MICRONEKTON OF THE EASTERN TROPICAL PACIFIC OCEAN: FAMILY COMPOSITION, DISTRIBUTION, ABUNDANCE, AND RELATIONS TO TUNA [1] [2]

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ABSTRACT

The taxonomic composition and distribution of micronekton (fishes, crustaceans, and cephalopods about 1 to 10 cm. in largest dimension) were studied from catches of night net hauls in the upper 90 m. in most parts of the eastern tropical Pacific Ocean. One type of haul (net 1.5 m. square at mouth, uniform mesh size throughout, hauled obliquely at ship speed of 5 knots) contributed most of the data and is considered to be superior to any other existing type of haul with a net or trawl of comparable size for quantitative work on micronekton.

Ten families (Myctophidae, Gonostomatidae, Galatheidae, Euphausiidae, Penaeidae, Squillidae, Portunidae, Sergestidae, Enoploteuthidae, and Cranchiidae) and one suborder (Apodes: leptocephali) contributed 93.4 percent of the volume of the total catch. Some of these groups are localized, and others are widely distributed geographically; abundance varies according to the distribution of physical phenomena which are responsible for eutrophic conditions. Agreement in family composition was poor for fishes between the net catches and the stomach contents of yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Euthynnus pelamis*) from the same areas; agreement between catches and stomach samples was fair for crustaceans. The reasons for the differences are discussed. The commonly held opinion, that tunas are opportunistic feeders, within their sensory limitations, remains tenable.

To the extent that the net hauls sample kinds of micronekton which are important as food for tunas, they can be used to compare quantities of tuna prey in different areas. This comparison shows that the richest tuna forage is off western Baja California and that an area west of Ecuador and northern Peru with practically no surface fishing probably has about as much forage as some areas which support commercial surface fishing.

Comprehensive biological-oceanographic investigations in the eastern tropical Pacific Ocean began with expeditions Eastropic (1955) and Scope (1956). Much attention was given on these expeditions to distributions of primary productivity, standing crop of chlorophyll *a*, and standing crop of zooplankton (Holmes, Schaefer, and Shimada, 1957; Holmes and others, 1958); these observations were intended to contribute to the understanding of the ecology of the tunas of the region and to oceanographic knowledge. Much of this work was done by the Scripps Institution of Oceanography, University of California. In 1957 the Institution's work in this field was put on a continuing basis in the STOR Program, with support from the Bureau of Commercial Fisheries. As a result, several more cruises were made in the eastern tropical Pacific, which differed from Eastropic and Scope in that measurements of an additional biological property, namely standing crop of micronekton, were made routinely.

Micronekton, a term occasionally found in marine biological literature (e.g., Marshall, 1954), is here defined as the assemblage of actively swimming fishes, crustaceans, and cephalopods, ranging from about 1 cm. to 10 cm. in greatest dimension. In this paper it means all fishes, crustaceans, and cephalopods caught by a net designed to sample

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Some preliminary results of this research were given in a symposium at the Tenth Pacific Science Congress of the Pacific Science Association, held at the University of Hawaii in August and September 1961. The symposium was entitled "Factors affecting the behavior of predaceous marine fishes, especially sharks."

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the animals mentioned above. The catches included some animals smaller than 1 cm. or larger than 10 cm., but they probably contributed less than 5 percent of the total volume. Micronekton and zooplankton overlap in catches in plankton nets—for instance, euphausiids occur in both.

The reasons for measuring the standing crop of micronekton and each of its main components were as follows:

(1) Because tunas feed on micronekton, a knowledge of its distribution might help to explain the variable distribution of tunas in the eastern tropical Pacific.

(2) Comparisons of net-caught and tuna-caught micronekton (the latter from tuna stomachs) might be of value in the study of feeding behavior of tunas, especially in the matter of possible selection of organisms.

(3) Food-chain relations in the ocean have had much physiological and statistical study between the producer and herbivore trophic levels, but comparatively little study has been made between those levels and the carnivore levels. This deficiency seems to reflect a shortage of data on standing crops of oceanic carnivores, especially primary carnivores such as small fish and cephalopods which are eaten by secondary carnivores; where such data are available, they generally refer to a few species for which there are commercial fisheries (e.g., herring, *Clupea harengus*). Because good programs of measurement of phytoplankton and zooplankton were already operating in the eastern tropical Pacific, it seemed worthwhile to measure micronekton as well.

This paper presents a summary of most of the micronekton data obtained before 1964 in the eastern tropical Pacific and analyzes them in reference to distribution and relation to contents of stomachs of tuna. Statistical analysis in reference to food-chain relations has been made, in part, elsewhere (Blackburn, 1966a).

MATERIAL AND METHODS

The net-caught micronekton obtained in the eastern tropical Pacific and adjacent waters was taken in the following three ways:

(1) In standard (identically made) night hauls of a net called the 1.5-m. (or 5-foot) net (described below), at a ship speed of 5 knots.

(2) In nonstandard night or day hauls of the same net.

(3) In hauls of a net called the high-speed net, described below, made at the ordinary cruising speed of the vessel (which ranged from about 9 to 12 knots, for the different vessels used).

The most useful quantitative data are those from standard night hauls, and this paper is concerned almost entirely with them. They were obtained on the following cruises: TO-58-1 (or SCOT), April–June 1958; TO-59-1, January–February 1959; TO-59-2, August–September 1959; TO-60-1; May 1960; TO-60-2 (or STEP-1), September–December 1960; and TO-61-1, March–April 1961 (see figs. 1 and 2 for areas covered). The total number of standard night hauls from all these cruises was 131 (see table 1). In addition, brief mention is made of 38 standard hauls (19 night, 19 day) made on cruise TO-62-1 (or TEMPO), August 1962, off Acapulco, Mexico. The hauls in this series (see table 2) are separated from the main data because they were made close together in space and time; they were not comparable with the other 131 hauls which were much more widely distributed in space and time in the eastern tropical Pacific.

Nonstandard hauls, occasionally made by day or night, are not discussed. The high-speed hauling method, and some data from it, are briefly described and evaluated.

1.5-M. NET: DESCRIPTION, OPERATION, AND PERFORMANCE

Figure 3 shows the 1.5-m. net. It is in the form of an elongated pyramid; the base (the mouth of the net) is 1.5 m. square, and the measurement from the center of the base to the apex is 5.8 m. The base or mouth is surrounded by a narrow selvage laced to a square frame of galvanized iron, to which the towing bridles and depressors are attached. The apex is open and the opening contains a brass fitting set in canvas, by which a cod end (not included in the 5.8-m. length) can be attached. The material and mesh of the net (excluding selvage and cod end) are uniform throughout: Marion Textiles 467-pattern nylon netting,[3] with meshes approximately oblong and measuring about 5.5 mm. by 2.5 mm. The long

[3] Mention of manufacturer does not imply endorsement of the product.

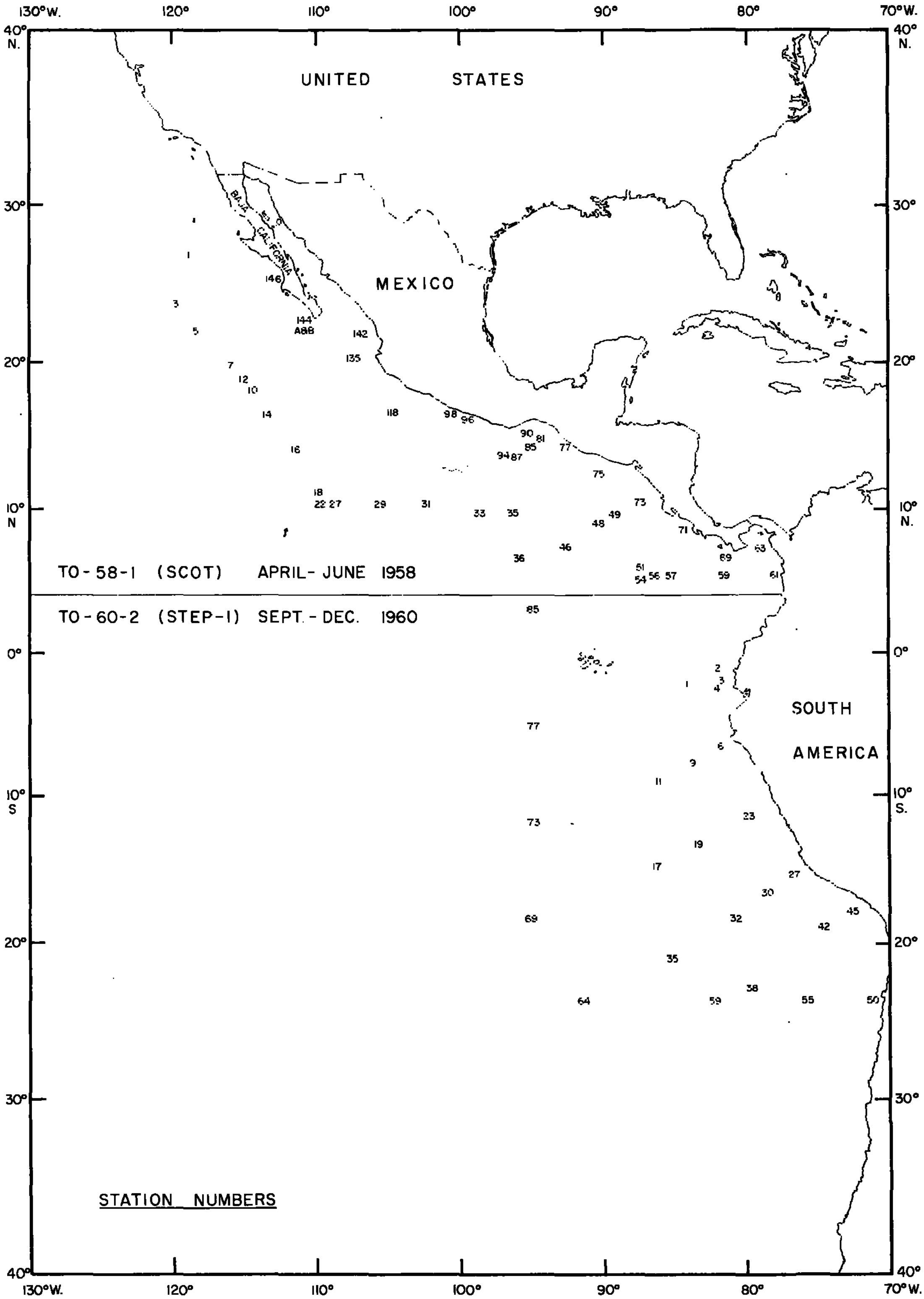

FIGURE 1.—Serial numbers and positions of stations at which standard night micronekton hauls were made on cruises TO-58-1 and TO-60-2.

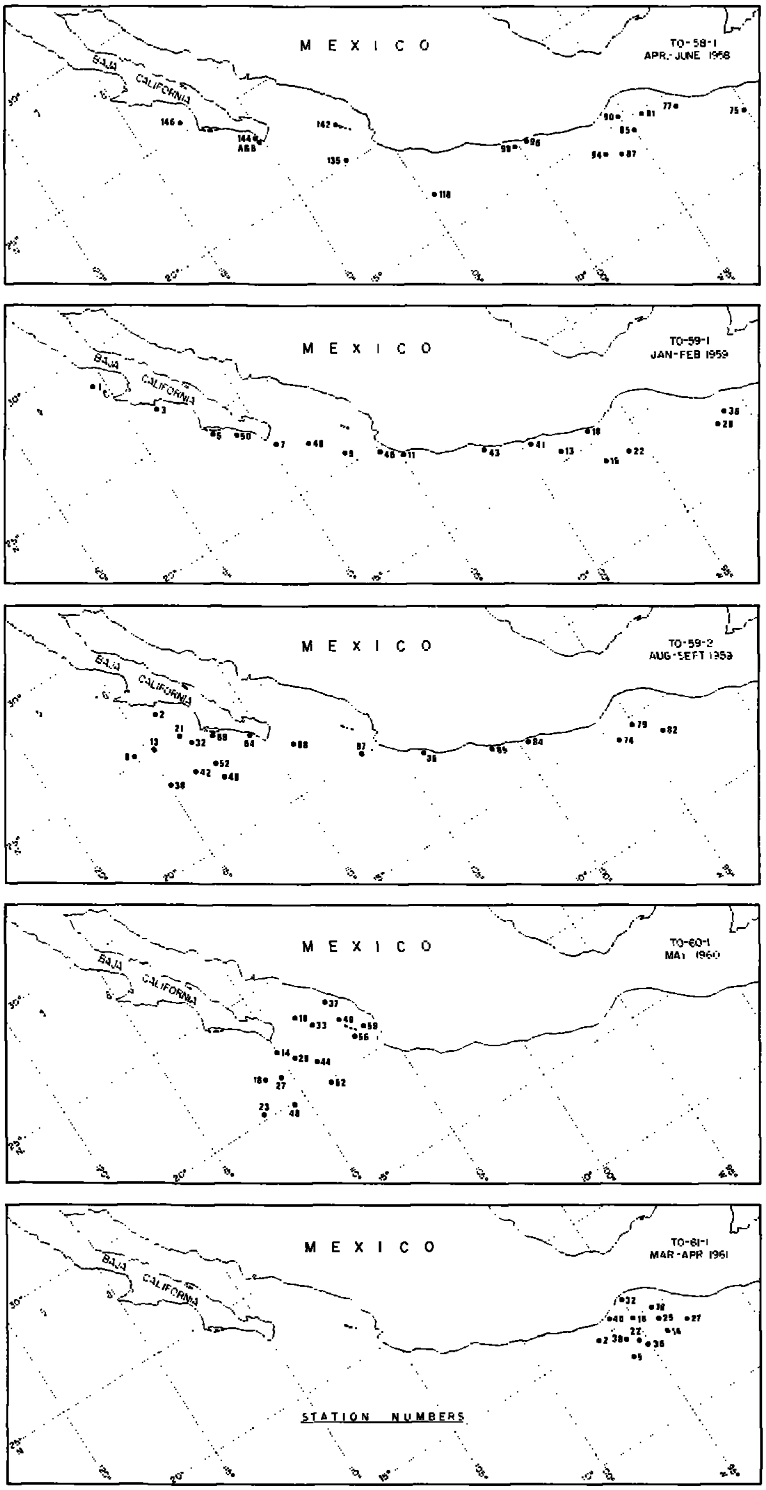

FIGURE 2.—Serial numbers and positions of stations at which standard night micronekton hauls were made in waters adjacent to Mexico and Guatemala, on cruises prior to 1962.

TABLE 1.—*Actual volumes and standardized volumes for fishes, crustaceans, cephalopods, and total micronekton from 131 standard night hauls of a 1.5–m. net*

[Asterisk means that the station did not fall within the area stated, but has been included in it]

Station [1] number	Date	Area [2]	Time [3]	Depth [4]	Actual volumes				Standardized volumes			
					Fishes	Crusta-ceans	Cepha-lopods	Total	Fishes	Crusta-ceans	Cepha-lopods	Total
A. Cruise TO-58-1 (SCOT): April-June 1958												
		Number	*Minutes*	*M.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml./10³m.³*	*Ml./10³m.³*	*Ml./10³m.³*	*Ml./10³m.³*
1	Apr. 25	15	65	----------	26	67	3	96	1.5	3.8	0.2	5.5
3	26	15	65	----------	44	104	<1	148	2.5	5.9	<.1	8.4
5	27	15	64	----------	17	35		52	1.0	2.0		3.0
7	28	*02	64	----------	55	28	----------	83	3.2	1.6	----------	4.8
10	28	02	65	----------	47	13	<1	60	2.7	.7	<.1	3.4
12	29	02	75	----------	2	471	----------	473	.1	23.2	----------	23.3
14	30	02	64	----------	109	5	3	117	6.3	.3	.2	6.8
16	May 1	*02	72	----------	45	4	3	52	2.3	.2	.2	2.7
18	2	*09	65	----------	18	13	2	33	1.0	.7	.1	1.8
22	2	09	65	----------	1	9	2	12	.1	.5	.1	.7
27	3	09	65	----------	14	10	2	26	.8	.6	.1	1.5
29	5	16	64	----------	64	10	9	83	3.7	.6	.5	4.8
31	6	16	64	----------	63	18	8	89	3.6	1.0	.5	5.1
33	7	16	65	----------	131	63	10	204	7.4	3.6	.6	11.6
35	8	16	65	----------	57	44	9	110	3.2	2.5	.5	6.2
36	9	16	64	----------	147	56	19	222	8.5	3.2	1.1	12.8
46	12	16	64	----------	152	69	7	228	8.8	4.0	.4	13.2
48	13	05	63	----------	189	70	43	302	11.1	4.1	2.5	17.7
49	13	05	64	----------	189	62	130	381	10.9	3.6	7.5	22.0
51	15	11	69	----------	59	52	11	122	3.1	2.8	.6	6.5
54	15	11	65	----------	87	58	3	148	4.9	3.3	.2	8.4
56	16	11	64	----------	93	82	15	190	5.4	4.7	.9	11.0
57	17	11	63	----------	60	58	9	127	3.5	3.4	.5	7.4
59	18	12	62	----------	106	126	19	271	6.3	8.7	1.2	16.2
61	19	10	65	----------	91	143	7	241	5.2	8.1	.4	13.7
63	20	10	67	----------	398	113	72	583	22.0	6.2	4.0	32.2
69	24	*12	64	90	147	113	20	280	8.5	6.5	1.2	16.2
71	25	05	66	105	110	68	21	199	6.2	3.8	1.2	11.2
73	26	05	64	80	183	68	95	346	10.6	3.9	5.5	20.0
75	27	05	63	83	196	111	62	369	11.5	6.5	3.7	21.7
77	28	04	60	100	319	58	90	467	19.7	3.6	5.5	28.8
81	29	04	71	----------	533	72	124	729	27.8	3.7	6.5	38.0
85	30	04	66	110	168	88	88	344	9.4	4.9	4.9	19.2
87	30	04	68	----------	109	28	18	155	5.9	1.5	1.0	8.4
90	31	04	66	72	150	17	62	229	8.4	.9	3.5	12.8
94	June 1	04	65	72	147	11	20	178	8.4	.6	1.1	10.1
96	2	04	65	115	221	36	10	267	12.6	2.0	.6	15.2
98	6	04	65	100	248	23	30	301	14.1	1.3	1.7	17.1
118	11	04	64	83	211	18	19	248	12.2	1.0	1.1	14.3
135	14	03	65	72	201	31	41	273	11.4	1.8	2.3	15.5
142	16	03	64	----------	329	62	35	426	19.0	3.6	2.0	24.6
144A	17	01	65	----------	266	67	6	339	15.2	3.8	.3	19.3
144B	17	01	65	----------	206	1,605	3	1,814	11.7	91.3	.2	103.2
146	18	01	63	----------	7	1,924	<1	1,931	.4	112.9	<.1	113.3
B. Cruise TO-59-1: January-February 1959												
1	Jan. 17	01	48	99	161	379	----------	540	12.4	29.2	----------	41.6
3	17	01	47	90	----------	102	----------	102	----------	8.0	----------	8.0
5	18	01	40	81	<1	358	<1	358	<.1	33.1	<.1	33.1
7	20	03	48	86	150	11	1	162	11.6	.8	.1	12.5
9	21	03	49	88	73	12	9	94	5.5	.9	.7	7.1
11	22	03	44	90	93	6	8	107	7.8	.5	.7	9.0
13	26	04	50	75	97	90	8	195	7.2	6.6	.6	14.4
15	27	04	53	80	125	66	8	199	8.7	4.6	.6	13.9
18	28	04	40	77	97	258	17	372	9.0	23.8	1.6	34.4
22	30	04	34	92	60	79	<1	139	6.5	8.6	<.1	15.1
28	Feb. 8	05	47	78	120	54	29	203	9.4	4.3	2.3	16.0
36	14	05	49	82	90	53	61	204	6.8	4.0	4.6	15.4
41	16	04	48	81	50	269	19	338	3.9	20.7	1.5	26.1
43	17	04	45	79	101	39	20	160	8.3	3.2	1.6	13.1
46	20	03	52	73	68	15	16	99	4.8	1.1	1.1	7.0
48	20	03	46	83	66	22	11	99	5.3	1.8	.9	8.0
50	21	01	50	94	20	807	----------	827	1.5	59.7	----------	61.2

See footuotes at end of table.

TABLE 1.—*Actual volumes and standardized volumes for fishes, crustaceans, cephalopods, and total micronekton from 131 standard night hauls of a 1.5–m. net*—Continued

Station [1] number	Date	Area [2]	Time [3]	Depth [4]	Actual volumes				Standardized volumes			
					Fishes	Crustaceans	Cephalopods	Total	Fishes	Crustaceans	Cephalopods	Total
C. Cruise TO-59-2: August-September 1959												
2	Aug. 15	01	52	----------	60	1,187	----------	1,247	4.3	84.5	----------	88.8
8	16	*01	48	----------	60	2,262	<1	2,322	4.6	174.4	<.1	179.0
13	17	01	49	115	18	779	----------	797	1.4	58.8	----------	60.2
21	19	01	49	85	42	907	1	950	3.1	68.5	.1	71.7
32	22	01	36	84	306	2,500	<1	2,806	31.5	257.0	<.1	288.5
38	24	01	44	82	92	637	3	732	7.7	53.6	.3	61.6
42	24	01	43	80	59	1,585	----------	1,644	5.1	136.3	----------	141.4
52	26	01	49	99	81	1,552	<1	1,633	6.1	117.2	<.1	123.3
58	27	01	46	93	149	530	9	688	12.0	42.6	.7	55.3
64	28	01	58	85	3	19	5	27	.2	1.2	.3	1.7
74	Sept. 8	04	44	85	85	11	10	106	7.2	.9	.8	8.9
79	10	04	46	81	100	18	19	137	8.1	1.4	1.5	11.0
82	11	05	49	91	81	37	25	143	6.1	2.8	1.9	10.8
84	13	04	47	90	267	82	16	365	21.0	6.4	1.3	28.7
85	15	04	51	84	203	34	14	251	14.7	2.5	1.0	18.2
86	16	03	49	91	98	8	39	145	7.4	.6	2.9	10.9
87	17	03	42	77	44	14	6	64	3.9	1.2	.5	5.6
88	18	03	48	80	122	250	8	380	9.4	19.3	.6	29.3
89	19	01	42	89	1	13	2	16	.1	1.1	.2	1.4
D. Cruise TO-60-1: May 1960												
10	May 6	08	52	160	26	110	----------	136	1.9	7.8	----------	9.7
14	7	03	36	150	7	5	<1	12	.7	.5	<.1	1.2
18	8	01	30	145	9	72	----------	81	1.1	8.9	----------	10.0
23	9	01	35	91	21	6	----------	27	2.2	.6	----------	2.8
27	10	01	25	114	34	56	<1	90	5.0	8.3	<.1	13.3
29	11	03	39	93	9	5	----------	14	.8	.5	----------	1.3
33	12	03	45	91	67	11	----------	78	5.5	.9	----------	6.4
37	13	08	44	122	338	14	11	363	28.4	1.2	.9	30.5
40	15	03	44	95	70	32	----------	102	5.9	2.7	----------	8.6
44	16	03	45	114	40	26	9	75	3.3	2.1	.7	6.1
48	17	02	43	109	29	10	3	42	2.5	.9	.2	3.6
52	18	03	43	110	77	8	2	87	6.6	.7	.2	7.5
56	19	03	37	120	14	9	----------	23	1.4	.9	----------	2.3
59	20	03	43	150	60	1,532	4	1,596	5.2	131.8	.3	137.3
E. Cruise TO-60-2 (STEP-1): September-December 1960												
1	Sept. 27	17	36	----------	29	20	2	51	3.0	2.0	.2	5.2
2	30	06	52	----------	148	34	11	193	10.5	2.4	.8	13.7
3	Oct. 1	06	62	----------	126	53	8	187	7.5	3.2	.5	11.2
4	2	06	53	----------	151	29	3	183	10.5	2.0	.2	12.7
6	8	06	50	----------	166	449	2	617	12.3	33.2	.1	45.6
9	10	*06	45	----------	113	50	22	185	9.3	4.1	1.8	15.2
11	11	11	48	----------	83	15	3	101	6.4	1.2	.2	7.8
17	15	17	51	----------	26	27	6	59	1.9	2.0	.4	4.3
19	16	17	51	----------	52	11	8	71	3.7	.8	.6	5.1
23	17	17	49	----------	94	40	4	138	7.1	3.0	.3	10.4
27	29	14	52	----------	19	124	1	144	1.4	8.8	.1	10.3
30	30	*14	47	----------	28	55	<1	83	2.2	4.3	<.1	6.5
32	31	18	51	----------	20	4	3	27	1.5	.3	.2	2.0
35	Nov. 1	18	51	----------	6	21	2	29	.4	1.5	.2	2.1
38	3	18	57	----------	10	60	4	74	.6	3.9	.3	4.8
42	5	14	49	----------	29	3	7	39	2.2	.2	.5	2.9
45	7	14	52	----------	86	16	28	130	6.1	1.1	2.0	9.2
50	18	18	54	----------	56	34	<1	90	3.8	2.3	<.1	6.1
55	19	18	49	----------	26	170	<1	196	2.0	12.8	<.1	14.8
59	22	18	50	----------	37	19	----------	56	2.7	1.4	----------	4.1
64	24	18	49	----------	16	1	2	19	1.2	.1	.1	1.4
69	27	18	45	----------	17	13	2	32	1.4	1.1	.1	2.6
73	29	17	49	----------	64	2	<1	66	4.8	.2	<.1	5.0
77	Dec. 2	17	49	----------	78	7	3	88	5.9	.5	.2	6.6
85	4	16	49	----------	68	11	8	87	5.1	.8	.6	6.5

See footnotes at end of table.

TABLE 1.—*Actual volumes and standardized volumes for fishes, crustaceans, cephalopods, and total micronekton from 131 standard night hauls of a 1.5-m. net*—Continued

Station [1] number	Date	Area [2]	Time [3]	Depth [4]	Actual volumes				Standardized volumes			
					Fishes	Crusta-ceans	Cepha-lopods	Total	Fishes	Crusta-ceans	Cepha-lopods	Total
F. Cruise TO-61-1: March-April 1961												
2	Mar. 17	04	53	----------	83	30	8	121	5.8	2.1	.5	8.4
5	19	04	50	----------	177	59	96	332	13.1	4.4	7.1	24.6
14	22	05	51	----------	142	48	32	222	10.3	3.5	2.3	16.1
16	23	04	50	----------	94	432	5	531	6.9	32.0	.4	39.3
18	24	04	49	----------	116	50	22	188	8.7	3.8	1.7	14.2
22	29	04	49	----------	138	20	40	198	10.4	1.5	3.0	14.9
27	Apr. 1	05	49	----------	43	43	15	101	3.2	3.2	1.2	7.6
29	2	04	51	----------	69	55	26	150	5.0	4.0	1.9	10.9
32	3	04	49	----------	84	32	4	120	6.3	2.4	.3	9.0
36	4	04	49	----------	81	30	54	165	6.1	2.3	4.1	12.5
38	6	04	49	----------	87	22	18	127	6.6	1.7	1.3	9.6
40	7	04	49	----------	36	7	36	79	2.7	.5	2.7	5.9
Total, all cruises					12,756	25,240	2,008	40,004				

[1] See figure 1 for location of stations.
[2] See figure 5 for location of areas.
[3] Duration of haul.
[4] Maximum depth of haul measured by bathythermograph.

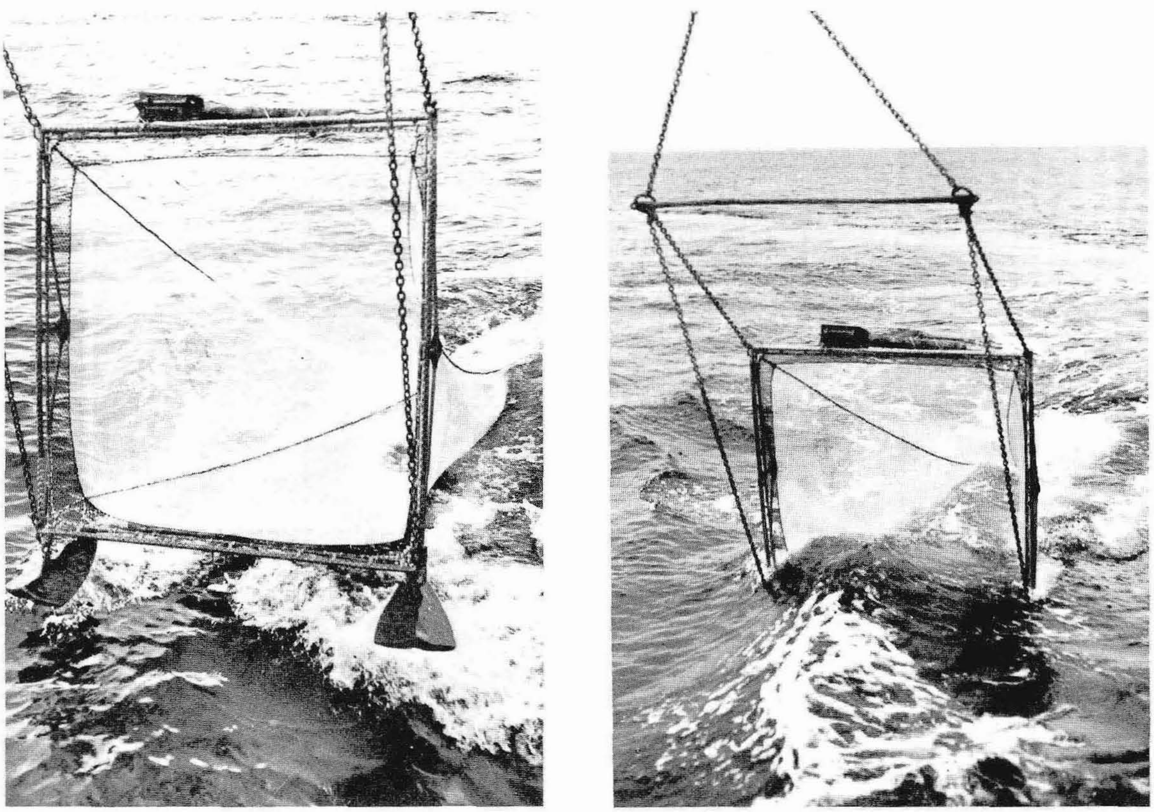

FIGURE 3.—Views of the 1.5-m. net, showing attachment of towing bridles, depressors, and bathythermograph (along upper side of square frame).

axis of the mesh is parallel to the long axis of the net. The ratio of total filtering area to area of mouth aperture (area of nylon thread included in the filtering area) is about 7.6:1. The detachable cod end is made of 56XXX nylon or silk grit gauze, with mesh apertures 0.31 mm. wide; the choice of this material was dictated purely by convenience (the same type of cod end was routinely used on the same cruises for collecting zooplankton). A larger mesh might have served equally well. Lengths of 6-mm. galvanized-iron welded-link chain are attached at one end to the four corners of the square frame and at the other end (in pairs, right side and left side) to the ends of a 1.5-m. galvanized-iron bar of 25-mm. diameter. Two similar chain bridles from the ends of the bar are attached to a swivel at the end of the 10-mm. towing wire rope. The arrangement and approximate lengths of the chain bridles are shown in figure 3. One sinker was attached to each bottom corner of the square frame; two 45-kg. cylindrical iron weights were used during cruise TO-58-1, but these were replaced by two 20-kg. bronze streamlined depressors during the other cruises.

When the 45-kg. weights were used, the hauling operation was as follows: 450 m. of the 10-mm. wire rope were paid out at 25 m./min. and then immediately retrieved at 10 m./min., all at a ship speed of 5 knots. The haul, thus, took about 63 min. (in practice there was some variation from the desired winching speeds—see table 1). It was found, by attaching a bathythermograph to the frame of the net, that the maximum depth ranged from 72 to 115 m. and averaged 90.2 m. (12 hauls). When the 20-kg. depressors were used, 350 m. of wire were paid out and retrieved at the same winch and ship speeds, for a total hauling time of about 49 min.; the maximum depth ranged from 73 to 160 m. and averaged 95.5 m. (48 hauls). Because the difference between the means is small, the two types of operation have been considered comparable except for the time; the second type has been continued routinely, and the catches from both types of hauls have been considered to represent broadly the quantity and quality of micronekton present at night that can be caught by the net in the upper 90 to 95 m. of ocean. The actual depths, where obtained by bathythermograph, are listed in table 1. The depressors were, as expected, more effective in sinking the net than the much heavier cylindrical weights. A sampling depth of 90 to 95 m. would be expected with the Isaacs-Kidd midwater trawl also, if used on 350 m. of cable at a towing speed of 5 knots, according to tests made by Aron, Ahlstrom, Bary, Bé, and Clarke (1965).

No attempt was made to use a flowmeter in the net routinely, because it was thought that it might prevent the entry of some of the micronekton. Flowmeters were used twice to estimate the filtration coefficient of the net by making successive tows in a precisely identical manner, and of precisely the same duration, first with a flowmeter in the mouth of a fully rigged net, and then with the net removed and only flowmeter, frame, bridles, and depressors remaining. The ratio of flowmeter readings was 0.757 on the first trial and 0.738 on the second trial (3 years later). The net, used as described, apparently filters 74 to 76 percent of the water available (product of net-mouth area in square meters and distance towed in meters). Because the two estimates of the filtration coefficient are so close, the one first obtained, which had already been used to calculate volume of water strained on many of the hauls, was used for all. Water was available for filtration at the rate of 1,000 m.^{3} every 2.79 min. at a speed of 5 knots; the rate of actual filtration was estimated by the coefficient 0.757 to be 1,000 m.^{3} every 3.69 min. By dividing the measured volume by the total number of minutes for the haul and multiplying by 3.7, the micronekton was standardized to volume per 1,000 m.^{3} of water strained (see table 1).

The most important feature of this net is the mesh size, which retains most of the micronekton and releases most of the zooplankton, and, more importantly, is uniform throughout the net. This uniformity gives the standardized volumes a much more precise biological meaning than would be possible for similar measurements with a mixed-mesh net; some parts of a mixed-mesh net permit more escapement of organisms than other parts. Aron (1959, 1962a, 1962b) admitted this problem in relation to the Isaacs-Kidd midwater trawl, which has larger meshes near the mouth than near the cod end (as do most other nets and trawls hitherto used for catching micronekton and zooplankton). King and Iversen (1962), who used the Isaacs-Kidd and other trawls, observed that

"The nature of the trawling gear * * * did not permit or justify an exact quantitative evaluation of the catch." The Isaacs-Kidd and similar mixed-mesh midwater trawls seem to be much more useful for qualitative than for quantitative sampling. Pearcy and Laurs (1966) used an Isaacs-Kidd trawl lined with material of uniform small mesh size (5 mm. square).

The main difficulty with the 1.5–m. net is that some organisms, presumably the larger and more mobile ones—e.g., flying fish (Exocoetidae)—probably avoid the net or escape through the mouth after entry; doubtless similar escapement also occurs from the Isaacs-Kidd trawl and others of similar size. Apart from such unknown losses, standardized volumes from the 1.5–m. net estimate real concentrations of micronekton in the water.

The 1.5–m. net has proved to be easy to operate; it can be fished by two men, plus a winchman, except in rough weather or heavy swells, when it is prudent to employ a third man. Specimens caught generally are in good condition.

The standard 1.5–m. net hauls were made at night—usually about midnight—because most kinds of micronekton are more readily caught in near-surface waters by night than by day (Aron, 1959, 1962a; King and Iversen, 1962; Pearcy, 1964; and table 2 of this paper). It would be necessary to lower the net to greater depths, at appreciably greater cost in ship time, to obtain similar samples in the daytime. Pearcy (1964) found no obvious difference in numbers of mesopelagic fishes caught with the Isaacs-Kidd midwater trawl at different times of night at the same station, and I assume that time of night is equally unimportant for the other animals sampled.

HIGH-SPEED NET: DESCRIPTION, OPERATION, AND PERFORMANCE

The high-speed net is an elongated cone with a base (the mouth of the net) 70 cm. in diameter and measures 2.6 m. from the center of the base to the apex (fig. 4). The base or mouth is surrounded by a narrow selvage laced to a circular frame of galvanized iron. The opening at the apex

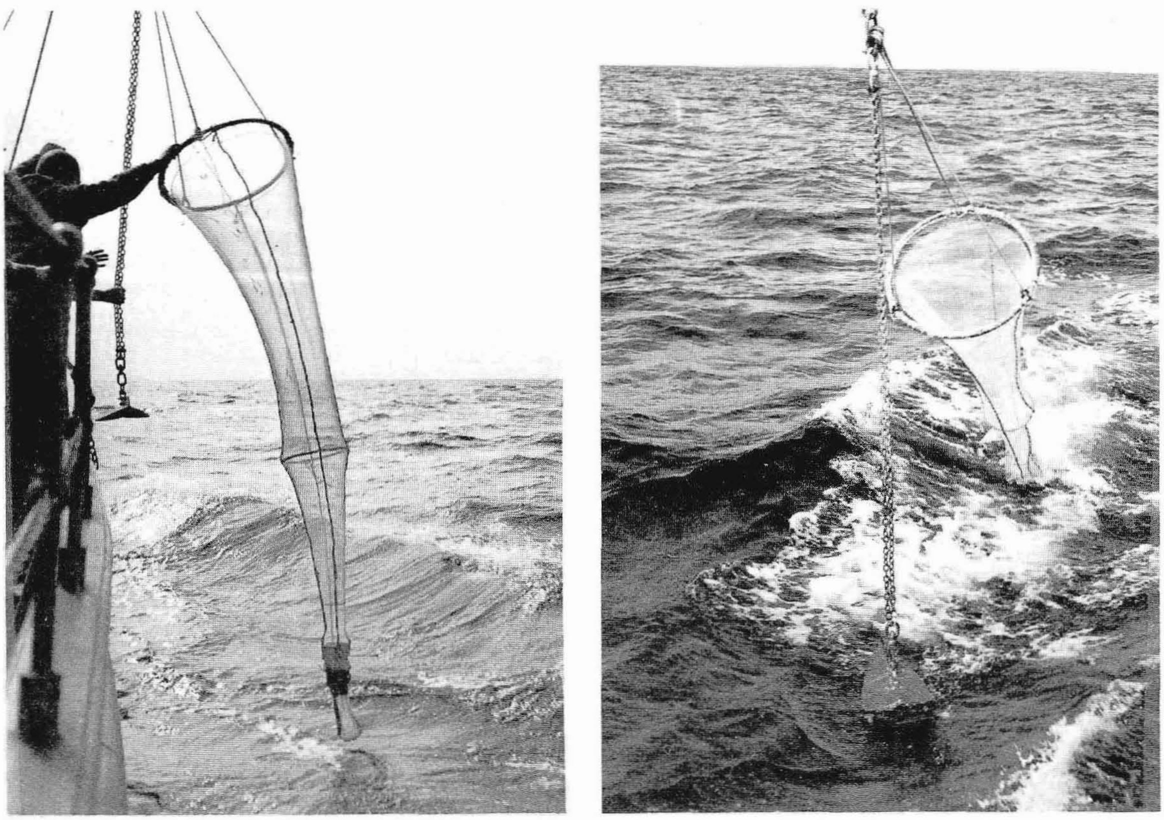

FIGURE 4.—Views of the high-speed net, showing attachment of towing bridles and depressor.

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contains a brass fitting set in canvas, by which a cod end (the same cod end as for the 1.5–m. net; length not included in the 2.6–m. length of net) can be attached. The material and mesh of the net are the same as for the 1.5–m. net and uniform throughout. The ratio, total filtering area to mouth-aperture area (area of nylon thread included in the filtering area), is about 7.5 :1. Three plastic cord bridles extend from the circular frame to the swivel at the end of the towing wire (the same as for the 1.5–m. net).; one 20–kg. bronze streamlined depressor is also attached to this swivel on a 2.4–m. length of 6–mm. welded-link chain so that it is below the net when both are in the water.

This net has been used only for horizontal hauls at cruising speeds of 9 to 12 knots, with 50 m. of towing wire out. Under these conditions it is about 10 m. below the surface (as determined with an attached bathythermograph). Most hauls with the high-speed net were made at night, because daytime hauls caught little. Generally, only one man and a winchman were required to operate the net; when other operations were compatible, the normal routine was to tow the net about 2 or 3 hours, haul it up to change the cod ends, and put it out again for a similar tow, all without stopping or slowing the ship. The main difficulties (in order of magnitude) were that (a) other operations often did not permit a reasonably uniform time for each tow, (b) the organisms caught were generally in poor condition (with much flesh lost) when removed from the cod end, and (c) wear generally forced replacement of the net after about 1,000 to 1,500 nautical miles (1,850 to 2,780 km.) of towing (sooner, if catches were heavy).

The filtration coefficient (at 9 knots), estimated twice in 3 years in the same way as described for the 1.5–m. net, was 0.938 for the first trial and 0.811 for the second. This coefficient shows that the high-speed net filters more efficiently at 9 knots than the 1.5–m. net does at 5 knots; the two estimates do not agree as well as the two for the 1.5–m. net.

The value of 0.938 for the coefficient had been used to standardize the volumes of catches from two cruises before the 0.811 value was determined; these standardized volumes have been retained for the present, since there is no reason to prefer the second value of the coefficient to the first. Volumes were standardized by dividing actual volumes by the number of minutes for the haul and multiplying by 10.0, since I calculated (from the 0.938 coefficient) that the net actually strained 1,000 $m.^3$ of water every 9.96 minutes. The standardized volumes are not tabulated in this paper, but the actual volumes for cruises TO–59–2 and TO–60–2 have been listed elsewhere (Blackburn, Griffiths, Holmes, and Thomas, 1962; Scripps Institution of Oceanography, 1961), and some of the standardized volumes for those cruises are summarized here in figures 18 and 19.

TREATMENT OF COLLECTED MATERIAL

The net catches were preserved in 10 percent buffered formalin (4 percent formaldehyde). All organisms except sea snakes, which are dangerous to handle, were included. Later I sorted the material (a few days later for the major cruises TO–58–1 and TO–60–2; up to 3 years later for other cruises) into four components—fish, crustaceans, cephalopods, and others—and measured the displacement volume of each of the first three components. I also noted the taxonomic composition of each component, by volume or number of individuals, as far as I was able. The fourth component consisted of tunicates, medusae, siphonophores, chaetognaths, heteropods, and pteropods, which are not considered to be micronekton and are not significant in the diets of tropical tunas.

Subsequently, the fish, crustaceans, and cephalopods were sorted, generally to family or, for cephalopods, to genus and species. Displacement volumes of these groups for each haul were then measured (for large samples of fish and crustaceans) or estimated from the number and size of the organisms (for cephalopods, and small samples of fish and crustaceans), and these measurements were reconciled with the original measurements of the three main groups. Occasionally the reconciliation was impossible as a result of unauthorized removal of specimens between the first and the second sorting; the taxonomic composition of the catch by volume was then estimated from the notes made at the first sorting and, rarely, from the catch at another station adjacent in space and time. I realize that the measurements of minor groups are not entirely free from error, but the errors are small and scattered and mostly affect the scarcer groups. The sorted material from these hauls has been catalogued and stored at the Scripps Institution of Oceanography.

CHANGES IN MICRONEKTON FROM DAY TO NIGHT ON SUCCESSIVE DAYS IN THE SAME AREA

Table 2 gives the standardized volumes from standard hauls made alternately about local noon and midnight during a 20-day period of tracking a drifting surface-current drogue off the coast of southern Mexico (cruise TO-62-1 or TEMPO, August 1962). The hauls were encompassed by a rectangle bounded by lat. 14°58.0′ N. and 15°17.8′ N. and long. 99°49.7′ W. and 100°48.0′ W.; the same body of surface water was sampled throughout the period. Table 2 shows the expected striking difference between noon and midnight volumes of total micronekton, which have ranges of 0.4 to 2.1 and 4.3 to 14.3 ml. per 1,000 m.³ respectively. The main reason for this difference is that several families of mesopelagic fishes—Myctophidae, Gonostomatidae, Stomiatidae, Bathylagidae, and Melamphaidae—occurred frequently in midnight catches although they were practically unrepresented in noon catches. Bregmacerotidae also occurred exclusively in the midnight catches, and Carangidae and Leptocephali were taken in larger numbers at midnight than at noon. The principal crustacean groups in this series of micronekton samples were hyperiid amphipods and stomatopod (squillid) larvae, both of which tended to be more abundant in the noon catch than in the midnight catch on any particular day. These groups were the most abundant in the noon samples, which contained comparatively few fishes. Cephalopods occurred in small, broadly similar, amounts in both noon and night samples.

The noon and night series are, thus, greatly different quantitatively and qualitatively; on the other hand, the hauls in each of these series have a great deal of similarity, especially between those made on consecutive days. Consecutive night hauls seldom differed in total volume by a factor of >2 and consecutive noon hauls seldom differed by a factor of >3. Consecutive samples in either series

TABLE 2.—*Micronekton from standard 1.5-m. net hauls made alternately about local noon (D) and local midnight (N) during a 20-day drogue-tracking experiment on cruise TO-62-1 (TEMPO), August 11 to 30, 1962*

[Asterisk means <0.1 ml. per 1,000 m.³]

Haul No.	D or N	Time (minutes)	Group (Ml./10³m.³)													
			Myctophids	Gonostomatids	Leptocephali	Carangids	Stomiatids	Bathylagids	Melamphaids	Bregmacerotids	Other fishes	Hyperiids	Squillid larvae	Other crustaceans	Cephalopods	Total micronekton
1	D	55	--	--	--	--	--	--	--	--	0.3	0.3	(*)	--	0.1	0.7
2	N	50	2.8	1.1	0.3	--	--	1.0	0.6	0.3	.3	.6	--	0.3	.3	7.6
3	D	50	.1	.2	--	--	--	--	--	--	.1	1.4	(*)	--	.3	2.1
4	N	50	8.9	.4	.2	2.0	--	--	--	--	--	.2	0.2	.1	.2	12.2
5	D	50	--	--	--	--	--	--	--	--	.1	.2	.1	--	--	.4
6	N	50	6.1	.7	.2	--	--	--	.1	--	.1	.2	(*)	--	.1	7.5
7	D	49	--	--	.2	--	--	--	--	--	.1	.4	.1	(*)	.1	.9
8	N	50	5.8	.2	1.5	(*)	--	--	--	--	.1	.1	(*)	.1	.1	7.9
9	D	49	--	--	(*)	--	--	--	--	--	(*)	.4	.2	.1	.1	.8
10	N	49	2.9	.3	1.7	(*)	--	--	--	--	(*)	.3	.1	.1	--	5.4
11	D	49	--	--	--	--	--	--	--	--	.2	.2	(*)	.1	.6	1.1
12	N	50	6.6	.6	.2	--	--	--	--	--	.1	.2	(*)	.1	.2	8.0
13	D	49	--	--	--	--	--	--	--	--	.2	.7	.1	(*)	.2	1.2
14	N	50	5.9	.5	2.0	.4	--	--	--	--	(*)	.2	(*)	.1	.1	9.2
15	D	49	--	(*)	.1	--	--	--	--	--	.1	.7	.1	.1	.2	1.3
16	N	47	7.3	2.2	2.2	1.6	--	--	--	--	.1	(*)	(*)	.1	--	13.5
17	D	48	--	--	.1	--	--	--	--	--	(*)	.2	.1	.1	.1	.6
18	N	50	6.3	.9	.8	--	0.4	--	--	--	.1	.2	(*)	.2	.4	9.3
19	D	48	--	--	--	--	--	--	--	--	--	1.0	.1	--	.1	1.2
20	N	49	.8	12.8	.1	(*)	.4	--	--	(*)	.1	(*)	--	.1	(*)	14.3
21	D	49	--	--	--	--	--	--	--	--	--	.2	.2	--	--	.4
22	N	49	2.9	1.3	.5	.8	.4	--	.1	(*)	.2	.1	(*)	.1	.1	6.5
23	D	50	--	--	.1	.2	--	--	--	--	.1	.3	.1	--	.3	1.1
24	N	50	3.2	.9	.4	--	.7	.2	.8	.1	--	(*)	(*)	.1	(*)	6.4
25	D	50	--	--	(*)	.4	--	--	--	--	.4	.2	.2	.1	--	1.3
26	N	50	3.9	.3	.2	--	.3	.4	.7	.1	.1	--	--	.1	(*)	6.1
27	D	49	--	--	(*)	--	--	--	--	--	(*)	.4	.2	--	.2	.8
28	N	50	4.7	1.0	(*)	(*)	.3	.1	--	--	.1	(*)	--	--	.2	6.4
29	D	48	--	--	--	--	--	--	--	--	.1	.8	.5	--	--	1.4
30	N	50	2.8	.9	--	--	.2	.4	.2	(*)	.1	--	--	.1	--	4.7
31	D	49	--	--	--	--	--	--	--	--	.2	.5	.7	.1	.1	1.6
32	N	55	3.3	.5	.1	--	.2	.6	.1	(*)	.1	(*)	(*)	.1	(*)	5.0
33	D	49	--	--	--	--	--	--	--	--	--	.4	.3	.1	.1	.9
34	N	50	5.7	1.0	.4	--	(*)	.3	(*)	.3	.1	(*)	(*)	.1	(*)	7.9
35	D	49	--	--	--	--	--	--	--	--	(*)	.3	.2	--	(*)	.5
36	N	50	3.3	.4	.2	(*)	.1	.2	.3	(*)	.1	--	(*)	(*)	.2	4.8
37	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
38	N	50	1.3	.7	.2	--	.8	.5	.4	.2	(*)	(*)	--	.2	(*)	4.3
39	D	49	--	--	--	--	--	--	--	--	--	--	.2	--	.2	.4

[1] Haul omitted.

also did not differ greatly in taxonomic composition (table 2). These results were expected because all the catches were made in the same body of surface water. They suggest that the catches of the other, more isolated, single hauls listed in this paper are reasonably representative, both qualitatively and quantitatively, of the micronekton population sampled.

AREAL DISTRIBUTION OF MICRONEKTON BY TAXA

Table 1 gives the actual and standardized volumes of fish, crustaceans, and cephalopods for each of the 131 standard night hauls of the 1.5-m. net, excluding the special series mentioned in the previous section. It also gives the number, date, and area (see below) of each of the stations at which each haul was made.

The approximate position of each station is shown in figure 1 or figure 2. The actual positions of the stations are available from the following sources: cruise TO–58–1, Holmes and Blackburn, 1960; TO–59–1 and TO–59–2, Blackburn et al., 1962; TO–60–1, Scripps Institution of Oceanography, 1967; TO–60–2, Scripps Institution of Oceanography, 1961; TO–61–1, Blackburn, unpublished.

The stations were assigned to areas which are shown in figure 5. Areas 1 to 14 are those recognized by Alverson (1963a) in a study of the food of tropical tunas taken in the U.S. surface tuna fishery. Areas 15 to 18 enclose stations occupied farther offshore. No stations with micronekton hauls were occupied in areas 7 and 13; areas 11 and 12 have been combined in this paper; a few stations close to the boundaries of certain areas have been assigned to those areas for convenience.

For the 131 hauls, the actual total volumes were: 12,756 ml. of fish; 25,240 ml. of crustaceans; and 2,008 ml. of cephalopods; grand total, 40,004 ml. These numbers are given by taxa (including some species) and areas in table 3, which is the most convenient way of presenting the composition of the whole material. Some of these data are used in later sections (tables 8–15).

Although many families are listed in table 3, only 10, together with the Leptocephali of the suborder Apodes (Pisces) which have not been classified to family, contributed more than 1 percent of the grand total; these 11 groups combined accounted for 93.4 percent (table 4). The Euphausiacea of table 3 are all members of the family Euphausiidae.

Table 5 gives standardized volumes of the principal fish and crustacean components of the micronekton as listed in table 4, for each station. The sum of volumes equals the standardized volumes for total fish and total crustaceans in table 1.

Figures 6 to 13 show distributions of standardized group volumes for the two most extensive cruises, TO–58–1 (SCOT) and TO–60–2 (STEP–1); figure 1 identifies the stations; the data are from tables 1 and 5. These cruises were made in the Northern Hemisphere in the northern spring and the Southern Hemisphere in the southern spring, respectively. The two space-time situations were comparable climatically; trade winds were declining in average strength from their seasonal maximum about late winter or early spring. A general similarity should, therefore, exist between the two situations in certain wind-connected upper-ocean features which affect the production and distribution of organisms. For instance, amount of coastal upwelling, mean depth of mixed layer, and mean velocity of westerly surface currents would all be expected to be declining, as a result of the decrease in the trade winds, in each situation. Because the two cruises were comparable in range of latitude from the Equator, and range of distance offshore, it is reasonable to combine biological data from both in the way that has been done in figures 6 to 13. These figures, then, give the best available picture of regional distribution of the standing crops of various kinds of micronekton over a large part of the eastern tropical Pacific, under comparable physical conditions.

Figures 6, 7, and 8 chart the distribution of fish, crustaceans, and cephalopods, respectively (data from table 1). They show clearly that the standing crop of each of these three components of the micronekton declines from onshore to offshore. Table 6 shows the magnitude of these changes.

This distribution is rather similar to that of standing crops of chlorophyll *a* and zooplankton in the same region (Brandhorst, 1958; Bennett, 1963; Forsbergh and Joseph, 1964; Blackburn, 1966b). Each of the three standing crops—chloro-

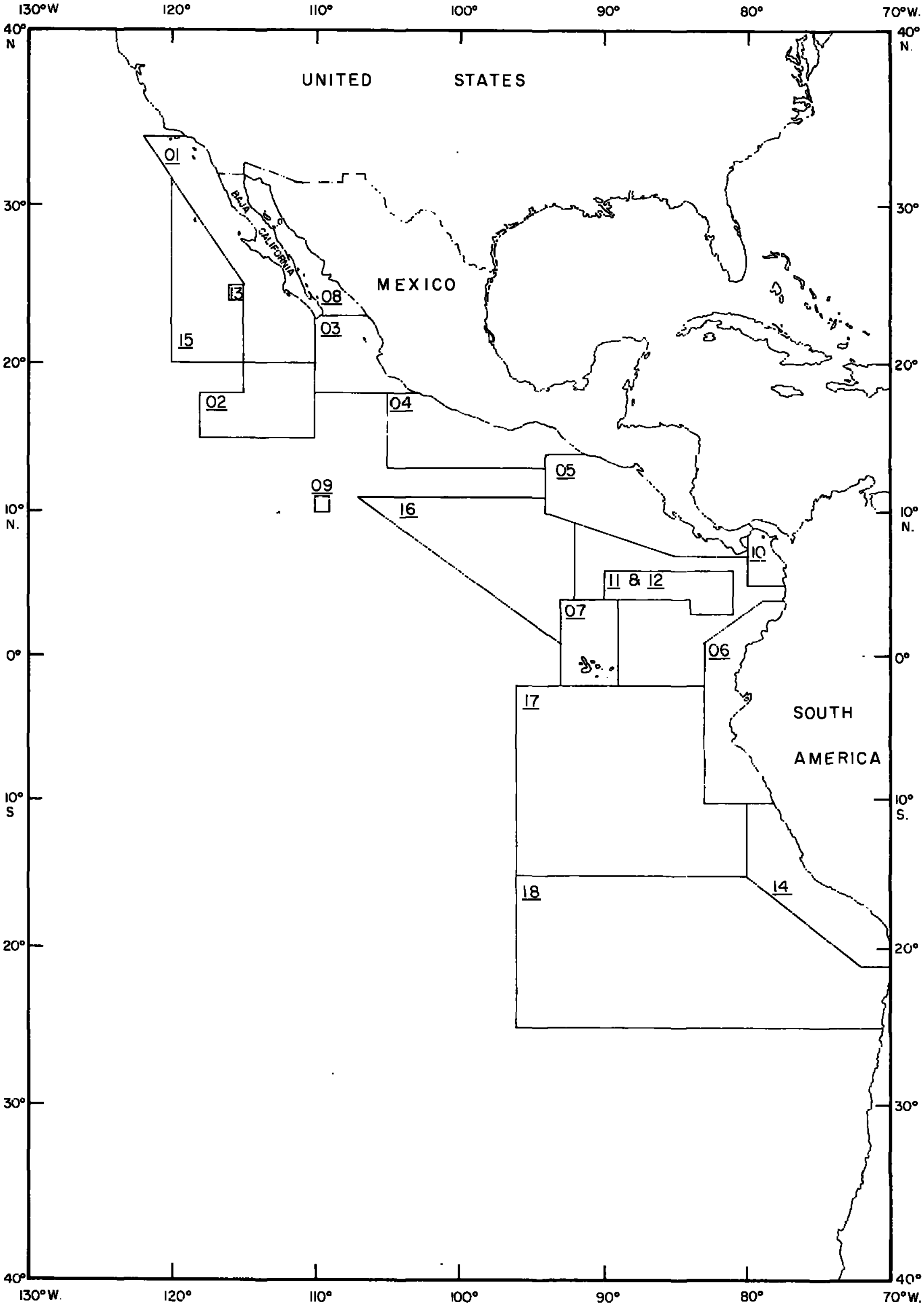

FIGURE 5.—Areas to which standard night hauls were assigned in table 1.

Table 3.—*Actual volumes of micronekton from table 1, classified by taxa and areas*

[Groups with <1 ml. for the combined areas are unlisted; asterisk means <1 ml. for a particular area. Abbreviations in the left-hand column signify: a.—adult, j.—juvenile, l.—larva, m.—megalops, ph.—phyllosoma, po.—postlarva, pu.—puerulus, r.—remains, unid.—unidentified, z.—zooea; if no ontogenetic stage is specified, the adult stage, or a mixture of adults and younger stages is meant.]

Animals	Area Number															
	01	02	03	04	05	06	08	09	10	11, 12	14	15	16	17	18	Total
CEPHALOPODA																
Decapoda																
Enoploteuthidae:	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	
Pterygioteuthis giardi	7					6			15	8			4	6	3	49
Do. j	(*)								1				1	4	2	8
Pterygioteuthis sp. j			1													1
Abraliopsis morisi	9	7	116	434	305	18	9		55	45	6	3	15	7		1,029
Do. j			5	24	7	4	2		3	5			1			51
Do. l			1		1											2
Abraliopsis sp			2	9	3						2				1	17
Do. j															1	1
Abralia sp			2	13	5			1								21
Do. j													1			1
Onychoteuthidae:																
Onychoteuthis banksi				7	5											12
Do. j				11	1											12
Onychoteuthis sp. j					1											1
Unid. Onychoteuthidae					1											1
Do. j				1	1									1		3
Cranchiidae:																
Leachia eschscholtzi	2	1	35	342	88	12		5		11	23		40	5	3	567
Do. j		(*)	8	15	7			(*)	(*)	2	2		3		2	39
Do. l					1										(*)	1
Leachia sp				2												2
Do. j			1	1												2
Pyrgopsis sp	(*)		1	3	4						1				1	10
Do. j	1		12	7	1						1					22
Liocranchia reinharti									5							5
Do. j			1			1							1			3
Teuthowenia sp										2						2
Do. l					(*)	1										1
Unid. Cranchiidae j	(*)		1													1
Do. l				(*)	1								1			2
Bathyteuthidae:																
Ctenopteryx sicula					1					3						4
Ctenopteryx sp						2								1		3
Octopodoteuthidae:																
Octopodoteuthis sp													1			1
Ommastrephidae unid	5															5
Histioteuthidae unid				2	2											4
Unid. squid r	2		3	20	72					1	(*)			1		99
Do. j					1	1					1					3
Do. l	(*)	(*)	(*)	2	1	1		(*)	(*)	(*)		(*)	2	1	(*)	7
Octopoda																
Tremoctopodidae:																
Tremoctopus sp. j	2															2
Argonautidae:																
Argonauta sp		1														1
Do. j	1				2											3
Amphitretidae:																
Amphitretus sp				5												5
Do j				2						(*)						2
Do. l			(*)	1	2	(*)					(*)			(*)		3
Total Cephalopoda	29	9	189	901	513	46	11	6	79	77	36	3	70	26	13	2,008
CRUSTACEA																
Isopoda	(*)	1	(*)	(*)	(*)											1
Amphipoda																
Gammaridea		(*)	(*)	(*)	(*)			2	(*)				3			5
Hyperiidea:																
Phronimidae	4	2	13	33	24	5	2	2	1	13	2	(*)	8	6	6	121
Phrosinidae	(*)	(*)	3	7	7	4		1	2	7			5	1	7	44
Oxycephalidae	2	1	9	23	12	5	(*)	3	1	5	2		7	5	5	80
Platyscelidae			2	7	7	4		(*)	(*)	1			7	(*)	(*)	28
Paraphronimidae				3	5	(*)		(*)	1	5	2		3	3	2	24
Vibiliidae	3	4	4	9	6	(*)	(*)	1	1	3	2		(*)	3	4	40
Scinidae	(*)	2	(*)	(*)	(*)	3		(*)	(*)	(*)				(*)	3	8
Unid. Hyperiidea	1	(*)	6	17	6	5		2	1	5	5		4	4	4	60
Euphausiacea	1,528	38	265	91	101	438	104	6	23	163	170	6	71	29	250	3,283
Decapoda																
Sergestidae	8	1	17	82	181	40	2	2	49	138	2	4	92	27	10	655
Do. po			2	(*)	5	(*)		1	(*)	(*)			3	2	2	15
Penaeidae	1		1,516	(*)	20	46	4		(*)	8	3	1	8	28	16	1,651
Do. z	2	(*)	8	27	10	5	2		1	(*)			(*)	(*)		55
Pasiphaeidae	277												4			281
Oplophoridae				(*)		2									2	4
Pandalidae	1					2							3	(*)	(*)	6
Amphionidae l	(*)		2	(*)	5	3		2	1	(*)			4	(*)	3	20
Unid. Caridea				2												2
Palinuridae ph	2	1	4	13	10	(*)		1	(*)	7			8			46
Do. pu			2	8	(*)				1	1			(*)			12
Galatheidae:																
Pleuroncodes planipes	15,474	470	2									191				16,137
Unid. Galatheidae z & j	(*)		1	15	(*)	3	1						(*)	(*)		20
Porcellanidae z	1	2	5	19	5	3		1	1	5	1		1	(*)	(*)	44
Paguridae m	(*)		6	17	6	(*)			1	5			(*)			35
Hippidae z	(*)		2	11	(*)						(*)		(*)	(*)	(*)	13

Table 3.—*Actual volumes of micronekton from table 1, classified by taxa and areas*—Continued

Animals	Area Number															
	01	02	03	04	05	06	08	09	10	11, 12	14	15	16	17	18	Total
CRUSTACEA—Continued	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	*Ml.*	
Albuneidae z	(*)		3	23	5	(*)	(*)		(*)	(*)			3			34
Portunidae:																
Portunus affinis				830	37				130	65						1,062
Euphylax dovii									1							1
Unid. Portunidae					4											4
Do. j				1						(*)						1
Dorippidae z	(*)		4	18	7	5	1		2	(*)			(*)	1		38
Unid. crab m	3		8	36	8	5	1	2	1	6	2		1	2	(*)	75
Unid. decapod l	4	1	9	25	8	5	2	2	1	6	5		4	3	4	79
Do. r	(*)		2	(*)	(*)	(*)								(*)		2
Stomatopoda																
Squillidae l	33	8	164	228	109	32	5	4	31	45	2	3	32	5	(*)	701
Do. po. & a.	(*)		(*)	477	15											492
Unid. crustacea r	3			12	11	(*)			6	21		1		3	4	61
Total Crustacea	17,347	531	2,059	2,034	614	615	124	32	256	509	198	206	271	122	322	25,240
PISCES																
Albulidae l				2		2										4
Gonostomatidae:																
Vinciguerria spp.	125	62	272	322	84	33	14	6	60	28	17	19	48	69	22	1,181
Unid. Gonostomatidae	4	7	24	(*)	3							4	4	1	19	66
Stomiatidae	16		20	42	46	10		2	53	31	(*)	5	18	27		270
Melanostomiatidae				14	8								3			25
Astronesthidae l									1	(*)						1
Sternoptychidae	(*)			2	1	46		(*)	1	(*)			3	1	21	75
Idiacanthidae		3		55	45			1	6	34						144
Myctophidae	1,342	134	523	1,557	403	452	304	21	240	225	125	52	278	311	115	6,082
Bathylagidae	8		3	27	39	13			5	1	2		11	5	(*)	114
Paralepididae	1		2	13	6	4		(*)	8	1		(*)	1		1	37
Scopelarchidae	1		2	13	9	7	(*)	(*)						2	(*)	34
Synodontidae l					1											1
Nemichthyidae	3			22	60	21				5			4			115
Apodes: leptocephali	89	78	651	2,030	558	96	30	2	97	199	2	7	294	(*)	6	4,139
Belonidae l			1													1
Scomberesocidae j											6					6
Hemirhamphidae l						1										1
Exocoetidae j			7													7
Gadidae l			(*)			2								(*)		2
Bregmacerotidae	5	2	50	36	6				7	18			11			135
Trachypteridae l													1			1
Regalecidae l										2			2			4
Heterosomata po	(*)			45	28	4	(*)						1			78
Holocentridae l			1													1
Melamphaidae			5	20	4	4	16				1			1		51
Syngnathidae l				2												2
Thunnidae po	(*)		(*)	(*)	2				(*)							2
Trichiuridae po						6			5							11
Gempylidae po														3	(*)	3
Coryphaenidae l			(*)	2						(*)			(*)			2
Bramidae l				(*)									1			1
Stromateidae	(*)		7	8	23		(*)			2			1	2	2	45
Carangidae	(*)			5	1	2			2		9			4	2	25
Serranidae j			2	4	3				1	(*)						10
Priacanthidae l				1	1											2
Callionymidae l										1						1
Scorpaenidae po	(*)		3	15	5				3	1						27
Labridae po	(*)		4	2	4			(*)		1			(*)			11
Blennidae l			1							1						2
Ophididae l			5	2	2	1				1						11
Balistidae l	1															1
Ostracidae j		1														1
Tetraodontidae j			1					1		1						3
Diodontidae j				2												2
Unid. pisces			4	13	1								1			19
Total Pisces	1,595	287	1,588	4,256	1,343	704	364	33	489	552	162	87	682	426	188	12,756

TABLE 4.—*Major components of the micronekton; actual volumes from table 3, for all areas combined*

Family or suborder	Actual volume	Percentage of total volume
	Ml.	*Percent*
Enoploteuthidae	1,180	2.95
Cranchiidae	657	1.64
Euphausiidae	3,283	8.21
Sergestidae	670	1.68
Penaeidae	1,706	4.26
Galatheidae	16,157	40.39
Portunidae	1,068	2.67
Squillidae (larvae)	701	1.75
Squillidae (postlarvae and adults)	492	1.23
Gonostomatidae	1,247	3.12
Myctophidae	6,082	15.20
Apodes (Leptocephali)	4,139	10.35
All others	2,622	6.55
Total micronekton	40,004	100.00

phyll *a*, zooplankton, and micronekton—is positively correlated with the others in the area of cruise TO–58–1 (Blackburn, 1966a). The distributions reflect the fact that physical situations which lead to high production of organisms, namely upwelling and vertical mixing by wind over shoal pycnoclines, are better developed along the eastern sides than in other parts of tropical oceans, except along the Equator (Wooster and Reid, 1963; Wyrtki, 1966). Crops of chlorophyll *a* and zooplankton are fairly high in offshore waters along the Equator (Forsbergh and Joseph, 1964; Blackburn, 1966b); this paper presents no data on micronekton for those waters, but King and Iversen (1962) found more micronekton near the Equator than elsewhere in the central tropical Pacific. In nonequatorial offshore waters the pycnoclines lie deeper and mixed layers are thicker (Wyrtki, 1964b); the likelihood of chemical enrichment from below is diminished, and, if there is such enrichment, part of the resulting plant crop will be carried by mixing below the compensation depth.

The standing crop of micronekton is not uniformly high in the coastal region. It tends to be higher in some parts of the region than in others. The standardized volumes of total micronekton for the 40 onshore stations (table 6) range from 113.3 to 2.9 ml. per 1,000 m.^{3}, and this group can be divided into an upper two deciles (8 stations) and a lower eight deciles (32 stations). Table 7 shows that the eight stations with the higher total volumes also had the higher mean volumes for each of three main components of the micronekton.

The eight stations with high volumes are numbers 49, 63, 77, 81, 142, 144B, and 146 of cruise TO–58–1, and number 6 of cruise TO–60–2. With the possible exception of station 142, they all occur in localities which are known to be especially productive of organisms, as a result of physical processes which operate at or a few months prior to the season at which the micronekton was collected. Stations 144B and 146 occur in the coastal upwelling region off Baja California (Reid, Roden, and Wyllie, 1958; Blackburn, 1966b); stations 77 and 81 are in the Gulf of Tehuantepec where vertical mixing occurs over a shoal thermocline (Blackburn, 1962); station 49 lies in the "Costa Rica Dome" region where upwelling, from cyclonic flow, takes place (Wyrtki, 1964a; Holmes, MS.[4]); station 63 occurs in the coastal upwelling region of the Gulf of Panama (Forsbergh, 1963); and station 6 is in the coastal upwelling region off Peru (Wyrtki, 1963; Forsbergh and Joseph, 1964).

Station 142 is in the mouth of the Gulf of California, which is not known to be as biologically productive as the other areas just mentioned. The mixed layer is <20 m. thick in an average June, however (Wyrtki, 1964b) and was so when the station was occupied in June 1958; the possibility of chemical and biological enrichment, as a result of vertical mixing, therefore, exists. On the other hand, this station is very close to an island; the high volume of micronekton (mainly fishes, see table 1), therefore, may represent an "island effect."

The standing crop of cephalopod micronekton appears to diminish polewards from the tropics (fig. 8) even along the coast, but this trend does not hold with the fish and crustaceans.

Figures 9 to 13 show similar data, from table 5, for some of the major groups of fish and crustaceans. The distribution of myctophids (fig. 9), the largest group by volume among the fishes, is broadly similar to that of all fish (fig. 6). Standing crops decline from onshore to offshore, although not as markedly as crops of some of the other groups (table 6). Myctophids are also well represented in the micronekton off the west coast of the United States (Aron, 1962a; Pearcy, 1964) and in the central Pacific (King and Iversen, 1962); it is impossible to make close quantitative comparisons of standing crops from those regions with crops

[4] Holmes, Robert W. A contribution to the physical, chemical, and biological oceanography of the northeastern tropical Pacific (Scripps Institution of Oceanography, University of California. 357 pp.).

Table 5.—*Standardized volumes of the principal components of fish and crustacean micronekton in the hauls listed in table 1*

[Asterisk means <0.1 ml. per 1,000 m.³; see table 1 for standardized volumes of total fish and total crustaceans]

Station number	Fish components				Crustacean components							
	Myctophids	Leptocephali	Gonostomatids	Others	Galatheids	Euphausiids	Penaeids	Portunids	Sergestids	Squillid larvae	Squillid adults	Others
	Ml./10³m.³											
A. Cruise TO-58-1 (SCOT): April to June, 1958												
1	1.1	0.1	0.3	(*)	3.4	0.2	(*)		0.1	0.1		
3	1.4		.8	0.3	5.7	.1	(*)		.1	(*)		(*)
5	.4	.3	.2	.1	1.8	.1			(*)	(*)		0.1
7	1.6	.7	.9			1.4				(*)		.2
10	1.0	1.2	.5			.5			(*)	.1		.1
12		(*)	(*)		23.2							(*)
14	3.8	1.4	1.0	.1		.2			(*)	.1		(*)
16	.8	.8	.5	.2		(*)				(*)		.2
18	.9	(*)	.1	(*)		.2			(*)	(*)		.5
22		.1	(*)	(*)		.1			(*)	(*)		.4
27	.3	.1	.2	.2		.1			(*)	.1		.4
29	1.4	1.3	.7	.3		.1			(*)	.1		.4
31	1.3	1.8	.3	.2		.2			.1	.2		.5
33	2.8	4.0	.4	.2		.3			2.3	.3		.7
35	2.0	.6	.3	.3		.7			1.3	.1		.4
36	4.3	3.3	.5	.4		1.6	0.3		.3	.4		.6
46	2.9	3.5	.6	1.8		.9	.2		1.3	.6		1.0
48	3.8	4.4	.5	2.4		.8	.1	0.2	1.5	.8		.7
49	3.5	2.3	1.7	3.4		.5	.2		.9	.8		1.2
51	1.1	1.1	.2	.7		.8	(*)		.9	.2		.9
54	2.0	2.1	(*)	.8		.7	.1		1.4	.4		.7
56	1.7	2.8	(*)	.9		1.8	(*)		1.4	.5		1.0
57	1.5	1.4	(*)	.6		.6	(*)	.7	.8	.4		.9
59	2.7	2.3	.6	.7		3.5	(*)	.8	2.1	1.0		1.3
61	1.7	.1	1.4	2.0		.3	(*)	6.3	.8	.4		.3
63	11.6	5.2	1.9	3.3		1.0	(*)	1.1	1.9	1.3		.9
69	4.0	1.8	.9	1.8		2.1	.1	2.3	1.0	.2		.8
71	1.9	1.8	.3	2.2		.7	.8	.4	1.0	.2		.7
73	2.6	4.9	.7	2.4		1.4	(*)	.4	.8	.6		.7
75	1.8	7.0	.9	1.8		.8	(*)		3.5	.8		1.4
77	2.2	14.4	2.2	.9		.7	(*)		.9	.8	(*)	1.2
81	7.0	16.4	2.1	2.3	(*)	.5	.1		.3	1.6		1.2
85	3.8	3.5	.5	1.6		.5	(*)		1.3	.6	1.5	1.0
87	.5	4.9	.3	.2		.3	(*)		.2	.3		.7
90	5.2	2.4	.7	.1		(*)	(*)		(*)	.2		.7
94	1.8	5.5	.9	.2		(*)	(*)			.1	(*)	.5
96	1.1	10.8	.2	.5		(*)	(*)	.4	(*)	.5	.1	1.0
98	6.4	4.6	2.2	.9		.1	(*)		.1	.3		.8
118	2.4	3.8	3.2	2.8		.1	(*)		(*)	.2		.7
135	3.7	4.0	2.2	1.5		.7			(*)	.5		.6
142	1.0	12.7	3.1	2.2		.3	(*)		.2	2.3	(*)	.8
144A	10.2	4.0	.6	.4	.2	2.5	(*)		(*)	.7		.4
144B	9.4	.3	.9	1.1	89.9	1.1	(*)		(*)	.2		.1
146	.2	.1		.1	100.7	(*)				(*)	(*)	12.2
B. Cruise TO-59-1: January to February, 1959												
1	12.1		.2	.1	26.4	2.8			(*)	(*)		
3					8.0	(*)	(*)					
5			(*)		32.7	.3				(*)		.1
7	3.5	7.2	.8	.1	.2	(*)	(*)			.5		.1
9	1.9	2.3	.7	.6		.1	(*)		(*)	.5		.3
11	5.0	2.6	.2	(*)		(*)	(*)			.2		.3
13	4.8	2.3	.1	(*)		(*)	(*)	5.7	.3	.1		.5
15	4.3	3.5	.1	.8		.3	(*)	3.5	(*)	.1		.7
18	6.1	2.4	.1	.4		.2	(*)	21.6		.9		1.1
22	1.4	4.4	.2	.5	1.6	.4	(*)	3.5	(*)	2.2		.9
28	2.9	4.7	.1	1.7	(*)	.4	(*)	.3	.3	1.3		2.0
36	2.3	2.3	.2	2.0		.7	(*)		.7	1.6	(*)	1.0
41	1.8	1.7	.2	.2	(*)	.1		20.0	.5	.1		(*)
43	4.0	4.1	.1	.1		.1		1.7	(*)	.5		.9
46	2.1	1.8	.3	.6	(*)	.1	(*)		(*)	.4		.6
48	.6	4.0	.5	.2		(*)	(*)		(*)	1.0		.8
50	.8	.4	.3	(*)	55.1	3.6				(*)		1.0

TABLE 5.—*Standardized volumes of the principal components of fish and crustacean micronekton in the hauls listed in table 1*—Continued

	Fish components				Crustacean components							
Station number	Myctophids	Leptocephali	Gonostomatids	Others	Galatheids	Euphausiids	Penaeids	Portunids	Sergestids	Squillid larvae	Squillid adults	Others
C. Cruise TO-59-2: August to September, 1959												
2	4.3		(*)	(*)	81.5	(*)						3.0
8	4.6		(*)		165.3	9.0			(*)	(*)		.1
13	1.2		.2		46.5	12.3			(*)			
21	3.1		(*)		65.3	2.6			(*)	(*)		.6
32	31.5		(*)		222.6	34.2				.1		.1
38	7.0		.7	(*)	40.6	13.0			(*)	(*)		(*)
42	4.4	(*)	.7		132.5	3.8			(*)	(*)		(*)
52	5.9		.2	(*)	107.6	9.4			(*)	.2		(*)
58	7.2	(*)	4.7	.1	20.0	22.0			(*)	(*)		.6
64	.1	(*)		.1	(*)	.4	(*)		(*)	.1		.7
74	4.0	2.0	.2	1.0		.1	(*)			.2		.6
79	2.3	4.8	.2	.8		(*)	(*)		.1	.7		.6
82	3.4	1.5	.2	1.0		.2	(*)	1.1	.2	.5		.8
84	9.4	10.6	(*)	1.0		(*)	(*)	4.9	.1	.2		1.2
85	10.2	3.3	(*)	1.2		.1	(*)	1.4	.1	.7		.2
86	4.9	2.0	(*)	.5		(*)	(*)		.1	.4		.1
87	3.6	.3	(*)	(*)		(*)	(*)		(*)	.7		.5
88	3.9	1.1	4.2	.2		18.1			(*)	.4		.8
89	(*)	.1	(*)	(*)		.3	(*)			.4		.4
D. Cruise TO-60-1: May 1960												
10	.4	.2	.1	1.2	.1	7.3	.3		(*)	.1		(*)
14	.2	.1	.1	.3	(*)	.2	.1		(*)	.1		.1
18	.5		.5	.1		8.3	(*)		.1	(*)		.5
23	1.4	.3	.5	(*)		.4				.1		.1
27	3.4	.3	1.3	(*)		7.7			(*)	(*)		.6
29	.5	.1	.2			.1				(*)		.4
33	3.5	.8	1.1	.1		(*)			(*)	.3		.6
37	25.1	2.2	1.1	(*)		.1	(*)		.2	.3		.6
40	1.8	3.9	.2	(*)		.1	(*)		.1	1.9		.6
44	2.4	.4	.4	.1		.2	(*)		.2	1.2		.5
48	.7	.3	1.5	(*)		(*)	(*)		(*)	.3		.6
52	1.4	.8	4.4	(*)		(*)			(*)	.3		.4
56	(*)	.6	.8	(*)		(*)	(*)			.4		.5
59	(*)	.7	2.9	1.6		(*)	130.1			1.3	(*)	.4
E. Cruise TO-60-2 (STEP-1): September to December, 1960												
1	.9		1.4	.7	(*)	.2	.2		.2	.2		1.2
2	7.1	1.1	1.1	1.2		.4	.4		.1	.7		.8
3	5.7	.4	.6	.8	(*)	.1	1.2		.5	.5		.9
4	9.6	.3	.2	.4	(*)	.1	(*)		.3	.5		1.1
6	5.6	5.0	.3	1.4		29.0	1.5		1.6	.4		.7
9	3.7	.2	.1	5.8	(*)	3.0	.1		.2	.1		.7
11	4.3		.6	1.5		.6			.1	.1		.4
17	1.6		.3			.3	.4		1.0			.3
19	2.3		.9	.5		.1			.3	(*)		.4
23	4.3		1.9	.9		.8	1.6		.2	(*)		.4
27	1.0		.3	.1		8.2	(*)		(*)	(*)		.6
30	.8		.7	.7		3.8	(*)		.1			.4
32	1.2		.2	.1		.1			.1			.1
35	.3	.1	(*)	(*)		.5			.1			.9
38	.5		.1			3.5			(*)			.4
42	1.6	.2	.1	.3		.1			(*)	(*)		.1
45	5.7		.2	.2	(*)	.4			(*)	(*)		.7
50	1.6		.8	1.4		1.1	.5		.2	(*)		.5
55	.7		1.1	.2		11.9	.5		.1			.3
59	1.8		.6	.3		.8	.1		.1			.4
64	1.0	.2	(*)			(*)			(*)			.1
69	1.0	.2	.2			.2			.2	(*)		.7
73	4.5	(*)	.4			(*)			(*)			.2
77	5.7		.2			.3			.2	(*)		(*)
85	1.6	3.2	.3		(*)	.5			(*)	.2		.1
F. Cruise TO-61-1: March to April, 1961												
2	3.9	1.3	.1	.5		.1	(*)	.9		.4	.1	.6
5	3.9	2.1	4.2	2.9		1.6	.1	.6	.3	.5	.1	1.2
14	2.8	5.8	.4	1.3	(*)	.5	.1	.3	.1	.6	1.0	.9
16	4.4	2.1	.2	.2	(*)	.1	(*)			.5	31.0	.4
18	3.4	3.4	.2	1.7	(*)	.4	(*)		(*)	.7	2.1	.6
22	3.1	6.8	.1	.4		(*)	(*)	.1	.2	.6		.6
27	1.4	1.4	.3	.1	(*)	.5	.1		2.0	.2	.1	.3
29	.9	2.8	1.0	.3		.1	.2	1.5	.1	1.5		.6
32	3.9	1.7	.3	.4		(*)	(*)	.9	(*)	.7		.8
36	.8	4.6	.1	.6	(*)	(*)	(*)	.6	.2	.8		.7
38	4.5	1.1	.9	.1		.2	(*)	.6	(*)	.2		.7
40	.8	1.9		(*)		(*)	(*)		(*)	.2		.3

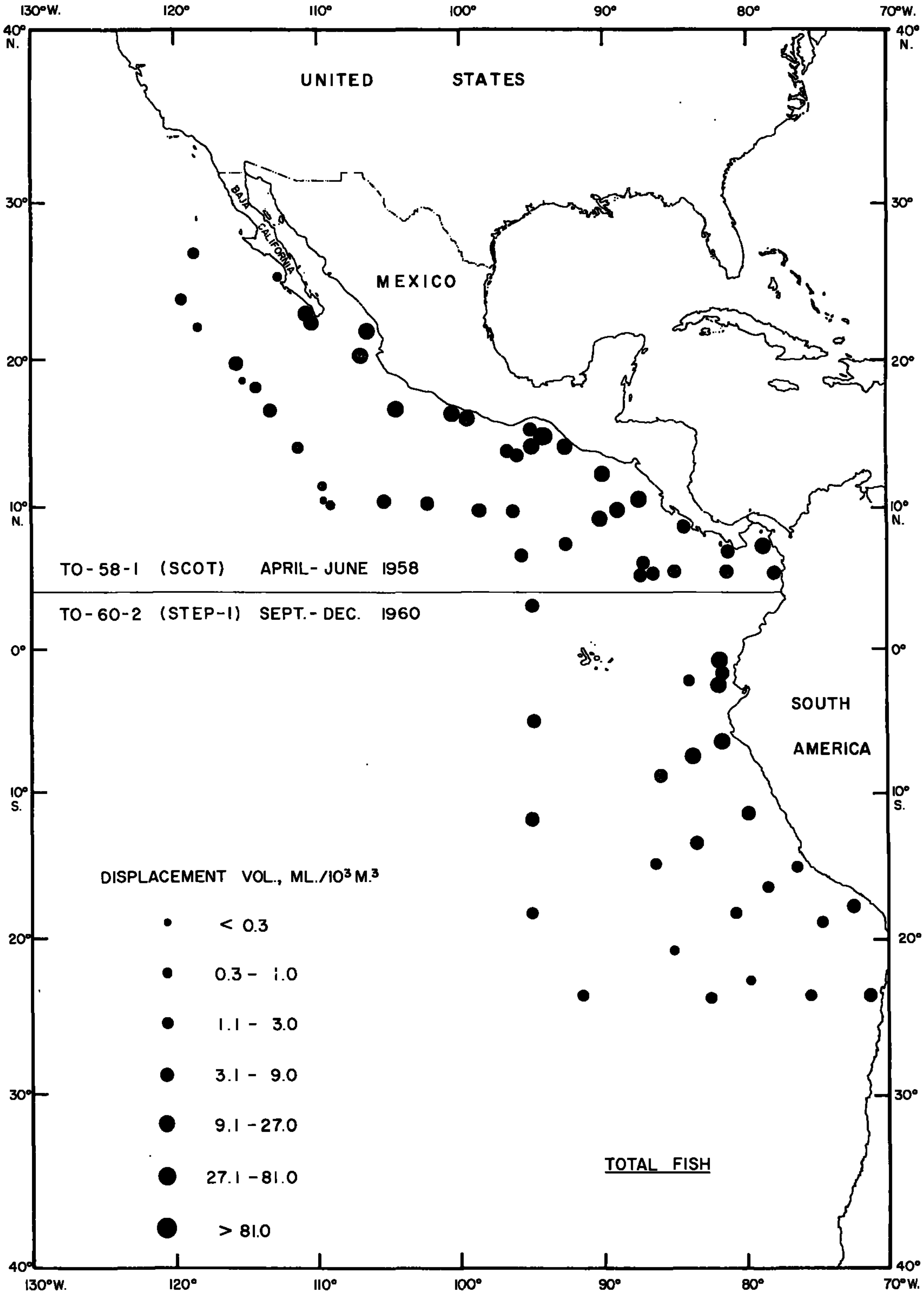

FIGURE 6.—Distribution of standing crop (standardized volume) of total fish taken in night micronekton hauls on cruises TO-58-1 and TO-60-2.

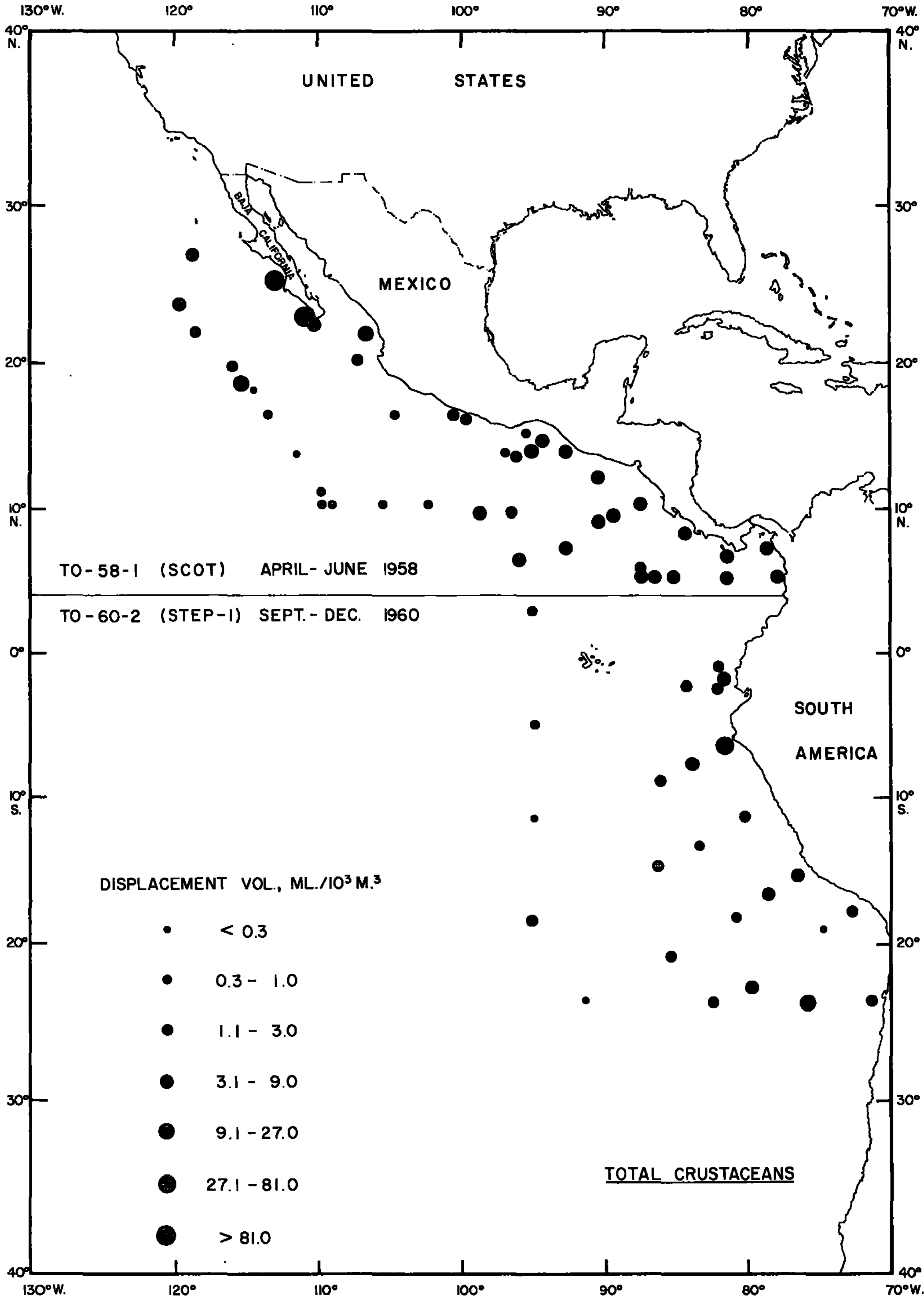

FIGURE 7.—Distribution of standing crop (standardized volume) of total crustaceans taken in night micronekton hauls on cruises TO–58–1 and TO–60–2.

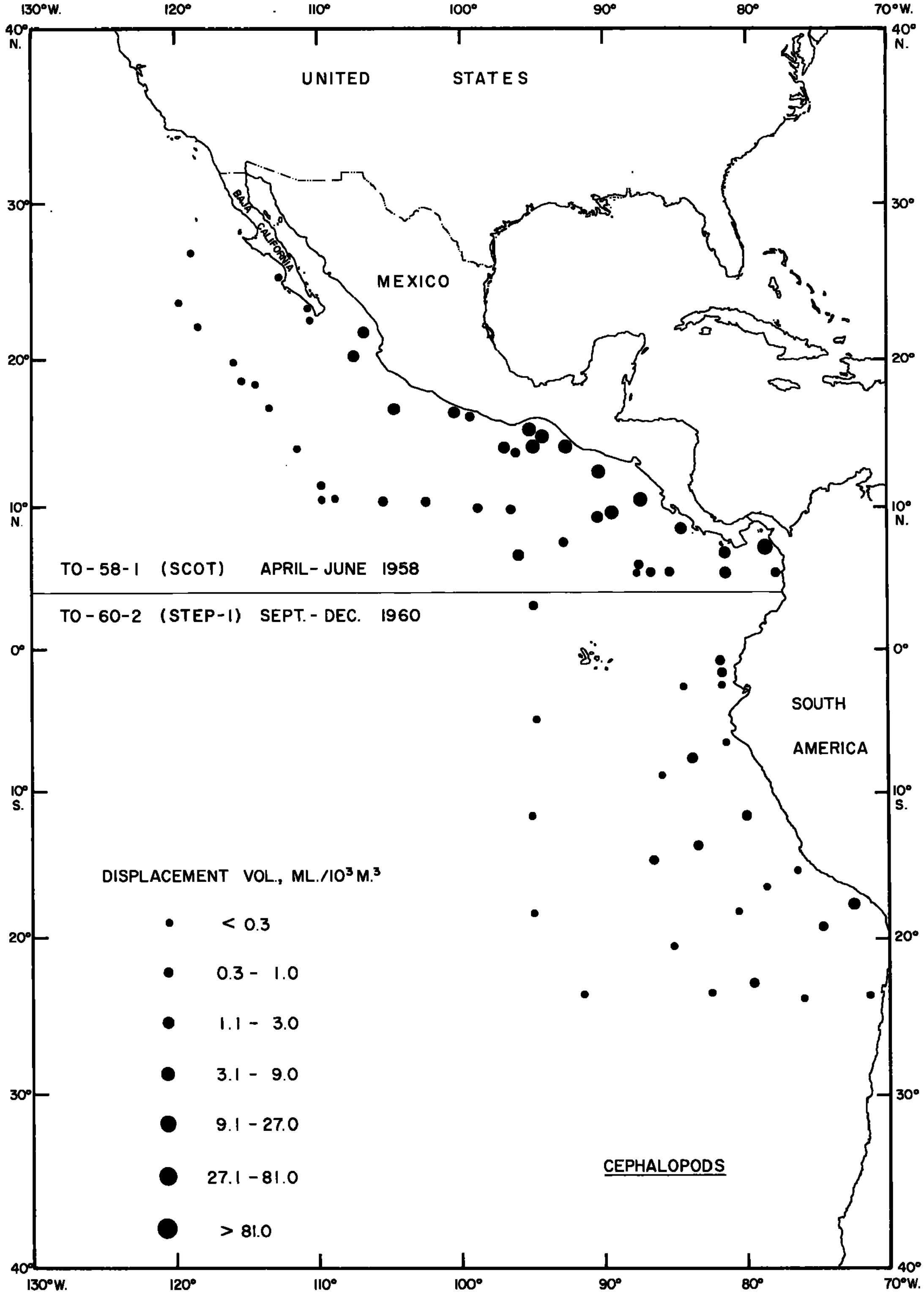

FIGURE 8.—Distribution of standing crop (standardized volume) of total cephalopods taken in night micronekton hauls on cruises TO-58-1 and TO-60-2.

TABLE 6.—*Means and medians of standardized micronekton volumes (milliliters per 1,000 m.³) from stations shown in figures 1, 6, 7, and 8, grouped by distance in miles from the mainland coast*

[Data from tables 1 and 5; n means number of stations]

Micronekton components	<300 miles [1] (n=40)		300 to 600 miles [2] (n=19)		>600 miles [3] (n=10)	
	Mean	Median	Mean	Median	Mean	Median
			Ml./10³ m.³			
Myctophids	3.59	2.50	1.80	1.40	1.71	1.00
Leptocephali	3.30	2.20	1.00	.60	.39	.10
Gonostomatids	.90	.65	.52	.50	.20	.20
Total fishes	9.07	8.40	3.65	3.20	2.34	1.30
Euphausiids	1.73	.55	1.03	.30	.27	.20
Stomatopod (squillid) larvae	.46	.40	.10	<.10	.03	<.10
Sergestids	.66	.25	.31	.10	.06	<.10
Total crustaceans	9.22	3.60	3.67	2.00	.74	.65
Total cephalopods	1.67	.95	.30	.20	.15	.10
Total micronekton	19.96	14.00	7.62	5.10	3.23	2.35

[1] TO-58-1 stations 1, 48 to 146; TO-60-2 stations 1 to 9, 23 to 30, 42 to 50.
[2] TO-58-1 stations 3 to 16, 29 to 46; TO-60-2 stations 11 to 19, 32, 38, 55.
[3] TO-58-1 stations 18 to 27; TO-60-2 stations 35, 59 to 85.

TABLE 7.—*Means of standardized micronekton volumes from two groups of the 40 onshore stations of table 6*

[Data from table 1]

Micronekton component	8 stations with total micronekton volumes each ≥22.0 ml./10³m.³ [1]	32 stations with total micronekton volumes each <22.0 ml./10³m.³ [2]
	Ml./10³m.³	*Ml./10³m.³*
Fishes	15.48	7.47
Crustaceans	32.26	3.46
Cephalopods	3.22	1.28
Total	50.96	12.21

[1] TO-58-1 stations 49, 63, 77, 81, 142, 144B, 146; TO-60-2 station 6.
[2] Stations in table 6, footnote 1, except those in footnote above.

from the eastern tropical Pacific because of the differences in sampling gear.

The distribution of leptocephali, the second largest group by volume among the fishes, is shown in figure 10. Standardized volumes are again higher near the coast than offshore (table 6), but they decline toward the south (table 5) and possibly also to the north. On a cruise made in June 1964, the mean standardized volume of leptocephali recorded at seven stations along the west coast of Baja California was < 0.1 ml. per 1,000 m.³ Leptocephali have been recorded in micronekton catches off the United States west coast and in the central Pacific, but apparently in much smaller quantities than in the coastal waters of the eastern tropical Pacific (Aron, 1959, 1962a; Pearcy, 1964; King and Iversen, 1962).

The distribution of gonostomatids—mainly *Vinciguerria* spp., as shown in table 3—is similar in its general features to the distribution of total fishes (fig. 6) and is, therefore, not shown. Volumes decline from onshore to offshore (table 6), and the volumes in table 5 show no obvious change with latitude for stations located at similar distances from the coast.

Similar data for two of the more common crustaceans, euphausiids and stomatopod (squillid) larvae, are given in figures 11 and 12. Euphausiids (fig. 11) are more abundant onshore than offshore (table 6) and may increase in biomass toward the poles. Figure 11 and table 5 show higher concentrations south of the Equator than elsewhere, and similar concentrations occurred on a cruise made in June 1964 along the west coast of Baja California (mean standardized volume for seven stations, 14.6 ml. per 1,000 m.³). Euphausiids are well represented in the material from Pacific regions farther north and west (Aron, 1959, 1962a; King and Iversen, 1962), although, again, the nature of the collecting gear used in those regions prevents quantitative comparisons with the eastern tropical Pacific.

The distribution of volumes of stomatopod larvae (fig. 12) is similar to that of leptocephali: higher onshore than offshore (table 6), and diminishing polewards. Figure 12 and table 5 show low concentration south of lat. 10° S., and similar concentrations occurred on a cruise made in June 1964 along the west coast of Baja California (mean standardized volume for seven stations, 0.1 ml. per 1,000 m.³). Stomatopod larvae were not mentioned by Aron (1959, 1962a) in his reports on micronekton collections west of the United States. King and Iversen (1962) obtained them fairly regularly in central Pacific waters between about lat. 19° S. (the southern limit of their sampling) and lat. 35° N.; they were not taken north of lat. 35° N.

The distribution of sergestids is similar in its general features to the distribution of stomatopod larvae and is, therefore, not shown. Volumes decline from onshore to offshore (table 6), and from the tropics toward the poles; all volumes ≥ 1.0 ml. per 1,000 m.³ in table 5 are from stations located between lat. 15° N. and 15° S.

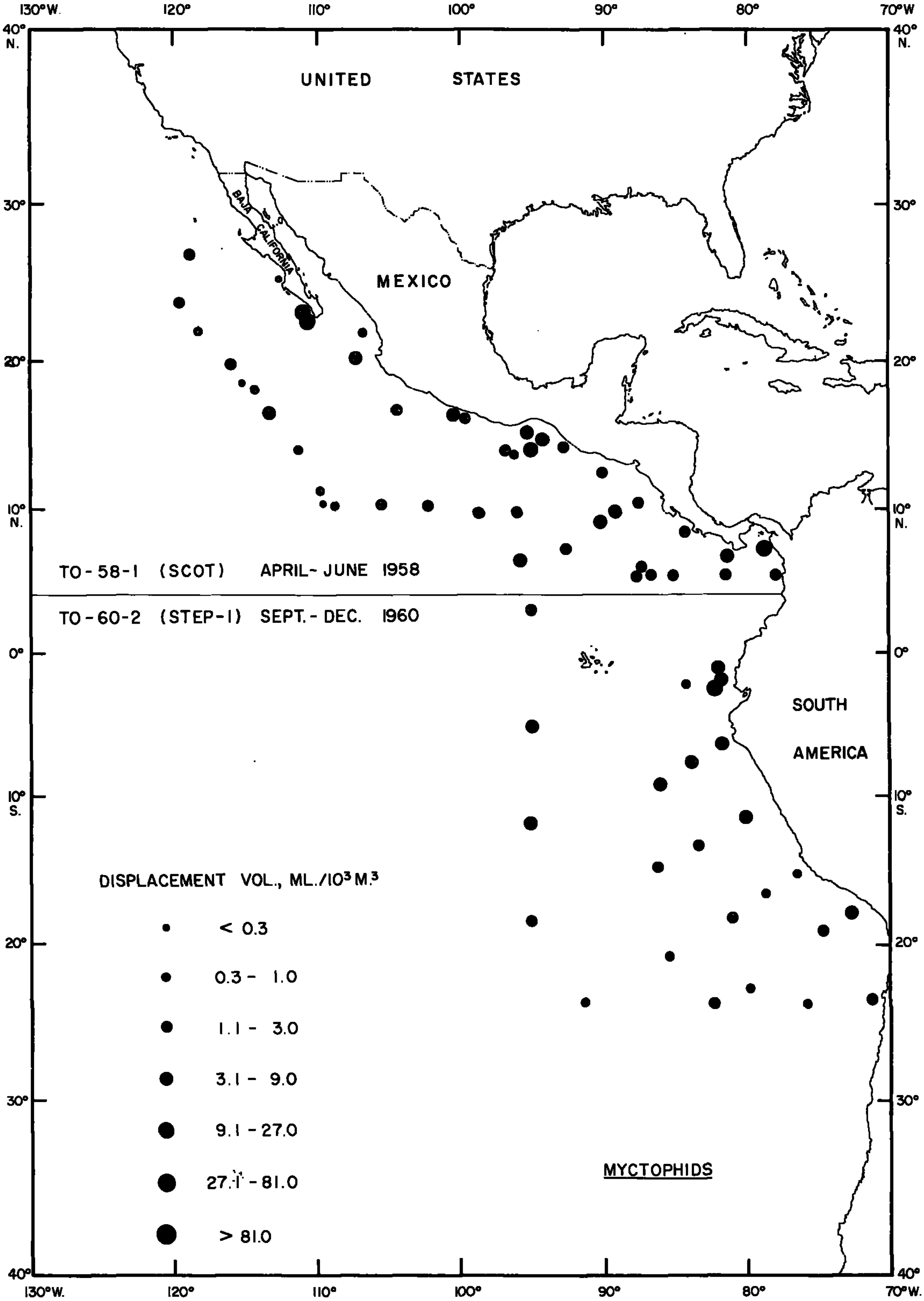

FIGURE 9.—Distribution of standing crop (standardized volume) of myctophids taken in night micronekton hauls on cruises TO-58-1 and TO-60-2.

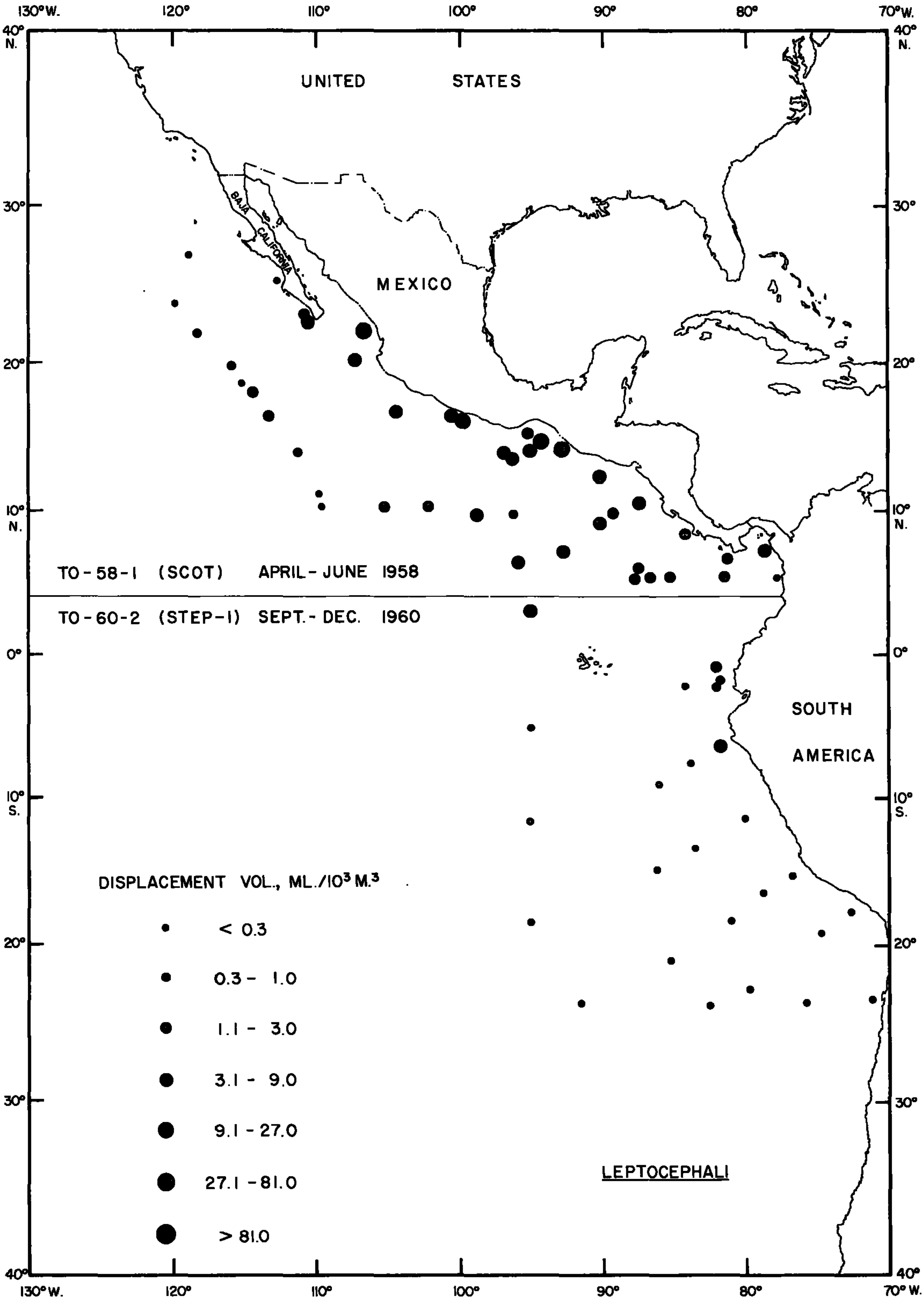

FIGURE 10.—Distribution of standing crop (standardized volume) of leptocephali taken in night micronekton hauls on cruises TO-58-1 and TO-60-2.

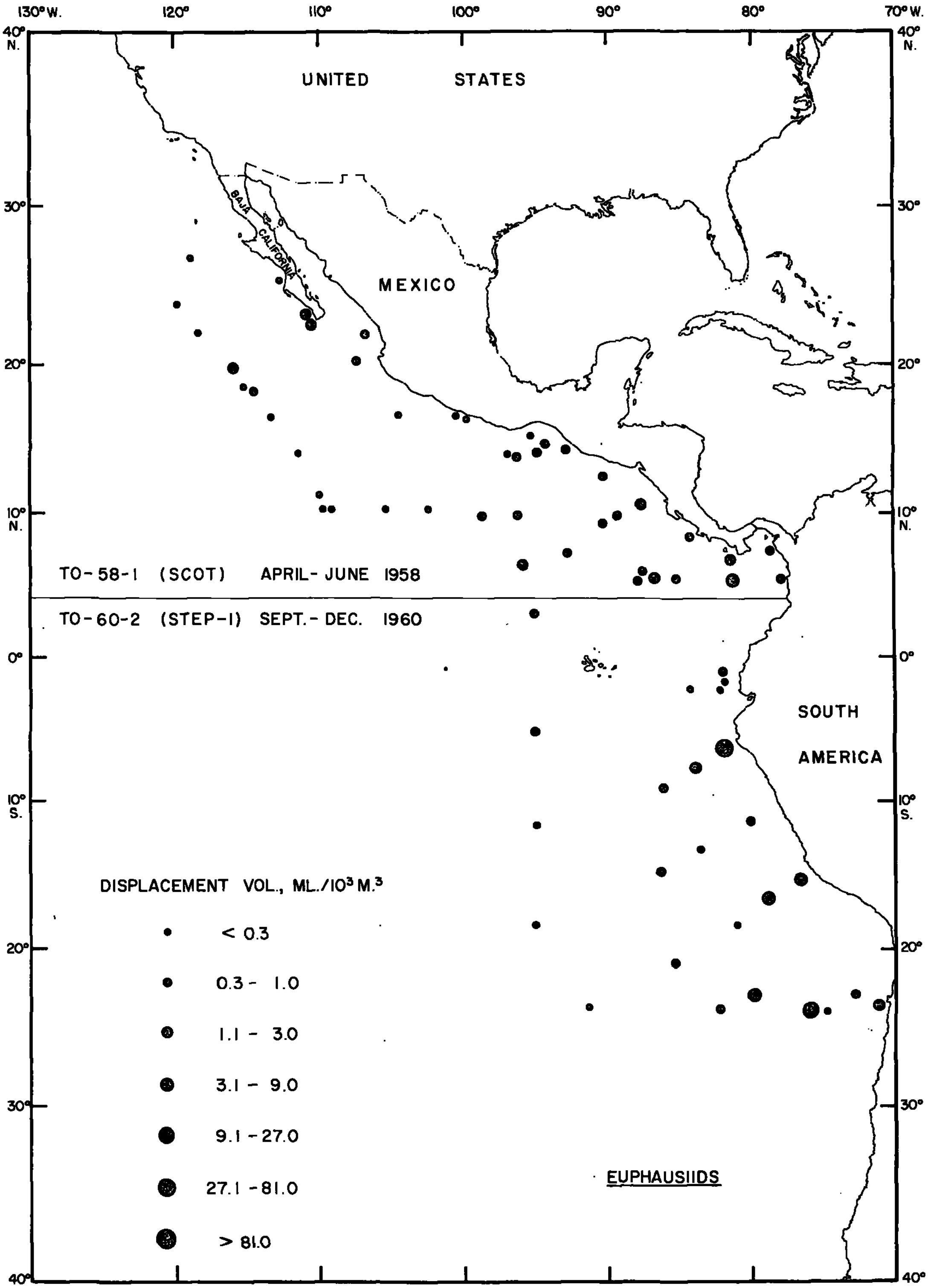

FIGURE 11.—Distribution of standing crop (standardized volume) of euphausiids taken in night micronekton hauls on cruises TO-58-1 and TO-60-2.

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Figure 13 gives similar data for three other important crustacean components of the micronekton, namely galatheids, portunids, and adult stomatopods (squillids). These forms were not taken during cruise TO-60-2 and occurred at only 17 stations on cruise TO-58-1, generally only one kind to a station (although both portunids and stomatopods were collected at station 96, in a 4:1 ratio by volume, see table 5). Their distribution is much more localized than the distribution of the other components previously discussed.

The galatheids were all adult *Pleuroncodes planipes* ("red crab"); a few small samples of galatheid juveniles, which could not be identified to species, are listed in tables 3 and 5 but are not shown in figure 13. This family was by far the largest in volume for the total micronekton of all the cruises (tables 3 and 4), but it was taken only in a small part of the region covered, where it was generally very abundant. The area of occurrence shown in figure 13 (and in fig. 15, which gives data for other cruises) is the west coast of Baja California and offshore in the California Current Extension as far west as long. 120° W. and as far south as lat. 18°30′ N. (Clarion Island); table 5 gives the data on which figures 13 and 15 are based. These western and southern limits are approximately the same as reported by Alverson (1963a) and Longhurst (1967); according to these authors, *P. planipes* also occurs farther east (across the Gulf of California) and farther north (to Monterey in central California). It did not occur in the material of Aron (1959, 1962a) or King and Iversen (1962). Because of the generally high standing crops of this animal encountered in area 1, this area yielded 47.4 percent of all the total micronekton collected in the 18 areas (table 3), although only 21 hauls (16.0 percent of the total for all areas) were made there (table 1); mean standardized volume of *P. planipes* for the hauls was 56.9 ml. per 1,000 m.^{3} (table 5). Area 1 includes several localities where coastal upwelling occurs seasonally, as noted earlier.

The portunid material of figures 13 and 15 was 99.4 percent *Portunus affinis* (table 3). Portunids were taken in the 1.5-m. net only along the coast from southeastern Mexico to northern Colombia, to about 200 nautical miles (370 km.) offshore. Alverson (1963a) charted a distribution of *P. affinis* which has a greater range in latitude (about 23° N. to 10° S.) and a wider range offshore (to about 700 nautical miles—1,300 km.—from the continent). Aron (1959, 1962a) did not mention portunids; King and Iversen (1962) recorded only two individuals from the central Pacific, both from tropical latitudes.

The stomatopod adults (or near-adults—our specimens were pelagic, whereas adults are generally regarded as benthic) were even more localized than the galatheids and portunids. They were taken only along the coast of southeastern Mexico, especially in the Gulf of Tehuantepec (figs. 13 and 15). Alverson (1963a) noted that they occurred in tuna stomachs only in areas 4 and 5, which include the Gulf of Tehuantepec. Their abundance in that region may be associated in some way with the fact that the Continental Shelf is wider in the eastern part of the Gulf of Tehuantepec and in the western part of area 5 than it is along most parts of the eastern side of the eastern tropical Pacific.

Figures 14 to 16 give information for total fish, crustacean, and cephalopod micronekton taken in night hauls on four other cruises (TO-59-1, TO-59-2, TO-60-1, and TO-61-1), which were made only along the Pacific coasts of Mexico and Guatemala; to the extent that cruise TO-58-1 was concerned with that area, the information about it (the same as in figs. 6 to 8) has been included to facilitate comparison between seasons (see below). Figure 2 identifies the stations (see also table 1).

The main features of distribution by area which these figures show have already been mentioned. In figure 15, code letters indicate the kind of crustaceans which accounted for half or more of the volume of Crustacea at a particular station. Included were penaeids at station 59 of cruise TO-60-1, which contributed practically all the material of this family for all the cruises, as well as the groups listed above. Many of the stations had a heterogeneous crustacean fauna, of which no one group made up half or more of the volume (table 5); the number of these stations increased toward the tropics.

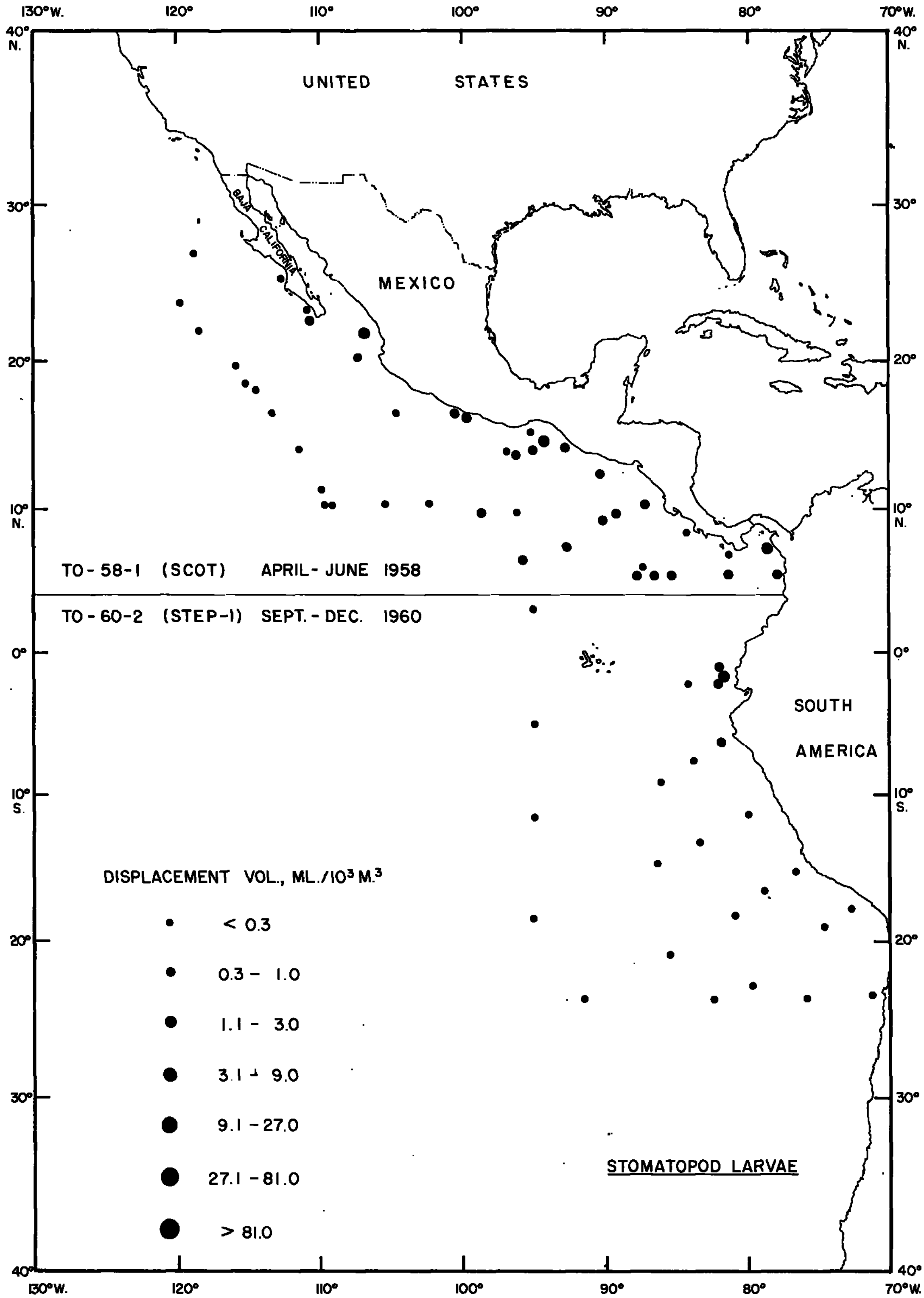

FIGURE 12.—Distribution of standing crop (standardized volume) of stomatopod (squillid) larvae taken in night micronekton hauls on cruises TO–58–1 and TO–60–2.

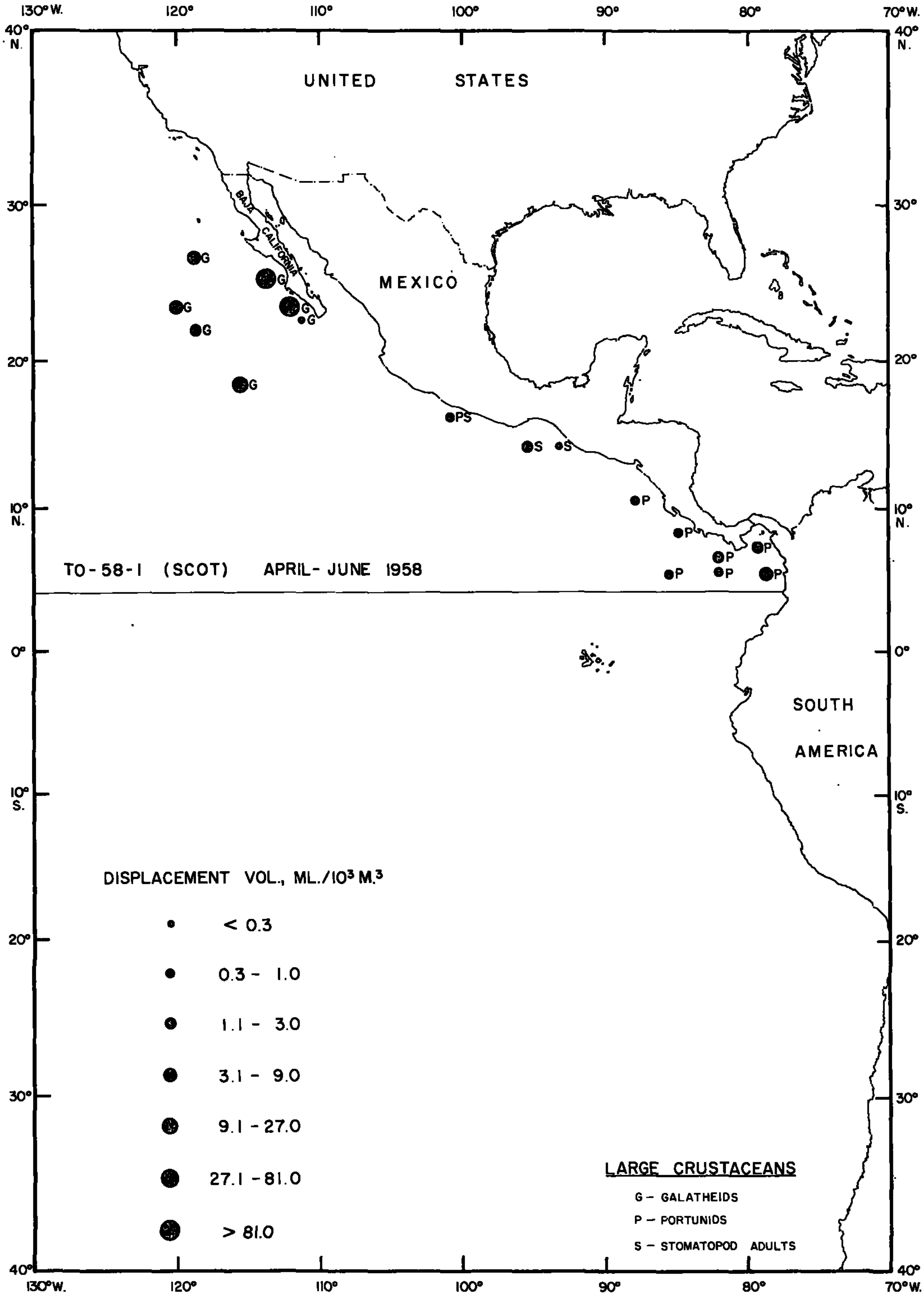

FIGURE 13.—Distribution of standing crop (standardized volume) of large crustaceans, namely galatheids, portunids, and adult stomatopods (squillids), taken in night micronekton hauls on cruises TO–58–1 and TO–60–2.

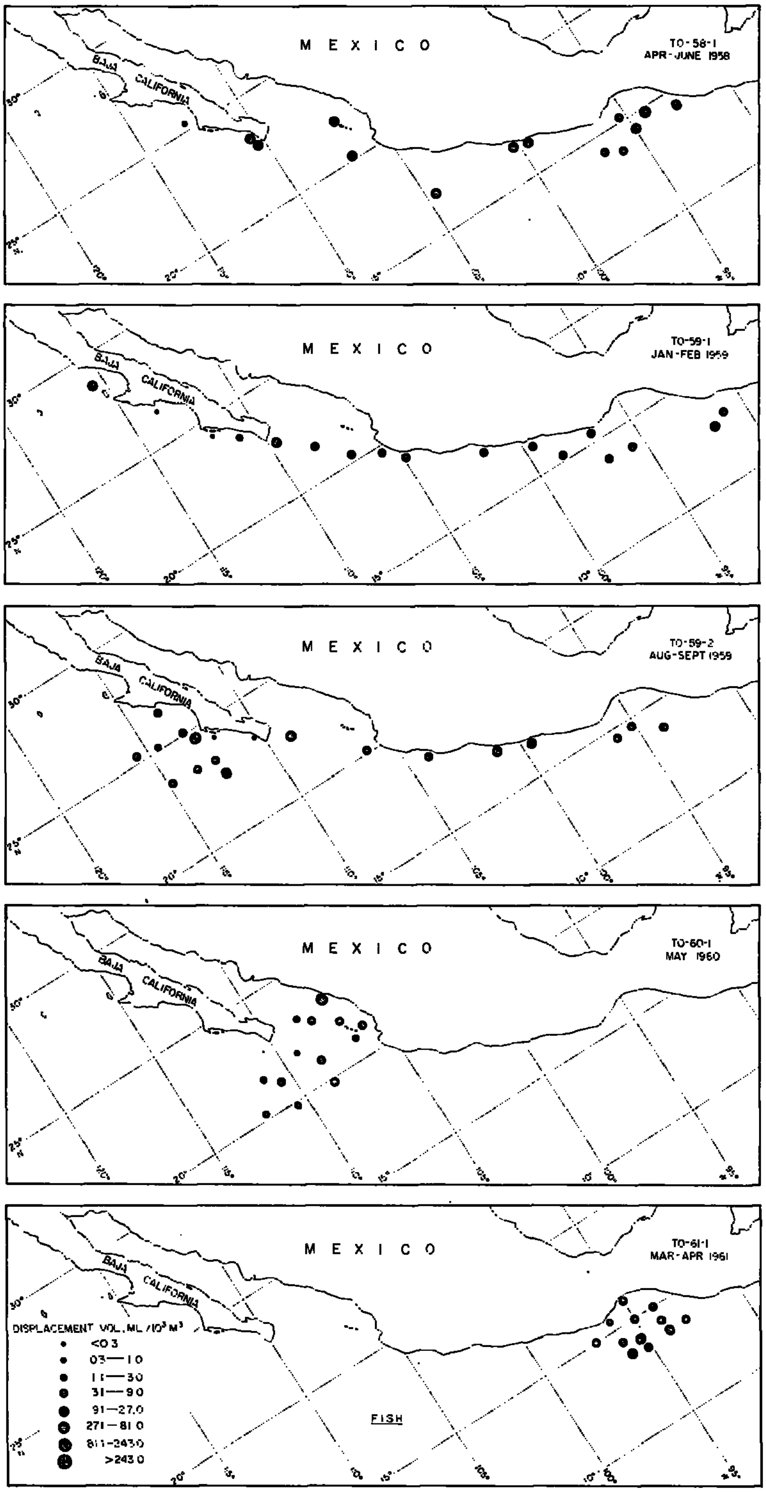

Figure 14.—Distribution of standing crop (standardized volume) of total fish taken in night micronekton hauls on cruises made along the Pacific coasts of Mexico and Guatemala.

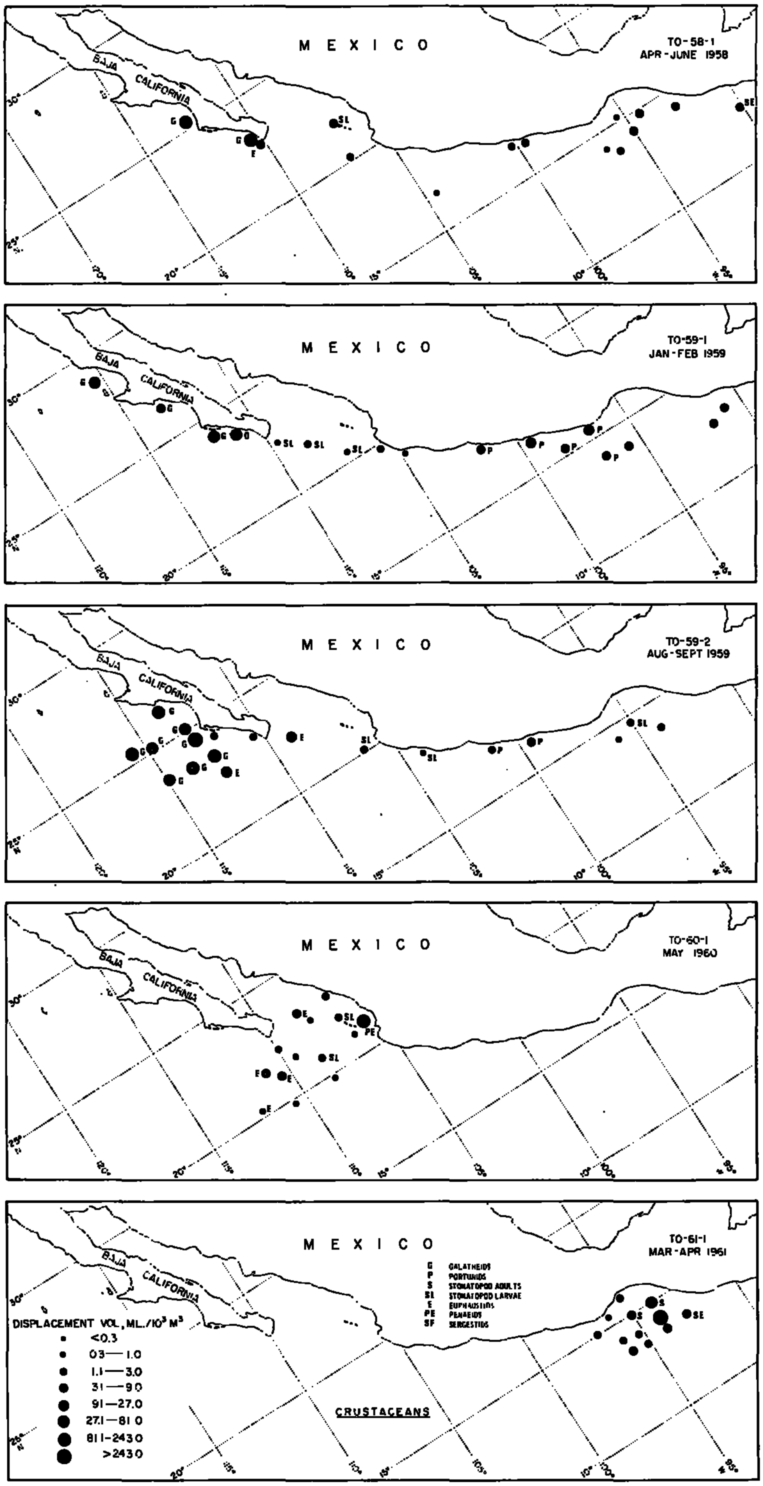

FIGURE 15.—Distribution of standing crop (standardized volume) of total crustaceans taken in night micronekton hauls on cruises made along the Pacific coasts of Mexico and Guatemala. Code letters, explained in the bottom panel, indicate the group, if any, which represented half or more by volume of the catch of crustaceans.

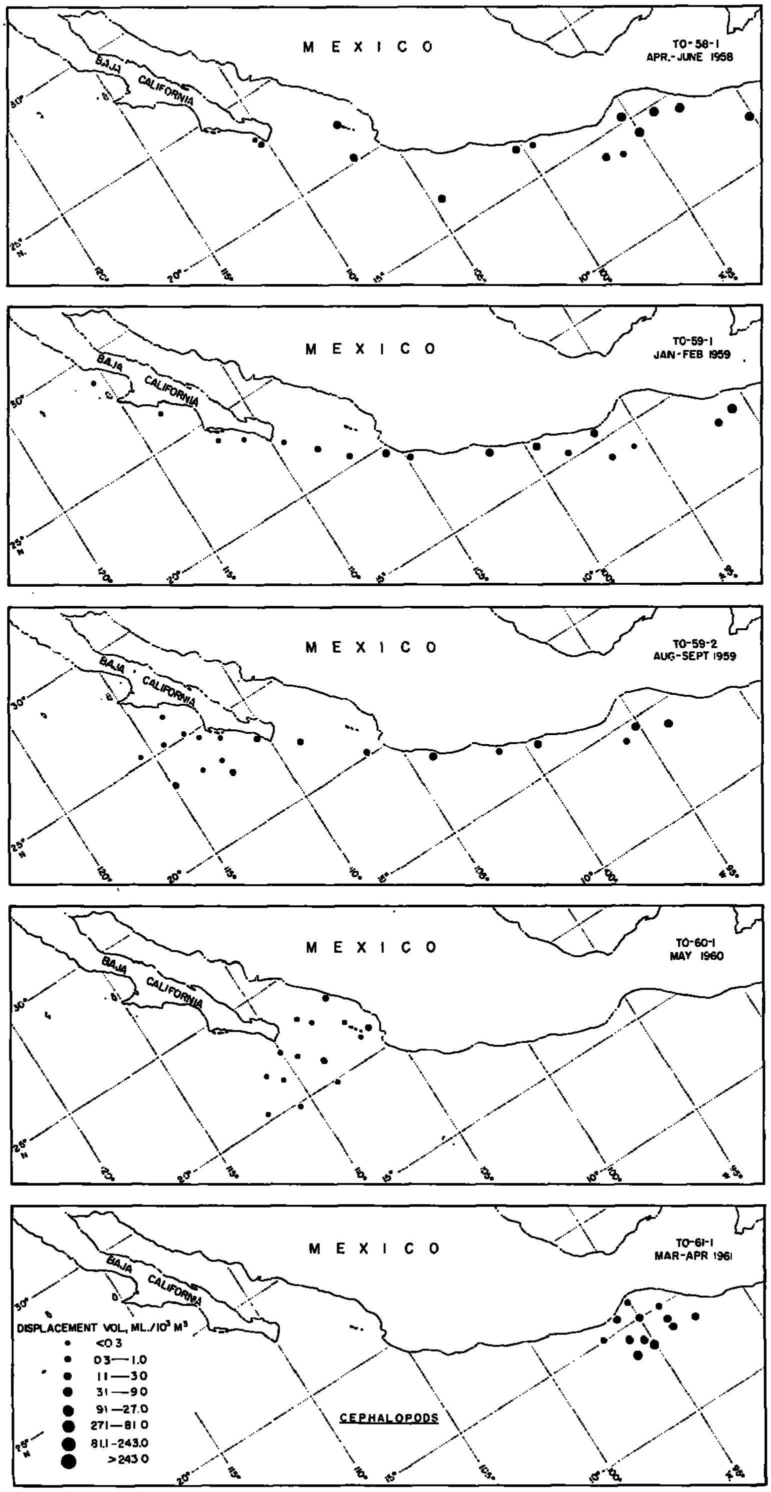

Figure 16.—Distribution of standing crop (standardized volume) of total cephalopods taken in night micronekton hauls on cruises made along the Pacific coasts of Mexico and Guatemala.

DISTRIBUTION OF MICRONEKTON BY SEASONS

The only series of cruises which could possibly reveal seasonal changes in the micronekton of standard night hauls is the series for the Pacific coasts of Mexico and Guatemala —cruise TO–58–1 in part, and cruises TO–59–1, TO–59–2, TO–60–1, and TO–61–1 —for which results are summarized in figures 14 to 16.

Except for TO–60–1, these cruises were planned to determine certain seasonal changes in the standing crop of micronekton, and other ocean properties, in the Gulf of Tehuantepec (long. 95° W.). Comparisons for this area are available for the months January–February (TO–59–1; no data for the center of the Gulf, because of bad weather), March–April (TO–61–1), May–June (TO–58–1), and August–September (TO–59–2). The data in figures 14 to 16 show that all three main components of the micronekton were scarcer by volume in this area in August–September than in March–June (possibly January–June). This difference is to be expected from the study by Blackburn (1962, 1963) of seasonal changes in the physical, chemical, and biological oceanography of the Gulf. The physical processes that cause shoaling of the pycnocline in certain areas and intermittent vertical mixing in parts of these areas are well developed in winter, and nutrient-rich water brought to the surface could be expected to result in a high crop of micronekton by spring. On the other hand, the eutrophic conditions decline through the spring, and the micronekton crop of late summer should be low. The time required for a crop of micronekton to grow has been discussed by Blackburn (1966a).

Off the west coast of Baja California, eutrophic conditions (coastal upwelling) are generally most pronounced in spring (Reid et al., 1958). If a lag of a few months is assumed between the appearance of a physical eutrophic process and the appearance of the resulting crop of micronekton (see previous paragraph), an increase in micronekton volume from winter through spring to late summer might be expected. The data for fish and cephalopods (figs. 14 and 16) are not inconsistent with this hypothesis, but they are generally scanty (except for August–September). For crustaceans (mainly *Pleuroncodes planipes*) the data in figure 15 suggest a rather high abundance throughout the whole period mentioned above. Longhurst (1967), who analyzed occurrences of *P. planipes* in zooplankton net hauls, drew a similar conclusion. Practically no quantitative data are yet available from micronekton hauls on occurrences of *P. planipes* in October through December, although it was abundant in hauls made with the high-speed net in December 1960. Data on *P. planipes* from zooplankton net hauls also are scanty at this period, and it is possible that the species is then less abundant than during the rest of the year, although the evidence is inconclusive (Longhurst, 1967). The distribution and ecology of this animal are being further studied in the Scripps Tuna Oceanography Research Program.

Elsewhere along the Mexican coast, namely across the mouth of the Gulf of California and thence southwards along the coast to the Gulf of Tehuantepec, no hypothesis about seasonal distribution of micronekton has been developed to test, and the scanty data in figures 14 to 16 do not suggest any particular seasonal change.

COMPARISON OF MICRONEKTON CAUGHT BY NETS AND TUNAS

Alverson (1963a), who sorted stomach contents of 2,846 yellowfin tuna [5] and 1,010 skipjack tuna [5] from the eastern tropical Pacific, published tables showing the percentage composition by volume of this material by taxa (including some species) for each of the areas 1 to 14 of figure 5.

Alverson's specimens of tuna were obtained from commercial catches made by surface hooking (bait-and-pole) or surface netting (purse seine). Yellowfin tuna are caught also by subsurface hooking (pelagic long-line) in parts of the eastern tropical Pacific, but few data on stomach contents are available for fish from that region (Juhl, 1955; Blunt, 1960).

Tables 8 to 14 compare the percentage composition of actual volumes of micronekton from standard night hauls with the actual volumes of stomach contents of yellowfin and skipjack tuna, for areas in which at least five hauls were available (namely areas 1, 2, 3, 4, 5, 6, and areas 11 and 12

[5] These two species of tuna were called, respectively, *Neothunnus macropterus* and *Katsuwonus pelamis*, by Alverson; according to Collette and Gibbs (1963), they should be known as *Thunnus albacares* (Bonnaterre) and *Euthynnus pelamis* (Linnaeus).

combined). The source of data for the net hauls is table 3 of this paper; the sources for the tuna stomach contents are various tables by Alverson (1963a).

Each of the tables 8 to 14 shows the percentage composition of fish, crustaceans, and cephalopods in material caught by the 1.5-m. net, by yellowfin tuna, and by skipjack tuna, respectively, for a particular area. Each of the three main categories is then further divided into components (generally families), of which each accounted for at least 0.5 percent by volume of the total material (from 1.5-m. net, yellowfin tuna, or skipjack tuna), for the area; other components (including material not identified to family) were lumped. The percentages in tables 12 and 14 for skipjack tuna differ slightly from the corresponding percentages in Alverson's tables, because he included small amounts of materials from stomachs of skipjack tuna (1.5 percent in area 5; 0.3 percent in areas 11 and 12) which are not regarded as micronekton. Alverson separated Thunnidae from Katsuwonidae in the fish families represented in his material, but they are here combined as Thunnidae, and have been so entered in table 3 and tables 8 to 14. Volumes for groups of animals in tables 8 to 14 include all ontogenetic stages unless otherwise stated.

TABLE 8.—*Percentage taxonomic composition of micronekton in area 1 of figure 5, from net hauls and tuna stomachs*

[21 standard night net hauls of 1.5-m. net (18,971 ml.); 567 stomachs of yellowfin tuna (37,489 ml.); 151 stomachs of skipjack tuna (4,661 ml.): asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Myctophidae	7.1		
Leptocephali	.5		
Gonostomatidae (*Vinciguerria*)	.7		
Engraulidae		9.6	28.3
Scomberesocidae			9.5
Scombridae		2.0	
Other fish	.1	7.8	5.6
Total fish	8.4	19.4	43.4
Galatheidae	81.5	78.1	36.8
Euphausiidae	8.1		19.2
Pasiphaeidae	1.5		
Other crustaceans	.3	.3	(*)
Total crustaceans	91.4	78.4	56.0
Cephalopods	.2	2.2	.6
Grand total	100.0	100.0	100.0

TABLE 9.—*Percentage taxonomic composition of micronekton in area 2 of figure 5, from net hauls and tuna stomachs*

[6 standard night net hauls of 1.5-m. net (827 ml.); 328 stomachs of yellowfin tuna (62,225 ml.); 48 stomachs of skipjack tuna (1,862 ml.); asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Myctophidae	16.2		
Leptocephali	9.4		
Gonostomatidae (*Vinciguerria*)	7.5	(*)	5.3
Gonostomatidae (others)	.8		
Ostracidae	(*)	21.1	.5
Thunnidae		19.9	
Tetraodontidae		15.6	
Serranidae		4.7	5.0
Exocoetidae		1.9	
Balistidae		.6	
Carangidae		.5	
Other fish	.8	3.7	10.1
Total fish	34.7	68.0	20.9
Galatheidae	56.8	31.1	78.3
Euphausiidae	4.6	(*)	.1
Squillidae (larvae)	1.0	(*)	(*)
Other crustaceans	1.8	.1	.2
Total crustaceans	64.2	31.2	78.6
Enoploteuthidae	.9		
Other cephalopods	.2	.8	.5
Total cephalopods	1.1	.8	.5
Grand total	100.0	100.0	100.0

TABLE 10.—*Percentage taxonomic composition of micronekton in area 3 of figure 5, from net hauls and tuna stomachs*

[18 standard night net hauls of 1.5-m. net (3,836 ml.); 155 stomachs of yellowfin tuna (12,062 ml.); 5 stomachs of skipjack tuna (247 ml.); asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Leptocephali	17.0		
Myctophidae	13.6	0.1	
Gonostomatidae (*Vinciguerria*)	7.0	.5	27.2
Gonostomatidae (others)	.7		
Bregmacerotidae	1.3	(*)	
Stomiatidae	.5		
Thunnidae	(*)	12.2	23.9
Coryphaenidae	(*)	7.0	
Polynemidae		1.6	34.1
Carangidae		1.5	
Balistidae		.7	
Exocoetidae	.2	.6	
Other fish	1.1	10.9	14.0
Total fish	41.4	35.1	99.2
Penaeidae	39.8		
Euphausiidae	6.9		
Squillidae (larvae)	4.3	.7	.8
Galatheidae	(*)	41.0	
Other crustaceans	2.7	.2	
Total crustaceans	53.7	41.9	.8
Enoploteuthidae	3.3		
Cranchiidae	1.5		
Onychoteuthidae		4.7	
Other cephalopods	.1	18.3	(*)
Total cephalopods	4.9	23.0	(*)
Grand total	100.0	100.0	100.0

TABLE 11.—*Percentage taxonomic composition of micronekton in area 4 of figure 5, from net hauls and tuna stomachs*

[29 standard night net hauls of 1.5-m. net (7,191 ml.); 247 stomachs of yellowfin tuna (14,839 ml.); 1 stomach of skipjack tuna (97 ml.); asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Leptocephali	28.3		
Myctophidae	21.7	1.8	
Gonostomatidae (*Vinciguerria*)	4.5	(*)	
Idiacanthidae	.8		
Heterosomata	.6		
Stomiatidae	.6		
Bregmacerotidae	.5		
Thunnidae	(*)	10.8	
Carangidae	(*)	10.4	
Exocoetidae		8.8	93.8
Balistidae		.8	
Other fish	2.2	8.0	6.2
Total fish	59.2	40.6	100.0
Portunidae	11.6	40.6	
Squillidae (adults)	6.6	13.5	
Squillidae (larvae)	3.2	.3	
Euphausiidae	1.3		
Sergestidae	1.3		
Unid. crab megalopa	.5		
Galatheidae	.2	1.0	
Other crustaceans	3.6		
Total crustaceans	28.3	55.4	
Enoploteuthidae	6.7		
Cranchiidae	5.1		
Ommastrephidae		.7	
Other cephalopods	.7	3.3	
Total cephalopods	12.5	4.0	
Grand total	100.0	100.0	100.0

TABLE 12.—*Percentage taxonomic composition of micronekton in area 5 of figure 5, from net hauls and tuna stomachs*

[10 standard night net hauls of 1.5-m. net (2,470 ml.); 319 stomachs of yellowfin tuna (16,256 ml.); 42 stomachs of skipjack tuna (661 ml.); asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Leptocephali	22.6		
Myctophidae	16.3	21.6	
Gonostomatidae (*Vinciguerria*)	3.4	.7	
Nemichthyidae	2.4		
Stomiatidae	1.9		
Idiacanthidae	1.9		
Bathylagidae	1.6		
Heterosomata	1.1	(*)	
Stromateidae	.9		
Exocoetidae		17.4	
Thunnidae	(*)	1.5	
Balistidae		.8	0.7
Sternoptychidae	(*)		1.0
Other fish	2.3	11.8	61.4
Total fish	54.4	53.8	63.1
Sergestidae	7.5		
Squillidae (larvae)	4.4	2.2	7.1
Euphausiidae	4.1	(*)	(*)
Portunidae	1.7	27.2	2.7
Penaeidae	1.2		
Phronimidae	1.0		
Squillidae (adults)	.6	1.1	
Oxycephalidae	.5		
Unid. crab megalopa	.3	.3	12.4
Galatheidae	(*)	1.8	
Other crustaceans	3.5	.2	.6
Total crustaceans	24.8	32.8	22.8
Enoploteuthidae	13.0		
Cranchiidae	4.1		
Argonautidae	(*)	.9	3.7
Other cephalopods	3.7	12.5	10.4
Total cephalopods	20.8	13.4	14.1
Grand total	100.0	100.0	100.0

Differences between micronekton from nets and tuna stomachs were rather marked as far as percentages of fish families are concerned. Myctophidae was the largest fish component of net material in most areas, but in tuna stomachs it was generally a small component, where it occurred at all. Only in area 5 (yellowfin tuna) and possibly area 6 (skipjack tuna) were the percentages for tuna comparable with those for nets. Leptocephali, a large item in net catches in most areas, were represented in tuna stomachs only as a negligible percentage in area 6 (yellowfin tuna). The occurrence of the gonostomatid fish *Vinciguerria* (which is shown separately from other members of the family because it is the only one recorded from tuna stomachs) was reasonably similar in the three kinds of material in tables 8 to 14 considered as a whole. Sternoptychidae, Bregmacerotidae, Nemichthyidae, Stomiatidae, Idiacanthidae, and Bathylagidae were significant components of net micronekton in some areas, but never of tuna stomach contents (unless they occurred in the unidentifiable fish remains, which have been included in "other fish"). Most of the families mentioned in this paragraph are generally regarded as mesopelagic.

On the other hand, some significant fish components of tuna stomach contents were absent or scarce in net catches—Engraulidae, Scombridae, Scomberesocidae, Ostracidae, Tetraodontidae, Thunnidae, Serranidae, Exocoetidae, Coryphaenidae, Polynemidae, Carangidae, Gadidae, and Trichiuridae. These families are generally regarded as epipelagic. Engraulidae occurred in tuna stomachs only in area 1, and their absence in net catches for that area may reflect the fact that they occur mainly in the northern half of the area, whereas the net hauls were made principally in the southern half; the 1.5-m. net has some capacity for catching engraulids, because a specimen of *Engraulis mordax* was caught in area 1 in June 1964, after the tables in this paper were compiled. The absence or scarcity of Ostracidae, Tetraodontidae, Serranidae, Gadidae, and Trichiuridae in

TABLE 13.—*Percentage taxonomic composition of micronekton in area 6 of figure 5, from net hauls and tuna stomachs*

[5 standard night net hauls of 1.5-m. net (1,365 ml.); 204 stomachs of yellowfin tuna (15,698 ml.); 517 stomachs of skipjack tuna (26,583 ml.); asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Myctophidae	33.2	1.4	5.7
Leptocephali	7.0	(*)	
Sternoptychidae	3.4		(*)
Gonostomatidae (*Vinciguerria*)	2.4	4.7	13.4
Nemichthyidae	1.5	(*)	
Bathylagidae	1.0		
Stomiatidae	.7		
Scopelarchidae	.5		
Scombridae		25.0	
Thunnidae		16.0	
Gadidae	.1	4.7	.3
Exocoetidae		.7	4.9
Carangidae	.1	3.2	.2
Trichiuridae	.4	1.2	6.4
Other fish	1.3	20.1	4.1
Total fish	51.6	77.0	35.0
Euphausiidae	32.0	(*)	59.9
Penaeidae	3.7		
Sergestidae	2.9		
Squillidae (larvae)	2.3	.4	.2
Portunidae		10.2	
Other crustaceans	4.0	.5	.7
Total crustaceans	44.9	11.1	60.8
Enoploteuthidae	2.0		1.6
Cranchiidae	1.0		.2
Ommastrephidae		1.4	
Other cephalopods	.5	10.5	2.4
Total cephalopods	3.5	11.9	4.2
Grand total	100.0	100.0	100.0

TABLE 14.—*Percentage taxonomic composition of micronekton in areas 11 and 12 of figure 5, from net hauls and tuna stomachs*

[6 standard night net hauls of 1.5-m. net (1,138 ml.); 72 stomachs of yellowfin tuna (4,880 ml.); 37 stomachs of skipjack tuna (2,321 ml.); asterisk means <0.05 percent]

Group of animals	Source of material		
	1.5-m. net	Yellowfin tuna	Skipjack tuna
	Percent	*Percent*	*Percent*
Myctophidae	19.8	1.0	
Leptocephali	17.5		
Idiacanthidae	3.0		
Stomiatidae	2.7		
Gonostomatidae (*Vinciguerria*)	2.5	(*)	
Bregmacerotidae	1.6		
Carangidae		9.8	2.8
Exocoetidae		1.5	89.8
Paralepididae	(*)	.5	
Other fish	1.4	6.6	6.8
Total fish	48.5	19.4	99.4
Euphausiidae	14.3	.1	
Sergestidae	12.1	1.4	
Portunidae	5.7	71.7	(*)
Squillidae (larvae)	4.0	(*)	(*)
Phronimidae	1.1	(*)	
Penaeidae	.7		
Palinuridae	.7		
Phrosinidae	.6		
Unid. crab megalopa	.5		(*)
Other crustaceans	5.0	1.2	
Total crustaceans	44.7	74.4	0.1
Enoploteuthidae	5.1	(*)	
Cranchiidae	1.3		
Loliginidae		(*)	
Other cephalopods	.4	6.2	.5
Total cephalopods	6.8	6.2	.5
Grand total	100.0	100.0	100.0

net catches, in areas where they were significant in tuna stomachs, may reflect the fact that only five or six net hauls were made in each of those areas. The other major differences in representation of families in net catches and tuna stomach contents probably indicate real differences between the catching performance of the net and of the tunas, discussed below. Carangidae are possibly underrepresented in the net material of area 4; some hauls taken in that area on cruise TO–62–1, which are neglected in most parts of this paper for reasons given elsewhere, were moderately rich in carangids (table 2).

A similar situation is suggested by the cephalopod data of tables 8 to 14, which show the main families in net catches little represented in tuna stomachs and vice versa; but the component "other cephalopods" (which is mainly material that was too much digested for identification) was relatively large in the tuna stomach contents, and the principal components of the net catches (Enoploteuthidae and Cranchiidae) might have occurred in it.

The crustacean components were much more alike than the fish and cephalopod components, qualitatively and quantitatively, in the micronekton from nets and in the stomachs of yellowfin and skipjack tunas. The galatheids were represented by large and somewhat comparable percentages in all three series in areas 1 and 2, where the material was mostly *Pleuroncodes planipes*. Percentages of similar material were very different in area 3 (very low in net catches, high in stomachs of yellowfin tuna, nil in the scanty material from skipjack tuna), but the percentage in net catches would have been higher if a special group of hauls from the Cape San Lucas front had been included (see Griffiths, 1965). Percentages of galatheids in areas 4 and 5 were small and similar for net catches and yellowfin tuna, and this material consists mainly of juveniles. Percentages of euphausiids in net micronekton were comparable with those in stomachs of skipjack tuna in some areas (especially 1 and 6) but the percentages were uniformly very low, or nil, in yellowfin tuna. Squillid larvae occurred in net catches and in stomachs of both tuna species in most areas in somewhat similar percentages, although those in net micronekton were generally higher than those in tuna stomachs. Adult squillids were a significant item only in areas 4 and 5. There they occurred comparably in net catches and stomachs of yellowfin tuna; the skipjack material, in which they did not occur, was scanty for those areas.

Percentages of portunids were less similar; they were generally much higher for yellowfin tuna stomachs than for net catches or skipjack tuna stomachs. Percentages of unidentified crab megalopa were variable, but generally low except in stomachs of skipjack tuna from area 5. Sergestids occurred in the net micronekton of some areas, sparsely in the yellowfin tuna stomachs of areas 11 and 12, and not at all in skipjack tuna. Other crustacean families and groups in tables 8 to 14 (Pasiphaeidae, Penaeidae, Phronimidae, Oxycephalidae, Phrosinidae, and Palinuridae) appeared in the net catches only and on the whole sparsely, in the areas to which the tables refer.

Possible reasons for the differences in percentage composition of the micronekton as caught by nets and by tunas are given in the following paragraphs. These reasons are in addition to the sparse and probably unrepresentative sampling for net micronekton and skipjack tuna stomachs in some areas, to which reference has already been made. It is also possible that tuna concentrate for feeding upon aggregations of certain species of prey; such species might, therefore, be better represented in tuna stomachs than in net catches.

(1) The nets were used at night, but most tunas from the surface-hook and surface-net fisheries are caught in the daytime. Because diurnal vertical movement causes many kinds of micronekton to be more plentiful in near-surface waters by night than by day, the nets and tunas probably sample different assemblages of micronekton. This point was discussed by King and Iversen (1962), who found some of the same differences between net-caught and tuna-caught micronekton as those described above.

(2) The nets fish through a layer of water some 90 to 95 m. thick, but the range of depth at which surface-caught yellowfin tuna and skipjack tuna feed is unknown. If, as seems likely, the tuna feed closer to the surface than the average depth of the net, epipelagic organisms would probably be better represented in tuna stomachs than in net catches.

(3) Tuna may fail to catch organisms which are available for capture, for lack of stimuli which release feeding behavior. Such stimuli can be visual or chemical (Magnuson, 1963, and references there). Visual stimuli could be lacking in the presence of suitable prey by night, or by day if the organisms are translucent.

(4) Nets, even at a speed of 5 knots, may fail to catch certain kinds of alert or strong micronekton that could be captured by tunas, which are credited with swimming speeds up to 40 knots in short bursts (Walters and Fierstine, 1964).

(5) Tuna stomachs frequently contain a significant proportion of semidigested material which is not identifiable to family. This was so in Alverson's material. Some families of micronekton might, therefore, be eaten by tunas despite their absence in the appropriate columns of tables 8 to 14.

A combination of the first and third points (netting by night, but tuna feeding by day) could explain the much better representation of myctophids, sternoptychids, nemichthyids, stomiatids, idiacanthids (and perhaps other mesopelagic fish families mentioned above, and sergestids), in the net-caught than in the tuna-caught micronekton. These groups are known to move closer to the sea surface by night (when tunas probably cannot see them well) than by day (when they are probably too deep, generally, for the tunas to catch). Alverson (1961) showed that tunas will catch the myctophid *Benthosema pterota* when it is available at the surface in daylight. It is not clear that this explanation could apply to leptocephali, but these animals might not be taken by tunas because of their translucence; the same might apply to the phronimids, oxycephalids, phrosinids, and palinurids (the last is represented in the net catches only as translucent larvae).

The second and fourth points (the net catching at greater depth and slower speed than the tunas) could explain the greater occurrence of active epipelagic fish (scombrids, scomberesocids, thunnids, exocoetids, coryphaenids, polynemids, carangids, and perhaps others) in tuna-caught than in net-caught micronekton. The Exocoetidae (flyingfishes) are a good example: only one small specimen was taken in the 131 hauls of the 1.5-m. net, but several, including large ones, have been taken at various times in hauls of the high-speed net. Under the circumstances in which we have used these nets, the high-speed net is obviously the more efficient (behaving more like a tuna) for catching exocoetids, in spite of its smaller mouth. This greater efficiency arises from the greater speed of hauling or because we have towed it only in the upper 10 m., where exocoetids are probably most abundant.

The apparent scarcity of enoploteuthid and cranchiid cephalopods in tuna stomachs might not be real, because of their inclusion in unidentifiable material, as noted in the fifth point above. This explanation might also apply to leptocephali.

For some of these reasons, it is perhaps surprising that the percentages for some other groups (Galatheidae, Euphausiidae, Squillidae, and *Vinciguerria*) agree as well as they do in the net-caught and tuna-caught micronekton; euphausiids certainly, and probably *Pleuroncodes planipes* (Longhurst, 1967), and *Vinciguerria* (Ahlstrom, personal communication), are more abundant near the surface by night than by day. These kinds of micronekton sometimes occur at the sea surface in full daylight, however, and possibly their daytime submergence is not so great or so regular as to make them entirely unavailable to tunas.

It is possible that records of the percentages of individual species of Crustacea, which are mostly not available at present, would remove some of the similarities which appear to exist between net catches and contents of tuna stomachs—for example, in the euphausiids. Such records would not affect the galatheids greatly, however, since nearly all were *Pleuroncodes planipes* in both the net catches and the contents of tuna stomachs. *Vinciguerria* would not be seriously affected either, because all of Alverson's specimens and most of mine were *V. lucetia*, although my material included a few *V. nimbraria*, and several specimens that were doubtful (see Ahlstrom and Counts, 1958, concerning *Vinciguerria* in the eastern Pacific).

These considerations give insufficient reason to doubt the commonly held opinion that yellowfin and skipjack tuna feed on most kinds of micronekton which occur in their habitat, with the qualification that the prey must occur under conditions in which the tuna could perceive them visually. The tunas are opportunistic feeders, within their sensory limitations. The only important exception to this generalization is the apparent failure of yellowfin tuna to eat euphausiids, which are much used by skipjack tuna. Efficient capture of euphausiids by large pelagic fish may require special behavior, however (see Blackburn, 1957, on the gempylid scombriform *Thyrsites atun*), and it is possible that these behavior patterns have not evolved in yellowfin tuna.

COMPARATIVE ABUNDANCE OF POTENTIAL TUNA PREY BY AREAS

From tables 8 to 14, and the tables of Alverson (1963a) which show percentage composition of tuna stomach contents for other areas, a list was made of families and other groups which made up 5 percent or more by volume of stomach contents of yellowfin and skipjack tunas in any one of the areas 1 to 14.[6] These groups were considered potential tuna prey in all areas where they occur. Groups which were not represented in the net hauls—the Engraulidae and Polynemidae—were disregarded. This omission left the following groups, which represent kinds of potential tuna prey which the net is capable of catching to some extent in standard night hauls:

Yellowfin tuna prey	*Skipjack tuna prey*
Fish:	Fish:
Gonostomatidae	Gonostomatidae
Myctophidae	Myctophidae
Exocoetidae	Exocoetidae
Thunnidae	Thunnidae
Carangidae	Serranidae
Stromateidae	Scomberesocidae
Coryphaenidae	Trichiuridae
Ostracidae	
Tetraodontidae	
Crustaceans:	Crustaceans:
Galatheidae	Galatheidae
Portunidae	Portunidae
Sergestidae	Euphausiidae
Squillidae (adults)	Squillidae (larvae)
	Phrosinidae
Cephalopods:	Unidentified crab megalopa
Ommastrephidae	

The total volume of net-caught potential prey for yellowfin tuna and for skipjack tuna was standardized (as explained above) for each area (1 to

[6] Stromateidae (table 3, and below) are equivalent to Nomeidae as listed by Alverson.

18). Although it cannot be assumed that each of the prey groups was captured by the net or by the tunas with the same degree of efficiency in each area, the standardized volumes may be compared from area to area (for the prey of each tuna species separately), to indicate broad quantitative differences and similarities among areas in the extent to which they support standing crops of potential tuna prey. Obviously, these volumes do not represent absolute concentrations of tuna prey.

Standardized volumes of skipjack tuna prey were higher than those of yellowfin tuna prey (table 15) for most areas, because they included euphausiids and squillid larvae. Volumes in area 1 were by far the highest, because of the great abundance of *Pleuroncodes planipes;* they are further discussed below. The next highest volumes were in areas 8 and 10, but they are based on only two hauls per area and may, therefore, not be representative; volumes for areas 9, 14, and 15 are likewise ignored because only three or four hauls were made per area.

TABLE 15.—*Standardized volumes (ml./10^3m.^{3}) of total potential prey of yellowfin and skipjack tuna as taken in standard night hauls of the 1.5–m. net, for the areas shown in figure 5*

[Actual volumes (ml.) from table 3, other data from table 1; for further explanation see text]

Area	Hauls	Total time	Prey of yellowfin tuna		Prey of skipjack tuna	
			Actual	Standardized	Actual	Standardized
	Number	*Minutes*	*Ml.*	*Ml./10^3m.^{3}*	*Ml.*	*Ml./10^3m.^{3}*
1	21	984	16,951	63.7	18,497	69.5
2	6	383	674	6.5	716	6.9
3	18	839	845	3.7	1,255	5.5
4	29	1,546	3,277	7.8	3,039	7.3
5	10	565	747	4.9	748	4.9
6	5	262	527	7.5	961	13.5
8	2	96	318	12.2	428	16.5
9	3	195	28	.5	35	.7
10	2	132	481	13.4	501	13.9
11 and 12	6	387	455	4.3	528	5.0
14	4	200	152	2.8	318	5.8
15	3	194	270	5.1	274	5.2
16	7	435	418	3.5	437	3.7
17	7	333	414	4.6	414	4.6
18	8	406	170	1.6	410	3.7
Total	131					

Comparisons may now be made between volumes for areas 1, 2, 3, 4, 5, 6, and 11–12, which have a significant commercial surface fishing for yellowfin and skipjack tunas and volumes for areas 16, 17, and 18, in which there is no significant fishery (see Alverson, 1960, 1963b, for distribution of the surface fishery). The lowest volume of yellowfin tuna prey in an area which supports a fishery was 3.7 ml. per 1,000 m.^{3}, in area 3; the lowest for skipjack tuna prey was 4.9 ml. per 1,000 m.^{3}, in area 5. Volumes for area 16 were slightly below, and those for area 18 well below, these figures; but in area 17 the volume was higher than 3.7 for prey of yellowfin tuna and only slightly lower than 4.9 for prey of skipjack tuna.

Such small differences among areas should be interpreted very cautiously, for reasons given above. It could be argued, however, that area 17 has a sufficiently high standing crop of tuna prey to support a standing crop of yellowfin tuna, and possibly one of skipjack tuna, which might profitably be fished. Of course, the presence of an adequate crop of tuna food does not guarantee the presence of tuna, as is shown by the general scarcity of skipjack tuna in areas 3 and 4 in the years in which the micronekton was collected (Alverson, 1960, 1963b); high sea temperatures may have been limiting in those years, however (Blackburn and associates, 1962; Blackburn, 1963). A more conservative conclusion from the data of table 15 is that some areas west of the existing surface fishery might support commercial surface-fishing operations and should be further explored; and that area 17 is likely to be the best and area 18 the poorest of the three areas considered, as far as abundance of yellowfin and skipjack tunas are concerned.

A Japanese commercial subsurface hook fishery for yellowfin tuna exists at about the same latitudes as area 17; it is located west of area 17 but seems to be extending into that area. Similar fishing is carried on west of, and to some extent in, area 16, but the catch per unit of fishing is lower than in area 17. No longline fishery exists in or near area 18 (Suda and Schaefer, 1965). Skipjack tuna are not commonly taken by subsurface hooking.

The high standardized volumes of potential tuna prey in area 1 warrant comment. Although area 1 is eutrophic, its mean rate of primary production appears to be comparable with that of some other areas, such as 5 and 6, in which tuna prey are much scarcer (Holmes, 1958; Hela and Laevastu, 1962; Blackburn, 1966b). The special feature of area 1, as far as trophic relationships of yellowfin and skipjack tunas are concerned, appears to be the presence of an abundant herbivore, *Pleuroncodes planipes*, which is large enough to release feeding behavior in tunas. By feeding on this animal, yellowfin and skipjack tunas probably consume a much greater fraction of the organic material produced by photosynthesis in this area than they do in other areas where herbivores are small and carnivores make up most of the tuna diet (see King and Iversen, 1962, table 15, for probable trophic levels of several groups of tuna prey listed above).

QUANTITATIVE COMPARISON OF CATCHES BY 1.5-M. AND HIGH-SPEED NETS

Reference was made previously to qualitative differences between the catches of the 1.5-m. net and the high-speed net; the example given was the greater representation of flyingfish in catches of the high-speed net. The high-speed net was hauled much faster and much closer to the sea surface, on the average, than the 1.5-m. net. It is of interest to compare quantitatively certain areal distributions of micronekton as measured by the two nets for the cruises (TO-59-2 and TO-60-2) for which both sets of material have been fully worked up. The volumes were standardized, as explained earlier, so that all volumes for both nets are comparable in ml. of micronekton per 1,000 $m.^3$ of water strained.

Figure 17 summarizes the distribution of total micronekton (fish, crustaceans, and cephalopods combined) in standard night hauls of the 1.5-m. net on cruise TO-60-2; the volumes are the sum of the volumes shown for the same stations in figures 6, 7, and 8. Figure 18 gives similar information for night hauls of the high-speed net (only hauls lasting between 2½ and 3½ hours) on the same cruise.

As far as they are comparable, figures 17 and 18 show similar trends in distribution of micronekton from place to place within the area, especially from onshore (high volumes) to offshore (low volumes) for the area as a whole. Standardized volumes for the 1.5-m. net, however, tend to be about 9 or 10 times higher than those of the high-speed net, in the same area on the same night.

Figure 19 shows a similar comparison, for part of cruise TO-59-2 for catches of red crab (*Pleuroncodes planipes*) only. As far as the 1.5-m. net and high-speed net catches occur in the same areas, they are broadly comparable in general distribution—particularly as between the area east of long. 112° W., where the crabs were scarce, and the rest of the region, where they were abundant. It is again evident that the volumes from the 1.5-m. net were generally much higher than volumes from the high-speed net when both were available at the same time and place.

The reason for the difference between the volumes is uncertain. Possible reasons that have been advanced are: (1) the catches in the high-speed net tend to get shredded by the fast towing so that much material is lost through the meshes; (2) micronekton is actually scarcer at 10 m., where the high-speed net fishes, than it is over the whole water column 0-90 m., where the 1.5-m. net fishes; and (3) the micronekton at 10 m. is disturbed by the ship, and some of it submerges or escapes laterally before the net reaches it. Inspection of catches shows that the first point probably does not apply to the extent that would be required to explain the observed difference, although it does apply to some extent; for instance, it is common to find fish reduced to skeletons in the high-speed net. There is no information on which to base a judgment on the other points. Aron (1962b) noted that catches of the Isaacs-Kidd midwater trawl were invariably low when the net was towed at the surface and attributed this effect to disturbance by the ship.

SUMMARY

Micronekton (fishes, crustaceans, and cephalopods about 1 to 10 cm. long) was collected on oceanographic cruises in most parts of the eastern tropical Pacific Ocean, mainly from 1958 to 1961. The most commonly used collecting method was to haul a large net (mouth 1.5 m. square; length about 5.8 m.) of uniform mesh size obliquely through the upper 90 m. of water at night, at a ship speed of 5 knots. Catches (total micronekton and its family components) were measured by displacement volume; these volumes were then standardized to 1,000 $m.^3$ of water strained, by using data on the length of the haul and an empirical filtration coefficient of 76 percent. These measurements of standing crop of micronekton are superior to those that can be obtained with mixed-mesh nets or trawls of the same general size.

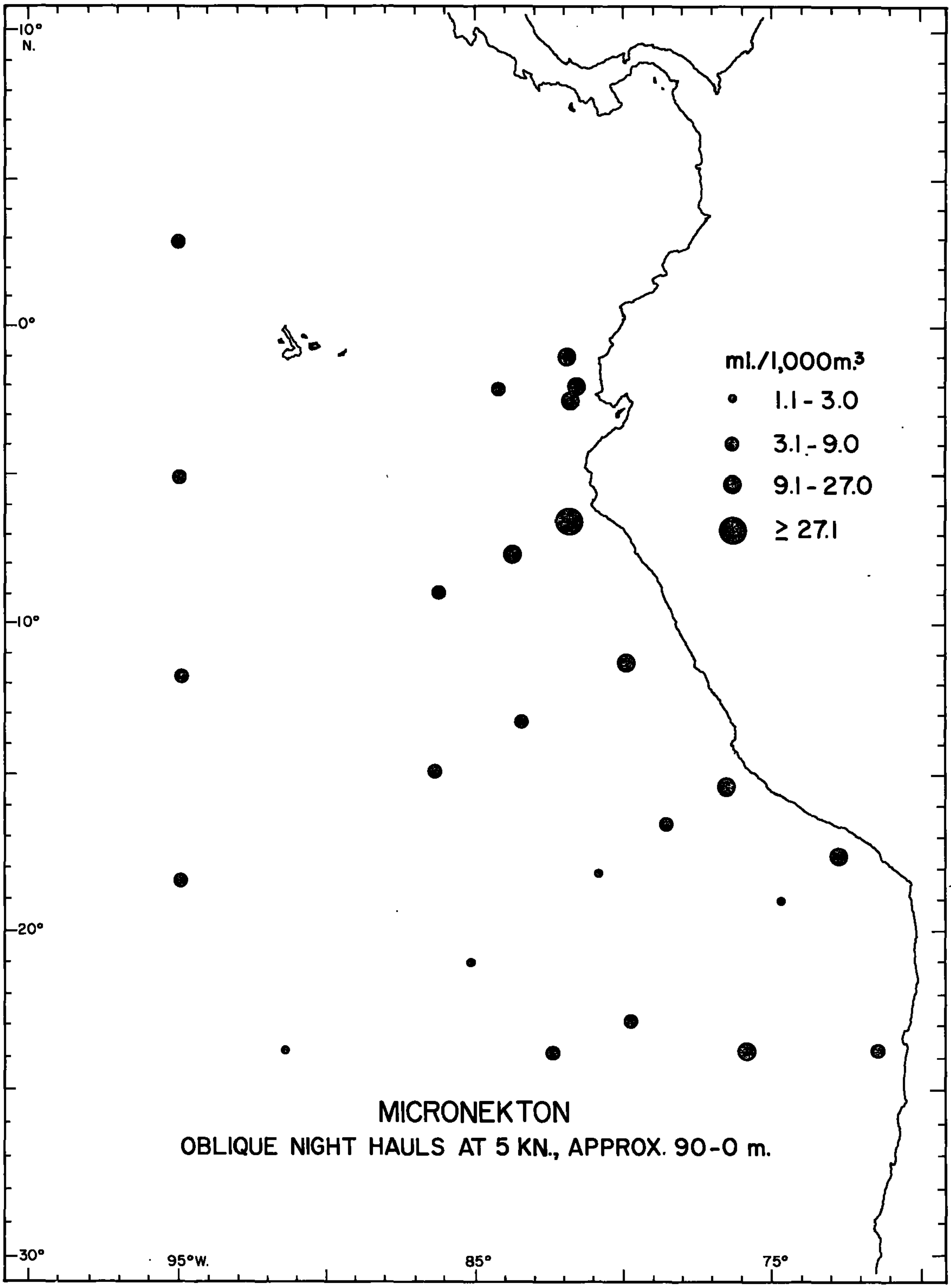

FIGURE 17.—Distribution of standing crop (standardized volume) of total micronekton taken in standard night hauls of the 1.5-m. net on cruise TO-60-2.

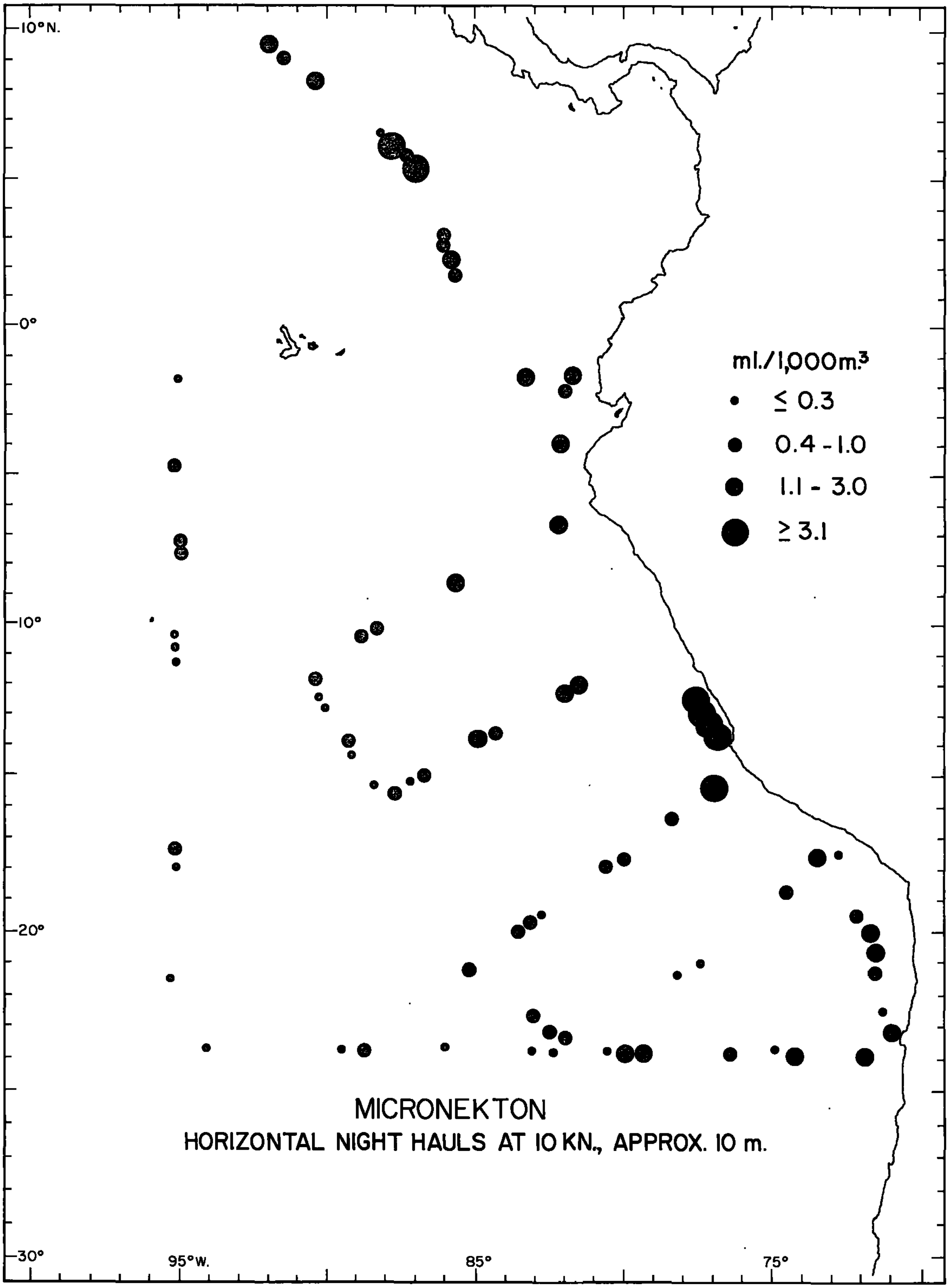

FIGURE 18.—Distribution of standing crop (standardized volume) of total micronekton in night hauls of 2½ to 3½ hours' duration with the high-speed net on cruise TO-60-2.

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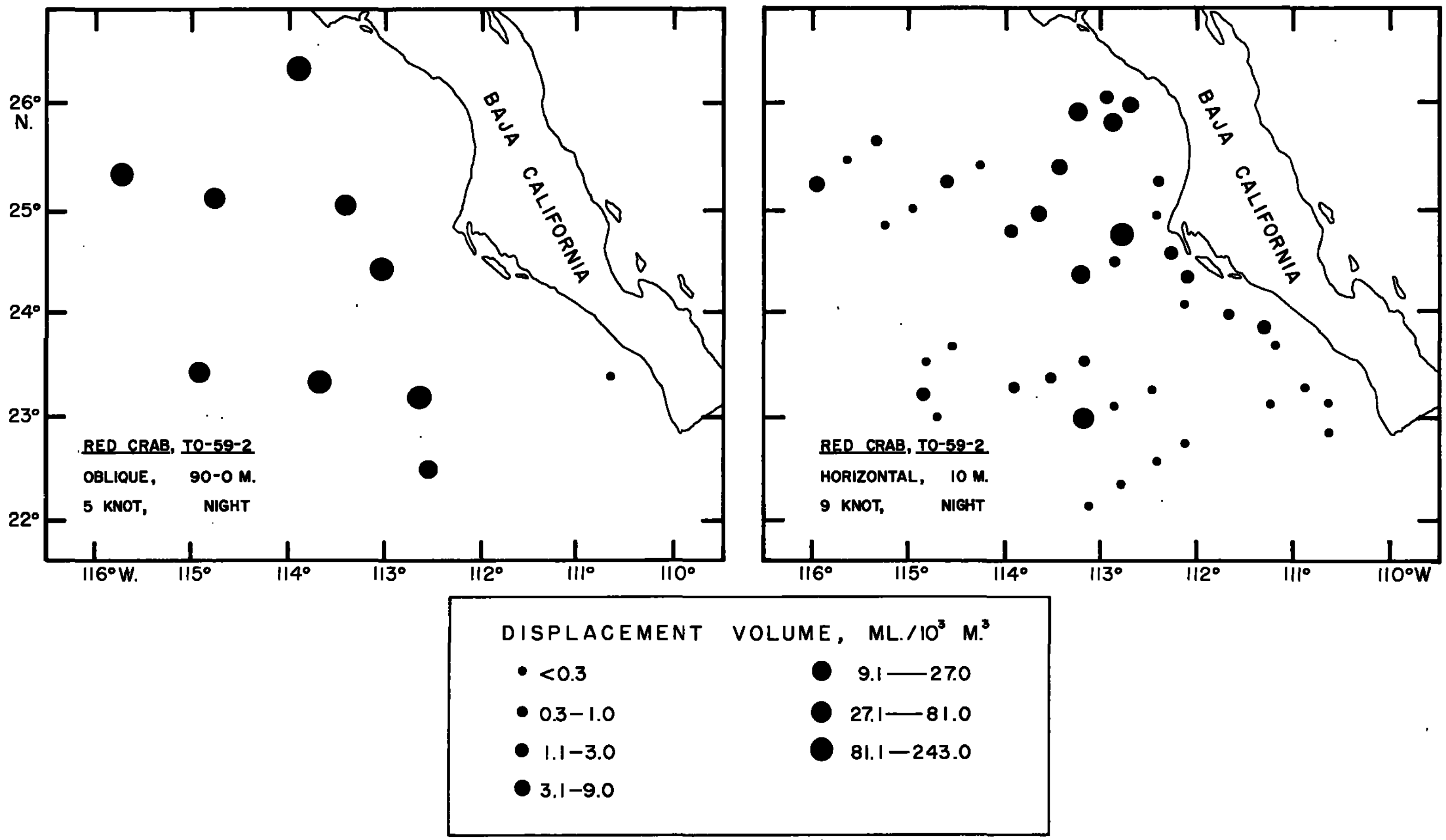

FIGURE 19.—Distribution of standing crop (standardized volume) of *Pleuroncodes planipes* taken in standard night hauls of the 1.5-m. net (left) and in night hauls of the high-speed net (right), on part of cruise TO-59-2. Duration of hauls of the high-speed net ranged from 2 to 3 hours.

Ten families (Myctophidae, Gonostomatidae, Galatheidae, Euphausiidae, Penaeidae, Squillidae, Portunidae, Sergestidae, Enoploteuthidae, and Cranchiidae), and one suborder (Apodes; leptocephali only), which was not sorted to family, made up 93.4 percent of the total volume of micronekton collected in 131 standard night hauls. The areal distribution of standing crop was broadly the same for most of the groups; crops were higher onshore than offshore and highest in onshore areas where physical processes that enrich the upper water layer are known to operate. Three groups of crustaceans (Galatheidae, Portunidae, and adult Squillidae) were confined to relatively small, mainly onshore, areas. The data were insufficient for comparison of standing crops at different seasons, except in the Gulf of Tehuantepec, where the crops appear to fall a few months after enriching physical processes decline.

The composition of the net-caught micronekton was compared with the composition of stomach contents of yellowfin and skipjack tunas as published elsewhere, for certain areas of the eastern tropical Pacific. As compared with tuna, the nets caught different fishes, but broadly similar crustaceans. The differences are attributed to: the fact that the nets catch large quantities of night-rising mesopelagic fishes which do not occur in the tunas' habitat by day, and are probably not seen by the tunas at night; leptocephali are probably not perceptible to tunas in the daylight, since they are translucent; and the more active epipelagic fishes are more efficiently caught by tunas than by nets.

Families which made up at least 5 percent of the stomach contents of yellowfin or of skipjack tuna in any area were considered to be potential prey for the species. To the extent that the net sampled these families, comparisons could be made of potential tuna prey in ml. per 1,000 m.³ in different areas (with and without a commercial fishery), for which net data were available. The comparisons suggested that one virtually unfished area supports a crop of potential prey of yellowfin tuna which is higher than that in one of the well-fished yellowfin tuna areas; and also a crop of potential skipjack tuna prey which is nearly as high as that in one of the well-fished skipjack tuna areas. This area, which lies west of the existing fishery area for surface tuna along the coasts of Ecuador and northern Peru, might, therefore, contain yellowfin or skipjack tuna in commercial quantities. Crops of potential tuna prey are much higher off western Baja California than elsewhere; the principal prey species there is the galatheid pelagic crab *Pleuroncodes planipes*, which is in part a herbivore (giving the tunas a more efficient food chain than in most other areas) and extremely abundant.

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LITERATURE CITED

AHLSTROM, ELBERT H., and ROBERT C. COUNTS.
1958. Development and distribution of *Vinciguerria lucetia* and related species in the eastern Pacific. U.S. Fish Wildl. Serv., Fish. Bull. 58: 363–416.

ALVERSON, FRANKLIN G.
1960. Distribution of fishing effort and resulting tuna catches from the eastern tropical Pacific by quarters of the year, 1951–1958. Inter-Amer. Trop. Tuna Comm., Bull. 4: 321–446. [English and Spanish.]

1961. Daylight surface occurrence of myctophid fishes off the coast of Central America. Pac. Sci. 15: 483.

1963a. The food of yellowfin and skipjack tunas in the eastern tropical Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 7: 295–396. [English and Spanish.]

1963b. Distribution of fishing effort and resulting tuna catches from the eastern tropical Pacific Ocean, by quarters of the year, 1959–1962. Inter-Amer. Trop. Tuna Comm., Bull. 8: 319–379. [English and Spanish.]

ARON, WILLIAM.
1959. Midwater trawling studies in the North Pacific. Limnol. Oceanogr. 4: 409–418.

1962a. The distribution of animals in the eastern North Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Bd. Can. 19: 271–314.

1962b. Some aspects of sampling the macroplankton. Cons. Perma. Int. Explor. Mer, Rapp. Proc.-Verb. Réun. 153: 29–38.

AHRON, WILLIAM, ELBERT H. AHLSTROM, BRIAN McK. BARY, ALLAN W. H. BÉ, and WILLIAM D. CLARKE.
1965. Towing characteristics of plankton sampling gear. Limnol. Oceanogr. 10: 333–340.

BENNETT, EDWARD B.
1963. An oceanographic atlas of the eastern tropical Pacific Ocean, based on data from Eastropic Expedition, October-December 1955. Inter-Amer. Trop. Tuna Comm., Bull. 8: 33–165. [English and Spanish.]

BLACKBURN, MAURICE.
1957. The relation between the food of the Australian barracouta, *Thyrsites atun* (Euphrasen), and recent fluctuations in the fisheries. Aust. J. Mar. Freshwater Res. 8: 29–54.
1962. An oceanographic study of the Gulf of Tehuantepec. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 404, 28 pp.
1963. Distribution and abundance of tuna related to wind and ocean conditions in the Gulf of Tehuantepec, Mexico. FAO Fish. Rep. 6: 1557–1582.
1966a. Relationships between standing crops at three successive trophic levels in the eastern tropical Pacific. Pac. Sci. 20: 36–59.
1966b. Biological oceanography of the eastern tropical Pacific: summary of existing information. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 540, 18 pp.

BLACKBURN, MAURICE, and ASSOCIATES.
1962. Tuna oceanography in the eastern tropical Pacific. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 400, 48 pp.

BLACKBURN, MAURICE, RAYMOND C. GRIFFITHS, ROBERT W. HOLMES, and WILLIAM H. THOMAS.
1962. Physical, chemical, and biological observations in the eastern tropical Pacific Ocean: three cruises to the Gulf of Tehuantepec, 1958–1959. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 420, 170 pp.

BLUNT, C. E.
1960. Observations on the food habits of longline caught bigeye and yellowfin tuna from the tropical eastern Pacific 1955–1956. Calif. Fish Game 46: 69–80.

BRANDHORST, WILHELM.
1958. Thermocline topography, zooplankton standing crop, and mechanisms of fertilization in the eastern tropical Pacific. J. Cons. 24: 16–31.

COLLETTE, BRUCE B., and ROBERT H. GIBBS.
1963. A preliminary review of the fishes of the family Scombridae. FAO Fish. Rep. 6: 23–32.

FORSBERGH, ERIC D.
1963. Some relationships of meteorological, hydrographic, and biological variables in the Gulf of Panama. Inter-Amer. Trop. Tuna Comm., Bull. 7: 3–109. [English and Spanish.]

FORSBERGH, ERIC D., and JAMES JOSEPH.
1964. Biological production in the eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 8: 479–527. [English and Spanish.]

GRIFFITHS, RAYMOND C.
1965. A study of ocean fronts off Cape San Lucas, Lower California. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 499, 54 pp.

HELA, ILMO, and TAIVO LAEVASTU.
1962. Fisheries hydrography. Fishing News (Books), London. 137 pp.

HOLMES, ROBERT W.
1958. Surface chlorophyll "a", surface primary production, and zooplankton volumes in the eastern Pacific Ocean. Cons. Perma. Int. Explor. Mer, Rapp. Proc.-Verb. Réun. 144: 109–116.

HOLMES, ROBERT W., and MAURICE BLACKBURN.
1960. Physical, chemical, and biological observations in the eastern tropical Pacific Ocean: SCOT Expedition, April–June 1958. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 345, 106 pp.

HOLMES, ROBERT W., and OTHERS.
1958. Physical, chemical, and biological oceanographic observations obtained on Expedition SCOPE in the eastern tropical Pacific, November–December 1956. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 279, 117 pp.

HOLMES, ROBERT W., MILNER B. SCHAEFER, and BELL M. SHIMADA.
1957. Primary production, chlorophyll, and zooplankton volumes in the tropical eastern Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Bull. 2: 129–169. [English and Spanish.]

JUHL, ROLF.
1955. Notes on the feeding habits of subsurface yellowfin and bigeye tunas of the eastern tropical Pacific Ocean. Calif. Fish Game 41: 99–101.

KING, JOSEPH E., and ROBERT T. B. IVERSEN.
1962. Midwater trawling for forage organisms in the central Pacific, 1951–1956. U.S. Fish Wildl. Serv., Fish. Bull. 62: 271–321.

LONGHURST, ALAN R.
1967. The pelagic phase of *Pleuroncodes planipes* Stimpson (Crustacea, Galatheidae) in the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 11: 142–154.

MAGNUSON, JOHN J.
1963. Tuna behavior and physiology, a review. FAO Fish. Rep. 6: 1057–1066.

MARSHALL, N[ORMAN] B[ERTRAM].
1954. Aspects of deep sea biology. Philosophical Library, New York. 380 pp.

PEARCY, WILLIAM G.
1964. Some distributional features of mesopelagic fishes off Oregon. J. Mar. Res. 22: 83–102.

PEARCY, WILLIAM G., and R. M. LAURS.
1966. Vertical migration and distribution of mesopelagic fishes off Oregon. Deep-Sea Res. 13: 153–165.

REID, JOSEPH L., GUNNAR I. RODEN, and JOHN G. WYLLIE.
1958. Studies of the California Current System. Calif. Coop. Oceanic Fish. Invest. Progr. Rep. 1 July 1956–1 January 1958: 27–56.

SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA.

1961. STEP–1 Expedition, preliminary report. II. Biological, photometric and additional chemical data. Scripps Inst. Ref. Rep. 61–18, 66 pp.

1967. Physical, chemical, and biological data, cruise TO–60–1. Scripps Inst. Ref. Rep. 67–24, 32 pp.

SUDA, AKIRA, and MILNER B. SCHAEFER.

1965. General review of the Japanese tuna longline fishery in the eastern tropical Pacific Ocean, 1956–1962. Inter-Amer. Trop. Tuna Comm., Bull. 9: 307–462. [English and Spanish.]

WALTERS, VLADIMIR, and HARRY L. FIERSTINE.

1964. Measurements of swimming speeds of yellowfin tuna and wahoo. Nature (London) 202: 208–209.

WOOSTER, WARREN S., and JOSEPH L. REID.

1963. Eastern boundary currents. *In* The sea: ideas and observations on progress in the study of the seas, 2: 253–280. Interscience Publishers, New York.

WYRTKI, KLAUS.

1963. The horizontal and vertical field of motion in the Peru Current. Scripps Inst. Oceanogr., Bull. 8: 313–346.

1964a. Upwelling in the Costa Rica Dome. U.S. Fish Wildl. Serv., Fish. Bull. 63: 355–372.

1964b. The thermal structure of the eastern Pacific Ocean. Deutsch. Hydrogr. Zeitschr., Ergänzungsheft (A) 6, 84 pp.

1966. Oceanography of the eastern tropical Pacific Ocean. Oceanogr. Mar. Biol. Annu. Rev. 4: 33–68.