ZOOPLANKTON ABUNDANCE IN HAWAIIAN WATERS, 1953-54

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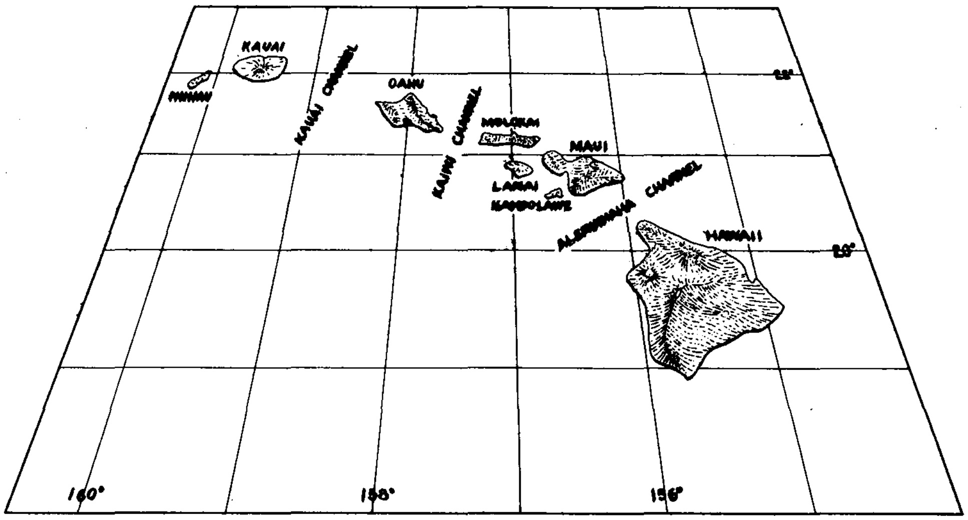

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By

Joseph E. King
Fishery Research Biologist

and

Thomas S. Hida
Fishery Aid
Pacific Oceanic Fishery Investigations
Honolulu, T. H.

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ABSTRACT

This report describes the results of zooplankton sampling on 10 cruises in Hawaiian waters during the years 1953-54. The collections were obtained with 1-meter nets employed in 30-minute oblique hauls to about 200 meters. A short series of 0 - 100 m. hauls was made for purposes of comparison.

The abundance of zooplankton was remarkably uniform throughout island waters. Although the eastward or upstream portion of the survey area produced consistently low catches, there were no statistically significant differences between cruises, between windward and leeward areas or among six subareas. The large eddies characteristic of the surface currents, particularly to the leeward of the islands, apparently had no influence on variations in the volume of zooplankton. Also, evidence of enrichment from upwelling, land drainage, or other littoral influence was obscure or lacking.

Zooplankton volumes were not significantly correlated with water temperature, salinity, inorganic phosphate, thermocline depth, or skipjack catch. There was a trend, however, of increasing temperature, zooplankton abundance, and skipjack catch from March to July, but we doubt that there were direct or causal relationships among these variables.

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In conjunction with researches on the tuna resources of the Hawaiian offshore waters, the Pacific Oceanic Fishery Investigations (POFI) has studied the geographical and seasonal variations in zooplankton abundance. Tuna presence and abundance may be dependent to a great extent upon food supply, and zooplankton is directly or indirectly an important food source for these large, oceanic fishes (Reintjes and King 1953, King and Ikehara 1956).

During the years 1950 to 1954 plankton sampling was conducted on 17 POFI cruises in Hawaiian waters. An earlier report (King and Hida 1954) presented an analysis of collections obtained on 7 cruises in 1950-52. The present report is concerned with collections from 10 cruises in 1953-54. In addition to zooplankton sampling, on all cruises a number of observations and measurements were made of the chemical and physical environment. For example, two of the cruises included oceanographic observations to 500 - 1,200 meters depth, with temperature, salinity, and phosphate measured at each depth sampled. Bathythermograph observations were made routinely on all cruises. The results of the oceanographic observations have appeared in previous publications (McGary 1955, Seckel 1955).

The primary purpose of this report is to present the results of the plankton sampling, information which is applicable to the study of the abundance and distribution of skipjack, Katsuwonus pelamis (Linnaeus), in Hawaiian waters. The skipjack catch is characterized by a marked seasonal variation and is also subject to annual fluctuations which are as yet unexplained. In the years 1950 and 1951, zooplankton samples collected in midsummer during the height of the skipjack season were about 20 percent larger in volume than those taken in late summer and fall after the close of the season (King and Hida 1954). This difference in relative food abundance may have had no direct influence, however, on skipjack presence and distribution.

One hypothesis seeming worthy of further 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 was drawn (King and Hida 1954) connecting the various islands of the group and thus dividing the island waters into windward and leeward areas. In order to examine statistically differences between, and within, these major areas, they were subdivided into 6 subareas, 3 leeward and 3 windward of the islands.

Although the abundance of zooplankton was again found to be remarkably uniform, geographically, throughout the Hawaiian area, the easterly region adjacent to, and upstream from, the island of Hawaii consistently yielded the lowest volumes. With the benefit of recent analyses of the physical environment (McGary 1955, Seckel 1955) we can now better understand the general uniformity in the plankton and also the causes for small but possibly significant variations.

SOURCE OF MATERIAL

This study is based primarily on 215 quantitative zooplankton collections obtained on 6 cruises of M/V Hugh M. Smith and 4 cruises of M/V Charles H. Gilbert. Several of these expeditions were of short duration and consisted of repeated visits to three set locations, or stations, which were selected as being representative of plankton and hydrographic conditions on the skipjack fishing grounds. Smith cruises 20 and 21 were of longer duration and provided synoptic observations of both insular and oceanic waters throughout the Hawaiian area. On Gilbert cruise 16, a short series of hauls was made to determine the difference in catch of zooplankton and tuna larvae in 0- to 100-meter and in 0- to 200-meter tows during day and night hours.

The approximate locations of the plankton stations are shown in figures 1 to 4. More exact positions together with date and hour of hauling, amount of water strained, and the zooplankton volumes for each station are given in the Appendix, tables 6 to 11. Data collected on earlier cruises in 1950-52 and published in a previous report (King and Hida 1954), are also utilized in this study.

METHODS

All of the collections were obtained with 1-meter (mouth diameter) nets of 30XXX silk grit gauze (apertures averaging 0.65 mm. in width), equipped with flowmeters. Oblique hauls of approximately 30 minutes' duration to a depth of about 200 meters were employed at most stations. At station C, one of the "permanent" stations visited on a number of cruises, hauls were made to 40 or 50 meters because of the shallow depth of water (50 to 100 meters); on Gilbert cruise 16 a short series of oblique hauls was made to 100 meters depth. A more complete description of the net used and of the method of hauling plus the calculation of sampling depth and amount of water strained have been provided in an earlier report (King and Demond 1953).

The method of processing the samples in the laboratory was essentially as employed by King and Hida (1954). Following the usual procedure at the POFI laboratory, the volume of all organisms less than 2 cm. in length plus the volume of organisms 2 to 5 cm. in length that might be considered of significant nutritional value, were combined to give a single volume measurement for each sample. This figure was divided by the estimated amount of water passing through the net, as determined from the flowmeter reading, to obtain the volume of zooplankton, as food, per unit of water strained.

The volumes from all standard hauls were adjusted to remove the effects of diurnal variation by the method described by King and Hida (1954). Briefly, this consists of calculating the regression of plankton volume on solar time of day, the latter expressed as a sine function. The zooplankton volumes are increased or reduced dependent upon the hour of hauling and adjusted to 0600 or 1800 hours when the corresponding sine value is 0. Solar time is presently used in the calculations. The method provides a reasonably good correction for day-night differences as judged by the significance of the "t" values and the night/day ratios for the adjusted volumes (table 1).

The data from the 7 cruises listed in table 1 were adjusted by individual cruise. A pooled regression coefficient (b = 0.1110) calculated from the combined data of these 7 cruises, most of which provided rather thorough coverage of the Hawaiian area and during which stations were visited consecutively regardless of time of day or night, was used in adjusting the few volumes of cruises 11, 12, 13, and 16 of the Gilbert and cruises 22, 23, 24, and 26 of the Smith. On these latter cruises sampling was not conducted around the clock, or there were too few data to be adjusted by individual cruise. Throughout this report we have employed the adjusted volumes, except when noted for shallow hauls.

VARIATION WITH DEPTH

A short series of experimental hauls made on Gilbert cruise 16 provided an opportunity to compare the difference between the standard, 200-meter, oblique haul and a 100-meter, oblique haul in the catch of zooplankton during both day and night periods. A special effort was made to obtain an accurate count of the tuna larvae and other fish larvae in these samples. The results, summarized in table 2, demonstrate the superiority of night over day and of shallow over deeper hauls in the capture of zooplankton, tuna larvae, and other fish larvae. Disregarding depth of hauling, the night samples averaged 2.5 times as great in bulk as the day samples. In respect to depth, disregarding time of hauling, the 100-meter hauls averaged 1.6 times as great as the deeper 200-meter hauls.

Although the data are very limited they provide some other interesting conclusions. For zooplankton as a whole the difference in catch rate between 0- to 100- and 0- to 200-meter hauls is slightly less in the daytime than at night, resulting, we believe, from a downward migration and general dispersal of the plankton throughout the upper layers during the day, and its greater concentration near the surface at night. The tuna and other fish larvae were generally more abundant near the surface at both times, but the vertical differences in their distribution were not quite as great at night as in the day. Also in respect to the fish larvae, there was a higher night/day ratio for the 200-meter hauls than for the 100-meter hauls. Both

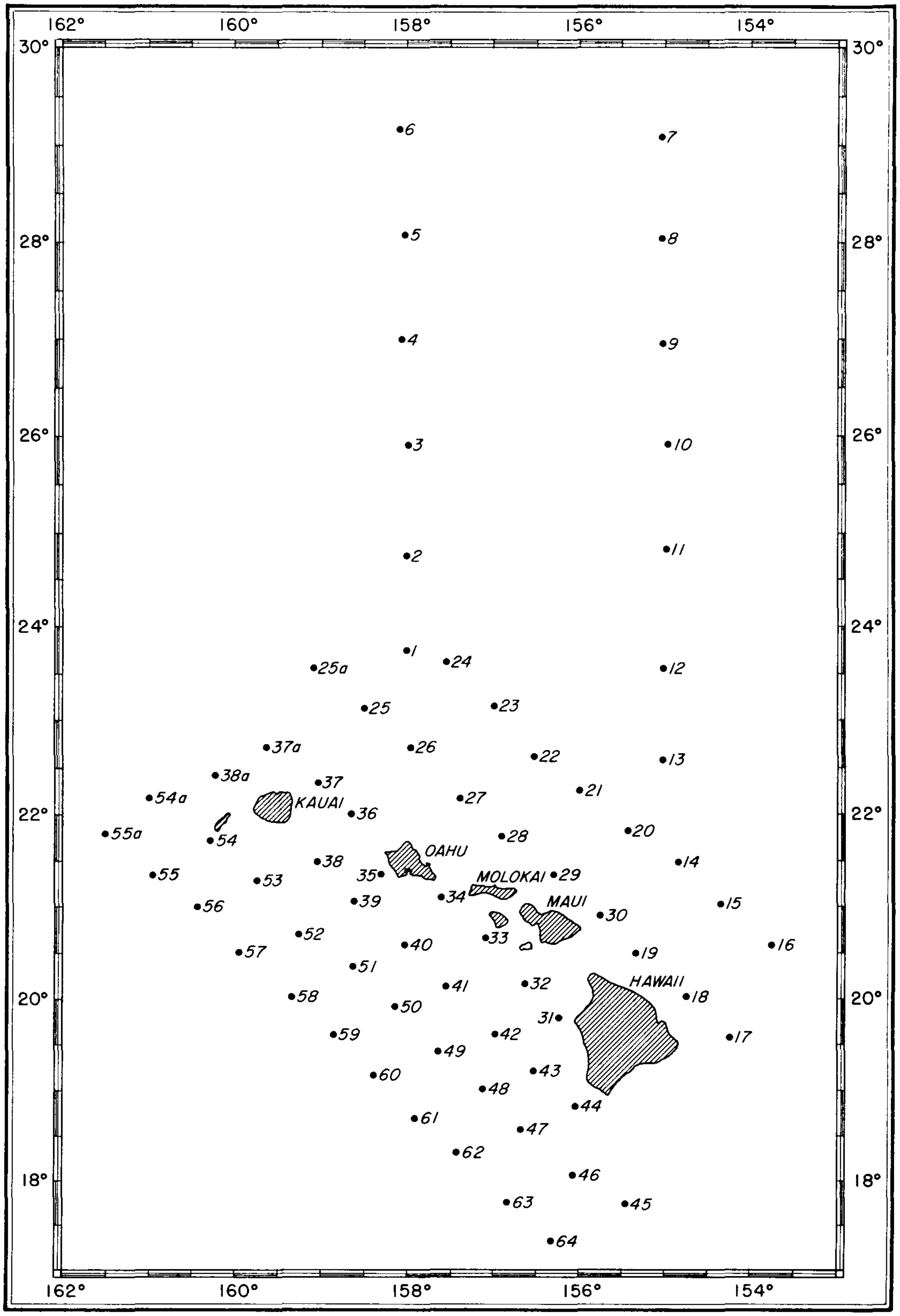

Figure 1.--Plankton-station positions of Hugh M. Smith cruise 20 (February - April 1953).

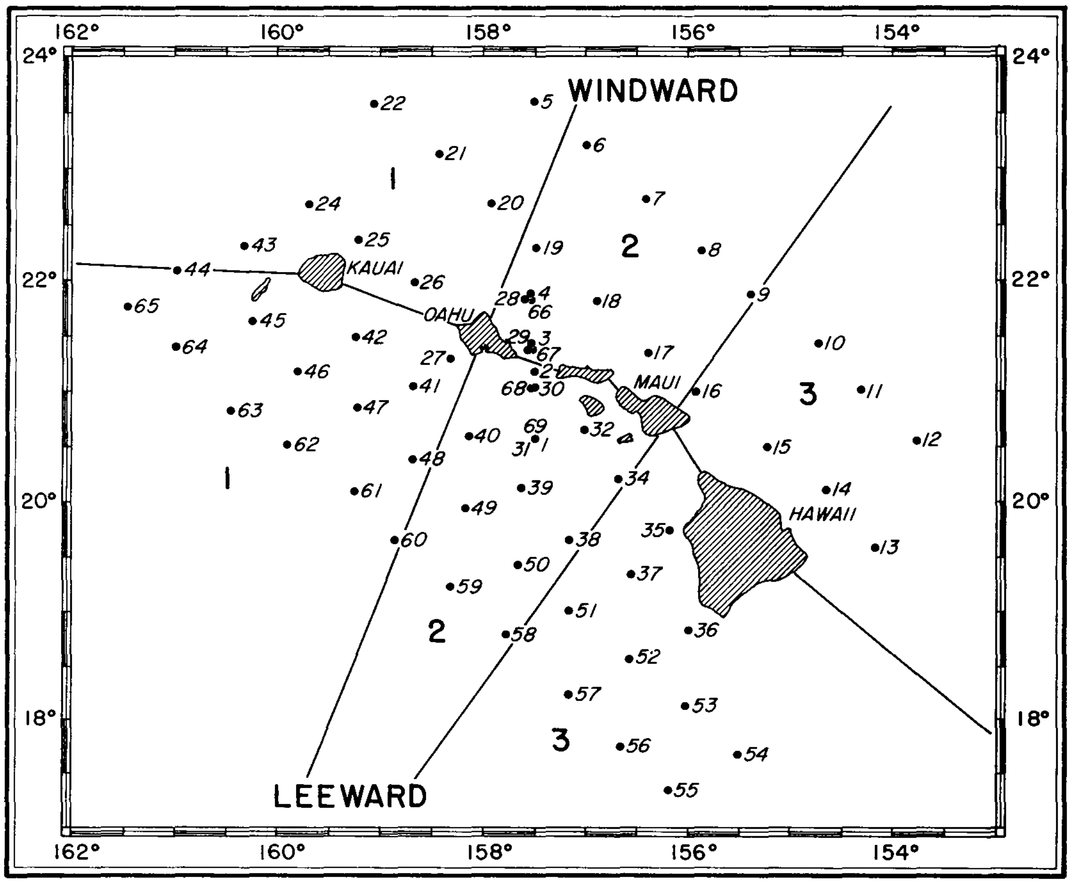

Figure 2.--Plankton-station positions of Hugh M. Smith cruise 21 (August 1953), showing the boundaries of the 6 geographical subdivisions used in comparing areal differences in zooplankton abundance.

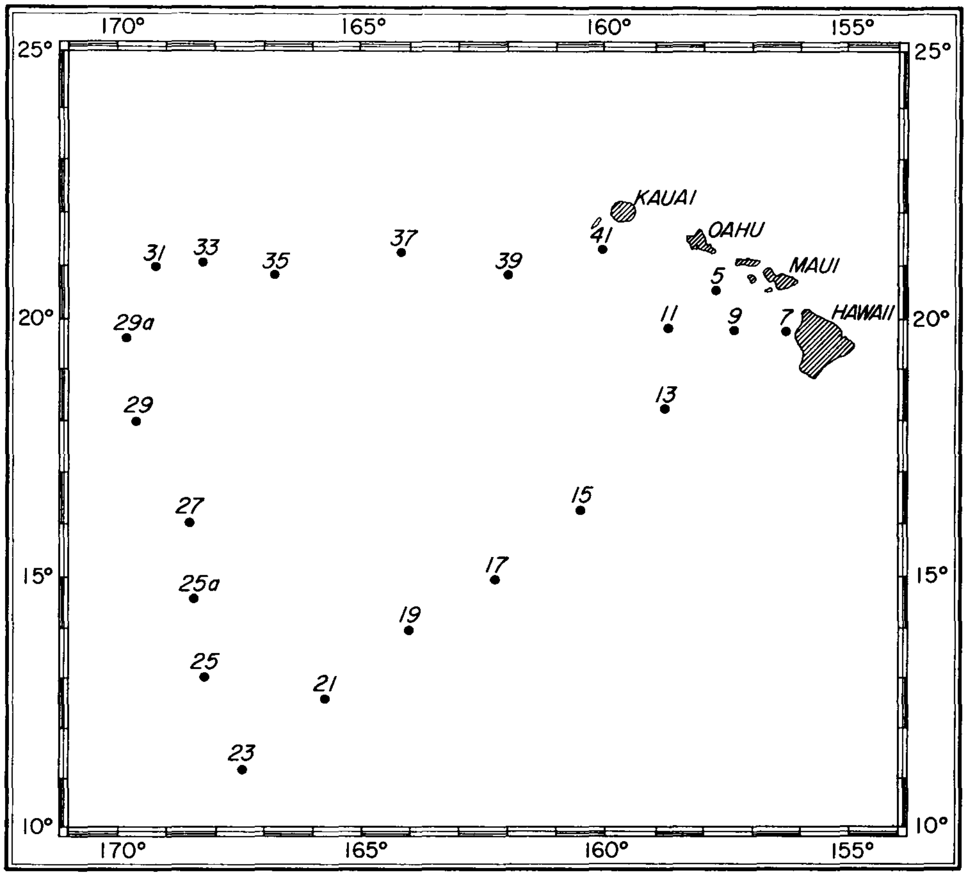

Figure 3.--Plankton-station positions of Hugh M. Smith cruise 26 (May - June 1954).

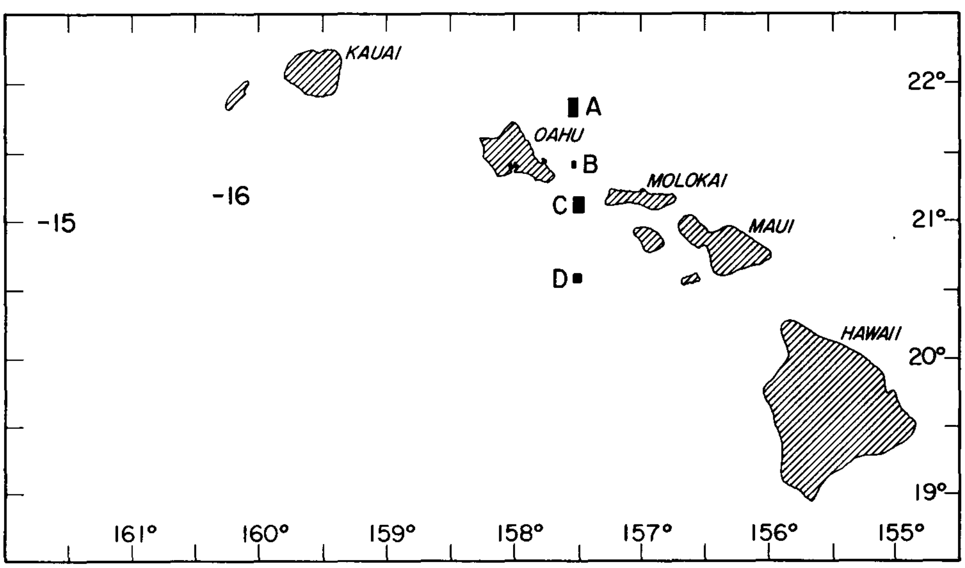

Figure 4.--General locality of stations A, B, C, and D visited repeatedly on Charles H. Gilbert cruises 11, 12, and 13 (April - June 1953), and Hugh M. Smith cruises 21, 22, 23, and 24 (August - December 1953); plankton hauls were made at station B only on Hugh M. Smith cruise 21. Also shown are positions (-) of plankton stations 15 and 16 of Charles H. Gilbert cruise 16 (August 1954).

Table 1.--Comparison of the means and night/day ratios of unadjusted and adjusted volumes, also the regression coefficients (b), "t" values, and probability values for the sine transformation method of adjustment for 7 cruises in Hawaiian waters

Vessel and cruise	Period	Mean volume		Night/day ratio		b	t	Degrees of freedom	P
		Unad-justed	Ad-justed	Unad-justed	Ad-justed				
Hugh M. Smith-10	July 1951	26.0	25.6	1.39	0.97	0.1128	2.945	32	< 0.01
John R. Manning-8	Sept.-Oct. 1951	22.2	21.2	1.70	1.03	0.1488	8.313	34	< 0.001
Hugh M. Smith-12	Oct.-Nov. 1951	20.2	20.3	1.57	1.04	0.1231	4.076	28	< 0.001
John R. Manning-9	Nov. 1951	27.0	26.5	1.30	1.00	0.0688	5.375	30	< 0.001
Hugh M. Smith-17	Sept. 1952	26.5	26.4	1.47	1.05	0.1033	4.943	28	< 0.001
Hugh M. Smith-20	Feb.-Apr. 1953	16.5	16.2	1.44	1.07	0.0884	5.632	67	< 0.001
Hugh M. Smith-21	Aug. 1953	16.4	16.0	1.55	1.04	0.1238	6.732	62	< 0.001
Average		22.1	21.7	1.49	1.03	0.1099			

Table 2.--Variation in volume of zooplankton and in numbers of fish larvae with depth of hauling, Charles H. Gilbert cruise 16

Station	Time	Sample	Approx. depth, m.	Zooplankton volume, cc./1000m.^{3}	Fish larvae number/1000m.^{3}	
					Tuna	Total
15	Night	1	200	43.7	6.0	121.4
	(2121-	2	100	56.1	7.5	116.5
	2336)	3	200	32.3	2.9	96.6
		4	100	69.4	15.2	235.1
16	Day	1	200	17.2	0	54.6
	(0926-	2	100	24.4	2.2	85.5
	1138)	3	200	15.8	1.3	34.8
		4	100	24.6	1.6	106.0
15	Night	Mean	200	38.0	4.4	109.0
	"	"	100	62.8	11.4	175.8
16	Day	"	200	16.5	0.6	44.7
	"	"	100	24.5	1.9	95.8
15	Night	Mean	Depths	50.4	7.9	142.4
16	Day	"	combined	20.5	1.3	70.2
Stations	Times	Mean	200	27.2	2.5	76.8
combined	combined	"	100	43.6	6.6	135.8
Ratios						
15	Night		100/200	1.65	2.59	1.61
16	Day		100/200	1.48	3.17	2.14
15/16	Night/Day		200	2.30	7.33	2.44
	"		100	2.56	6.00	1.84

of these conditions are just the reverse of that found for the zooplankton as a whole.

GEOGRAPHICAL AND TEMPORAL VARIATIONS

Oceanographic observations have shown that Hawaiian waters provide a comparatively homogeneous environment both in time and space in respect to surface temperature, salinity, and inorganic phosphate. The surface current pattern, however, is of complex nature (fig. 5) and is characterized, particularly to the leeward of the islands, by large cyclonic or anticyclonic vortices (McGary 1955, Seckel 1955). A comparison of sigma-t and inorganic phosphate cross-sections has indicated that enrichment of the surface layers through lateral mixing associated with these eddies is insignificant (McGary 1955). There are, therefore, no a priori reasons to expect large variations in plankton abundance either geographically or seasonally. The relatively slight but consistent variations that do occur are noteworthy, however.

In figure 6 we have attempted to show areas of similar zooplankton concentration for the two cruises of the Smith which employed oblique hauls to 200 meters depth and afforded general coverage of the area. Although the results indicate conditions of remarkable uniformity throughout the island waters, there were certain localities which, in agreement with past sampling, were generally richer or poorer than other areas. For example, stations southwest of Oahu produced volumes higher than average, and the eastern portion of the survey area again produced consistently low catches. The area north to northeast of Kauai, which was considerably above average on two earlier cruises (King and Hida 1954), yielded only one unusually large sample.

From an analysis of variance of completely randomized design, employing the zooplankton volumes from cruises 20 and 21, we conclude that there were no statistically significant differences ($P > 0.05$) between cruises, between windward and leeward areas, or among the 6 subareas with boundaries as shown in figure 2. In an analysis of earlier data we found significant differences ($P < 0.05$) among cruises but no significant differences among areas or subareas (King and Hida 1954). Despite the lack of statistically significant differences among subdivisions of the region, the repeated occurrence of low catches to the east or just upstream of the

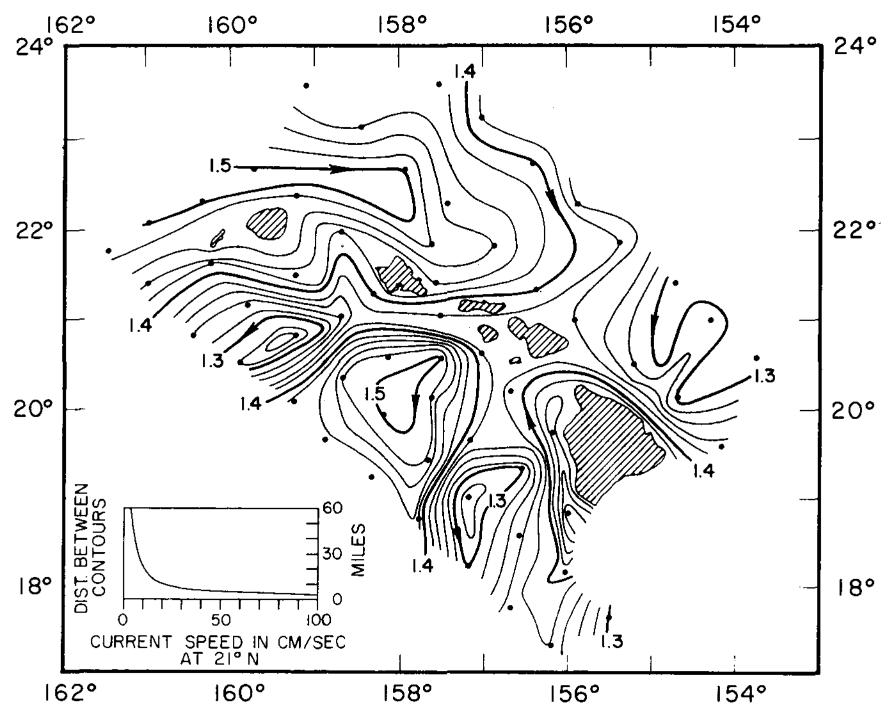

Figure 5.--Dynamic height anomalies (dynamic meters) at the surface relative to 500 m., Hugh M. Smith cruise 21, August 1953. Contour interval 0.02 dynamic meters. [From Seckel 1955, fig. 29]

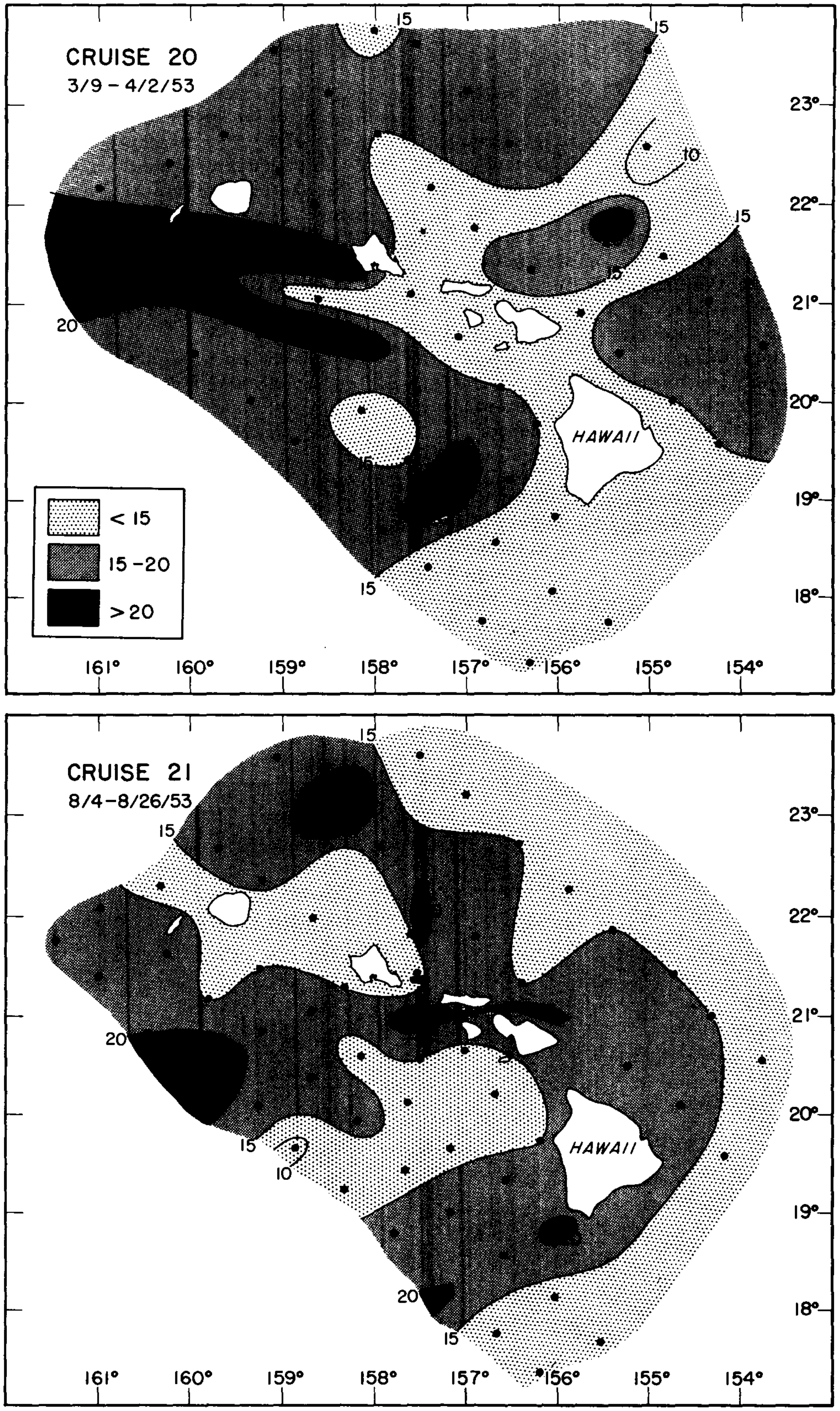

Figure 6. --Variations in zooplankton abundance, based on time-adjusted volumes as cc./1000 m.^{3}, for two cruises of the Hugh M. Smith.

island chain would seem to have definite ecological significance.

McGary (1955) pointed out that, on Smith cruises 10 and 12, zooplankton maxima were associated with the cyclonic eddies in the lee of the islands, and concluded that "the occurrence of the zooplankton maxima at or near the centers of the cyclonic eddies and the frequent occurrence of high salinities and low temperatures at their centers are the result of divergent motion which causes some enrichment of the surface water. The slightness of the maxima and the number of exceptions to the increase of salinity and decrease of temperature at the centers indicate that vertical motion is small and intermittent at best."

One method, perhaps, of testing for signs of occasional enrichment resulting from the eddies is to compare the standard deviation of the means of zooplankton volumes obtained from areas with eddies (i.e. areas in which the eddies are centered) with the standard deviation from areas without eddies. If the occasional occurrence of unusually large volumes were particularly associated with the eddy systems (as defined and located by McGary 1955 and Seckel 1955), then the means from these areas might be expected to have a high variance. In table 3 we show the means and standard deviations for 5 cruises of the Smith which provided comprehensive coverage of Hawaiian waters. There is no evidence supporting the assumption as stated above. In fact, the average standard deviation (5.2) for areas without eddies was larger than for areas with eddies (4.8), but the difference was not great.

According to Seckel (1955), on cruises 17 and 21 conducted during late summer months under conditions of normal tradewind weather, the greatest extremes in surface temperature occurred on the leeward side of the island chain; on cruise 21 the surface inorganic phosphate averaged 0.2 µg at./L. for the windward side and 0.3 µg at./L. on the leeward side. In respect to the zooplankton, on these two cruises the highest variability and the highest average volumes were obtained on the windward side (table 3); the differences between windward and leeward areas are statistically not significant, however. It is of interest that on cruise 20, conducted during a late winter month (March) and also under tradewind conditions, the highest variability and highest average volume were obtained on the leeward side; again the differences were not statistically significant. It is possible, therefore, that the differences shown in table 3 for five cruises providing comprehensive coverage of the Hawaiian area are the result of chance variation; they supply no conclusive evidence of enrichment downstream from the islands as the result of eddy systems, upwelling, land drainage, or other influence of the littoral waters.

Although we have collected a rather large number of plankton samples in Hawaiian waters during the years 1950 - 1954, they are not adequate to describe seasonal variations or differences among years. In figure 7 we show the mean volumes obtained on all cruises employing a uniform sampling method (i.e. oblique hauls to 200 meters depth with 1-meter nets of 30XXX grit gauze). Some of the cruises gave compresive coverage of the Hawaiian area, whereas

Table 3.--Comparison of mean zooplankton volume ($\bar{x}$), as cc./1000 m.^{3}, and standard deviation (s) of the mean, for 6 subareas of the windward and leeward Hawaiian waters, sampled on 5 cruises of the Hugh M. Smith. An asterisk indicates the presence (center) of an eddy in the subarea at time of sampling

Cruise	Period		Windward				Leeward				Cruise average
			1	2	3	Area average	1	2	3	Area average	
10	7/21-30/51	$\bar{x}$	36.5	26.0	22.8	27.4	26.8	21.4	24.2	24.0	25.6
		s	17.3	4.6	9.6	11.3	7.9	10.7*	9.0*	9.1	10.2
12	10/24-11/1/51	$\bar{x}$	22.6	16.9	15.1	18.1	28.6	19.3	19.1	21.9	20.3
		s	3.1	2.7	2.1	4.0	5.8*	2.9	4.7*	6.0	5.5
17	9/6-14/52	$\bar{x}$	27.4	29.9	24.1	26.9	27.6	27.8	23.2	25.8	26.4
		s	3.2	9.5	4.0	6.2	3.4	4.0*	3.0	4.0	5.2
20	3/9-4/2/53	$\bar{x}$	16.8	15.4	15.5	16.0	19.4	16.1	16.9	16.9	16.2
		s	1.6*	3.8*	2.3	2.5	3.6*	3.0*	3.6	3.9	3.4
21	8/4-26/53	$\bar{x}$	17.8	16.0	15.8	16.4	17.0	15.1	16.4	16.1	16.2
		s	8.4	3.2	2.7	5.0	3.3*	4.0*	4.0*	3.8	4.3

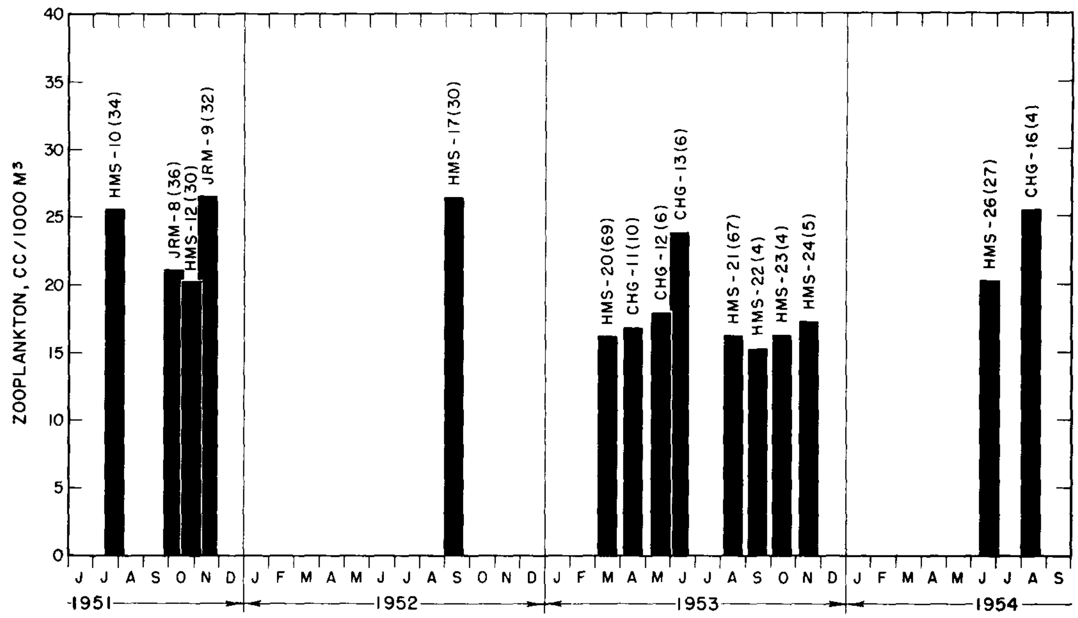

Figure 7.--Mean zooplankton volumes by cruise for each month of sampling during the period July 1951 - August 1954. Number of samples is shown in parentheses.

others were greatly limited in scope, but the localities sampled were thought to be representative of the region. Perhaps the most outstanding feature of the data is the uniformly low average volumes obtained in 1953. Sampling conducted during 8 months of that year revealed a persistent low level of plankton abundance, broken only in the month of June.

Although our sampling was also inadequate for a seasonal comparison, when data for like months are combined the results (fig. 8) show a trend of increasing zooplankton abundance from March to July. Following July, the average volumes became quite variable. Unfortunately we have no plankton data for the months of January, February, and December.

In his study of the chemical and physical properties of Hawaiian waters, Seckel (1955) stated that he could discern no definite seasonal cycle in temperature or salinity as observed on one winter and two summer cruises. The seasonal range in temperature was about 4°F. which was less than the range which might be encountered on any one cruise as the result of geographical variations. So it is perhaps not surprising that we found no marked seasonal variation in zooplankton abundance.

As judged by the catch of the Hawaiian pole-and-line fishery (Yamashita 1957), the abundance of skipjack varies greatly with season, the bulk of the catch, on the average, being obtained during the months of June, July, and August (fig. 8). Although we obtained the highest average volume of zooplankton in July that month was sampled in only one year; moreover, the differences between months throughout the year were slight as compared with the wide variation in fish catch. Although there is a rough seasonal correspondence between zooplankton abundance and water temperature (fig. 8), we must conclude that, when our data are summarized as in figure 8, there is little evidence of any causal relationship or close covariation between zooplankton and surface temperature or zooplankton and skipjack catch.

CORRELATIONS WITH ENVIRONMENTAL FACTORS

Despite evidence of great uniformity in both the biological and the physical and chemical environment, we thought it worthwhile to examine the degree of correlation of zooplankton catch and certain factors considered most likely to have biological significance. The results from three major cruises, summarized in table 4, show lack of significant correlation between zooplankton volumes and temperature (at 10 meters depth), surface inorganic phosphate[1/]

[1/] The temperature and phosphate data employed in these statistical tests have been published in reports of McGary (1955) and Seckel (1955).

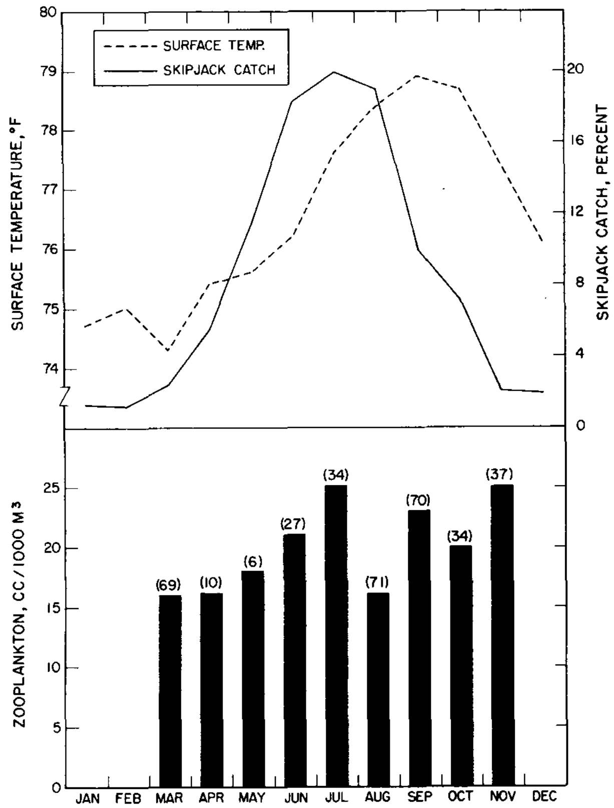

Figure 8.--Monthly variation in zooplankton abundance, surface temperature, and skipjack catch in Hawaiian waters. The zooplankton data are for the years 1951 - 1954 and were obtained on Hugh M. Smith cruises 10, 12, 17, 20, 21, 22, 23, 24, and 26; John R. Manning cruises 8 and 9; and Charles H. Gilbert cruises 11, 12, 13, and 16. Number of zooplankton samples is shown in parentheses. The temperature data constitute a 6-year average, 1950 - 1955, and were assembled by Gunter Seckel, Oceanographer, POFI. The skipjack catch data are a 4-year average, 1951 - 1954, derived from monthly catch data supplied by the Territory of Hawaii, Division of Fish and Game.

Table 4.--Results of correlation analyses comparing adjusted zooplankton volumes of Hugh M. Smith cruises 20, 21, and 26, and certain environmental factors

Cruise	X_1 variate	X_2 variate	Degrees of freedom	Correlation coefficient, r	P
20	Zooplankton volumes (cc./1000 m.^{3})	Temperature (°C) at 10 meters depth	67	0.214	> 0.05
20	do.	Thermocline depth (meters)	67	-0.019	> 0.05
21	do.	Temperature (°C) at 10 meters depth	65	0.124	> 0.05
21	do.	Thermocline depth (meters)	65	0.032	> 0.05
21	do.	Surface inorganic phosphate (µg at./L.)	65	-0.044	> 0.05
26	do.	Temperature (°C) at 10 meters depth	19	-0.103	> 0.05
26	do.	Thermocline depth (meters)	19	0.332	> 0.05

and depth to the top of the thermocline. This lack of correlation with the fields chosen may be of significance in itself, and would seem to indicate that other, more fundamental factors of the environment may be the causative agents for the variations observed.

During the period April - December 1953, four "permanent" stations between Oahu and Molokai were visited at approximately weekly intervals with sampling of zooplankton (at three of the stations only), temperature, phosphate, and salinity, for the purpose of following detailed changes in the environment associated with the opening of the skipjack season in the early summer months and the decline in the catch during the fall. It was assumed that these selected locations would yield data fairly representative of conditions throughout Hawaiian waters.

The northernmost station, station A (fig. 4), was positioned so as to sample "open ocean" water to the windward of the islands, station B to sample channel water, station C to sample water over Penguin Bank where the depth ranged from 50 to 100 meters, and station D the open ocean to the leeward of the islands. Station A was normally visited at about 1300, station B at 1900, station C at 2300, and station D 0300 hours. At each station where depth of water permitted, samples were taken between 0 and 250 or 300 meters (500 meters on Smith cruise 21) for salinity and phosphate measurements. Surface temperatures were taken with a bucket thermometer; subsurface temperatures were recorded with a bathythermograph. Only the surface data are utilized in this report, however.

Plankton hauls were made at station B on only one cruise. The 3 samples obtained at this location on Smith cruise 21 averaged 13.2 cc./1000 m.^{3}. The 19 successful hauls made at station C on Penguin Bank, which were shallow tows between the surface and 40 or 50 meters depth, yielded an average volume of 29.3 cc./1000 m.^{3}. This mean had considerably higher variance than the means for station A (16.2 cc./1000 m.^{3}) and station D (19.4 cc./1000 m.^{3}), both the latter stations being in deep water and sampled with 0- to 200-meter oblique hauls.

When the various observations obtained at stations A and D are plotted as in figure 9, we obtain a complex and confusing picture of rapid fluctuations in the environment with no definite seasonal trends and with very little agreement between the two stations. Surface temperatures of the two localities varied in somewhat parallel manner, however, with station A being about 1°F. cooler on the average than station D. Correlation analyses based on the repeated observations made at station D, summarized in table 5, showed no significant correlations between zooplankton volume and surface temperature, surface inorganic phosphate, thermocline depth, surface salinity, and the weekly skipjack catch for the Hawaiian area.

If we replot the temperature and zooplankton data obtained at station D during the early weeks (April - June) of the survey, together with the skipjack catch for the entire Hawaiian area for the same period, we find an interesting covariation (fig. 10). Warming of the water in early April was accompanied by an increase in zooplankton and in catch of skipjack. Subsequent cooling about the middle of April was associated with a drop both in zooplankton and skipjack catch. As the temperature increased during May and June there was again a corresponding general increase in zooplankton and skipjack abundance. We are not able to define the causative factors in this sequence of events. The correlation coefficients for surface temperature and zooplankton ($r = 0.385$) and for skipjack and zooplankton ($r = 0.593$) were below the 5-percent level of significance ($r_{.05} = 0.602$). Surface temperature and skipjack, however, showed a highly significant correlation ($r = 0.777$), beyond the 1-percent level of significance ($r_{.01} = 0.735$). It is possible that none of the factors examined are directly related, but that all exhibit chance variations, or that all are governed by changes in the general circulation or some other basic, underlying condition in the environment as yet undetermined.

SUMMARY

1. In this second report of the Pacific Oceanic Fishery Investigations on variations in zooplankton abundance in Hawaiian waters, we summarize the results of plankton hauling on 10 cruises during the years 1953 - 54. Data from earlier cruises, included in a previous report (King and Hida 1954) were also utilized to some extent in drawing conclusions.

2. The collections were obtained with 1-meter nets of 30XXX grit gauze (aperture widths 0.65 mm.). Oblique hauls to about 200 meters' depth were employed at most stations. The results from a short series of 0- to 100-meter hauls are also included.

3. The displacement volumes of all samples were measured in the laboratory. For each sample there was calculated the volume of

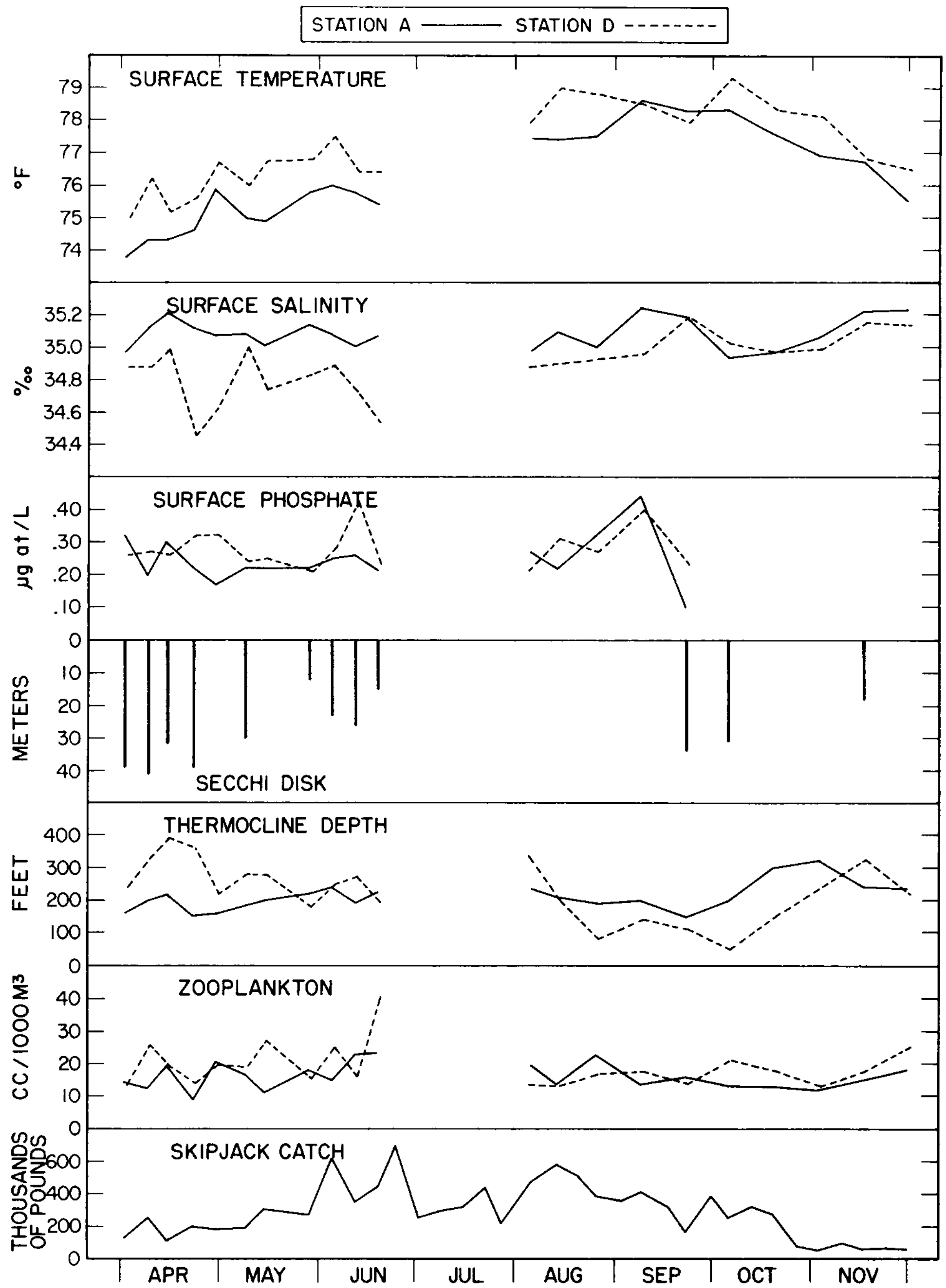

Figure 9.--Variations in surface temperature, surface salinity, surface phosphate, Secchi disk visibility (station A only), thermocline depth, and zooplankton volumes at stations A and D, located at the positions shown in figure 4, as compared with the weekly skipjack catch of the Hawaiian pole-and-line fishery for the same period of time, April to November 1953.

Table 5.--Results of correlation analyses based on repeated observations made at station D (position shown in fig. 4), comparing adjusted zooplankton volumes with several environmental factors and with the weekly skipjack catch of the Hawaiian area

X_1 variate	X_2 variate	Degrees of freedom	Correlation coefficient, r	P
Zooplankton volumes (cc/1000 m.^{3})	Surface temperature (°F)	19	-0.194	> 0.05
do.	Surface inorganic phosphate (µg at./L.)	14	-0.198	> 0.05
do.	Thermocline depth (feet)	19	-0.001	> 0.05
do.	Surface salinity (‰)	19	-0.275	> 0.05
do.	Skipjack catch (pounds per week)	19	0.219	> 0.05

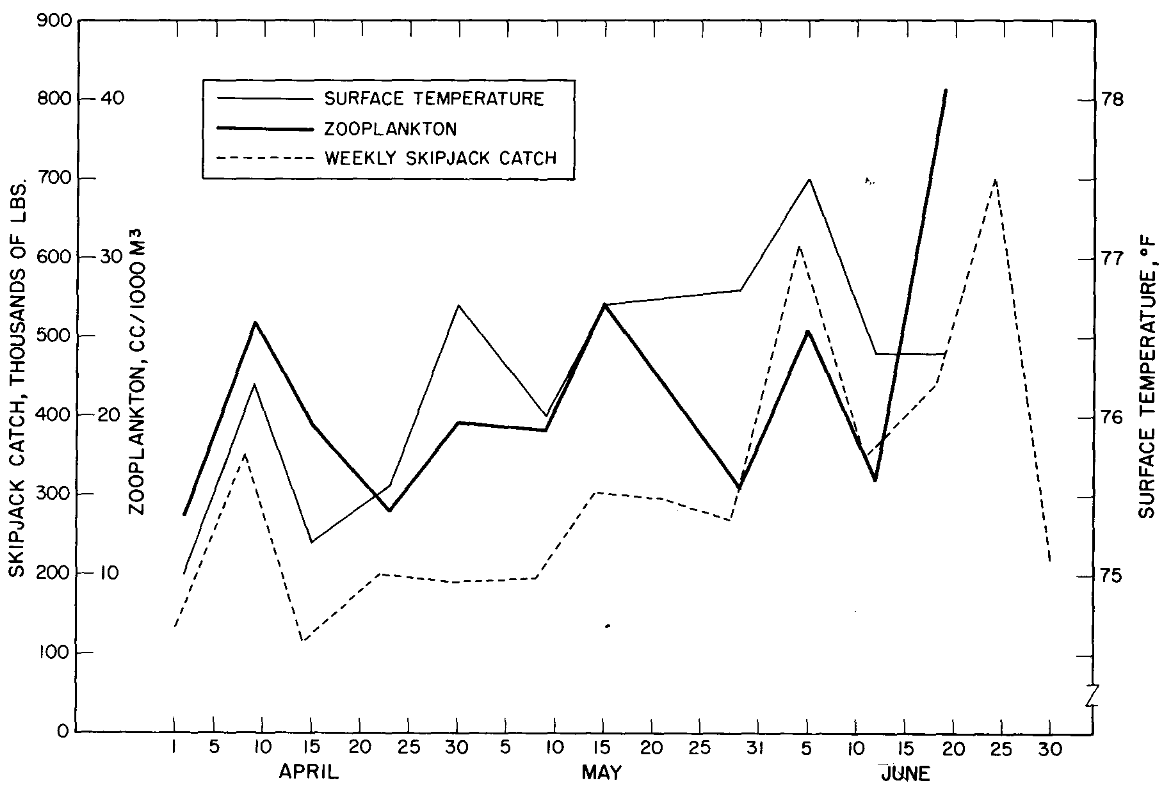

Figure 10.--Variations in surface temperature and zooplankton volume at station D, compared with the weekly Hawaiian skipjack catch for the period April 1 to June 30, 1953.

the more nutritious zooplankton per unit of water strained.

4. The night hauls yielded volumes averaging 1.49 times the volumes of day hauls. A method of adjustment was employed to reduce these differences associated with the hour of hauling.

5. A short series of experimental hauls indicated the superiority of night over day and 0- to 100-meter over 0- to 200-meter hauls in the catch of zooplankton and of fish larvae.

6. The distribution of zooplankton was remarkably uniform throughout the island waters. From an analysis of variance we concluded that there were no significant differences between cruises, between windward and leeward areas, or among six subareas.

7. Although the physical and chemical environments are also quite uniform in general respects, the surface currents are exceedingly complex and are characterized, particularly on the leeward side of the islands, by large vortices or eddies. We found no evidence that the eddies had any influence on the volume of zooplankton. Also evidence of the effects of upwelling, land drainage, or other littoral influence was obscure or lacking.

8. There was a trend of increasing zooplankton abundance from March to July; our data are not adequate, however, to provide a complete seasonal picture. Although surface temperature and the catch of the Hawaiian skipjack fishery also increase during the spring and early summer months, we doubt that there is a direct relationship among these variables.

9. Zooplankton volumes were not significantly correlated with water temperature, salinity, inorganic phosphate, thermocline depth, or skipjack catch. This lack of correlation between zooplankton and those factors considered most likely to have biological significance may indicate that other, more fundamental factors of the environment may be the causative agents for the variations observed.

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APPENDIX

Table 6.--Zooplankton volumes obtained on cruise 20 of the Hugh M. Smith, employing 1-meter nets of 30XXX grit gauze and oblique hauls to 200 meters depth (except as noted)

Station	Position		Date 1953	Time[1/]	Water strained, $m.^3$	Zooplankton, $cc./1000 m.^3$	
	North latitude	West longitude				Sample volume	Adjusted volume[2/]
1	23°43.5'	158°01.5'	3-9	0044-0117	1806.0	17.6	14.5
2	24°45.5'	158°02'	3-9	1047-1115	1051.7	12.1	14.7
3	25°53.5'	157°59'	3-9	2112-2142	1008.9	18.7	16.0
4	27°00'	158°04.5'	3-10	0925-0955	1185.1	13.8	16.3
5	28°04'	158°02'	3-10	2136-2207	1139.1	19.8	16.6
6	29°10.5	158°06'	3-11	0831-0900	1177.3	11.1	12.6
7	29°06'	155°02'	3-12	1431-1500	1095.3	14.1	16.5
8	28°03'	155°02'	3-13	0041-0111	1291.8	16.2	13.3
9	26°57'	155°01'	3-13	1307-1337	1509.2	12.7	15.4
10	25°54'	154°57'	3-13	2325-2357	1369.3	12.8	10.4
11	24°49'	154°58.9'	3-14	0930-1000	1311.0	10.4	12.3
12	23°33.5'	155°01.5'	3-14	2056-2127	1375.0	17.6	15.1
13	22°34'	155°01.5'	3-15	0601-0629	1466.4	7.3	7.4
14	21°28.5'	154°51'	3-15	1543-1612	1537.6	10.5	11.6
15	21°02'	154°20'	3-15	2355-0026	1332.6	23.3	19.0
16	20°35'	153°46'	3-16	0808-0838	1482.8	14.4	16.2
17	19°35.5'	154°13.5'	3-16	1747-1817	1547.8	14.7	14.7
18	20°02.5'	154°43.5'	3-17	0105-0135	1419.3	17.8	14.7
19	20°30'	155°19'	3-17	0846-0916	1410.1	14.5	16.7
20	21°50'	155°25.5'	3-17	2045-2114	1671.3	25.2	21.8
21	22°15.5'	155°59.5'	3-18	0358-0428	1562.2	15.9	14.6
22	22°37.5'	156°31.5'	3-18	1102-1132	1548.8	13.5	16.5
23	23°08.5'	156°59.5'	3-18	1815-1846	1728.6	17.0	16.4
24	23°37.5'	157°32.5'	3-19	0101-0132	1492.9	20.2	16.7
25a	23°33'	159°05.5'	3-19	1202-1232	1297.3	14.3	17.5
25	23°07'	158°30'	3-19	1936-2007	1401.7	21.0	19.0
26	22°42.5'	157°57'	3-20	0510-0540	1242.1	15.5	15.0
27	22°11.5'	157°22.5'	3-20	1519-1549	1323.4	12.5	14.1
28	21°46'	156°53'	3-21	0048-0118	1245.8	18.5	15.2
29	21°21.5'	156°17.5'	3-21	1003-1034	1461.0	14.8	17.8
30	20°55'	155°43.5'	3-21	1817-1847	1588.1	15.9	15.3
31	19°47'	156°13.5'	3-22	0503-0534	1890.2	15.4	14.9
32	20°09'	156°37'	3-22	1118-1148	1418.0	12.4	15.2
33[3/]	20°38'	157°05'	3-22	1727-1757	1511.9	13.0	13.2
34[3/]	21°05'	157°36.5'	3-22	2326-2357	1680.4	18.2	14.9
35	21°20.5'	158°18'	3-23	1910-1944	1693.7	24.3	22.7
36	22°01'	158°38'	3-24	0238-0308	1415.2	19.9	17.3
37	22°19.5'	159°03'	3-24	0833-0902	1464.0	14.6	16.6
37a	22°43.5'	159°38.5'	3-24	1533-1603	1654.8	13.6	15.3
38a	22°24.5'	160°13'	3-24	2144-2214	1385.0	23.1	19.4
38	21°29.5'	159°03'	3-25	1059-1129	1419.6	19.1	23.3
39	21°03'	158°36.5'	3-25	1732-1804	1879.6	11.5	11.7
40	20°35'	158°01.5'	3-26	0139-0209	1285.1	26.9	22.5
41	20°07.5'	157°32'	3-26	0824-0854	1217.4	14.0	16.0
42	19°36.5'	156°58.5'	3-26	1551-1621	1497.7	17.6	19.5

1/ Apparent solar time.

2/ Adjusted for day-night difference by the sine transformation method.

3/ Surface haul in shoal water.

Table 6. --Zooplankton volumes obtained on Hugh M. Smith cruise 20 (Cont'd)

Station	Position		Date 1953	Time[1/]	Water strained, m.[3]	Zooplankton, cc./1000 m.[3]	
	North latitude	West longitude				Sample volume	Adjusted volume[2/]
43	19°13'	156°31'	3-26	2145-2215	1105.2	20.7	17.3
44	18°49.5'	156°02.5'	3-27	0517-0547	1229.7[4/]	11.5	11.3
45	17°45'	155°27'	3-27	1553-1623	1335.5	10.3	11.4
46	18°04.5'	156°04'	3-27	2221 2251	1090.5	15.2	12.6
47	18°33.5'	156°40'	3-28	0558-0626	997.5	10.1	10.3
48	18°59'	157°06.5'	3-28	1207-1237	1384.5	17.6	21.6
49	19°25.5'	157°38'	3-28	1822-1852	1787.6	15.6	15.1
50	19°54'	158°07.5'	3-29	0032-0102	1536.6	15.4	12.6
51	20°21.5'	158°37.5'	3-29	0703-0732	1284.2	16.2	17.4
52	20°42'	159°15'	3-29	1354-1424	1554.9	17.0	20.3
53	21°16.5'	159°44'	3-29	2031-2102	1515.1	23.9	20.9
54	21°43.5'	160°17'	3-30	0242-0310	1475.4	25.9	22.4
54a	22°09'	160°59'	3-30	2125-2159	1788.9	20.0	16.9
55a	21°48'	161°29.5'	3-31	0348-0418	1593.4	25.9	23.4
55	21°21.5'	160°56'	3-31	1020-1048	1310.8	16.9	20.5
56	21°00'	160°25'	3-31	1621-1650	1364.4	18.6	20.0
57	20°31'	159°56'	3-31	2224-2253	1298.4	17.7	14.6
58	20°02'	159°21.5'	4-1	0500-0530	1561.6	17.7	17.1
59	19°36'	158°51.5'	4-1	1056-1124	1223.3	14.1	17.2
60	19°09'	158°22.5'	4-1	1701-1732	1297.3	15.6	16.1
61	18°42.5'	157°53'	4-1	2316-2346	1312.9	23.1	18.9
62	18°18'	157°25'	4-2	0536-0607	1152.3	12.8	12.8
63	17°45.5'	156°50'	4-2	1424-1453	1332.8	11.9	13.9
64	17°19'	156°19'	4-2	2136-2204	948.5	18.4	15.4

1/ Apparent solar time.

2/ Adjusted for day-night difference by the sine transformation method.

3/ Surface haul in shoal water.

4/ Based on an estimated meter reading.

Table 7.--Zooplankton volumes obtained on cruises 11, 12, and 13 of the Charles H. Gilbert, employing 1-meter nets of 30XXX grit gauze. Oblique hauls to 200 meters depth were made at the A and D stations; oblique hauls to 40 or 50 meters depth were made at the C station

Station	Position		Date 1953	Time[1/]	Water strained, $m.^3$	Zooplankton, $cc./1000m.^3$	
	North latitude	West longitude				Sample volume	Adjusted volume[2/]
Cruise 11							
5A	21°49.3'	157°32.2'	4-1	1342-1411	1616.7	11.7	14.6
7C	21°04.6'	157°31.5'	4-1	2149-2219	1376.2	42.3	-
8D	20°35.1'	157°32'	4-2	0209-0238	1388.4	16.9	13.7
9A	21°49.3'	157°32.4'	4-8	1317-1347	1594.1	9.7	12.2
11C	21°04.5'	157°31.6'	4-8	2142-2216	1991.6	31.3	-
12D	20°34.6'	157°32.5'	4-9	0155-0227	1936.5	31.9	25.9
13A	21°49.9'	157°32'	4-14	1259-1328	1318.3	15.3	19.5
15C	21°05.2'	157°32'	4-14	2158-2230	1319.8	25.9	-
16D	30°35'	157°32.2'	4-15	0220-0250	1740.4	23.7	19.5
17A	21°48.8'	157°32'	4-22	1300-1333	1815.1	7.0	8.9
19C	21°04.5'	157°32.2'	4-22	2149-2221	1059.2	31.6	-
20D	20°35'	157°32'	4-23	0156-0226	1480.3	17.2	14.0
21A	21°50.7'	157°31'	4-29	1248-1312	1024.1	16.2	20.7
23C	21°04.7'	157°31.9'	4-29	-	-	No sample	-
24D	20°35'	157°32'	4-30	0407-0436	1442.2	22.0	19.7
Cruise 12							
1A	21°50'	157°32'	5-8	1507-1533	1206.5	14.3	16.8
3C	21°06'	157°31.9'	5-8	-	-	No sample	-
4D	20°35'	157°32'	5-9	0244-0310	980.1	23.0	19.2
13A	21°50'	157°32'	5-14	1309-1337	1200.0	8.8	11.2
15C	21°04.6'	157°31.8'	5-14	2154-2226	1918.2	20.9	-
16D	20°35'	157°32.2'	5-15	0224-0251	1228.7	33.0	27.1
17A	21°45'	157°32'	5-28	1433-1503	1506.4	14.9	18.1
19C	21°05'	157°32'	5-29	0013-0041	1448.1	65.3	-
20D	20°35.2'	157°31.5'	5-29	0458-0530	1547.5	16.2	15.5
Cruise 13							
1A	21°50'	157°32'	6-4	1500-1536	2007.9	12.5	14.7
3C	21°04.1'	157°32'	6-4	2247-2319	2084.7	27.4	-
4D	20°35.3'	157°32.3'	6-5	0332-0402	2032.6	29.6	25.5
6A	21°50'	157°32'	6-11	1440-1513	2323.0	19.0	22.8
8C	21°05'	157°31.6'	6-11	2155-2226	2012.1	16.3	-
9D	20°35'	157°32'	6-12	0228-0256	1682.1	19.6	16.1
10A	21°50'	157°32'	6-18	1504-1532	1548.2	19.8	23.3
12C	21°05'	157°31.5'	6-18	2109-2136	1850.8	33.7	-
13D	20°35'	157°32'	6-19	0124-0155	2034.0	51.4	40.7

[1/] Apparent solar time.

[2/] Adjusted for day-night difference by the sine transformation method using the pooled regression coefficient (b = 0.1110).

Table 8.--Zooplankton volumes obtained on cruise 21 of the Hugh M. Smith, employing 1-meter nets of 30XXX grit gauze and oblique hauls to 200 meters depth (except as noted)

Station	Position		Date 1953	Time[1/]	Water strained, $m.^3$	Zooplankton, $cc./1000m.^3$	
	North latitude	West longitude				Sample volume	Adjusted volume[2/]
1D	20°33.8'	157°30.8'	8-4	1958-2027	1765.6	16.0	13.6
2C[3/]	21°10'	157°28'	8-5	0204-0230	1372.0	22.7	18.0
3B	21°25'	157°32.4'	8-5	0540-0608	1634.6	12.1	12.1
4A	21°52.9'	157°31.8'	8-5	1011-1041	1898.8	15.3	19.8
5	23°36.9'	157°30'	8-5	2342-0013	1698.9	16.2	12.2
6	23°13'	157°00'	8-6	0632-0702	2125.9	13.1	13.8
7	22°44'	156°21'	8-6	1309-1338	1709.4	11.2	14.6
8	22°18'	155°52'	8-6	1953-2023	1863.9	16.7	14.5
9	21°53'	155°20.5'	8-7	0249-0320	1470.5	18.4	15.0
10	21°26.1'	154°41'	8-7	1004-1033	1639.6	11.8	15.3
11	21°00'	154°16'	8-7	1555-1624	1579.6	13.0	15.0
12	20°34'	153°44.9'	8-7	2214-2245	1533.9	17.7	13.7
13	19°36.1'	154°10'	8-8	0702-0730	1846.6	10.7	11.8
14	20°06'	154°37.8'	8-8	1323-1353	1845.3	13.4	17.3
15	20°30.1'	155°12.2'	8-8	2018-2048	1485.0	21.2	17.6
16	21°00'	155°52.5'	8-9	0312-0343	1469.9	23.8	19.8
17	21°19.1'	156°21.1'	8-9	0850-0920	1694.9	12.3	15.1
18	21°48'	156°51.1'	8-9	1516-1546	1429.4	15.6	18.4
19	22°16.1'	157°24'	8-9	2133-2203	1395.1	25.4	20.1
20	22°39.7'	157°54.9'	8-10	0353-0423	1763.8	18.7	16.2
21	23°11.1'	158°26.6'	8-10	1019-1048	1310.5	28.8	37.6
22	23°34.6'	159°02.5'	8-10	1653-1723	1729.5	18.0	19.4
24	22°40'	159°41.8'	8-11	0310-0341	1715.0	19.8	16.5
25	22°22.2'	159°11'	8-11	0931-1002	1730.4	12.4	15.6
26	21°59.2'	158°38.8'	8-11	1615-1646	1569.1	11.2	12.3
27	21°17.4'	158°18.1'	8-11	2308-2342	2608.0	16.8	12.7
28A	21°52.2'	157°34.7'	8-13	1621-1651	1867.6	12.6	13.9
29B	21°24'	157°32.9'	8-13	2142-2212	1784.5	16.8	13.1
30C[3/]	21°03'	157°31'	8-14	0205-0236	1953.8	25.2	20.0
31D	20°33.1'	157°29.5'	8-14	0729-0800	1691.2	11.7	13.2
32	20°38.8'	157°01.1'	8-14	1202-1232	2145.7	7.9	10.5
34	20°12'	156°39.8'	8-14	2053-2123	1589.5	14.8	12.1
35	19°43'	156°12.2'	8-15	0317-0347	1940.8	17.7	15.0
36	18°50'	155°58.5'	8-15	1236-1304	960.1	17.5	23.1
37	19°20.8'	156°33.8'	8-15	1915-1946	1904.0	17.6	15.6
38	19°40'	157°05.1'	8-16	0133-0203	1613.9	16.2	12.5
39	20°07.4'	157°36.1'	8-16	0912-0943	1753.0	10.8	13.4
40	20°35.8'	158°06.2'	8-16	1759-1829	2104.3	13.5	13.2
41	21°02.1'	158°39.7'	8-17	0041-0111	1736.0	25.6	19.4
42	21°29.3'	159°13.2'	8-17	0702-0731	1605.6	14.0	15.4
43	22°20.2'	160°18.5'	8-17	1717-1747	2000.2	12.4	12.7
44	22°05.8'	160°56.9'	8-17	2334-0004	1815.1	25.7	19.4
45	21°38.1'	160°13.9'	8-18	0655 0726	1952.9	14.7	16.2
46	21°10.8'	159°46'	8-18	1305-1336	1714.3	11.6	15.1
47	20°50'	159°11.5'	8-18	2021-2051	1142.4	22.8	19.0
48	20°21'	158°32.8'	8-19	0431-0502	1452.6	17.6	16.0

1/ Apparent solar time.

2/ Adjusted for day-night difference by the sine transformation method.

3/ Shallow hauls on Penguin Bank.

Table 8.--Zooplankton volumes obtained on Hugh M. Smith cruise 21 (Cont'd)

Station	Position		Date 1953	Time[1]	Water strained, $m.^3$	Zooplankton, cc./1000$m.^3$	
	North latitude	West longitude				Sample volume	Adjusted volume[2]
49	19°56.4'	158°10.3'	8-19	1109-1139	1668.6	14.1	18.7
50	19°27'	157°38.1'	8-19	1826-1857	1489.4	11.9	11.3
51	19°00'	157°08.1'	8-20	0052-0123	1135.3	24.0	18.2
52	18°36.1'	156°33.9'	8-20	0959-1028	1519.0	12.3	15.9
53	18°08.1'	156°01.1'	8-20	1741-1812	1398.5	13.5	13.5
54	17°40'	155°30'	8-21	0055-0127	2006.3	26.0	19.9
55	17°19'	156°10.9'	8-21	0724-0754	1996.1	10.6	11.9
56	17°46.2'	156°39.9'	8-21	1317-1347	1708.8	8.3	10.7
57	18°14'	157°08.5'	8-21	2006-2036	1920.7	24.1	20.5
58	18°44.2'	157°46'	8-22	0432-0502	2122.8	18.3	16.6
59	19°13'	158°21'	8-22	1120-1150	2357.7	8.2	10.9
60	19°38.1'	158°51.3'	8-22	1722-1752	2289.1	9.0	9.2
61	20°03.8'	159°16.1'	8-22	2253-2322	2175.4	24.8	18.8
62	20°30.5'	159°49.9'	8-23	0534-0604	1686.5	22.5	21.9
63	20°49.7'	160°27.5'	8-23	1221-1252	2082.0	15.4	20.4
64	21°24.8'	160°58'	8-23	1904-1933	1636.8	19.6	17.8
65	21°46.8'	161°25'	8-24	0117-0147	1851.8	21.4	16.5
66A	21°49.3'	157°31.8'	8-25	1338-1408	1646.4	17.6	22.5
67B	21°22.5'	157°31.5'	8-25	1825-1855	1634.6	15.2	14.5
68C[3]	21°03.5'	157°29.8'	8-25	2235-2302	1458.2	32.4	24.8
69D	20°34.2'	157°29.6'	8 26	0352-0422	1558.7	19.7	17.1

1/ Apparent solar time.

2/ Adjusted for day-night difference by the sine transformation method.

3/ Shallow hauls on Penguin Bank.

Table 9.--Zooplankton volumes obtained on cruises 22, 23, and 24 of the Hugh M. Smith for stations A, C, and D on the sections east of Cahu, employing 1-meter nets of 30XXX grit gauze. Oblique hauls to 200 meters depth were made at the A and D stations; oblique hauls to 40 or 50 meters depth were made at the C station

Station	Position		Date 1953	Time 1/	Water strained, m.³	Zooplankton, cc./1000m.³	
	North latitude	West longitude				Sample volume	Adjusted volume 2/
Cruise 22							
5A	21°50.8'	157°32.8'	9-8	1317-1353	1506.4	10.7	13.5
7C	21°05.3'	157°32.0'	9-8	1945-2016	1253.3	27.8	-
8D	20°36.6'	157°30.8'	9-9	0023-0054	1384.1	22.8	17.7
18A	21°50.6'	157°30.8'	9-22	1314-1347	1557.3	12.6	15.9
20C	21°06.3'	157°30.6'	9-22	1941-2013	1539.8	21.6	-
21D	20°35.3'	157°29.5'	9-23	0011-0042	1386.0	18.0	13.9
Cruise 23							
1A	21°50'	157°30.4'	10-5	1429-1500	1624.5	10.6	12.9
3C	21°05'	157°31'	10-5	2132-2202	1496.6	63.7	-
4D	20°33.8'	157°31'	10-6	0210-0241	1425.3	26.2	21.2
14A	21°49.5'	157°31.2'	10-19	1405-1435	1289.9	10.5	12.9
16C	21°04.7'	157°31.2'	10-19	2137-2207	1743.3	29.5	-
17D	20°36'	157°30.2'	10-20	0157-0227	1385.9	22.3	18.1
Cruise 24							
1A	21°49'	157°31.4'	11-2	1617-1646	1280.1	11.0	12.0
3C	21°04.4'	157°31.7'	11-2	2238-2319	1427.6	10.0	-
4D	20°35'	157°30.6'	11-3	0320-0352	1499.5	15.1	13.0
14A	21°47.6'	157°31.9'	11-16	No sample	-	-	-
16C	21°04.9'	157°30.7'	11-16	2320-2348	1240.7	17.8	-
17D	20°37.1'	157°30.5'	11-17	0326-0356	1450.0	20.8	17.9
22A	21°50.4'	157°31.3'	11-30	1446-1515	1079.2	15.3	18.3
24C	21°06.5'	157°31.4'	11-30	2203-2232	1355.1	11.7	-
25D	20°35.6'	157°30.4'	12-1	0226-0256	1384.6	30.6	25.2

1/ Apparent solar time.

2/ Volumes at stations A and D adjusted by the sine transformation method using the pooled regression coefficient (b = 0.1110).

Table 10.--Zooplankton volumes obtained on cruise 26 of the Hugh M. Smith, employing 1-meter nets of 30XXX grit gauze and oblique hauls to 200 meters depth

Station	Position		Date 1954	Time[1]	Water strained, $m.^3$	Zooplankton, $cc./1000m.^3$	
	North latitude	West longitude				Sample volume	Adjusted volume[2]
5	20°33'	157°44'	5-29	0432-0507	1584.3	21.5	19.7
7	19°45'	156°18'	5-30	0435-0508	2193.5	24.1[3]	22.5
9	19°47'	157°23'	6-2	0430-0500	1460.6	29.5	27.0
11	19°51'	158°43'	6-3	0417-0448	1753.1	35.8[4]	32.8
13	18°12'	158°51'	6-4	0408-0440	1497.6	23.1	20.7
15	16°16'	160°28'	6-5	0359-0430	1398.2	16.7[5]	15.0
17	14°56'	162°16'	6-6	0356-0427	1512.2	19.8	17.8
19	13°54'	164°01'	6-7	0345-0418	1523.1	15.4	13.6
21	12°35'	165°45'	6-8	0353-0423	1337.7	33.6	29.5
23	11°11'	167°26'	6-9	0329-0400	1523.4	35.4	30.6
25	13°00'	168°13'	6-10	0332-0403	1456.0	21.2	18.3
25a	14°33'	168°25'	6-10	1626-1657	1420.4	16.4	17.9
27	16°01'	168°36'	6-11	0401-0432	1504.5	11.4	10.2
29	17°55'	169°37'	6-12	0355-0426	1331.9	30.1[6]	27.0
29a	19°37'	169°50'	6-12	1623-1653	1385.2	14.3	15.6
31	20°59'	169°12'	6-13	0359-0433	2022.9	19.0	17.1
33	21°05'	168°16'	6-14	0359-0430	1626.6	21.3	19.1
35	20°51'	166°48'	6-15	0407-0438	1628.4	22.2	19.9
37	21°14'	164°11'	6-16	0411-0442	1695.8	19.5	17.5
39	20°51'	161°59'	6-17	0423-0453	1655.0	20.9	19.1
41	21°17'	160°01'	6-18	0451-0522	1443.3	15.7	14.7

1/ Apparent solar time.

2/ Adjusted for day-night difference by the sine transformation method using the pooled regression coefficient (b = 0.1110).

3/ About 50 percent, by volume, *Pyrosoma* < 2 cm. longest dimension.

4/ About 15 percent, by volume, *Pyrosoma* < 2 cm. longest dimension.

5/ About 40 percent, by volume, *Pyrosoma* < 2 cm. longest dimension.

6/ About 15 percent, by volume, *Pyrosoma* < 2 cm. longest dimension.

Table 11.--Zooplankton volumes obtained on cruise 16 of the <u>Charles H. Gilbert</u>, employing 1-meter nets of 30XXX grit gauze and oblique hauls to the depth indicated

Station	Sample	Position		Date 1953	Time[1/]	Estimated depth of haul, m.	Water strained, $m.^3$	Zooplankton, cc./$1000m.^3$	
		North latitude	West longitude					Sample volume	Adjusted volume[2/]
15	1	20°59'	161°44'	8-11	2121-2155	191	1844.9	43.7	35.4
15	2	20°59'	161°43'	8-11	2158-2226	99	1330.1	56.1	44.5
15	3	21°00'	161°41'	8-11	2228-2305	200	1717.8	32.3	25.4
15	4	21°00'	161°40'	8-11	2308-2336	102	1250.7	69.4	54.0
16	1	21°11'	160°22'	8-12	0926-0958	204	1282.8	17.2	21.2
16	2	21°11'	160°21'	8-12	1000-1027	106	900.4	24.4	30.8
16	3	21°12'	160°19'	8-12	1029-1105	206	1551.7	15.8	20.1
16	4	21°12'	160°18'	8-12	1108-1138	102	1273.4	24.6	31.6

1/ Apparent solar time.

2/ Adjusted for day-night difference by the sine transformation method using the pooled regression coefficient (b = 0.1110).