VARIATIONS IN ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1950-52

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United States Department of the Interior, Douglas McKay, Secretary
Fish and Wildlife Service, John L. Farley, Director

VARIATIONS IN ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1950-52

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VARIATIONS IN ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1950-52

One of the major projects in the research program of the Pacific Oceanic Fishery Investigations of the Fish and Wildlife Service is to obtain information on the relative or potential productivity of different areas of the tropical and subtropical Pacific. As indexes to productivity we have considered the oceanic circulation, the concentration of a chemical nutrient (inorganic phosphate), the amount of dissolved oxygen, and the abundance of zooplankton.

The purpose of this report is to present the results of our zooplankton sampling in waters adjacent to the main or windward islands of the Hawaiian archipelago. We shall consider how the abundance of zooplankton varied geographically and in time during the period of study and to what extent these variations were related to hydrographic conditions. The data contribute information on vertical distribution and diurnal variation in zooplankton abundance and indicate differences in relative productivity between the Hawaiian area and other regions of the central Pacific.

Zooplankton is essential fish food. It is important in the food of juvenile tunas and also occurs in wide variety in the food of adult tunas (Reintjes and King 1953). The bulk of the zooplankton, however, reaches the tunas -- the group of fish presently under study by these investigations -- through the intermediary forage organisms, such as squid, shrimp, and small fish. The standing crop of zooplankton is rather easily measured in quantitative fashion and, we believe, is a reliable index to available food.

Although the primary aim of our plankton sampling was to obtain information on the zooplankton population, a secondary objective was to collect tuna eggs and larvae for use in the study of the spawning habits of tuna[1/]. Sampling gear and procedures, therefore, were utilized which would contribute toward both objectives.

These collections constitute the first comprehensive survey of zooplankton abundance in the offshore waters of the Hawaiian Islands. Sampling of the offshore waters heretofore was limited to occasional hauls made by the various oceanographic expeditions crossing the Pacific. In 1875 the *Challenger* made surface hauls at a few stations close to the islands (Murray 1895). In 1902 the U. S. Fisheries Steamer *Albatross* occupied a number of stations in the Hawaiian area, at which surface plankton hauls were made (Wilson 1950). When the *Carnegie* visited the Islands in 1929,

1/ This will be the subject of a separate report by other staff members of POFI.

quantitative hauls, both vertical and horizontal, were carried out and while the resulting data are difficult to compare with our own, they do provide comparisons of plankton volumes and dry weights between Hawaii and other regions visited on the cruise (Graham 1941, Wilson 1942).

The inshore environment has received more recent attention. Edmondson (1937) did quantitative sampling in the shore waters of Oahu at a number of stations visited repeatedly during the year September 1931 to September 1932. He concluded that the copepods were an important food item in the reef and bay habitats, since he found the most luxuriant growth of coral and other sessile organisms as well as the largest numbers of plankton-feeding fishes in areas of greatest abundance of free-swimming copepods. The University of Hawaii and the Division of Fish and Game of the Territory of Hawaii have in recent years made an intensive study of the early life history of the nehu, one of the important tuna bait fishes occurring in the Islands. A large number of quantitative plankton samples, obtained from the inshore waters of Oahu, have been examined for the eggs and larvae of the fish under investigation (Tester 1951). These collections have not as yet been analyzed for other plankton constituents, but they should provide suitable material for a study of variations in plankton composition and abundance in the inshore waters and for comparison with the available data from the offshore environment.

We wish to express our appreciation to fellow staff members of POFI and the officers and crews of the Hugh M. Smith and the John R. Manning for their assistance in obtaining the plankton collections on which this report is based. We are indebted to O. E. Sette, Director of the Pacific Oceanic Fishery Investigations, for his many helpful suggestions during the examination of the data and the preparation of the report. The hydrographic data employed in this study were collected and processed under the supervision of Thomas S. Austin and Townsend Cromwell. Mr. Tamotsu Nakata prepared the illustrations.

SOURCE OF MATERIAL

During the years 1950, 1951, and 1952, POFI vessels collected zooplankton on seven cruises in Hawaiian waters; 365 meter-net hauls were obtained at 204 stations by the U. S. Fish and Wildlife Service vessels Hugh M. Smith, on cruises 4, 6, 10, 12, and 17, and John R. Manning, on cruises 8 and 9. The approximate locations of the stations are shown in figures 1 and 2. More exact positions, together with dates, depths of hauling, and other pertinent data are given in tables 16 through 22 in the appendix. The time of hauling, as given in these seven tables, is local civil time for the Hawaiian area (Greenwich time + 10 hours).

The five cruises of the Hugh M. Smith provide synoptic observations over the area from the island of Kauai on the west to the island of Hawaii on the east and adjacent waters to about 100 miles offshore in a north-south direction. On Cruise 8 of the John R. Manning, a line of stations west of Oahu was visited weekly for four successive weeks. Cruise 9 of the Manning was conducted in waters adjacent to Oahu for the purpose of measuring the variance among repeated hauls at the same station and other short-term variations in zooplankton abundance.

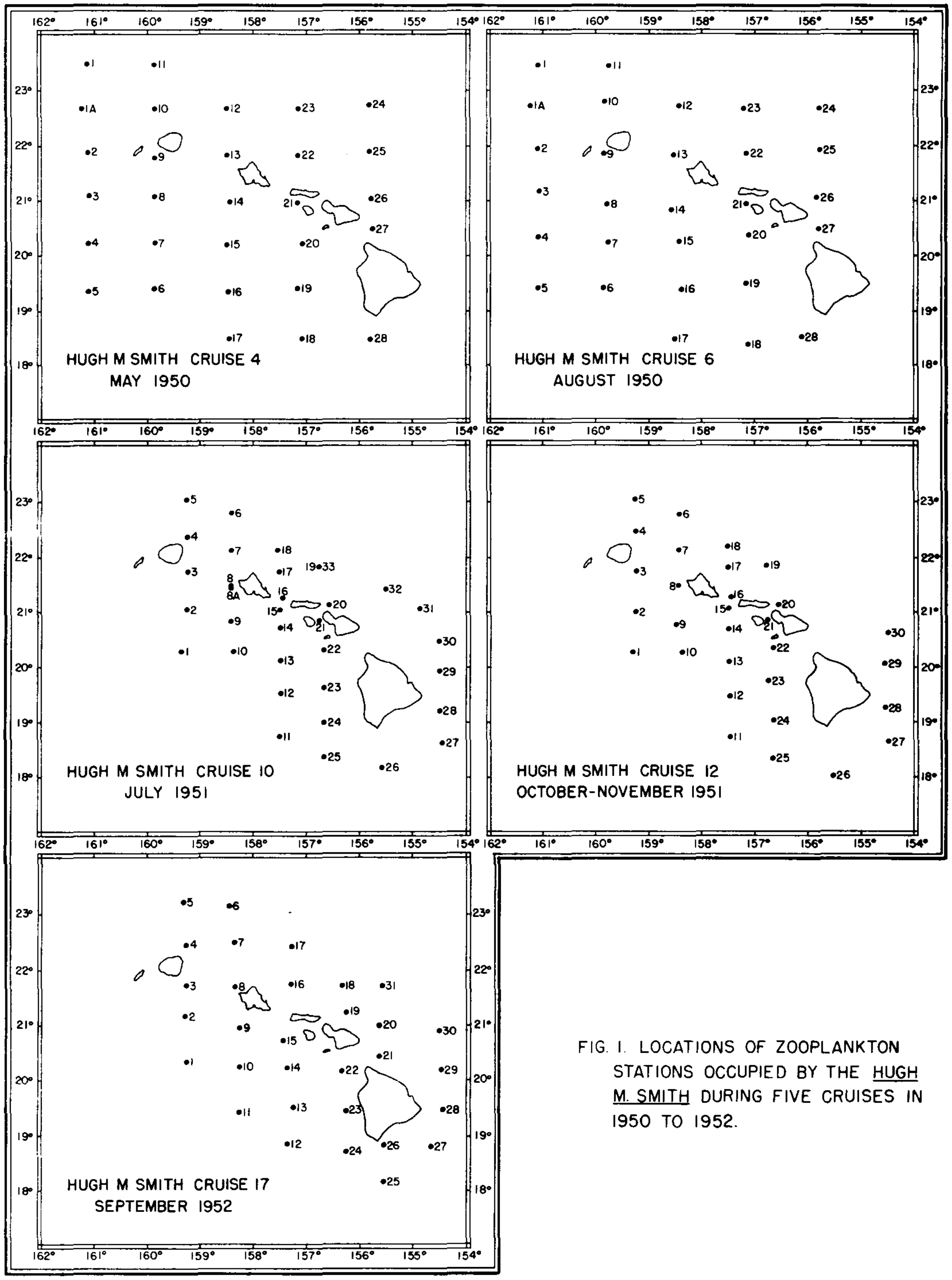


FIG. I. LOCATIONS OF ZOOPLANKTON STATIONS OCCUPIED BY THE HUGH M. SMITH DURING FIVE CRUISES IN 1950 TO 1952.

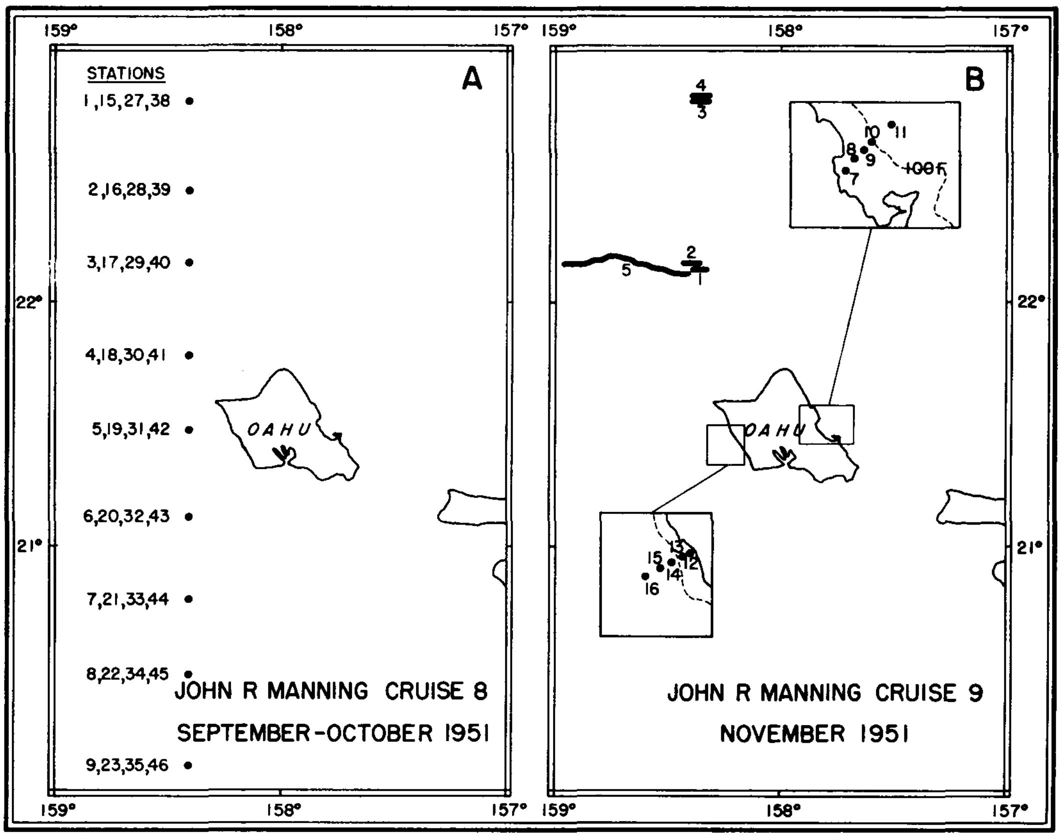


FIG. 2. LOCATIONS OF ZOOPLANKTON STATIONS OCCUPIED BY THE JOHN R. MANNING ON TWO CRUISES IN 1951.

METHODS

In the Field

All collections reported on here were taken with nets of one type, i.e., 1-meter (mouth diameter) nets with body (front and middle sections) of 30XXX silk grit gauze (apertures 0.65 x 0.65 mm.), rear section and bag of 56XXX silk grit gauze (apertures 0.31 x 0.31 mm.). The 30XXX mesh makes up about 97 percent of the straining surface of the net, and the 56XXX mesh about 3 percent. Details of the construction of the net and the method of hauling have been described in a previous report (King and Demond 1953).

In this study two general types of hauls were employed: horizontal, with three nets towed simultaneously; and oblique, using a single net. Horizontal hauls of about 1 hour's duration, with sampling at three levels, were carried out on *Smith* cruises 4 and 6. Oblique hauls of about 30 minutes' duration to a depth of 200 meters were used on *Smith* cruises 10, 12, and 17 and *Manning* cruise 8; oblique hauls to 200, 300, and 500 meters were used on *Manning* cruise 9.

The amount of water strained during each haul was estimated by measuring the flow past a current meter suspended in the mouth of the net and computing the total volume, assuming that the flow rate was uniform throughout the mouth of the net. The depth of the net during hauling was estimated by measuring at 2-minute intervals the angle of the towing wire and the length of wire out and making the appropriate calculation, assuming the towing wire to represent a straight line in the water. A 75 or 100-pound streamlined weight was attached to the end of the towing wire.

At the end of each haul the net was washed down thoroughly, concentrating the catch in the plankton sock or bag. The collection was then transferred to a 1-quart jar and sufficient formalin added to approximate a 10-percent solution. The formalin was neutralized with borax and a completed label was placed in the jar.

That this method of hauling is capable of producing repeatable results is demonstrated by a test of the experimental or sampling error among pairs of consecutive 200-meter oblique hauls made on cruise 9 of the *Manning*. A comparison of 16 pairs of replicate samples (following Snedecor 1946, p. 44) having a mean of 27.0 cc./1000 m.^{3}, gave a mean sample difference of 0.67 cc./1000 m.^{3}, which by the "t" test was shown to be not significantly different ($P > 0.4$) from zero. The standard deviation of the differences was 2.07, indicating that the two members of a pair of replicate hauls would be within 8.28 cc./1000 m.^{3} in 95 percent of the instances.

In the Laboratory

The collections received the following treatment in the laboratory:

(1) All fish eggs and larvae were removed from samples taken on Smith cruises 4 and 6. These amounted to a negligible fraction of the sample and were omitted from the volume measurements. For the other cruises the fish eggs and larvae were not removed from the collections.

(2) All organisms whose longest dimension was greater than 5 cm. were removed from the sample. The kind of organism removed and its displacement volume were recorded. As such organisms occurred infrequently, they are omitted from this analysis.

(3) All organisms whose longest dimension was between 2 and 5 cm. were next removed from the sample, identified as nearly as possible, and their displacement volume was measured.

(4) The remainder of the sample, those organisms measuring less than 2 cm. in their longest dimension and constituting the bulk of the sample, was examined under a binocular dissecting microscope and its general composition was noted. The displacement volume of this fraction was then determined after any artifacts, such as refuse from the ship, had been removed. This portion of the sample was not further subdivided.

In measuring the displacement volume, the plankton was poured into a draining sock of 56XXX grit gauze to filter off the preserving liquid. The drained plankton was then placed in a graduated cylinder of approximate size (usually of 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 net wet volume of that portion of the plankton sample.

For an estimate of the amount of zooplankton in each sample that was potentially fish food of significant nutritional value, the displacement volumes of the following were used:

(1) The entire remaining fraction of the sample after the larger organisms, 2 cm. or greater in their longest dimension, had been removed.

Ordinarily this portion of the sample was composed primarily of crustaceans and chaetognaths with a small percentage by number and volume of "watery" organisms of low food value, such as jellyfish and salps. As stated earlier, this portion of the sample was examined under the microscope and classified as to its make-up, whether of average (mixed) composition, composed primarily of a swarm of one organism, or containing an unusual amount of nonnutritious forms.

(2) All annelids, crustaceans, cephalopods, and fish in the 2 to 5 cm. size category.

The following organisms in the 2 to 5 cm. category were not included as food: siphonophores, medusae, ctenophores, heteropods[2], and tunicates.

The sum of items (1) and (2) provided a single volume measurement for each sample which we accepted as the best available estimate of the amount of zooplankton -- as food -- present at that time and place and subject to capture by the gear employed.

VERTICAL AND DIURNAL VARIATIONS

The collections resulting from cruises 4 and 6 of the Hugh M. Smith provide information of interest on the vertical distribution of zooplankton. The chief purpose of these two cruises was to investigate the time and extent of tuna spawning in Hawaiian waters. A sampling plan to examine horizontal and vertical variations in the abundance of tuna eggs and larvae was carried out at each station, with meter-net hauls being made simultaneously at three levels: 0, 50, and 150 meters; 0, 100, and 200 meters; or 0, 150, and 500 meters. There was no means of closing the nets while they were being lowered and raised, but the percentage of towing time during this phase of the haul was small and is not likely to have affected greatly the results. It was not possible to hold the ship's speed constant throughout the haul nor to change the spacing of the nets on the towing wire once the haul had started. Therefore the nets were not always at the intended depth. We believe, however, from calculations based on wire angle and meters of wire out that the actual towing depth ordinarily did not vary by more than ± 20 percent of the desired depth.

The data were classified into day, night, and twilight hauls on the criteria of times of sunrise, sunset, and the beginning and end of twilight periods as defined by the American Nautical Almanac. Averages were calculated for zooplankton volumes obtained at each haul level and the day collections were compared with the night collections. The

2/ Bigelow and Sears (1939) and also Clarke (1940) considered the crustaceans, chaetognaths, and molluscs as being of high nutritive value. It was our judgment, however, that the heteropod molluscs of the family Pterotracheidae, which are of common occurrence in the plankton of the tropics and subtropics of the Pacific, do not belong with this group because of their watery structure and should be classed with the nonnutritious forms.

twilight hauls were few in number and were omitted from the comparison. The results show (fig. 3) that for both cruises the greatest average volume of zooplankton occurred at the 50-meter level in both the day and the night hauls. It is obvious that the increase in the night over the day hauls, which is shown at all sample levels, could not have occurred by a shifting upward of the zooplankton population from the 100-to the 50-meter level, the 150-to the 100-meter level, etc. It would appear that the greater volumes of the night hauls at all levels above 300 meters may be explained by the migration of zooplankton from below this depth, by the plankton's escaping the net to a much greater extent during daylight hours, or by a combination of both factors. The possibility that this difference in catch rate is not the result of an elaborate diurnal migration[3] but rather of a simple dodging of the net during daylight hours, as suggested by Franz (1913), has been the subject of considerable speculation on the part of plankton biologists but has actually received little experimental effort.

On cruise 9 of the John R. Manning a sampling experiment was conducted to determine (1) the variation between a series of day hauls and night hauls at the same locality, and (2) variations between two localities not widely separated in distance and time. The results, graphically portrayed in figure 4, when examined by an analysis of variance, indicate no significant difference ($P > 0.05$) between stations, no significant difference ($P > 0.05$) between times (day or night), but show a highly significant ($P < 0.01$) interaction (table 1). This latter feature results from the fact that the day-night variation was markedly different for the two localities: the night/day ratio was 1.04 for stations 1 and 2, and 1.50 for stations 3 and 4. We cannot account for this difference; weather and sea conditions varied very little during the $1\frac{1}{2}$-day period in which the hauls were made and without a detailed count of organisms in the samples, there were no apparent differences in composition. The close correspondence within each series of four hauls is further assurance, however, that the method of hauling is capable of producing repeatable results.

Another experiment conducted on cruise 9 of the John R. Manning was designed to measure differences among oblique hauls to three depths, 200, 300, and 500 meters, with samples taken at approximately hourly intervals over a 24-hour period. The hauls were made by running the vessel between drifting buoys which were lighted at night; therefore, discounting wind, we were sampling the same surface water mass throughout the 24-hour period, although there was a westerly drift of about 30 miles during this time. The results shown in figure 5, when tested with an analysis of variance (table 2), yielded the following conclusions: (1) differences among times of hauling, with the 24-hour series divided into four 6-hour periods, were highly significant ($P < 0.01$); (2) differences among depths were also highly significant ($P < 0.01$); while the interaction or sampling error was non-significant ($P > 0.05$). The latter indicates that the variation with time followed the same pattern for all

3/ The phenomenon of vertical migration has been comprehensively reviewed by Kikuchi (1930) and more recently by Cushing (1951).

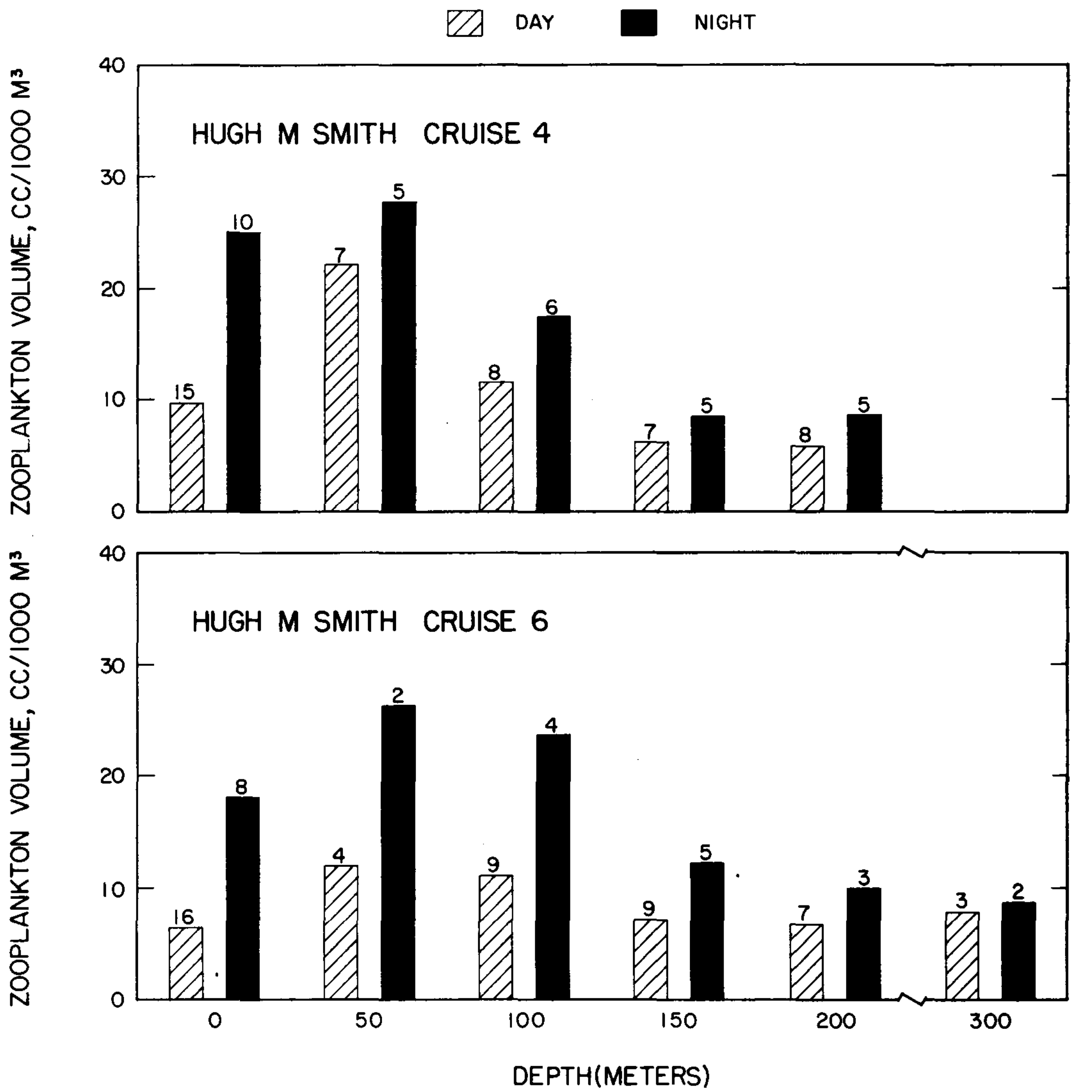


FIG. 3. COMPARISON OF AVERAGE ZOOPLANKTON VOLUMES RESULTING FROM DAY AND NIGHT HORIZONTAL HAULS AT DIFFERENT DEPTHS; CRUISES 4 AND 6, HUGH M. SMITH. (NUMBER OF SAMPLES IS INDICATED ABOVE EACH BLOCK).

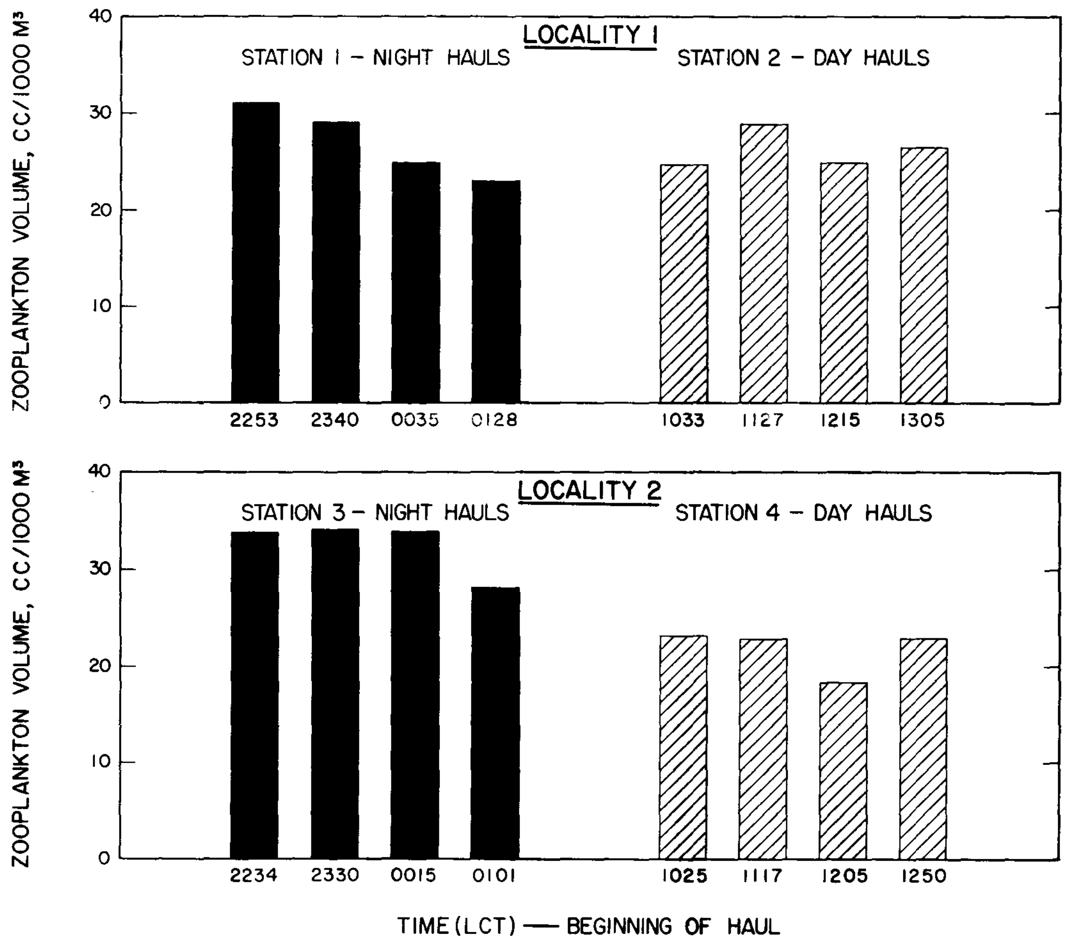


FIG 4. ZOOPLANKTON VOLUMES COLLECTED AT FOUR STATIONS (TWO LOCALITIES) ON *JOHN R. MANNING* CRUISE 9 COMPARING LOCALITIES, STATIONS AND TIME OF SAMPLING.

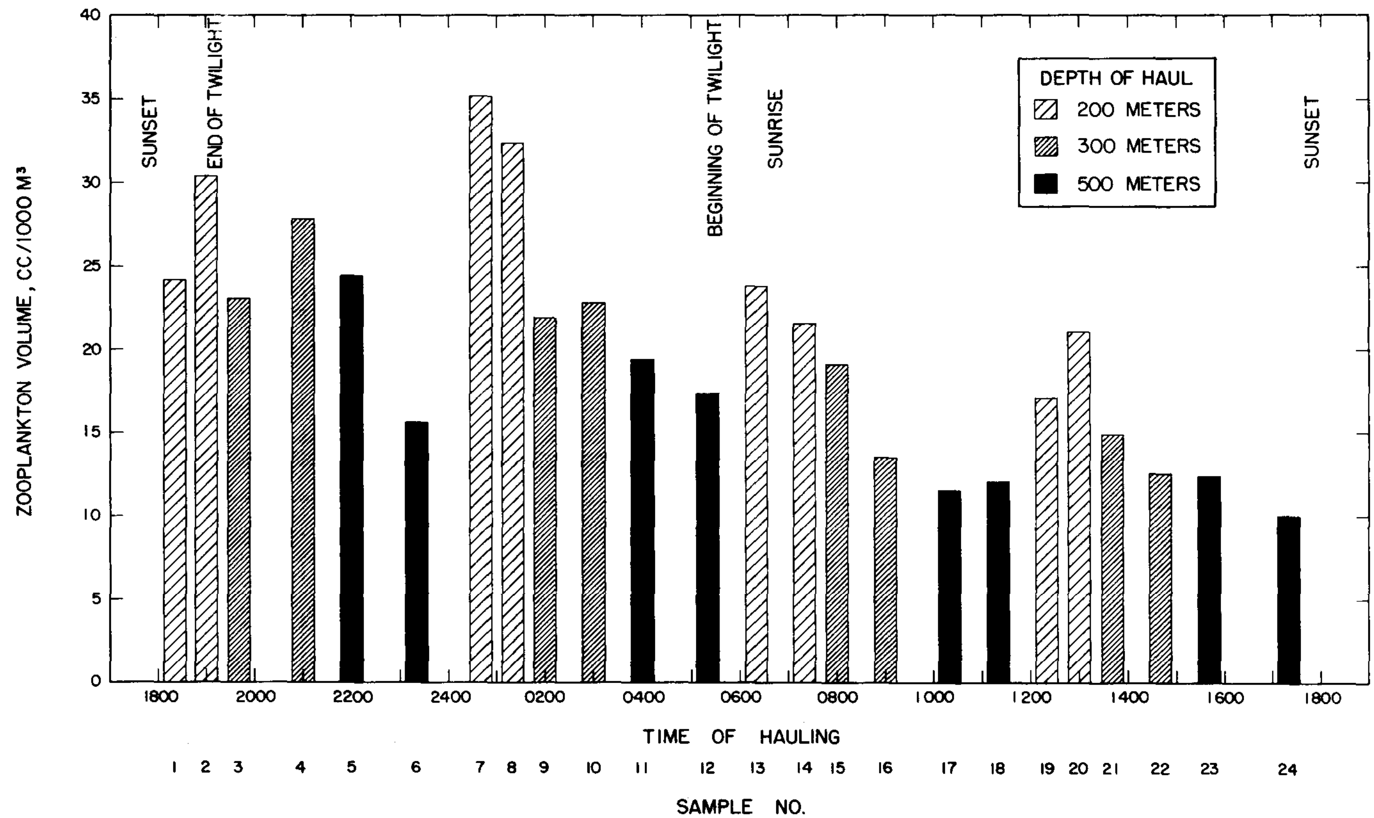


FIG. 5. ZOOPLANKTON VOLUMES FOR A 24-HOUR SERIES OF SUCCESSIVE OBLIQUE HAULS TO 200, 300, AND 500 METERS DEPTH, FROM JOHN R. MANNING CRUISE 9, STATION 5.

three depths. The correspondence within the paired hauls was satisfactory. Table 3 indicates that the coefficient of variation increased with depth -- signifying that, in relation to the means, the variation among samples increased with greater depth.

Table 1. Analysis of variance of zooplankton volumes collected on cruise 9, John R. Manning, showing differences between day and night samples at two localities northwest of Oahu.

Time	Sample	Locality: A (Stations 1 and 2)	Locality: B (Stations 3 and 4)	Mean
Night	1	31.2	33.7	
	2	29.3	34.2	29.9
	3	25.0	34.0	
	4	23.2	28.3	
Day	1	24.7	23.2	
	2	29.1	22.9	24.1
	3	24.9	18.4	
	4	26.6	22.9	
Mean		27.2	26.8	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Localities	1	0.81	0.81	0.01	> 0.05
Times	1	133.40	133.40	1.37	> 0.05
Locality x time interaction	1	97.02	97.02**	13.01	< 0.01
Within subclasses	12	93.84	7.82		
Total	15	325.07			

** Indicates a highly significant mean square value.

Table 2. Analysis of variance of zooplankton volumes collected on a 24-hour series of successive oblique hauls to 200, 300, and 500 meters, obtained on cruise 9, _John R. Manning_.

Haul depth	Time (6-hour periods)				Mean
	A (1800 - 0000)	B (0000 - 0600)	C (0600 - 1200)	D (1200 - 1800)	
200 m.	24.2 30.4	35.2 32.4	23.8 21.6	17.2 20.1	25.6
300 m.	23.1 27.8	21.9 22.8	19.2 13.6	14.9 12.6	19.5
500 m.	24.5 15.7	19.4 17.4	11.6 12.1	12.4 10.0	15.4
Mean	24.3	24.8	17.0	14.5	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Times	3	484.49	161.50**	15.08	< 0.01
Depths	2	423.67	211.84**	19.78	< 0.01
Time X depth interaction	6	64.25	10.71	1.24	> 0.05
Within subclasses	12	103.27	8.61		
Total	23	1075.68			

** Indicates a highly significant mean square value.

Table 3. Summary of certain statistics calculated for the 24-hour series of oblique hauls to three depths made on cruise 9, *John R. Manning*.

	Depth of haul (meters)		
	200	300	500
Number of samples	8	8	8
Mean sample volume (cc./1000 m.^{3})	25.6	19.5	15.4
Standard deviation (s) of mean volume	6.4	5.4	4.9
Coefficient of variation (C) of mean volume	24.8%	27.5%	31.7%
Night/day ratio	1.72	1.58	1.67
Coefficient of regression (b) of zooplankton volume on sine function	0.1379	0.1456	0.1306
"t" value for significance of the regression	8.673	4.853	2.902
P " " " " " "	< 0.001	< 0.01	> 0.05
Correlation coefficient (r), for zooplankton volumes and sine function	0.961	0.891	0.764
Coefficient of determination (r^2)	0.924	0.794	0.584

The experiment showed that the 200-meter oblique haul produced larger zooplankton volumes per unit of water strained than did the 300-meter or 500-meter hauls, thus indicating that within the range of depths sampled the largest amounts of zooplankton were found between 200 meters and the surface during both day and night periods. Judging from the night/day ratios (table 3), the volumes of the deeper hauls were as much affected by the diurnal variation as were the 200-meter hauls. In view of these circumstances, together with the saving in vessel time for the shallower hauls, we believe that of the three depths tested, the 200-meter oblique haul provides the most satisfactory method for estimating the abundance of zooplankton in the upper level of the ocean - the environment of the tunas.

An important source of variation in quantitative measurements of zooplankton abundance is related, therefore, to the time of day of hauling. In Hawaiian waters the volumes of night hauls, using a 200-meter oblique tow, have averaged about $1\frac{1}{2}$ times the volumes of day hauls. This is sufficient variation to obscure the geographical and seasonal features of distribution which are of primary interest in this study. An adjustment to remove the effect of diurnal change in volume is the obvious solution to this difficulty. A suitable adjustment must not only take into account the contrast between full daylight and night-time conditions but also the intermediate dawn and twilight effects on plankton volume.

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 greater ability of the plankton to dodge the net when there is light, or to a combination of these two. In any case, one would expect the amount caught to depend basically on the amount of plankton generally present at the time and place of hauling and the diurnal change to be a percentage of that amount. This being true, the plankton volumes should either be expressed as ratios to the basic population level or as logarithms. The logarithmic transformation is by far the most convenient and has the additional advantage of correcting for the natural skewness in the zooplankton volumes when arranged according to frequency of occurrence; after transformation the frequency distribution more closely approximates a normal distribution.

The authors are indebted to O. E. Sette for suggesting the method, which we present here, for adjusting the zooplankton data for this diurnal variation. As we are not aware of any previous references to this method in plankton literature, we will describe it in some detail.

Method of Adjusting for Diurnal Variation

To study the nature of the diurnal cycle it would be desirable to have zooplankton hauls made throughout the day and night in the same place or in the same water mass, so that geographical, ecological, or faunal differences would not obscure the diurnal cycle. Among the hauls available to us the group resulting from Manning cruise 8 most nearly approaches this condition. On this cruise a set of 9 stations on a 160-mile section on 158° 25' W. longitude, lying just west of the island of Oahu, was visited weekly for 4 weeks, with hauls made around the clock as the stations were reached in consecutive order.

If the logarithms of the plankton volumes are plotted as ordinates against time of day as the abscissa, without regard to date or locality and with midnight at the center of the abscissa, as in figure 6, it is seen that there is a period from about 1900 to 0600 hours when catches are high and a period from about 0800 to 1800 hours when they are low. The hours from 0400 to 0800 and from 1600 to 2000 appear to include the periods of maximum change. A mathematical curve approximately describing this type of change is the sine function, when midnight is equated to the angle whose sine is $+1.0$ (fig. 7). To fit this curve to

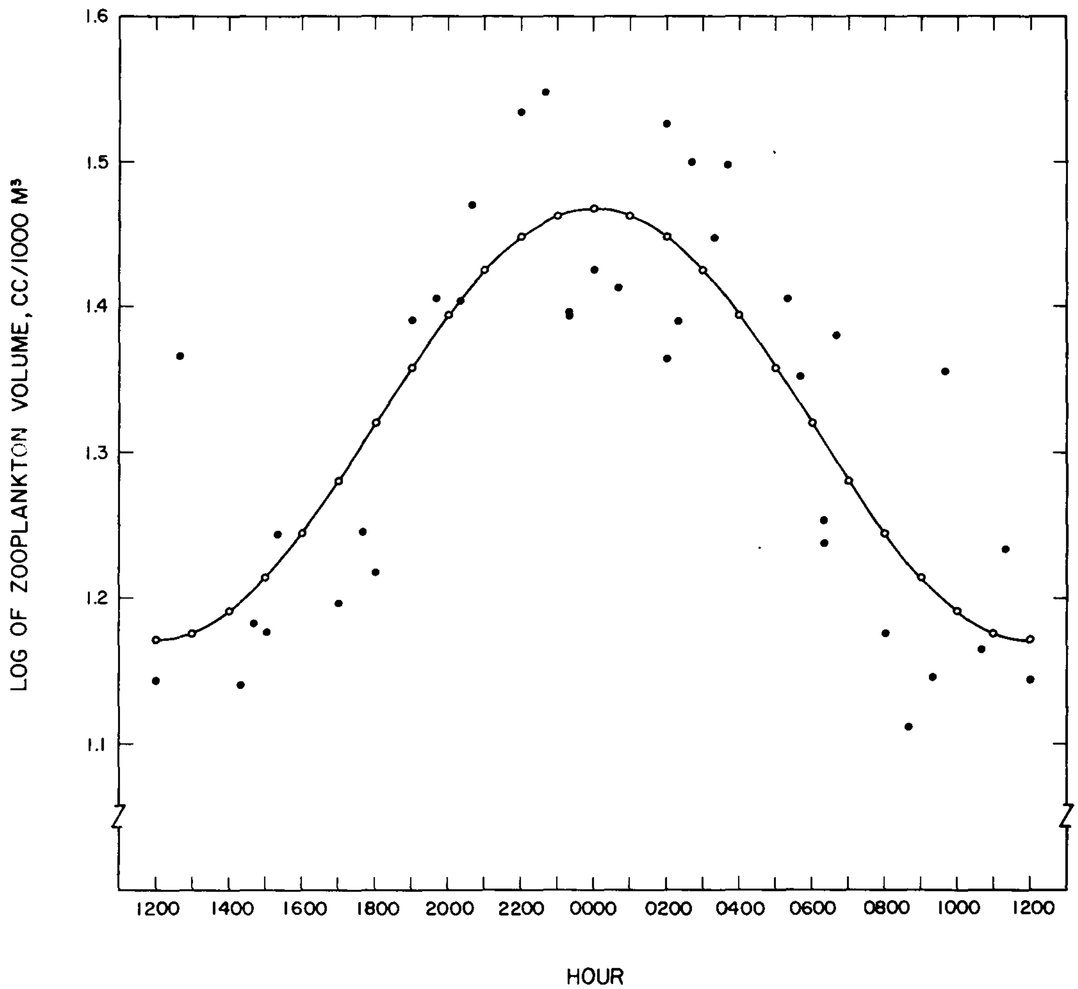


FIG. 6. LOGARITHMS OF ZOOPLANKTON VOLUMES COLLECTED ON <u>JOHN R. MANNING</u> CRUISE 8, PLOTTED AGAINST HOUR OF HAULING TO DEMONSTRATE THE RESEMBLANCE BETWEEN VARIATION WITH TIME OF HAULING AND THE SINE CURVE (FIG. 7).

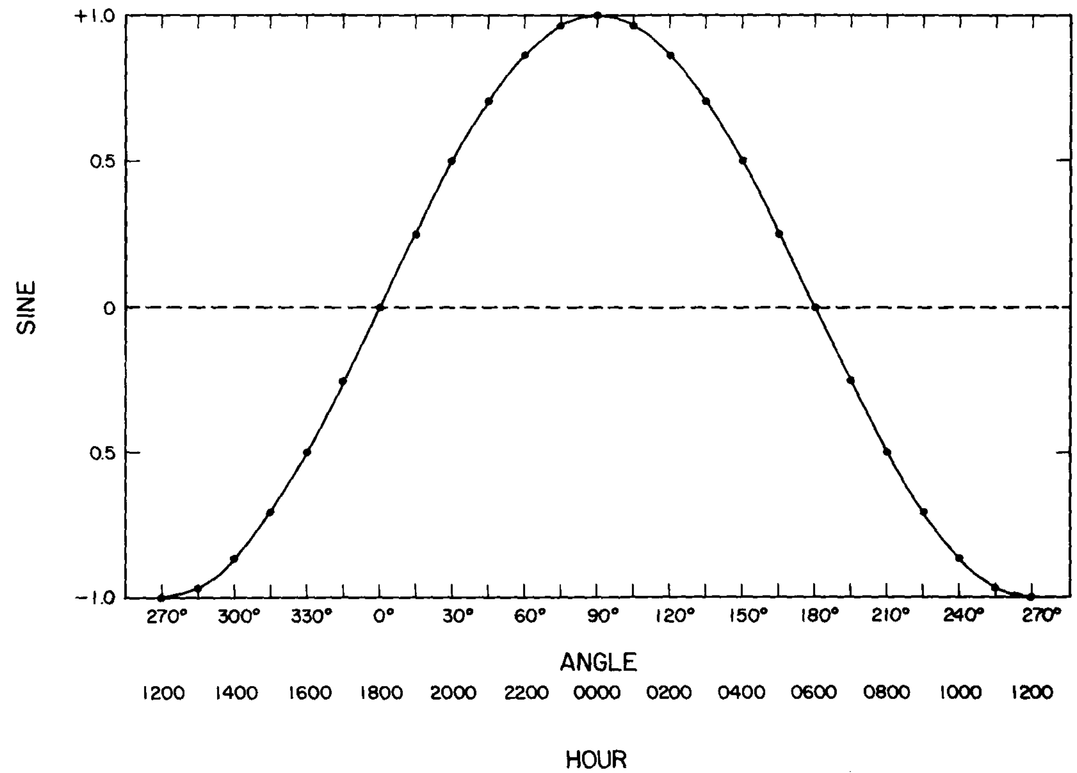


FIG. 7. GRAPH OF THE SINE CURVE SHOWING RELATIONSHIP BETWEEN THE SINE FUNCTION AND CORRESPONDING HOUR OF THE DAY WHEN THE 1800 HOUR IS EQUATED TO ANGLE WHOSE SINE IS ZERO.

the data of figure 6 it is only necessary to transform the abscissa to the sine of the angle, replot as in figure 8, and fit a straight line to the now nearly rectilinear distribution of values. Transferring the straight line to the coordinates of figure 6 produces the curve drawn there, which is seen to describe fairly well the general course of change in logarithmic plankton volume with time of day. The scatter to both sides of the curve is considerable and presumably reflects chance variations, locality differences, and the discrepancies between the arbitrary sine function and the true nature of the diurnal change.

That for this particular cruise there is a discrepancy between the mathematical function and the empirical situation is suggested by the excess of points above the curve in the neighborhood of 0400 hours and the deficiencies in the neighborhood of 1600 hours. It appears that the rise in the catches begins somewhat later in the afternoon and then rises more steeply than the corresponding sine curve, and that the decline in the morning departs similarly. We have not tested the significance of these departures, but similar graphs for the data of other cruises do not show any consistency in the time or direction of discrepancies. It is probable that the sine curve describes the general diurnal fluctuation as well as may be expected of any simple mathematical function. It accounts for an important part of the variability in the plankton hauls, as may be seen from the coefficient of determination (r^2) (Ezekiel 1950, p. 139), as given in table 7 for each of the several cruises.

Accepting, then, the sine function as describing the locus of the diurnal cycle and the fitted regression line in the transformed data as the quantitative effect of this cycle on the particular group of hauls for cruise 8, the adjustment to remove the diurnal effect has been computed as set forth in table 4.

Cruise 8 of the Manning was not designed, however, to investigate the diurnal cycle, but was intended to determine whether or not there was any indication of a definite decline or increase in the plankton during the late summer season. A series of stations, rather than a single one, was selected to give a more general sampling of the plankton population and therefore general significance to any change which might be observed. An analysis of variance of the unadjusted data (table 5), with two-way classification (following Snedecor 1946), indicates no significant differences among stations nor among weeks. The mean square for discrepance is large, however, and tends to render less sensitive the test of significance for the other mean square values. Analysis of the adjusted data (table 5) shows a greatly reduced total variance from that of the unadjusted data, indicating that the chief source of variation was the time of hauling. The mean square for weeks now emerges as larger than that of the discrepance and just under the 0.05 level of significance. Although we still conclude that there were not significant differences among stations or among weeks during the period of sampling, we now gain the idea that the weekly difference is much more important than the locality differences. Variation in zooplankton volume with sampling time and the smoothing effect of the sine adjustment on the data are illustrated in figure 9.

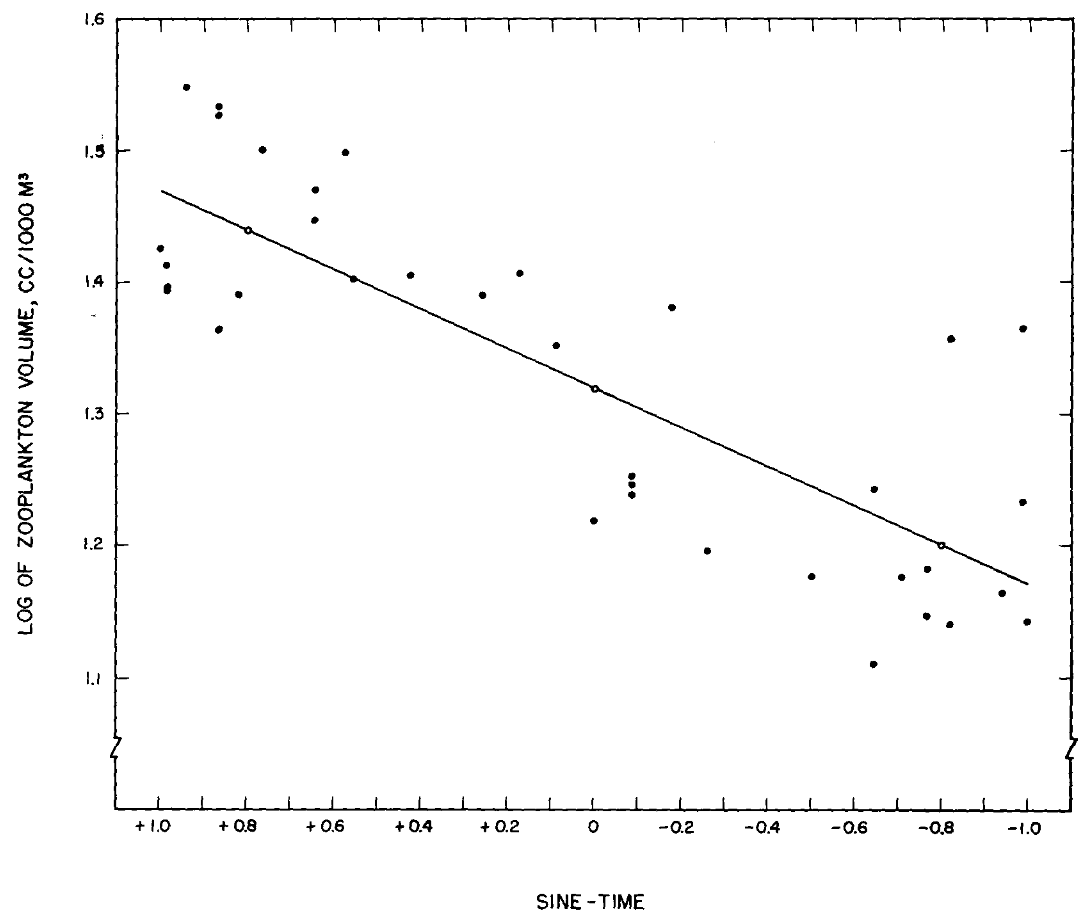


FIG. 8. LOGARITHMS OF ZOOPLANKTON VOLUMES OF JOHN R. MANNING CRUISE 8, PLOTTED AGAINST THE SINE VALUE CORRESPONDING TO THE HOUR OF HAULING, AND SHOWING THE REGRESSION LINE CALCULATED FOR THE RELATIONSHIP.

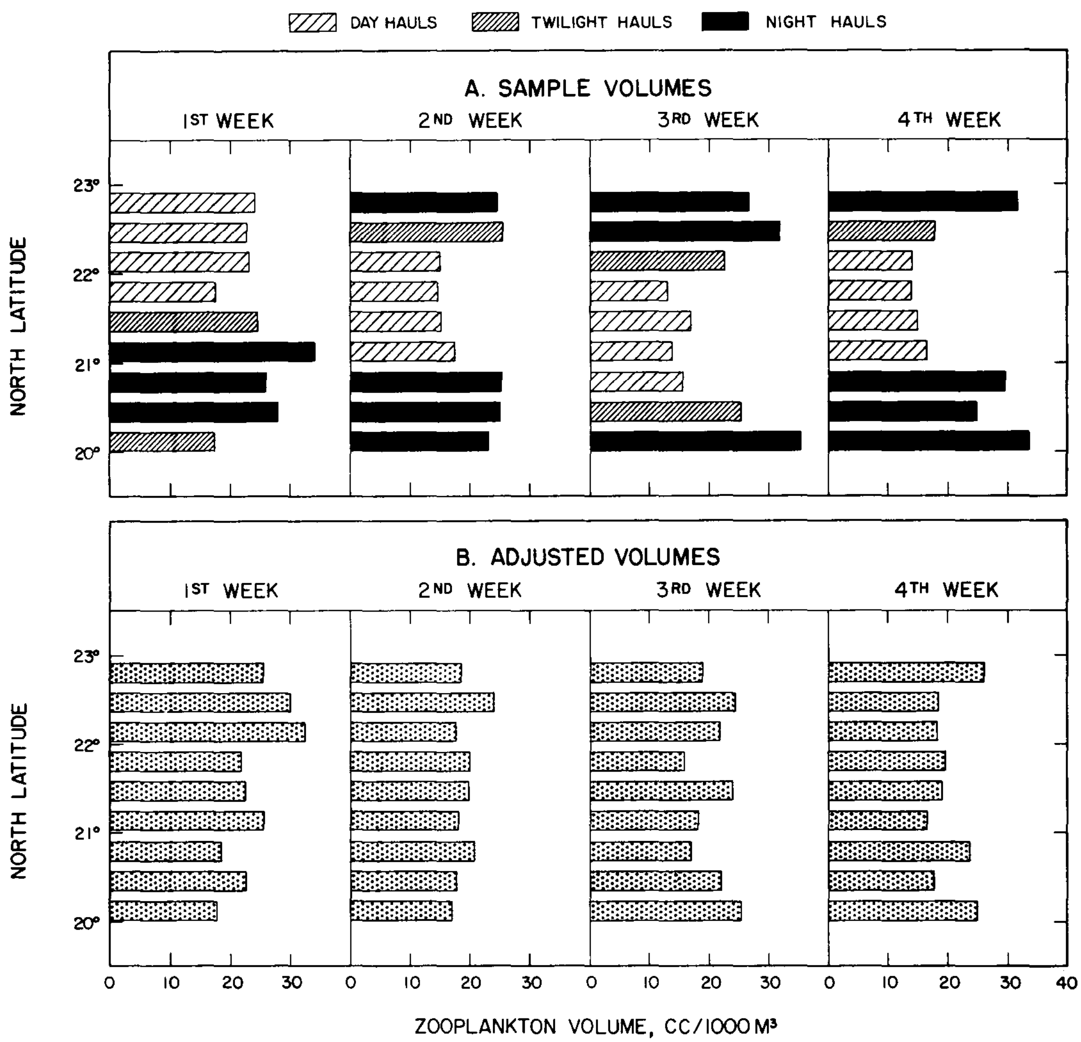


FIG. 9. ZOOPLANKTON VOLUMES, COLLECTED ON THE NORTH-SOUTH SECTION ALONG 158° 25' W. LONGITUDE ON JOHN R MANNING CRUISE 8, BEFORE (A) AND AFTER (B) ADJUSTMENT BY THE SINE METHOD TO EQUILIBRATE FOR THE DIURNAL VARIATION.

Table 4.—Calculations for the sine method of adjusting zooplankton sample volumes for differences related to time of day of hauling, using as an example volumes from cruise 8, *John R. Manning*.

Station	Time (LCT)	Mid-time	Sample volume, cc./1000m.³	Y Log of volume	X Sine-time	bX	Y-bX	Adjusted volume, cc./1000m.³
1	0640 - 0654	0640	24.0	1.380	-.174	-.026	1.406	25.5
2	0930 - 1005	0940	22.7	1.356	-.819	-.122	1.478	30.1
3	1217 - 1253	1240	23.1	1.364	-.985	-.147	1.511	32.4
4	1506 - 1545	1520	17.5	1.243	-.643	-.096	1.339	21.8
5	1837 - 1918	1900	24.6	1.391	.259	.039	1.352	22.5
6	2132 - 2210	2200	34.1	1.533	.866	.129	1.404	25.4
7	0021 - 0100	0040	25.9	1.413	.985	.147	1.266	18.5
8	0305 - 0343	0320	28.0	1.447	.643	.096	1.351	22.4
9	0606 - 0642	0620	17.3	1.238	-.087	-.013	1.251	17.8
15	0204 - 0240	0220	24.6	1.391	.819	.122	1.269	18.6
16	0455 - 0537	0520	25.5	1.406	.174	.026	1.380	24.0
17	0741 - 0816	0800	15.0	1.176	-.500	-.074	1.250	17.8
18	1026 - 1054	1040	14.6	1.164	-.940	-.140	1.304	20.1
19	1430 - 1508	1440	15.2	1.182	-.766	-.114	1.296	19.8
20	1714 - 1748	1740	17.6	1.246	-.087	-.013	1.259	18.2
21	2007 - 2040	2020	25.3	1.403	.574	.085	1.318	20.8
22	2253 - 2329	2320	24.9	1.396	.985	.147	1.249	17.7
23	0149 - 0222	0200	23.1	1.364	.866	.129	1.235	17.2
27	2343 - 0012	0000	26.7	1.426	1.000	.149	1.277	18.9
28	0230 - 0306	0240	31.6	1.500	.766	.114	1.386	24.3
29	0525 - 0600	0540	22.5	1.352	.087	.013	1.339	21.8
30	0817 - 0850	0840	12.9	1.111	-.643	-.096	1.207	16.1
31	1107 - 1140	1120	17.1	1.233	-.985	-.147	1.380	24.0
32	1355 - 1427	1420	13.8	1.140	-.819	-.122	1.262	18.3
33	1640 - 1710	1700	15.7	1.196	-.259	-.039	1.235	17.2
34	1921 - 1954	1940	25.4	1.405	.423	.063	1.342	22.0
35	2225 - 2259	2240	35.3	1.548	.940	.140	1.408	25.6
38	0330 - 0402	0340	31.5	1.498	.574	.085	1.413	25.9
39	0612 - 0645	0620	17.9	1.253	-.087	-.013	1.266	18.4
40	0859 - 0931	0920	14.0	1.146	-.766	-.114	1.260	18.2
41	1144 - 1214	1200	13.9	1.143	-1.000	-.149	1.292	19.6
42	1450 - 1522	1500	15.0	1.176	-.707	-.105	1.281	19.1
43	1737 - 1808	1800	16.5	1.218	.000	.000	1.218	16.5
44	2021 - 2049	2040	29.5	1.470	.643	.096	1.374	23.7
45	2308 - 2341	2320	24.8	1.394	.985	.147	1.247	17.7
46	0150 - 0222	0200	33.6	1.526	.866	.129	1.397	24.9
S			800.7		2.188			762.8
n			36		36			36
Mean			22.24		0.061			21.19

Table 4. Calculations for the sine method of adjusting zooplankton sample volumes for differences related to time of day of hauling, using as an example volumes from cruise 8, <u>John R. Manning</u>. (Cont'd.)

n	=	36
SX	=	2.188
$\bar{x}$	=	0.061
SX^2	=	18.107260
$(SX)^2/n$	=	0.132982
Sx^2		17.874278

SY	=	47.828
$\bar{y}$	=	1.3286
SY^2	=	64.133048
$(SY)^2/n$	=	63.542155
Sy^2		0.590893

SXY	=	5.566545
$(SX)(SY)/n$	=	2.906880
Sxy	=	2.659665

$$b = Sxy/Sx^2$$
$$= 2.659665/17.874278 = \underline{0.1488}$$

$$\hat{Y} = \bar{y} + b\,(X - \bar{x})$$
$$= 1.3195 + 0.1488\,X$$

Test of significance of the regression:

$$Sd_{y.x}^2 = Sy^2 - (Sxy)^2/Sx^2 = \underline{0.195139}$$

$$s_{y.x}^2 = Sd_{y.x}^2/n-2 = \underline{0.005739}$$

$$s_b^2 = s_{y.x}^2/Sx^2 = \underline{0.00032110}$$

$$s_b = \underline{0.0179}$$

$$t = b/s_b = \underline{8.313},\ P < 0.001$$

With 34 degrees of freedom, $t_{.001} = 3.608$; thus there is evidenced a highly significant regression of Y on X.

Table 5. Demonstration of differences between adjusted and unadjusted zooplankton volumes (cc./1000 m.^{3}), using samples from cruise 8, John R. Manning.

A. Analysis of variance of the unadjusted data, showing largest mean square values associated with stations and with discrepance, as a result of the large day-night difference among samples.

Station	Week 1	Week 2	Week 3	Week 4	Mean
1, 15, 27, 38	24.0	24.6	26.7	31.5	26.7
2, 16, 28, 39	22.7	25.5	31.6	17.9	24.4
3, 17, 29, 40	23.1	15.0	22.5	14.0	18.6
4, 18, 30, 41	17.5	14.6	12.9	13.9	14.7
5, 19, 31, 42	24.6	15.2	17.1	15.0	18.0
6, 20, 32, 43	34.1	17.6	13.8	16.5	20.5
7, 21, 33, 44	25.9	25.3	15.7	29.5	24.1
8, 22, 34, 45	28.0	24.9	25.4	24.8	25.8
9, 23, 35, 46	17.3	23.1	35.3	33.6	27.3
Mean	24.1	20.6	22.3	21.9	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	8	628.24	78.53	2.34	> 0.05
Weeks	3	56.58	18.86	0.56	> 0.05
Discrepance	24	805.65	33.57		
Total	35	1490.47			

Table 5 (Cont'd.)

B. Analysis of variance of the adjusted data, showing the largest mean square value now related to weeks.

Station	Week				Mean
	1	2	3	4	
1, 15, 27, 38	25.5	18.6	18.9	25.9	22.2
2, 16, 28, 39	30.1	24.0	24.3	18.4	24.2
3, 17, 29, 40	32.4	17.8	21.8	18.2	22.6
4, 18, 30, 41	21.8	20.1	16.1	19.6	19.4
5, 19, 31, 42	22.5	19.8	24.0	19.1	21.4
6, 20, 32, 43	25.4	18.2	18.3	16.5	19.6
7, 21, 33, 44	18.5	20.8	17.2	23.7	20.0
8, 22, 34, 45	22.4	17.8	22.0	17.7	20.0
9, 23, 35, 46	17.8	17.2	25.6	24.9	21.4
Mean	24.0	19.4	20.9	20.4	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	8	82.20	10.28	0.74	> 0.05
Weeks	3	108.96	36.32	2.63	> 0.05
Discrepance	24	331.71	13.82		
Total	35	522.87			

The 24-hour series of oblique hauls made on Manning cruise 9 affords a further test of the sine method of adjustment. As previously stated, the series consisted of paired oblique hauls to three depths --200, 300, and 500 meters--all taken within a relatively small area. The results of the adjustment for the three depths are shown in table 10. As evidenced by the coefficient of determination (r^2), for the 200-meter hauls 92 percent of the variation in the zooplankton volumes is associated with correlated changes in the sine function. The degree of correlation is less, however, for the 300-meter hauls and still less for the 500-meter hauls. This is accompanied by a parallel decrease in the significance of the regression of Y (zooplankton volumes) on X (sine function).

Data from all seven cruises in local waters were adjusted by the sine method. The adjusted values for cruises employing 200-meter oblique hauls are given in tables 18, 19, 20, 21, and 22; adjusted values for cruises employing horizontal hauls are given in table 6. Table 7 provides a comparison of the results of the adjustment for the various cruises. Among the 200-meter oblique hauls the night/day ratio for unadjusted volumes ranged from 1.30 to 1.70, while for the adjusted volumes the ratio varied from 0.97 to 1.05. For the horizontal hauls, after adjustment, the ratio ranged from 0.69 to 1.13, indicating the presence of considerable variation in the horizontal hauls which is possibly not associated with the day-night differences.

The high significance shown by the "t" tests for the regression of zooplankton volumes on the sine curve and the relatively high value of r^2 (table 7) are general evidence in favor of the method. It is conceivable, however, that both "t" and "r^2" might vary inversely with the amount of variation--other than diurnal--present in the data, even though the diurnal effect were constant. Therefore these two statistics possibly do not provide a crucial test of the adjustment method. Since this transformation appeared to correct--to a large extent at least--for the day-night differences among the 200-meter oblique hauls, the adjusted volumes were used for examining geographical and short-term variations and for correlations with environmental factors.

GEOGRAPHICAL AND TEMPORAL VARIATIONS

In figure 10 we have attempted to show lines of equal zooplankton concentration or "isoplankts" for the three cruises of the Hugh M. Smith which were based on 200-meter oblique hauls and provided general coverage of the area. From an examination of these charts we conclude that although the abundance of zooplankton was remarkably uniform throughout the Island waters, there were certain areas which were consistently richer or poorer than other areas. For example, stations southwest of Oahu, in all three cruises, produced volumes somewhat higher than average. Also, an area north of Kauai showed an unusually high concentration on two cruises. The southeast corner of the survey area produced consistently low catches.

Table 6. Adjusted zooplankton volumes, cc/1000 m.^{3}, for the surface hauls and for the mean of three horizontal hauls at each station of cruises 4 and 6 of the Hugh M. Smith.

A. Cruise 4, May 1950.

Station	Haul depths, meters	Surface sample volume	Surface adjusted volume	Mean volume for 3 depths	Adjusted mean volume
1	0, 50, 150	10.7	23.6	13.8	20.3
1A	0, 50, 150	25.7	25.7	19.6	19.6
2	0, 100, 200	9.4	4.1	15.9	10.6
3	0, 50, 150	2.3	5.1	9.7	14.3
4	0, 100, 200	9.4	11.0	8.5	9.2
5	0, 50, 150	21.5	8.9	19.1	12.4
6	0, 100, 200	1.2	3.0	3.8	5.9
7	0, 50, 150	142.3	112.2	53.2	47.3
8	0, 100, 200	20.6	11.5	15.2	11.4
9	0, 50, 150	4.9	11.6	8.9	13.5
10	0, 100, 200	5.1	8.6	12.4	16.0
11	0, 50, 150	44.6	17.9	25.5	16.3
12	0, 100, 200	35.3	32.6	19.4	18.7
13	0, 50, 150	29.3	13.9	22.6	15.7
14	0, 100, 200	9.6	22.6	8.6	13.1
15	0, 50, 150	10.0	13.7	10.7	12.4
16	0, 100, 200	14.8	6.0	12.2	7.8
17	0, 50, 150	22.2	24.0	15.5	16.1
18	0, 100, 200	2.2	3.5	6.3	7.9
19	0, 50, 150	19.5	7.9	21.1	13.6
20	0, 100, 200	4.0	8.5	7.2	10.4
21	0, 50, 150	9.6	11.3	16.0	17.3
22	0, 100, 200	30.0	13.6	19.2	13.0
23	0, 50, 150	43.9	32.1	26.7	22.9
24	0, 100, 200	29.5	56.4	16.0	21.9
25	0, 50, 150	5.3	11.7	10.7	15.7
26	0, 100, 200	22.1	10.4	15.6	10.8
27	0, 50, 150	23.8	11.8	18.3	13.0
28	0, 100, 200	16.4	15.1	9.8	9.4
Mean		21.6	18.6	15.9	15.1

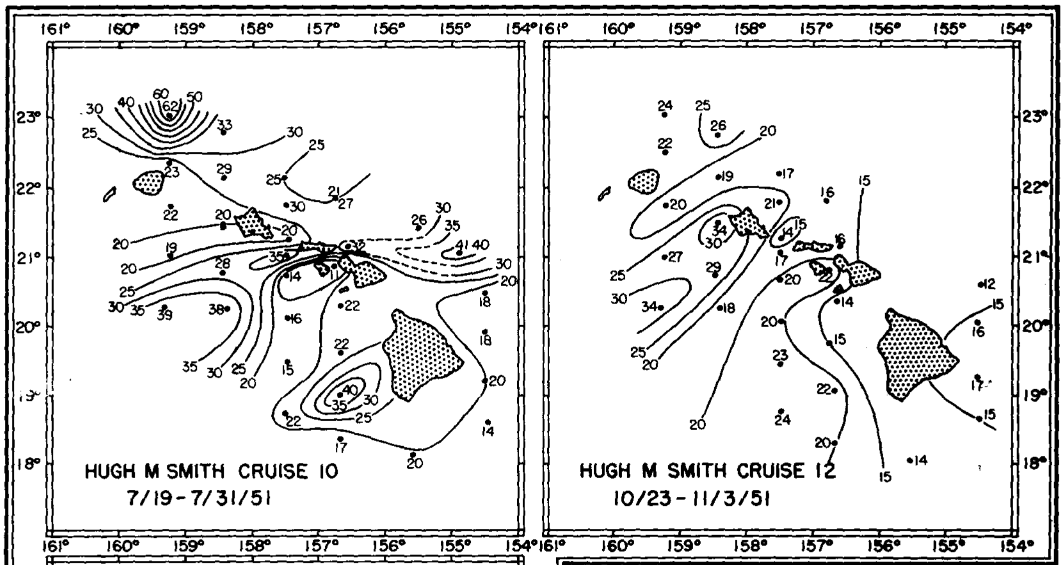
Table 6. (Cont'd)

B. Cruise 6, August 1950

Station	Haul depths, meters	Surface sample volume	Surface adjusted volume	Mean volume for 3 depths	Adjusted mean volume
1	0, 50, 150	5.2	9.9	8.2	11.6
1A	0, 50, 150	8.1	5.0	14.1	10.9
2	0, 100, 200	7.4	4.8	11.1	8.9
3	0, 50, 150	2.4	5.5	5.7	8.9
4	0, 100, 200	8.8	7.6	7.8	7.2
5	0, 150, 300	7.4	3.4	8.7	5.8
6	0, 100, 200	4.8	10.6	7.3	11.1
7	0, 50, 150	16.5	11.6	13.2	10.9
8	0, 100, 200	14.8	14.8	12.6	12.6
9	0, 50, 150	4.3	8.2	6.7	9.4
10	0, 150, 300	11.4	4.9	11.3	7.2
11	0, 50, 150	17.9	16.6	13.6	13.1
12	0, 100, 200	3.7	8.0	6.9	10.4
13	0, 50, 150	42.6	45.8	26.9	28.0
14	0, 100, 200	11.2	11.2	9.4	9.4
15	0, 150, 300	19.6	8.5	17.3	11.1
16	0, 100, 200	7.4	12.7	7.8	10.4
17	0, 150, 200	2.0	3.1	7.3	9.1
18	0, 100, 200	36.8	20.2	24.2	17.7
19	0, 150, 200	23.6	10.1	19.2	12.3
20	0, 150, 300	3.5	6.7	7.2	10.1
21	0, 150, 200	14.1	25.6	9.4	12.9
22	0, 100, 200	88.3	76.2	36.6	33.9
23	0, 50, 150	1.9	4.3	6.4	9.9
24	0, 100, 200	17.1	7.7	19.9	13.1
25	0, 150, 300	4.8	7.3	7.4	9.2
26	0, 100, 200	14.0	21.4	9.3	11.6
27	0, 50, 150	25.7	12.9	19.5	13.5
28	0, 100, 200	3.2	7.4	10.7	16.7
Mean		14.8	13.5	12.6	12.3

Table 7. Summary of results of adjustment by the sine method for data from 7 cruises in Hawaiian waters. The coefficient of determination, r^2, represents the fraction of the variation in the plankton volumes associated with the correlated changes in plankton volume and the sine function.

Cruise	Period	Type of haul	Mean volume, cc./1000 m.^{3}		Night/day ratio		b	t	df	P	r^2
			Un-adjusted	Adjusted	Un-adjusted volumes	Adjusted volume					
HMS-4	May 1950	horizontal (surface)	21.6	18.6	2.42	0.69	0.3972	4.355	27	<0.001	0.41
"	"	horizontal (mean of 3 levels)	15.9	15.1	1.71	0.90	0.1942	4.240	27	<0.001	0.40
HMS-6	Aug. 1950	horizontal (surface)	14.8	13.5	2.84	0.94	0.3672	4.377	27	<0.001	0.42
"	"	horizontal (mean of 3 levels)	12.6	12.3	2.10	1.13	0.1941	4.644	27	<0.001	0.44
HMS-10	July 1951	200m. oblique	26.0	25.6	1.39	0.97	0.1128	2.945	32	<0.01	0.21
JRM-8	Sept.-Oct. 1951	200m. oblique	22.2	21.2	1.70	1.03	0.1488	8.313	34	<0.001	0.67
HMS-12	Oct.-Nov. 1951	200m. oblique	20.2	20.3	1.57	1.04	0.1231	4.076	28	<0.001	0.37
JRM-9	Nov. 1951	200m. oblique	27.0	26.5	1.30	1.00	0.0688	5.375	30	<0.001	0.45
HMS-17	Sept. 1952	200m. oblique	26.5	26.4	1.47	1.05	0.1033	4.943	28	<0.001	0.47



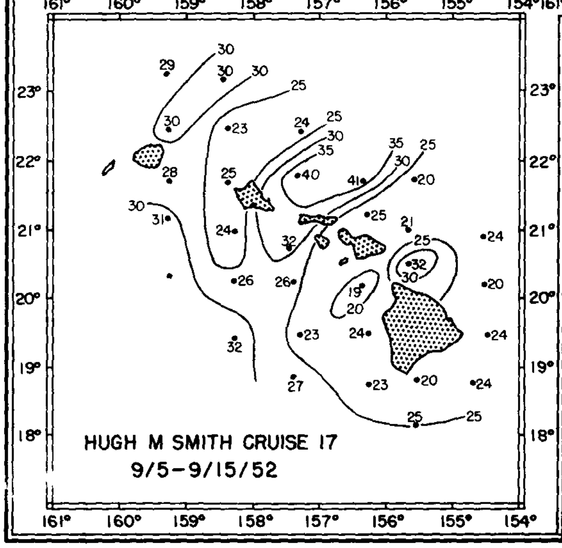


FIG. 10. LINES OF EQUAL ZOOPLANKTON ABUNDANCE, BASED ON TIME-ADJUSTED VOLUMES, FOR THREE CRUISES OF THE HUGH M. SMITH.

One hypothesis seeming worthy of testing was that areas to the lee of the island chain might be higher in zooplankton abundance than areas to windward because of the possible enrichment from the littoral waters of the islands and from the upwelling which may theoretically occur in the lee of oceanic islands. As the Hawaiian archipelago extends generally in a southeast-northwest direction, and since the prevailing tradewinds are from the northeast and the major ocean currents from the east and northeast, a line connecting the various islands of the group as in figure 11 divides the island waters into windward and leeward areas. In order to examine statistically differences between, and within, these major areas, they were each subdivided (fig. 11) into six subareas, three leeward and three windward of the islands. Using an analysis of variance, of completely randomized design, we compared the adjusted zooplankton volumes obtained on cruises 10, 12, and 17 of the Smith for these six subareas. From the results of the analysis, summarized in table 8, we conclude that there were significant differences ($P < 0.05$) among cruises, but no significant differences ($P > 0.05$) between windward and leeward areas or among the six subareas. From an examination of the means (table 8) it is apparent that, on the windward side, subarea 3 produced the lowest mean on all 3 cruises; subarea 2 was intermediate in rank in two of the three cruises, and subarea 1 ranked first in two of the three cruises. On the leeward side, subarea 3 was lowest in two of three cruises, but subareas 1 and 2 fail to follow in any particular order. Therefore, while the summary means for both windward and leeward areas show a trend of slightly increasing zooplankton volumes from east to west, the individual cruises do not follow this in all instances.

Although the seven cruises on which this report is based were not properly distributed in time to adequately describe seasonal or annual variations in plankton abundance, they provide some information of interest on differences in zooplankton abundance between the summer and fall seasons and between the years 1951 and 1952. It is evident from table 6 that the mean volumes collected in May 1950 (Smith cruise 4) were somewhat larger than the volumes collected in August 1950 (Smith cruise 6). The time-adjusted means, 15.1 cc./1000 $m.^3$ for cruise 4 and 12.3 cc./1000 $m.^3$ for cruise 6 are roughly indicative of the degree of change. Smith cruise 10 in July 1951 produced an adjusted mean of 25.6 cc./1000 $m.^3$, which is significantly different ($P < 0.05$) from the mean, 20.3 cc./1000 $m.^3$, of Smith cruise 12 in October-November 1951. Manning cruise 8, September-October 1951, which sampled along just one north-south section west of Oahu (fig. 2), was intermediate in time and also in zooplankton volume with a mean of 21.2 cc./1000 $m.^3$.

In table 9 we have assembled all data obtained during summer and fall of 1951 for the one section, stations 6 to 10 (as numbered on Smith cruise 10), and through an analysis of variance have examined the data for spatial and short-term variations. While the tests of significance indicate that there were no significant differences among stations ($P > 0.05$) or among visits ($P > 0.05$), the mean square value for visits is quite near the 0.05 level of probability.[4/]

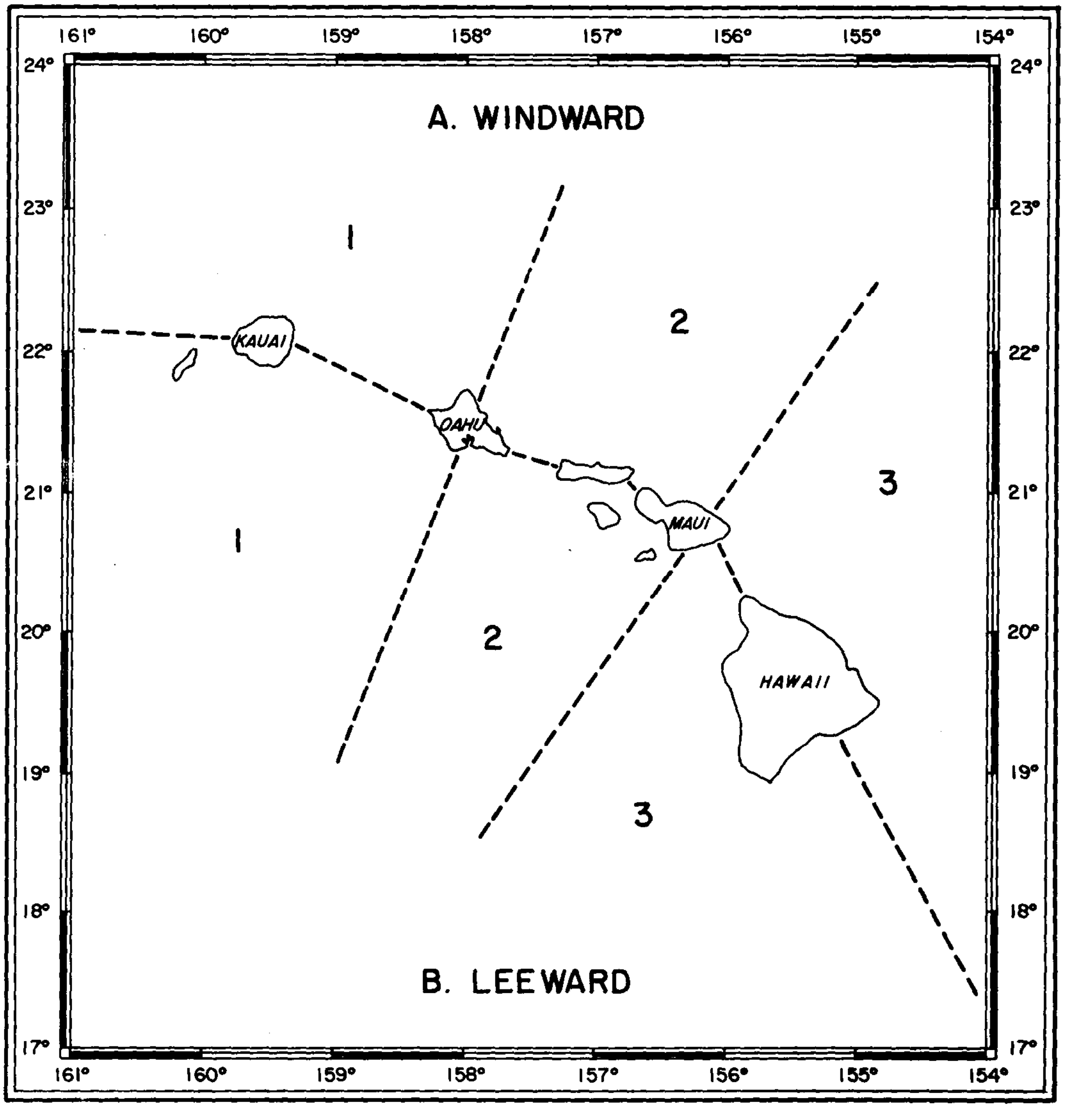


FIG. 11. CHART OF THE MAJOR HAWAIIAN ISLANDS SHOWING THE BOUNDARIES OF THE SIX GEOGRAPHICAL SUBDIVISIONS USED IN COMPARING AREAL DIFFERENCES IN ZOOPLANKTON ABUNDANCE.

Table 8. Analysis of variance of adjusted zooplankton volumes, cc./1000 m.^{3}, for different areas (shown in fig. 11) of the Hawaiian region, as obtained on three cruises of the *Hugh M. Smith* employing 200-meter oblique hauls.

Summary Table

Cruise		A. Windward area				B. Leeward area				Cruise total
		Sub-area				Sub-area				
		1	2	3	Total	1	2	3	Total	
HMS-10	S	146.0	156.1	137.0	439.1	160.8	149.9	120.9	431.6	870.7
	n	4	6	6	16	6	7	5	18	34
	$\bar{x}$	36.5	26.0	22.8	27.4	26.8	21.4	24.2	24.0	25.6
HMS-12	S	90.4	84.5	60.3	235.2	142.8	134.8	95.4	373.0	608.2
	n	4	5	4	13	5	7	5	17	30
	$\bar{x}$	22.6	16.9	15.1	18.1	28.6	19.3	19.1	21.9	20.3
HMS-17	S	136.8	149.4	144.5	430.7	82.8	139.1	138.9	360.8	791.5
	n	5	5	6	16	3	5	6	14	30
	$\bar{x}$	27.4	29.9	24.1	26.9	27.6	27.8	23.2	25.8	26.4
Area total	S	373.2	390.0	341.8	1105.0	386.4	423.8	355.2	1165.4	2270.4
	n	13	16	16	45	14	19	16	49	94
	$\bar{x}$	28.7	24.4	21.4	24.6	27.6	22.3	22.2	23.8	24.2

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Areas	1	13.97	13.97	0.08	> 0.05
Sub-areas	4	673.33	168.33	1.48	> 0.05
Cruises	12	1,368.57	114.05*	2.31	< 0.05
Stations	76	3,747.68	49.31		
Total	93	5,803.55			

* Indicates a significant mean square value.

Table 9. Analysis of variance of adjusted zooplankton volumes (cc./1000 m.^{3}) for a series of 5 stations (numbered 6 to 10 on Smith cruise 10) just west of Oahu. The data were obtained on 6 traverses of the section during the period 7/22 to 10/26/51.

Visit	Date	Station 6	7	8	9	10	Mean
HMS-10	7/22-24	32.6	28.7	20.2	28.2	37.7	29.5
JRM-8 1	9/24-25	25.5	32.4	22.5	18.5	17.8	23.3
2	10/1-2	18.6	17.8	19.8	20.8	17.2	18.8
3	10/7-8	18.9	21.8	24.0	17.2	25.6	21.5
4	10/15-16	25.9	18.2	19.1	23.7	24.9	22.4
HMS-12	10/25-26	26/2	18.8	33.7	28.8	18.4	26.2
Mean		24.6	23.0	23.2	22.9	23.6	23.4

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	4	12.16	3.04	0.11	> 0.05
Visits	5	328.04	65.61	2.29	> 0.05
Discrepance	20	574.19	28.71		
Total	29	914.39			

This period, from August to November, marked the end of the 1951 season for the live-bait skipjack fishery of Hawaii. While our data show that the zooplankton abundance decreased considerably during these same months (fig. 12), we have no evidence that this reduction in the amount of zooplankton was a limiting factor, but rather the decline in both faunal elements may have had a common cause in some other factor of the environment.

The skipjack catch for the Territory of Hawaii for the summer of 1951 was considerably above average, whereas the catch for the 1952 season was somewhat below average and seemed particularly poor after the excellent season of the previous year.5/ Unfortunately, there were no plankton cruises during midsummer of 1952 to provide data comparable to those of 1951. Smith cruise 17, however, occurred in September 1952 during the decline of the skipjack season and provided an adjusted zooplankton mean (26.4 cc./1000 $m.^3$) not differing greatly from that of Smith cruise 10 (25.6 cc./1000 $m.^3$) of July 1951 and somewhat larger than the mean (20.3 cc./1000 $m.^3$) of Smith cruise 12 of October-November 1951. From this small amount of evidence we can conclude at least that the marked difference in skipjack catch between the 1951 and 1952 seasons was not a reflection of a corresponding reduction in zooplankton abundance.

4/ According to Snedecor (1946) the analysis of variance is a valid test of individual and population differences if the groups of samples are randomly drawn from a normally distributed population and have similar variances. He states, however, (p. 221) "...but it has been found that little bias is introduced into the test of significance by moderately skewed distributions." Much of our plankton volume data possesses a moderate skewness which is not, in many instances, corrected by the usual logarithmic transformation. Since the distribution of the data included in table 9 was improved by a logarithmic transformation, and since the F value for visits was quite near the 0.05 level of probability, it was considered advisable to recalculate the analysis using the logarithms of the volumes. The new F values were 0.13 for stations and 2.19 for visits, which are very similar to those obtained previously and do not change our conclusions. The hypothesis that the groups have similar variances was tested by Bartlett's Test (Snedecor 1946, p. 250). The chi-square value obtained was well below the 0.05 level of probability, permitting the conclusion that the separate variances of these 6 groups do not differ sufficiently to disturb the validity of the F tests. We believe that the data in table 9 are representative of those included in the other statistical tests appearing in the report.

5/ From records supplied by the Territory of Hawaii, Division of Fish and Game the average skipjack catch for the season May to September for the 3 years 1948, 1949, and 1950 was 6,576,000 pounds. The 1951 catch for these 5 months was 11,235,000 pounds, while the 1952 catch for this same period dropped to 5,795,000 pounds.

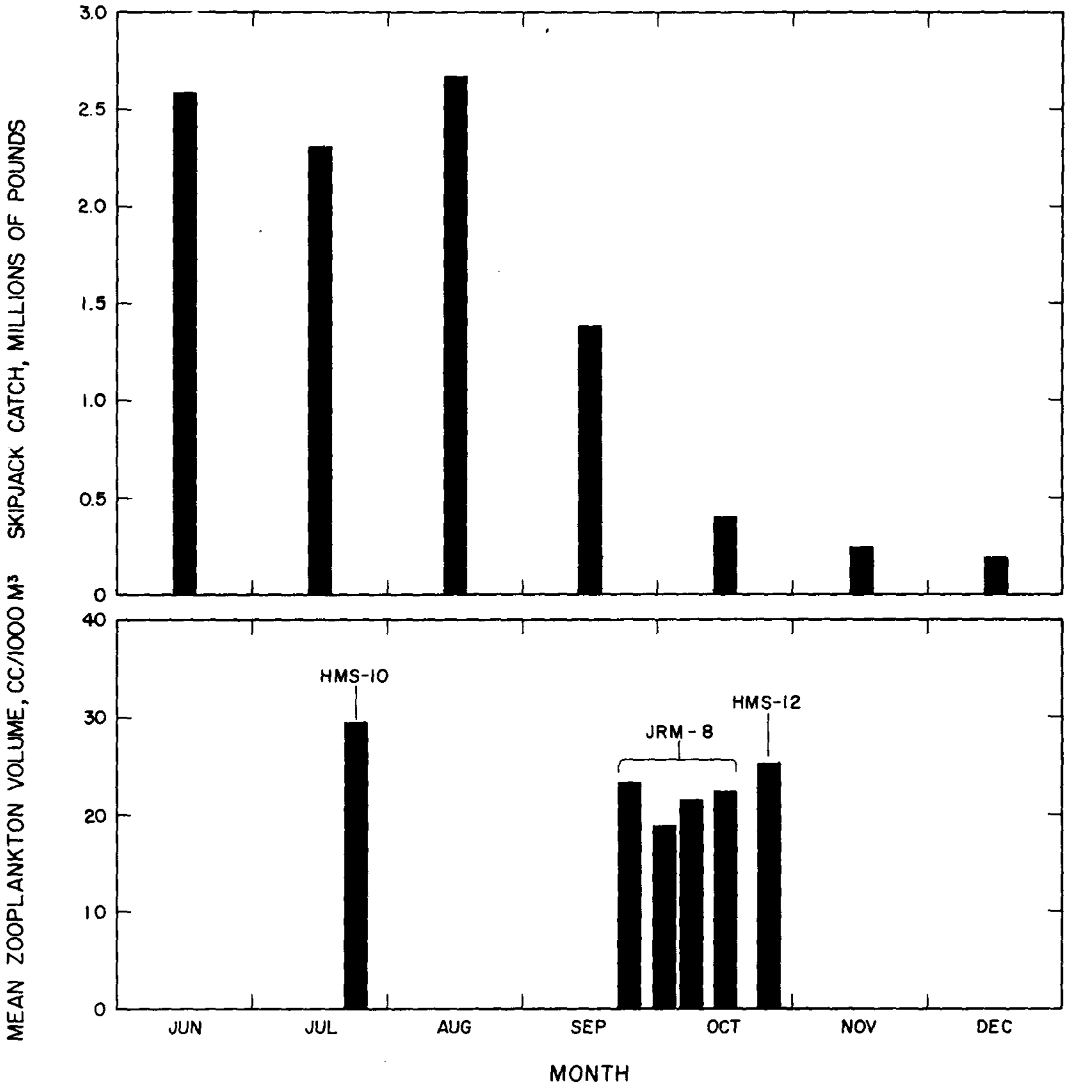


FIG. 12. VARIATIONS IN SKIPJACK CATCH AND IN ZOOPLANKTON ABUNDANCE FOR HAWAIIAN WATERS, DURING THE SUMMER AND FALL OF 1951. THE MEAN ZOOPLANKTON VOLUMES ARE FOR THE ONE SECTION LINE JUST WEST OF OAHU, WHICH WAS VISITED REPEATEDLY DURING THIS PERIOD.

To determine the variations in zooplankton abundance related to distance from land, differences between inshore and offshore areas, or between the windward and leeward sides of these oceanic islands would require a very detailed and elaborate study. An opportunity to obtain a small amount of information on these problems was afforded by cruise 9 of the Manning. Paired hauls were made at a series of 5 stations (fig. 2, part B) extending from about ½ mile from the beach--the closest the vessel could approach-- to 5 miles offshore. Two such sections were occupied, one starting in Kaneohe Bay on the windward side of Oahu and extending offshore and the other extending offshore from Waianae, on the leeward side of Oahu. Unfortunately, however, the Kaneohe series was taken during daylight hours and the Waianae series at night. Also, because of insufficient depth, the standard 200-meter oblique haul could not be employed at all stations. A stair-stepped haul from the bottom to the surface was carried out at the inshore stations where the depth was less than 200 meters. Despite these unavoidable sources of variation, rather consistent results were obtained at the two locations (fig. 13). On both series the greatest plankton volumes were secured at the 2-mile station; volumes decreased to a moderate degree in both inshore and offshore directions. Treating the data with an analysis of variance (table 10) revealed significant differences ($P < 0.05$) between the two localities, Kaneohe and Waianae, and also significant differences ($P < 0.05$) among stations. The interaction was not significant, thus indicating parallel variations for the two localities. We believe the differences between localities to be related primarily to the time of hauling and the associated diurnal variation in plankton abundance. An adjustment of the 200-meter hauls according to the usual procedure appeared to eliminate the day-night difference (table 22). The significant variation among stations may be real and related to basic differences in productivity or possibly to differences in the hauling method. No definite conclusions, however, can be drawn from these few observations.

CORRELATIONS WITH ENVIRONMENTAL FACTORS

The available hydrographic data demonstrate that the Hawaiian waters comprise a relatively homogeneous environment characterized by slight geographical variations in physical and chemical factors. Our plankton sampling indicated correspondingly uniform conditions of zooplankton abundance throughout the islands (fig. 10). Nevertheless, the authors thought it worthwhile to determine the degree of correlation of zooplankton catch and certain environmental factors considered most likely to have biological siginificance.

Surface and subsurface temperatures obtained by means of a bathythermograph were available for all seven cruises covered in this report. Three of the cruises--10, 12, and 17 of the Smith--were combined hydrographic and plankton cruises and furnished additional measurements of the environment. Inorganic phosphate analyses were

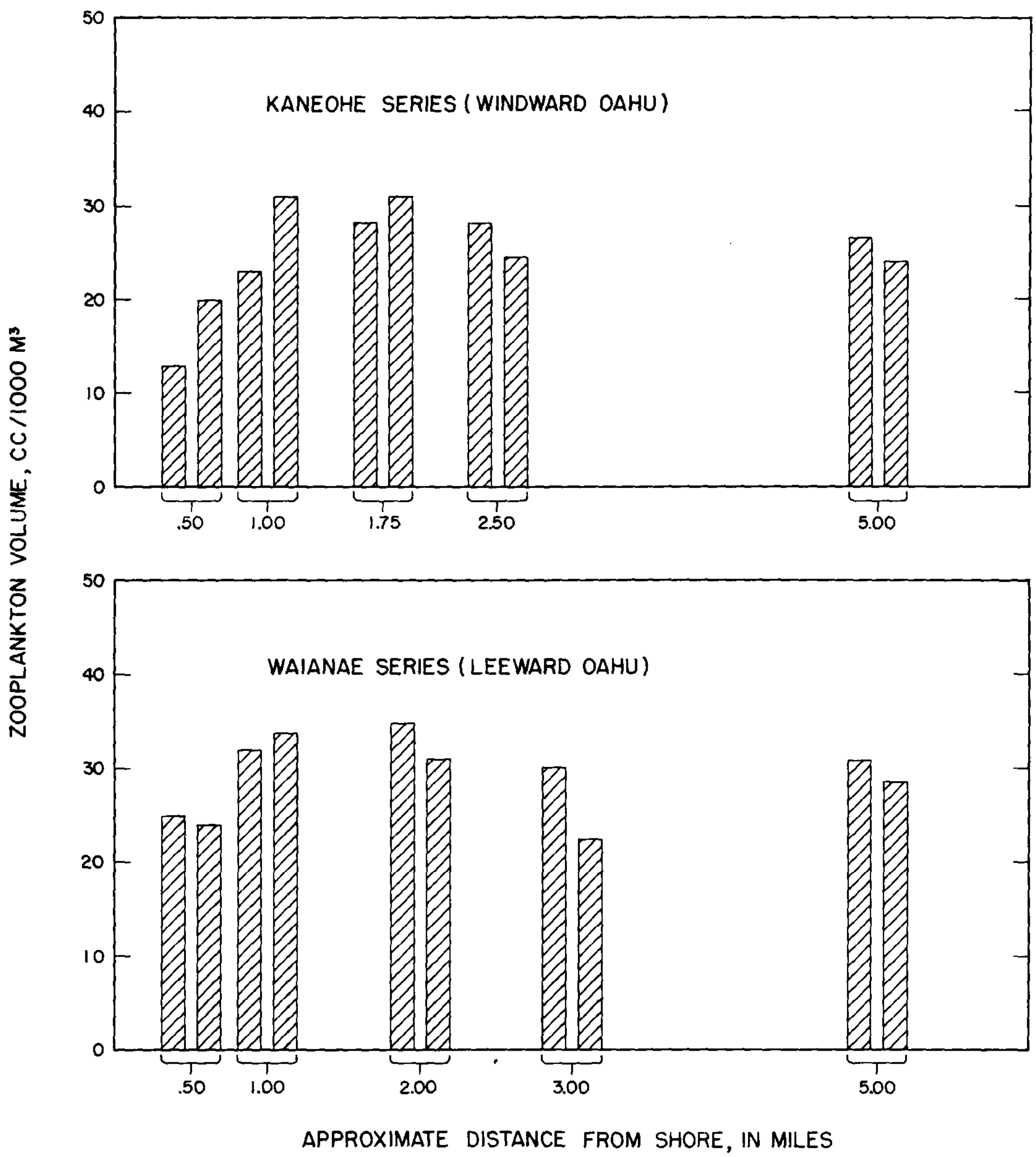


FIG. 13. ZOOPLANKTON VOLUMES ALONG TWO SERIES OF STATIONS EXTENDING FROM NEAR THE SHORELINE TO FIVE MILES OFFSHORE FROM THE ISLAND OF OAHU. THE WINDWARD SERIES WAS OCCUPIED DURING THE DAY OF NOVEMBER 18, 1951, WHILE THE LEEWARD SERIES TOOK PLACE ON THE NIGHT OF NOVEMBER 18-19, 1951, JOHN R. MANNING CRUISE 9.

Table 10. Analysis of variance of zooplankton volumes collected on cruise 9, John R. Manning; for the windward and leeward sides of the island of Oahu.

Stations	Approx. distance from shore (miles)	Windward (day hauls)	Leeward (night hauls)	Mean
7 and 12	1/2	12.8 19.9	24.8 23.9	20.4
8 and 13	1	22.9 30.9	32.1 33.8	29.9
9 and 14	2	28.2 31.1	34.7 31.0	31.2
10 and 15	3	28.1 24.6	30.2 22.4	26.3
11 and 16	5	26.6 24.1	30.8 28.6	27.5
Mean		24.9	29.2	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Localities	1	92.88	92.88*	10.07	<0.05
Stations	4	286.18	71.54*	7.76	<0.05
Locality x station interaction	4	36.89	9.22	0.82	>0.05
Within subclasses	10	112.19	11.22		
Total	19	528.14			

* Indicates a significant mean square value.

made at the 13 sample levels at each station of cruises 12 and 17. Dissolved oxygen was measured at all sample levels throughout cruise 10. Salinity and reversing thermometer data were available for all three cruises. The hydrographic data resulting from these three cruises have not as yet received thorough oceanographic study. The conclusions expressed here are based on information available at the time of this writing and are, therefore, of a preliminary nature.

Temperature

For Smith cruises 4 and 6, in May and August 1950 respectively, the deviations from the mean zooplankton volume at the 50-meter level and the ratios of 50-meter/surface zooplankton volumes were examined in respect to the depth to the top of the thermocline, the hypothesis being that a large positive deviation or a large ratio should more likely occur at stations with a shallow thermocline. A shallow thermocline would result in nutrient-rich water's being nearer the surface and more available to plant life than in the case of a deep thermocline with the discontinuity occurring below the photosynthetic zone. The results did not confirm this hypothesis. Graphs of the data (not presented here) showed a random distribution in relation to thermocline depth for both deviation from the mean and the 50-meter/surface ratios.

Since surface temperature may fluctuate as a result of diurnal heating, the authors chose the 10-meter depth as providing a temperature more truly indicative of temperature conditions in the surface layer. Figure 14 shows the isotherms for the 10-meter depth as found on three cruises of the Smith. Although conditions were remarkably uniform throughout the area, waters to the southwest held the highest temperatures while the northeastern and southeastern areas showed the lowest temperatures. Correlations between adjusted zooplankton volumes and temperatures at 10 meters were calculated for cruises 10, 12, and 17 of the Smith and cruise 8 of the Manning (table 11). For only one of the four cruises (Smith cruise 12) was a significant correlation obtained.

As stated previously, we believe that thermocline depth may have a significant influence on biological productivity. Occasionally, however, the thermal structure is such that no distinct thermocline is present or more than one gradient may be shown on the BT trace. Thus it is frequently difficult to follow set rules in designating thermocline depth and as a result the measurement tends to be rather subjective. The depth to the 70° isotherm may be more objectively read from the BT traces and, in this area of the central Pacific, falls within the thermocline and varies generally with thermocline depth. Adjusted zooplankton volumes and depth to the 70° isotherm were compared for cruises 10, 12, and 17 of the Smith and cruise 8 of the Manning (table 11). No significant correlation was found in any of the four analyses.

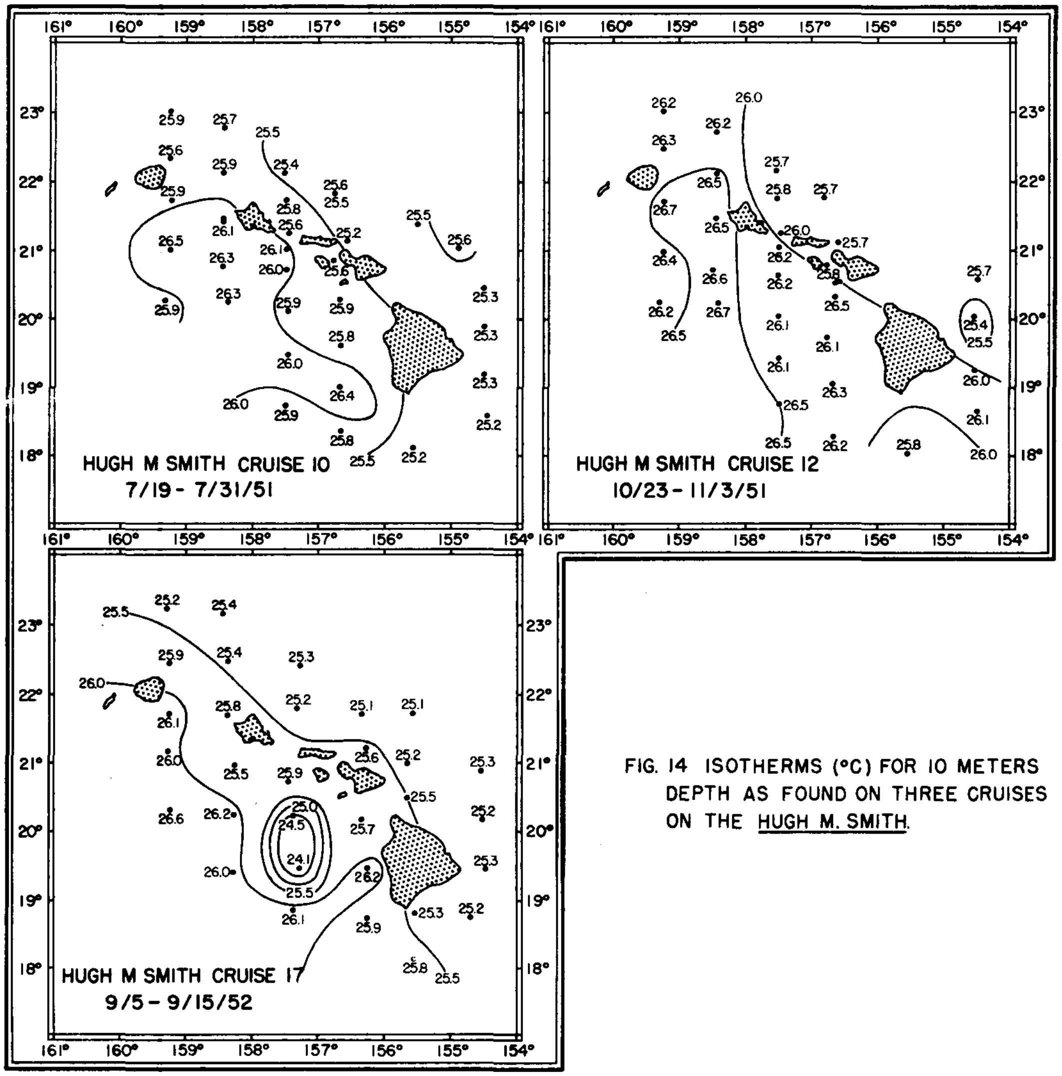


FIG. 14 ISOTHERMS (°C) FOR 10 METERS DEPTH AS FOUND ON THREE CRUISES ON THE HUGH M. SMITH.

Table 11. Summary of correlations of adjusted zooplankton volumes and certain physical and chemical environmental factors.

Cruise	X_1	X_2	Degrees of freedom	Correlation coefficient (r)	P
HMS-10	Zooplankton volumes (cc./1000 m.^{3})	Temperature (°C) at 10-meter depth	32	0.263	>0.05
"	"	Depth (meters) to 70° isotherm	28	0.172	>0.05
"	"	Dissolved O_2 (percent saturation) at 10-meter depth	32	-0.147	>0.05
"	"	Dissolved O_2 (percent saturation) at 100-meter depth	30	-0.024	>0.05
HMS-12	"	Temperature (°C) at 10-meter depth	28	0.453	<0.05
"	"	Depth (meters) to 70° isotherm	26	0.055	>0.05
"	"	Surface inorganic phosphate (μg at./L.)	28	-0.132	>0.05
HMS-17	"	Temperature (°C) at 10-meter depth	28	0.102	>0.05
"	"	Depth (meters) to 70° isotherm	28	0.236	>0.05
"	"	Surface inorganic phosphate (μg at./L.)	28	0.506	<0.01
JRM-8	"	Temperature (°C) at 10-meter depth	34	-0.151	>0.05
"	"	Depth (meters) to 70° isotherm	34	-0.217	>0.05

It was stated earlier (p. 30) that no significant differences were found among stations nor among visits for the zooplankton volumes obtained along the north-south section just west of Oahu during the summer and fall of 1951. For this same group of stations we employed an analysis of variance with two-way classification to examine the temperature at the 10-meter depth (table 12) and also depth to the 70° isotherm (table 13) for evidence of changes in thermal characteristics during this period of time. From the analyses we conclude that for the temperature at 10 meters there were highly significant differences ($P < 0.01$) among stations and among visits during the period of observations. The arithmetic means for visits show that the temperature of the surface layer fluctuated considerably during the period of observation. In late September the temperature was higher than in July; the cooling which took place during the first part of October was followed by a rise in late October and the highest mean of the group. The figures representing depth to 70°, however, showed no significant difference ($P > 0.05$) among stations or among visits.

The zooplankton means (table 9) show peaks in July and late October with reduced volumes in September and early October. The only justifiable conclusion appears to be that during the period from July through October 1951, which bracketed the end of the skipjack season for that year, there were significant changes in temperature in the surface layer which were not closely correlated with changes in the depth of the 70° isotherm or in the zooplankton population.

Inorganic Phosphate

On meridional sections crossing the Equator in the central Pacific we have found highly significant positive correlations between zooplankton abundance and inorganic phosphate concentrations (King and Demond 1953). We thought it of interest to investigate this relationship for the Hawaiian area. A comparison of adjusted zooplankton volumes and surface inorganic phosphate showed confusing results. On *Smith* cruise 12 there was no significant correlation, but on *Smith* cruise 17 of the following year (table 12) the correlation was highly significant. Figure 15 shows lines of equal phosphate concentration as found on these two cruises. There is no obvious pattern in the variations shown by the cruise 12 data. The cruise 17 data, however, show a definite east-west gradient of increasing phosphate values with the greatest zooplankton volumes being obtained in regions of high phosphate concentration. The mean zooplankton and phosphate values for these two cruises provide an interesting comparison (table 14). Cruise 12, in the fall of 1951, had relatively low mean values for both zooplankton and phosphate, while cruise 17, in the fall of 1952, had high values for both means.

Dissolved Oxygen

In the equatorial region of the central Pacific, where waters with reduced oxygen content occur in the region of upwelling, a significant negative correlation was found between zooplankton volumes and dissolved oxygen as percent saturation (King and Demond 1953). Oxygen and zooplankton data from *Smith* cruise 10 were examined for evidence of

Table 12. Analysis of variance of temperatures (in degrees centigrade) at 10-meter depth for the section of stations (numbered 6 to 10 on Smith cruise 10) as obtained on 3 cruises during the summer and fall of 1951.

Visit	Date	Station					Mean
		6	7	8	9	10	
HMS-10	7/22-24	25.7	25.9	26.1	26.3	26.3	26.06
JRM-8 1	9/24-25	25.6	26.2	26.6	26.8	26.9	26.42
2	10/1-2	25.4	25.8	26.3	26.1	26.4	26.00
3	10/7-8	25.4	26.3	26.7	25.8	26.0	26.04
4	10/15-16	25.6	26.1	26.2	26.1	25.6	25.92
HMS-12	10/25-26	26.2	26.5	26.5	26.6	26.7	26.50
Mean		25.65	26.13	26.40	26.28	26.32	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	4	2.14	0.535**	7.75	< 0.01
Visits	5	1.45	0.290**	4.20	< 0.01
Discrepance	20	1.38	0.069		
Total	29	4.97			

** Indicates a highly significant mean square value.

Table 13. Analysis of variance of depths (in meters) to the 70° isotherm for the section of stations (numbered 6 to 10 on Smith cruise 10) as obtained on 3 cruises during the summer and fall of 1951.

Visit	Date	Station					Mean
		6	7	8	9	10	
HMS-10	7/22-24	189	195	161	115	76	147.2
JRM-8 1	9/24-25	140	146	180	178	210	170.8
2	10/1-2	96	154	172	201	168	158.2
3	10/7-8	145	212	187	202	139	177.0
4	10/15-16	106	126	111	134	73	110.0
HMS-12	10/25-26	148	137	148	146	146	145.0
Mean		137.3	161.7	159.8	162.7	135.3	

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Stations	4	4,556.8	1,139.2	1.05	> 0.05
Visits	5	14,252.6	2,850.5	2.62	> 0.05
Discrepance	20	21,733.6	1,086.7		
Total	29	40,543.0			

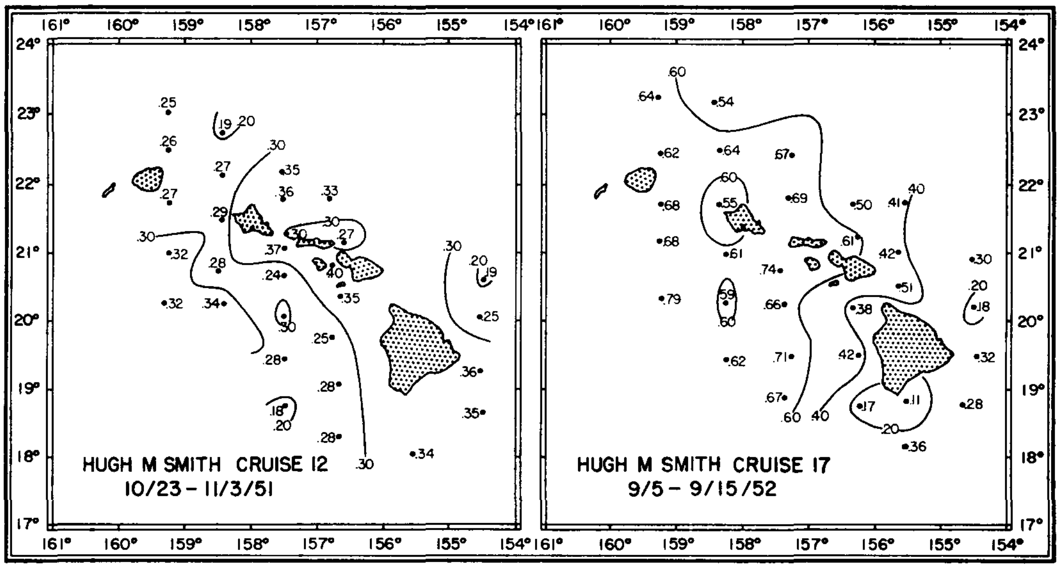


FIG. 15. LINES OF EQUAL INORGANIC PHOSPHATE CONCENTRATION (µg at/L) FOR THE SURFACE, AS FOUND ON TWO CRUISES OF THE HUGH M. SMITH.

Table 14. Comparison of mean values of zooplankton volume, temperature at 10-meter depth, depth to the 70° isotherm, and surface inorganic phosphate for four cruises in Hawaiian waters.

Cruise	Month	Year	Zooplankton volume		Mean temp. at 10 m. (°C)	Mean depth to 70° isotherm (meters)	Mean phosphate (µgat./L.)
			Sample mean (cc./1000m.^{3})	Adjusted mean (cc./1000m.^{3})			
HMS-10	July	1951	26.0	25.6	25.8	157	--
JRM- 8	Sept., Oct.	1951	22.2	21.2	26.2	159	--
HMS-12	Oct., Nov.	1951	20.2	20.3	26.1	142	0.29
HMS-17	Sept.	1952	26.5	26.4	25.5	151	0.51

such a relationship. Correlation of zooplankton volumes resulting from 200-meter oblique hauls and percent saturation of oxygen at the 10-meter depth gave a correlation coefficient (r) of —0.147 (table 11). Correlation of zooplankton with oxygen at 100 meters gave an "r" value of —0.024. These coefficients are well below the level of statistical significance and indicate an almost complete lack of correlation between the two variables. The fact that negative coefficients, such as had been obtained for the equatorial region, were derived in both instances is of interest.

Temperature - Salinity Relations

Sverdrup et al. (1942, p. 740) show the Hawaiian Islands to be located near the junction of three different water masses of the central Pacific. The authors state that "....the region around the islands is a boundary region within which water masses of very different character may be encountered." One means of identifying a particular water mass is by its temperature-salinity relations or "T-S" curve.

It would seem possible that a change in plankton or pelagic fish abundance might follow a change of the water mass bathing the Islands. During the summer and fall of 1951 a significant change was noted between the zooplankton volumes collected on Smith cruise 10 in July and those of Smith cruise 12 in October. A comparison of the T-S curves for these two cruises with those shown in Sverdrup et al. (1942, p. 741), indicates that during the time of both cruises the Islands lay in the "Eastern North Pacific Central Water Mass". The change in zooplankton abundance was, therefore, not a reflection of a change in water mass as indentified by the T-S curve.

During the summer of 1952 the skipjack catch for the Hawaiian Islands was about half that of the previous summer. The zooplankton volumes on the other hand (*Smith* cruise 17), as previously stated, were considerably larger in the late summer than in the year before (*Smith* cruise 12). The T-S curve representing data collected in September 1952, on *Smith* cruise 17, has not yet been worked out.

COMPARISONS WITH ZOOPLANKTON ABUNDANCE OF OTHER REGIONS OF THE PACIFIC

As previously stated (p. 4), the *Challenger* expedition visited the Hawaiian Islands in 1875. Qualitative surface hauls were made at intervals while enroute from Japan to Hawaii and from Hawaii to Tahiti. Although apparently no measurements were made of the total numbers of organisms nor the volumes of the samples to permit detailed comparisons between areas, Tizard et al. (1885) reported that for the portion of cruise from Hawaii to Tahiti "The tow-net gatherings were very productive throughout the trip, the abundance of life in the Equatorial and Counter Equatorial Currents being very remarkable both for the number of species and individuals."

The *Carnegie* traversed the central Pacific during the fall of 1929. Vertical plankton hauls from depths of 100 and 150 meters were made with a $\frac{1}{2}$-meter net of No. 15 silk bolting cloth. Dry weights of the plankton samples varied from 90 and 140 mg. for two stations (stations 139 and 140) about 100 miles north of the Hawaiian Islands to values as great as great as 520 mg. at about 5° N. latitude (station 155) and 450 mg. at about 2° S. latitude (Graham 1941).

During the years 1950 to 1952 quantitative zooplankton collections were obtained by the *Hugh M. Smith* on ten cruises in the equatorial Pacific between 120° W. and 180° W. longitude. When the resulting data are combined for this range of longitude and then separated into 5° latitudinal groups, they present the picture shown in figure 16. It is evident that within this range of latitude the greatest standing crop of zooplankton occurred in the region of the Equator. This increased productivity is the result of upwelling at the Equator associated with the equatorial divergence, which replenishes the supply of nutrients in the euphotic zone and creates especially favorable conditions for the growth of plant and animal life (Graham 1941, Sverdrup et al. 1942, Cromwell 1951, 1953, King and Demond 1953).

The amount of zooplankton in the Hawaiian area was greater than in certain regions of the North Equatorial Current (10° to 15° N. latitude and 20° to 25° N. latitude) and of the South Equatorial Current (5° to 10° S. latitude), but was distinctly less than that found in the "rich zone" from 5° S. to 5° N. latitude. We believe that these differences in zooplankton abundance are indicative of differences in basic productivity among these various regions of the central Pacific.

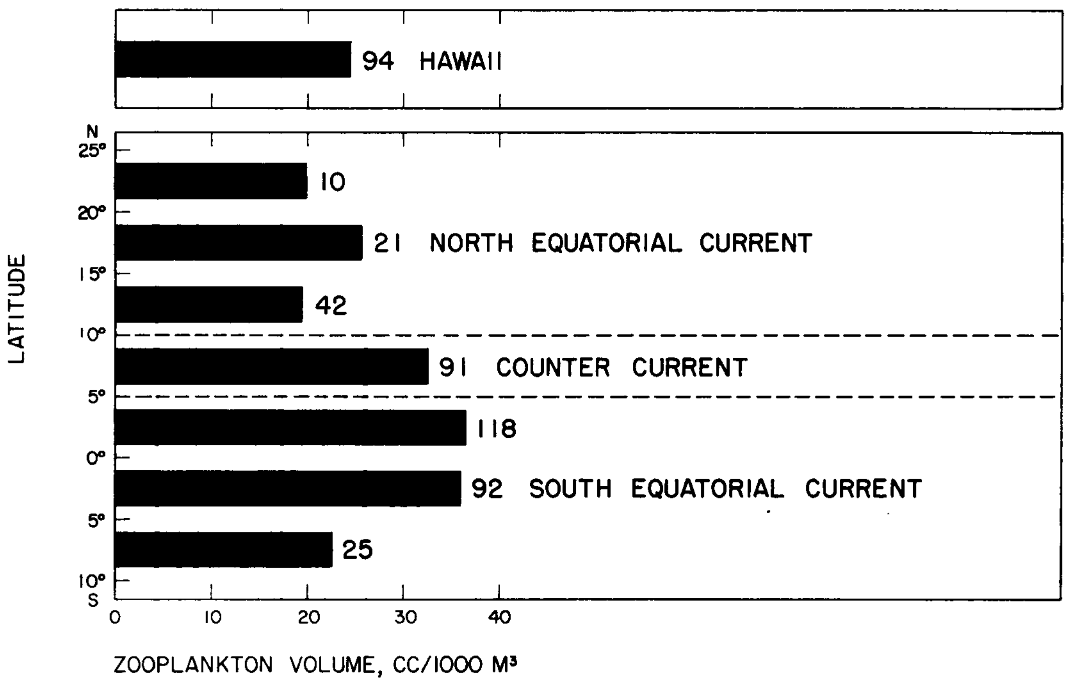


FIG. 16. COMPARISON OF ZOOPLANKTON ABUNDANCE IN DIFFERENT REGIONS AND DIFFERENT WATER MASSES OF THE CENTRAL PACIFIC. THE DATA FOR HAWAII ARE BASED ON CRUISES 10, 12, AND 17 OF THE HUGH M. SMITH; THE REMAINING DATA FOR THE EQUATORIAL PACIFIC WERE DERIVED FROM SMITH CRUISES 2, 5, 7, 8, 9, 11, 14, 15, 16, AND 18. (THE NUMBER OF SAMPLES FOR EACH INTERVAL OF LATITUDE IS INDICATED FOR EACH BAR IN THE HISTOGRAM).

Some information on zooplankton concentrations in waters to the north and east of Hawaii is furnished by the Northern Holiday Expedition of Scripps Institution of Oceanography and cooperating agencies[6], conducted in August-September 1951. The resulting data may be compared with those of POFI for the Hawaiian and equatorial regions as generally similar methods were employed in making the hauls and in processing the collections. Table 15 presents data, collected on the westernmost stations of the expedition, which indicate in general a marked increase in zooplankton concentration with increasing latitude. Two chief differences are apparent between these data and those for the Hawaiian area: (1) the latitudinal means for the Northern Holiday Expedition are, with one exception (35° 00' - 39° 59' N. latitude), considerably larger, and (2) there is a much greater variation among the individual volumes than appears in the Hawaiian samples. We believe that this high variation among plankton volumes taken within a relatively short interval of space and time is particularly characteristic of temperate and higher latitudes and is not found to such an extent, as indicated by our data, in the tropics and subtropics.

6/ The plankton collections were processed by Dr. E. H. Ahlstrom and staff, South Pacific Investigations, Fish and Wildlife Service, and were made available to the authors through the courtesy of Dr. Ahlstrom.

Table 15. Zooplankton volumes (cc./1000 m.^{3}) arranged to show variation with latitude, as obtained on the Northern Holiday Expedition[1/] to the northeastern Pacific in August-September 1951. Only volumes obtained on the western portion of the cruise between 145° and 160° W. longitude were included in the table.

	Latitudes						
	25° 00'-29° 59'N	30° 00'-34° 59'N	35° 00'-39° 59'N	40° 00'-44° 59'N	45° 00'-49° 59'N	50° 00'-54° 59'N	55°00'-59°59'N
	467[2/]	15	6	32	180	242	241
	43	41	44	14	85	75	235
	39	49	7	76	117	92	
		42		55	104	147	
				32	122	83	
				75	155	39	
				54		111	
				77		60	
				33		151	
				32		61	
						21	
						60	
Mean	41.0	36.8	19.0	48.0	127.2	95.2	238.0

1/ This expedition was sponsored by the Scripps Institution of Oceanography and collaborating agencies. The zooplankton collections were processed by Dr. E. H. Ahlstrom and staff of the South Pacific Investigations, Fish and Wildlife Service. These data, previously unpublished, were made available to the authors through the courtesy of Dr. Ahlstrom and Mr. Warren Wooster of the Scripps Institution of Oceanography.

2/ This sample was reported (Ahlstrom) to consist primarily of salps; therefore, we choose to omit it from this comparison of latitudinal variation.

SUMARY AND CONCLUSIONS

1. This report presents an analysis of 365 quantitative zooplankton collections obtained on seven cruises in Hawaiian waters during the years 1950 to 1952.

2. The collections were taken by a variety of hauling methods: horizontal hauls at several depths ranging from the surface to 300 meters, and oblique hauls to depths of 200, 300, and 500 meters.

3. One type of net was used throughout, a 1-meter net with body of 30XXX grit gauze, rear section and bag of 56XXX. The net was equipped with a flow meter which gave an estimate of the volume of water strained.

4. In the laboratory the displacement volumes of all samples were measured in uniform fashion. For each sample there was calculated the volume of the more nutritious zooplankton per unit of water strained.

5. For the two cruises employing horizontal hauls, the greatest zooplankton volumes occurred on the average at the 50-meter level in both day and night samples.

6. A 24-hour series of successive oblique hauls to 200, 300, and 500 meters showed significant differences among depths and among hauling times. A marked diurnal variation in catch was found among hauls to all three depths.

7. A method is presented for adjusting the zooplankton volumes for differences associated with diurnal variations in the catch. The method is based upon the similarity between 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 $+1.0$.

8. Geographically the abundance of zooplankton was remarkably uniform throughout the Islands. On the average, however, the southeastern region, i.e. waters adjacent to the island of Hawaii yielded the lowest zooplankton volumes.

9. For the years 1950 and 1951 zooplankton samples collected in early and midsummer, during the skipjack season, were significantly larger than those taken in the late summer and fall after the close of the season. This decrease in the amount of zooplankton may bear some direct or indirect influence on the exodus of skipjack from Hawaiian waters, although the decrease was certainly not of sufficient degree to be a major or determining factor.

10. In a preliminary sampling experiment no significant differences in zooplankton abundance were found between the coastal waters of windward and leeward Oahu; differences were found, however, on both sides of the island among a series of stations extending from close to the shoreline to 5 miles offshore.

11. In only one of four cruises tested was there a significant correlation between zooplankton volumes and temperatures at a depth of 10 meters.

12. No significant correlation was found between zooplankton volumes and depth to the 70° isotherm for any of the four cruises tested.

13. During the late summer and fall of 1951 there were statistically significant changes in temperature at the 10-meter depth along a north-south section just west of Oahu which were not accompanied by any significant change in zooplankton concentration.

14. A comparison of zooplankton volumes and surface inorganic phosphate showed no significant correlation for Smith cruise 12, but a highly significant correlation for Smith cruise 17.

15. Correlations of zooplankton volume and dissolved oxygen as percent saturation at the 10-meter and the 100-meter depths gave low negative coefficients of no statistical significance.

16. An examination of temperature-salinity relations indicated that during July and October, 1951, the water surrounding the Hawaiian Islands yielded T-S curves characteristic of the "Eastern North Pacific Central Water Mass." The change in zooplankton abundance between the summer and fall conditions in 1951 was therefore not a reflection of a change of water mass.

17. In view of the uniformity in the amount of zooplankton and in the properties of the sea water forming its environment, it is not surprising that we found few instances of correlations with these properties. The few significant correlations that did occur are noteworthy, however, and suggest the idea that zooplankton and these factors are not directly related but are all governed by some as yet unexplained condition in the environment that is more fundamental and more variable than the temperature or the phosphate itself.

18. During the period of observation the amount of zooplankton in Hawaiian waters was greater than in the North Equatorial Current south of the Islands, but distinctly less than that found near the Equator from 5° N. to 5° S. latitude. Data from the Northern Holiday Expedition of Scripps Institution of Oceanography and collaborating agencies provide evidence that zooplankton increases markedly in abundance to the north and northeast of the Islands, reaching concentrations at 50° to 60° N. latitude several times those found near Hawaii and in the rich zone near the Equator.

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APPENDIX

Table 16. Zooplankton volumes collected on cruise 4, Hugh M. Smith, May 1950. All hauls were horizontal tows at the depth indicated (plus or minus up to 20 percent for the deeper hauls).

Station	Sample	Position		Date	Time[1]	Depth of haul, meters	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}
		North latitude	West longitude					
1	1	23°31'	161°07'	5/16/50	0934-1031	0	2255.3	10.7
1	2	"	"	"	0928-1045	50	2466.7	22.3
1	3	"	"	"	0921-1054	150	3168.1	8.3
1A	1	22°40'	161°15'	5/16/50	1722-1819	0	2604.7	25.7
1A	2	"	"	"	1716-1828	50	1956.3	22.3
1A	3	"	"	"	1710-1833	150	2060.7	10.8
2	2	21°52.5'	161°07'	5/17/50	0106-0224	100	2523.7	9.4
2	3	"	"	"	0100-0239	200	2347.2	13.3
2	4	"	"	"	0240-0341	0	2504.5	25.0
3	1	21°06'	161°05.5'	"	0925-1026	0	2699.9	2.3
3	2	"	"	"	0920-1031	50	2603.4	23.1
3	3	"	"	"	0913-1038	150	3364.7	3.7
4	1	20°14.5'	161°07.5'	"	1640-1741	0	2124.9	9.4
4	2	"	"	"	1635-1745	100	2229.0	10.1
4	3	"	"	"	1630-1750	200	2670.9	6.1
5	1	19°23.8'	161°06.3'	5/18/50	0028-0130	0	2231.5	21.5
5	2	"	"	"	0021-0136	50	2589.5	28.0
5	3	"	"	"	0015-0141	150	3494.0	7.9
6	1	19°25'	159°50'	"	1048-1148	0	2271.9	1.2
6	2	"	"	"	1040-1154	100	3392.9	6.0
6	3	"	"	"	1030-1201	200	3991.6	4.3
7	1	20°14.5'	159°50'	"	1835-1937	0	2967.4	142.3
7	2	"	"	"	1831-1941	50	2318.7	10.6
7	3	"	"	"	1825-1946	150	2633.4	6.7
8	1	21°05'	159°50'	5/19/50	0255-0357	0	2472.3	20.6
8	2	"	"	"	0250-0403	100	2821.9	17.0
8	3	"	"	"	0245-0408	200	2860.7	7.9
9	1	21°47.7'	159°51'	"	1000-1101	0	2585.2	4.9
9	2	"	"	"	0953-1107	50	2714.2	16.2
9	3	"	"	"	0945-1114	150	3865.7	5.5
10	1	22°40'	159°50	5/15/50	1456-1557	0	2742.2	5.1
10	2	"	"	"	1448-1623	100	4104.8	25.7
10	3	"	"	"	1440-1632	200	4560.7	6.5
11	1	23°30'	159°50	5/15/50	2316-0018	0	2704.2	44.6
11	2	"	"	"	2308-0022	50	2996.1	23.5
11	3	"	"	"	2300-0033	150	3541.9	8.5
12	1	22°40'	158°30'	"	0503-0604	0	2642.3[2]	35.3
12	2	"	"	"	0453-0612	100	3068.8	16.0
12	3	"	"	"	0445-0622	200	--	--

1/ Local civil time corresponding to + 10 zone time.

2/ Based on a calculated meter reading derived from average performance of current meter at similar vessel speed.

Table 16. (Cont'd)

Station	Sample	Position		Date	Time 1/	Depth of haul, meters	Water strained in m.3	Zooplankton cc./1000m.3
		North latitude	West longitude					
13	1	21°51'	158°29'	5/21/50	0150-0254	0	2906.2	29.3
13	2	"	"	"	0146-0307	100	2763.8	27.0
13	3	"	"	"	0140-0308	150	3033.6	10.0
13	4	21°45.5'	158°29'	"	0320-0425	50	2561.0	28.6
14	1	20°58'	158°26'	"	0950-1123	200	4334.0	3.2
14	2	"	"	"	0957-1117	100	3181.6	13.0
14	3	"	"	"	1005-1105	0	2265.3	9.6
15	1	20°12.3'	158°30'	"	1610-1713	0	2950.2	10.0
15	2	"	"	"	1605-1718	50	3033.6	16.6
15	3	"	"	"	1600-1724	150	3383.2	5.5
16	1	19°22'	158°28'	5/21/50	2253-2357	0	3017.4	14.8
16	2	"	"	"	2246-2404	100	3178.6	15.6
16	3	"	"	"	2239-2410	200	3975.3	6.2
17	1	18°32.5'	158°27.8'	5/22/50	0546-0648	0	2594.0	22.2
17	2	"	"	"	0541-0652	50	1444.3 3/	20.2 3/
17	3	"	"	"	0535-0700	150	3652.4	4.1
18	1	18°32'	157°05'	5/22/50	1531-1634	0	2768.9	2.2
18	2	"	"	"	1526-1645	100	3023.6	11.0
18	3	"	"	"	1520-1650	200	3433.8	5.6
19	1	19°24.3'	157°10'	5/23/50	0018-0119	0	3097.3	19.5
19	2	"	"	"	0013-0124	50	2010.3	36.2
19	3	"	"	"	0006-0131	150	2451.6	7.5
20	1	20°14'	157°03.5'	"	0911-1016	0	3346.3	4.0
20	2	"	"	"	0905-1022	100	2741.2	9.5
20	3	"	"	"	0859-1028	200	2758.6	8.0
21	1	20°58.7'	157°10.2'	"	1648-1749	0	2739.9	9.6
21	2	"	"	"	1641-1757	50	2284.7	31.5
21	3	"	"	"	1635-1803	150	2825.5	7.0
22	1	21°53'	157°08.5'	5/24/50	0120-0220	0	2705.6	30.0
22	2	"	"	"	0116-0227	100	2262.1	17.5
22	3	"	"	"	0110-0233	200	2544.8	10.0
23	1	22°40'	157°10'	5/14/50	1852-1952	0	2191.5	43.9
23	2	"	"	"	1845-1958	50	2419.9	27.1
23	3	"	"	"	1837-2004	150	3030.9	9.1
24	1	22°45'	155°49'	"	0820-0915	0	1254.7	29.5
24	2	"	"	"	0815-0931	100	2231.8	10.4
24	3	"	"	"	0807-0939	200	2971.0	8.1
25	1	21°54'	155°48.2'	5/24/50	1333-1434	0	2644.7	5.3
25	2	"	"	"	1330-1439	50	2275.0	23.4
25	3	"	"	"	1325-1445	150	2773.5	3.5
26	1	21°02.5'	155°45.5'	"	2107-2208	0	2815.1	22.1

3/ Gear fouled; questionable meter reading and zooplankton volume.

Table 16. (Cont'd)

Station	Sample	Position		Date	Time[1]	Depth of haul, meters	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}
		North latitude	West longitude					
26	2	21°02.5'	155°45.5'	5/24/50	2101-2213	100	2263.7	18.6
26	3	"	"	"	2055-2218	200	2631.1	6.0
27	1	20°30'	155°45'	5/25/50	0214-0314	0	3098.8	23.8
27	2	"	"	"	0208-0320	50	2786.9	22.2
27	3	"	"	"	0200-0326	150	3069.5	8.9
28	1	18°33.5'	155°48'	"	1740-1844	0	3169.4	16.4
28	2	"	"	"	1735-1850	100	2404.0	7.4
28	3	"	"	"	1730-1855	200	2787.0	5.5

Table 17. Zooplankton volumes collected on cruise 6, Hugh M. Smith, August 1950. All hauls were horizontal tows at the depth indicated (plus or minus up to 20 percent for the deeper hauls).

Station	Sample	Position: North latitude	Position: West longitude	Date	Time[1]	Depth of haul, meters	Water strained in m.³	Zooplankton cc./1000m.³
1	1	23°30'	161°05.5'	8/25/50	1417-1518	0	2046.6	5.2
1	2	"	"	"	1412-1523	50	1993.3	13.9
1	3	"	"	"	1405-1531	150	3143.3	5.6
1A	1	22°45'	161°15'	"	2048-2148	0	2634.5	8.1
1A	2	"	"	"	2040-2155	50	2810.6	27.0
1A	3	"	"	"	2030-2206	150	3316.3	7.3
2	1	21°57'	161°05'	8/26/50	0331-0433	0	2255.7	7.4
2	2	"	"	"	0323-0441	100	3069.2	19.0
2	3	"	"	"	0315-0449	200	4007.6	7.0
3	1	21°09.5'	161°03'	"	1057-1158	0	2149.8	2.4
3	2	"	"	"	1052-1203	50	2067.7	11.8
3	3	"	"	"	1042-1211	150	2595.6	3.0
4	1	20°20'	161°05'	"	1809-1910	0	2251.3	8.8
4	2	"	"	"	1801-1918	100	2795.5	8.4
4	3	"	"	"	1750-1927	200	3566.6	6.1
5	1	19°25.5'	161°05'	8/27/50	0108-0210	0	2309.5	7.4
5	2	"	"	"	0055-0222	150	3112.2	12.8
5	3	"	"	"	0042-0232	300	3701.0	6.0
6	1	19°26'	159°50'	"	1007-1108	0	2392.6	4.8
6	2	"	"	"	0958-1116	100	2482.6	9.4
6	3	"	"	"	0950-1126	200	3982.7	7.8
7	1	20°16.5'	159°44'	"	1911-2012	0	3033.6	16.5
7	2	"	"	"	1903-2024	50	3220.6	14.5
7	3	"	"	"	1853-2036	150	4295.8	8.7
8	1	20°54'	159°47'	8/28/50	0527-0628	0	2840.4	14.8
8	2	"	"	"	0516-0639	100	2665.7	12.8
8	3	"	"	"	0507-0647	200	3684.0	10.2
9	1	21°50.1'	159°50.5'	"	1403-1507	0	2456.3	4.3
9	2	"	"	"	1358-1512	50	2486.8	10.2
9	3	"	"	"	1350-1520	150	3061.5	5.5
10	1	22°48.5'	159°51'	8/24/50	2307-0011	0	2334.5	11.4
10	2	"	"	"	2253-0031	150	3609.3	15.3
10	3	"	"	"	2239-0041	300	5799.4	7.3
11	1	23°27'	159°45.7'	8/25/50	0517-0617	0	2373.9	17.9
11	2	"	"	"	0510-0624	50	2847.2	14.2
11	3	"	"	"	0500-0633	150	4214.0	8.8
12	1	22°43.3'	158°26'	8/24/50	1314-1415	0	2706.0	3.7
12	2	"	"	"	1302-1424	100	2900.5	11.1
12	3	"	"	"	1250-1432	200	3951.4	5.9

1/ Local civil time corresponding to + 10 zone time.

Table 17. (Cont'd)

Station	Sample	Position: North latitude	Position: West longitude	Date	Time[1]	Depth of haul, meters	Water strained in m.^{3}	Zooplankton cc./1000m.^{3}
13	1	21°50'	158°30.6'	8/24/50	0541-0643	0	2007.5	42.6
13	2	"	"	"	0536-0649	50	3137.8	29.0
13	3	"	"	"	0528-0657	150	3564.4	9.0
14	1	20°50'	158°32'	8/18/50	1730-1830	0	2286.6	11.2
14	2	"	"	"	1725-1838	100	2173.1	10.1
14	3	"	"	"	1720-1844	200	2250.1	6.9
15	1	20°15'	158°24'	8/19/50	0004-0108	0	2717.6	19.6
15	2	"	"	"	2352-0121	150	3807.3	21.0
15	3	"	"	"	2340-0132	300	5280.2	11.4
16	1	19°24'	158°23'	8/19/50	0810-0911	0	3380.4	7.4
16	2	"	"	"	0759-0922	100	3484.3	7.5
16	3	"	"	"	0750-0930	200	3064.9	8.6
17	1	18°30'	158°29'	"	1536-1636	0	2239.5	2.0
17	2	"	"	"	1528-1649	100	3314.6	16.0
17	3	"	"	"	1522-1654	150	4090.8	4.0
18	1	18°22'	157°07.5'	8/20/50	0239-0341	0	1609.4	36.8
18	2	"	"	"	0228-0351	100	2430.1	24.0
18	3	"	"	"	0210-0356	200	3608.6	11.7
19	1	19°31'	157°10'	"	2329-0030	0	2727.9	23.6
19	2	"	"	"	2317-0040	100	3929.9	20.6
19	3	"	"	"	2311-0045	150	4781.8	13.3
20	1	20°23'	157°07'	8/21/50	0859-1000	0	2112.4	3.5
20	2	"	"	"	0842-1011	150	3147.3	10.5
20	3	"	"	"	0815-1021	300	4289.0	7.6
21	1	20°55.5'	157°10.3'	8/21/50	1426-1527	0	2767.3	14.1
21	2	"	"	"	1418-1533	100	2447.1	6.9
21	3	"	"	"	1412-1537	150	2806.2	7.1
22	1	21°50'	157°10.5'	8/23/50	1810-1911	0	2586.4	88.3
22	2	"	"	"	1802-1920	100	3070.2	12.9
22	3	"	"	"	1754-1928	200	4067.0	8.7
23	1	22°39'	157°13'	"	1038-1138	0	2840.8	1.9
23	2	"	"	"	1030-1144	50	2990.0	12.0
23	3	"	"	"	1020-1154	150	3640.0	5.4
24	1	22°40'	155°47'	8/22/50	2212-2313	0	2903.5	17.1
24	2	"	"	"	2201-2324	100	3338.2	31.2
24	3	"	"	"	2149-2334	200	5030.5	11.3
25	1	21°56.3'	155°45.3'	"	1519-1620	0	2815.6	4.8
25	2	"	"	"	1510-1633	150	3431.8	8.5
25	3	"	"	"	1500-1644	300	3916.6	8.9
26	1	21°03.5'	155°60'	"	0728-0830	0	2107.3	14.0
26	2	"	"	"	0720-0840	100	3071.7	8.6
26	3	"	"	"	0711-0850	200	4688.0	5.2
27	1	20°30'	155°47.2'	"	0152-0253	0	2178.2	25.7
27	2	"	"	"	0148-0258	50	2305.0	25.6
27	3	"	"	"	0140-0304	150	3884.7	7.2
28	1	18°32.5'	156°07'	8/20/50	1157-1256	0	2219.6	3.2
28	2	"	"	"	1145-1303	100	2578.0	21.9
28	3	"	"	"	1136-1307	200	4080.2	7.1

Table 18. Zooplankton volumes collected on cruise 10, Hugh M. Smith, July 1951. All hauls were oblique tows to 200 meters depth except at stations 15 and 21 located in shoal water.

Station	Position		Date	Time 1/	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}	
	North latitude	West longitude				Sample volume	Adjusted volume
1	20°18'	159°19.5'	7/21/51	0907-0940	1404.1	31.8	38.7
2	21°02.5'	159°14'	7/21/51	1753-1828	1754.2	19.1	18.7
3	21°44'	159°13'	7/21/51	2352-0020	1396.0	28.5	22.0
4	22°22'	159°15'	7/22/51	0715-0752	1600.1	20.6	23.0
5	23°02'	159°15'	7/22/51	1354-1419	1244.6	49.2	61.7
6	22°48'	158°24.5'	7/22/51	2215-2240	1336.2	41.2	32.6
7	22°08'	158°24'	7/23/51	0428-0505	2076.4	31.4	28.7
8	21°29'	158°25'	7/23/51	1125-1159	1946.3	15.6	20.2
8A	21°26.5'	158°24'	7/19/51	1427-1502	1896.5	27.1	33.0
9	20°50'	158°25'	7/23/51	2330-0000	1040.8	36.5	28.2
10	20°17'	158°21.5'	7/24/51	0608-0641	1683.5	36.8	37.7
11	18°45'	157°30'	7/24/51	2122-2157	1887.7	27.3	22.1
12	19°32'	157°28'	7/25/51	0508-0539	1866.0	15.5	14.8
13	20°07'	157°28'	7/25/51	1052-1125	1450.7	12.5	16.1
14	20°43'	157°29'	7/25/51	1617-1650	1874.0	13.0	14.2
15 2/	21°02.5'	157°29'	7/25/51	1934-2004	1276.6	38.9	34.8
16	21°17'	157°26'	7/25/51	2302-2335	1872.7	26.4	20.5
17	21°44.5'	157°29'	7/26/51	0407-0439	1532.8	33.1	29.6
18	22°08.5'	157°32'	7/26/51	0913-0945	1595.6	20.6	25.1
19	21°51'	156°45'	7/26/51	1744-1819	1848.3	21.3	21.3
20	21°10'	156°35'	7/27/51	0000-0030	1666.1	41.8	32.3
21 3/	20°50	156°45'	7/27/51	0358-0429	2013.4	11.9	10.7
22	20°20'	156°39.5'	7/27/51	0915-0947	1937.5	17.5	21.6
23	19°37.5'	156°40'	7/27/51	1457-1530	1662.6	18.8	22.2
24	19°01.5'	156°40'	7/27/51	2020-2050	1355.6	47.2	39.9
25	18°22'	156°40'	7/28/51	1039-1109	1557.4	13.4	17.2
26	18°10'	155°35'	7/28/51	2120-2150	1454.3	24.1	19.5
27	18°37'	154°26.5'	7/29/51	0955-1027	1284.4	11.0	13.9
28	19°13.5'	154°30'	7/29/51	1405-1437	1851.1	16.6	20.5
29	19°54.5'	154°29'	7/29/51	2008-2038	1342.7	20.5	17.7
30	20°30'	154°30'	7/30/51	0153-0224	1535.6	22.7	18.1
31	21°05.5'	154°53.5'	7/30/51	0740-0810	1482.5	35.7	40.6
32	21°25'	155°30'	7/30/51	1343-1414	1721.1	20.9	26.2
33	21°51'	156°45'	7/30/51	2340-0011	1690.9	35.4	27.3

1/ Local civil time corresponding to + 10 zone time.

2/ Stair-stepped oblique haul to 40 meters depth.

3/ " " " " " 30 meters depth.

Table 19. Zooplankton volumes collected on cruise 12, Hugh M. Smith, October-November 1951. All hauls were oblique tows to 200 meters depth except at stations 15 and 21 located in shoal water.

Station	Position		Date	Time[1]	Water strained in $m.^3$	Zooplankton, cc./1000 $m.^3$	
	North latitude	West longitude				Sample volume	Adjusted volume
1	20°18'	159°18'	10/24/51	0413-0454	2804.6	37.0	33.6
2	21°01'	159°14'	10/24/51	1152-1222	1857.8	20.3	27.0
3	21°46'	159°12'	10/24/51	2119-2156	1984.3	24.9	19.7
4	22°28'	159°14'	10/25/51	0214-0242	1580.9	27.7	21.9
5	23°02'	159°15'	10/25/51	0817-0845	1345.5	19.6	23.5
6	22°46'	158°25'	10/25/51	1552-1628	2251.0	23.3	26.2
7	22°09'	158°24'	10/25/51	2244-2314	1389.2	24.8	18.8
8	21°30'	158°26'	10/26/51	0515-0549	2121.9	34.6	33.7
9	20°46'	158°28'	10/26/51	1155-1225	1425.7	21.7	28.8
10	20°17.5'	158°22'	10/26/51	1733-1806	1947.3	18.0	18.4
11	18°47'	157°27'	10/27/51	0810-0838	1249.5	20.5	24.2
12	19°28.5'	157°27'	10/27/51	1520-1548	2088.5	19.6	23.1
13	20°06'	157°28'	10/27/51	2222-2258	2191.6	26.2	20.1
14	20°40'	157°28'	10/28/51	0527-0602	2257.6	20.6	20.1
15[2]	21°05'	157°28'	10/28/51	1032-1058	1497.3	13.0	17.0
16	21°17'	157°25'	10/28/51	1249-1319	2076.1	10.9	14.3
17	21°48'	157°29'	10/28/51	1826-1856	1492.0	22.5	21.4
18	22°12'	157°31'	10/28/51	2339-0009	1410.7	22.3	16.8
19	21°50'	156°47'	10/29/51	0725-0759	2179.0	13.7	15.5
20	21°09.5'	156°35'	10/29/51	1350-1421	2283.9	12.9	16.5
21[3]	20°49'	156°45'	10/29/51	1745-1813	1594.3	21.6	21.8
22	20°22'	156°39'	10/29/51	2245-2317	1409.7	18.8	14.3
23	19°44'	156°44'	10/30/51	0632-0710	2424.9	13.6	14.7
24	19°04'	156°38'	10/30/51	1520-1552	1849.7	19.0	22.4
25	18°21'	156°38.5'	10/30/51	2223-2255	1586.4	26.7	20.5
26	18°03'	155°33'	10/31/51	0737-0809	1393.6	11.8	13.6
27	18°39.5'	154°28'	10/31/51	1730-1803	1669.8	14.2	14.6
28	19°16.5'	154°32'	10/31/51	2323-2357	1399.7	22.4	16.9
29	20°04'	154°33'	11/1/51	0615-0648	1791.3	15.7	16.5
30	20°37.5'	154°28'	11/1/51	1126-1158	1652.4	9.3	12.3

1/ Local civil time corresponding to + 10 zone time.

2/ Stair-stepped oblique haul to 35 meters depth.

3/ " " " " " 25 meters depth.

Table 20. Zooplankton volumes collected on cruises 17, *Hugh M. Smith* September 1952. All hauls were oblique tows to 200 meters depth.

Station	Position		Date	Time 1/	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}	
	North latitude	West longitude				Sample volume	Adjusted volume
1	20°20'	159°14'	9/6/52	0314-0344	--	--	--2/
2	21°11'	159°17'	9/6/52	1010-1047	2009.1	25.0	31.0
3	21°43'	159°16'	9/6/52	1535-1606	1340.5	24.4	27.5
4	22°27.5'	159°15'	9/6/52	2221-2251	1330.3	37.7	30.1
5	23°14	159°18'	9/7/52	0519-0554	1728.0	29.7	29.1
6	23°09'	158°26'	9/7/52	1222-1253	1614.9	23.5	29.7
7	22°30'	158°20'	9/7/52	1810-1841	1488.7	23.6	23.1
8	21°42.5'	158°20'	9/8/52	0106-0139	1738.1	31.0	24.8
9	20°58'	158°14'	9/8/52	1136-1205	1357.5	19.1	24.3
10	20°16'	158°15'	9/8/52	1740-1811	1401.7	25.5	25.5
11	19°26'	158°15'	9/9/52	0011-0042	1643.3	41.0	32.4
12	18°52'	157°21'	9/9/52	0922-0950	1312.3	22.3	27.1
13	19°29'	157°15.5'	9/9/52	1507-1540	1716.4	20.1	23.4
14	20°15'	157°22'	9/9/52	2136-2214	2252.6	31.9	26.0
15	20°43'	157°26'	9/10/52	0313-0346	1614.6	37.0	31.8
16	21°47.5'	157°18'	9/10/52	1149-1216	1109.8	31.2	39.6
17	22°26'	157°16'	9/10/52	1802-1835	1631.9	24.9	24.4
18	21°45'	156°20'	9/11/52	0308-0340	1365.7	47.2	40.6
19	21°17'	156°15.5'	9/11/52	0835-0908	1450.6	20.8	24.6
20	21°02'	155°37'	9/11/52	1432-1503	1583.5	17.4	20.9
21	20°28.5'	155°37'	9/11/52	1930-2002	1679.4	35.0	31.7
22	20°12'	156°19'	9/12/52	0152-0228	1587.2	22.9	18.9
23	19°30'	156°15'	9/12/52	0759-0830	2326.2	21.3	24.4
24	18°46'	156°14'	9/12/52	1401-1434	1732.7	19.0	23.1
25	18°10'	155°33'	9/12/52	2212-2245	1408.1	31.0	25.0
26	18°49'	155°32'	9/13/52	0421-0453	1497.3	22.2	20.4
27	18°46'	154°39'	9/13/52	1155-1226	1545.7	19.1	24.2
28	19°30'	154°26'	9/13/52	1828-1900	1408.9	24.6	23.6
29	20°13'	154°28'	9/14/54	0112-0142	1667.0	25.6	20.5
30	20°54'	154°30'	9/14/52	0740-0814	1615.4	20.9	23.6
31	21°44'	155°34'	9/14/52	1750-1820	1517.1	20.2	20.2

1/ Local civil time corresponding to + 10 zone time.

2/ Sample lost at sea as result of torn net.

Table 21. Zooplankton volumes collected on cruise 8, *John R. Manning*. All hauls were oblique tows to 200 meters depth.

Station	Position		Date	Time[1]	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}	
	North latitude	West longitude				Sample volume	Adjusted volume
1	22°48'	158°25'	9/24/51	0640-0654	1653.4	24.0	25.5
2	22°27'	158°25'	9/24/51	0930-1005	1328.2	22.7	30.1
3	22°09'	158°25'	9/24/51	1217-1253	1556.9	23.1	32.4
4	21°47'	158°25'	9/24/51	1506-1545	1585.9	17.5	21.8
5	21°27'	158°25'	9/24/51	1837-1918	1989.9	24.6	22.5
6	21°07'	158°25'	9/24/51	2132-2210	1964.6	34.1	25.4
7	20°47'	158°25'	9/25/51	0021-0100	1608.8	25.9	18.5
8	20°27'	158°25'	9/25/51	0305-0343	1549.3	28.0	22.4
9	20°06'	158°25'	9/25/51	0606-0642	1510.5	17.3	17.8
15	22°48'	158°25'	10/1/51	0204-0240	1427.1	24.6	18.6
16	22°28'	158°25'	10/1/51	0455-0537	1618.0	25.5	24.0
17	22°08'	158°25'	10/1/51	0741-0816	1632.1	15.0	17.8
18	21°48'	158°25'	10/1/51	1026-1054	1280.4	14.6	20.1
19	21°27.5'	158°25'	10/1/51	1430-1508	1931.6	15.2	19.8
20	21°07.5'	158°25'	10/1/51	1714-1748	1521.2	17.6	18.2
21	20°47'	158°25'	10/1/51	2007-2040	1475.3	25.3	20.8
22	20 27'	158 25'	10/1/51	2253-2329	1424.1	24.9	17.7
23	20°07'	158°25'	10/2/51	0149-0222	1070.3	23.1	17.2
27	22°48'	158°25'	10/7/51	2343-0012	1032.9	26.7	18.9
28	22°28'	158°25'	10/8/51	0230-0306	1693.6	31.6	24.3
29	22°08'	158°25'	10/8/51	0525-0600	1556.5	22.5	21.8
30	21°48'	158°25'	10/8/51	0817-0850	1288.4	12.9	16.1
31	21°27.5'	158°25'	10/8/51	1107-1140	1574.8	17.1	24.0
32	21°07.5'	158°25'	10/8/51	1355-1427	1264.7	13.8	18.3
33	20 47'	158 25'	10/8/51	1640-1710	1329.0	15.7	17.2
34	20°27'	158°25'	10/8/51	1921-1954	1790.9	25.4	22.0
35	20°07'	158°25'	10/8/51	2225-2259	1891.4	35.3	25.6
38	22°48'	158°25'	10/15/51	0330-0402	1549.7	31.5	25.9
39	22°28'	158°25'	10/15/51	0612-0645	1544.9	17.9	18.4
40	22°08'	158°25'	10/15/51	0859-0931	1709.3	14.0	18.2
41	21°48'	158°25'	10/15/51	1144-1214	1318.6	13.9	19.6
42	21°27.5'	158°25'	10/15/51	1450-1522	1161.8	15.0	19.1
43	21°07.5'	158°25'	10/15/51	1737-1808	1373.8	16.5	16.5
44	20°47'	158°25'	10/15/51	2021-2049	1230.1	29.5	23.7
45	20°27'	158°25'	10/15/51	2308-2341	1509.5	24.8	17.7
46	20°07'	158°25'	10/16/51	0150-0222	1028.3	33.6	24.9

1/ Local civil time corresponding to + 10 zone time.

Table 22. Zooplankton volumes collected on cruise 9, John R. Manning. All hauls were oblique tows to the depth indicated.

Station	Sample	Position: North latitude	Position: West longitude	Date	Time1/	Depth of haul meters	Water strained in m.^{3}	Zooplankton cc./1000 m.^{3}: Sample volume	Zooplankton cc./1000 m.^{3}: Adjusted volume
1	1	22°08'	158°24'	11/13/51	2252-2322	200	1378.9	31.2	26.8
1	2	22°08'	158°23.5'	11/13/51	2340-0009	200	1130.9	29.3	25.0
1	3	22°08'	158°23'	11/14/51	0035-0108	200	1421.0	25.0	21.5
1	4	22°08'	158°22.5'	11/14/51	0128-0159	200	1411.1	23.2	20.1
2	1	22°09'	158°24'	11/14/51	1033-1110	200	1578.8	24.7	28.8
2	2	22°09'	158°25'	11/14/51	1127-1158	200	1179.7	29.1	34.1
2	3	22°09'	158°25'	11/14/51	1215-1244	200	1174.3	24.9	29.2
2	4	22°09'	158°26'	11/14/51	1305-1336	200	1132.1	26.6	30.9
3	1	22°48'	158°24'	11/14/51	2234-2311	200	1562.4	33.7	29.0
3	2	22°48'	158°23.5'	11/14/51	2330-0000	200	1242.5	34.2	29.2
3	3	22°48'	158°23'	11/15/51	0015-0045	200	1125.9	34.0	29.0
3	4	22°48'	158°22.5'	11/15/51	0101-0132	200	1252.4	28.3	24.4
4	1	22°48'	158°24'	11/15/51	1025-1055	200	1251.9	23.2	27.0
4	2	22°48.5'	158°24'	11/15/51	1117-1149	200	1182.0	22.9	26.9
4	3	22°49'	158°24'	11/15/51	1205-1236	200	1203.3	18.4	21.6
4	4	22°49.5'	158°24'	11/15/51	1250-1319	200	1109.6	22.9	26.7
5	1	22°08'	158°24'	11/15/51	1759-1827	200	1304.6	24.2	23.9
5	2	22°08'	158°26'	11/15/51	1843-1915	200	1168.8	30.4	29.2
5	3	22°08'	158°28'	11/15/51	1929-2000	300	1440.5	23.1	--
5	4	22°09'	158°30'	11/15/51	2032-2111	300	1449.0	27.8	--
5	5	22°09'	158°32'	11/15/51	2128-2224	500	1658.4	24.5	--
5	6	22°09'	158°34'	11/15/51	2243-2345	500	1981.0	15.7	--
5	7	22°10'	158°35'	11/16/51	0021-0046	200	1038.0	35.2	30.1
5	8	22°10'	158°37'	11/16/51	0102-0127	200	907.3	32.4	27.9
5	9	22°10'	158°39'	11/16/51	0138-0217	300	1368.3	21.9	--
5	10	22°11'	158°41'	11/16/51	0233-0310	300	1221.1	22.8	--
5	11	22°11'	158°42'	11/16/51	0324-0422	500	1975.3	19.4	--
5	12	22°11'	158°43'	11/16/51	0442-0546	500	2131.0	17.4	--
5	13	22°12'	158°44'	11/16/51	0615-0645	200	1168.8	23.8	24.2
5	14	22°12'	158°46'	11/16/51	0700-0728	200	1140.5	21.6	22.8

1/ Local civil time corresponding to + 10 zone time.

Table 22. (Cont'd)

Station	Sample	Position		Date	Time1/	Depth of haul meters	Water strained in $m.^3$	Zooplankton cc./1000 $m.^3$	
		North latitude	West longitude					Sample volume	Adjusted volume
5	15	22°12'	158°48'	11/16/51	0743-0819	300	1485.8	19.2	--
5	16	22°11'	158°49'	11/16/51	0839-0924	300	1859.3	13.6	--
5	17	22°11'	158°50'	11/16/51	0942-1040	500	2453.6	11.6	--
5	18	22°11'	158°51'	11/16/51	1058-1148	500	1825.4	12.1	--
5	19	22°10'	158°53'	11/16/51	1213-1238	200	1100.9	17.2	20.2
5	20	22°10'	158°54'	11/16/51	1249-1314	200	1098.6	20.1	23.4
5	21	22°10'	158°55'	11/16/51	1324-1405	300	1538.4	14.9	--
5	22	22°10'	158°56'	11/16/51	1419-1458	300	1601.2	12.6	--
5	23	22°10'	158°57'	11/16/51	1509-1614	500	2163.8	12.4	--
5	24	22°10'	158°58'	11/16/51	1646-1739	500	2006.5	10.0	--
7	1	21°29.5'	157°50'	11/18/51	1002-1039	5	1575.7	12.8	--
7	2	21°28.4'	157°49.8'	11/18/51	1044-1112	5	1147.8	19.9	--
8	1	21°30.8'	157°49.1'	11/18/51	0930-0950	5	1367.5	22.9	--
8	2	21°30.8'	157°49.1'	11/18/51	1149-1217	5	1360.7	30.9	--
9	1	21°31.2	157°48.9'	11/18/51	1250-1322	20	948.0	28.2	--
9	2	21°31.2'	157°48.6'	11/18/51	1333-1403	20	1376.8	31.1	--
10	1	21°31.9'	157°47.8'	11/18/51	1418-1448	125	1140.5	28.1	--
10	2	21°31.9'	157°47.8'	11/18/51	1457-1525	125	1106.5	24.6	--
11	1	21°33.2'	157°46'	11/18/51	1539-1606	200	1157.5	26.6	28.3
11	2	21°33.2'	157°46'	11/18/51	1616-1640	200	939.6	24.1	25.8
12	1	21°26.7'	158°12'	11/18/51	2249-2317	10	1225.4	24.8	--
12	2	21°26.7'	158°12'	11/18/51	2323-2351	10	1253.7	23.9	--
13	1	21°26.4'	158°12.5'	11/19/51	0002-0033	30	1615.1	32.1	--
13	2	21°26.4'	158°12.5'	11/19/51	0057-0129	30	1714.4	33.8	--
14	1	21°26'	158°13.6'	11/19/51	0145-0214	200	1237.5	34.7	30.2
14	2	21°26'	158°13.5'	11/19/51	0226-0256	200	1201.3	31.0	27.4
15	1	21°25.3'	158°14.5'	11/19/51	0308-0337	200	1166.0	30.2	27.3
15	2	21°25.3'	158°14.5'	11/19/51	0346-0418	200	1086.7	22.4	20.7
16	1	21°24.4'	158°16.3'	11/19/51	0434-0500	200	1044.3	30.8	29.2
16	2	21°24.4'	158°16.3'	11/19/51	0510-0537	200	929.0	28.6	27.8

1/ Local civil time corresponding to + 10 zone time.