations. Methods of hauling and calculation of sampling depth and amount of water strained have been explained in previous reports (King and Demond, 1953; King and Hida, 1954).

TREATMENT OF SAMPLES IN THE LABORATORY

First the few organisms with longest dimension greater than 2 cm. were removed from each sample, identified as precisely as possible, and their displacement volume determined. 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 in 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 50 or 100 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 liquid alone was recorded as the displacement or wet volume of that portion of the sample.

Following the 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 [2] were combined to give a single volume

[2] We consider annelids, chaetognaths, crustaceans, cephalopods, and fish to be of significant nutritional value, and siphonophores, medusae, ctenophores, heteropods, and tunicates as non-nutritious. Bigelow and Sears (1939) and also Clarke (1940) considered the crustaceans, chaetognaths, and mollusks as being of high nutritive value. It is our judgment, that the heteropod mollusks of the family Pterotracheidae, which are of common occurrence in the plankton of the tropical and subtropical Pacific, do not belong with this group because of their watery structure and should be classed with the non-nutritious forms.

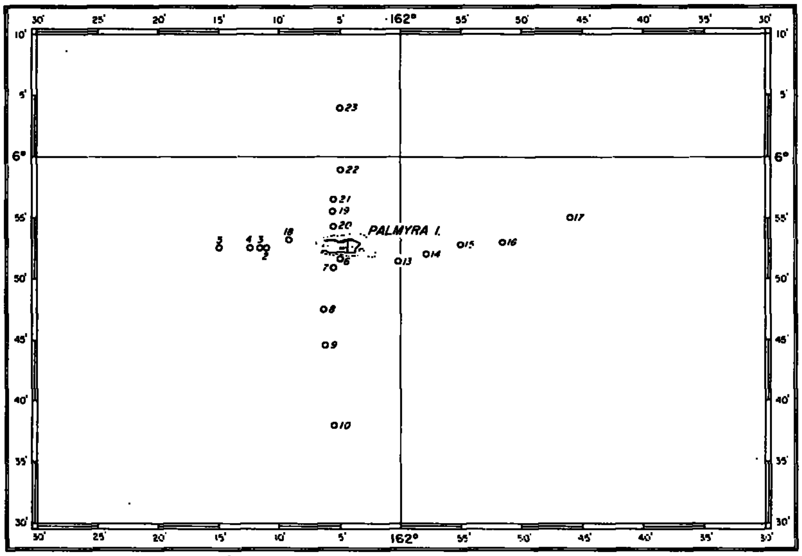

FIGURE 3.—Plankton-station positions of *Hugh M. Smith* cruise 19 (January 1953).

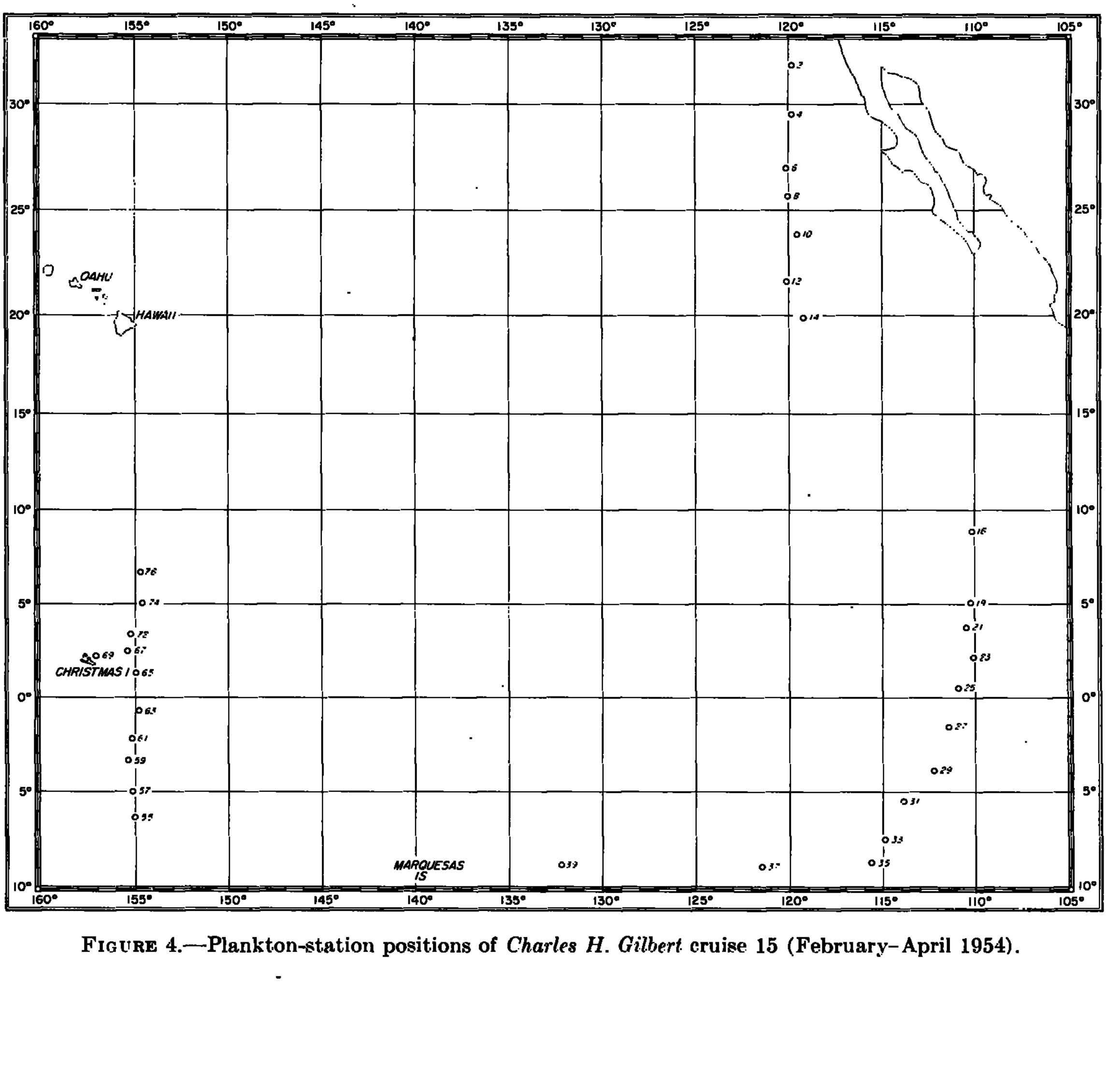

FIGURE 4.—Plankton-station positions of *Charles H. Gilbert* cruise 15 (February–April 1954).

measurement for each sample. This figure was divided by the estimated amount of water passing through the net to obtain the volume of zooplankton, as food, per unit of water strained.

The contents of 6 samples obtained on cruise 15 of the *Hugh M. Smith* were counted for the purpose of comparing the catches obtained with 30XXX and 56XXX grit gauze nets. The counting method was essentially the same as that employed by King and Demond (1953).

The zooplankton volumes have been examined by simple statistical analysis where it was apparent that a test of significance would aid in interpreting the results. Group comparisons, correlation, regression, and analysis of variance have been used, following Snedecor (1946). Since it was not possible to design the sampling program to isolate sources of variation determined from a priori knowledge, in our analysis of variance we have been limited to a single criterion of classification with subsampling, i. e., a "completely randomized" design (Snedecor, 1946: 240–241). While the method is conveniently adaptable to unequal subsampling, it is less sensitive and less efficient than one based on a more advanced experimental design. Inferences from the analysis are modified occasionally by consideration of the 0.95 fiducial intervals of means based on their individual variances.

Although the distribution of the zooplankton volumes is slightly skewed to the left and the means correlated to some degree with the standard deviations, in tests of significance we have used untransformed data. Initially, various lots of data were transformed to logarithms and employed in statistical tests. The results and conclusions in each were the same as those reached through an analysis of the untransformed data. Snedecor (1946: 42, 252) states that little bias is introduced into the analysis of variance and the "t" test by moderately skewed populations. We assume, therefore, that the moderate abnormality in the zooplankton population has little effect on the inferences made in this report.

EFFECTS OF MESH SIZE ON ZOOPLANKTON CATCH

Early in our zooplankton studies we adopted the 1-meter, 30XXX grit gauze net (average aperture width 0.65 mm.) as being the best suited for our purposes. Nets of this mesh size retain the tuna eggs (of about 0.80 mm.) and tuna larvae, the capture of which was one object of our sampling,[3] but allow almost all phytoplankton to pass through the net; consequently, a relatively "clean" sample of zooplankton is obtained. Some preliminary hauls indicated that, at least on this occasion, nets of 56XXX (aperture width 0.31 mm.) and 72XXX grit gauze (aperture width 0.21 mm.) retained some of the larger phytoplankton as well as micro-zooplankton, thus making analysis and sorting of the sample more difficult.

A comparison of the catch of Clarke–Bumpus samplers (with 5-inch mouth opening), equipped with 56XXX nets, with the catch of 1-meter, 30XXX nets indicated that neither the sample volumes nor their variance differed appreciably between the two types of gear (Hida and King, 1955). The greater retention by the finer mesh of small Copepoda, Foraminifera, Appendicularia, and invertebrate eggs was at least partially compensated for in the large net of coarser mesh by the less successful avoidance of the net by the larger organisms.

To obtain a more precise comparison of the catching abilities of 1-meter nets of 30XXX and 56XXX grit gauze, 6 special hauls were made on the *Hugh M. Smith* cruise 15. A pair of consecutive hauls, the first with a 30XXX net and the second with a 56XXX net, were completed at 3 stations on 140° W. longitude: station 45, at 7° S. in the South Equatorial Current, a "poor zone" in respect to zooplankton; station 52 at 1° N., in the "rich zone" of the equatorial divergence; and station 60 at 9° N. in the Equatorial Countercurrent, which in the eastern Pacific is also a "rich zone" (p. 377). All were oblique hauls to an estimated 200 meters' depth and all were taken at night.

As to volume, the catch of the 56XXX nets was about 1¼ to 1¾ times that of the coarser meshed 30XXX nets (table 9, appendix B). Unfortunately, one of the samples contained an estimated 30 percent by volume of very small salps which were not separated from the bulk of the sample and therefore complicated the volume comparison. In respect to the number of organisms, the finer meshed nets retained 3 to 5 times

[3] Results are reviewed in unpublished manuscript of W. M. Matsumoto entitled, Description of Larvae of Four Species of Tuna and Their Distribution in Central Pacific Waters.

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TABLE 1.—*Average number of zooplankters per unit of water strained and percentage composition of the catch obtained with 30XXX grit gauze (apertures 0.65 mm.) and 56XXX (apertures 0.31 mm.) grit gauze at three stations of* Hugh M. Smith *cruise 15 in June 1952*

Organisms	Station 45 (7°00′ S.)				Station 52 (1°00′ N.)				Station 60 (9°00′ N.)			
	Average number per 100 m.³		Percent composition		Average number per 100 m.³		Percent composition		Average number per 100 m.³		Percent composition	
	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX
Foraminifera	214	1,257	9.0	8.8	156	1,665	3.4	7.3	16	299	0.5	3.0
Radiolaria	0	35	0	0.2	104	0	2.3	0	0	0	0	0
Coelenterata	51	70	2.2	0.5	139	166	3.1	0.7	317	220	8.9	2.2
Chaetognatha	489	1,188	20.4	8.3	521	1,332	11.5	5.9	269	439	7.6	4.3
Annelida	0	70	0	0.5	0	33	0	0.1	32	140	0.9	1.4
Copepoda	1,072	9,745	44.8	68.0	2,811	17,145	62.1	75.4	1,473	6,924	41.5	68.6
Ostracoda	51	244	2.2	1.7	17	233	0.4	1.0	0	439	0	4.3
Euphausiacea	274	349	11.5	2.4	174	333	3.8	1.5	48	220	1.3	2.2
Amphipoda	17	35	0.7	0.2	17	0	0.4	0	0	0	0	0
Shrimp	0	0	0	0	17	0	0.4	0	16	0	0.5	0
Crustacean larvae	17	175	0.7	1.2	0	67	0	0.3	16	60	0.5	0.6
Mollusca	43	140	1.8	1.0	35	266	0.8	1.2	111	299	3.1	3.0
Tunicata	17	978	0.7	6.8	330	466	7.3	2.0	1,061	778	29.9	7.7
Fish	51	0	2.2	0	52	67	1.1	0.3	0	40	0	0.4
Eggs	77	0	3.2	0	156	932	3.4	4.1	0	120	0	1.2
Miscellaneous	17	35	0.7	0.2	0	33	0	0.1	190	120	5.4	1.2
Total for sample	2,390	14,321	100.1	99.8	4,529	22,738	100.0	90.9	3,549	10,098	100.1	100.1

as many plankters as the coarser meshed nets. Table 1 gives for each sample the average number per unit (100 m.³) of water strained and the percentage composition for the major constituents. It appears that the greatest difference in the catch of the 2 nets is in the larger numbers of foraminifers and copepods retained by the 56XXX net.

The results show a marked difference between the 2 nets in average size (volume) of individual organisms in the catch (table 2); plankters in the catch of the 30XXX net were about 3 times as large as those taken by the 56XXX net, primarily because of the difference in catch of small copepods such as the microcalanoids and cyclopoids. As the result of an increased catch of the larger zooplankton forms (coelenterates, salps) and fewer of the smaller forms (foraminifers, chaetognaths), both nets yielded larger organisms, on the average, at the northernmost station (station 60).

TABLE 2.—*Average size (i. e., volume of catch divided by the number of organisms) of zooplankters captured in 30XXX and 56XXX grit gauze nets at three stations of* Hugh M. Smith *cruise 15 in June 1952*

Item	Station 45 (7°00′ S.)		Station 52 (1°00′ N.)		Station 60 (9°00′ N.)	
	30XXX	56XXX	30XXX	56XXX	30XXX	56XXX
Average number of organisms per 100 m.³	2,390	14,321	4,529	22,738	3,549	10,098
Volume of catch, cc. per 100 m.³	3.22	5.07	6.98	12.21	8.04	9.09
Average size of organism, cc.x10⁻⁴	13.5	3.5	15.4	5.4	22.7	9.0

It is obvious that these 2 nets of different mesh exercised a strong size-selection in sampling the zooplankton community. The question as to which net-size yielded the most reliable measure of abundance of zooplankton as potential fish food cannot be decided from the few data presented here. It is generally known that no one net or other sampling device will quantitatively sample the entire zooplankton community, and therefore the investigator must choose the method and gear that in his opinion will contribute the most toward his particular objective. Our objectives, to obtain a representative sample of the larger zooplankton forms and to retain all tuna eggs and larvae with a minimum of mesh-clogging, were realized, we believe, with the use of 1-meter nets of 30XXX grit gauze.

VARIATION IN CATCH WITH SAMPLING DEPTH

On 7 stations of *Hugh M. Smith* cruise 14 in February 1952, horizontal hauls were made simultaneously at 3 levels with open 1-meter nets. The hauls were of 1-hour duration; the nets were lowered and raised at the start and end of the haul as rapidly as possible to minimize contamination in the intermediate and deep samples. All 7 stations were off Canton Island in the South Equatorial Current between 2°41′ S. and 2°45′ S. latitude at about 172° W. longitude, and were occupied consecutively between 1315 and 0338 hours of February 9–10, 1952. Although the primary purpose of the sampling was to investigate the abundance and vertical distribution of tuna eggs and larvae in this area, some information was obtained on the variation in zooplankton volumes with depth and with time over a 14-hour period.

According to the results shown in table 8B (appendix B) and figure 5, at each of the 7 stations (S1 to S7) the largest volume of zooplankton was taken in the surface net. At station S5, hyperid amphipods were apparently swarming at the surface and resulted in an unusually large catch.

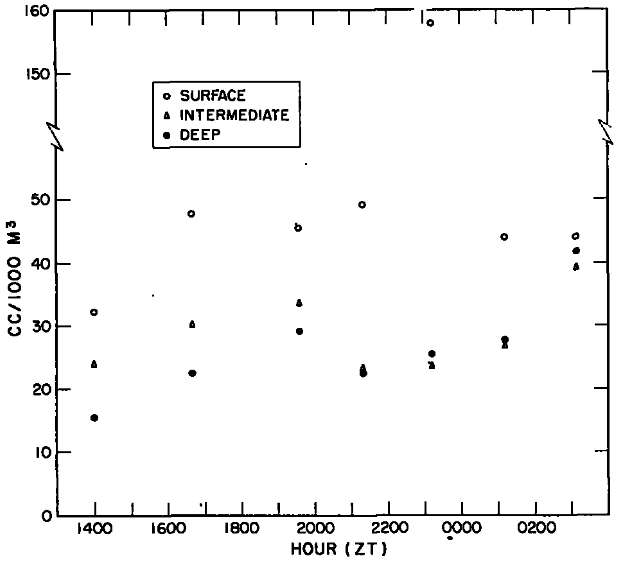


FIGURE 5.—Variation in zooplankton volumes with hour of hauling, as obtained with horizontal hauls at the 3 depths: surface, intermediate (105–120 meters), and deep (210–240 meters); *Hugh M. Smith* cruise 14 February 9–10, 1952.

The other samples were of mixed composition, typical of this area. At four of the 7 stations the intermediate net, fishing just above the thermocline at a depth of 105 to 120 meters, caught more than the deep net fishing below the thermocline at 210 to 240 meters. These results are generally similar to those obtained with Clarke-Bumpus samplers (employing 56XXX nets) on a series of 30 stations extending from 12° N. to 7° S. latitude along 150° N. longitude (Hida and King, 1955). The surface samples of the latter series averaged 60.7 cc./1,000m.^{3}, the intermediate samples (from within the thermocline) averaged 29.2, and the deep samples (at 200–300 meters) averaged 16.6.

Although this sampling period of about 14 hours is not adequate to demonstrate the diurnal cycle, there is some evidence of an "evening rise" between 1400 and 2000 hours, followed by a drop in catch at the intermediate and deep levels and then what is possibly the start of a "morning rise" at these levels. The parallel variation ($r=0.837$, $P<0.05$) in volume of catch at the intermediate and deep levels is of interest and suggests that the zooplankton at these depths was behaving differently from that at the surface in response to varying illumination.

ADJUSTMENT FOR DIURNAL VARIATION

The hour of hauling provides an important source of knowledge of the variation in quantitative measurements of zooplankton abundance. Presumably, the difference between day and night hauls is due either to an augmentation in the upper strata of water by upward migration of the plankton at night or to a reduction in catch in the daytime owing to the greater ability of the plankton to dodge the net when there is light, or to a combination of the two. In some areas of the tropical Pacific the day-night difference is sufficiently great, if no correction is applied, to obscure the geographical and seasonal differences which are of primary interest in this study.

Significant differences in zooplankton volume, associated with latitude, were observed among the night samples and not among the day samples on cruises 5 and 8 of the *Hugh M. Smith* in the central equatorial Pacific (King and Demond, 1953). In Hawaiian waters the volumes of night hauls have averaged about 1½ times the volumes of day hauls (King and Hida, 1954). In the present instance during the 6 cruises in the equatorial region on which sampling was conducted around the clock, night hauls yielded volumes about 1½ times the volume of the day hauls (table 3), while the twilight hauls were intermediate in average volume.[4] Some of the variation among cruises, as shown in table 3, may be due to differences in season, longitude, and range of latitude sampled. Variations in the night/day ratio associated with the current system will be discussed later.

[4] For purposes of this comparison we designated the twilight hours as 0430 to 0730 and 1630 to 1930, which periods include sunrise and sunset and the beginning and end of twilight as specified by the American Nautical Almanac; the day period was thereby limited to 0730–1630 and the night to 1930–0430 hours.

TABLE 3.—*Differences in the average volumes of day, night, and twilight hauls and in the night/day ratios for six cruises of the Hugh M. Smith in the equatorial Pacific*

Cruise No.	Cruise period	Number of samples	Zooplankton—mean volume, cc./1000 m.[3]				Night/day ratio
			Night hauls	Day hauls	Twilight hauls	Total	
2	Jan.-Feb. 1950	[1] 24	45.5	24.0	26.6	[1] 33.6	1.90
5	June-Aug. 1950	51	40.3	27.9	37.1	34.7	1.44
8	Jan.-Mar. 1951	87	30.7	18.2	23.9	23.9	1.69
11	Sept.-Oct. 1951	[2] 23	41.7	32.1	33.2	[2] 36.0	1.30
14	Jan.-Mar. 1952	47	30.7	22.8	25.3	24.5	1.34
15	May-June 1952	60	50.6	31.6	36.9	39.9	1.60
Average			39.9	26.1	30.5	32.1	1.54

[1] Sections A and C only (King and Demond, 1953, table 1).
[2] Northbound section only.

On the majority of cruises sampling was conducted around the clock so that there were about equal numbers of night and day stations. Under this system there rarely were more than two day stations or two night stations occupied consecutively. On certain cruises, however, such as cruise 18 of the *Hugh M. Smith*, and cruise 15 of the *Charles H. Gilbert*, hauls were made at about the same hour throughout the cruise; e. g., on cruise 18 all hauls were made near midnight, on cruise 15 between 1900 and 2000. The resulting data are most useful for within-cruise comparisons, but some modification is necessary if they are to be compared or combined with the results of the other cruises.

An adjustment to remove the effect of diurnal change in zooplankton catch was described by King and Hida (1954). The method is based on the similarity of diurnal variation in zooplankton abundance to the curve of the sine function when midnight is equated to the angle whose sine is +1.0. The zooplankton volumes are increased or lowered dependent on the hour of hauling and adjusted to 0600 or 1800 hours, when the sine=0. Since illumination is the major factor controlling the diurnal migration of plankton (Kikuchi, 1930; Cushing, 1951), solar time is used in the calculations.

The method as originally designed was applied to zooplankton volumes from the Hawaiian Islands area, where the geographical variation was slight and the night/day ratio rather uniform from cruise to cruise. On the long sections crossing the Equator we found considerable variation in the night/day ratio associated with latitude and the current system (p. 380), and the geographical variation is much greater than in the Hawaiian area. Although these factors lessen the accuracy and effectiveness of the method, it still provides a reasonably good correction for day-night differences as judged by the significance of the "t" values and the night/day ratios for the adjusted volumes (table 4), and has therefore been applied to the equatorial data.

TABLE 4.—*Regression coefficients (b), "t" values and probability values for the sine transformation method of adjustment for 5 cruises of the* Hugh M. Smith *in the equatorial Pacific.*

[A comparison of the night/day ratios for the zooplankton volumes before and after adjustment indicates the general validity of the method]

Cruise No.	Number of samples	b	t	P	Night/day ratios	
					Before adjustment	After adjustment
5	51	0.0941	2.077	<0.05	1.44	1.14
8	87	.1534	5.046	<0.001	1.69	0.96
11	23	.0842	1.251	>0.05	1.30	0.95
14	47	.1340	3.472	<0.01	1.34	1.06
15	60	.1186	3.228	<0.01	1.60	1.03

Throughout this report we have employed the adjusted volumes in examining the variation in zooplankton abundance with respect to special features of the current system, with longitude, and with season. The data from cruises 5, 8, 11, 14, and 15 of the *Hugh M. Smith* were adjusted by individual cruise. A pooled regression coefficient (b=0.1248) calculated from the combined data of these 5 cruises that covered large areas of the equatorial Pacific during which the stations were visited consecutively regardless of the time of day or night, was used in adjusting the volumes of cruises 2, 7, 9, 16, 18, and 19 of the *Hugh M. Smith* and of cruise 15 of the *Charles H. Gilbert*. On the latter cruises, sampling was not conducted around the clock, or there were too few data to be adjusted by individual cruises. Unadjusted volumes for the *Hugh M. Smith* cruises 2, 5, 7, and 8 have previously been published (King and Demond, 1953). The adjusted volumes for these cruises are provided herewith in table 14 (appendix B).

DESCRIPTION OF THE ENVIRONMENT

The general pattern of the Pacific equatorial current system has been described by Sverdrup and others (1942:708–712). In brief, the major surface currents of this region are the North and South Equatorial Currents flowing toward the west, and the eastward flowing Equatorial Countercurrent sandwiched in between. Although the boundaries of the Countercurrent may vary meridionally with longitude and season, its southern and northern boundaries ordinarily occur near 5° N. and 10° N. latitude in the mid-Pacific. The South Equatorial Current is therefore on both sides of the Equator while the North Equatorial Current is confined entirely to the Northern Hemisphere. As previously stated, the Equator is the site of upwelling resulting from divergence of the surface waters. It is also the location of the newly discovered subsurface Equatorial Undercurrent flowing to the eastward (Cromwell and others, 1954). The region between the Equator and the southern boundary of the Countercurrent is a zone of convergence. Under certain conditions, as described by Cromwell (1953) and Cromwell and Reid (1956), a sharply defined convergence or "front" [5] may be formed in the South Equatorial Current between the Equator and the southern boundary of the Countercurrent.

The motion of these currents is either directly or indirectly the result of wind stress on the surface of the ocean, and it is logical that variations in these currents are a reflection of variations in the prevailing winds or "trades."

The Climatic Charts of the Oceans (U. S. Weather Bureau, 1938), based on averages of 50 years of observations, provide a general picture of the velocity and direction of prevailing winds in the equatorial Pacific. Average wind conditions for the months of March and August, which represent the extremes of the seasonal variation, are shown in figure 6.

In the region of our zooplankton studies (110° W. to 180° long.), the charts show longitudinal and latitudinal as well as seasonal variations in the tradewinds. In an east-west direction along the Equator there is a general decrease in intensity from Beaufort force 3 and 4 east of 160° W. longitude to force 1 and 2 west of that meridian. Between 100° W. and 140° W. the southeast trades are dominant (>60 percent constant) along the Equator in all months of the year. Between 140° W. and 160° W. they are dominant from May to January; between 160° W. and 180° they are only of importance from July to October. At other months of the year the resultant wind at the Equator is from the east between 140° W. and 160 W., and from the northeast between 160° W. and 180°.

North of the Equator in the region of the Countercurrent, the period of strongest winds is from December to May when the northeast trades prevail. At other months of the year the winds are light and variable; in the eastern part of the region, from 120° W. to 140° W., the southeast trades exert a slight influence. Longitudinally the northeast trades reach their highest velocity between 140° W. and 170° W. longitude.

According to the wind drift model of Cromwell (1953), convergence and sinking of the surface waters will occur to the north of the Equator in the South Equatorial Current during a south or southeast wind, and conversely to the south of the Equator under the influence of a north or northeast wind. A pronounced convergence or front has been encountered south of the Equator on only one of the many POFI hydrographic and fishing surveys. This is not surprising in view of the slight influence of north or northeast winds at the Equator in the eastern and central Pacific. Evidence of convergence north of the Equator has been observed, though, on several occasions.

When the generally westward current near the Equator has a northward component, as during southeast trade winds, we anticipate that the zone of greatest zooplankton abundance will be north of the Equator, due both to the physical displacement of the organisms and the time lag in their development, with the peak of abundance occurring somewhere in the zone of convergence between the region of upwelling and the southern boundary of the Countercurrent. With a prevailing northeast wind the zooplankton maximum should theoretically occur to the south of the Equator and, with an east wind, more nearly on the Equator or with a double peak.[6]

In summary, then, as a result of the direction and relative high velocity of the trade winds, we expect to find larger concentrations of zooplankton

[5] Defined by Cromwell (1953) as "a pronounced oceanic convergence," and by Cromwell and Reid (1956) as "a narrow band along the sea surface across which the density changes abruptly" and "the surface temperature gradient is often of the order of degrees per 1/100 mile."

[6] Murphy and Shomura (1953b) have shown that the latitudinal variation in the zone of best-yellowfin-catch also coincides with differences in the prevailing winds. Fishing sections along 120° W. and 130° W. longitude, associated with southeast winds, indicated the peak abundance to be north of the Equator; the catch along 155° W. and 169° W., associated with variable winds, showed the peak abundance to be nearly centered on the Equator, while a section along 180°, associated with northeast winds, indicated the peak of yellowfin abundance to be displaced to the south.

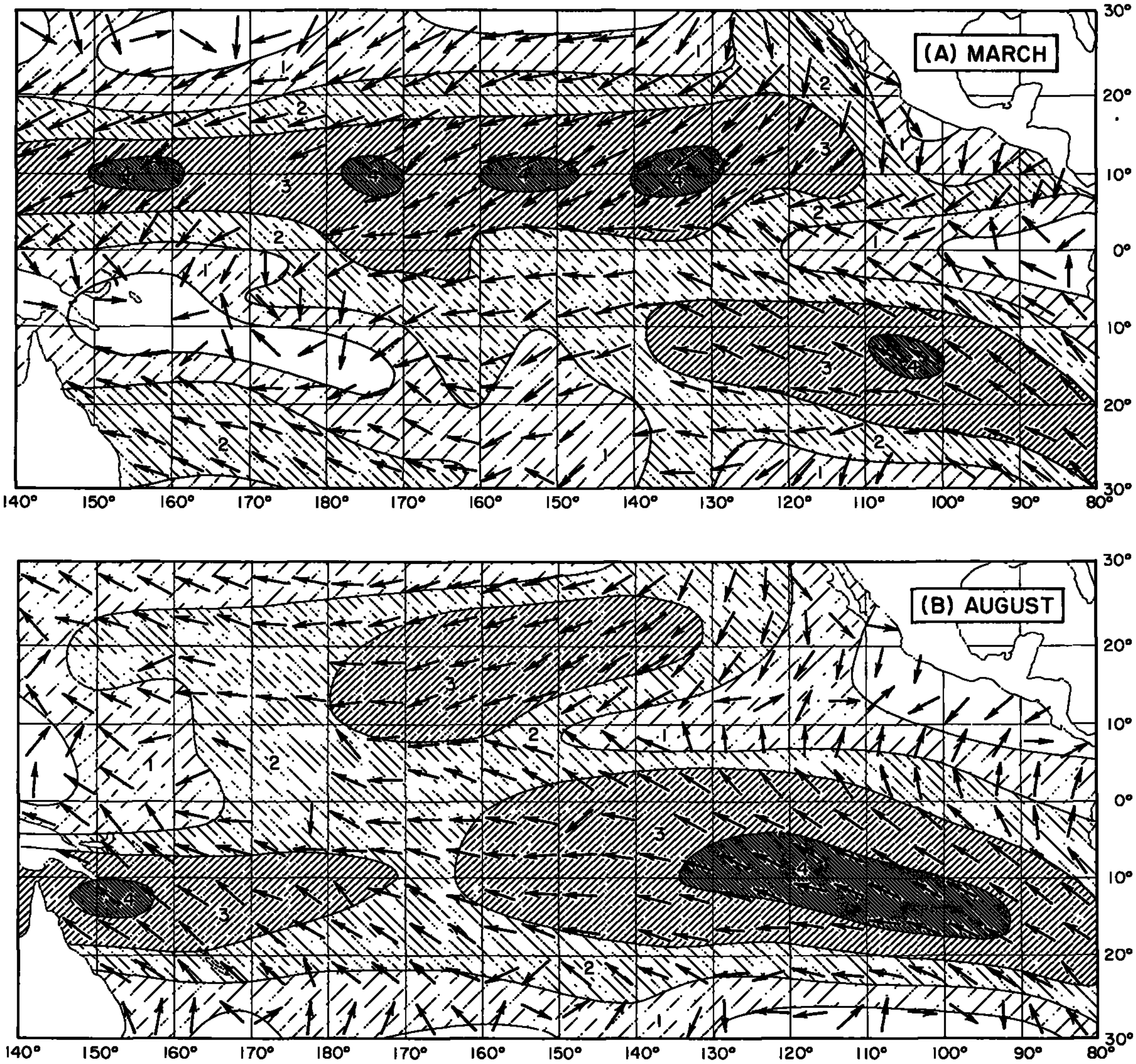


FIGURE 6.—Resultant direction and force of surface winds in the central equatorial Pacific during March (A), a month of light and variable winds on the Equator but strong northeast trades in the region of the Countercurrent, and during August (B), a month of strong southeast trades on the Equator and light winds along the Counter-current. [From Atlas of Climatic Charts of the Oceans, U. S. Weather Bureau, 1938. Arrows show resultant wind direction computed for each 5-degree unit area. Shadings indicate gradations of resultant velocities scaled in Beaufort units of wind force.]

east of 160° W. than to the west of that longitude and also more to the north of the Equator than to the south. A narrow convergent zone which theoretically should concentrate the zooplankton is most likely to occur east of 160° W., and particularly east of 140° W., because of the prominence of the southeast trades in that region.

ZOOPLANKTON AND THE CURRENT SYSTEM

Within the range of latitude sampled, there are certain natural subdivisions of the environment which may be established on the basis of the current structure. These may be defined as follows: (1) the North Equatorial Current from

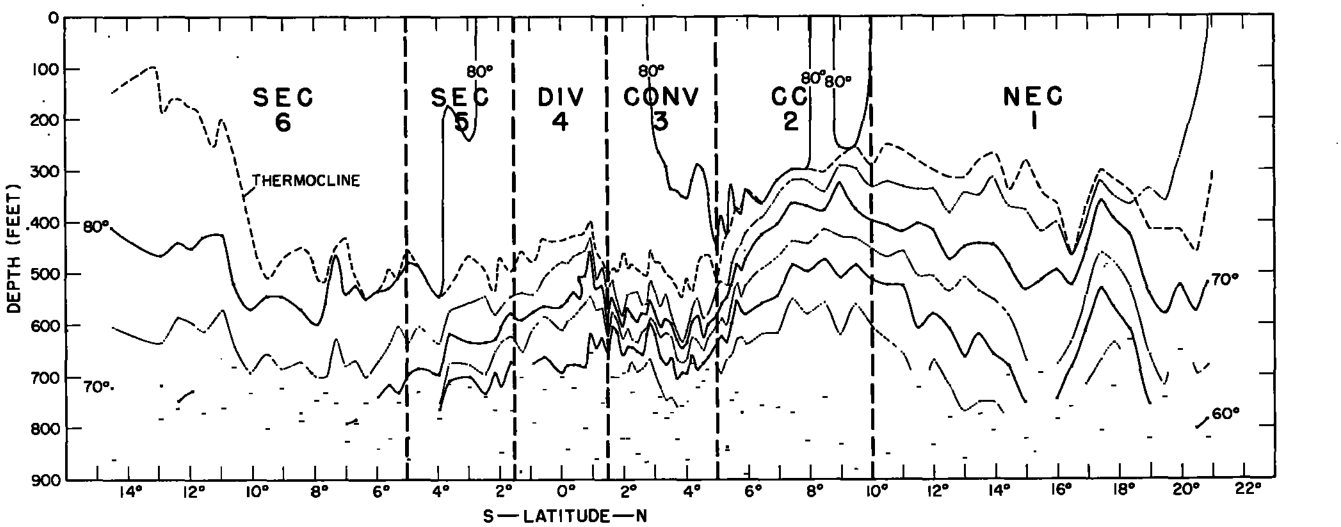


FIGURE 7.—Vertical temperature section (adapted from Cromwell and Austin, 1954, figure 28) based on bathythermograph observations along 172° W. longitude, made February 27–March 12, 1951, on *Hugh M. Smith* cruise 8, showing the boundaries of the 6 areas used in this study in relating variations in zooplankton abundance to particular features of the equatorial current systems.

the northern limit of our sampling to the northern boundary of the Countercurrent, a region of relatively shallow thermocline; (2) the Countercurrent with its boundaries being determined at the time of each crossing from vertical temperature sections, a region with shallow thermocline to the north, deepening to the south; (3) a zone of convergence in the South Equatorial Current extending (according to our definition) from the southern boundary of the Countercurrent to 1½° N. latitude, a region of deep thermocline; (4) a zone of divergence and upwelling in the South Equatorial Current along the Equator from 1½° N. to 1½° S. latitude, evidenced by a doming of the isotherms, a reduction in surface temperature, and an increase in surface inorganic phosphate; (5) the South Equatorial Current from 1½° S. to 5° S. latitude, a region of deep thermocline; and (6) the South Equatorial Current from 5° S. latitude to the southern limit of our sampling (about 14° S.), a region of shoaling thermocline to the south. Figure 7 shows the boundaries of these six areas superimposed on a vertical temperature section based on bathythermograph observations along 172° W. longitude.

When the zooplankton volumes, adjusted for the day-night variation but disregarding differences related to longitude and season, are combined according to these natural divisions of the current system, we obtain the distribution shown in figure 8, with the greatest concentration of zooplankton occurring at the Equator (1½° N. to 1½° S.) in the region of divergence. Average volumes for the areas just north of the Equator, i. e., the convergent zone and the Countercurrent were considerably higher than those for the corresponding areas south of the Equator. The North Equatorial Current and the South Equatorial Current at the southern extent of our sampling were equally poor in zooplankton. From an analysis of variance we conclude that the

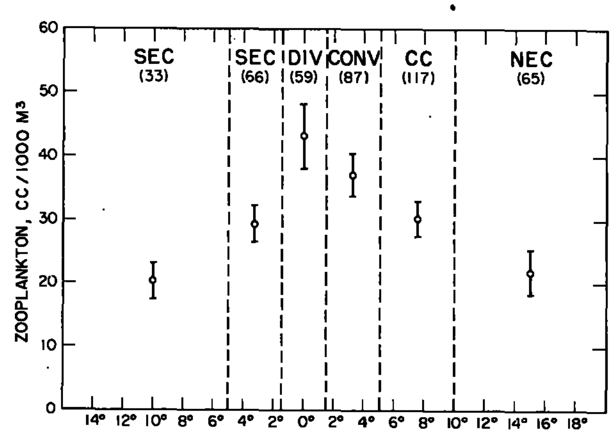


FIGURE 8.—Variations with the current system in zooplankton volumes (adjusted) for longitudes 120° W. to 180°, with the limits of the 0.95 fiducial interval shown for each mean. [The number of samples for each area is indicated in parentheses].

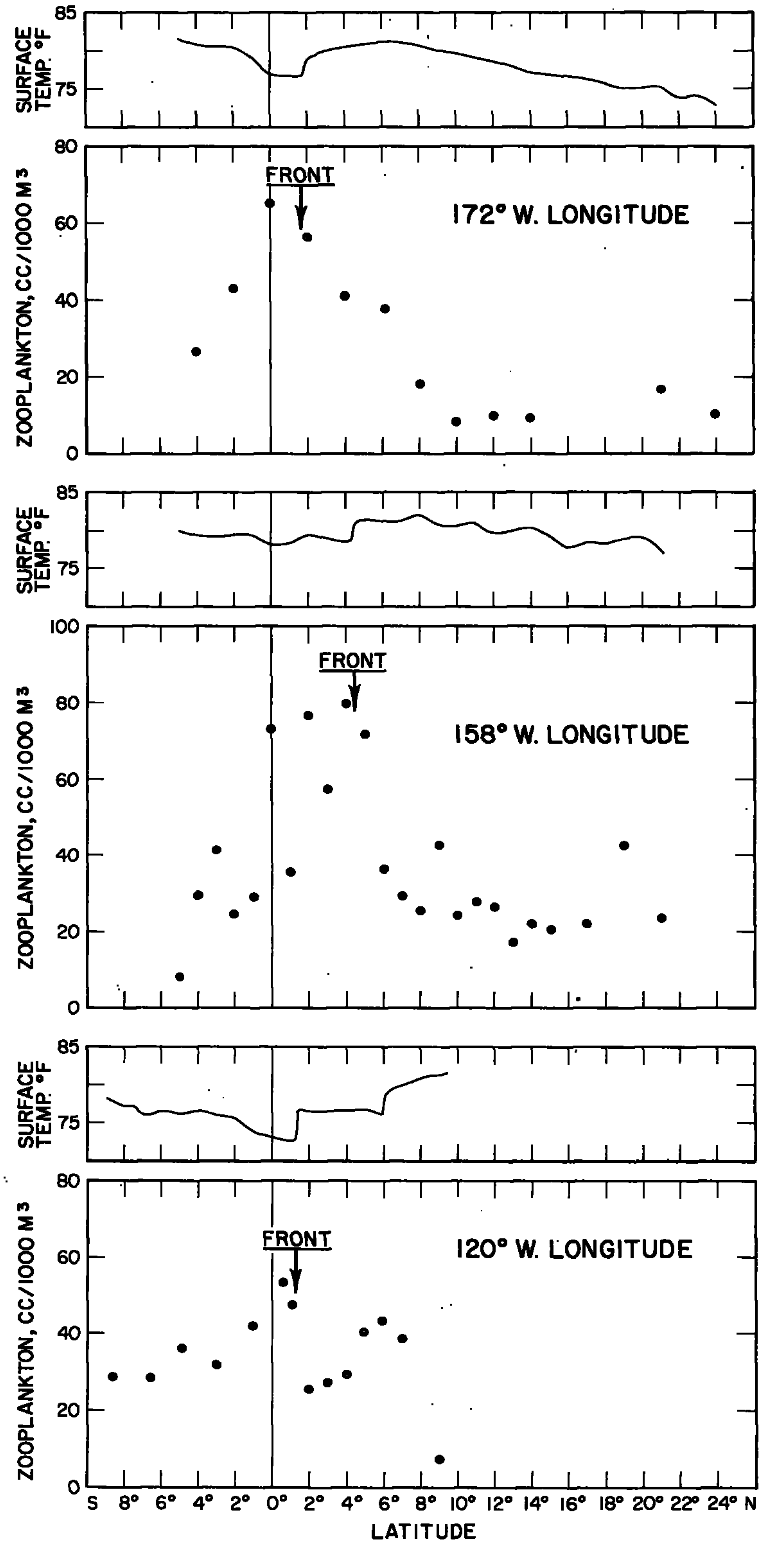


FIGURE 9.—Relation of an oceanographic front to the distribution of zooplankton (adjusted volumes) as demonstrated by 3 series of stations along 172°, 158°, and 120° W. longitude of *Hugh M. Smith* cruises 2, 5, and 18, respectively.

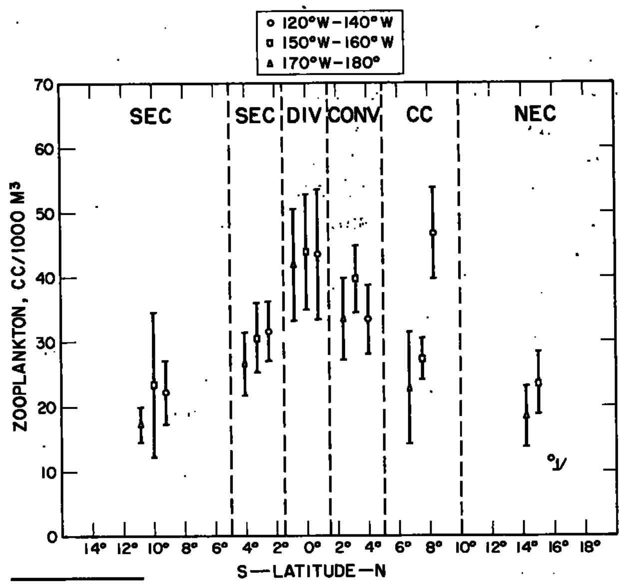
differences among subdivisions of the current system are highly significant ($F=4.08$ $P<0.01$). The degree of overlap in the 0.95 fiducial intervals of the means is shown in figure 8.

The asymmetrical distribution of the zooplankton in respect to the Equator results, we believe, from the prevalence of the southeast trades during most of the year. The occurrence of the zooplankton peak at the site of the divergence in an area of newly upwelled water, rather than in "older" water to the north or south of the Equator, is somewhat surprising and may be evidence that, on the average, the northward and southward components in the westerly surface current at the Equator are slight compared with the rate of development of zooplankton.

The distribution of zooplankton around well-marked fronts suggests a causal relation. Three well-defined fronts have been observed on POFI cruises in the convergent or transition zone to the north of the Equator. On all three occasions strong southeast winds were experienced between the Equator and the region of the front. The latitudinal variation in zooplankton abundance as related to these fronts is illustrated in figure 9 for the three series of stations along 120° W., 158° W., and 172° W. longitude. On each of the three meridians the zooplankton abundance peaks south of the front and drops off sharply to the north.

VARIATION WITH LONGITUDE

To examine the east-west variation in zooplankton abundance in respect to divisions of the current system as previously defined, the adjusted volumes were first combined by 10-degree intervals of longitude disregarding season. Because of the shortage of data for some subdivisions, longitudes 170° W. and 180°; were then combined as were 150° W. and 160° W.; 120° W. was grouped with 130° W. and 140° W. The latitudinal zooplankton distributions in the two western regions, 150° W.–160° W. and 170° W.–180°, are essentially alike (fig. 10) with peak abundance occurring at the equatorial divergence, and with the convergent zone next in importance. In the eastern region (120° W.–140° W.), we find the highest average volume in the Countercurrent with the area of divergence second in rank. Only in the Countercurrent are there significant differences among longitudes, as indicated by the



[1] Only 1 sample.

FIGURE 10.—Longitudinal and latitudinal variations in the distribution of zooplankton volumes (adjusted) with the data segregated into three longitudinal groups and in accordance with natural features of the current system. The limits of the 0.95 fiducial interval are indicated for each mean.

lack of overlap in the 0.95 fiducial intervals of the means. And it is only in the eastern Pacific that production in the Countercurrent equals that of the divergent zone. While these apparent relations may change with further sampling and more complete seasonal coverage, we believe the results are logical in view of longitudinal variations in thermocline depth and winds.

As previously mentioned, toward the northern boundary of the Countercurrent in the eastern and central Pacific, there is a doming in the isotherms (figs. 7 and 17) and the thermocline is relatively shallow; consequently high-phosphate water is within the photosynthetic zone and within the reach of wind-induced turbulence. To the westward the thermocline deepens (Sverdrup and others, 1942: 708), reducing the likelihood of such enrichment. Figure 11 shows the relation of the average zooplankton volumes for the range of latitude 8° N. to 11° N., and the depth of the 70° isotherm for four meridians (140° W., 150° W., 160° W., and 170° W. long.). The chosen range of latitude (8° N.–11° N.) includes the doming in the isotherms at the northern boundary of the Countercurrent and represents the zone of most shallow thermocline in the tropical Pacific. The results indicate a highly significant inverse correlation ($r = -0.688$, $P < 0.01$) from east to west between zooplankton volume and depth of the 70° isotherm which lies within the thermocline. We believe this relation results because of differences in depth of high-phosphate water and amount of wind-induced enrichment, although there is some evidence (Moore and others, 1953) that a shallow thermocline may act as a thermal floor in controlling the vertical distribution of zooplankton. Probably the correct explanation cannot be obtained from our 200-meter hauls but would require a detailed study employing horizontal hauls with closing nets.

In general, zooplankton volumes from the eastern and central longitudes were higher than in the west. When the volumes are combined by 10-degree intervals of longitude for the Countercurrent with boundaries at about 5° N. and 10° N. latitude, and for the South Equatorial Current from about 5° N. to 5° S. latitude, we obtain the results shown in figure 12. In the Countercurrent there was a sharp peak in abundance at 140° W. longitude and a marked reduction both to the east and west. In the South Equatorial Current, bracketing the Equator, the highest average volume occurred at 150° W., but there was actually little variation with longitude between 120° W. and 170° W. The few collections taken along 110° W. were omitted from this comparison. We should point out that the means shown for 120° W., 130° W., and 180° are based on few samples with poor seasonal coverage.

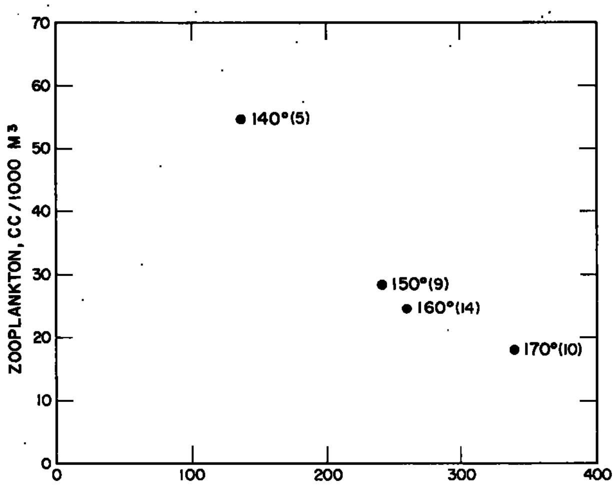


FIGURE 11.—Variation of zooplankton volume (adjusted) with depth to the 70° F. isotherm for the latitudes 8° N.–11° N. on longitudes 140° W. to 170° W. [Number of stations providing zooplankton and temperature observations are shown in parentheses.]

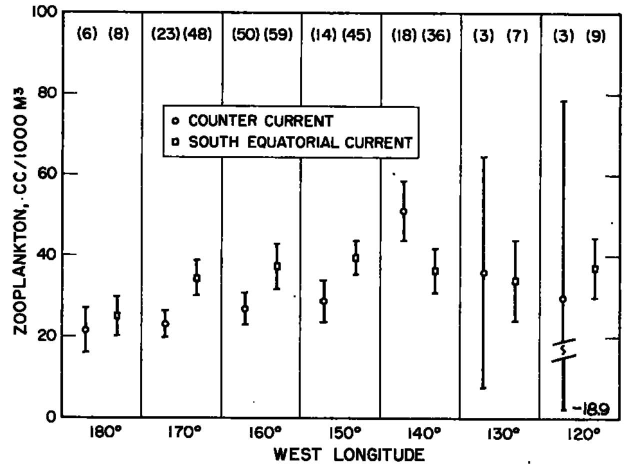


FIGURE 12.—Longitudinal variation in zooplankton volumes (adjusted) for the Countercurrent, extending from about 5° to 10° N. latitude, and for the South Equatorial Current from about 5° N. to 5° S. latitude. The limits of the 0.95 fiducial interval are shown for each mean. [The number of samples for each area is indicated in parentheses.]

From an analysis of variance we conclude that differences between the two subdivisions of the current system are highly significant ($F=5.57$, $P<0.01$), but that differences associated with longitudes are not significant ($F=0.76$, $P>0.05$). Despite the statistical evidence that the differences among longitudes are not significant (with the exception of that between 140° W. and 150° W. in the Countercurrent, as indicated by lack of overlap of the 0.95 fiducial intervals of the means), the general picture of decreasing zooplankton abundance from 140° W. to 180° parallels certain changes in the environment. Along the Equator, with decrease in wind velocity from east to west, we may expect a corresponding decrease in upwelling and enrichment of the surface waters; in the region of the Countercurrent, the possibility of enrichment through wind-induced turbulence decreases from east to west with the deepening in thermocline.

DIFFERENCES AMONG SEASONS AND YEARS

It was pointed out by King and Demond (1953) that the zooplankton volumes taken in January and February in the equatorial Pacific averaged significantly less than those obtained in June and

July. With further sampling the results showed a rather uniform level of abundance for the 9-month period April through December (King, 1954) with a reduction from January to March. Figure 13 shows the results of our sampling to date for the Countercurrent and for the equatorial region of the South Equatorial Current with the volumes combined, irrespective of longitude, into four quarterly periods of 3 months each. In the Countercurrent the highest average volume was obtained for the second quarter, April, May, and June, which occurs during the period when northeast trade winds are predominant at those latitudes. Along the Equator the last six months of the year, the period of strong southeast trade winds (Crowe, 1952) averaged higher than for the first two quarters. From an analysis of variance, however, we conclude that the differences among seasons are not statistically significant ($F=1.87$, $P>0.05$), but again differences between subdivisions of the current system are highly significant ($F=8.38$, $P<0.01$).

If we segregate the data geographically according to divisions of the current system and seasonally into two 6-month periods, i. e., (1) January to June, which includes roughly the time of lightest winds along the Equator in the central Pacific, and (2) July to December, the period of

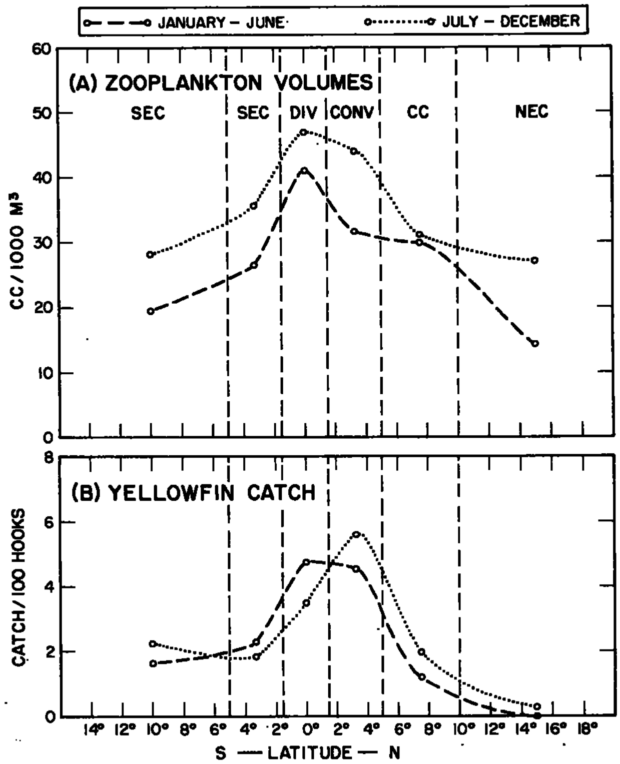


Figure 14.—Variation with the current system in (A) zooplankton volumes (adjusted) and (B) yellowfin longline catch for the two 6-month periods, January–June, a period with northeast or light and variable winds, and July–December, a period of prevailing southeast trade winds (in the central equatorial Pacific).

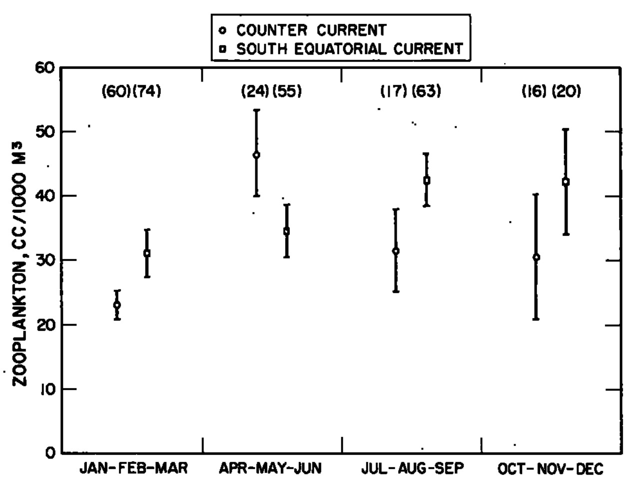
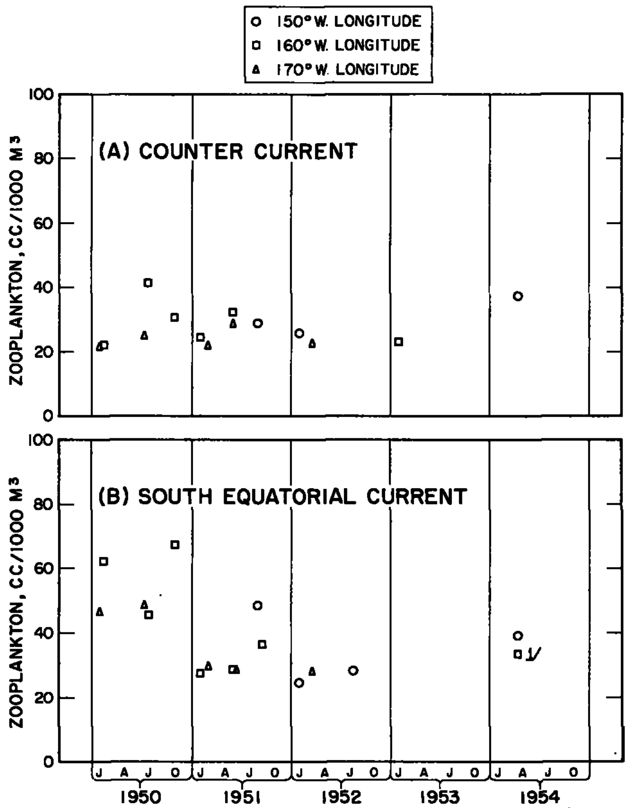


Figure 13.—Seasonal variations in zooplankton volumes (adjusted) for the Countercurrent with boundaries at about 5° N. and 10° N. latitude, and for the South Equatorial Current from about 5° N. to 5° S. latitude; longitudes 120° W. to 180° combined; the limits of the 0.95 fiducial interval are shown for each mean. [The number of samples for each season and each subdivision of the current system is indicated in parentheses.]

strong southeast trades, we find an interesting difference (fig. 14A). In both groups, the peak abundance in zooplankton occurred at the Equator, but during the latter half of the year under the influence of the southeast trades the abundance continued high into the convergent zone. When the data from this zone are examined by means of the "t" test we find, however, that the mean for January–June is not significantly different ($P>0.05$) from the mean for July–December.

Our data indicate that along the Equator there was considerable difference in zooplankton abundance among years. Figure 15 presents average zooplankton volumes for the Countercurrent and the equatorial region of the South Equatorial Current which were visited repeatedly from 1950 to 1954. From an analysis of variance we may conclude that differences between the two subdivisions of the current systems are highly significant ($F=27.60$, $P<0.01$), differences among years are also highly significant ($F=7.33$, $P<0.01$), but



[1] Only 1 sample

FIGURE 15.—Annual variation in zooplankton abundance for the most frequently sampled longitudes of (A) the Countercurrent with boundaries at about 5° N. and 10° N. latitude, and (B) the South Equatorial Current from about 5° N. to 5° S. latitude.

differences among longitudes are not significant ($F=0.178$, $P>0.05$). It is obvious that the differences among years are derived principally from variations within the South Equatorial Current. The general agreement among longitudes is in line with results from the previous tests.

Along the Equator the volumes for longitudes 160° W. and 170° W. averaged considerably higher in 1950 than in subsequent years. On longitude 150° W., August–September 1951 provided much higher volumes than January and August 1952. In both the Countercurrent and the South Equatorial Current there is some indication of a rise in 1954.

Possibly related changes are evidenced in other environmental factors. From a study of the rather sparse rainfall records available for the central equatorial Pacific,[8] Austin concludes that in the year 1950 the precipitation at Fanning Island (located at about 4° N. latitude, 159° W. longitude) was unusually low and infers that southeast winds predominated throughout the year.[9] On the other hand, judging by the climatological summaries, the years 1951, 1952, and 1953 may be considered as normal years in respect to rainfall and also, by inference, in respect to winds, i. e., with northeast and variable winds during the first 6 months and east to southeast winds during the latter half of the year. Therefore the year of highest apparent productivity in the zone of interest coincided with the year in which the southeast trades appear to have been unusually vigorous, thus perhaps causing the upwelling mechanism to operate more energetically.

DIURNAL VARIATION AND THE CURRENT SYSTEM

Many physical and biotic conditions influence the vertical movement of planktonic animals (Kikuchi, 1930; Cushing, 1951). The diurnal variation which we have observed in the zooplankton catch from 200-meter oblique hauls probably results from a combination of factors which include: (1) vertical migration of the organisms in response to changes in illumination, and (2) their increased ability to dodge the net during daylight hours. In Hawaiian waters and in the central equatorial Pacific, night hauls yield catches about 1½ times the volume of day hauls (table 1). When the average volumes of night, day, and twilight hauls are segregated with respect to subdivisions of the current system, as in figure 16, we find a marked variation in the night/day ratio from north to south. In the North Equatorial Current, Countercurrent, and convergent zone the ratios range from 1.31 to 1.43, while in the divergent zone and the South Equatorial Current to the southward the ratios are much higher, ranging from 1.76 to 1.94. This trend appears consistently in the individual cruises.

The North Equatorial Current, an area of relatively shallow thermocline within the latitudes considered (fig. 7), has a very low night/day ratio; the convergent zone, with a deep thermocline, also has a low ratio, while the South Equatorial Current south of 5° S. latitude, which is an area

[8] In unpublished manuscript entitled, Review of Central Equatorial Pacific Oceanography, 1950–52.

[9] A study of the records had shown that a period of "doldrums" or northeast winds bring heavy rains to the northern Line Islands.

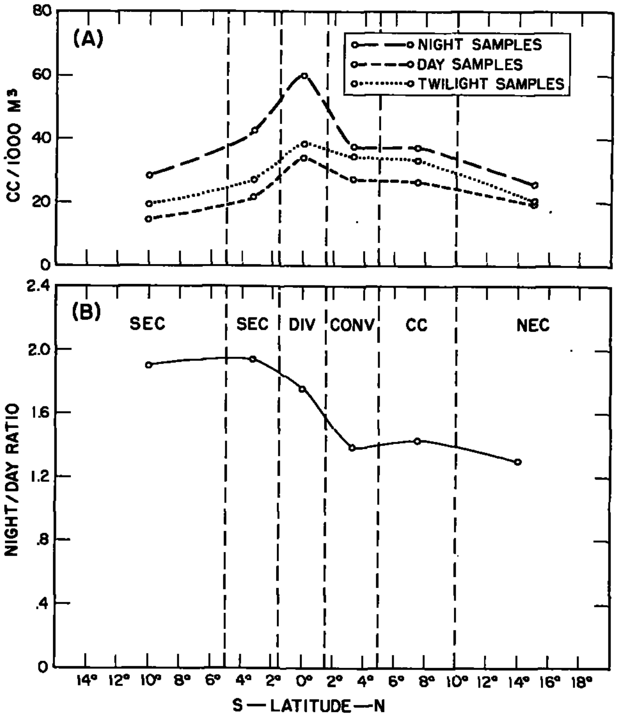


FIGURE 16.—Variations with the current system in (A) average volumes of night, day, and twilight hauls and in (B) the ratio of night to day zooplankton volumes.

of moderate to deep thermocline, has a high ratio. We must conclude, therefore, that neither thermocline depth in itself nor the night/day ratio appears to be related to the general level of zooplankton abundance. Both high and low ratios are found in areas of poor zooplankton catch. We must leave this problem for the present without an explanation.

SHORT-TERM VARIATIONS

Two cruises of the *Hugh M. Smith* (cruise 11 and 15) crossing the equatorial currents on 150° and 140° W. longitude provide information on temporal changes in zooplankton volume and distribution as related to changes in the physical environment.

On cruise 11 in August–October 1951, the northbound leg (stations 28–50) was worked immediately after the southbound leg (stations 1–28). During the time interval (approximately 6 days) between crossings of the Equator, the wind (SE.) decreased from about 20 knots to about 12 knots. As indicated by the change in positions of the 80° F. isotherm (fig. 17), the zone of mixing at the Equator, i. e., the zone of cool, newly upwelled water, shifted to the south and narrowed in width during the 6-day interval. On the first leg the zooplankton maximum occurred at 1° N. latitude; on the second leg it occurred at 0° with a second peak of almost equal abundance at 2° S. latitude. These changes would seem to be evidence that during this 6-day period there was a shift in zooplankton distribution correlated with changes in zonal flow.

In the region of the Countercurrent during cruise 11, there was little change in winds within the interval (about 32 days) between sections, but there was a marked increase in rate of flow, as indicated by the broadening of the Countercurrent and steepening of the thermocline. These changes in the current were accompanied by a significant change in the zooplankton distribution (fig. 17). At the time of the first crossing there was little variation among stations within the Countercurrent; at the second crossing, following an increase in the current velocity from 45 to 80 cm./sec., there was a marked gradient in zooplankton concentration with the larger volumes being taken in the area of shallow thermocline at the northern boundary of the Countercurrent.

Additional information on time changes in the environment and the distribution of zooplankton along a particular meridian was obtained during May 1953 on *Hugh M. Smith* cruise 15 when 4 consecutive hydrographic and plankton sections were completed along 140° W. longitude with sampling from 9° N. to 7° S. latitude. The time

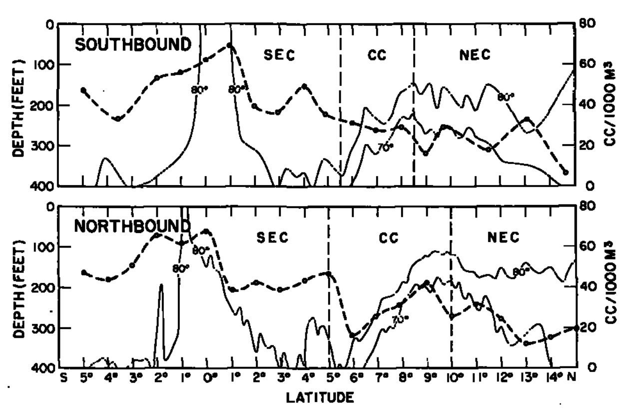


FIGURE 17.—South and northbound sections of *Hugh M. Smith* cruise 11 in August–October 1951, showing associated changes in zooplankton distribution (adjusted volumes) and temperature along 150° W. longitude. [Temperature sections adapted from Austin 1954a.]

interval between the first and fourth crossings of the Equator was 16 days and from the start of section 1 to the end of section 4 was 23 days. Austin (1954b) summarizes the hydrographic changes during this period as follows:

1. The slope of the isotherms associated with the Countercurrent is greater in the fourth than in the first leg, suggesting an increased easterly flow of the Countercurrent. This was substantiated in the calculated velocities, 60 cm./sec. on the first leg and 120 cm./sec. on the fourth leg.

2. The 80° isotherm-surface intercepts for the fourth section have moved to the north and south of those for the first section.

3. The 70° isotherm shows considerably more doming at the Equator in the fourth section.

4. Between the first and fourth sections there is a generally southerly shift in selected isohalines. There is a similar change in the slope of sigma-t isopleths in the region of the Countercurrent. Selected sigma-t surfaces show a general displacement to the south when comparing the first and fourth sections.

5. The most apparent change in the phosphate sections is the deepening of the 0.8 and 2.0 μg at/L isopleths in the region of the Countercurrent which is associated with the suggested change in flow, and the change in configuration of the 0.8 μg at/L isopleth near to and south of the Equator.

Observations of wind speed and velocity along the four section lines, as diagramed by Austin (1954b), show this was a period of moderate and variable winds. Since we did not have observations simultaneously to the north and south of the section lines, the changes with time are complex and difficult to summarize. In the region of the Countercurrent there appears to have been a reduction in the northeast trade winds and an extension to the northward of the moderate southeast trades. South of the Equator there was first a slackening in the winds followed by an increase, with the strongest winds of the cruise being recorded on the southern ends of the third and fourth sections.

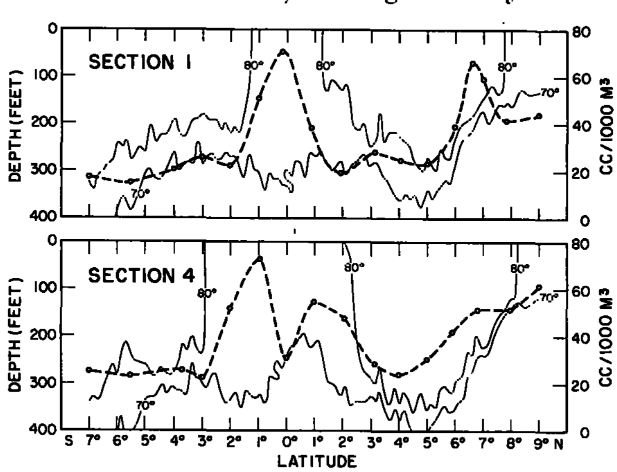


FIGURE 18.—Variation in (adjusted) zooplankton volumes and in the configuration of the 70° and 80° F. isotherms on sections 1 and 4 of *Hugh M. Smith* cruise 15, along 140° W. longitude in May–June 1952. [Temperature sections adapted from Austin 1954b.]

When the adjusted zooplankton volumes (table 9, appendix B) from the four series of stations along 140° W. are subjected to an analysis of variance with two-way classification, we find there are no significant ($P>0.05$) differences among the four sections but highly significant ($P<0.01$) differences among stations (latitudes). The latter significance results from the wide difference between the high volumes obtained in the Countercurrent and at the Equator and the low volumes from about 3° S. to 7° S. latitude.

When we examine differences in zooplankton distribution between the first and fourth legs in relation to changes in the temperature structure at the Equator (fig. 18), we find that the increased distance between the 80° isotherm-surface intercepts (an indication of an increase in width of the mixing zone) was accompanied by a broadening of the zooplankton "rich zone." On the first section there was a single peak of abundance directly on the Equator; on the fourth section there were two peaks, at about 1° S. and 1° N. latitude, with a trough at the Equator. In the Countercurrent the zooplankton catch was high in volume on all four sections. The suggested change in rate of flow in the Countercurrent was not reflected in any noticeable change in zooplankton abundance or distribution.

It is difficult to explain or to draw conclusions from these events. In one instance (cruise 11) a change in rate of flow of the Countercurrent was accompanied by a change in zooplankton distribution; in the second instance (cruise 15) changes in the Countercurrent were not evidenced by any noticeable change in the volume of zooplankton. On both cruises an increase in breadth of the zone of divergence or mixing at the Equator was followed by a corresponding broadening in the plankton rich zone. It does not seem likely that these rather quick responses of zooplankton to variations in the physical environment are the result of immediate changes in biological productivity reflected in growth of the population, but are simply a shifting and perhaps dispersal or concentration of the population associated with changes in the water mass.

PHOSPHATE, ZOOPLANKTON, AND TUNA

The primary objective of our zooplankton studies has been to obtain an estimate of the basic fish food present in different areas of the sea with the hope that this information would increase our understanding of variations in the abundance and distribution of the tunas. Where other factors, temperature for example, are not of a limiting nature, fast-swimming oceanic fishes such as the tunas will occur, we believe, in proportion to the amount of substance available for their nutriment. This does not mean that we expect to find a high positive correlation at all times and places between the volume of food and the abundance of tunas. In fact, it is probable that an inverse relation may exist locally after a period of intensive feeding. In general, however, when broad areas of the sea are being compared, we believe that high abundance of fish is most likely to occur in areas of high concentration of zooplankton and other forage organisms.

The distribution of yellowfin tuna, *Neothunnus macropterus* (Temminck and Schlegel), summarized in figure 19, is derived from 12 cruises in the central equatorial Pacific during the years 1950–53.[10] The highest average catch (5.3 yellowfin per 100 hooks) was obtained in the convergent zone, with the second highest catch in the region of the divergence. Although the peaks in abundance do not exactly coincide, it is obvious that there is more than a casual relation between zooplankton and yellowfin. The best catches of bigeye, *Parathunnus sibi* (Temminck and Schlegel), were made in the North Equatorial Current and Countercurrent (fig. 19). This species appears to respond in a different manner than the yellowfin to the better foraging conditions in the convergent and divergent zones. A comparative study of the food of the two species failed to show differences in the

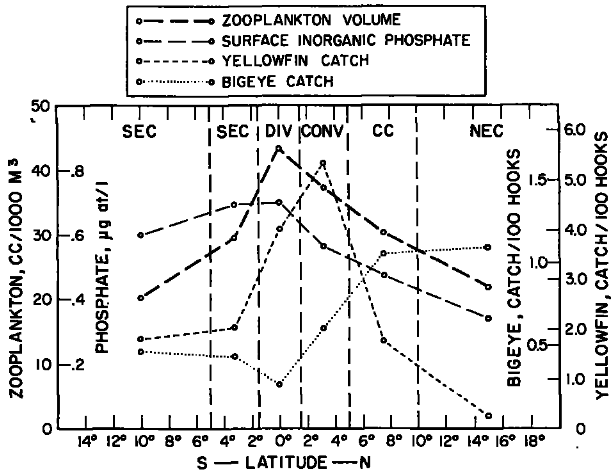


FIGURE 19.—Variations with the current system in yellowfin and bigeye catch on longline gear, zooplankton volumes (adjusted) and surface inorganic phosphate, for the range of longitude 120° W. to 180°. The tuna catch data are derived from cruises 7, 11, and 18 of the *Hugh M. Smith*, cruises 11, 12, 13, 14, 15, 16, and 18 of the *John R. Manning*, cruise 1 of the *Charles H. Gilbert*, and cruise 1 of the *Cavalieri*. The phosphate data are from cruises 2, 5, 8, 11, 14, 15, 16, 18, and 19 of the *Hugh M. Smith*.

diet which might explain this marked difference in distribution (King and Ikehara, 1956).

Measurements of inorganic phosphate performed on POFI hydrographic cruises during the years 1950–53 show that the zone of divergence and the South Equatorial Current immediately south of the Equator contained the highest concentrations of this basic chemical nutrient while the North Equatorial Current contained the lowest (fig. 19). This variation may result from unequal utilization of phosphate and/or the unequal mixing of high and low phosphate water to the north and south of the Equator as the result of the asymmetrical effects of the southeast winds. As evidenced by the zooplankton and yellowfin catch, the greatest organic productivity occurred on, or to the north of the Equator. The difference in degree of northward displacement for the two eutrophic levels, zooplankton and tuna, may to some extent be indications of the lag periods in their development and may also be related to the slow northward drift in the surface currents under the influence of east and southeast winds.

When long series of stations extending in a north-south direction are examined, we usually find a highly significant positive correlation be-

[10] The tuna catch records employed in this report have resulted from exploratory longline fishing conducted by POFI vessels and are analyzed in other POFI reports (Murphy and Shomura 1953a, 1953b, 1955; Shomura and Murphy 1955; Iversen and Yoshida, 1956.

TABLE 5.—*Correlations of adjusted zooplankton volumes (cc./1000 m.³) as the X_1 variate, with X_2 variate the surface inorganic phosphate or yellowfin longline catch from same locality*

X_2 variate	Motor vessel and cruise No.	Range of latitude	Degrees of freedom	Correlation coefficient(r)	P
Inorganic phosphate, μg at/L	Hugh M. Smith—2	24° N.–5° S.	22	0.771	<0.01
Inorganic phosphate, μg at/L	Hugh M. Smith—5	27° N.–5° S.	41	0.678	<0.01
Inorganic phosphate, μg at/L	Hugh M. Smith—8	21° N.–14° S.	50	0.365	<0.01
Inorganic phosphate, μg at/L	Hugh M. Smith—11	19° N.–4° S.	20	0.631	<0.01
Yellowfin catch per 100 hooks	Hugh M. Smith—11	15° N.–5° S.	25	0.381	0.05
Inorganic phosphate, μg at/L	Hugh M. Smith—14	9° N.–8° S.	34	0.277	>0.05
Yellowfin catch per 100 hooks [1]	John R. Manning—11	8° N.–8° S.	24	0.286	>0.05
Inorganic phosphate, μg at/L	Hugh M. Smith—15	9° N.–7° S.	58	−0.294	<0.05
Inorganic phosphate, μg at/L	Hugh M. Smith—18	9° N.–9° S.	16	0.101	>0.05
Yellowfin catch per 100 hooks	Hugh M. Smith—18	9° N.–9° S.	22	−0.177	>0.05

[1] In this instance zooplankton volumes obtained by *Hugh M. Smith* cruise 14 were correlated with longline catches of *John R. Manning* cruise 11, the two cruises occurring during the same period of time.

tween surface inorganic phosphate and zooplankton volumes (table 5). With a short series of stations the correlation may be nonsignificant as that for the *Hugh M. Smith* cruises 14 and 18, or even be significantly negative as for cruise 15. The latter is perhaps an example of an inverse relation resulting from high utilization. The correlation of zooplankton volume and yellowfin catch was significant (P=0.05) for *Hugh M. Smith* cruise 11, but non-significant for cruise 11 of the *John R. Manning* and cruise 18 of the *Hugh M. Smith.*

Within the equatorial "rich zone," from the southern boundary of the Countercurrent at about 5° N. latitude to 5° S. latitude, zooplankton and yellowfin showed a gradient of increasing abundance between 180° and 150° W. (fig. 20). The yellowfin catch continued high at 140° W. and then dropped off sharply to the east, while zooplankton volume varied somewhat irregularly to the east but remained moderately high. The variation in surface inorganic phosphate was roughly just the reverse (fig. 20), with high concentrations on the eastern and westernmost longitudes and low values in between. We have no empirical explanation at present for this distribution of phosphate. It may possibly result from differences in rate of utilization as the most productive areas appear to be the mid-longitudes.

In the equatorial region of the central Pacific, July, August, and September was the period of best yellowfin catch (fig. 21). It was also the period of highest zooplankton abundance, although the quarter October, November, and December was essentially of equal rank. Phos-

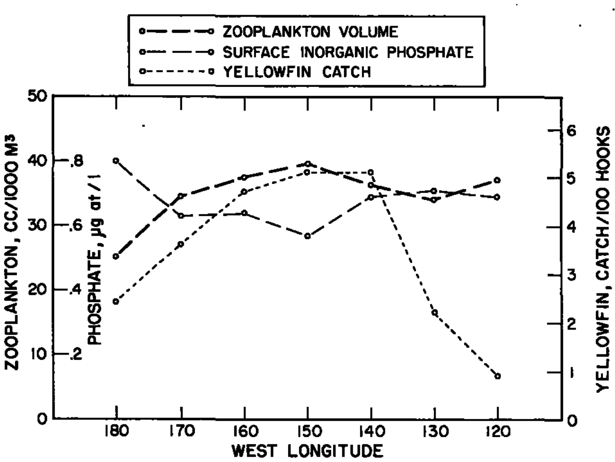


FIGURE 20.—Longitudinal variations in yellowfin longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the Countercurrent, at about 5° N. latitude to 5° S. latitude, with the data segregated by 10-degree intervals of longitude.

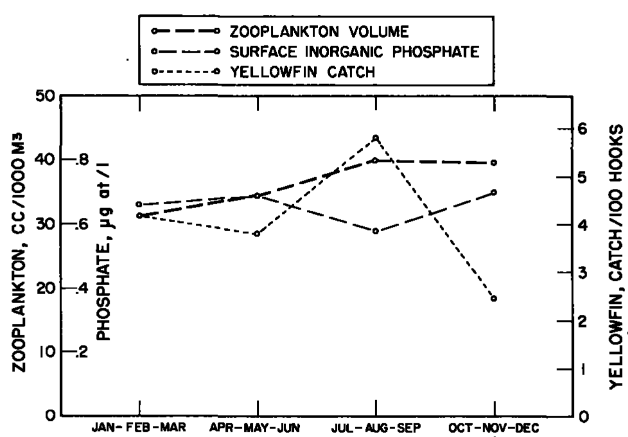


FIGURE 21.—Seasonal variations in yellowfin longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the Countercurrent at about 5° N. latitude to 5° S. latitude, with the data segregated into quarterly periods of 3 months each.

phate again showed an inverse correlation, particularly with the yellowfin catch. Figure 14B demonstrates the difference in yellowfin catch for the two 6-month periods: (1) January–June, a period of generally light, variable or northeast winds, and (2) July–December, a period of strong southeast trades. With the change in winds during the latter half of the year there was apparently a shift to the northward in the area of best catch. The zooplankton exhibited a general increase during this period, especially in the convergent zone.

SUMMARY AND CONCLUSIONS

1. This is the second report of the Pacific Oceanic Fishery Investigations on variations in zooplankton abundance in the central Pacific; it presents the results of 270 quantitative hauls made on eight cruises during the years 1951 to 1954. Data from earlier cruises, included in a previous report (King and Demond, 1953), were also utilized in this study.

2. The majority of the collections were obtained with 1-meter nets of 30XXX grit gauze (aperture widths 0.65 mm.). For comparison, a few hauls were made with 56XXX nets (aperture widths 0.31 mm.). Oblique hauls to 200 meters' depth were employed at most stations. The results from a short series of horizontal hauls are included.

3. The displacement volumes of all samples were measured in the laboratory. For each sample there was calculated the volume of the more nutritious zooplankton per unit of water strained. Counts were made on six samples to examine the composition of the catch from nets of different mesh size.

4. The catch of 56XXX grit gauze nets (aperture widths 0.31 mm.) was about 1¼ to 1¾ times greater in volume than that of the catch of the 30XXX nets (aperture widths 0.65 mm.). The number of plankters retained by the finer-meshed net was 3 to 5 times that retained by the coarser-meshed net. At three stations, two rich and one poor, the catches for the two nets were generally proportional.

5. Horizontal hauls made simultaneously at three levels showed that the greatest bulk of zooplankton was near the surface even in the daytime, rather than at depths just above or below the thermocline.

6. The night hauls yielded volumes averaging 1.57 times the volumes of day hauls; twilight hauls were intermediate in volume. To reduce these differences associated with hour of hauling, a method of adjustment was employed based upon the similarity between the diurnal variation in zooplankton abundance in the upper 200 meters and the curve of the sine function, with midnight equated to the angle whose sine is +1.0.

7. When the adjusted zooplankton volumes were combined according to natural subdivisions of the equatorial current system, disregarding differences associated with longitude and season, we found the greatest concentration of zooplankton occurring at the Equator in the region of upwelling and divergence. Average volumes for the convergent zone and the Countercurrent were greater than for the South Equatorial Current south of the Equator. This asymmetrical distribution of zooplankton in respect to the Equator may result from the prevalence of southeast trade winds in this part of the Pacific.

8. As determined from exploratory longline fishing conducted by POFI, in the central equatorial Pacific the greatest abundance of yellowfin tuna occurred in the convergent zone just to the north of the area of highest zooplankton abundance, and although the peaks did not exactly coincide, there was a high degree of co-variation in yellowfin and zooplankton in respect to the current system.

9. Oceangraphic fronts occurring in the transition zone between the Equator and the southern boundary of the Countercurrent appeared to demarcate areas of high zooplankton abundance on the south from areas of poor to moderate abundance on the north.

10. The Countercurrent in the east-central Pacific produced unusually high zooplankton volumes. As this is an area of shallow thermocline, with high-phosphate water within the photosynthetic zone and within reach of wind-induced turbulence, conditions are more favorable for plankton production than farther to the westward where the thermocline deepens.

11. Within the equatorial region there was a west-east gradient of increasing zooplankton abundance from 180° to 150° W. longitude which was correlated positively with average wind velocity and inversely with thermocline depth, and was closely paralleled by a gradient of increasing yellowfin catch. East of 140° W. the yellowfin catch

dropped sharply, but zooplankton volumes remained high.

12. Largest zooplankton volumes occurred in the quarter, July, August, and September, with October, November, and December essentially equal in rank, and the lowest in January, February, and March. Best yellowfin catches were obtained in July, August, and September.

13. Zooplankton volumes averaged considerably higher in the year 1950 than in 1951, 1952, and 1953. There was some indication of a rising trend in 1954.

14. The ratio of the volumes of night hauls to day hauls ranged from 1.31 to 1.43 in divisions of the current system north of the Equator, and from 1.76 to 1.94 at the Equator and in the South Equatorial Current to the southward. The night/day ratio did not appear to be related to thermocline depth or to general level of plankton abundance.

15. With an increase in breadth of the mixing zone associated with the divergence at the Equator, there was a corresponding broadening in the zooplankton rich zone. On one cruise an increase in rate of flow of the Countercurrent was accompanied by a marked change in the distribution of zooplankton within the current. These observations indicate that the zooplankton was quick to respond to physical changes in the environment by dispersal or concentration of the population following changes in the water mass.

16. On long series of stations extending from the phosphate-poor North Equatorial Current to south of the Equator, we found highly significant positive correlations between zooplankton volume and surface inorganic phosphate. On series covering a short range of latitude the correlation was insignificant or even negative.

Although the highest concentration of phosphate occurred in the divergent zone at the Equator, agreeing in this respect with zooplankton, longitudinally and seasonally there was some evidence of an inverse relationship with zooplankton and yellowfin; this may result from differences in rate of utilization.

17. Zooplankton distribution was rather uniform throughout the island waters of Palmyra, an atoll lying in the Countercurrent at about 162° W. longitude. Sampling along four station lines extending from a few hundred yards from the outer reef to about 14 miles offshore revealed no significant change in zooplankton abundance with distance from land (appendix A).

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APPENDIX A

ZOOPLANKTON DISTRIBUTION ABOUT AN OCEANIC ISLAND

Palmyra Island lies 352 nautical miles north of the Equator and about a thousand miles south of Honolulu. In relation to other islands of the Line Islands group, Palmyra is located about 33 miles southeast of Kingman Reef and 120 miles northwest of Washington Island. The island is an atoll consisting of 40 to 50 small islets arranged in a rectangle about 4 miles long and 1½ miles wide. The islets rest on a shallow reef platform 6 miles long and 2 miles wide with the long axis of the platform extending in an east-west direction. Outside the 10-fathom line the submarine slope is steep, ranging from 2,500 to 3,000 feet to the mile and descending to the general depth of about 15,000 feet (Wentworth 1931).

Occupying latitudes 5°52′ N. to 5°54′ N. at approximately 162° W. longitude, Palmyra lies close to the southern boundary of the Countercurrent and ordinarily is bathed by it throughout the year. The surface current was flowing to the east at the time of our observations, as was to be expected, since, in the region of the Line Islands, the southern boundary of the Countercurrent has always occurred south of 5½° N. latitude on the numerous crossings of POFI vessels.

The zooplankton abundance about the island was investigated in January 1953, on *Hugh M. Smith* cruise 19, by running lines of stations out to the north, south, east, and west, starting as close to the reef as the vessel's safety permitted and extending out to a maximum of about 14 miles (fig. 3). A total of 20 hauls were made, all at night. With the exception of a single haul made on the shallow shelf west of the island which yielded a sample about twice the average volume of the 200-meter oblique tows, the results indicated a rather uniform distribution of zooplankton throughout the island waters.[11] From an analysis of variance we conclude that the differences between the four series of stations were not significant ($F=0.896$, $P>0.05$). There was a slight indication of an inverse relation between the zooplankton catch and distance from land (fig. 22); a regression analysis showed, however, that this trend was not significantly different ($b=-0.431$, $P>0.1$) from a random distribution.

The variation about Palmyra was less than we found in two series of stations extending offshore from Oahu, Hawaii. Here the largest volumes occurred at one or two miles from shore and the difference between stations was significant (King and Hida, 1954). Although the sampling was entirely inadequate for any broad conclusions, it appears evident that at the time of our visit to Palmyra there was no definite gradient in zooplankton abundance along four station lines extending from a few hundred yards from the outer reef to about 14 miles offshore.

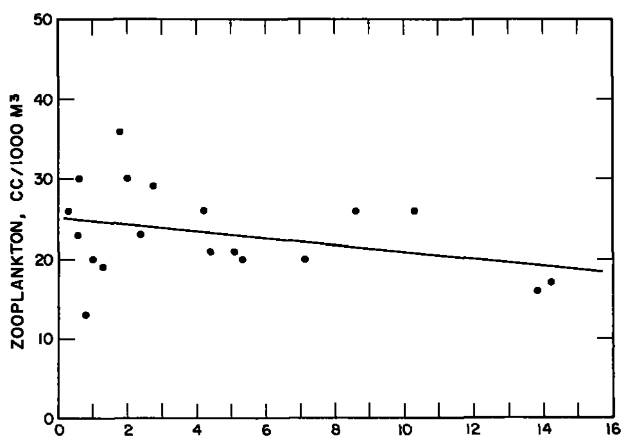

FIGURE 22.—Zooplankton volumes (adjusted) in relation to distance offshore from the 10-fathom line, Palmyra Island, January 1953, *Hugh M. Smith* cruise 19.

[11] The salinity and temperature data collected on this cruise indicated that the waters about Palmyra were also rather uniform as to chemical and physical conditions; e. g., the maximum variation in surface temperature was less than 0.5° C.

APPENDIX B

TABLE 6.—*Zooplankton volumes obtained on cruise 9 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	25°40′ N	175°24′ W	May 21, 1951	1202–1235	3304.0	10.3	13.7
2	22°45′ N	173°16′ W	May 22, 1951	1210–1237	1932.5	15.7	20.9
3	19°33′ N	171°32′ W	May 23, 1951	1214–1238	1385.4	23.0	30.6
4	16°05′ N	169°06′ W	May 26, 1951	1224–1250	1312.7	18.0	23.9
5	13°15′ N	166°45′ W	May 27, 1951	1233–1301	[3] 1366.4	10.5	13.9
6	10°16′ N	164°49′ W	May 28, 1951	(4)			
7	7°27′ N	163°05′ W	May 29, 1951	1246–1316	1505.0	18.7	24.7
8	5°35′ N	161°44′ W	June 3, 1951	1545–1614	1480.8	35.0	40.4
9	4°23′ N	160°02′ W	June 5, 1951	1358–1430	1517.2	22.5	28.4
10	2°43′ N	158°15′ W	June 7, 1951	1203–1235	1656.3	29.5	39.3
11	1°28′ N	158°02′ W	June 10, 1951	1206–1243	3026.6	14.4	19.1
12	0°27′ S	160°20′ W	June 11, 1951	1200–1235	2531.3	21.2	28.2
13	1°31′ S	164°05′ W	June 12, 1951	1144–1216	2302.6	22.1	29.4
14	2°04′ S	168°16′ W	June 13, 1951	1224–1254	1930.0	19.4	25.8
15	3°05′ S	172°07′ W	June 17, 1951	1408–1438	1997.6	23.2	29.4
16	4°32′ S	172°48′ W	June 19, 1951	0804–0834	1647.5	24.3	28.7
17	4°28′ S	171°38′ W	June 20, 1951	1207–1240	1975.4	30.1	40.1
18	3°59′ S	171°26′ W	June 21, 1951	1209–1242	2336.1	25.1	33.4
19	0°32′ S	170°33′ W	June 24, 1951	1213–1243	2103.3	17.6	23.4
20	2°18′ N	168°43′ W	June 25, 1951	1222–1251	1994.2	15.7	20.8
21	5°12′ N	166 46′ W	June 26, 1951	1232–1304	2275.1	17.8	23.6
22	8°05′ N	165°11′ W	June 27, 1951	1233–1302	1978.8	25.2	33.4
23	11°24′ N	163°37′ W	June 28, 1951	1240–1307	1521.6	14.2	18.8
24	14°40′ N	161°49′ W	June 29, 1951	1250–1322	2371.7	8.2	10.8
25	17°40′ N	159°57′ W	June 30, 1951	1253–1324	2716.2	11.3	14.9
26	20°34′ N	158°15′ W	July 1, 1951	1200–1231	2622.3	17.5	23.1

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (0.1248).
[3] Based on an estimated meter reading.
[4] No sample.

TABLE 7.—*Zooplankton volumes obtained on cruise 11 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.³	Zooplankton, cc./1000 m.³	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	14°37′ N	150°12′ W	Aug. 24, 1951	0851–0922	1437.7	5.9	6.8
2	13°06′ N	149°58′ W	Aug. 25, 1951	0826–0853	1223.7	29.2	33.0
3	11°31′ N	150°02′ W	Aug. 26, 1951	0830–0902	1898.0	15.8	17.9
4	9°41′ N	150°01′ W	Aug. 27, 1951	0759–0828	1363.2	26.3	29.4
5	8°58′ N	150°08′ W	Aug. 28, 1951	0720–0754	1852.4	15.2	16.5
6	7°59′ N	149°51′ W	Aug. 29, 1951	0754–0832	2838.5	26.2	29.2
7	6°55′ N	149°51′ W	Aug. 30, 1951	0734–0805	1693.4	25.7	27.9
8	5°59′ N	149°55′ W	Aug. 31, 1951	0742–0810	1540.6	28.8	31.7
9	4°49′ N	150°02′ W	Sept. 1, 1951	0734–0804	1954.6	32.8	35.6
10	4°00′ N	150°02′ W	Sept. 2, 1951	0739–0812	699.9	45.1	49.7
11	2°55′ N	150°09′ W	Sept. 3, 1951	0738–0807	1699.8	33.0	36.3
12	1°59′ N	150°04′ W	Sept. 4, 1951	0741–0811	1935.4	36.0	39.6
13	2°02′ N	151°39′ W	Sept. 5, 1951	0729–0800	1034.0	28.2	30.6
14	2°03′ N	153°05′ W	Sept. 6, 1951	0729–0758	1458.4	35.5	38.5
15	1°53′ N	155°18′ W	Sept. 12, 1951	0729–0759	1773.6	46.9	50.9
16	2°02′ N	156°13′ W	Sept. 13, 1951	0718–0749	1752.6	33.8	36.7
17	1°58′ N	157°32′ W	Sept. 14, 1951	0713–0746	1683.2	26.6	28.4
18	1°21′ N	157°18′ W	Sept. 15, 1951	0731–0803	1827.2	26.7	29.0
19	1°54′ N	156°15′ W	Sept. 16, 1951	0725–0753	1358.8	34.3	37.2
20	2°02′ N	154°43′ W	Sept. 17, 1951	0733–0803	1455.1	34.1	37.1
21	2°03′ N	153°04′ W	Sept. 18, 1951	0742–0813	1492.3	55.8	61.5
22	2°00′ N	151°18′ W	Sept. 19, 1951	0744–0812	1294.5	52.0	57.3
23	0°55′ N	149°54′ W	Sept. 20, 1951	0748–0818	1311.3	63.1	69.5
24	0°01′ S	149°56′ W	Sept. 21, 1951	0750–0820	1471.2	56.7	62.5
25	1°03′ S	150°16′ W	Sept. 22, 1951	0752–0808	1133.4	51.3	56.5
26	2°01′ S	150°08′ W	Sept. 23, 1951	0743–0813	1187.4	48.8	53.7
27	3°34′ S	150°05′ W	Sept. 24, 1951	0748–0820	1546.0	30.1	33.2
28	4°57′ S	150°04′ W	Sept. 25, 1951	0914–0944	1337.3	41.1	47.6
29	4°00′ S	150°00′ W	Sept. 26, 1951	0000–0033	1882.7	53.4	44.1
30	3°00′ S	149°57′ W	do	0906–0937	1635.0	44.3	51.3
31	2°00′ S	150°02′ W	do	1728–1758	1389.5	65.0	66.1
32	1°00′ S	149°58′ W	Sept. 27, 1951	0219–0249	1505.7	71.9	62.1
33	0°02′ N	150°00′ W	do	1309–1338	1124.0	56.7	68.1
34	1°02′ N	150°01′ W	do	2341–0011	1569.9	47.2	38.9
35	2°01′ N	149°53′ W	Sept. 28, 1951	0849–0920	1544.3	36.9	42.3
36	3°00′ N	150°03′ W	do	1724–1755	1628.2	38.2	38.8
37	3°58′ N	150°00′ W	Sept. 29, 1951	0201–0231	1531.2	51.8	44.2
38	4°59′ N	149°56′ W	do	1048–1119	1072.2	38.9	46.9
39	5°56′ N	150°00′ W	do	1929–2000	1660.0	18.3	16.8
40	6°51′ N	149°57′ W	Sept. 30, 1951	0353–0423	1632.2	28.7	26.1
41	7°51′ N	149°57′ W	do	1307–1338	1932.1	26.2	31.4
42	8°57′ N	149°58′ W	do	2243–2312	1465.9	51.0	42.4
43	10°00′ N	150°13′ W	Oct. 1, 1951	0718–0749	1790.3	24.0	26.1
44	10°58′ N	150°02′ W	do	1604–1634	1733.7	29.5	32.1
45	11°59′ N	150°03′ W	Oct. 2, 1951	0052–0123	1471.2	29.8	24.7
46	13°00′ N	149°56′ W	do	0918–0948	1596.4	10.8	12.6
47	14°01′ N	150°03′ W	do	1744–1815	1782.5	15.7	15.7
48	15°02′ N	150°01′ W	Oct. 3, 1951	0155–0226	1596.4	23.2	19.8
49	17°00′ N	150°42′ W	do	1701–1733	1942.7	13.7	14.2
50	19°00′ N	151°19′ W	Oct. 4, 1951	0756–0826	1965.3	12.3	13.7

[1] Apparent solar time. [2] Adjusted for day-night difference by the sine transformation method.

TABLE 8A.—*Zooplankton volumes obtained on cruise 14 of the* Hugh M. Smith, *and collection data*

Station No.	Position		Date	Time[1]	Water strained, m.³	Zooplankton, cc./1000 m.³	
	Latitude	Longitude				Sample volume	Adjusted volume[2]
A. Oblique hauls to 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	7°57′ N	154°57′ W	Jan. 27, 1952	1125–1151	1014.4	23.5	31.9
2	6°55′ N	154°57′ W	do	2059–2129	1334.6	43.2	34.1
3	5°53′ N	154°55′ W	Jan. 28, 1952	0740–0810	1128.6	10.1	11.8
4	4°55′ N	154°51′ W	do	1635–1711	1533.9	22.6	24.5
5	3°54′ N	154°51′ W	Jan. 29, 1952	0135–0205	1325.4	28.0	21.4
6	2°56′ N	154°59′ W	do	1024–1054	1033.8	24.5	32.7
7	1°54′ N	155°03′ W	do	1937–2008	1150.5	27.6	23.7
8	0°54′ N	155°11′ W	Jan. 30, 1952	0803–0836	1330.0	8.4	10.0
9	0°06′ S	155°14′ W	do	1831–1915	2054.2	35.1	32.4
10	1°10′ S	155°08′ W	Jan. 31, 1952	0418–0457	1647.3	42.7	38.4
11	2°00′ S	155°03′ W	do	1127–1159	1479.6	22.7	30.8
12	3°00′ S	154°58′ W	do	2051–2122	1511.2	26.3	21.1
13	4°00′ S	155°07′ W	Feb. 1, 1952	0633–0709	1394.6	16.5	17.9
14	4°58′ S	155°00′ W	do	1846–1918	1246.3	25.0	23.1
15	5°53′ S	155°03′ W	Feb. 2, 1952	0421–0458	1334.6	27.8	25.0
16	6°50′ S	155°05′ W	do	1333–1402	1316.0	13.3	17.6
17	7°56′ S	179°53′ W	Feb. 15, 1952	0102–0137	1878.2	9.6	7.2
18	7°01′ S	179°49′ W	do	1040–1110	1670.5	15.0	20.2
19	6°05′ S	179°58′ W	do	1946–2016	1546.1	17.3	14.8
20	5°04′ S	179°58′ W	Feb. 16, 1952	0515–0550	1755.6	19.9	19.4
21	4°03′ S	179°58′ W	do	1452–1522	1307.1	23.0	28.6
22	2°56′ S	180°00′ W	Feb. 17, 1952	0026–0057	1389.7	31.4	23.2
23	1°52′ S	180°06′ W	do	1053–1122	1342.1	15.0	20.2
24	0°59′ S	180°03′ W	do	1918–1951	1642.0	34.1	29.9
25	0°02′ N	180°01′ W	Feb. 18, 1952	0506–0539	1214.6	31.7	30.1
26	1°03′ N	179°58′ W	do	1601–1637	1505.8	23.6	26.9
27	2°07′ N	179°57′ W	Feb. 19, 1952	0156–0227	1067.7	35.4	27.5
28	3°06′ N	179°57′ W	do	1051–1124	1738.6	10.1	13.6
29	4°05′ N	179°55′ W	do	1954–2025	1472.9	35.4	30.3
30	5°06′ N	179°50′ W	Feb. 20, 1952	0452–0525	1699.5	23.8	22.0
31	6°06′ N	179°44′ W	do	1358–1428	1451.3	16.9	21.8
32	7°04′ N	180°01′ W	do	2254–2326	1605.2	20.9	15.4
33	8°03′ N	179°58′ W	Feb. 21, 1952	0745–0814	1296.3	20.1	23.4
34	8°58′ N	179°55′ W	do	1707–1737	1329.9	16.1	17.0
35	4°59′ S	168°59′ W	Mar. 1, 1952	1705–1737	1779.1	11.9	12.6
36	4°03′ S	168°58′ W	Mar. 2, 1952	0155–0224	1506.7	26.9	20.6
37	3°04′ S	168°59′ W	do	1131–1202	1158.3	10.7	14.5
38	2°04′ S	168°57′ W	do	2211–2241	1028.6	19.5	14.8
39	1°03′ S	168°54′ W	Mar. 3, 1952	0805–0833	994.1	24.6	29.4
40	0°02′ S	169°00′ W	do	1800–1831	1228.4	41.6	40.5
41	1°03′ N	169°00′ W	Mar. 4, 1952	0354–0426	1176.7	61.5	54.0
42	2°05′ N	168°57′ W	do	1544–1613	946.0	28.8	33.6
43	3°04′ N	169°00′ W	Mar. 5, 1952	0116–0147	1150.5	43.2	32.7
44	4°05′ N	168°57′ W	do	1025–1050	828.5	22.5	30.1
45	4°57′ N	168°56′ W	do	1910–1936	1091.4	12.3	11.1
46	5°56′ N	169°00′ W	Mar. 6, 1952	0416–0449	1583.8	31.5	28.3
47	6°57′ N	168°54′ W	do	1742–1811	1455.4	21.6	21.6

[1] Apparent solar time. [2] Adjusted for day-night difference by the sine transformation method.

TABLE 8B.—*Zooplankton volumes obtained on cruise 14 of the* Hugh M. Smith, *with collection data*

Special station	Sample	Position		Date	Time[1]	Estimated depth of haul, m.	Water strained, m.³	Sample volume cc./1000 m.³
		Latitude	Longitude					
Horizontal hauls at various depths:								
S1	1	2°41′ S	171°44′ W	Feb. 9, 1952	1315–1443	210	2694.6	15.4
	2	2°41′ S	171°44′ W	do	1322–1438	105	2594.1	23.9
	3	2°41′ S	171°44′ W	do	1329–1429	0	2591.9	32.2
S2	1	2°41′ S	171°44′ W	do	1557–1724	210	3378.0	22.6
	2	2°41′ S	171°44′ W	do	1603–1719	105	2508.1	30.1
	3	2°41′ S	171°44′ W	do	1610–1711	0	2504.2	47.8
S3	1	2°43′ S	171°43′ W	do	1848–2021	210	1433.7	29.2
	2	2°43′ S	171°43′ W	do	1856–2012	105	1309.3	33.7
	3	2°43′ S	171°43′ W	do	1903–2004	0	2317.2	45.5
S4	1	2°44′ S	171°45′ W	do	2034–2205	240	1835.5	22.4
	2	2°44′ S	171°45′ W	do	2042–2159	120	2472.1	23.2
	3	2°44′ S	171°45′ W	do	2050–2151	0	2302.8	49.2
S5	1	2°45′ S	171°43′ W	do	2221–2355	240	1378.6	25.4
	2	2°45′ S	171°43′ W	do	2232–2347	120	1843.1	23.6
	3	2°45′ S	171°43′ W	do	2242–2341	0	2332.7	[2] 157.8
S6	1	2°41′ S	171°43′ W	Feb. 10, 1952	0029–0157	220	1448.6	27.8
	2	2°41′ S	171°43′ W	do	0036–0149	110	2175.2	26.9
	3	2°41′ S	171°43′ W	do	0043–0142	0	2616.5	44.1
S7	1	2°41′ S	171°43′ W	do	0225–0354	240	1118.1	41.8
	2	2°41′ S	171°43′ W	do	0230–0345	120	1137.2	39.3
	3	2°41′ S	171°43′ W	do	0238–0338	0	2464.7	44.2

[1] Apparent solar time. [2] Estimated 50 percent amphipods.

TABLE 9.—*Zooplankton volumes obtained on cruise 15 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
1	8°59′ N	139°56′ W	May 28, 1952	0714–0745	1,421.8	40.1	44.1
2	7°51′ N	139°46′ W	do	1822–1855	1,617.5	43.7	41.6
3	7°00′ N	140°00′ W	May 29, 1952	0258–0328	1,731.8	70.7	59.3
4	6°36′ N	139°44′ W	do	1018–1049	1,868.8	51.4	66.4
5	6°00′ N	140°00′ W	do	1710–1743	2,059.1	37.4	39.3
6	5°02′ N	139°58′ W	May 30, 1952	0151–0223	1,896.4	42.4	33.4
7	4°05′ N	139°58′ W	do	0946–1016	2,167.6	27.4	34.8
8	3°09′ N	139°53′ W	do	1821–1853	1,510.8	29.4	28.0
9	1°57′ N	140°03′ W	May 31, 1952	0326–0401	2,465.2	22.5	19.2
10	0°53′ N	140°02′ W	do	1219–1249	1,702.0	29.5	38.6
11	0°11′ S	139°52′ W	do	2121–2151	2,060.9	[3] 88.0	70.3
12	1°02′ S	139°52′ W	June 1, 1952	0458–0530	1,947.7	53.8	51.3
13	2°00′ S	139°50′ W	do	1240–1311	1,572.7	17.1	22.3
14	3°00′ S	139°52′ W	do	2009–2040	1,523.7	30.0	25.6
15	4°00′ S	140°05′ W	June 2, 1952	0610–0640	1,323.8	20.2	20.7
16	5°30′ S	139°57′ W	do	1821–1851	1,361.6	16.0	15.2
17	7°00′ S	139°58′ W	June 3, 1952	0651–0722	1,716.5	16.5	17.7
18	5°26′ S	140°00′ W	do	1928–1958	1,350.5	14.1	12.6
19	3°52′ S	140°04′ W	June 4, 1952	0659–0730	1,793.9	23.1	25.4
20	2°50′ S	140°06′ W	do	1454–1529	1,840.9	25.3	30.2
21	1°46′ S	140°09′ W	do	2225–2250	1,326.1	38.0	29.4
22	0°43′ S	140°11′ W	June 5, 1952	0644–0713	1,321.5	33.0	35.4
23	0°00′	139°59′ W	do	1315–1345	1,250.6	23.3	29.8
24	1°02′ N	139°58′ W	do	2240–2308	1,377.5	44.7	34.3
25	2°04′ N	139°57′ W	June 6, 1952	0805–0832	1,251.3	23.2	27.2
26	3°06′ N	140°00′ W	do	1701–1733	1,391.4	39.0	40.9
27	4°09′ N	140°06′ W	June 7, 1952	0214–0254	1,948.1	48.8	39.5
28	5°10′ N	140°12′ W	do	1116–1147	1,438.7	44.8	58.7
29	6°07′ N	140°11′ W	do	1848–1920	1,569.8	58.7	54.7
30	7°04′ N	140°10′ W	June 8, 1952	0334–0407	1,758.9	[4] 88.6	77.3
31	8°00′ N	140°00′ W	do	1043–1112	1,396.0	57.5	75.0
32	7°04′ N	140°04′ W	do	1859–1929	1,441.8	70.4	64.1
33	6°05′ N	139°58′ W	June 9, 1952	0541–0614	1,978.1	46.8	46.8
34	5°00′ N	139°51′ W	do	1605–1641	1,856.1	22.2	24.9
35	4°01′ N	139°55′ W	June 10, 1952	0107–0137	1,493.2	27.1	21.0
36	3°00′ N	139°57′ W	do	0927–0954	1,874.0	48.3	60.4
37	2°00′ N	139°56′ W	do	1757–1828	1,773.8	22.4	21.9
38	0°58′ N	139°56′ W	June 11, 1952	0243–0314	1,279.3	25.1	20.7
39	0°04′ S	139°54′ W	do	1131–1210	2,463.1	21.5	28.2
40	1°06′ S	139°51′ W	do	2123–2151	1,811.1	[5] 106.7	85.3
41	2°08′ S	139°50′ W	June 12, 1952	0606–0637	1,727.0	43.8	44.9
42	3°13′ S	139°49′ W	do	1313–1344	1,706.5	21.6	27.9
43	4°05′ S	139°49′ W	do	2133–2203	1,879.2	45.9	36.7
44	5°32′ S	139°54′ W	June 13, 1952	0918–0946	1,379.6	29.6	37.0
45	7°00′ S	140°00′ W	do	2156–2226	1,399.6	32.2	25.2
46	5°29′ S	140°05′ W	June 14, 1952	1541–1611	1,142.1	20.6	23.6
47	3°43′ S	140°04′ W	June 15, 1952	0725–0756	1,729.4	23.0	25.8
48	3°00′ S	140°00′ W	do	1444–1514	1,723.2	18.7	22.7
49	2°00′ S	139°53′ W	June 16, 1952	0019–0049	1,856.6	68.0	51.9
50	0°57′ S	139°45′ W	do	0937–1007	1,577.7	57.4	72.8
51	0°01′ S	139°43′ W	do	1621–1653	1,703.4	28.2	31.0
52	1°00′ N	139°51′ W	June 17, 1952	0116–0148	1,383.2	69.8	54.6
53	2°06′ N	140°02′ W	do	1051–1120	1,240.3	36.5	47.5
54	3°11′ N	140°13′ W	do	1924–1954	1,447.7	32.0	28.5
55	4°00′ N	140°09′ W	June 18, 1952	0259–0329	1,296.8	28.7	24.1
56	5°00′ N	140°04′ W	do	1023–1054	1,699.0	23.7	30.6
57	5°54′ N	140°00′ W	do	1748–1823	1,903.3	42.0	42.0
58	6°47′ N	139°56′ W	June 19, 1952	0351–0421	1,514.0	59.1	51.6
59	8°00′ N	139°52′ W	do	1419–1449	1,532.0	41.8	51.5
60	9°00′ N	140°00′ W	do	2244–2315	1,515.5	[6] 80.4	61.7
Special hauls with 56XXX grit gauze nets:							
45	7°00′ S	140°00′ W	June 13, 1952	2231–2302	1,374.2	50.7	....
52	1°00′ N	139°51′ W	June 17, 1952	0156–0228	1,441.8	122.1	....
60	9°00′ N	140°00′ W	June 19, 1952	2323–2354	1,202.7	90.9	....

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method.
[3] Estimated 50 percent euphausiids.
[4] Estimated 30 percent euphausiids.
[5] Estimated 50 percent amphipods.
[6] Estimated 30 percent salps.

TABLE 10.—*Zooplankton volumes obtained on cruise 16 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
31	3°12′ S.	149°28′ W.	Aug. 5, 1952	1236–1309	1356.7	15.8	20.9
32	3°12′ S.	149°33′ W.	Aug. 6, 1952	0040–0119	1430.3	21.1	16.0
33	3°06′ S.	149°40′ W.	do.	1233–1305	1241.7	20.7	27.5
34	3°04′ S.	149°42′ W.	Aug. 7, 1952	0103–0134	1236.8	33.0	25.2
36	2°57′ S.	149°58′ W.	Aug. 8, 1952	0030–0100	1683.2	26.6	20.0
37	0°06′ N.	149°33′ W.	Aug. 10, 1952	0042–0117	1355.6	38.9	29.4
38	0°22′ N.	149°36′ W.	Aug. 11, 1952	0035–0108	1239.9	31.6	23.9
39	0°59′ N.	149°43′ W.	Aug. 13, 1952	0037–0109	1702.6	37.5	28.4
41	1°41′ N.	149°59′ W.	Aug. 15, 1952	0028–0101	1355.4	37.3	28.1
42	1°58′ N.	150°15′ W.	Aug. 16, 1952	0027–0059	1669.2	42.2	31.8
43	2°15′ N.	150°35′ W.	Aug. 17, 1952	0038–0110	1513.9	[3] 58.6	44.4
44	2°29′ N.	150°47′ W.	Aug. 18, 1952	0027–0057	1498.6	50.8	38.3
45	2°39′ N.	151°17′ W.	Aug. 19, 1952	0025–0058	1862.5	37.2	28.0
46	2°47′ N.	151°38′ W.	Aug. 20, 1952	0028–0101	2033.3	45.4	34.2

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Estimated 30–40 percent siphonophores.

TABLE 11.—*Zooplankton volumes obtained on cruise 18 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
2	9°00′ N.	120°50′ W.	Oct. 19, 1952	0024–0050	1529.2	[3] 9.7	7.3
4	7°06′ N.	120°00′ W.	Oct. 21, 1952	0215–0245	1237.5	48.3	38.7
5	5°50′ N.	120°16′ W.	Oct. 22, 1952	0231–0304	[4] 2489.5	54.1	43.3
6	4°53′ N.	119°59′ W.	do.	2341–0010	1454.8	54.0	40.5
7	4°01′ N.	120°06′ W.	Oct. 24, 1952	0016–0048	1532.4	39.3	29.6
8	3°03′ N.	120°05′ W.	Oct. 25, 1952	0020–0051	1543.8	36.3	27.3
9	1°55′ N.	120°14′ W.	Oct. 26, 1952	0120–0200	3048.7	32.9	25.4
10	1°02′ N.	120°17′ W.	Oct. 27, 1952	0126–0154	1458.5	61.8	47.6
11	0°39′ N.	120°14′ W.	Oct. 28, 1952	0130–0200	[4] 1465.7	69.3	53.5
13	1°04′ S.	120°07′ W.	do.	2326–2356	1617.5	55.9	42.0
15	3°06′ S.	120°10′ W.	Oct. 29, 1952	2325–2356	1363.8	42.7	32.1
17	4°50′ S.	120°21′ W.	Oct. 31, 1952	0021–0100	766.0	48.0	36.1
19	6°37′ S.	120°24′ W.	do.	2321–2352	1367.3	37.7	28.3
21	8°40′ S.	120°35′ W.	Nov. 1, 1952	2322–2355	884.5	38.3	28.8
24	4°12′ S.	130°14′ W.	Nov. 5, 1952	2246–2316	874.1	43.5	32.9
26	2°15′ S.	130°11′ W.	Nov. 6, 1952	2245–2319	1121.3	54.0	40.8
28	0°27′ S.	130°09′ W.	Nov. 7, 1952	2245–2319	1307.0	34.4	26.1
30	1°10′ N.	130°08′ W.	Nov. 9, 1952	0038–0125	[4] 1812.0	21.9	16.6
31	1°42′ N.	130°22′ W.	do.	2304–2338	1306.8	41.7	31.4
32	3°15′ N.	130°14′ W.	Nov. 10, 1952	2340–0009	1398.2	56.4	42.3
33	4°08′ N.	130°07′ W.	Nov. 11, 1952	2351–0020	714.3	64.5	48.4
34	5°42′ N.	130°50′ W.	Nov. 12, 1952	2241–2316	[4] 1622.5	55.8	42.3
36	7°35′ N.	131°14′ W.	Nov. 13, 1952	2333–0006	1180.4	30.2	22.9
37	9°00′ N.	131°46′ W.	Nov. 15, 1952	0032–0105	596.7	57.1	43.0

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Doubtful volume; most likely the net was not properly washed down.
[4] Based on estimated meter readings.

TABLE 12.—*Zooplankton volumes obtained on cruise 19 of the* Hugh M. Smith, *with collection data*

Station No.	Position		Direction from island	Hauling course	Distance (naut. miles)		Date	Time [1]	Water strained m.[3]	Zooplankton, cc./1000m.[3]	
	N. lat.	W. long.			From outer reef	From 10-fathom line				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth:											
1-meter nets, 30XXX grit gauze:											
2	5°52.6′	162°11.1′	W	120°	4.3	0.8	Jan. 14, 1953	0007–0040	1,592.5	17.6	13.2
3	5°52.6′	162°11.6′	W	120°	4.8	1.3	do	0111–0154	[3] 2,105.8	24.7	19.0
4	5°52.6′	162°12.3′	W	120°	5.5	2.0	do	0240–0319	2,053.0	36.5	29.8
5	5°52.6′	162°14.7′	W	120°	7.9	4.4	do	0400–0438	1,514.0	23.3	20.6
6	5°51.7′	162°05.0′	S	105°	0.4	0.3	do	2043–2115	1,054.0	31.9	26.1
7	5°51.0′	162°05.5′	S	105°	1.1	1.0	do	2143–2219	1,384.5	26.1	20.4
8	5°47.6′	162°06.2′	S	105°	4.5	4.2	do	2300–2327	1,073.5	34.8	26.2
9	5°44.7′	162°06.2′	S	105°	7.4	7.1	Jan. 15, 1953	0000–0035	1,423.5	26.6	20.1
10	5°38.0′	162°05.5′	S	105°	14.1	13.8	do	0119–0157	1,551.5	20.2	15.5
13	5°51.4′	162°00.3′	E	80°	1.8	0.6	Jan. 16, 1953	2040–2117	1,136.2	36.1	29.5
14	5°52.0′	161°57.8′	E	80°	4.2	2.4	do	2150–2229	1,299.0	29.4	22.9
15	5°52.8′	161°55.1′	E	80°	6.9	5.1	do	2246–2322	1,178.0	28.2	21.3
16	5°53.0′	161°51.6′	E	80°	10.4	8.6	Jan. 16–17, 1953	2350–0023	1,163.8	34.1	25.6
17	5°55.0′	161°46.0′	E	80°	16.0	14.2	Jan. 17, 1953	0112–0149	1,587.2	21.8	16.7
18 [4]	5°53.2′	162°09.2′	W	140°	2.4	------	do	1956–2026	1,671.2	54.9	------
19	5°55.5′	162°05.5′	N	90°	2.0	1.8	do	2121–2155	1,215.0	45.0	36.0
20	5°54.3′	162°05.5′	N	85°	0.8	0.6	do	2228–2256	1,220.5	30.4	23.2
21	5°56.5′	162°05.5′	N	90°	3.0	2.8	Jan. 17–18, 1953	2335–0004	1,180.8	38.1	28.6
22	5°59.0′	162°05.0′	N	85°	5.5	5.3	Jan. 18, 1953	0036–0104	1,145.0	26.0	19.6
23	6°04.0′	162°05.0′	N	85°	10.5	10.3	do	0153–0221	971.0	33.4	26.1

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Based on an estimated flow-meter reading.
[4] This station was located on a shoal with depth of water about 10 fathoms; the haul was made between the surface and about 5 fathoms.

TABLE 13.—*Zooplankton volumes obtained on cruise 15 of the* Charles H. Gilbert, *with collection data*

Station No.	Position		Date	Time [1]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	Latitude	Longitude				Sample volume	Adjusted volume [2]
Oblique tows, 200 m. depth; 1-meter nets, 30XXX grit gauze:							
2	31°56′ N	119°48′ W	Feb. 19, 1954	1908–1949	2586.6	58.3	52.8
4	29°38′ N	119°50′ W	Feb. 20, 1954	1900–1928	1132.8	54.9	49.8
6	27°40′ N	120°10′ W	Feb. 21, 1954	1852–1918	863.5	[3] 17.8	16.5
8	25°49′ N	120°02′ W	Feb. 22, 1954	1856–1921	1053.5	33.0	30.6
10	23°48′ N	119°30′ W	Feb. 23, 1954	1857–1929	1086.5	16.9	15.3
12	21°36′ N	120°08′ W	Feb. 24, 1954	[1]	------	------	------
14	19°53′ N	119°10′ W	Feb. 25, 1954	1900–1925	1166.5	13.2	12.0
16	8°54′ N	110°10′ W	Mar. 3, 1954	1847–1921	2112.2	[5] 125.1	116.2
19	5°05′ N	110°16′ W	Mar. 5, 1954	1935–2006	853.8	53.6	46.5
21	3°43′ N	110°34′ W	Mar. 6, 1954	1902–1924	564.0	82.4	74.7
23	2°08′ N	110°03′ W	Mar. 7, 1954	1916–1946	1261.2	64.7	57.3
25	0°32′ N	110°55′ W	Mar. 8, 1954	1904–1940	2619.1	[6] 172.5	156.3
27	1°37′ S	111°28′ W	Mar. 9, 1954	[7]	------	------	------
29	3°55′ S	112°17′ W	Mar. 10, 1954	1901–1938	1096.5	47.4	42.9
31	5°35′ S	113°52′ W	Mar. 11, 1954	1854–1923	546.1	57.7	53.6
33	7°29′ S	114°49′ W	Mar. 12, 1954	1856–1927	1725.5	21.6	19.5
35	8°42′ S	115°39′ W	Mar. 13, 1954	1902–1932	1448.8	23.7	21.5
37	8°58′ S	121°28′ W	Mar. 15, 1954	1903–1937	1537.6	23.6	21.4
39	8°53′ S	132°07′ W	Mar. 18, 1954	1857–1924	1203.2	14.8	13.4
55	6°25′ S	155°04′ W	Apr. 9, 1954	1926–1957	1250.5	17.7	15.7
57	5°04′ S	155°08′ W	Apr. 10, 1954	1910–1942	1398.4	19.6	17.5
59	3°25′ S	155°20′ W	Apr. 11, 1954	1916–1949	1428.5	16.5	14.6
61	2°17′ S	155°10′ W	Apr. 12, 1954	1917–1946	1255.7	20.9	18.5
63	0°42′ S	154°50′ W	Apr. 13, 1954	1917–1948	1292.2	54.6	48.3
65	1°14′ N	154°58′ W	Apr. 14, 1954	1916–1949	2075.8	33.6	29.7
67	2°23′ N	155°26′ W	Apr. 15, 1954	1909–1948	2257.4	33.4	30.3
69	2°09′ N	157°05′ W	Apr. 16, 1954	1904–1933	1999.3	34.5	31.3
72	3°16′ N	155°13′ W	Apr. 20, 1954	1917–1947	1348.5	[8] 83.4	73.8
74	5°00′ N	154°41′ W	Apr. 21, 1954	1916–1948	1375.2	52.1	46.1
76	6°42′ N	154°47′ W	Apr. 22, 1954	1913–1944	1682.0	31.2	28.3

[1] Apparent solar time.
[2] Adjusted for day-night difference by the sine transformation method using a pooled regression coefficient (b=0.1248).
[3] Small hole (¼″) in bag of net at end of haul.
[4] Sample not quantitative.
[5] Principally euphausiids.
[6] Plus about 12 qts. of salps discarded.
[7] No sample.
[8] Estimated 60 percent salps.

TABLE 14.—*Zooplankton volumes, cc./1000m.³, adjusted for hour of hauling, for* Hugh M. Smith *cruises 2, 5, 7 and 8*

[For unadjusted volumes together with station position, date, time of hauling and description of method, refer to King and Demond (1953)]

Station No.	Cruise 2	Cruise 5	Cruise 7	Cruise 8	Station	Cruise 8
1	10.4	13.9	32.0	12.9	53	24.9
2		23.0	97.5	14.0	54	25.2
3	17.8	14.2	37.7		55	16.7
4		22.8	16.2	30.3	56	26.9
5		19.1	25.0		57	27.6
6		48.2	39.9	22.5	62	19.1
7	9.4	23.7	24.8	10.9	63	25.9
8		19.0	47.2	11.1	64	21.0
9	9.9	14.9	36.3	18.5	65	13.7
10		8.4	35.6	23.5	66	25.5
11	8.3	32.1	32.7	15.9	67	31.1
12		31.3	18.7	46.2	68	40.8
13	18.6	27.0	13.5	24.4	69	36.1
14		17.9	20.6	12.4	70	24.4
15	37.8	25.4	77.1	16.3	71	29.2
16		28.6	64.0	19.9	72	23.5
17	41.2	25.6	43.5	16.9	73	24.1
18		41.5	75.3	24.1	74	17.5
19	56.5	33.0	87.5	28.8	75	24.4
20		37.3	25.8	67.9	76	12.8
21	65.3	57.7	54.6	40.1	77	14.1
22		49.3	17.9	29.0	78	16.2
23	42.9	86.5	17.7	22.3	79	16.9
24		46.9	20.0	47.4	80	15.3
25	26.7	54.2		29.2	81	21.4
26		28.2		11.6	82	14.1
27		27.0			83	18.4
28		8.4			84	11.1
29		29.4			85	18.3
30	42.9	41.5			86	13.3
31		24.4			87	27.7
32	28.5	29.0		18.5	88	44.3
33		73.0		44.8	89	44.9
34	73.1	35.3		27.5	90	38.5
35		76.7		25.1	91	51.9
36	92.5	57.3		48.0	92	37.8
37		79.8		31.5	93	27.6
38	75.9	71.8			94	33.7
39		36.6			95	21.6
40	11.6	29.2			96	11.4
41		25.6			97	13.3
42	8.8	42.8		14.1	98	9.7
43		24.2		17.7	99	11.2
44	46.6	27.9		15.0	100	13.2
45		26.4		18.2	101	13.9
46	10.8	17.3		21.3	102	9.9
47		22.0		14.9	103	12.2
48	3.7	20.6			104	23.2
49		22.2			105	10.7
50	2.9	42.7			106	13.2
51		23.6				
52	13.6			31.2		

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