ZOOPLANKTON ABUNDANCE IN THE CENTRAL PACIFIC

BY JOSEPH E. KING AND JOAN DEMOND

FISHERY BULLETIN 82

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*

FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

ABSTRACT

Zooplankton abundance in the central Pacific was investigated on four cruises of the *Hugh M. Smith* in 1950 and 1951. Quantitative oblique hauls were made to 200 meters' depth, employing 1-meter nets of 30xxx grit gauze. Composition of the collections was remarkably uniform and averaged by number 57 percent Copepoda, 12 percent Chaetognatha, 6 percent Tunicata, 5 percent Euphausiacea, 4 percent Siphonophora, and 4 percent Foraminifera. An analysis of variance of zooplankton volumes demonstrated significant differences between day and night hauls, between cruises, and among latitudes but not between longitudes.

The greatest abundance, both by number and volume, of zooplankton occurred in the region of the Equator. The rich zone, extending from about 6° N. to 5° S. latitude, supported populations three to four times as great as more northerly or southerly latitudes. The greatest concentrations were found north of the Equator, when related to a "convergence;" when no marked convergence existed the peak of abundance was displaced a few degrees southward. The abundance of zooplankton was correlated with inorganic phosphate, oxygen, temperature, and thermocline depth. These environmental factors are influenced by upwelling associated with the equatorial divergence, which replenishes the supply of nutrients in the euphotic zone and creates favorable conditions for the growth of plant and animal life. While the data presented do not give a measure of the rate of production, they do provide a useful index to the relative productivity of different areas of the central Pacific.

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From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 54

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON : 1953

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 25 cents.

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By JOSEPH E. KING, *Fishery Research Biologist,* and
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The Pacific Oceanic Fishery Investigations is authorized and directed to gather information which will ensure the maximum development and utilization of the high-seas fishery resources of the United States territories and island possessions in the tropical and subtropical Pacific. One project of fundamental importance in the research program concerns the relative productivity of different areas of the sea.

Productivity has been defined by Ivlev (1945) as the "capacity of a body of water to produce a given quantity of organic matter in some particular form." A direct measurement of the "rate of production" (Clarke 1946) would require that all processes by which organic matter is built up and destroyed be known and that the rates of these processes be determined. This is difficult to do and seldom has been done even for enclosed bodies of water. In mid-ocean the difficulties are vastly greater. We believe, however, that relative productivity, or productivity as defined by Ivlev, may be estimated indirectly by measuring the amounts of basic chemical nutrients in the water and the standing crops of plankton and fish. This report considers the quantity of zooplankton, 1 of the 2 main constituents of the total plankton crop, and its relation to certain physical and chemical factors in the central Pacific environment.

Zooplankton is essential food for much of the vertebrate fauna of the sea. It is utilized both directly and indirectly by tunas (the group of fish presently under study by these investigations). Kishinouye (1924) and Imamura (1949) have shown that zooplankton is prominent in the food of juvenile tunas. A variety of zooplankton organisms has also been observed in the food of adult tunas (Kishinouye 1917; Beebe 1936; Suyehiro 1942; Clemens and Wilby 1946; Reintjes and King 1953). The bulk of the zooplankton, however, reaches the tuna indirectly, being utilized by plankton-feeding animals which are in turn eaten by the tunas.

Potential food-fish resources are likely to exist in proportion to the amount of substance available for their nutriment. When vast areas of the sea are to be investigated, the several physical, chemical, and biotic properties of water associated with the production of nutriment for fish can be more readily and reliably surveyed than the abundance of the fish themselves. This report is concerned with the zooplankton from the particular viewpoint of its usefulness as an indicator of the relative productivity of the various portions of the area covered.

The literature includes a number of papers dealing with the plankton of the tropical and subtropical Pacific. One of the most valuable of these is the report by Graham (1941) on plankton collections taken by the *Carnegie* in the eastern and central Pacific. Kramer (1906) reported on a series of collections extending from Samoa to the Marshall Islands. Jesperson (1935) described results obtained by the *Dana* while traversing a series of stations reaching from Panama to the western Pacific, south of the Equator. For the western Pacific there are the publications of Matsuya (1937), Motoda (1940), Haneda (1942), and Tokioka (1942), which deal mainly with the plankton of lagoon, bay, and coastal waters but also provide some data on offshore plankton. The several papers of Marshall (1933), Russell (1934), and Russell and Colman (1931, 1934, 1935) supply a wealth of information on the plankton of the Great Barrier Reef Lagoon, but little on oceanic plankton. The papers of Johnson (1949) on the plankton of Bikini, and Sargent and Austin (1949) on the productivity of an atoll in the northern Marshalls, also deal primarily with the lagoon environment. The California Cooperative Sardine Research Program—a cooperative undertaking of the Scripps Institution of Oceanography, the United States Fish and Wildlife Service, the California Department of Fish and Game, the California Academy of Sciences, and the Hopkins Marine Station of Stanford University—is collecting considerable information on the zooplankton of the eastern Pacific Ocean in subtropic and temperate latitudes. This organization has supplied our laboratory with copies of its unpublished data, which, when compared with our own results, show interesting differences between the zooplankton crops of the eastern and central Pacific. Reports of many of the expeditions which have entered the Pacific, such as those of the *Challenger*, the *Albatross*, and the *Meteor*, provide extensive information on the systematics and distribution of species or groups of the zooplankton, but supply little quantitative data that may be used to evaluate the zooplankton crop in the different regions visited.

The authors wish to acknowledge their indebtedness to Dr. Milner B. Schaefer,[1] under whose direction this project was initiated, and to Dr. Albert L. Tester[2] for his very valuable assistance in the statistical phases of the study and his constructive criticism of the manuscript. We are also grateful to fellow staff members and the officers and crew of the *Hugh M. Smith* for their interest and efforts in obtaining this extensive series of collections.

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[2] Professor of Zoology, University of Hawaii.

COLLECTION OF ZOOPLANKTON SAMPLES

AREAS SAMPLED

This study is based on 210 collections made in the central Pacific on cruises 2, 5, 7, and 8 of the United States Fish and Wildlife Service vessel *Hugh M. Smith* in 1950 and 1951. Cruise 2 was made in January and February 1950; cruise 5 in June, July, and August 1950; cruise 7 in October and November 1950; and cruise 8 in January, February, and March, 1951. Thus, there were 2 cruises (2 and 8) at a time corresponding to the northern winter season, and 1 cruise each (5 and 7) for summer and autumn. The approximate locations of the stations are shown in figures 1a and 1b, and more exact positions are given in tables 1, 2, 3, and 4. The data are distributed in 7 long north-south sections, 6 of which cross the Equator, and in a number of shorter series of stations (cruise 8).

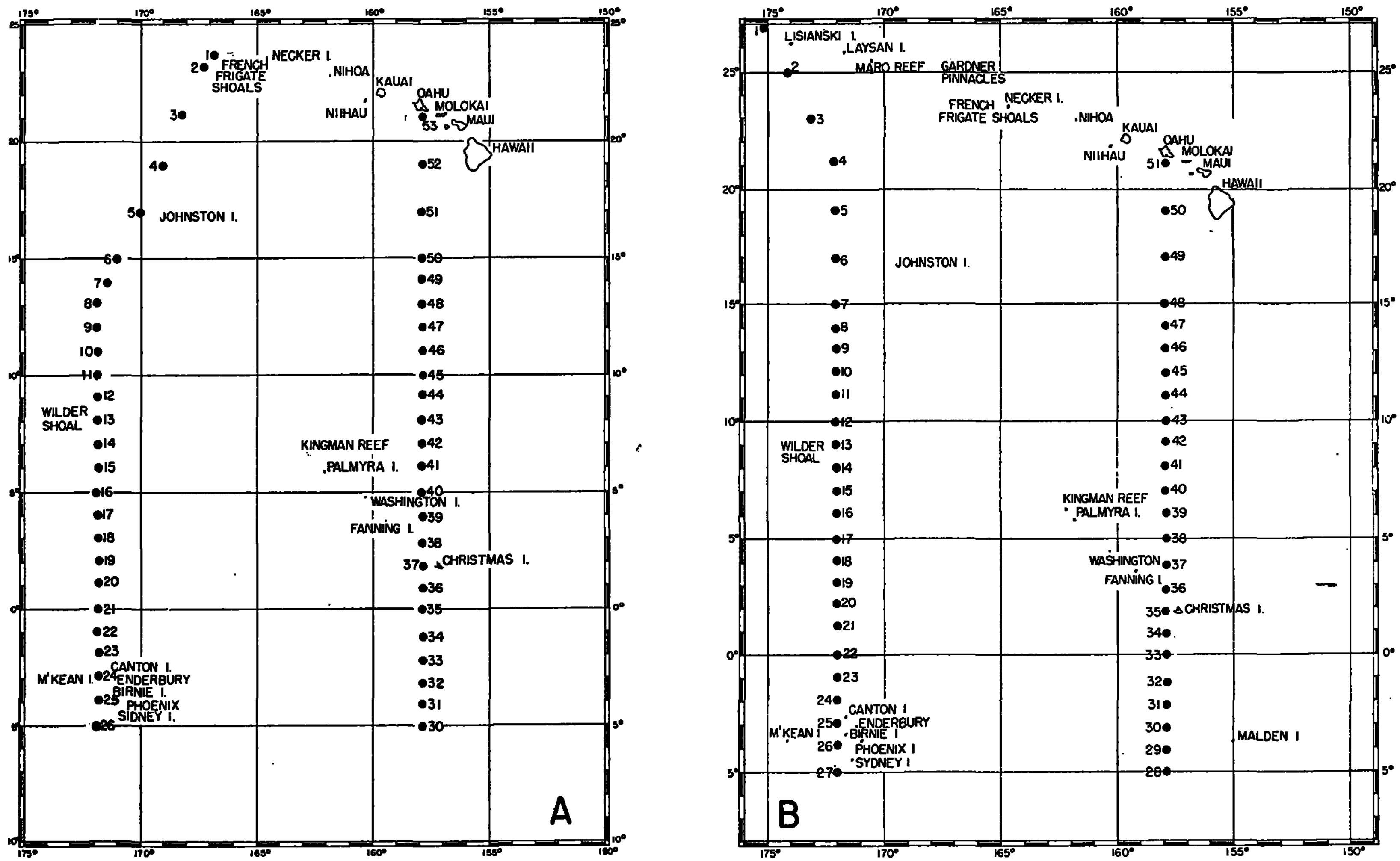


FIGURE 1a.—Plankton-station positions of the *Hugh M. Smith*. A, cruise 2, January–March, 1950. B, cruise 5, June–August 1950.

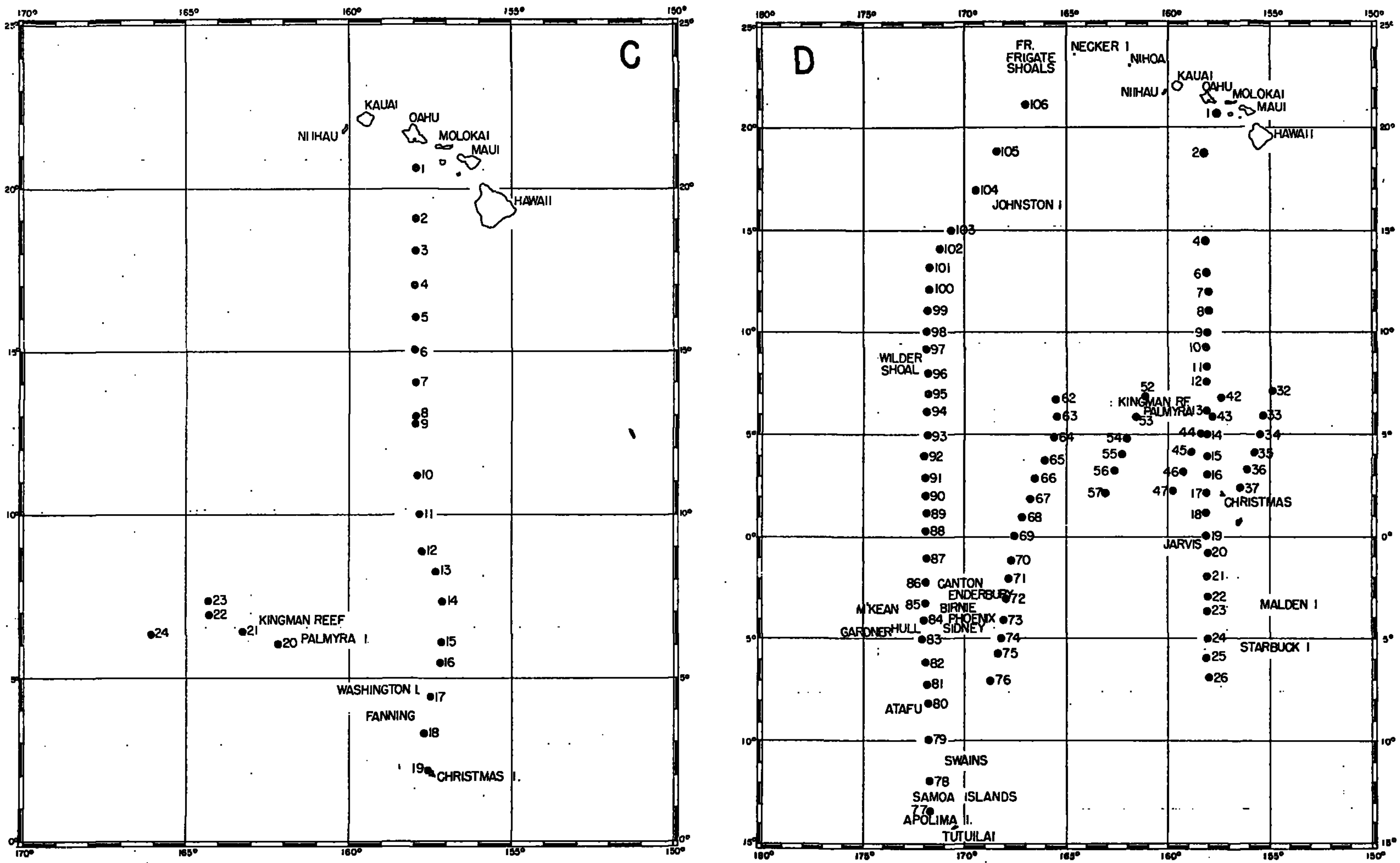


FIGURE 1b.—Plankton-station positions of the *Hugh M. Smith*. C, cruise 7, October–November, 1950. D, cruise 8, January–March, 1951.

TABLE 1.—*Cruise 2: Estimated numbers and volumes of zooplankton collected, January to March, 1950*

Station No.	Position		Date	Time [1]	Water strained, in m.^{3}	Number of organisms per m.^{3}	Wet volume, cc. per m.^{3}
	Latitude	Longitude					
A. Oblique tows to 200 m. (1-meter net, 30xxx mesh):							
1	23°54′ N.	166°51′ W.	Jan. 26	1100–1128	757.2	15	0.0079
3	20°59′ N.	168°16′ W.	Jan. 27	1401–1419	539.2	20	.0137
7	13°54′ N.	171°36′ W.	Jan. 30	0326–0351	937.5	15	.0115
9	12°02′ N.	172°04′ W.	...do...	2315–2337	837.5	15	.0129
11	10°02′ N.	171°55′ W.	Jan. 31	1946–2003	544.5	9	.0092
13	8°00′ N.	171°48′ W.	Feb. 1	1745–1805	631.2	25	.0177
15	6°07′ N.	171°56′ W.	Feb. 3	1300–1328	1,030.0	45	.0285
17	3°58′ N.	172°00′ W.	Feb. 4	0855–0921	837.5	43	.0349
19	2°00′ N.	172°05′ W.	Feb. 5	0245–0321	1,047.0	61	.0714
21	0°00	171°59′ W.	Feb. 6	0250–0326	1,104.0	109	.0826
23	2°00′ S.	172°02′ W.	...do...	2235–2257	782.5	25	.0549
25	4°00′ S.	171°58′ W.	Feb. 7	1646–1712	694.0	44	.0236
B. Oblique tows to 200 m. (2-meter net, 3/16-inch mesh, rear section 18xxx mesh):							
2	23°10′ N.	167°00′ W.	Jan. 26	1921–1959	6,766.0	1	.0003
6	15°00′ N.	171°06′ W.	Jan. 29	1746–1811	3,852.4	.8	.0019
8	13°00′ N.	172°00′ W.	Jan. 30	1213–1240	3,195.5	.3	.0009
10	11°03′ N.	172°00′ W.	Jan. 31	1035–1056	3,610.5	1	.0032
12	9°00′ N.	172°00′ W.	Feb. 1	0546–0635	8,951.4	7	.0040
14	7°00′ N.	172°00′ W.	Feb. 2	1827–1858	3,716.6	3	.0081
16	5°02′ N.	172°01′ W.	Feb. 4	0034–0112	5,232.2	3	.0101
18	2°56′ N.	172°04′ W.	...do...	1824–1855	4,644.9	10	.0117
20	1°01′ N.	172°09′ W.	Feb. 5	1624–1647	2,369.9	6	.0122
22	1°01′ S.	172°00′ W.	Feb. 6	1236–1259	2,453.4	5	.0114
24	3°00′ S.	172°04′ W.	Feb. 7	0755–0779	3,226.8	5	.0146
26	5°02′ S.	171°53′ W.	Feb. 8	0230–0252	2,579.6	1	.0012
C. Surface tows (1-meter net, 30xxx mesh):							
30	4°55′ S.	158°13′ W.	Feb. 18	0545–0616	1,300.5	83	.0451
32	3°06′ S.	158°21′ W.	Feb. 19	0212–0243	1,067.0	38	.0370
34	1°07′ S.	158°28′ W.	...do...	2200–2232	1,231.0	57	.0911
36	1°02′ N.	158°05′ W.	Feb. 20	1030–1101	1,357.2	64	.0721
38	3°02′ N.	157°51′ W.	Feb. 22	1820–1850	1,035.5	58	.0759
40	5°00′ N.	157°59′ W.	Feb. 23	1255–1326	1,139.0	26	.0088
42	7°00′ N.	157°58′ W.	Feb. 24	0725–0756	1,148.0	27	.0082
44	8°53′ N.	157°54′ W.	Feb. 25	0025–0056	1,112.0	62	.0622
46	11°02′ N.	158°06′ W.	...do...	2220–2302	1,284.8	19	.0139
48	13°02′ N.	157°51′ W.	Feb. 26	1830–1901	1,084.5	16	.0037
50	14°57′ N.	157°59′ W.	Feb. 27	1325–1356	1,332.5	5	.0022
52	19°00′ N.	157°42′ W.	Mar. 1	0215–0246	1,310.0	23	.0176
D. Surface tows (1-meter net, 18xxx mesh):							
31	3°53′ S.	157°47′ W.	Feb. 18	1604–1636	1,066.0	17	.0255
33	2°03′ S.	158°28′ W.	Feb. 19	1231–1304	1,105.5	3	.0054
35	0°04′ S.	158°22′ W.	Feb. 20	0900–0931	1,307.8	4	.0044
37	2°03′ N.	158°08′ W.	Feb. 21	2045–2116	1,272.5	18	.0520
39	4°03′ N.	157°53′ W.	Feb. 23	0412–0442	1,205.5	34	.0499
41	6°00′ N.	158°03′ W.	...do...	2150–2251	1,550.0	12	.0329
43	8°02′ N.	157°49′ W.	Feb. 24	1607–1638	1,190.5	6	.0049
45	9°55′ N.	157°54′ W.	Feb. 25	0952–1023	1,567.0	1	.0003
47	12°01′ N.	158°03′ W.	Feb. 26	0725–0755	1,772.8	1	.0003
49	14°00′ N.	157°51′ W.	Feb. 27	0427–0500	1,232.8	11	.0190
51	17°01′ N.	157°56′ W.	Feb. 28	0730–0801	1,620.0	2	.0019
53	20°54′ N.	158°04′ W.	Mar. 1	2056–2136	2,012.8	3	.0053

[1] Time corresponding to +11 zone time (Greenwich Civil Time −11 hours) was used for all stations 1 to 26, and +10 zone time on stations 30 to 53.

TABLE 2.—*Cruise 5: Estimated numbers and volumes of zooplankton collected, June to August, 1950*

[All tows oblique, surface to 200 m. to surface; all nets with body of 30xxx grit gauze, cod end of 56xxx grit gauze]

Station No.	Position		Date	Time [1]	Water strained in m.^{3}	Number of organisms per m.^{3}	Wet volume, cc. per m.^{3}
	Latitude	Longitude					
1	27°00′ N.	175°11′ W.	June 30	0945–1012	1,248.7	26	0.0118
2	25°00′ N.	174°10′ W.	July 1	0258–0325	1,322.7	46	.0271
3	22°58′ N.	173°00′ W.	...do...	2315–2337	1,343.9	40	.0175
4	21°00′ N.	172°00′ W.	July 2	0415–0431	739.5	33	.0254
5	19°00′ N.	171°52′ W.	July 3	0807–0831	1,254.8	35	.0174
6	17°01′ N.	171°46′ W.	...do...	1219–1246	1,434.4	22	.0388
7	15°00′ N.	171°54′ W.	July 4	1649–1710	888.1	45	.0216
8	14°00′ N.	171°57′ W.	July 5	0123–0145	854.8	40	.0234
9	13°00′ N.	172°01′ W.	...do...	0950–1019	1,327.5	32	.0125
10	12°00′ N.	172°00′ W.	...do...	1815–1833	882.8	14	.0084
11	11°03′ N.	172°00′ W.	July 6	0315–0342	1,333.3	34	.0374
12	9°54′ N.	172°03′ W.	...do...	1213–1244	1,777.0	20	.0252
13	8°54′ N.	172°00′ W.	...do...	2012–2036	1,190.2	31	.0301
14	7°59′ N.	171°57′ W.	July 7	0350–0420	1,623.7	18	.0203
15	6°59′ N.	171°46′ W.	...do...	1226–1258	1,579.4	27	.0204
16	6°02′ N.	171°56′ W.	...do...	2130–2201	1,382.2	30	.0338
17	5°00′ N.	172°02′ W.	July 8	0845–0918	1,821.1	40	.0226

Footnote at end of table.

251381—53——2

TABLE 2.—*Cruise 5: Estimated numbers and volumes of zooplankton collected, June to August, 1950*—Con.

Station	Position		Date	Time [1]	Water strained, in m.³	Number of organisms per m.³	Wet volume, cc. per m.³
	Latitude	Longitude					
18	4°00′ N.	172°03′ W.	...do.....	1659–1729	1,346.2	65	.0385
19	3°00′ N.	172°01′ W.	July 9	0036–0101	1,063.8	59	.0410
20	2°00′ N.	171°53′ W.	...do.....	0838–0909	1,800.2	58	.0330
21	0°54′ N.	172°12′ W.	...do.....	1746–1815	1,586.0	67	.0556
22	0°08′ S.	172°02′ W.	July 10	0143–0214	1,943.8	94	.0604
23	1°00′ S.	171°57′ W.	...do.....	0925–0951	1,256.9	107	.0742
24	2°00′ S.	171°55′ W.	...do.....	1740–1809	1,406.4	52	.0452
25	2°59′ S.	171°59′ W.	July 11	0133–0201	1,309.9	68	.0664
26	4°05′ S.	171°56′ W.	...do.....	1055–1127	1,585.3	36	.0230
27	5°04′ S.	171°58′ W.	...do.....	2110–2141	1,632.8	27	.0315
28	4°56′ S.	158°02′ W.	July 28	0556–0614	1,384.8	20	.0087
29	4°00′ S.	158°03′ W.	...do.....	1324–1338	642.8	47	.0239
30	3°03′ S.	158°00′ W.	...do.....	2137–2200	873.7	46	.0490
31	2°03′ S.	158°00′ W.	July 29	0550–0607	648.3	45	.0253
32	1°00′ S.	158°01′ W.	...do.....	1418–1436	996.0	43	.0239
33	0°02′ S.	157°58′ W.	...do.....	2221–2239	773.0	76	.0880
34	0°57′ N.	157°57′ W.	July 30	0646–0715	1,528.5	44	.0347
35	2°00′ N.	158°07′ W.	...do.....	1532–1553	851.2	62	.0658
36	3°00′ N.	157°58′ W.	...do.....	2302–2324	972.8	93	.0701
37	4°02′ N.	158°03′ W.	July 31	0640–0707	1,652.5	76	.0783
38	5°00′ N.	158°00′ W.	...do.....	1750–1816	1,175.4	74	.0691
39	6°00′ N.	157°57′ W.	Aug. 1	0144–0214	1,313.7	35	.0449
40	7°00′ N.	157°57′ W.	...do.....	0854–0919	954.3	43	.0258
41	8°00′ N.	157°50′ W.	...do.....	1620–1704	3,361.5	31	.0230
42	9°00′ N.	157°55′ W.	Aug. 2	0020–0046	1,136.6	38	.0531
43	10°00′ N.	157°53′ W.	...do.....	0744–0812	1,597.8	25	.0225
44	11°00′ N.	157°55′ W.	...do.....	1546–1615	1,141.7	40	.0242
45	11°59′ N.	158°04′ W.	...do.....	2343–0008	1,034.5	32	.0327
46	13°00′ N.	157°58′ W.	Aug. 3	0800–0827	1,455.8	19	.0158
47	14°00′ N.	157°54′ W.	...do.....	1639–1709	1,305.7	18	.0201
48	14°58′ N.	157°55′ W.	Aug. 4	0253–0311	592.8	19	.0246
49	17°00′ N.	158°08′ W.	...do.....	1741–1805	934.8	38	.0214
50	19°02′ N.	157°59′ W.	Aug. 5	1006–1031	1,035.0	29	.0357
51	20°53′ N.	158°02′ W.	...do.....	2300–2324	852.2	37	.0289

[1] +11 zone time on stations 1 to 27, +10 zone time on stations 28 to 51.

TABLE 3.—*Cruise 7: Estimated numbers and volumes of zooplanton collected, October to November 1950*

[All tows oblique, surface to 200 m. to surface; all nets with body of 30xxx grit gauze, cod end of 56xxx grit gauze]

Station No.	Position		Date	Time [1]	Water strained, in m.³	Number of organisms per m.³	Wet volume, cc. per m.³
	Latitude	Longitude					
1	20°30′ N.	158°00′ W.	Oct. 17	1925–1955	952.8	44	0.0353
2	19°10′ N.	158°02′ W.	Oct. 18	0532–0600	897.3	44	.1025
3	18°13′ N.	158°00′ W.	...do.....	1326–1355	1,112.5	30	.0288
4	17°10′ N.	158°00′ W.	...do.....	2159–2225	683.7	27	.0208
5	16°11′ N.	157°57′ W.	Oct. 19	0506–0530	699.0	21	.0269
6	15°02′ N.	157°58′ W.	...do.....	1250–1318	999.2	14	.0300
7	14°03′ N.	157°59′ W.	...do.....	1921–1955	1,220.6	27	.0274
8	12°57′ N.	157°57′ W.	Oct. 20	0330–0353	730.6	64	.0567
9	12°25′ N.	158°00′ W.	...do.....	1729–1804	1,217.9	38	.0345
10	11°08′ N.	158°01′ W.	Oct. 21	1526–1556	1,373.5	42	.0296
11	10°01′ N.	157°55′ W.	Oct. 22	0724–0804	1,426.0	40	.0296
12	8°52′ N.	157°45′ W.	Oct. 23	0722–0751	956.9	37	.0169
13	8°05′ N.	157°15′ W.	Oct. 24	0742–0813	1,413.5	19	.0119
14	7°17′ N.	157°04′ W.	Oct. 25	0727–0805	1,698.8	32	.0182
15	5°57′ N.	157°05′ W.	Oct. 26	0737–0810	1,572.1	59	.0682
16	5°19′ N.	157°20′ W.	Oct. 27	0725–0809	2,206.2	65	.0566
17	4°23′ N.	157°30′ W.	Oct. 28	0912–0945	1,872.1	40	.0348
18	3°17′ N.	157°53′ W.	Oct. 29	0802–0837	1,314.0	50	.0653
19	2°01′ N.	157°34′ W.	Nov. 1	0812–0844	1,587.3	75	.0741
20	6°07′ N.	162°06′ W.	Nov. 6	0950–1028	1,930.3	28	.0204
21	6°13′ N.	163°05′ W.	Nov. 7	0810–0837	1,565.8	63	.0483
22	6°59′ N.	163°54′ W.	Nov. 8	0808–0841	1,749.1	22	.0149
23	7°24′ N.	164°25′ W.	Nov. 9	0806–0838	1,442.4	27	.0147
24	6°31′ N.	165°45′ W.	Nov. 10	0813–0847	1,521.5	23	.0166

+10 zone time on stations 1 to 21, +11 zone time on stations 22 to 24.

TABLE 4.—*Cruise 8: Estimated numbers and volumes of zooplankton collected, January to March, 1951*

[All tows oblique, surface to 200 m. to surface; all nets with body of 30xxx grit gauze, cod end of 56xxx grit gauze]

Station No.	Position		Date	Time [1]	Water strained, in m.³	Number of organisms per m.³	Wet volume, cc. per m.³
	Latitude	Longitude					
1	20°48′ N.	157°30′ W.	Jan. 14	2012–2048	937.3	27	0.0154
2	18°47′ N.	158°01′ W.	Jan. 15	1449–1504	625.9	23	.0105
4	14°30′ N.	158°00′ W.	Jan. 17	0925–0940	433.1	43	.0236
6	12°57′ N.	157°58′ W.	do	2251–2318	819.0	46	.0310
7	11°59′ N.	157°50′ W.	Jan. 18	0811–0836	1,363.0	24	.0094
8	11°00′ N.	157°53′ W.	do	1633–1658	1,399.9	36	.0093
9	10°00′ N.	157°56′ W.	Jan. 19	0224–0255	1,830.5	30	.0251
10	9°00′ N.	157°58′ W.	do	1154–1216	985.1	33	.0166
11	8°04′ N.	157°58′ W.	do	2024–2047	1,244.0	31	.0190
12	7°08′ N.	157°58′ W.	Jan. 20	0615–0645	1,299.2	74	.0477
13	5°59′ N.	158°00′ W.	do	1505–1537	1,807.5	34	.0186
14	5°00′ N.	158°00′ W.	do	2338–2357	975.3	32	.0174
15	3°55′ N.	157°54′ W.	Jan. 21	1100–1118	984.1	31	.0118
16	3°02′ N.	157°57′ W.	do	2135–2155	1,018.2	43	.0255
17	2°00′ N.	158°01′ W.	Jan. 22	0802–0831	1,625.2	30	.0146
18	0°58′ N.	158°07′ W.	do	1730–1754	1,529.1	33	.0220
19	0°01′ N.	158°02′ W.	Jan. 23	0323–0356	1,925.6	32	.0370
20	0°55′ S.	157°54′ W.	do	1208–1233	1,509.4	90	.0478
21	2°00′ S.	158°00′ W.	do	2312–2336	1,273.4	80	.0558
22	3°04′ S.	158°05′ W.	Jan. 24	0744–0808	1,270.9	48	.0257
23	4°00′ S.	158°00′ W.	do	1550–1614	1,070.4	36	.0178
24	5°00′ S.	158°00′ W.	do	2330–2350	885.8	46	.0666
25	6°01′ S.	158°06′ W.	Jan. 25	0741–0806	1,234.2	48	.0266
26	7°00′ S.	158°01′ W.	do	1548–1616	1,352.6	23	.0092
32	6°57′ N.	154°56′ W.	Jan. 31	0208–0238	1,521.4	39	.0251
33	5°58′ N.	155°08′ W.	do	1040–1060	948.4	35	.0325
34	5°00′ N.	155°28′ W.	do	1836–1902	1,483.2	35	.0284
35	4°04′ N.	155°46′ W.	Feb. 1	0223–0250	1,254.0	49	.0340
36	3°06′ N.	156°09′ W.	do	1040–1061	1,676.0	66	.0348
37	2°00′ N.	156°30′ W.	do	1835–1902	1,556.8	46	.0315
42	6°50′ N.	157°33′ W.	Feb. 3	0612–0639	1,680.3	22	.0145
43	6°04′ N.	157°53′ W.	do	1337–1404	1,401.1	21	.0126
44	5°00′ N.	158°34′ W.	do	2245–2309	1,245.7	31	.0204
45	4°05′ N.	158°53′ W.	Feb. 4	0706–0727	1,063.9	41	.0177
46	3°03′ N.	159°10′ W.	Feb. 6	0441–0513	1,881.2	21	.0254
47	1°57′ N.	159°39′ W.	do	1343–1419	1,619.8	26	.0106
52	6°59′ N.	161°12′ W.	Feb. 7	1025–1049	1,744.5	29	.0224
53	5°55′ N.	161°28′ W.	Feb. 8	2030–2056	1,914.2	33	.0313
54	4°52′ N.	161°48′ W.	Feb. 9	0443–0513	1,835.9	33	.0276
55	3°58′ N.	162°02′ W.	do	1119–1143	1,488.0	17	.0118
56	2°58′ N.	162°25′ W.	do	1919–1946	1,819.0	30	.0303
57	2°00′ N.	162°57′ W.	Feb. 10	0259–0327	1,514.6	31	.0354
62	6°44′ N.	165°23′ W.	Feb. 11	1652–1718	1,330.2	21	.0170
63	5°51′ N.	165°28′ W.	Feb. 12	0021–0048	1,647.2	31	.0368
64	4°58′ N.	165°35′ W.	do	0758–0824	1,432.3	23	.0176
65	3°59′ N.	166°01′ W.	do	1626–1653	1,743.6	22	.0118
66	3°00′ N.	166°36′ W.	Feb. 13	0100–0130	1,760.7	37	.0359
67	2°04′ N.	166°47′ W.	do	0848–0913	1,618.2	26	.0248
68	1°02′ N.	167°02′ W.	do	1815–1839	1,116.2	52	.0408
69	0°01′ N.	167°23′ W.	Feb. 14	0240–0308	1,433.5	47	.0473
70	1°05′ S.	167°36′ W.	do	1132–1156	1,420.4	23	.0172
71	2°01′ S.	167°42′ W.	do	1903–1930	1,785.5	37	.0320
72	3°05′ S.	167°50′ W.	Feb. 15	0323–0353	1,740.7	34	.0295
73	4°00′ S.	167°58′ W.	do	1041–1109	2,008.7	20	.0175
74	5°03′ S.	168°09′ W.	do	1819–1848	1,942.1	19	.0175
75	5°59′ S.	168°29′ W.	Feb. 16	0208–0241	2,424.3	33	.0332
76	7°04′ S.	168°48′ W.	do	0923–0953	2,308.6	24	.0100
77	14°30′ S.	171°51′ W.	Feb. 26	1931–1958	1,876.1	28	.0154
78	11°56′ S.	171°59′ W.	Feb. 27	1129–1157	1,918.4	26	.0115
79	10°05′ S.	171°52′ W.	Feb. 28	0245–0309	1,735.6	41	.0226
80	8°00′ S.	171°56′ W.	do	1821–1846	1,452.5	29	.0153
81	7°01′ S.	171°54′ W.	Mar. 1	0238–0303	1,045.2	52	.0291
82	5°59′ S.	172°00′ W.	do	1118–1144	1,399.9	22	.0100
83	5°00′ S.	172°15′ W.	do	1930–1955	1,507.6	22	.0202
84	4°00′ S.	172°06′ W.	Mar. 2	0735–0758	1,510.7	18	.0101
85	3°00′ S.	171°50′ W.	do	1537–1605	1,510.7	20	.0146
86	2°00′ S.	172°02′ W.	Mar. 3	1612–1641	1,593.0	21	.0109
87	0°57′ S.	172°00′ W.	Mar. 4	0047–0115	1,392.3	43	.0394
88	0°09′ N.	171°58′ W.	do	0926–0947	1,066.0	56	.0345
89	1°04′ N.	172°00′ W.	do	1702–1727	979.6	73	.0398
90	1°54′ N.	172°02′ W.	Mar. 5	0034–0101	1,854.7	57	.0548
91	2°48′ N.	172°04′ W.	do	0834–0858	1,332.4	48	.0435
92	3°57′ N.	172°02′ W.	do	1816–1842	1,221.9	44	.0367
93	4°56′ N.	171°54′ W.	Mar. 6	0249–0315	1,621.0	51	.0369
94	5°55′ N.	171°50′ W.	do	1105–1130	1,428.2	43	.0242
95	6°58′ N.	171°49′ W.	do	1939–2011	1,907.6	24	.0244
96	7°56′ N.	171°51′ W.	Mar. 7	0407–0433	1,498.1	22	.0139
97	9°00′ N.	171°58′ W.	do	1315–1339	1,539.7	13	.0094
98	10°02′ N.	171°56′ W.	do	2147–2213	1,538.1	22	.0127
99	11°02′ N.	171°52′ W.	Mar. 8	0602–0629	1,576.9	23	.0115
100	12°00′ N.	171°52′ W.	do	1417–1443	1,507.0	11	.0097
101	13°01′ N.	171°48′ W.	do	2236–2301	1,720.5	20	.0192
102	13°58′ N.	171°24′ W.	Mar. 9	0650–0713	1,274.5	15	.0096
103	15°00′ N.	170°52′ W.	do	1557–1619	1,313.9	23	.0100
104	16°58′ N.	169°42′ W.	Mar. 10	0913–0940	1,993.3	25	.0181
105	18°58′ N.	168°27′ W.	Mar. 11	0207–0235	1,941.0	17	.0145
106	20°59′ N.	167°07′ W.	do	1913–1940	1,938.5	24	.0145

[1] +10 zone time on stations 1 to 49, +11 zone time on stations 50 to 106.

Cruises 2, 5, and 8 were combined hydrographic and plankton cruises, and thus provide information on currents, temperatures, oxygen, and inorganic phosphate for comparison with the zooplankton abundance. On cruise 7, which was a combination longline-fishing and plankton cruise, subsurface (to approximately 800 feet) and surface temperatures were obtained at all plankton stations.

SAMPLING IN THE FIELD

Although the primary aim of our plankton sampling was to obtain information on the zooplankton populations of different ocean areas, a secondary objective was to collect tuna eggs and larvae for use in the study of the spawning habits of tuna. Sampling methods and procedures were therefore designed to contribute information toward both objectives.

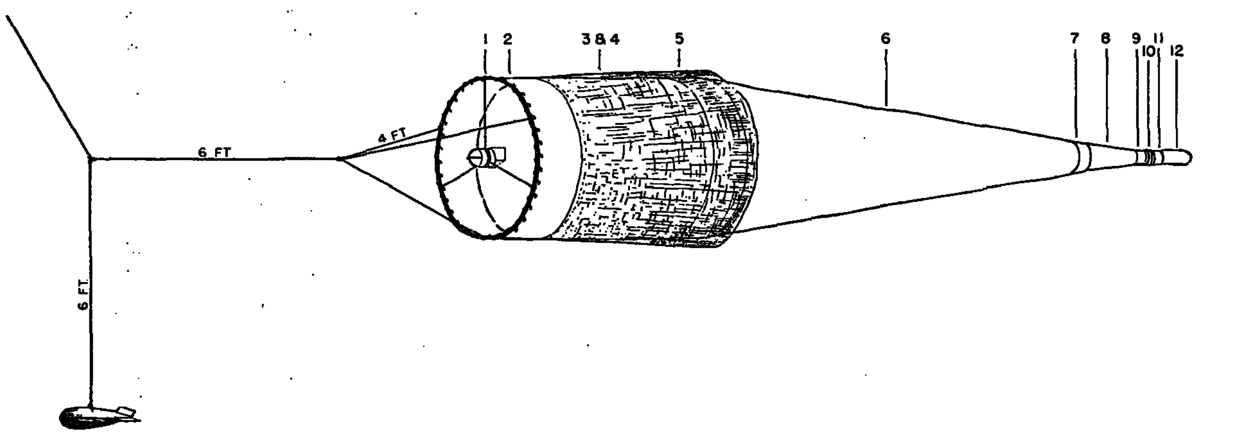
Plankton nets of the following three types were used on cruise 2:

1. 1-meter (mouth diameter) net with body (front and middle sections) of 30xxx silk grit gauze (width of apertures 0.65 mm.), rear section and bag of 56xxx silk grit gauze (width of apertures 0.31 mm.);
2. 1-meter net with body of 18xxx grit gauze (width of apertures 1.3 mm.), rear section and bag of 30xxx grit gauze; and
3. 2-meter net with body of 3/16 inch square cotton mesh, rear section and bag of 18xxx grit gauze.

The results of this cruise showed that the 1-meter net with a body of 18xxx grit gauze retained considerably less zooplankton than the 30xxx net; the 2-meter net captured almost no zooplankton and few fish or other large forms. Some preliminary tows, the results of which are not included in this report, indicated that nets of 56xxx and 72xxx grit gauze retained the larger phytoplankton as well as zooplankton, thus making analysis of the sample more difficult. On the basis of this experimentation and a review of methods used by other investigators for sampling zooplankton, we adopted the 1-meter, 30xxx net (fig. 2) as being the best suited for our purposes. Nets of this type were employed exclusively on cruises 5, 7, and 8.

In this study, sampling was limited to a single tow at each station. For this reason, we chose to use, for the greater part, an oblique tow (surface to 200 meters to surface) of approximately 30 minutes' duration. On cruise 2, both oblique and surface tows were used, but on all subsequent cruises the oblique tow was the only type employed.

The merits of the oblique haul have been well demonstrated by Winsor and Clark (1940). They obtained a percentage standard deviation (coefficient of variation) for a single observation of 31 percent for oblique hauls, 53 percent for verti-



DESCRIPTION OF PLANKTON NET SECTIONS

	1	2	3	4	5	6	7	8	9	10	11	12
MATERIAL	GALV. IRON RING	12 OZ. CANVAS	30 XXX GRIT GAUGE	3/16" BAIT NETTING	10 OZ. CANVAS	30 XXX GRIT GAUGE	10 OZ. CANVAS	56 XXX GRIT GAUGE	10 OZ. CANVAS	BUCKET COUPLING	10 OZ. CANVAS	56 XXX GRIT GAUGE
DIAMETER	39.4"	39.4"	39.4"	40"	39.4"	39.4" - 8"	8"	8"-4"	4"	4"	4"	4"
LENGTH	7/8" THICK	12"	38"	48"	10"	110"	3"	18"	2 1/2"	2 1/2"	2 1/2"	9"

FIGURE 2.—Diagram and description of the 1-meter net used in this investigation, showing general construction of the net and method of attachment to the weight and towing lines.

cal hauls, and 124 percent for horizontal hauls; and they concluded that oblique hauls gave more reliable and consistent results than vertical or horizontal hauls. The more erratic nature of the surface haul, as compared with the oblique, is evident from figure 4, showing the results of cruise 2, on which both types of haul were used.

That the oblique and surface hauls made on this cruise were not greatly different, however, is indicated by a comparison of the volumes (cc./m.^{3}) obtained at 12 pairs of stations (table 1, A and C), the members of each pair occurring at approximately the same latitude, but at a different longitude (fig. 1, A). It may be shown that the mean difference (0.00575 cc./m.^{3}) between the paired hauls does not differ significantly from 0 ($P=0.4$). Therefore, the few surface hauls made on cruise 2 have been included in this report but have been omitted from the statistical analysis dealing with sources of variation and correlations with environmental factors.

On cruises 2, 5, and 8, stations were visited consecutively regardless of the time of day or night. Because of this practice, the effects of diurnal migration must be considered in an evaluation of zooplankton abundance at any place and time. Initially we had hoped, through the use of the oblique tow to 200 meters' depth, to nullify to a large extent differences in the samples caused by vertical movements of the plankton. That we did not succeed is indicated by close perusal of the tables of data, particularly for cruise 5 (table 2), and cruise 8 (table 4), comparing successive day and night hauls. It will be seen that usually the night hauls produced a higher volume than the day hauls. This tendency will be discussed later in the section on sources of variation in zooplankton volumes.

Another problem that adds to the difficulty of estimating zooplankton abundance is the uneven distribution of plankton organisms. This has been referred to by many planktologists and is emphasized by Haeckel (1890), Herdman (1923), Gardiner (1931), Hardy (1936), Wilson (1942), Riley and Bumpus (1946), Sears (1950), and others. By our method of straining a large volume of water, averaging over 1,000 cubic meters per haul, and of sampling in uniform fashion from the surface to 200 meters' depth, it is assumed that the variation in catch due to the uneven distribution of organisms is minimized.

The amount of water strained during each haul was measured by a flow meter suspended in the mouth of the net. Each flow meter was calibrated by towing it over a measured course at approximately the same speed used in making the plankton hauls. The flow meters were calibrated before and after each cruise, and the average of these calibrations was used to compute the volume of water strained in cubic meters for each haul during that cruise. Within a limited range of towing speeds the number of revolutions registered by the meter indicates the length of the water column passing through the net; multiplying this length by the area of the mouth of the net gives an estimate of the water volume strained.

There has never been evidence of clogging on any of the tows, possibly because of the relatively coarse mesh used in the nets and the general paucity of plankton.

In making the tow, the net and a 75-pound streamlined weight were attached to the cable, which was paid out slowly at uniform speed. As the net was lowered, the length of wire out and the angle of stray were recorded at 2-minute intervals. As soon as a calculated depth of 200 meters was reached, the net was retrieved at a slow, uniform speed. The wire angle and the length of wire out were again recorded at 2-minute intervals. At a towing speed of about 2 knots, an oblique tow to a depth of 200 meters and return required about 30 minutes. A graph of depth reached plotted against time (fig. 3) for 3 tows made on cruise 5, shows that, for practical purposes, equal amounts of time are spent at all depths; i. e., assuming the towing wire represents a straight line in the water, the net strains approximately the same amount of water for each meter of depth passed through. It is recognized that the towing wire does not actually describe a straight line during the tow, but the error caused by a slight curve is small.

When the net reached the surface at the end of a tow, it was lifted out of the water, suspended vertically from a boom, and washed down with a hose. The plankton bucket was then detached, and its contents were washed into an enameled pan. Next, the sample was transferred to a 1-quart fruit jar, and sufficient formalin was added to approximate a 10-percent solution. The formalin was neutralized with borax. A completed label was placed in the jar.

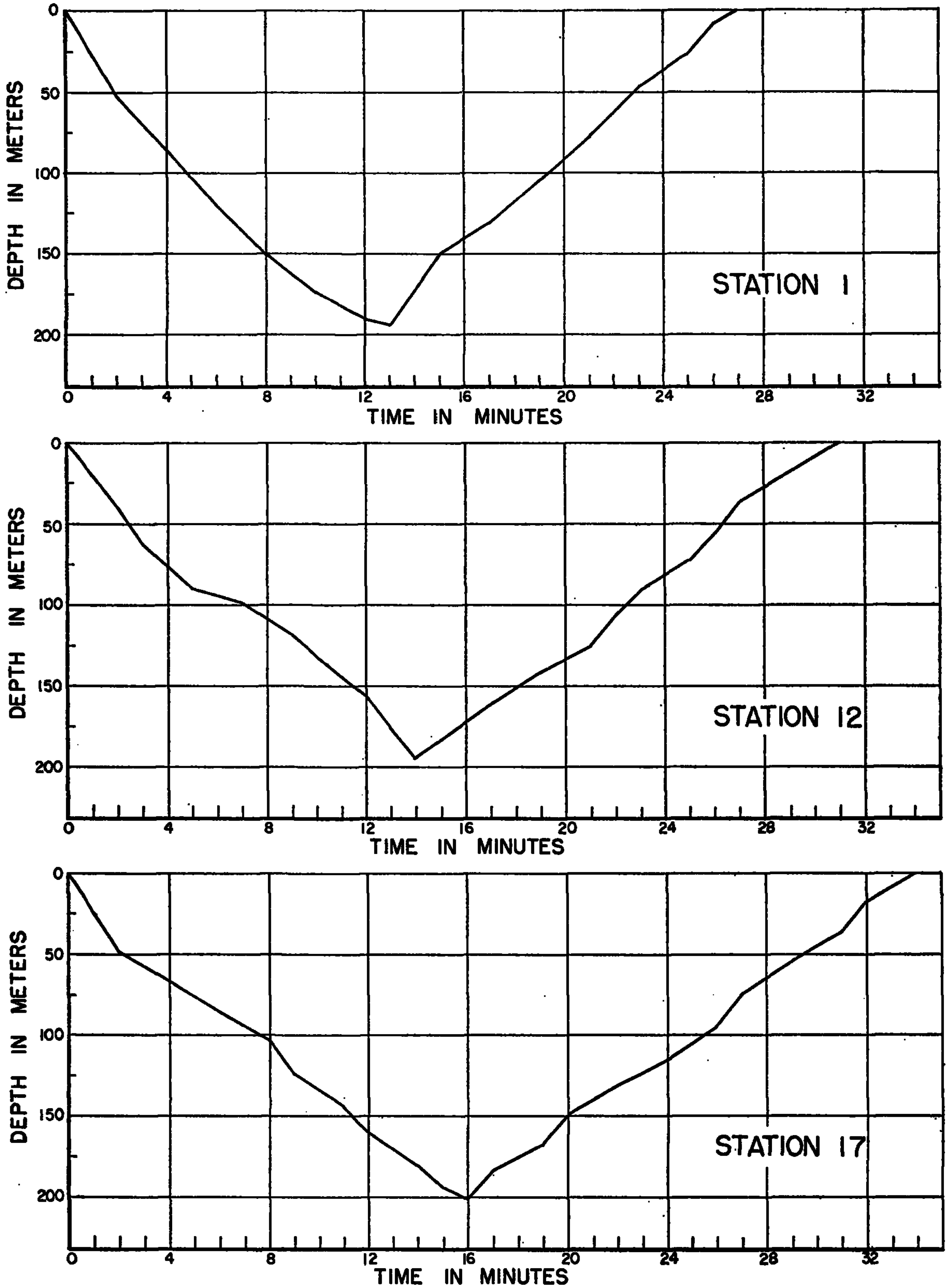


FIGURE 3.—Graphs of three typical tows (stations 1, 12, and 17) of cruise 5, showing depth estimated from wire angle and wire out.

TREATMENT OF SAMPLES

The zooplankton collections received the following treatment in the laboratory:

1. All fish eggs and larvae were removed. In all cases these have amounted to a negligible fraction of the sample and were omitted from the volume measurement.

2. Several portions of the remaining sample were examined microscopically, and the various groups of organisms were identified at least to the order. Where possible without great expenditure of time and effort, identifications were made to the genus and species. A list of constituents was thus compiled for each sample.

3. All organisms whose longest dimension was greater than 5 centimeters were removed from the sample. Such organisms occurred infrequently and were not considered in the analysis.

4. By means of a splitting chamber the remaining sample was then divided into halves; one-half was labeled and placed in a reference collection, the other was used for the organism counts and displacement-volume determinations.

5. In making the count, a given portion (usually a fourth, occasionally a half or an eighth) of the half reserved for this purpose, was placed in a 15 by 20 cm. counting chamber, thoroughly mixed, and distributed as evenly as possible over the entire cell area. Organisms between 2 and 5 cm. in their longest dimension were enumerated in counting-chamber fields 5 cm. square, without magnification. For counting smaller organisms (0.5 millimeter to 2.0 cm. in longest dimension), the counting cell was placed over a Wolffhuegel plate under a binocular microscope. Organisms in this size category were counted in fields 1 cm. square on the Wolffhuegel plate. Organisms less than 0.5 mm. long were identified but not counted, since the mesh of the nets employed was not sufficiently fine to catch these forms quantitatively. In counting organisms of all sizes, either (a) enough fields were counted to yield a minimum count of 100 for each type of organism, or (b) 10 fields were counted, whichever was reached first. The estimated number of zooplankters of each species or category in the total sample (minus fish eggs and larvae and organisms larger than 5 cm.) was computed by use of the following formula:

$$E=\frac{C\cdot A}{f\cdot a\cdot n}$$

where

E=estimated number in total sample
C=counted number
A=area of cell
f=fraction of total sample in the counting cell
a=area of field
n=number of fields counted

The estimated total number of zooplankters in the sample equals the sum of E values, i. e., the sum of the estimated numbers for each type or group of organisms. The estimated number per cubic meter of water was obtained by dividing the estimated total number in the sample by the cubic meters of water strained.

6. To measure the displacement volume, the half of the sample used for the organism counts was poured into a draining sock of 56xxx grit gauze to filter off the preserving liquid. The drained plankton was then placed in a 50- or 100-milliliter graduated cylinder, depending upon the size of the sample. 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 is the displacement volume or "wet volume" of the plankton half-sample. This figure was doubled to obtain the computed volume of the entire original sample (minus fish eggs and larvae and organisms larger than 5 cm.). When divided by cubic meters of water strained, this gave the volume (in cubic centimeters) of zooplankton per cubic meter of water.

The plankton counts given in this report, therefore, include those organisms between 0.5 mm. and 5 cm., longest dimensions; the volume measurements include all organisms in the sample less than 5 cm. in length.

Almost all stations occupied on the four cruises were in areas where the depth of water is 2,000 to 3,000 fathoms (roughly 4,000 to 6,000 meters). By sampling to a calculated depth of 200 meters (the actual depth attained was probably within 10 percent of this) we have done little more than "scratch the surface." No information was obtained on plankton abundance and distribution below the sampled depth. Therefore, we believe that our results are most properly expressed in terms of organisms per cubic meter in the upper 200 meters of water. If an estimate is desired of the areal abundance, i. e., the quantity of zooplankton in a column of water 200 meters in height and 1 meter square in cross section, it may be obtained by multiplying by 200 the numbers and volumes of zooplankton per cubic meter given in tables 1, 2, 3, and 4.

COMPOSITION OF THE ZOOPLANKTON

Tables 5, 6, 7, and 8 show for each cruise and station the percentage composition by number of the 6 major constituents of the zooplankton. It is evident that copepods—by number—were consistently the most important constituent. The chaetognaths usually were second in rank, followed by the tunicates, euphausiids, siphonophores, and foraminifers. At several stations other groups, such as radiolarians, annelids, amphipods, ostracods, and pteropods occurred in considerable numbers, but on the average these animals formed a very small percentage of the collections. As might be expected, the results vary to some extent from station to station; but when the data are summarized, as in table 9, there is revealed a marked and surprising uniformity in composition for the different longitudes and cruises. The percentages given are computed from the sums of estimated numbers for all stations. Percentages by volume for the separate groups were not determined.

The 210 samples include only a few instances of swarming: Collections taken at stations 7 and 9, cruise 5, contained unusually high percentages (60 and 58 percent) of foraminifers; the collection made at station 2, cruise 7, contained a high and unusual percentage (51 percent) of hyperid amphipods. In each case there was no marked change in number for the other major constituents.

As all of our plankton stations were located in the open ocean with very few within 100 miles of land, the collections consisted primarily of such forms as are permanently planktonic throughout their lives (holoplankton), and contained very few transitory young and larval stages (meroplankton) of bottom-dwelling forms such as echinoderms, crabs, and clams.

TABLE 5.—*Cruise 2: Percentage, by number, of six major constituents of zooplankton collections*

[Values less than 1 percent omitted]

Station No.	Copepoda	Chaetognatha	Tunicata	Euphausiacea	Siphonophora	Foraminifera	Miscellaneous
A. Oblique tows to 200 m. (1-meter net, 30xxx mesh):							
1	47	17	13	1	4	-------	17
3	35	19	31	4	2	1	8
7	64	10	1	6	2	-------	17
9	65	14	4	6	2	-------	9
11	50	16	11	4	3	1	15
13	61	10	3	4	-------	8	13
15	62	15	3	6	8	5	1
17	61	10	6	3	4	11	5
19	55	19	11	4	2	3	6
21	62	22	3	4	-------	1	7
23	66	16	2	7	2	-------	7
25	68	16	3	2	4	3	4
B. Oblique tows to 200 m. (2-meter net, 3/16-inch mesh, rear section 18xxx mesh):							
2	62	4	14	2	2	-------	16
6	34	-------	6	6	22	-------	32
8	56	6	8	6	8	-------	16
10	20	38	20	-------	17	1	4
12	47	16	11	6	10	-------	10
14	44	13	9	4	9	1	20
16	36	15	8	13	10	-------	18
18	67	12	3	4	5	-------	9
20	62	17	9	4	2	-------	6
22	67	20	------	3	5	-------	4
24	51	19	------	3	19	-------	7
26	19	21	4	12	8	-------	36
C. Surface tows (1-meter net, 30xxx mesh):							
30	79	11	3	3	-------	-------	3
32	65	12	9	6	3	-------	4
34	53	10	10	14	2	1	10
36	54	21	6	10	-------	6	2
38	43	15	15	10	1	4	12
40	51	26	16	-------	2	2	3
42	51	9	24	2	5	3	6
44	70	5	7	6	3	1	8
46	76	8	2	5	2	5	2
48	68	10	2	2	1	9	8
50	47	19	21	1	3	6	3
52	50	10	12	2	4	1	21
D. Surface tows (1-meter net, 18xxx mesh):							
31	50	14	------	26	3	-------	7
33	33	43	12	2	8	-------	2
35	24	37	18	-------	10	-------	11
37	33	18	9	22	9	-------	9
39	28	29	2	25	9	-------	7
41	57	6	5	25	4	-------	3
43	47	28	8	-------	6	-------	9
45	29	5	8	-------	12	-------	46
47	47	6	8	-------	24	-------	15
49	52	12	2	29	3	2	0
51	16	25	7	-------	13	1	38
53	37	11	8	-------	12	-------	32

TABLE 6.—*Cruise 5: Percentage, by number, of six major constituents of zooplankton collections*

[Values less than 1 percent omitted]

Station No.	Copepoda	Chaetognatha	Tunicata	Euphausiacea	Siphonophora	Foraminifera	Miscellaneous
1	53	4	9	4	-------	10	19
2	44	4	6	9	-------	6	30
3	58	6	8	5	3	2	18
4	35	7	11	1	2	21	23
5	46	5	8	6	3	12	20
6	41	7	3	12	5	20	12
7	25	4	4	-------	2	60	4
8	52	1	2	-------	3	34	7
9	22	6	3	2	1	58	8
10	66	11	6	2	-------	9	6
11	62	12	2	4	4	7	9

TABLE 6.—*Cruise 5: Percentage, by number, of six major constituents of zooplankton collections*—Continued

Station No.	Copepoda	Chaetognatha	Tunicata	Euphausiacea	Siphonophora	Foraminifera	Miscellaneous
12	73	8	3	1	8	------	6
13	61	14	6	4	1	2	12
14	77	3	3	3	3	------	11
15	59	9	5	2	7	11	7
16	52	6	5	2	8	3	24
17	67	5	3	4	4	2	15
18	55	11	8	3	10	2	11
19	68	4	8	8	5	2	5
20	60	9	8	6	4	2	11
21	61	11	6	6	1	------	14
22	56	8	5	6	10	5	10
23	60	8	5	4	7	7	9
24	57	10	3	8	4	1	17
25	54	12	9	5	7	2	11
26	67	13	7	2	4	------	7
27	61	16	4	8	2	------	8
28	70	9	7	4	2	------	8
29	51	10	5	4	------	9	20
30	47	10	7	3	2	6	25
31	56	9	4	7	2	8	14
32	56	12	8	4	1	3	16
33	55	14	4	6	3	4	14
34	53	17	4	2	2	9	13
35	35	16	3	3	4	26	13
36	39	9	7	3	5	12	25
37	50	8	7	4	4	11	16
38	52	5	6	3	4	13	17
39	41	5	8	6	4	19	17
40	56	14	4	2	2	9	13
41	69	6	1	1	5	10	8
42	49	11	4	6	2	11	17
43	58	18	4	2	3	4	11
44	53	15	6	3	4	8	11
45	61	13	2	2	3	11	8
46	63	9	0	6	2	3	8
47	65	11	4	2	3	11	4
48	35	6	31	1	------	21	6
49	58	2	5	1	4	10	20
50	58	8	6	5	3	2	18
51	51	4	10	5	5	3	22

TABLE 7.—*Cruise 7: Percentage, by number, of six major constituents of zooplankton collections*

[Values less than 1 percent omitted]

Station No.	Copepoda	Chaetognatha	Tunicata	Euphausiacea	Siphonophora	Foraminifera	Miscellaneous
1	47	6	4	4	5	7	27
2	24	5	2	5	2	2	60
3	51	13	4		8	6	14
4	51	12	16	4	1	6	10
5	57	7	10	3	5	7	11
6	59	21	4	2	------	11	3
7	56	12	3	4	4	6	15
8	68	11	5	5	4	2	5
9	68	9	5	2	2	2	12
10	78	6	4	------	1	2	8
11	60	8	14	------	3	2	12
12	75	6	6	3	4	1	5
13	63	8	6	2	10	3	8
14	78	4	3	2	2	2	9
15	52	24	4	4	3	2	11
16	63	11	2	2	4	5	13
17	55	17	4	4	4	6	10
18	61	12	4	2	7	3	11
19	60	16	2	1	5	2	14
20	64	14	2	3	7	------	10
21	60	12	7	4	6	1	10
22	66	8	2	3	6	------	15
23	62	14	5	5	3	1	10
24	62	6	11	5	4	2	10

TABLE 8.—*Cruise 8: Percentage, by number, of six major constituents of zooplankton collections*

[Values less than 1 percent omitted]

Station No.	Copepoda	Chaetognatha	Tunicata	Euphausiacea	Siphonophora	Foraminifera	Miscellaneous
1	36	10	11	9	6	------	27
2	52	11	10	3	5	------	16
4	49	10	12	2	10	13	4
6	70	6	4	4	1	7	8
7	58	11	2	3	3	11	12
8	64	9	3	2	6	8	8
9	60	4	19	3	3	4	7
10	66	4	6	3	9	6	6
11	58	4	4	6	2	12	14
12	63	5	1	10	4	4	13
13	59	10	4	7	4	3	13
14	56	16	2	11	2	2	11
15	61	14	2	7	1	2	13
16	58	12	4	4	7	4	11
17	49	16	3	5	6	7	14
18	65	10	6	6	3	------	10
19	58	11	4	8	3	2	14
20	54	14	4	3	6	9	10
21	52	16	2	13	4	3	10
22	59	20	9	3	------	3	6
23	63	21	3	3	------	3	6
24	51	17	2	11	3	6	10
25	59	17	12	4	2	4	2
26	66	20	8	------	3	------	3
32	64	8	4	8	4	------	12
33	56	22	8	3	4	------	7
34	64	14	4	6	5	------	7
35	55	16	6	7	6	------	9
36	57	19	4	3	4	2	11
37	50	22	2	10	5	1	10
42	68	8	------	11	3	------	10
43	74	11	2	4	1	------	8
44	66	12	3	8	1	------	10
45	56	19	4	9	2	------	10
46	59	22	------	10	4	------	4
47	59	10	10	5	2	------	13
52	62	17	7	1	4	3	6
53	62	12	5	6	3	2	10
54	55	17	6	6	2	------	13
55	54	22	7	2	1	4	10
56	51	13	8	2	3	------	22
57	56	20	2	11	2	1	8
62	64	13	3	2	4	2	12
63	58	14	5	9	3	3	8
64	59	12	3	9	4	4	9
65	63	21	6	2	1	------	6
66	61	6	7	7	5	4	10
67	56	19	5	2	2	2	14
68	47	18	2	2	4	7	20
69	67	8	3	6	3	3	10
70	62	18	4	1	4	2	9
71	53	10	4	7	8	3	15
72	55	11	2	6	9	2	15
73	60	22	8	2	1	2	5
74	55	24	10	6	2	------	3
75	67	11	1	8	2	------	10
76	51	24	9	5	3	------	8
77	43	6	5	9	14	1	22
78	55	7	6	1	11	4	16
79	66	12	5	3	7	1	6
80	74	7	3	2	3	------	10
81	65	16	5	5	3	------	6
82	74	10	5	3	2	------	6
83	59	19	------	9	2	------	11
84	68	10	6	1	2	2	11
85	51	19	12	2	10	------	5
86	55	27	4	6	------	------	8
87	54	19	5	6	5	1	10
88	51	17	5	4	6	1	16
89	49	17	7	3	4	5	15
90	60	10	5	6	3	3	13
91	46	15	10	3	5	2	19
92	47	17	4	7	9	2	14
93	70	10	1	5	4	------	9
94	56	18	7	4	5	4	6
95	72	6	3	4	3	2	10
96	72	7	7	7	------	------	5
97	53	17	10	2	4	8	6
98	59	9	10	5	4	------	12
99	55	13	6	5	4	4	13
100	43	8	16	1	9	2	21
101	57	9	11	4	8	------	10
102	54	14	1	9	2	------	19
103	67	2	9	3	6	------	13
104	67	11	6	1	5	------	10
105	70	4	4	3	8	------	11
106	49	7	15	9	5	------	15

TABLE 9.—*Percentage composition, by number, of the six major constituents of the zooplankton collections, by cruise and longitude*

Major constituents	Cruise 2 Jan.-Feb. 1950			Cruise 5 June-Aug. 1950			Cruise 7 Oct.-Nov. 1950	Cruise 8 Jan.-Mar. 1951		
	172° W.[1]	158° W.[2]	Total	172° W.[3]	158° W.	Total	158° W.	172° W.[4]	158° W.[5]	Total[6]
Copepoda	58.9	56.2	57.4	56.3	53.0	54.9	60.2	58.6	58.0	58.4
Chaetognatha	16.7	14.0	15.2	8.3	10.0	9.0	12.0	12.4	12.2	13.5
Tunicata	5.6	8.2	7.1	5.6	5.6	5.6	4.7	6.1	5.3	5.3
Euphausiacea	3.9	9.1	6.8	4.9	3.5	4.3	3.0	4.6	5.9	5.6
Siphonophora	4.2	2.9	3.5	5.0	3.4	4.3	4.3	5.2	4.0	4.3
Foraminifera	2.5	1.3	1.8	7.7	9.9	8.6	3.0	1.6	4.8	2.5
Miscellaneous	8.2	8.3	8.2	12.2	14.6	13.3	12.8	11.5	9.8	10.4

[1] Includes stations 1 to 26.
[2] Includes stations 30 to 53.
[3] Includes stations 1 to 27.
[4] Includes stations 77 to 106.
[5] Includes stations 1 to 26.
[6] Includes stations 1 to 106, all longitudes.

The uniform composition of the zooplankton, as shown by our measurements, indicates the existence of a stable ecological balance among the various components of the plankton and between them and their environment. This uniformity, or stability, is doubtless the result of a complex interaction of factors. The physical and chemical factors of the environment throughout the range sampled are rather homogeneous and, perhaps while capable of effecting differences in total abundance of organisms, do not provide sufficient variations to promote major differences in the composition of populations. The relative absence of irregularly occurring swarms of larval and adult forms may account for some of the uniformity. It is reasonable to assume that, despite the great species differences that may occur (Wilson 1942), there is a particular niche in this ecosystem of the tropical and subtropical Pacific which will support a certain number of copepods, and another which will accommodate a certain number of chaetognaths, and so forth. The uniformity of the data on plankton composition also argues that the collecting method and its uniformity of application were appropriate for producing repeatable results.

ZOOPLANKTON AS FOOD

It is generally recognized that neither an enumeration of organisms present nor a total-volume measurement shows the actual food value of a plankton sample. Food value could be estimated by chemical analysis of each sample, but this procedure is hardly practical when large numbers of samples must be examined. Sufficient work has been done on the chemical composition of the major zooplankton types to show that they vary widely in nutritive value among types and even within types for different localities.

According to Bigelow and Sears (1939), the separation of the crustaceans and chaetognaths from the other types of zooplankton permits an approximate division of the zooplankton into (1) more nutritive forms which may be important as fish food and (2) forms of little or no nutritive value, such as the tunicates and siphonophores. In our collections, the crustacean-chaetognath group averages 70 to 80 percent by number.

Nakai (1942) has shown that plankton animals from the southern part of the Sea of Japan generally contain less fat than those of northern areas. The inference is made that in the warmer waters to the south, the scarcity of phytoplankton, particularly of diatoms with their rich oil reserves, prevents the accumulation of fat by the zooplankton. Clarke (1940) found that in the western Atlantic the plankton of coastal water had a higher percentage of organic matter than that of continental-slope or Sargasso-Sea water. Subtropical plankton in general had a low organic content. It is possible, therefore, that while three-fourths by number, and a smaller fraction by volume, of the zooplankton of the central Pacific is theoretically nutritious, its actual food value in calories may be less than for similar organisms of higher latitudes.

The Pacific Oceanic Fishery Investigations is conducting a study of the food of tunas. The results to date show that a variety of zooplankton forms are utilized directly as food by these fish. For example, representatives of the following groups have been captured in our plankton nets and have also been found among the stomach contents of maturing and adult yellowfin tuna (Reintjes and King 1953):

mysids	brachyuran larvae
euphausiids	heteropods
amphipods	pteropods
stomatopod larvae	cephalopod young
shrimps	tunicates
palinurid larvae	fish young

References have been previously cited (p. 111) emphasizing the importance of plankton in the food of juvenile tunas.

ABUNDANCE OF THE ZOOPLANKTON

Estimated numbers and volumes of zooplankton, times of sampling, and amounts of water strained, are given in tables 1, 2, 3, and 4. Variations in abundance with latitude are demonstrated by the histograms of figures 4, 5, 6, 7, and 8. The results are briefly summarized in tables 10 and 11.

TABLE 10.—*Areas of greatest abundance of zooplankton, by cruise and longitude*

Zooplankton	Cruise 2		Cruise 5		Cruise 7	Cruise 8	
	172° W.	158° W.	172° W.	158° W.	158° W.	172° W.	158° W.
Greatest estimated number/m.³	109	83	107	93	75	73	90
Latitude of greatest estimated number	0°	5° S.	1° S.	3° N.	2° N.	1° N.	1° S.
Greatest displacement volume, cc./m.³	.0826	.0911	.0742	.0880	.0741	.0548	.0666
Latitude of greatest displacement volume	0°	1° S.	1° S.	0°	2° N.[1]	2° N.	5° S.
Boundaries of rich area (estimated numbers)	2° N.–0°	3° N.–5° S.	4° N.–3° S.	5° N.–0°	6° N.–2° N.	6° N.–1° S.	1° S.–6° S.
Boundaries of rich area (displacement volumes)	2° N.–2° S.	3° N.–1° S.	1° N.–3° S.	5° N.–0°	6° N.–2° N.	5° N.–1° S.	1° S.–5° S.
Latitudinal range of collection	24° N.–5° S.	19° N.–5° S.	27° N.–5° S.	21° N.–5° S.	20½° N.–2° S.	21°N .–14½° S.	21° N. –7° S.

[1] Sample at 19° N. latitude was greatest in volume but was atypical, as it contained a highly unusual number and volume of amphipods. (See table 3.)

TABLE 11.—*Numbers and volumes of zooplankton organisms as related to equatorial currents and latitudes*

[Data from the six major sections of cruises 2, 5, and 8, which crossed the Equator on 158° and 172° W. longitude]

Current	Latitude	Number of observations	Zooplankton organisms	
			Average number per m.³	Average volume, cc. per m.³
North Equatorial Current	27°–18° N.	14	28	0.0184
	17°–11° N.	27	26	.0176
Countercurrent	10°–6° N.	25	32	.0255
South Equatorial Current	5°–1° N.	25	53	.0430
	Equator	5	73	.0605
	1°–5°S.	25	46	.0373
	6°–14° S.	8	34	.0175

In general, at the time and through the range of latitudes sampled (27° N. to 14° S.), the greatest abundance of zooplankton was found in the region of the Equator, between 6° N. and 5° S. latitude. The latitude of peak abundance varied with longitude and cruise. Although not evaluated statistically, there appears in all sections a strikingly parallel variation between the estimated number for each sample and the displacement volume. Because of the disparity in size among the different kinds of zooplankton organisms, numbers are much less meaningful indicators of productivity, or available food, than sample volumes; therefore, our statistical studies have been based solely on volume determinations.

When the varying abundance of zooplankton is reviewed in respect to the presence or absence of a convergence north of the Equator, certain interesting relationships are indicated:

1. When a well-marked convergence is present, the rich zone of zooplankton appears to lie between the Equator and the convergence to the northward (fig. 4, left panel; fig. 5, right panel). The eastern section, cruise 2 (fig. 4, right panel) on which only surface tows were employed, does not conform to this generality. Much of the irregularity in this section, however, is due to differences between samples taken by day and by night.

2. The northern boundary of the rich zone is practically demarcated by the position of the convergence—when it occurs.

3. When a well-marked convergence is lacking, the peaks of abundance—both in number and volume—occur south of the Equator (fig. 5, left panel; fig. 7, right panel).

4. The cruise-8 hydrographic data are not as yet completely processed and the presence or absence of convergences has not been determined for all sections; however, there is no evidence of a convergence along 158° W. longitude (fig. 7, right panel).

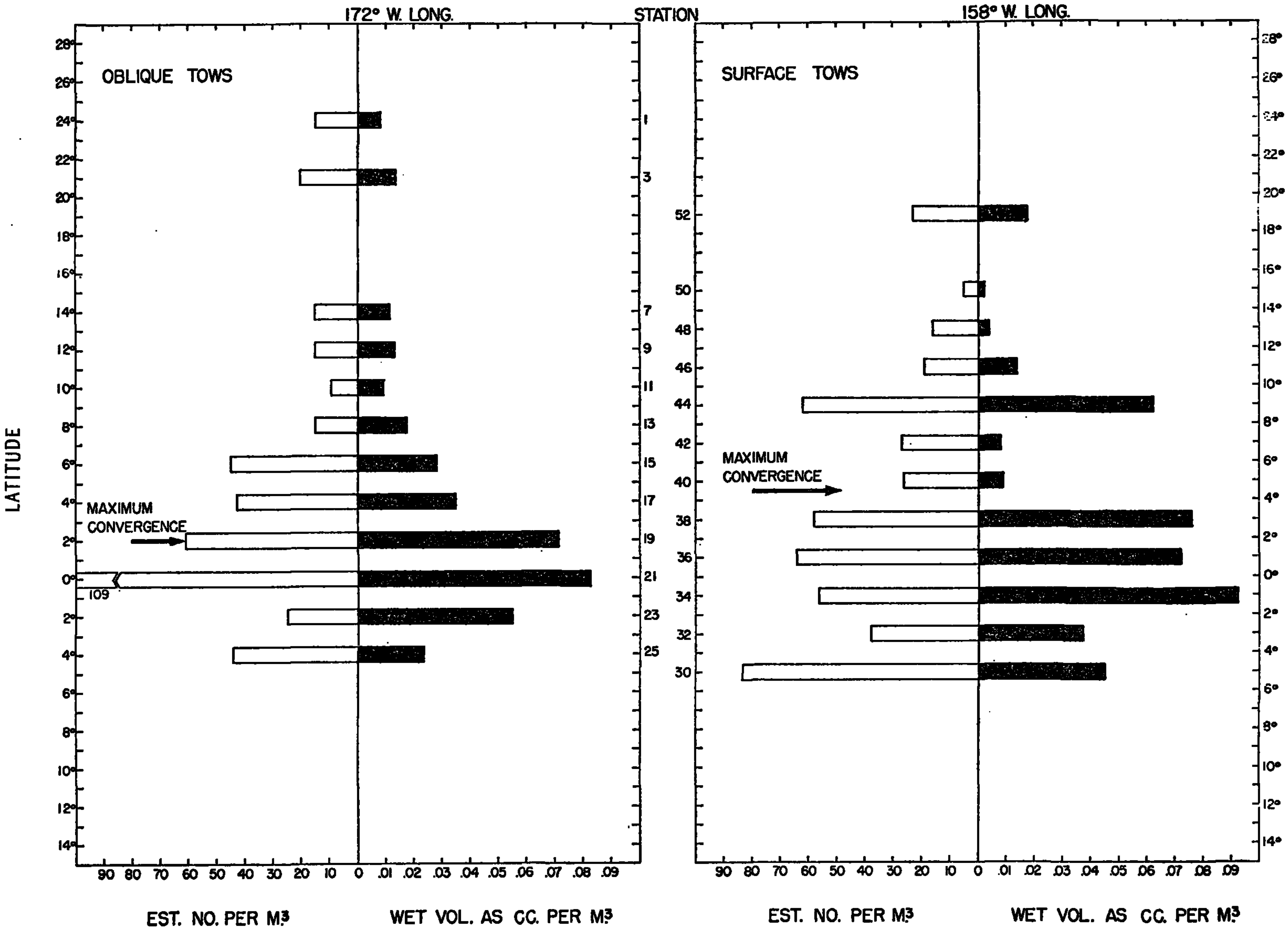


FIGURE 4.—Histograms of zooplankton abundance, as estimated numbers and volumes per m.³ of water strained, for cruise-2 stations.

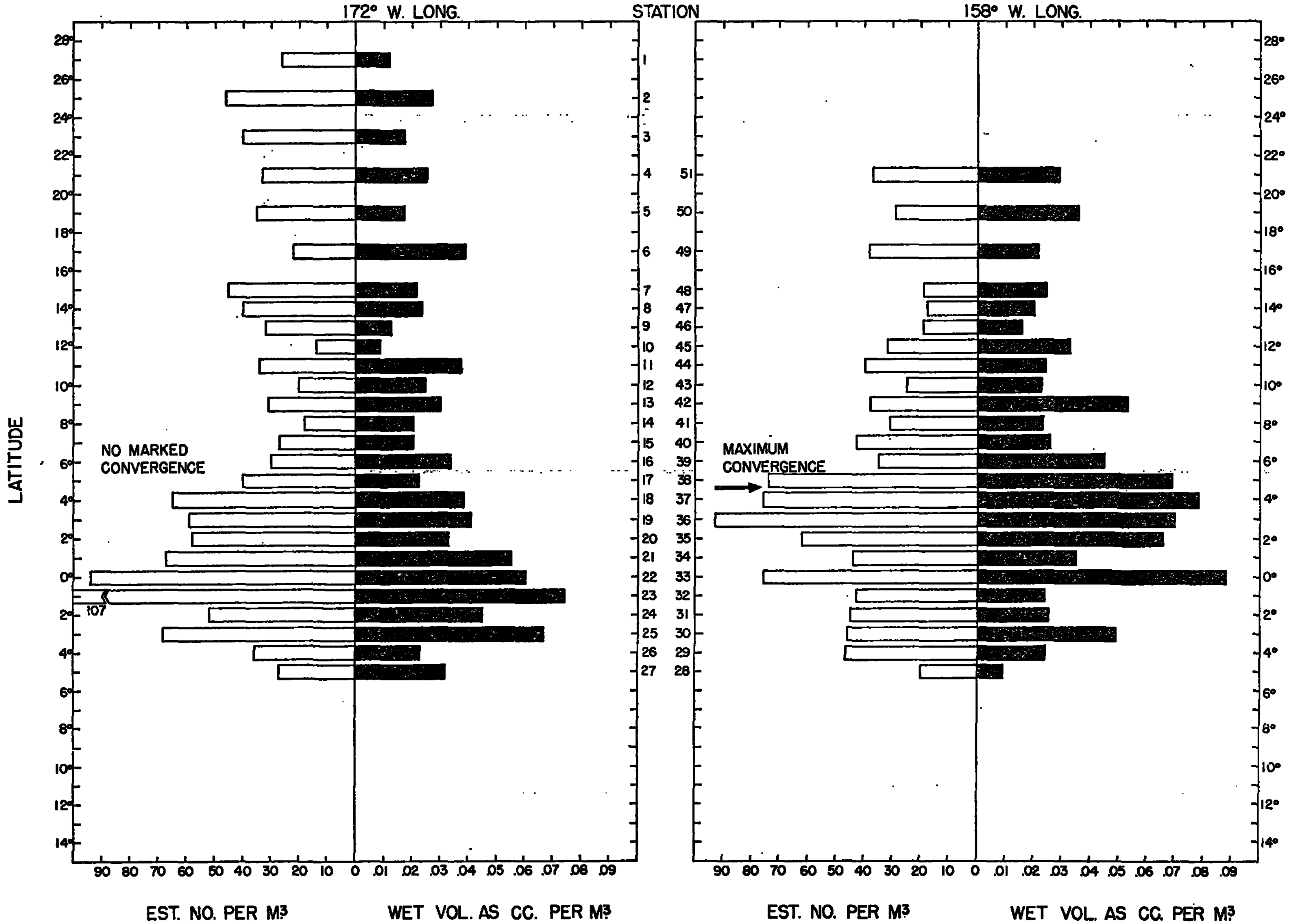


FIGURE 5.—Histograms of zooplankton abundance, as estimated numbers and volumes per m.^{3} of water strained, for cruise-5 stations.

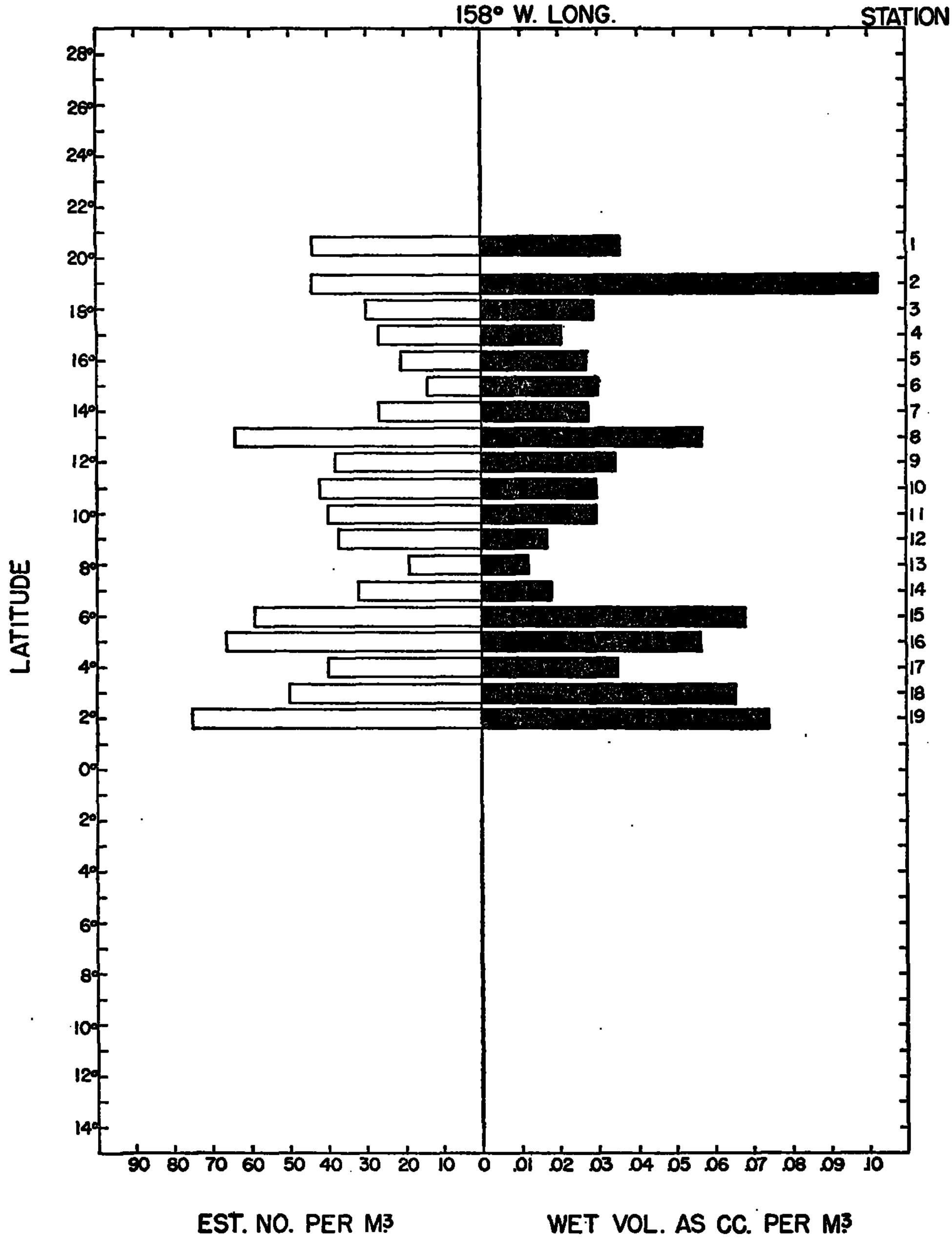


FIGURE 6.—Histogram of zooplankton abundance, as estimated numbers and volumes per m.³ of water strained, for cruise-7 stations.

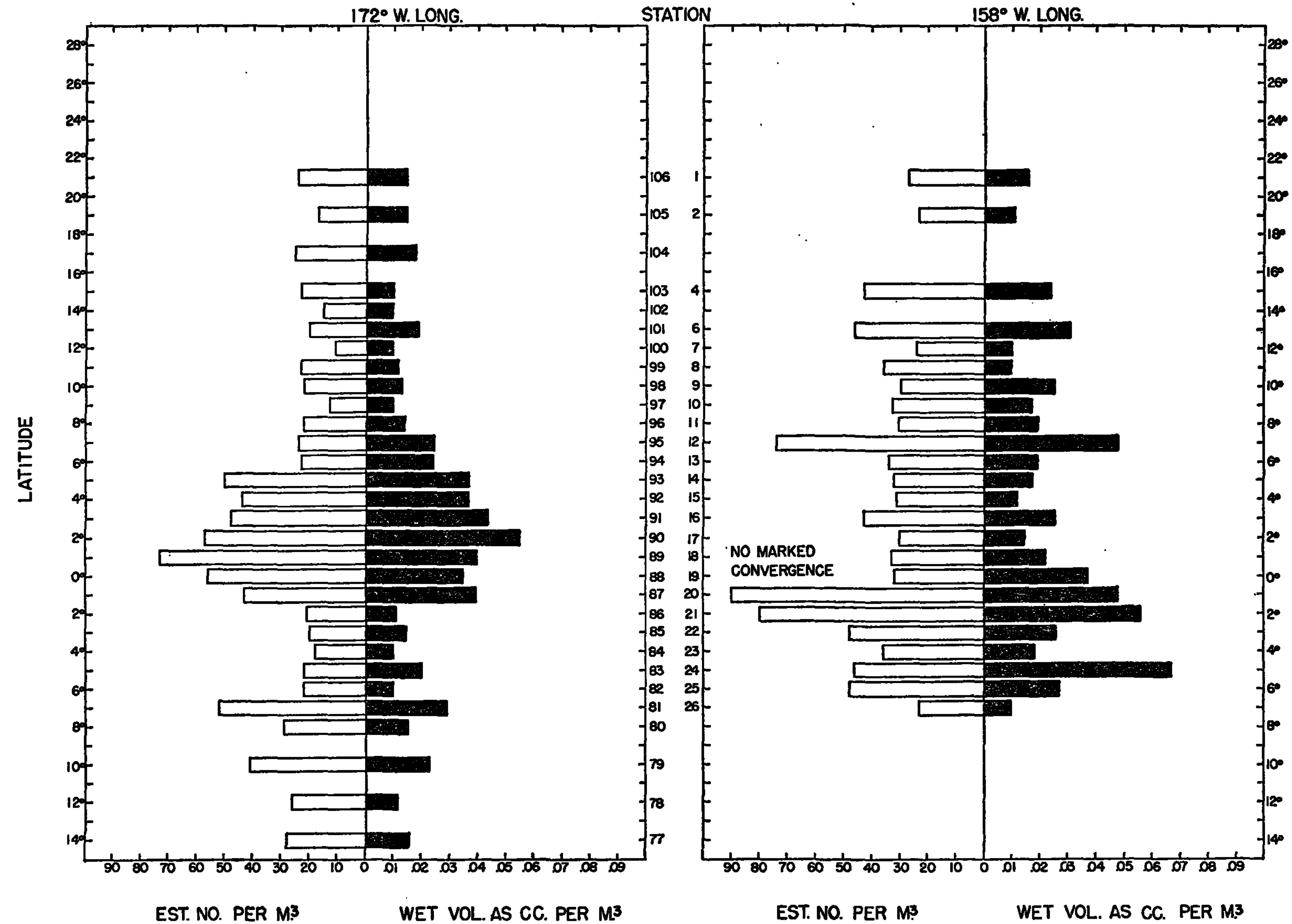


FIGURE 7.—Histograms of zooplankton abundance, as estimated numbers and volumes per m.[3] of water strained, for cruise-8 stations on longitudes 158° and 172° W.

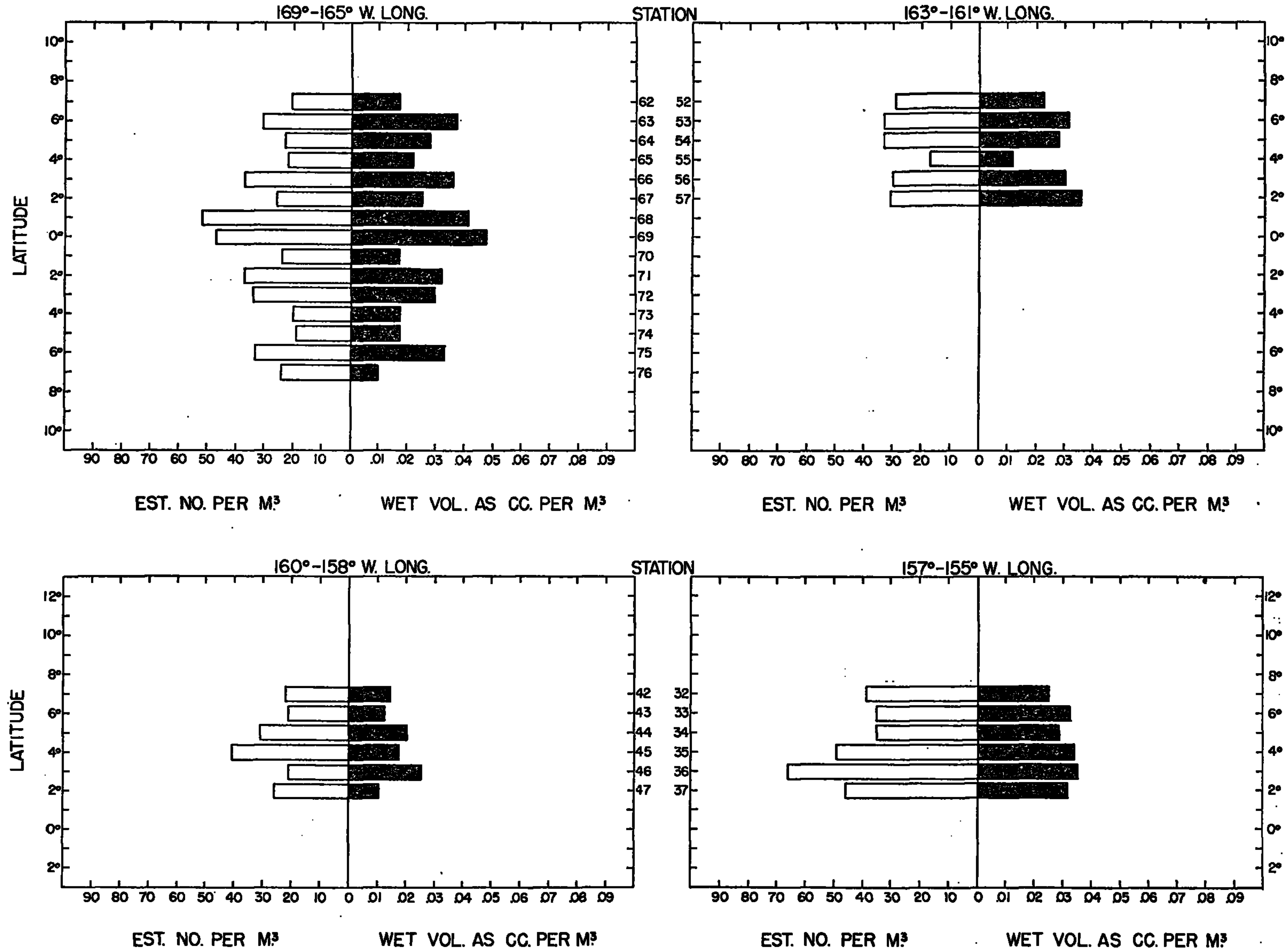


FIGURE 8.—Histograms of zooplankton abundance, as estimated numbers and volumes per m.³ of water strained, for cruise-8 stations located on the short sections between longitudes 155° and 169° W.

EFFECTS OF THE EQUATORIAL CURRENT SYSTEM

The general pattern of the Pacific Equatorial Current system has been described by Sverdrup, Johnson, and Fleming (1942, pp. 708–712). Cromwell (1951 and unpublished ms.[3]), on the basis of recent investigations by this laboratory, suggests certain modifications in the generally accepted ideas pertaining to the details of the circulation. The existence of the equatorial divergence with resultant upwelling of nutrient-rich water, as demonstrated by the *Carnegie* section of 1929 (Sverdrup, et al. 1942), is substantiated by the researches of this laboratory. The presence of a second major divergence at the northern boundary of the Countercurrent has not been confirmed, however. Cromwell concludes, on the basis of the information obtained on three cruises (2, 5, and 8) of the *Hugh M. Smith*, that there is no evidence that any enrichment of the surface layer—as a result of upwelling accompanying a divergence—is occurring at the boundary between the North Equatorial Current and the Countercurrent.

On cruise 2, a sharp temperature discontinuity, together with a local deepening of the thermocline, was found to occur at about 2° N. latitude on the western section and at about 4½° N. latitude on the eastern section (fig. 4). These conditions indicate the presence of a convergence or "front" (Cromwell ms.) in the surface currents. The northern boundary of the South Equatorial Current was discernible at 5½° N. latitude on the western section, but was not well defined on the eastern section. The convergence near 2° N. latitude was entirely within the South Equatorial Current and, therefore, was not associated with the boundary of this current and the Countercurrent as indicated by Sverdrup, et al. (1942, pp. 710, 711) and Arrhenius (1950). A well-defined convergence, as demonstrated by a marked temperature discontinuity and a deepening thermocline, occurred at 4½° N. latitude on the eastern section of cruise 5 (fig. 5) and again was entirely within the South Equatorial Current. An examination of the data from the oceanographic cruises (tables 6 to 8) indicates that the convergence was more pronounced in certain sections than in others and in some it was not strong enough to exhibit the usual signs and may have been entirely lacking, thus permitting the inference that it is shifting and transitory in nature.[4]

Newly upwelled water is at first poorly populated as regards both phytoplankton and zooplankton (Steemann Nielsen 1937). The latter does not benefit directly from the nutrient-rich water but must await the development of a phytoplankton population. In a region of fairly rapid currents, the phytoplankton maximum and the more slowly developing zooplankton maximum would be expected to occur at a considerable distance from each other both in time and space. Steemann Nielsen (1937) reports that in Iceland waters, when conditions for phytoplankton change from bad to good, the capacity for rapid reproduction in phytoplankton enables a few specimens to establish a rich population in 10 days; large quantities of zooplankton do not show up until about a month later. We are not aware of similar population-growth data for the tropics, but we can safely assume that the rate of development here would be considerably more rapid. Nevertheless, it is surprising that in our sampling we found the zooplankton maximum frequently occurring on or very near the site of the upwelling.

Since the days of Hensen and the German Plankton Expedition of 1889, tropical seas have been considered less productive than those of higher latitudes. Explanations for this are usually based on the theory that in the tropics surface heating results in a stable stratification of the sea, thus preventing any vertical mixing by convection which would bring nutrients to the euphotic zone (Delsman 1939; Graham 1941; Sverdrup, et al. 1942, p. 942; Arrhenius 1950). Such thermal stratification does apparently exist throughout much of the tropical, subtropical, and temperate Pacific in areas removed from land influence.

It was learned from the last cruise of the *Carnegie* in 1929, that these generally stable dynamic conditions are disrupted at the Equator by a strong divergence which is accompanied by upwelling. The latter was considered responsible for the enrichment of the surface layers and the production of much higher concentrations of plankton than

[3] Circulation in a meridional plane in the central equatorial Pacific.

[4] The Equatorial Current system is considerably more complex than indicated here. Details of the circulation at the divergence and the convergence and the causal forces involved, are presently being studied by members of this organization and the Scripps Institution of Oceanography.

were found in subtropical and temperate latitudes (Graham 1941). The frequently appearing convergence at 2° to 5° N. latitude also contributes to this apparent greater abundance of life in the equatorial region. Floating organisms with high buoyancy undoubtedly congregate here just as driftwood does along a current rip or other discontinuity zone; zooplankton capable of resisting the downward currents would also tend to concentrate in the surface layers. When a strong convergence has persisted for a sufficient length of time, an area of relatively high-plankton abundance should result, providing rich pasturage for plankton-feeding animals.

The unusual abundance of marine life in the equatorial region has been observed by many expeditions and world travelers while crossing the Pacific. Agassiz and Mayer (1902), in their report on observations and collections of the *Albatross* in the tropical Pacific, state,

> In fact it is evident that pelagic animals are not abundant in regions far from large land masses or where there are no well-defined oceanic currents or counter currents. As soon as one approaches the region of great currents or counter currents, or the coasts of continents and larger islands, the number of animals increases with remarkable suddenness.

Beebe (1926) describes masses of floating debris and the associated wealth of life in a current rip some 200 miles southeast (between 3° and 4° N. latitude) of Cocos Island in the eastern Pacific. Brooks (1934), in reporting his observations on certain relationships between ocean currents and birds, asks why it is that on ocean voyages day after day goes by and no birds or marine life are seen and then suddenly one passes into an area teeming with life. He observed that, as his vessel neared the Equator from the north, bird life increased greatly, as did other marine life such as flying fish, sharks, and whales; then as he crossed the Equator, the zone of abundant life was left behind.

Revelle (1944) points out the agreement between the southern boundary of the Countercurrent and the northern border of the Pacific *Globigerina* ooze area. In reporting on results of the recent Swedish Deep-Sea Expedition, Arrhenius (1950) states in respect to the Pacific,

> The biogenous component and simultaneously the rate of sedimentation increases strongly below the convergence where a biolith, rich in fossils of foraminifera, radiolaria and diatoms is thus deposited. North of the convergence of the Equatorial Counter Current, the share of the biogenous component in the sedimentation decreases and the fossil-rich biolith turns into a clay, poor in fossils and with a low intensity of sedimentation.[5]

As summarized by Herdman (1923),

> It is probable, on the whole, that the distribution and variation of ocean currents have more than latitude or temperature alone to do with any observed scantiness of tropical plankton. These mighty rivers of the ocean in places teem with animal and plant life, and may sweep abundance of food from one region to another in the open sea.

VARIATION IN ZOOPLANKTON ABUNDANCE

The sampling method used in the present study meets the criteria for randomness in most respects, allowing the use of standard methods of statistical analysis. Although the stations were located in systematic order, a random sample was probably obtained of the zooplankton population retained by a meter net with 0.65-mm. apertures from the upper 200 meters of water. There is some doubt, however, as to the type of distribution of the plankton population. Although our results indicate a rather uniform, but very dilute distribution of zooplankton, which would perhaps conform to a Poisson distribution, the majority of workers have reported clumping and lack of uniformity. Snedecor (1946, pp. 42 and 252) states that the requirement of randomness must be adhered to, but normal distribution of the population is a specification that can be considerably relaxed. Of course, there are devices appropriate for analyzing samples from nonnormal distributions. One commonly used method involving a transformation of the data to logarithms, was employed in certain initial tests of the volume data. The results and conclusions obtained were the same, however, as those reached through an analysis of the untransformed data. We assumed, therefore, that the degree of anormality in the zooplankton population would affect our inferences but little, and in this report have chosen to examine and base our conclusions upon tests of the untransformed data. We wish to emphasize the point that all statisti-

[5] The convergence here referred to by Arrhenius is that which theoretically occurs at the southern boundary of the Countercurrent and, as previously stated, has not been observed by these investigations. We have found the convergence 2° to 3° south of the current boundary and entirely within the South Equatorial Current.

cal analyses were made on zooplankton volumes rather than on numbers.

An examination of the histograms in figures 4, 5, 6, 7, and 8 reveals distinct variations in zooplankton abundance with latitude; differences between longitudes and between cruises are not so obvious, however. The hydrographic data obtained coincident with the zooplankton collections also show latitudinal variations in inorganic phosphate, surface and subsurface temperature, oxygen, and thermocline depth (fig. 9). The marked differences between day and night hauls have already been referred to in the discussion of methods. By employing an analysis of variance, we have attempted to determine the significance and magnitude of these space-time variations in zooplankton abundance; by using correlation and multiple-regression analyses we have been able to measure the degree of covariation between zooplankton and these different environmental factors.

Effect of time of sampling

Our sampling method was not specifically designed to evaluate variations among the zooplankton volumes resulting from differences between day and night hauls. An accurate measure of these differences would have required both day and night hauls (preferably within a 24-hour period) at every station. These day-night variations could perhaps have been eliminated by visiting every station at the same time of day or night. In view of the number of stations and the large area covered, neither procedure was practical.

Although on cruises 2, 5, and 8 there was, theoretically, opportunity for the occurrence of equal numbers of day and night collections, it so happened that the day collections outnumbered the night collections. Rarely, however, were more than 2 day stations or 2 night stations occupied consecutively.

An estimate of the importance of the day-night variation, as compared with the latitudinal variation, was obtained from the cruise-5 and cruise-8 data, using an analysis of variance with two criteria of classification (following Snedecor 1946, p. 256). We paired, impartially, successive night and day hauls, where both occurred on the same longitude and on about the same latitude, omitting those stations where two or more day hauls or night hauls were made in succession, and also omitting those stations worked during twilight periods.

An analysis of the cruise-5 volumes (table 12) indicates that for this cruise, there were significant ($P<0.05$) differences between the day and night hauls and also among latitudes. For the cruise-8 volumes (table 13), there were also significant ($P<0.01$) differences between the day and night hauls and among latitudes.

If the means for latitudes are compared using the "least significant difference" calculated according to the method of Johnson (1950, p. 123; $LSD=(t_{.05})\sqrt{2s^2/k}$), it is evident that for both cruises the means obtained near the Equator are significantly greater than those to the north or south of the Equator. For example, on cruise 8, the mean volume (0.0513 cc./m.^{3}) for 1° and 2° S. latitude differs from the mean volume (0.0178 cc./m.^{3}) for 8° and 9° N. latitude by a difference of 0.0335, which is considerably greater than the least significant difference, 0.0165.

TABLE 12.—*Cruise 5: Analysis of variance of volumes of paired samples taken by day and by night in about the same latitude*

[Two criteria of classification]

Station Nos.	Latitudes	Volume (cc./m.^{3})		Mean
		Day	Night	
1 and 2	27° and 25° N	0.0118	0.0271	0.0194
5 and 4	19° and 21° N	.0174	.0254	.0214
7 and 8	15° and 14° N	.0216	.0234	.0225
12 and 11	10° and 11° N	.0252	.0374	.0313
15 and 14	7° and 8° N	.0204	.0203	.0204
17 and 16	5° and 6° N	.0226	.0338	.0282
18 and 19	4° and 3° N	.0385	.0410	.0398
21 and 22	1° N. and 0°	.0556	.0604	.0580
24 and 25	2° and 3° S	.0452	.0664	.0558
26 and 27	4° and 5° S	.0230	.0315	.0272
29 and 30	4° and 3° S	.0239	.0490	.0370
32 and 33	1° S. and 0°	.0239	.0880	.0560
35 and 36	2° and 3° N	.0658	.0701	.0680
38 and 39	5° and 6° N	.0691	.0449	.0570
41 and 42	8° and 9° N	.0230	.0531	.0380
44 and 45	11° and 12° N	.0242	.0327	.0284
47 and 48	14° and 15° N	.0201	.0246	.0224
50 and 51	19° and 21° N	.0357	.0289	.0323
Mean		.0315	.0421	

Least significant difference for latitudinal means=.0268

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Times	1	0.00101336	0.00101336*	6.28	<0.05
Latitudes	17	.00814675	.00047922*	2.97	<0.05
Discrepancy	17	.00274379	.00016140		
Total	35	.01190390			

*Indicates a significant ($P<0.05$) mean square value.

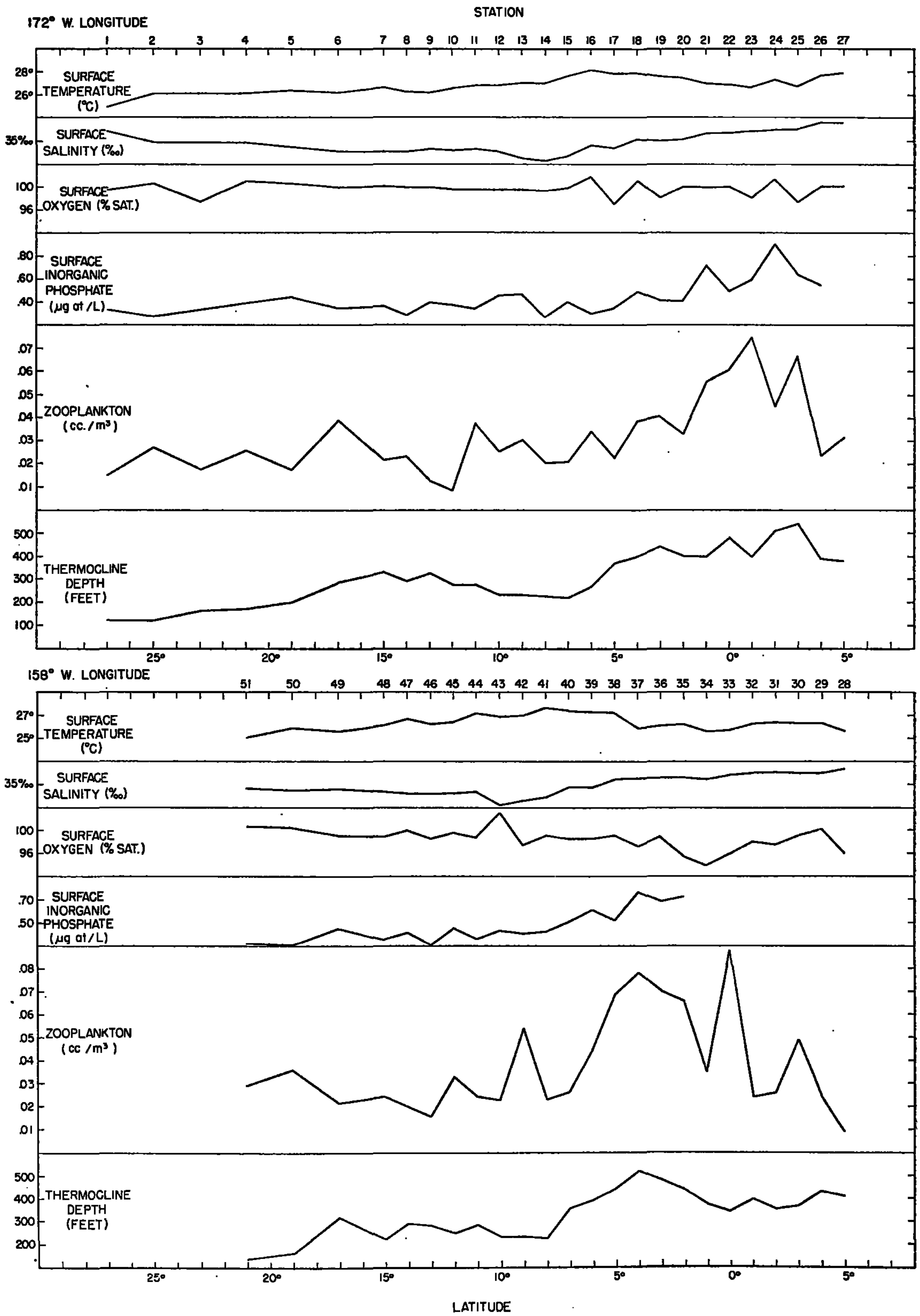


FIGURE 9.—Variations in temperature, salinity, oxygen, inorganic phosphate, thermocline depth, and zooplankton volume along 158° and 172° W. long. as found on cruise 5, *Hugh M. Smith*, June–August 1950.

TABLE 13.—*Cruise 8: Analysis of variance of volumes of paired samples taken by day and by night in about the same latitude*

[Two criteria of classification]

Station Nos.	Latitudes	Volume (cc./m.³)		Mean
		Day	Night	
2 and 1	19° and 21° N	0.0105	0.0154	0.0130
4 and 6	14½° and 13° N	.0236	.0310	.0273
8 and 9	11° and 10° N	.0093	.0251	.0172
10 and 11	9° and 8° N	.0166	.0190	.0178
13 and 14	6° and 5° N	.0186	.0174	.0180
15 and 16	4° and 3° N	.0118	.0255	.0186
18 and 19	1° N. and 0°	.0220	.0370	.0295
20 and 21	1° and 2° S	.0478	.0558	.0513
23 and 24	4° and 5° S	.0178	.0666	.0422
33 and 32	6° and 7° N	.0325	.0251	.0288
36 and 35	3° and 4° N	.0348	.0340	.0344
43 and 44	6° and 5° N	.0126	.0204	.0165
45 and 46	4° and 3° N	.0177	.0254	.0216
52 and 53	7° and 6° N	.0224	.0313	.0268
55 and 54	4° and 5° N	.0118	.0276	.0197
62 and 63	7° and 6° N	.0170	.0368	.0269
65 and 66	4° and 3° N	.0118	.0359	.0238
70 and 69	1° S. and 0°	.0172	.0473	.0322
73 and 72	4° and 3° S	.0175	.0295	.0235
76 and 75	7° and 6° S	.0100	.0332	.0216
78 and 79	12° and 10° S	.0115	.0226	.0170
82 and 81	6° and 7° S	.0100	.0291	.0196
84 and 83	4° and 5° S	.0101	.0202	.0152
86 and 87	2° and 1° S	.0109	.0394	.0252
89 and 90	1° and 2° N	.0398	.0548	.0473
94 and 93	6° and 5° N	.0242	.0369	.0306
97 and 98	9° and 10° N	.0094	.0127	.0110
100 and 101	12° and 13° N	.0097	.0192	.0144
104 and 105	17° and 19° N	.0181	.0145	.0163
Mean		.0182	.0306	

Least significant difference for latitudinal means = .0165

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Times	1	0.00225564	0.00225564**	34.60	<0.01
Latitudes	28	.00553218	.00019758**	3.03	<0.01
Discrepancy	28	.00182531	.00006519		
Total	57	.00961313			

**Indicates a highly significant ($P<0.01$) mean square value.

Thus, despite the important variation resulting from diurnal migration of the zooplankton, there still remain in our data significant differences among latitudes. Zooplankton populations occurring near the Equator are significantly greater in abundance than those of adjoining areas.

Variations between cruises, latitudes, and longitudes

To examine differences between cruises and between longitudes and to inspect further the differences among latitudes, an analysis of variance with multiple classification as outlined by Snedecor (1946, pp. 304–309) was utilized, employing as many of the cruise-5 and cruise-8 data as were available for similar latitudes and longitudes (table 14). The analysis is of the same general type as that used by Winsor and Clarke (1940) in their study of variation in the catch of plankton nets.

TABLE 14.—*Analysis of variance of volumes (cc./m.³) of zooplankton samples collected on cruises 5 and 8*

[Three criteria of classification]

Latitude	Series A (172° W. longitude)		Series B (158° W. longitude)		Mean
	Cruise 5	Cruise 8	Cruise 5	Cruise 8	
21° N	0.0254	0.0145	0.0289	0.0154	0.0210
19° N	.0174	.0145	.0357	.0105	.0195
15° N	.0216	.0100	.0246	.0236	.0200
13° N	.0125	.0192	.0158	.0310	.0196
12° N	.0084	.0097	.0327	.0094	.0150
11° N	.0374	.0115	.0242	.0093	.0206
10° N	.0252	.0127	.0225	.0251	.0214
9° N	.0301	.0094	.0531	.0166	.0273
8° N	.0203	.0139	.0230	.0190	.0190
7° N	.0204	.0244	.0258	.0477	.0296
6° N	.0338	.0242	.0449	.0186	.0304
5° N	.0226	.0369	.0691	.0174	.0365
4° N	.0385	.0367	.0783	.0118	.0413
3° N	.0410	.0435	.0701	.0255	.0450
2° N	.0330	.0548	.0658	.0146	.0420
1° N	.0556	.0398	.0347	.0220	.0380
0°	.0604	.0345	.0880	.0370	.0550
1° S	.0742	.0394	.0239	.0478	.0463
2° S	.0452	.0109	.0253	.0558	.0343
3° S	.0664	.0146	.0490	.0257	.0389
4° S	.0230	.0101	.0239	.0178	.0187
5° S	.0315	.0202	.0087	.0666	.0318
Mean	.0338	.0230	.0394	.0258	

Least significant difference for latitudinal means = .0218

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Main effects:					
Series (S)	1	0.00039964	0.00039964	1.67	>0.05
Cruises (C)	1	.00329280	.00329280**	13.79	<0.01
Latitudes (L)	21	.01052548	.00050121*	2.10	<0.02
First-order interactions:					
S×C	1				
S×L	21				
C×L	21	.01528396	.00023881		
Second-order interaction:					
S×C×L	21				
Total	87	.02950188			

* Indicates a significant ($P<0.05$) mean square value.
** Indicates a highly significant ($P<0.01$) mean square value.

The analysis was first carried out in full to determine the significance of the first-order interactions. As these proved to be nonsignificant, they were pooled (following Kendall 1948, p. 201) with the second-order interaction to give a new sum of squares with 64 degrees of freedom and a new mean square which was then used as the error term for testing the main effects. The following observations may be made from the tests of significance:

1. No significant differences ($P>0.05$) are demonstrated between the means for series (longitudes) (0.0284 cc./m.³ for 172° W. longitude, and 0.0326 cc./m.³ for 158° W. longitude).
2. Significant differences ($P<0.01$) are demonstrated between the means for cruises (0.0366 cc./m.³ for cruise 5 and 0.0244 cc./m.³ for cruise 8).
3. Significant differences ($P<0.02$) are demonstrated among the means for latitudes (these vary from 0.0550

cc./m.³ at the Equator to 0.0150 cc./m.³ at 12° N. latitude).

In this analysis no attempt has been made to isolate the component of variance resulting from time of day at which the hauls were made, and the data are insufficient for a 4-way analysis. In table 14, however, the night samples are rather evenly distributed throughout; e. g., the column for series A, cruise 5, contains 8 night hauls and 1 twilight haul; series A, cruise 8, contains 7 night hauls and 4 twilight hauls; series B, cruise 5, contains 8 night hauls and 2 twilight hauls; and series B, cruise 8, contains 9 night hauls and no twilight hauls. As a consequence we might assume that the day-night variation would tend to cancel out.

To test this assumption we have utilized the values given in table 14, and at the expense of considerable loss of data, we have constructed two 3-way tables, one including only day samples (table 15) and the other only night samples (table 16). An analysis of the day samples reveals quite different results than does an analysis of the night samples or of the combined day and night samples. For the day samples we find no significant differences ($P>0.05$) between series (longitudes), between cruises, or among latitudes. An analysis of the night samples provides the same conclusions as were derived from the combined day and night samples, there being no significant differences ($P>0.05$) between series (longitudes) but highly significant differences ($P<0.01$) between cruises and among latitudes.

TABLE 15.—*Analysis of variance of volumes (cc./m.³) of zooplankton samples taken in day hauls, cruises 5 and 8*

[Latitudes grouped to provide a value for each column; three criteria of classification]

Latitudes	Series A (172° W. longitude)		Series B (158° W. longitude)		Mean
	Cruise 5	Cruise 8	Cruise 5	Cruise 8	
15° and 13° N.	0.0216	0.0100	0.0158	0.0236	0.0178
12° and 11° N.	.0084	.0097	.0242	.0094	.0129
10° and 9° N.	.0252	.0094	.0225	.0166	.0184
7° and 6° N.	.0204	.0242	.0258	.0477	.0295
5° and 4° N.	.0385	.0367	.0783	.0118	.0413
3° and 2° N.	.0330	.0435	.0658	.0146	.0392
1° N. and 0°	.0556	.0398	.0347	.0220	.0380
1° and 2° S.	.0742	.0109	.0239	.0478	.0392
3° and 4° S.	.0230	.0146	.0239	.0257	.0218
Mean	.0333	.0221	.0350	.0244	

Least significant difference for latitudinal means=.0233

TABLE 15.—*Analysis of variance of volumes (cc./m.³) of zooplankton samples taken in day hauls, cruises 5 and 8*—Continued

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Main effects:					
Series (S)	1	0.00003481	0.00003481	0.14	>0.05
Cruises (C)	1	.00107584	.00107584	4.20	>0.05
Latitudes (L)	8	.00395996	.00049500	1.93	>0.05
First-order interactions:					
S×C	1				
S×L	8				
C×L	8	.00640043	.00025602		
Second-order interaction:					
S×C×L	8				
Total	35	.01147104			

TABLE 16.—*Analysis of variance of volumes (cc./m.³) of zooplankton samples taken in night hauls, cruises 5 and 8*

[Latitudes grouped to provide a value for each column; three criteria of classification]

Latitudes	Series A (172° W. longitude)		Series B (158° W. longitude)		Mean
	Cruise 5	Cruise 8	Cruise 5	Cruise 8	
13°, 12°, and 11° N.	0.0374	0.0192	0.0327	0.0310	0.0301
10°, 9° N.	.0301	.0127	.0531	.0251	.0302
8°, 7°, and 6° N.	.0338	.0139	.0449	.0190	.0279
5°, 4°, and 3° N.	.0410	.0369	.0701	.0255	.0434
2°, 1° N., and 0°	.0604	.0548	.0880	.0370	.0600
1°, 2°, and 3° S.	.0664	.0394	.0490	.0558	.0526
Mean	.0448	.0295	.0563	.0322	

Least significant difference for latitudinal means=.0159

Source of variation	Degrees of freedom	Sum of squares	Mean square	F	P
Main effects:					
Series (S)	1	0.00030246	0.00030246	2.67	>0.05
Cruises (C)	1	.00233248	.00233248**	20.62	<0.01
Latitudes (L)	5	.00364125	.00072825**	6.44	<0.01
First-order interactions:					
S×C	1				
S×L	5				
C×L	5	.00180978	.00011311		
Second-order interaction:					
S×C×L	5				
Total	23	.00808597			

**Indicates a highly significant ($P<0.01$) mean square value.

Although it has been possible to utilize only a portion of the data, the differences between cruises and among latitudes may be regarded as real, for they have been demonstrated not only in table 14 where the day-night component was present, but also in the last analysis, table 16, where the day-night component was removed. The evidence that there is less latitudinal variation in the day samples than in the night samples introduces a new feature and reveals another possible source of variation in the data. The cause, or causes, of this phenomenon, if real, are as yet obscure to the authors, but may be related to differences in basic productivity, depth of thermocline, or other factors of the environment.

In summary, through the foregoing analyses, we have demonstrated that the rich zooplankton catches from near the Equator were significantly greater than those of higher latitudes. We have learned also that there was little difference between the populations along the two longitudes, 172° W. and 158° W., over the range of latitudes sampled. We can state with assurance that there was a distinct difference between the amount of zooplankton taken on the two cruises, 5 and 8. The mean for cruise 5 (0.0366 cc./m.^{3}) conducted during the northern summer, was greater than that for cruise 8 (0.0244 cc./m.^{3}) conducted during the winter; therefore, a seasonal difference is suggested.

CORRELATIONS WITH ENVIRONMENTAL FACTORS

Some of the hydrographic data obtained on cruises of the *Hugh M. Smith* have been published (Cromwell 1951), and since the Pacific Oceanic Fishery Investigations plans to publish the hydrographic data on which these correlations are based, we have not included the data in this paper. Variations in certain features of the surface layer as measured on cruise 5, and graphically portrayed in figure 9, may be summarized as follows:

1. Surface inorganic phosphates—high concentrations of 0.80 to 0.90 µg at./L. were found in the immediate vicinity of the Equator; values decreased to the northward and southward to lows of 0.30 to 0.40 µg at./L.
2. Surface temperature—highest water temperatures, about 28° C., were recorded for latitudes 6° to 8° N.; temperature decreased gradually to the northward and to the southward, reaching 24° to 25° C.
3. Dissolved oxygen (percent saturation at surface)—ranged from 94 percent near the Equator to 102 percent at higher latitudes.
4. Thermocline depth—varied from about 120 feet in the north to over 500 feet in the region of the convergence.

Employing cruise-5 data,[6] a method of correlation analysis (following Snedecor 1946, p. 138) was used to examine the relation between zooplankton volumes and these environmental factors. The results, summarized in table 17, point out the following:

1. Statistically significant ($P<0.01$) positive correlations between zooplankton volume and inorganic phosphates at the surface, at the 100-meter depth, and at depths midway to the top of the thermocline;
2. Statistically nonsignificant ($P>0.05$) correlations between zooplankton volume and temperature, whether at the surface, the 100-meter depth, or at depths midway to the top of the thermocline;
3. Statistically significant negative correlations between zooplankton volume and oxygen (as percent saturation) at the surface ($P<0.05$), at the 100-meter depth ($P<0.01$), and at depths midway to the top of the thermocline ($P<0.01$);
4. Statistically significant ($P<0.01$) correlations between zooplankton volume and depth to the top of the thermocline.

In most ecological investigations it has been found that all factors examined are more or less interrelated, variations in one factor having an influence, either direct or indirect, on all the other factors (Riley 1939a). The multiple-regression method makes corrections for such interactions, and in a three-variate analysis tests the relation of a pair of variates irrespective of the influence of a third.

TABLE 17.—*Correlations of zooplankton abundance, as wet volumes, and certain environmental factors, cruise 5*

Variates X_1	Variates X_2	Degrees of freedom	Correlation coefficient (r)	P
Inorganic phosphates (µg at./L.) at surface.	Zooplankton wet volumes.	41	0.655**	<0.01
Inorganic phosphates (µg at./L.) at 100 m. depth.	do	41	0.580**	<0.01
Inorganic phosphates (µg at./L.) at depths midway to thermocline.	do	41	0.730**	<0.01
Temperature (° C.) at surface	do	49	0.008	>0.05
Temperature (° C.) at 100 m. depth.	do	49	0.227	>0.05
Temperature (° C.) at depths midway to thermocline.	do	49	−0.065	>0.05
Oxygen (percent saturation) at surface.	do	49	−0.291*	<0.05
Oxygen (percent saturation) at 100 m. depth.	do	49	−0.834**	<0.01
Oxygen (percent saturation) at depths midway to thermocline.	do	49	−0.489**	<0.01
Thermocline depth (feet)	do	49	0.566**	<0.01

** Indicates a highly significant correlation.
* Indicates a significant correlation.

In the correlation analyses a positive relation between zooplankton volumes and temperature at the 100-meter depth was indicated (table 17), but, being below the 0.05 level of probability, it was not considered statistically significant. It seemed of interest to examine the relation of zooplankton

[6] Since different methods of towing and nets of different mesh size were used on cruise 2, and since the hydrographic data of cruise 8 are not as yet entirely processed, we have used cruise-5 data for the correlation analyses.

and temperature at the 100-meter level independent of variation with inorganic phosphate. A multiple regression analysis (following Snedecor 1946, pp. 340–373) was therefore carried out employing cruise-5 data, treating zooplankton volumes (cc./m.^{3}) as the Y variate, inorganic phosphates (μg at./L) at 100 meters as the X_1 variate, and temperatures (°C.) at 100 meters as the X_2 variate.

The following multiple regression equation was obtained:

$$Y=0.0484X_1+0.0023X_2-0.044969.$$

The first partial regression coefficient ($b_{Y1\cdot2}=0.0484$; $t=5.232$, $P<0.001$, at 40 degrees of freedom) and the first partial correlation coefficient ($r_{Y1\cdot2}=0.638$; $P<0.01$) are highly significant, showing that there is a positive relation between zooplankton volumes and inorganic phosphates, independent of the variation with temperature, at the 100-meter level. This conclusion was expected from the previous correlation analysis. The second partial regression coefficient ($b_{Y2\cdot1}=0.0023$; $t=2.987$, $P<0.01$, at 40 degrees of freedom) and the second partial correlation coefficient ($r_{Y2\cdot1}=0.423$; $P<0.01$) are also highly significant, showing that there is also a positive relation between zooplankton volumes and temperature, independent of variation with inorganic phosphate, at the 100-meter level. This conclusion is of interest since it indicates a much higher degree of covariation between zooplankton and temperature, than was revealed by the previous correlation analysis.

We have shown that the abundance of zooplankton in the central Pacific is correlated with inorganic phosphates, temperature, dissolved oxygen, and thermocline depth. We do not believe, though, that the abundance of zooplankton is in any way limited by the conditions of temperature, oxygen, or thermocline depth prevailing throughout the region. The relationships between zooplankton and these three environmental factors, as indicated by the statistical correlations, are most likely independent variations due to common causes. Zooplankton is more directly linked with phosphate, however, through the phosphate→phytoplankton→zooplankton relation. Therefore, the causal agent for these several variations examined is directly or indirectly the Equatorial Current system, principally the divergence at the Equator which brings to the surface water that is relatively low in temperature, low in oxygen content, but high in chemical nutrients, and the convergence to the northward which results in a deepening of the thermocline and a possible concentration of the plankton.

Other investigators have found essentially similar correlations between plankton and these environmental factors. Marshall and Orr (1927) observed in the Clyde Sea area that where animal life was rich, phosphates were high, but dissolved oxygen and pH were low. Hardy and Gunther (1935) found in the Pacific that numbers of zooplankton were positively correlated with phosphate values. Jesperson (1935) states that there is a direct relation between quantities of nitrate and phosphate and macroplankton. Leavitt (1938) found in the Atlantic Basin a correlation between temperature, salinity, and density, and the vertical distribution of zooplankton; a negative correlation was found between oxygen and zooplankton. Graham (1941) reports that differences in productivity in the Pacific, as measured by plankton dry weight, are correlated with the concentration of phosphate.

COMPARISON WITH ZOOPLANKTON ABUNDANCE OF OTHER REGIONS

To facilitate the comparison of our data with that of other regions, we have calculated average numbers and volumes (table 11) which are representative of the quantity of zooplankton in different latitudinal zones of the central Pacific. It is a difficult task, however, to reduce to comparable terms plankton data which have been obtained by different investigators, using different methods, at different seasons, and with results expressed in different units. In surveying a considerable fraction of the great bulk of available literature on quantitative plankton sampling, we found only a few reports that have enough in common with our own work to permit a comparison of the results.

In Graham's report (1941) on plankton collected by the *Carnegie* along a series of stations extending from San Francisco to Samoa, he states, "In the open Pacific Ocean from September to November 1929, there was a greater production of total plankton in the tropics between latitudes 20° N. and 11° S. than between latitudes 20° and 34° N." The richest collection of this section (fig. 10) was taken at 13° N. latitude, but was considered atypical since it consisted largely of salps.

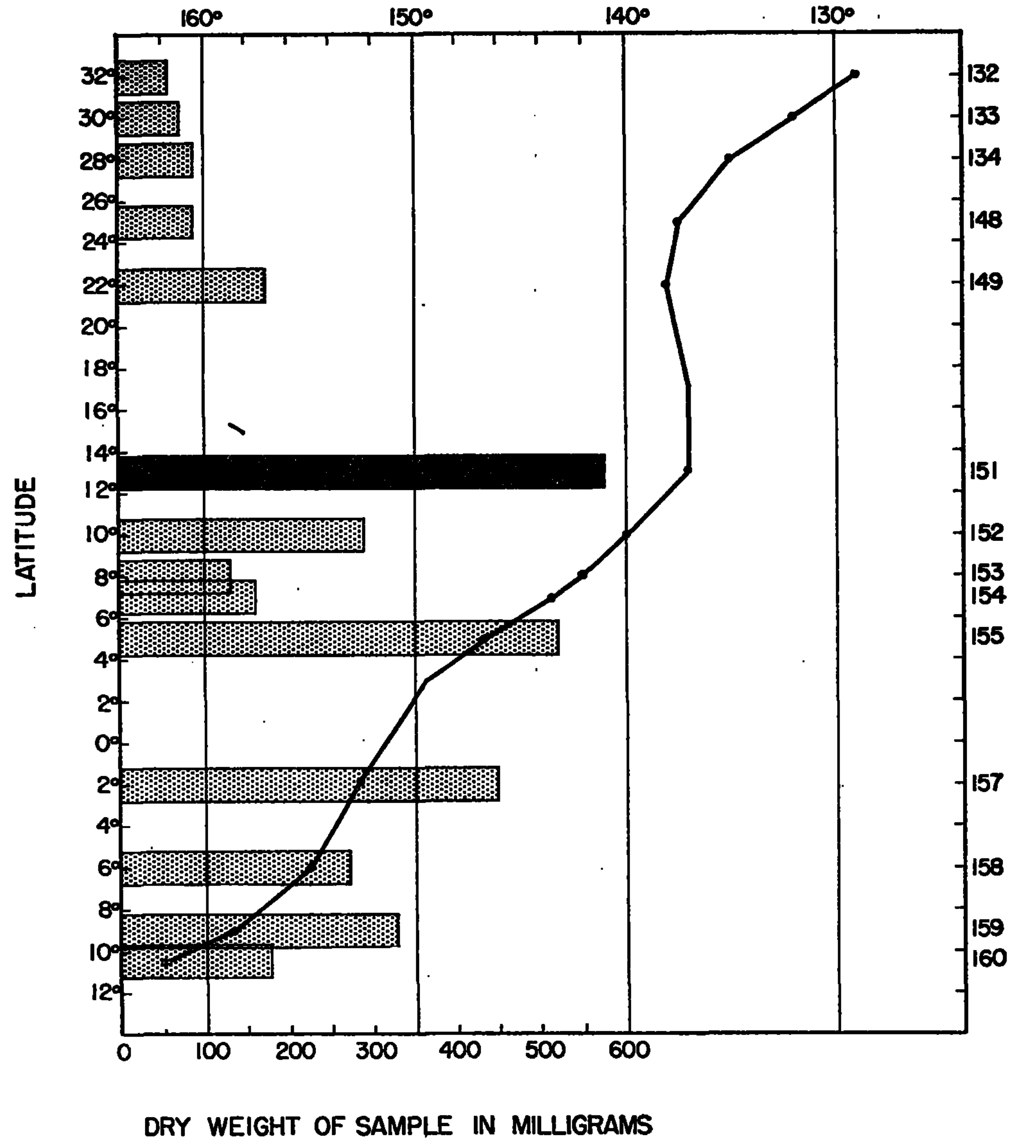


FIGURE 10.—Station positions and zooplankton abundance (as dry weight of sample in milligrams) found on the last cruise of the *Carnegie* in 1929 (data from Graham 1941).

The sample ranking second in dry weight came from 5°30′ N. latitude and the third-ranking sample from 2° S. latitude. These results, while based on a different method of analysis, are in general agreement with our own observations.

The Japanese have carried on extensive plankton investigations in waters adjacent to the Palau Islands and in the area between the Palaus and New Guinea. Results from the studies of Haneda (1942) and Tokioka (1942) are illustrated in figure 11. Although these data are rather limited in scope, the samples of Tokioka show quite definitely the influence of enrichment near the Equator.

These surveys and the work of the *Carnegie* are the only north-south plankton studies that we are aware of in the equatorial Pacific, other than our own. Unfortunately, the absolute values obtained in them cannot be compared with our results, but the generally similar variations with latitude are of interest.

While crossing the Pacific from Panama to the Indo-Pacific region, the *Dana* expedition made plankton tows at frequent intervals. Jesperson

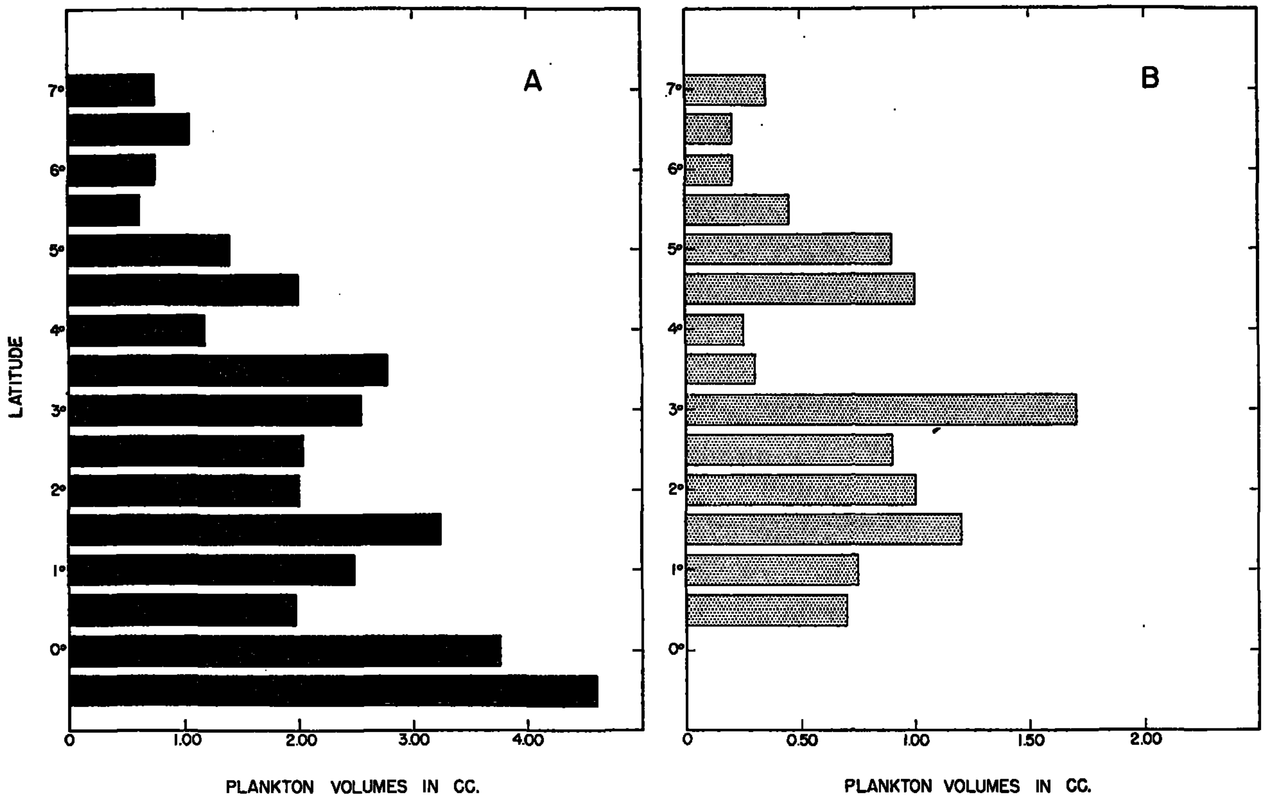


FIGURE 11.—Plankton abundance in the western Pacific: Results given are settlement volumes of total (?) plankton obtained by vertical hauls at 50 to 0 meters along 134° E. longitude. A. As reported by Tokioka (1942) for three cruises, December 1939, March 1940, and May 1940 (averaged by the senior author). B. As reported by Haneda (1942) for one cruise, December 1939.

(1935), summarizes the results as follows (the volumes expressed are catches per 1-hour haul using 1½-meter stramin nets with 50 and 100 meters of wire out):

> A notable fact here is, that we find specially large volumes in the eastern part of the Pacific, from the Bay of Panama to the Marquesas Is., with a distinct maximum (1,125 cc.) at St. 2,55S, which lies west of the Galapagos. On the stretch from the Marquesas to Tahiti we have decreasing quantities of plankton (ca. 150–200 cc.), whilst on the sections from Tahiti—Cook Island (Rarotonga)—Samoa—Fiji the quantities are very small, less than 100 cc. We thus have extremely little macroplankton in this area of the central part of the Pacific, yet a series of stations just north of Samoa yielded somewhat larger quantities (ca. 100–260 cc.). From Fiji to New Caledonia also the quantity of macroplankton increases (ca. 125–210 cc.) and a further increase is shown in the section from New Caledonia down towards Kermadec Islands.

For comparison, in the North Atlantic the expedition obtained volumes ranging from 90 to 7,250 cc. per hour of hauling.

The very extensive plankton data presently being collected by the California Cooperative Sardine Research Program (California, Progress Report 1950, and unpublished data) are quite comparable to our own in most respects. Similar nets have been used by both investigations, and the results are expressed in similar units. Whereas the Sardine Research Program employed an oblique tow to a depth of 70 meters for the collections reported here, our oblique tow descended to 200 meters. This difference in sampling method probably had no great influence on the difference in results obtained. If we consider 22 of their farthest offshore stations, located between 25° N. and 33° N. latitude and visited in September 1950, we find that the average for the group was 0.057 cc./m.^{3}, which is approximately equivalent to our average (table 11) for the South Equatorial Current near the Equator but 3 times the average for the North Equatorial Current. Values for regions of upwelling close in to the California coast were as high as 14.595 cc./m.^{3} in February 1950. This is many times our maximum value of 0.1025 cc./m.^{3} The average of 0.208 cc./m.^{3} for the entire West Coast between 25° N. and 47° N. in April and May 1949, is just about 10 times our mean for the central equatorial Pacific.

Other regions of sparse plankton are found in the Gulf Stream and in the Sargasso Sea of the Atlantic Ocean. These areas apparently have much poorer plankton populations than Atlantic coastal and continental shelf waters (Clarke 1940; Riley 1939b; Riley and Gorgy 1948).

Table 18 is a summary of representative plankton values for various areas of the Atlantic and Pacific Oceans. Part of the variation in these values may be due to differences in mesh size among the nets used by different investigators. The averages for the central Pacific are the poorest of the lot; in fact they are so low that one is inclined to speculate as to how the pelagic fish populations, particularly the relatively large population of tunas, are supported.

TABLE 18.—*Comparison of plankton abundance in various areas of the Atlantic and Pacific Oceans*

[Values given in wet volume, estimated number, or wet weight]

Area	Plankton values	Mesh aperture of net used	Reference
PACIFIC AREA:			
Samoa to the Marshalls via the Equator	0.4 to 0.95 cc./m.^{3}	0.33 mm	Kramer (1906).
Java Sea	Avg.=0.83 cc./m.^{3}	0.33 mm	Delsman (1939).
Open sea, Palau Is.	110 to 530, no./m.^{3}	0.33 mm	Motoda (1940).
Bikini, just outside reef	26.23 to 62.20 no./m.^{3}	0.37 mm	Johnson (1949).
West coast, U. S. (offshore stations)	0.016 to 0.129 cc./m.^{3} Avg.=0.057 cc./m.^{3}	0.65 mm	California prog. rept. (1950).
Central Pacific	5 to 109, no./m.^{3} Avg.=35 0.002 to 0.102 cc./m.^{3} Avg.=0.027 cc./m.^{3}	0.65 mm	This report.
ATLANTIC AREA:			
Baltic Sea	1.9 to 11.0 cc./m.^{3}	0.33 mm	Kramer (1906).
Gulf of Maine (10 to 100 m. depth)	0.12 to 4.30 cc./m.^{3}	1.25 mm., front; 0.8 mm., middle and rear	Bigelow (1926).
North Atlantic (coastal water)	Avg.=0.5 to 0.8 cc./m.^{3}	29.38 meshes/in., front; 48.54 meshes/in., rear	Bigelow and Sears (1939).
Florida Strait	0.02 cc./m.^{3}	0.158 mm	Riley (1939b).
Gulf Stream, off Florida	0.05 cc./m.^{3}		
Gulf Stream, off Georgia	0.07 cc./m.^{3}		
North Atlantic continental slope	4.3 cc./m.^{3}		
North Atlantic, coastal	8.1 cc./m.^{3}		
North Atlantic, coastal	Avg.=0.54 cc./m.^{3} Max.=15.5 cc./m.^{3}	10 strands/cm	Clark (1940).
North Atlantic, offshore	Avg.=0.40 cc./m.^{3} Max.=3.5 cc./m.^{3}		
Sargasso Sea	Avg.=0.045 gm./m.^{3}	0.158 mm	Riley and Gorgy (1948).
Gulf Stream	1 sta.=0.137 gm./m.^{3}		
Slope water	2 sta.=0.14 and 1.6 gm./m.^{3}		

PRODUCTIVITY

The practical application of most plankton research is to provide data for estimating and comparing the productivity, or available food, in various areas of the sea. It has been strongly emphasized in more recent plankton literature that the "standing crop" does not give a true measure of the rate of production. Harvey (1934) and Harvey et al. (1935) have shown that the size of the standing crop of phytoplankton is greatly affected by the grazing of animal herbivores and therefore at any one time is merely a momentary balance between the processes of production and consumption. In the tropics, steady grazing by predators may keep the zooplankton at a lower level of abundance than in higher latitudes where seasonal features of the environment allow the plankton to "pulse" or bloom and thus increase much faster than the predators. The apparently low standing crop may be considerably counterbalanced by a high rate of turnover and nearly uniform production throughout the year.

It is generally assumed that in water masses where the annual plant production is great the density of the animal population will also be great. This assumption is roughly borne out by general observations (Harvey 1945). Delsman (1939) has stated, "Where no rich plankton can develop, no rich macrofauna, no abundant fish population can either be expected." In the same vein, "The dependence of various elements of the food chain on a preceding one, conditions the distribution of the larger forms" (Hesse, Allee, and Schmidt 1951). Also, it is reasonable to believe that the zooplankton population will be the maximum that the plant crop can support. Local situations may not conform to this generality, but when large areas are considered, there is usually found a direct relation between concentrations of phytoplankton and zooplankton (Riley and Bumpus 1946). In conducting a fish-farming experiment, Raymont (1947) found that in both enclosed and unenclosed small sea areas the addition of a nitrate and phosphate fertilizer stimulated phytoplankton growth, which in turn maintained a high density of zooplankton which promoted a rapid growth of flatfish.

From tuna-catch records and observations on occurrence of surface schools, the Pacific Oceanic Fishery Investigations is accumulating evidence on the distribution of tunas which indicates quite definitely that areas of the greatest zooplankton abundance in the central Pacific are also areas of greatest tuna abundance.

We are fully aware that the data we have presented on the variation of zooplankton abundance with latitude does not in any way reflect the "rate of turnover," the most difficult element to determine in estimates of productivity. In this area of the tropical Pacific, with temperatures very uniform in time and space and zooplankton very uniform in composition, the rate of turnover should not be a disturbing feature in the comparison of the several parts of our area, i. e., for our data standing crop should be proportional to productivity.

SUMMARY AND CONCLUSIONS

1. This report presents the results of 210 quantitative zooplankton collections made in the central Pacific in 1950 and 1951, between 27° N. and 14° S. latitude, and 155° and 175° W. longitude.

2. Most of the collections were obtained by oblique hauls to 200 meters' depth, employing 1-meter nets of 30xxx grit gauze with aperture widths of 0.65 mm.

3. A method of sampling was developed that harmonized with hydrographic and fishing operations, required little of ship's time, and involved no particularly elaborate treatment of samples in the laboratory.

4. The zooplankton taken by our collecting method was composed on the average by number, of 57 percent Copepoda, with the other chief components ranking as follows: Chaetognatha, 12 percent; Tunicata, 6 percent; Euphausiacea, 5 percent; Siphonophora, 4 percent; and Foraminifera, 4 percent.

5. The composition of the collections was remarkably uniform when longitudes and cruises were compared.

6. Despite the use of oblique tows to 200 meters' depth, we found significant differences between day hauls and night hauls.

7. Since distinctly larger catches were obtained on the "summer" cruise (cruise 5) than on the "winter" cruise (cruise 8), a seasonal difference in zooplankton abundance is indicated.

8. Within the range of latitudes sampled, the greatest abundance, both by number and volume, of zooplankton occurred in the region of the Equator; sometimes the greatest concentrations were found north of the Equator, when related to a convergence, and to the south when no marked convergence existed.

9. The abundance of zooplankton is correlated with such chemical and physical environmental factors as inorganic phosphate, water temperature, dissolved oxygen, and thermocline depth, which are influenced by the upwelling resulting from the equatorial divergence.

10. Upwelling along the Equator replenishes the supply of nutrients in the euphotic zone, thus providing a favorable environment for the growth of phytoplankton. Since animal life fluctuates with its food supply, conditions in this region are favorable for the development of a zooplankton population.

11. While our observations on the standing crop of zooplankton do not give a measure of the rate of production in its strict sense, we believe that they do provide a useful index to the relative productivity of different areas of the central Pacific.

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