VARIATIONS IN MARINE ZOOPLANKTON FROM A SINGLE LOCALITY IN HAWAIIAN WATERS

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ABSTRACT

Data on marine zooplankton and hydrography were obtained off Oahu, Hawaii, at monthly intervals from June 1957 through December 1958.

Samples collected at 3-hour intervals for 48 hours in June 1957 were examined for diel variation. Volumes of zooplankton exhibited the expected sinusoidal variation during the first 24 hours, but not during the second. High volumes during the second morning were attributed to the presence of an unidentified diatom that retarded drainage of moisture during determination of volumes of zooplankton. Variations in abundance were sinusoidal for Ostracoda, Euphausiacea, Pteropoda, and fish larvae. Similar variations in surface temperature and depth from the surface to the top of the thermocline were attributed to solar heating and internal waves, respectively.

The 19 monthly samples showed correlations between volumes of zooplankton and salinities and between volumes of zooplankton and depth to the top of the thermocline. The 19 months were divided into nine successive periods, each with a temperature-salinity curve differing from that of the preceding and following periods. Volumes of zooplankton and the abundance of Siphonophora, Chaetognatha, Euphausiacea, decapod Crustacea, and Pteropoda increased when portions of the temperature-salinity curves greater than 35.0‰ increased during the nine periods; and, conversely, the volumes of zooplankton and the abundance of these groups of zooplankters decreased as the amount of water with salinity greater than 35.0‰ decreased.

Once every month from June 1957 through December 1958, members of the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, collected hydrographic and meteorological data from a station located at lat. 21°10.3′ N., long. 158°19.0′ W. for the Island Observatory Project of the International Geophysical Year Oceanographic Program (Scripps Institution of Oceanography, 1965). This position, referred to as the IGY station, is about 32 km. southwest of Barbers Point, Oahu, where the depth of the water is about 3,000 m.

Samples of zooplankton were also collected at the IGY station for studies of variations in the standing crop and composition of marine zooplankton in relation to environmental factors at a single locality in Hawaiian waters. The results showed that volumes of zooplankton were high in waters of high surface and subsurface salinities.

METHODS

The samples of zooplankton were collected with a net having a mouth diameter of 1 m.; a flowmeter was mounted in the center of the opening. The body of the net was constructed of synthetic fiber of 0.656 mm. aperture width; the rear section, including the cod end, was made of synthetic fiber of 0.308 mm. aperture width. Detailed descriptions of the construction of the net and the method of making the tow have been presented by King and Demond (1953).

The nets were towed obliquely from the surface to a depth of 60 m. and back in one-half hour. In June 1957, such hauls were made at 3-hour intervals over a 48-hour period to measure diel variations. In the succeeding months, four half-hour hauls were made each time the station was occupied: two successive daylight hauls starting at about 1600 l.s.t. (local standard time) and two successive night hauls between 2100 and 0300 l.s.t.

The methods of processing and determining the volumes of the samples of zooplankton have been described by King and Hida (1954, 1957a). Counts of various groups of plankters were made on the night samples.

For the counts, an aliquot of a sample was first placed in a counting cell (a 15 by 20 by 1.5-cm.

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plastic dish) which had 300 subdivisions ruled into its bottom. The organisms in 40 randomly selected squares were identified and counted under a dissecting microscope. The estimated number of a group of organisms in 1,000 m.^{3} of water was calculated by the following formula (modified from King and Demond, 1953):

$$E=\frac{CA}{fanW}1{,}000$$

where E=number of organisms per 1,000 m.^{3} of water

C=counted number of organisms

A=area of counting cell (300 cm.^{2})

f=fraction of total sample in the counting cell

a=area of square (1 cm.^{2})

n=number of squares counted (40)

W=cubic meters of water strained by net

Usually, on each visit to the IGY station, two hydrographic casts were made, one during the highest tide and the other during the lowest tide. Ordinarily, each cast was from 0 to 500 m. depth and consisted of 12 Nansen bottles, but on some occasions the casts were deeper. Temperature and salinity data were obtained with each cast, and with a few exceptions, oxygen and inorganic phosphate were also measured. Additional temperature data were obtained with bucket thermometers and bathythermographs.

Salinity determinations were made by a modification of the Knudsen method (Van Landingham, 1957); inorganic phosphate determinations were made with a Beckman [1] spectrophotometer.

Temperature, salinity, phosphate, and oxygen values used in the study were averaged as follows:

Surface value: average of measurements obtained at water surface during high tide and low tide.

0 to 60 m. value: average of measurements at depths of 0, 10, 20, 30, 40, 50, and 60 m. during high tide and low tide.

200 to 300 m. value: average of values at 15-unit increments between the 400 and 300 thermosteric anomaly surfaces on a temperature-salinity plot. These two anomaly surfaces represented approximately 200 and 300 m., respectively.

[1] Trade names referred to in this publication do not imply endorsement of commercial products.

Vertical temperature distribution: isotherms were contoured on the basis of the average temperatures at the following depths: 0, 9.2, 15.2, 30.5, 45.8, 61.0, 76.2, 91.5, 100.6, 122.0, 149.4, 152.5, 183.0, 199.8, 213.5, 244.0, and 274.5 m. Readings were limited to a maximum of five bathythermograms per month.

DIEL VARIATIONS

In central Pacific waters, diel variation in volumes of zooplankton and in abundance of certain zooplankton has been shown to vary as the curve of the sine function (King and Hida, 1954; Legand, 1958; Nakamura, 1967); the peak equated to midnight. The volumes and abundance of zooplankters determined from samples obtained at 3-hour intervals from June 21 to 23, 1957, were examined for similar variations. Temperatures and depths to the top of the thermocline for this period were also examined for diel variations.

VOLUMES OF ZOOPLANKTON

The volumes of zooplankton obtained for the 48-hour series ranged from a low of 13 cc./1,000 m.^{3} of water strained to a high of 40 cc./1,000 m.^{3}, with a mean of 26 cc./1,000 m.^{3} (fig. 1). The volumes of the samples obtained during the night were greater than those of the samples collected by daylight; the night to day ratio was 1.3 : 1. The greater abundance of zooplankton in darkness has been attributed by investigators to some combination of an upward migration by the zooplankters and an increased avoidance of the net by some organisms in daylight (King and Hida, 1954, 1957a; Fleminger and Clutter, 1965; Brinton, 1967).

The volumes from the 48-hour series appeared to conform approximately to a sinusoid for the first 24-hour period but not for the second. The volumes remained high through the second morning. An unusually large amount of an undetermined species of diatom was present in samples 11, 12, 15, and 16. The greater resistance of these samples to moisture drainage than of those without diatoms resulted in a greater determination of wet volume. This fact may have explained the unusually high volumes in samples 12, 15, and 16. On the other hand, the volume of sample 11 did not appear to be unusual even though it too contained diatoms.

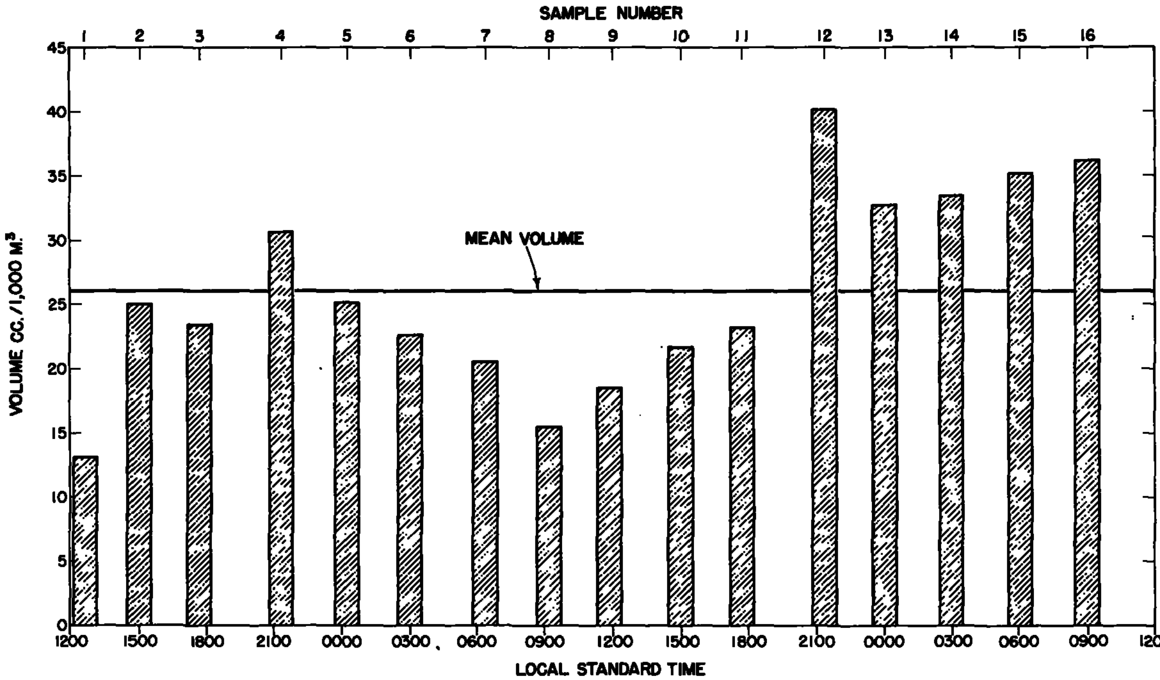

FIGURE 1.—Variations in volumes of zooplankton over a 48-hour period, June 21–23, 1957, at the IGY station. Sunrise during this period was at 0503 and sunset at 1846 hours.

COMPOSITION OF ZOOPLANKTON

Abundance of groups of plankters expressed as average numbers per 1,000 m.³ of water strained and as average percentages of total numbers of plankters is summarized in table 1. By far the most numerous organisms in the samples were copepods, which on the average constituted about 60 percent of all organisms present. Chaetognatha and *Halosphaera viridis*,[2] almost equal in average abundance, were the second and third most common organisms in the samples. Numerically, each averaged less than 10 percent of the copepods.

Distinct diel variations, with greater numbers during darkness, were exhibited by Ostracoda, Euphausiacea, Pteropoda, and fish larvae (fig. 2). Amphipoda exhibited such a diel variation only during the second half of the series (fig. 2). In addition to the aforementioned groups, Annelida (Polychaeta) and calanoid Copepoda have been shown previously to exhibit distinct diel variations in Hawaiian waters (Nakamura, 1967). In this study, these two groups did not show the characteristic peaks of abundance during darkness. Perhaps if specific or generic identifications had been made

[2] This phytoplankter was present in every sample and was included in all counts.

TABLE 1.—*Average abundance and average percentage composition of various plankters for 16 samples of the 48-hour series*

Plankters	Average abundance	Average composition
	No./1,000 m.³	*Percent*
Halosphaera[1]	1,654	5.6
Foraminifera	775	2.6
Radiolaria	572	1.9
Siphonophora	1,088	3.7
Chaetognatha	1,626	5.5
Annelida	132	.4
Calanoid Copepoda	17,788	59.8
Noncalanoid Copepoda	1,024	3.4
Ostracoda	866	2.9
Euphausiacea	664	2.2
Amphipoda	1,189	4.0
Decapod Crustacea	1,075	3.6
Pteropoda	290	1.0
Heteropoda	147	.5
Gastropod larvae	64	.2
Pelecypoda	50	.2
Thaliacea	51	.2
Appendicularia	422	1.4
Fish larvae	129	.4
Fish eggs	35	.2
Others	82	.3

[1] *Halosphaera viridis*, a phytoplankter, numerous in all samples.

diel fluctuations would have been revealed, for Nakamura (1967) found that the following genera of calanoid copepods were concentrated in the upper waters during darkness: *Pleuromamma*, *Neocalanus*, *Candacia*, *Undinula*, and *Euchaeta*. In the present study abundance of Heteropoda reached a peak during daylight as well as at night.

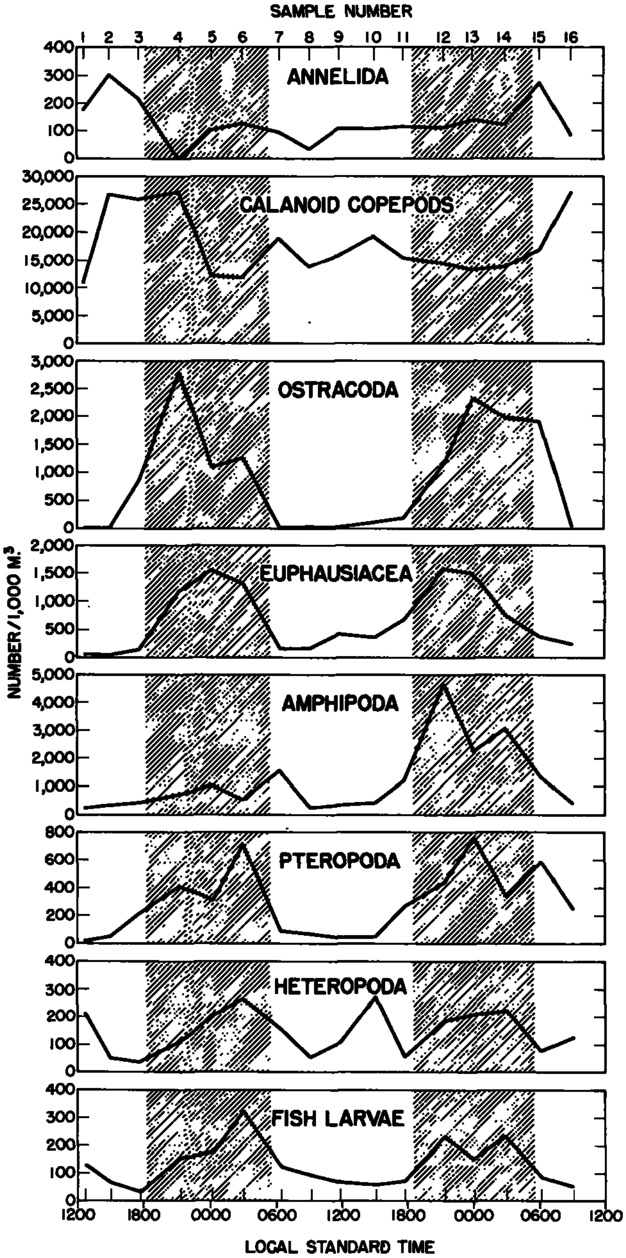

FIGURE 2.—Variation in the abundance of various groups of zooplankters during June 21–23, 1957, at the IGY station.

TEMPERATURE

The diel variation in surface temperature (fig. 3) was attributed to solar heating during the day and cooling at night. A subsurface thermal disturbance was evident between 0400 and 1200 hours, June 22. It was probably caused by advection; however, unusual changes in the volumes of zooplankton did not occur during the thermal disturbance.

DEPTH FROM SURFACE TO TOP OF THERMOCLINE

The sinusoidal variation in the depth from the surface to the top of the thermocline (fig. 3) showed fluctuations probably caused by internal waves. The variations in depth to the top of the thermocline, however, did not appear to influence the abundance or composition of the zooplankton during the 48-hour period. The depths for the hauls of zooplankton in this series ranged from 52 to 65 m. The depth from the surface to the top of the thermocline ranged from 23 to 61 m. Sample 8 was the only one collected entirely within the isothermal layer above the thermocline. The volume of sample 8 was not unusual. Chaetognatha had their least abundance and Pelecypoda their greatest abundance in this sample.

CORRELATIONS BETWEEN ZOOPLANKTON AND PHYSICAL AND CHEMICAL FACTORS

King and Hida (1954, 1957b), in their studies of the distribution and abundance of zooplankton in Hawaiian waters, were unable to show a consistent relation between the standing crop and temperature, surface phosphate, dissolved oxygen, and depth from the surface to the top of the thermocline. Analyses of their data from seven cruises gave one statistically significant correlation ($P<0.05$) between zooplankton and temperature (at 10-m. depth) and one significant correlation ($P<0.01$) between zooplankton and surface phosphate. King and Hida's samples were taken from a large area around the Hawaiian Islands.

Consistently high or low standing crops regardless of changes in the environment (McGary 1955; Seckel, 1955) have been found in certain areas in Hawaiian waters. For example, King and Hida (1954, 1957b) found consistently low volumes of zooplankton from immediately east of the island of Hawaii.

The results of the correlation analyses for the present study, where sampling was confined to one locality, are summarized in table 2. Volumes of zooplankton were examined in relation to the physical and chemical data for the surface, 0 to 60 m. (range in depth of the hauls for zooplankton),

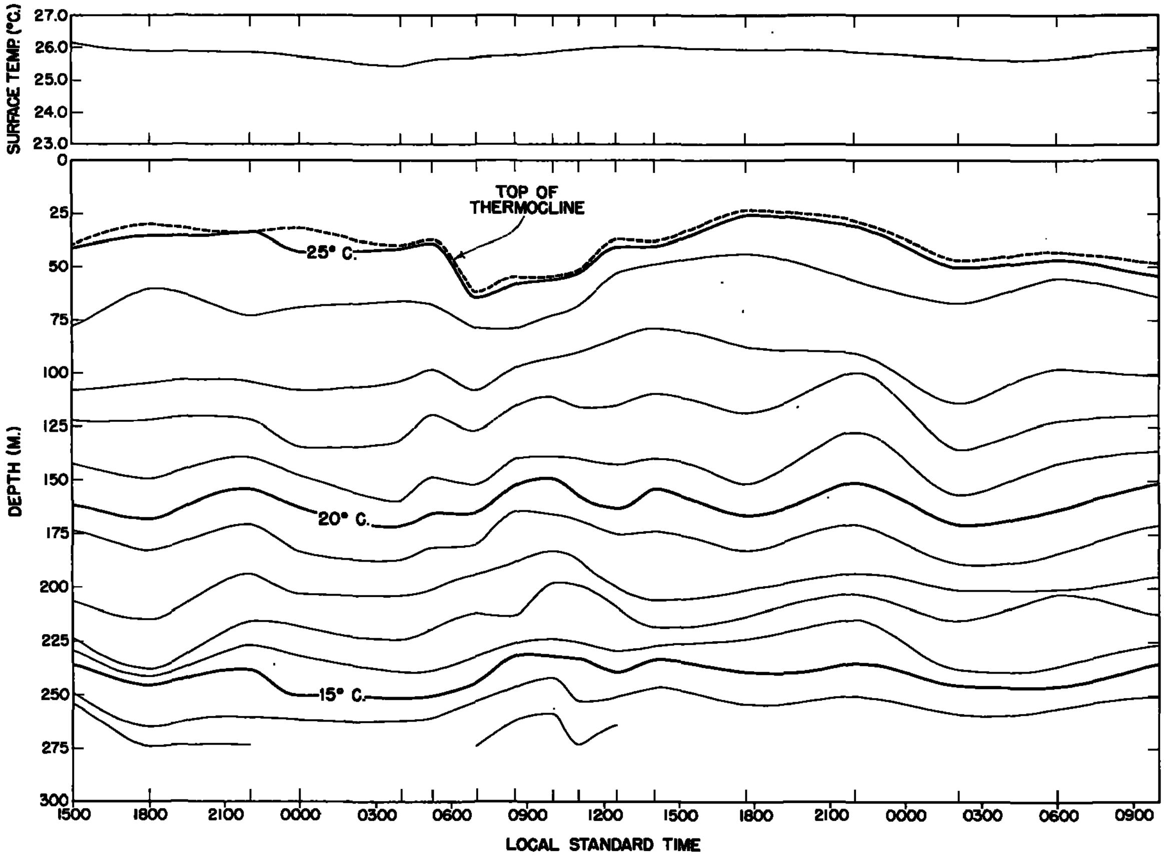

FIGURE 3.—Vertical distribution of temperature during June 21–23, 1957, at the IGY station.

TABLE 2.—*Summary of correlations between volumes of zooplankton and certain physical and chemical environmental factors*

First variate (X_1)	Second variate (X_2)		Degrees of freedom	Correlation coefficient (r)
Surface salinity (°/oo).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	16	0.397
		Day hauls..	16	**.655
Surface oxygen (ml./l).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	14	−.029
		Day hauls..	14	.228
Surface inorganic phosphate (µg.at./l).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	13	−.132
		Day hauls..	13	−.227
0–60 m. salinity (°/oo).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	16	.464
		Day hauls..	16	**.706
0–60 m. temperature (° C.).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	16	.025
		Day hauls..	16	−.236
200–300 m. salinity (°/oo).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	16	*.507
		Day hauls..	16	.455
Depth to top of thermocline (m.).	Zooplankton volume (cc./1,000 m.³).	Night hauls.	16	*−.524
		Day hauls..	16	*−.544

*Significant at 5-percent level.
**Significant at 1-percent level.

and about 200 to 300 m., and also the depth from the surface to the top of the thermocline. Changes in volumes of zooplankton and in physical and chemical factors of the environment during the 19 months are illustrated in figures 4, 5, and 6. Surface values are given in table 3.

Except for June 1957 and October 1958, the volumes of zooplankton obtained at night were greater than those collected by day (fig. 4). The ratio of night to day volumes ranged from 0.9 : 1 to 3.3 : 1 and averaged 1.8 : 1.

Volumes of zooplankton showed close correlations with salinities and depths of the isothermal layer but not with other environmental factors. Positive correlations were significant at either the 5 percent or 1 percent probabilities between volumes of zooplankton for day hauls and salinities at the surface and at 0 to 60 m., and for night hauls and salinities at 200 to 300 m. (table 2). Correlations between volumes of zooplankton for night hauls and salinities at 0 to 60 m. and for day hauls and salinities at 200 to 300 m. were very close

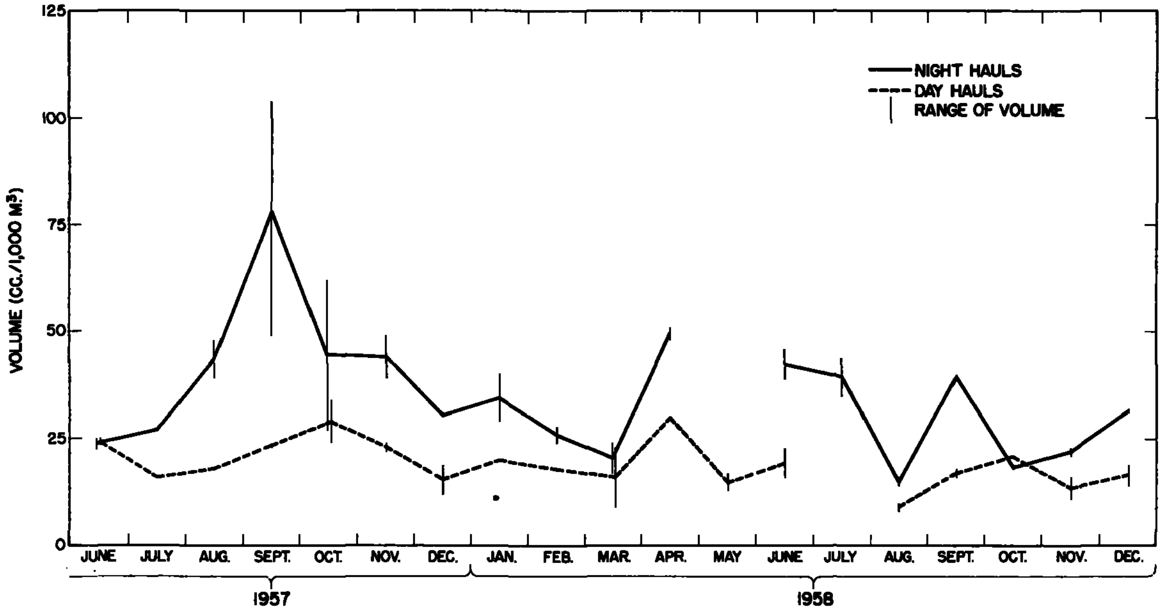

Figure 4.—Monthly variations in volumes of zooplankton collected by night and by day at the IGY station from June 1957 to December 1958.

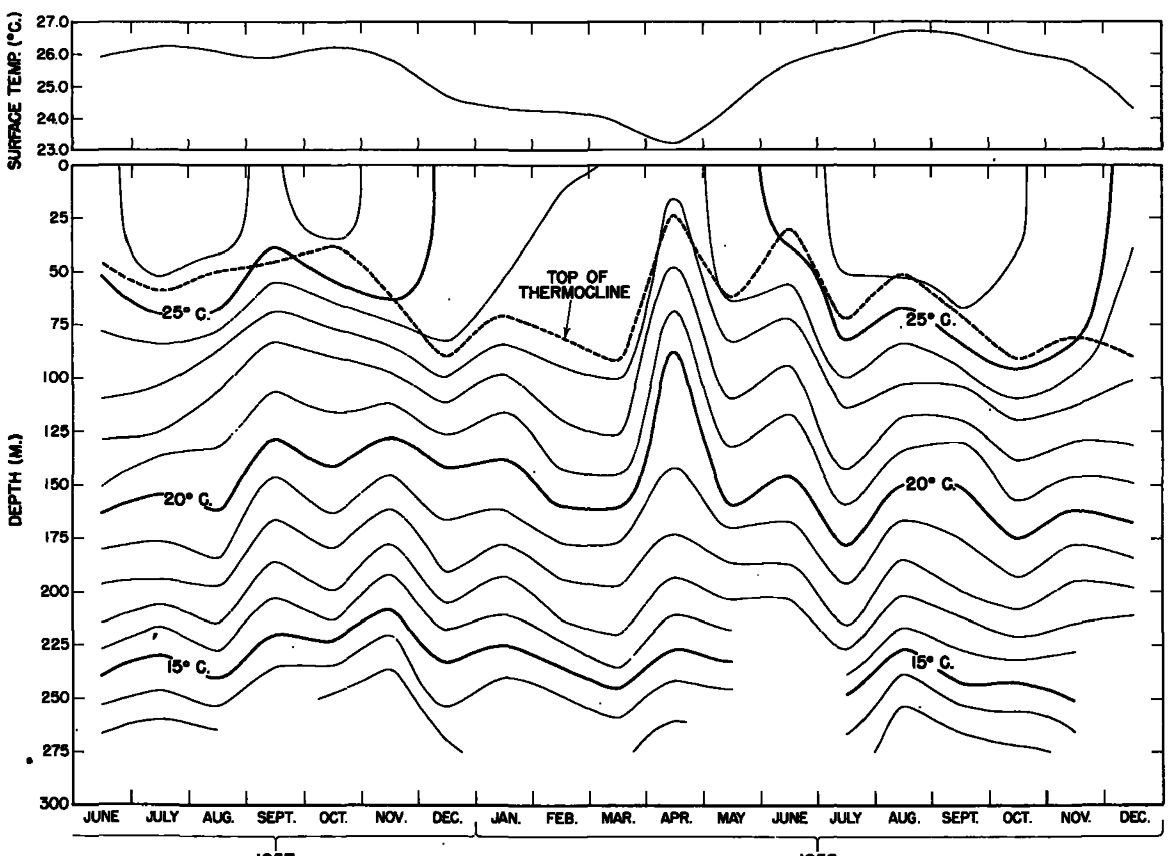

Figure 5.—Monthly vertical distribution of temperature at the IGY station from June 1957 to December 1958.

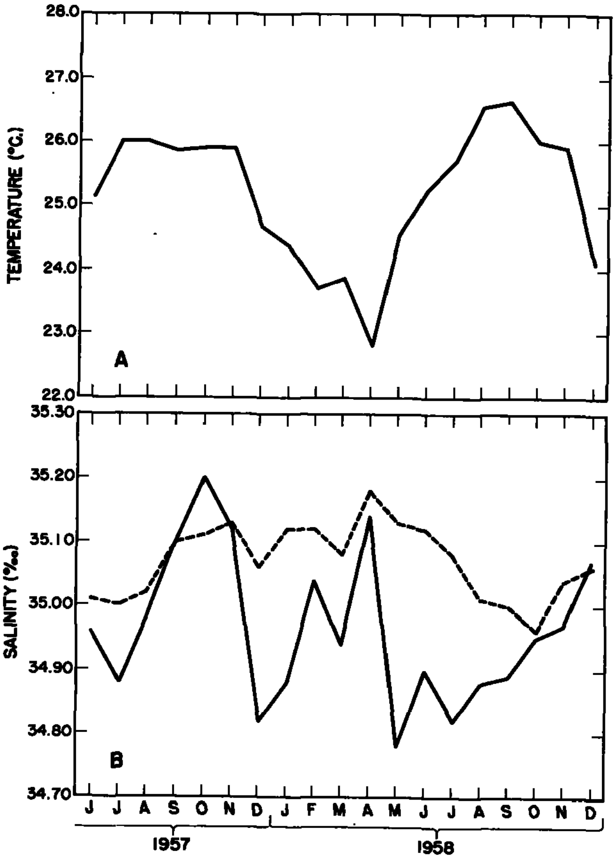

FIGURE 6.—Monthly variation in temperature and salinity at the IGY station from June 1957 to December 1958. A. Mean 0 to 60 m. temperatures. B. Mean 0 to 60 m. salinities (solid line) and mean 200 to 300 m. salinities (dashed line).

to significance at the 5 percent probability (for P = 0.05 and d.f. = 16, r = 0.468). Negative correlations were significant between volumes of zooplankton for both night and day hauls and depths from the surface to the top of the thermocline. Neither temperature, oxygen, nor inorganic phosphate was correlated with volumes of zooplankton.

We believe the significant relations between zooplankton and salinity and between zooplankton and the thickness of the isothermal layer resulted from the advection of different types of water into the Hawaiian area. The biomass of zooplankton was higher in waters of high salinity.

ZOOPLANKTON AND TEMPERATURE-SALINITY CURVES

Seckel (1962) indicated that the Hawaiian Islands are located near the northern boundary of the transition zone between two major types of

TABLE 3.—*Monthly values of surface salinity, inorganic phosphate, and oxygen during low and high tides at the IGY station*

Month	Salinity °/₀₀		Phosphate µg.at./l		Oxygen ml./l	
	Low tide	High tide	Low tide	High tide	Low tide	High tide
1957						
June	34.97	34.97	0.22	0.20	4.29	4.32
July	34.87	34.88	.29	.24	4.47	4.46
August	34.96	34.96	.20	.22	4.79	4.78
September	35.07	35.12	.13	.16	--------	4.45
October	35.19	35.16	.10	.16	4.53	4.51
November	35.12	35.12	.11	.16	4.78	4.64
December	34.72	34.81	3.65	--------	4.58	4.56
1958						
January	34.81	34.85	.12	.13	4.79	4.69
February	35.03	35.05	.22	.20	4.85	4.84
March	34.94	34.96	.64	1.60	4.60	4.66
April	35.10	35.07	--------	--------	--------	--------
May	34.80	34.77	.06	.62	4.55	4.62
June	34.90	34.82	--------	--------	4.08	4.18
July	34.81	34.80	.49	.70	4.77	4.80
August	34.91	34.89	.39	.22	4.43	4.55
September	34.86	34.87	--------	--------	4.55	4.64
October	34.94	34.96	.21	.23	--------	4.40
November	34.96	34.94	.11	.10	--------	--------
December	34.94	35.05	--------	.35	--------	4.64

surface water: (1) the high-salinity (surface values >35.0‰) North Pacific Central Water, and (2) the low-salinity (surface values <34.2‰) North Pacific Equatorial Water. These water types corresponded approximately with the subsurface water masses as defined by Sverdrup, Johnson, and Fleming (1942). Seckel (1962) classified the California Current Extension, which forms the core of the transition zone, as a third type. He showed that the boundaries of these water types shifted seasonally and affected the type of water to be found near Oahu.

Our data were analyzed from the standpoint of advection of different types of water as indicated by changes in the temperature and salinity during the 19 months of observation. The data were divided into the following nine chronological periods (fig. 7) on the basis of the similarity in the temperature-salinity (T-S) curves for successive months: June to July 1957, August 1957, September to November 1957, December 1957 to March 1958, April 1958, May 1958, June to July 1958, August to November 1958, and December 1958. Each period had temperature and salinity characteristics that were different from the preceding and succeeding periods. The average monthly (0–60 m.) temperatures, the average monthly salinities (0–60 m. and 200–300 m.), and the average depth from the surface to the top of the thermocline for the nine periods are illustrated in figure 8.

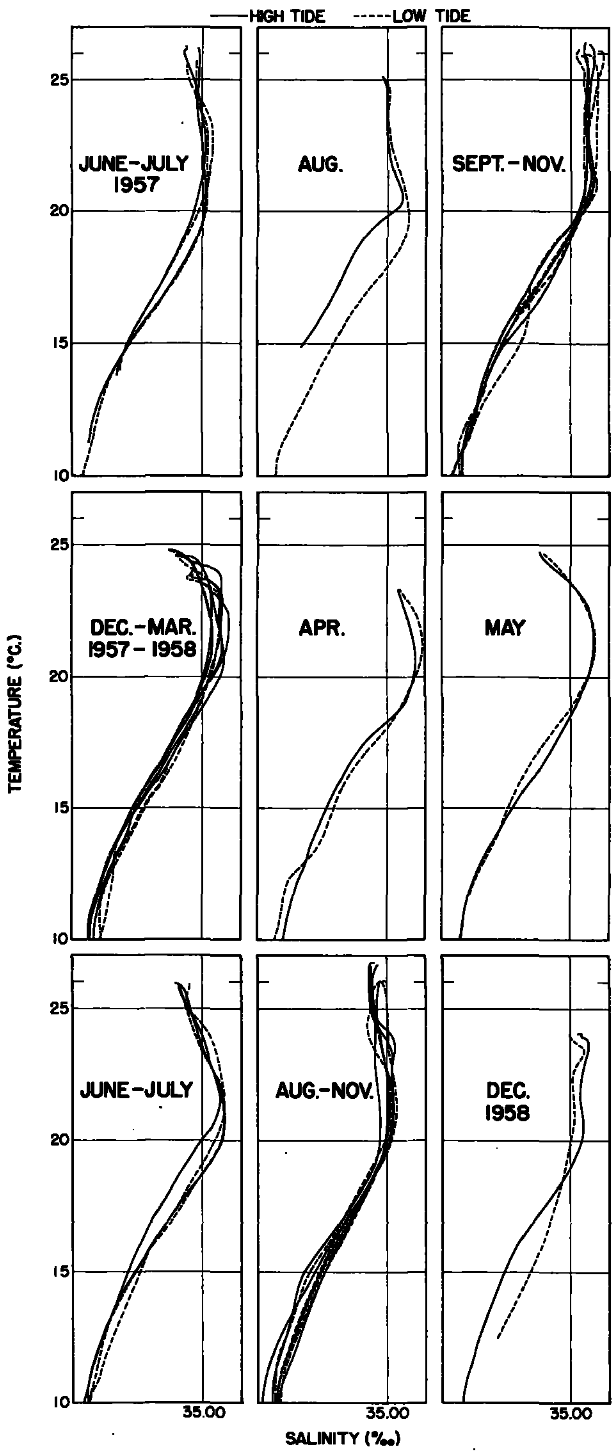

FIGURE 7.—Monthly temperature-salinity relation at highest high tide and lowest low tide at the IGY station by periods.

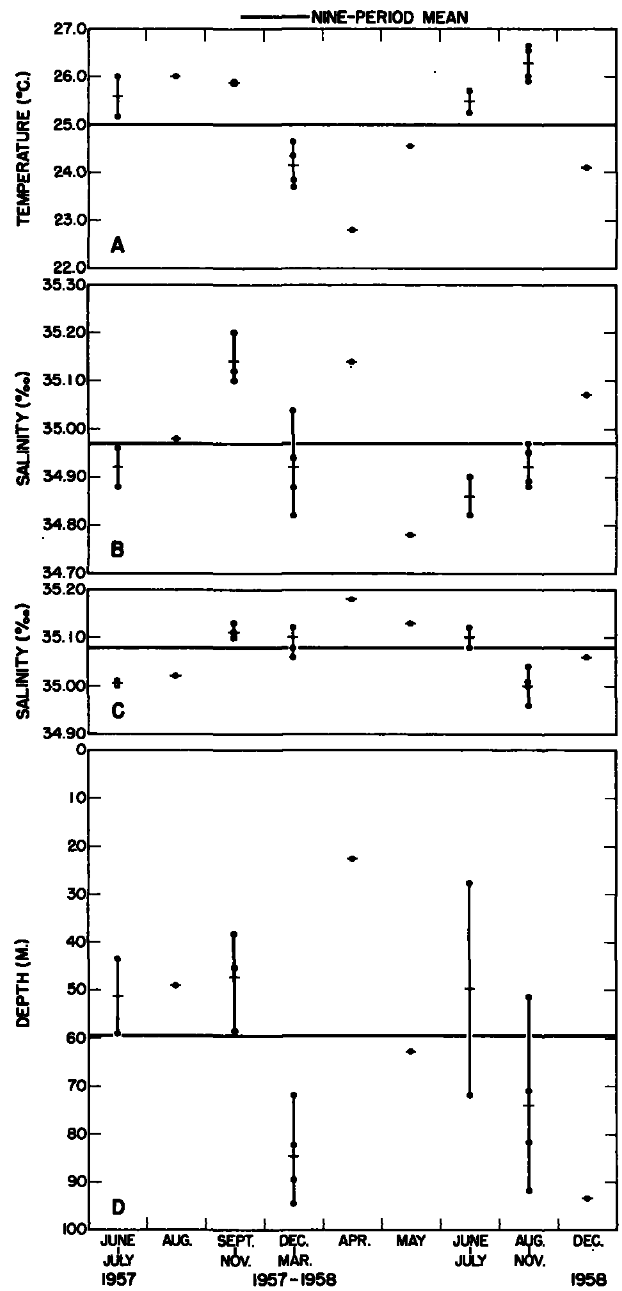

FIGURE 8.—Physical and chemical characteristics of the nine periods. A. Average 0 to 60 m. temperatures. B. Average 0 to 60 m. salinities. C. Average 200 to 300 m. salinities. D. Average depth from the surface to top of thermocline.

TABLE 4.—*Average abundance (No./1,000 m.³) of various plankters from samples taken at night at the IGY station*

Plankters	Period and (in parentheses) number of samples								
	June, July 1957 (2)	Aug. 1957 (1)	Sept., Oct., Nov. 1957 (3)	Dec. 1957, Jan., Feb., Mar. 1958 (4)	Apr. 1958 (1)	June, July 1958 (2)	Aug., Sept., Oct., Nov. 1958 (4)	Dec. 1958 (1)	Eight-period mean (8)
Halosphaera [1]	5,392	1,771	3,047	3,569	5,284	1,582	2,400	5,102	3,518
Foraminifera	660	551	283	286	1,308	94	274	559	502
Radiolaria	204	394	158	156	366	38	142	298	220
Siphonophora	2,196	3,543	5,943	3,055	4,185	6,137	3,723	4,358	4,142
Chaetognatha	1,346	2,834	2,955	1,259	4,813	2,420	2,346	3,128	2,638
Annelida	184	157	238	188	366	357	128	410	254
Calanoid Copepoda	12,762	38,733	32,069	18,704	30,395	20,078	13,489	24,916	23,893
Non-calanoid Copepoda	1,359	2,362	2,301	1,192	4,028	1,796	1,898	2,905	2,230
Ostracoda	1,974	2,559	2,633	3,515	6,069	607	550	1,937	2,480
Euphausiacea	1,338	2,440	4,541	1,673	3,139	1,662	1,893	1,788	2,309
Amphipoda	958	905	526	401	942	869	548	521	709
Decapod Crustacea	2,120	3,976	4,460	1,842	3,768	3,060	3,331	5,028	3,448
Pteropoda	486	945	1,361	546	1,360	446	1,049	1,378	946
Heteropoda	247	79	394	38	52	68	118	----------	124
Gastropod larvae	50	197	174	33	105	138	136	298	141
Pelecypoda	50	----------	74	177	----------	44	132	223	88
Thaliacea	11	157	202	464	1,308	668	146	372	416
Appendicularia	135	157	851	720	3,191	216	255	1,639	896
Fish larvae	234	236	269	292	366	692	171	----------	282
Fish eggs	96	79	31	90	314	25	21	112	96

[1] *Halosphaera viridis*, a phytoplankter.

The physical, chemical, and biological characteristics of each of the nine periods are discussed below. For the discussion the averages for each period are considered high or low relative to the overall average for the nine periods. A night sample of zooplankton was not taken in May 1958; thus, the counts of zooplankton for night collections are divided into eight rather than nine periods (table 4).

JUNE TO JULY 1957

This period was characterized by relatively high temperatures, low salinities, and a shallow isothermal layer. The average 0 to 60 m. temperature was 25.6° C. The 0 to 60 m. and 200 to 300 m. average salinities were 34.92‰ and 35.00‰, respectively, compared to the nine-period means of 34.97‰ and 35.08‰. The average depth to the top of the thermocline was 51.4 m. (fig. 8).

The average volume of zooplankton for day hauls equaled the nine-period mean of 20 cc./1,000 m.³ (fig. 9); the average night volume of 25 cc./1,000 m.³ was lower, however, than the eight-period mean of 37 cc./1,000 m.³ Most of the counts of groups of organisms were low (table 4); *Halosphaera*, Foraminifera, Amphipoda, and Heteropoda were exceptions. The abundance of calanoid Copepoda, which numerically make up about 59 percent of the total standing crop of zooplankton, was very low during this period.

AUGUST 1957

August 1957 appeared to be a transition period (fig. 7). The 0 to 60 m. salinity increased from 34.92‰ to 34.98‰, and the 200 to 300 m. salinity increased slightly from 35.00‰ to 35.02‰. The 0 to 60 m. temperature (26.0° C.) also increased. The depth of the isothermal layer (49.1 m.) decreased from the previous period.

The volume of zooplankton for the day hauls (18 cc./1,000 m.³) for this period was slightly less than the average for June to July 1957; however, the night volume (44 cc./1,000 m.³) showed a substantial increase. Radiolaria and calanoid Copepoda were more abundant in August 1957 than in any other period.

SEPTEMBER TO NOVEMBER 1957

Temperature and depth of the isothermal layer for this period were lower; salinities were higher than in the previous period. The average 0 to 60 m. temperature was 25.9° C. The depth to the top of the thermocline was 47.4 m. The 0 to 60 and 200 to 300 m. salinities were 35.14‰ and 35.11‰, respectively.

The average volumes and counts of zooplankton were high. Volumes for day (25 cc./1,000 m.³) and night (56 cc./1,000 m.³) samples were both higher than the corresponding averages (20 cc./1,000 m.³ and 37 cc./1,000 m.³) for all periods. Euphausiacea and Heteropoda were more abundant in this period than in any other.

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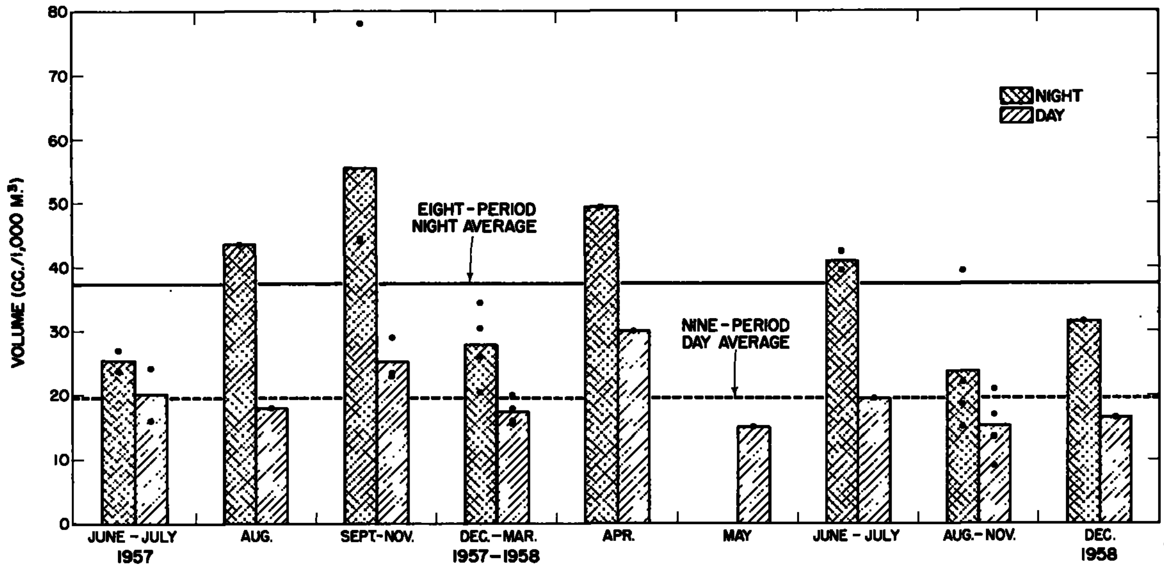

FIGURE 9.—Average volumes of zooplankton during nine periods at the IGY station.

DECEMBER 1957 TO MARCH 1958

Monthly changes of the measured properties from July to November 1957 were gradual; the change from November to December 1957, however, was abrupt. The 0 to 60 m. temperature dropped from an average of 25.9° C. in November 1957 to 24.6° C. in December 1957 (fig. 6A) and remained low, averaging 24.1° C. for December 1957 to March 1958 (fig. 8A). The monthly 0 to 60 m. salinity likewise changed considerably, dropping from 35.12‰ in November to 34.82‰ in December (fig. 6B). The December 1957 to March 1958 average was 34.92‰ (fig. 8B).

The 200 to 300 m. salinity (35.10‰) changed slightly (fig. 8C), but the depth to the top of the thermocline showed a considerable deepening from an average of 47.4 m. during September to November 1957 to 84.6 m. (fig. 8D) for this period.

The volumes of zooplankton declined markedly from the preceding period. The night volume dropped from an average of 56 cc./1,000 m.³ in September to November 1957 to 28 cc./1,000 m.³ The day volumes of zooplankton declined from 25 cc./1,000 m.³ to 17 cc./1,000 m.³ (fig. 9). Except for *Halosphaera*, Ostracoda, Pelecypoda, and Thaliacea the abundance of plankters was relatively low during this period.

APRIL 1958

Maximum and minimum values were recorded for the physical and chemical properties during April 1958 (figs. 6 and 8). The 0 to 60 m. temperature (22.8° C.) was the lowest recorded during the 19 months. The 0 to 60 m. salinity (35.14‰) equaled the September to November 1957 average, the highest average for the nine periods. The 200 to 300 m. salinity (35.18‰) was also the highest for the nine periods. The isothermal layer during this period was the shallowest (22.6 m.) of the nine periods.

The zooplankton showed marked differences from the preceding period. The day and night volumes of 30 cc./1,000 m.³ and 50 cc./1,000 m.³ for April were much higher than those for December 1957 to March 1958. With the exception of Pelecypoda, all of the organisms were more numerous than in the preceding period.

MAY 1958

In May the physical and chemical characteristics of the water differed markedly from those of April 1958. The 0 to 60 m. temperature increased from the low of 22.8° C. in April to 24.6° C. in May. The most important change, however, was in the 0 to 60 m. salinity, which decreased from 35.14‰ in April, the highest for the nine periods, to 34.78‰ in May, the lowest for the nine periods. The 200 to 300 m. salinity decreased slightly from 35.18‰ in April to 35.13‰ in May. These differences suggest that the major change from April to May was in the upper waters. The depth to the top of the thermocline (62.8 m.) was slightly greater than the nine-period mean (59.4 m.).

The average volume of zooplankton for the day hauls was 15 cc./1,000 m.^{3}, lower than that for any previous period.

JUNE TO JULY 1958

Except for a continued rise in temperature and a shallower isothermal layer, the changes during this period were not very great. The average 0 to 60 m. temperature was 25.5° C. The average 0 to 60 m. salinity increased to 34.86‰. The average 200 to 300 m. salinity declined further to 35.10‰. The average depth to the top of the thermocline was 49.8 m.

The night volumes of zooplankton for June to July averaged 41 cc./1,000 m.^{3} as compared to the eight-period average of 37 cc./1,000 m.^{3}, and the average day volume of 20 cc./1,000 m.^{3} was the same as the nine-period day average. Siphonophora, Annelida, Amphipoda, Thaliacea, and fish larvae were relatively abundant in this period.

AUGUST TO NOVEMBER 1958

Changes in temperature, salinity, and depth of isothermal layer continued. The 0 to 60 m. temperature reached its 1958 peak in this period with an average of 26.3° C. The average 0 to 60 m. salinity (34.92‰) increased over the preceding period (34.86‰). The average 200 to 300 m. salinity continued to decline to 35.00‰. This period and June to July 1957 had the lowest 200 to 300 m. salinities for the nine periods. The depth to the top of the thermocline deepened to an average of 74.0 m.

The low abundance of zooplankton was similar to the lows of June to July 1957, December 1957 to March 1958, and December 1958. Only the averages for Pteropoda and Pelecypoda were above the eight-period average.

DECEMBER 1958

This period was characterized by a marked decrease in temperature, rising salinities, and a progressively deepening isothermal layer. As in 1957, the 0 to 60 m. temperature underwent a large drop between November and December. For 1958 the decline was from 25.9° C. in November to 24.1° C. in December (fig. 6A). The 0 to 60 m. salinity of 35.07‰ continued to increase from 34.82‰ in July (fig. 6B). The 200 to 300 m. salinity (35.06‰) increased from the previous period. The depth to the top of the thermocline was 93.3 m.

The volume of zooplankton for December 1958 was again lower than the nine-period average. Except for seven groups (*Halosphaera*, Foraminifera, Ostracoda, Amphipoda, Heteropoda, Thaliacea, and fish larvae), however, the plankton during December 1958 was more abundant than in June to July 1957, December 1957 to March 1958, and August to November 1958.

COMPARISON BETWEEN PERIODS

A noticeable feature in the 19 months' observations was the dissimilarity of the hydrographic features for the same months of the 2 years. The 200 to 300 m. salinities for June to July were substantially lower in 1957 than in 1958, whereas the 0 to 60 m. and 200 to 300 m. salinities for August to November were higher in 1957 than in 1958. The depth to the top of the thermocline was shallower in the fall of 1957 than in the fall of 1958. The 0 to 60 m. temperatures reflected the seasonal fluctuations of high temperatures in summer and fall and low temperatures in winter and spring and so did not vary greatly between years for the same months.

Zooplankton was more abundant during the fall of 1957 than in the fall of 1958 (figs. 4 and 9). Previous studies of the distribution of zooplankton in Hawaii have indicated a lack of consistent seasonal change. In 1950 and 1951, volumes were significantly higher during early summer and midsummer than in late summer and fall (King and Hida, 1954). But in 1956, the standing crop of zooplankton was greatest in January, April, and September (Nakamura, 1967).

June to July 1957 and August to November 1958 were alike. Both had similar T-S curves (fig. 7), hence their temperature and salinity characteristics were similar (fig. 8). Both of these periods had low volumes of zooplankton (fig. 9). The day volume of zooplankton for June to July 1957 was equal to the nine-period mean while that for August to November 1958 was low.

December 1957 to March 1958 and May 1958 were also alike. Both had similar T-S curves (fig. 7). Both had low day volumes of zooplankton. A night volume was not available for May 1958.

The two periods (September to November 1957 and April 1958) that had high night and day volumes of zooplankton (fig. 9) also had high 0 to 60 m. and 200 to 300 m. salinities (fig. 8), but their temperatures were quite dissimilar (fig 8).

VARIATIONS OF ZOOPLANKTON AND SALINITY

Of great interest were the coincident variations in the night volumes of zooplankton with variations in the portions of the T-S curves with salinities >35.0‰. As shown in figures 7 and 9, increases or decreases in night volumes of zooplankton appeared with corresponding changes in the salinity. The T-S curves indicated a progressive invasion of high-salinity water in the upper surface layers from June to July 1957 to September to November 1957. The night volumes of zooplankton increased correspondingly during these same periods. In December 1957 to March 1958, less saline waters returned to the uppermost layer of the ocean and the volume of zooplankton dropped below that of the preceding period. Then in April 1958 high-salinity water again invaded the area, and the volume of zooplankton increased. During May 1958 the salinity maximum was about the same as in the previous period, but the surface water was less saline. A night volume of zooplankton was not available for this period. During the next two periods, June to July 1958 and August to November 1958, the occurrence of high-salinity waters decreased progressively. Corresponding decreases also were evident in the night volumes of zooplankton. Water of higher salinity returned again in the uppermost layer during December 1958 coincident with an increase in the night volume of zooplankton.

Thus, waters of high salinity appeared to sustain a greater biomass of zooplankton. The abundance of several groups of zooplankton fluctuated coincidentally with the night volumes and with salinity. These groups were Siphonophora, Chaetognatha, Euphausiacea, decapod Crustacea, and Pteropoda (fig. 10). Because of the correlation of the abundance of these zooplankters with water type, the possibility of finding endemic species appeared favorable. Sherman (1963) found certain species of calanoid Copepoda (Pontellidae) associated with, and thus useful as indicators of, waters of high salinity (North Pacific Central Water) in the Hawaiian area. These groups of zooplankton

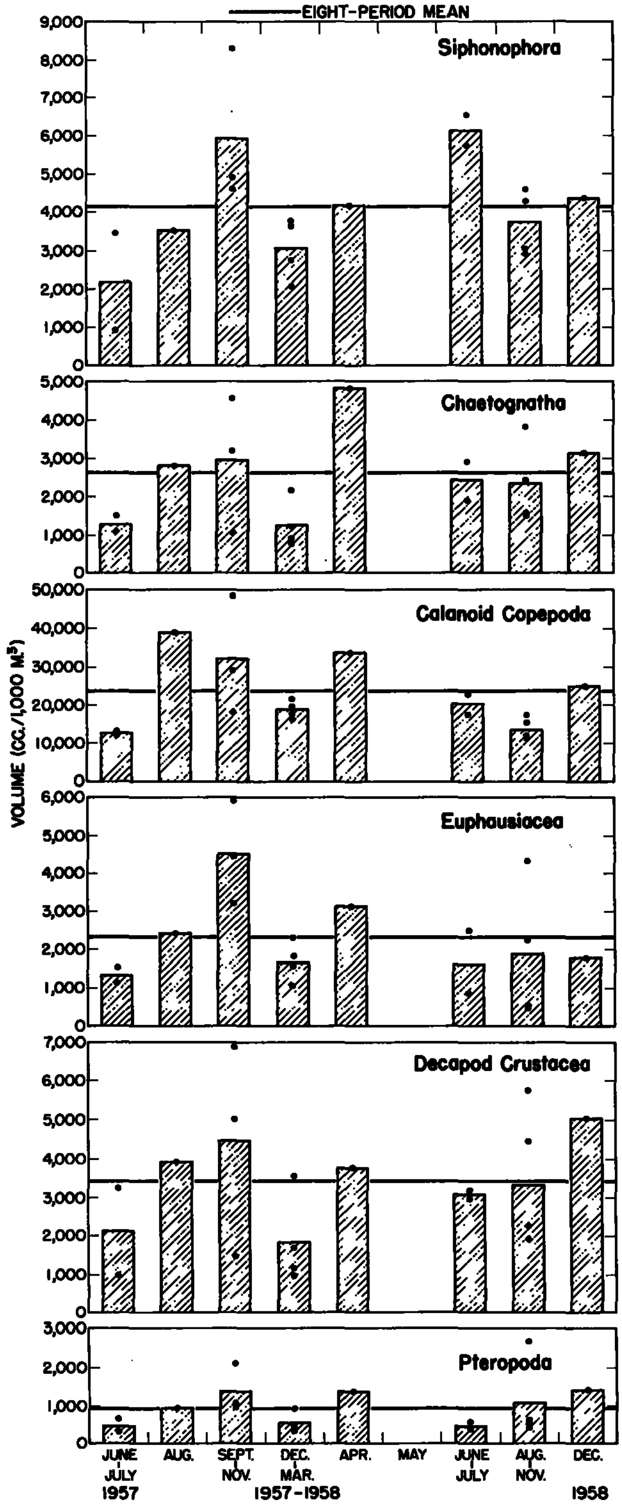

FIGURE 10.—Average abundance of six groups of zooplankton at night during eight periods at the IGY station.

may include other species possibly useful as indicators.

SUMMARY

1. Data on zooplankton and hydrography were obtained at lat. 21°10.3′ N., long. 158°19.0′ W. from June 1957 to December 1958. The station was visited once a month, and samples were taken once at highest tide and once at lowest tide. In June 1957, the station was occupied for 48 hours to obtain samples for studies of diel variation.

2. Volume of zooplankton from the 48-hour series conformed to the characteristic sinusoidal variation for the first day, but not for the second. A diatom that prevented drainage of moisture during determination of the volumes probably caused the high volumes during the morning of the second day. Variations in abundance were distinctly sinusoidal for Ostracoda, Euphausiacea, Pteropoda, and fish larvae. Variations in surface temperature were attributed to heating during the day and cooling during the night. Variations in the depth to the top of the thermocline were attributed to internal waves.

3. Correlations were significant and positive between day volumes of zooplankton and salinities at the surface and at 0 to 60 m., and for night volumes of zooplankton and salinities at 200 to 300 m. Positive correlations for night volumes of zooplankton and salinities at 0 to 60 m. and for day volumes and salinities at 200 to 300 m. were very close to the 5-percent probability. Correlations were significant and negative between both day and night volumes of zooplankton and depths to the top of the thermocline.

4. The 19 months were divided into nine periods, each period having a temperature-salinity curve different from the preceding and the following periods.

5. Salinities and depths to the top of the thermocline were dissimilar for the same months in 1957 and 1958. Night volumes of zooplankton were highest in the fall of 1957.

6. Variations in the night volumes of zooplankton coincided with variations in salinities > 35.0‰. As the salinity increased, zooplankton increased; as salinity decreased, zooplankton decreased. The abundance of Siphonophora, Chaetognatha, Euphausiacea, decapod Crustacea, and Pteropoda fluctuated coincidentally with the night volumes of zooplankton and with salinity.

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LITERATURE CITED

BRINTON, EDWARD.
1967. Vertical migration and avoidance capability of euphausiids in the California Current. Limnol. Oceanogr. 12: 451–483.

FLEMINGER, ABRAHAM, and ROBERT I. CLUTTER.
1965. Avoidance of towed nets by zooplankton. Limnol. Oceanogr. 10: 96–104.

KING, JOSEPH E., and JOAN DEMOND.
1953. Zooplankton abundance in the central Pacific. [U.S.] Fish Wildl. Serv., Fish. Bull. 54: 111–144.

KING, JOSEPH E., and THOMAS S. HIDA.
1954. Variations in zooplankton abundance in Hawaiian waters, 1950–52. [U.S.] Fish Wildl. Serv., Spec. Sci. Rep. Fish. 118, vi + 66 pp.
1957a. Zooplankton abundance in the central Pacific. Part II. U.S. Fish Wildl. Serv., Fish. Bull. 57: 365–395.
1957b. Zooplankton abundance in Hawaiian waters, 1953–54. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 221, iv + 23 pp.

LEGAND, MICHEL.
1958. Etude sommaire des variations quantitatives diurnes du zooplancton autour de la Nouvelle-Calédonie. Rapp. Sci. Inst. Franc. Océan. (6), 42 pp.

MCGARY, JAMES W.
1955. Mid-Pacific oceanography, Part VI, Hawaiian offshore waters, December 1949–November 1951. [U.S.] Fish Wildl. Serv., Spec. Sci. Rep. Fish. 152, iii + 138 pp.

NAKAMURA, EUGENE L.
1967. Abundance and distribution of zooplankton in Hawaiian waters, 1955–56. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 544, vi + 37 pp.

SCRIPPS INSTITUTION OF OCEANOGRAPHY OF THE UNIVERSITY OF CALIFORNIA.
1965. Oceanic observations of the Pacific: 1957. Berkeley and Los Angeles, University of California Press, 707 pp.

SECKEL, GUNTER R.
1955. Mid-Pacific oceanography, Part VII, Hawaiian offshore waters, September 1952–August 1953. [U.S.] Fish Wildl. Serv., Spec. Sci. Rep. Fish. 164, vi + 250 pp.
1962. Atlas of the oceanographic climate of the Hawaiian Islands region. U.S. Fish Wildl. Serv., Fish. Bull. 61: 371–427.

SHERMAN, KENNETH.
1963. Pontellid copepod distribution in relation to

surface water types in the central North Pacific. Limnol. Oceanogr. 8: 214–227.

SVERDRUP, H. U., MARTIN W. JOHNSON, and RICHARD H. FLEMING.
1942. The oceans; their physics, chemistry, and general biology. Prentice-Hall, Inc., New York. 1,087 pp.

VAN LANDINGHAM, JOHN W.
1957. A modification of the Knudsen method for salinity determination. J. Cons. 22: 174–179.

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