COMPOSITION, ABUNDANCE, AND DISTRIBUTION OF ZOOPLANKTON IN THE NEW YORK BIGHT, SEPTEMBER 1974-SEPTEMBER 1975

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ABSTRACT

Zooplankton taxa were counted in 8 to 19 samples from each of 11 cruises in the New York Bight between September 1974 and September 1975. Major seasonal events were an influx into the region of tropical-subtropical copepod species during autumn 1974 and summer 1975, an offshore (>50 m water depth) zooplankton abundance maximum in March dominated by the pteropod *Limacina retroversa*, a second offshore maximum in May characterized by high abundance of the copepods *Pseudocalanus* sp., *Calanus finmarchicus*, and *Oithona similis*, and an onshore (<50 m water depth) maximum in July characterized by high abundance of the copepods *Centropages typicus* and *Temora longicornis*. The offshore maxima occurred during or shortly after the local spring phytoplankton bloom (March-April). Advection of pteropod and copepod stocks into the region from the northeast probably contributed to these peaks. The July *C. typicus*-*T. longicornis* peak was associated with summer warming of the water column within the highly productive waters in the Bight apex and off the New Jersey coast. Comparison of our results with those of a study conducted in 1959-60 shows that the most abundant species of copepods were essentially the same during the two periods.

The New York Bight is the section of continental margin and overlying water within the bend of the Atlantic coastline bounded by Long Island on the north and New Jersey on the west (Figure 1). It is one of the most heavily used coastal regions of the world for a variety of human activities, including transportation, fisheries, recreation, and waste disposal (Gross et al. 1976). Exploration for and exploitation of potential offshore petroleum deposits may place additional burdens on the region's environment. Efforts to document changes in the biota because of these activities have generally been inadequate, especially in regards to the zooplankton. In a recent review, Malone (1977) observed that studies of the zooplankton of the New York Bight generally have been restricted to small geographic areas and to short periods of time, and consequently little data on species abundance and distribution exist for most of this heavily exploited area.

In this paper, we examine seasonal and onshore-offshore trends in occurrence and abundance of zooplankton taxa in waters of the New York Bight. These observations are based on analysis of the most comprehensive set of zooplankton samples obtained to date within the region and thus are invaluable for comparison with future studies. We compare our results with previous studies for evidence of the year-to-year variations in mean abundance of dominant species and in timing of peaks in their standing stocks. Finally, we examine occurrences of offshore water within the study area, and discuss zooplankton abundance maxima in relation to seasonal and regional variations in temperature and phytoplankton standing stocks and the environmental requirements of the dominant species.

METHODS

The station grid (Figure 1) was occupied 13 times between 25 July 1974 and 15 September 1975, with a cruise every month except December 1974 and January 1975. These cruises were part of an ichthyoplankton survey by the National Marine Fisheries Service (NMFS) Laboratory at Sandy Hook, N.J., funded by the Brookhaven National Laboratory. Zooplankton were analyzed in collections from the 11 cruises between 24 September 1974 and 15 September 1975 (Table 1).

Standard NMFS MARMAP gear was used that consisted of 60 cm diameter paired 333 μm and 505 μm mesh nets mounted on a "bongo" sampler without an opening-closing mechanism. Sampling accessories (flowmeters, depth recorder, depressor, towing cable) were rigged as specified by Smith and Richardson (1977). To obtain better estimates of small-bodied copepods, nets with 253

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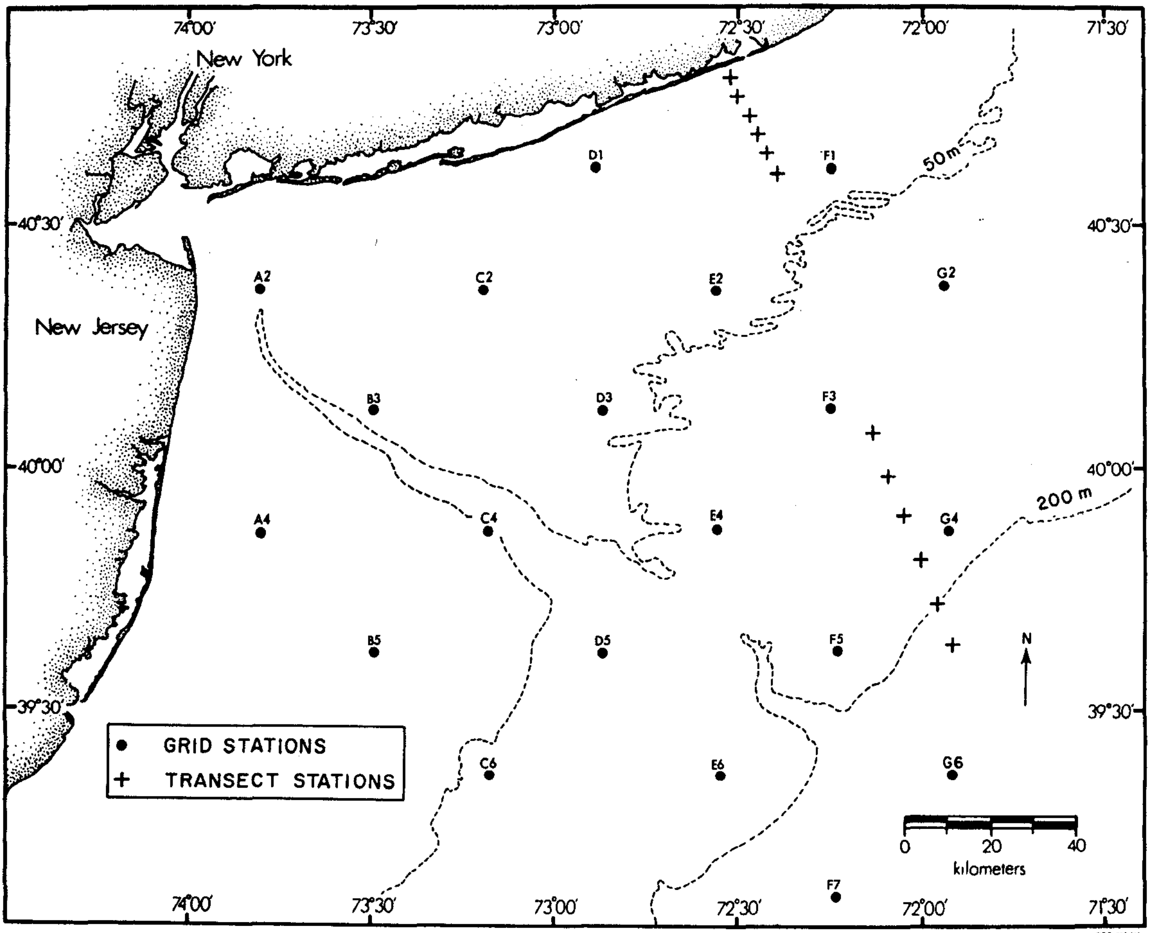


FIGURE 1.—New York Bight with stations for oblique net tows for zooplankton (grid) and chlorophyll, nutrient, and hydrographic measurements (grid and transect).

or 223 μm mesh were added to the sampling array in 1975. These nets were 20 cm in diameter and mounted as pairs on a bongo sampler rigged with a flowmeter in one mouth. The 20 cm sampler was attached to the towing wire immediately above the 60 cm frame, and the entire array was towed obliquely at 3.5 kn (6.5 km/h) from near bottom to surface, except at stations exceeding 200 m where tows were from 200 m to the surface. The samples from the two nets on the 20 cm frame were combined before preservation.

From 8 to 19 of the 20 grid stations (Figure 1) were sampled for zooplankton during the 11 cruises of the survey (Table 1). Samples were not available for every station because of gear failure, adverse weather, or contamination by algae or sediments. At all grid and transect stations (Figure 1) XBT's and nonmetallic sampling bottles were used to obtain temperature, salinity, nutrient, and chlorophyll data at discrete depths.

Samples were analyzed separately for chaetognaths, copepods, and "other" zooplankton (i.e., all taxa other than chaetognaths and copepods). We used only samples from 253 μm and 223 μm mesh nets to estimate the abundance of copepods and other zooplankton in 1975 but had to rely on 333 μm mesh nets for abundance estimates in 1974. In the separate analyses of copepods and other zooplankton, we removed aliquots from a sample with a piston pipette until a total of 500 or more individuals were identified and counted. We counted chaetognaths only in collections from 333 μm mesh nets, which retained most size classes of these large-bodied animals. We used a Folson plankton splitter to subsample collections with large numbers of chaetognaths until a total of 200

TABLE 1.—Zooplankton sampling data for the New York Bight region, 1974-75. Net mesh aperatures and mouth diameters indicated by letters: A, 333 μm, 60 cm; B, 253 μm (February 1975 only) or 223 μm, 20 cm. For station locations see Figure 1.

Station	Depth[1] (m)	Cruise 74-11 24-28 Sept.	74-13 23-28 Oct.	74-15 19-23 Nov.	75-1 1-6 Feb.	75-3 5-11 Mar.	75-4 2-10 Apr.	75-5 6-12 May	75-6 2-9 June	75-7 7-12 July	75-8 12-16 Aug.	75-14 8-15 Sept.
A2	27	A	A	—	A, B	A	A, B	A, B	A, B	A, B	A, B	B
A4	26	A	A	—	A, B	B	A, B	A, B	A, B	B	A, B	A, B
B3	40	A	A	A	A, B	A, B	A, B	A, B	A, B	A, B	A, B	A, B
B5	37	A	A	—	—	A, B	A, B	A, B	A, B	A, B	B	A, B
C2	33	A	A	A	A, B	A, B	A, B	A, B	A, B	A, B	A, B	A, B
C4	49	A	A	A	A	A, B	A, B	A, B	A, B	A, B	A, B	A, B
C6	59	—	A	—	—	B	A, B	A, B	A, B	A	A, B	A, B
D1	29	A	A	A	A, B	A, B	A, B	A, B	A, B	A, B	A, B	A, B
D3	49	A	A	A	A, B	A	A, B	A, B	A, B	A, B	—	A, B
D5	64	A	A	—	A, B	A, B	A	A, B	A. B	A, B	A, B	A, B
E2	48	A	—	A	A, B	A, B	A, B	A, B	A, B	A, B	A, B	A, B
E4	66	A	A	A	A, B	A, B	A, B	A, B	B	A, B	A, B	A, B
E6	124	A	A	—	A, B	A, B	A, B	A, B	A, B	A, B	A, B	A, B
F1	49	A	A	A	A	A, B	A, B	A, B	A, B	A, B	A, B	A, B
F3	71	A	A	—	A, B	A, B	—	A, B	A, B	A, B	A, B	A, B
F5	128	—	A	—	A, B	A, B	B	A, B	A, B	A, B	A, B	A, B
F7	2,800	A	A	—	A, B	A, B	A, B	A, B	A, B	A, B	A, B	A, B
G2	71	A	A	—	A, B	A, B	—	A, B	A, B	A, B	A, B	A, B
G4	146	A	A	—	A, B	—	A, B	A, B	A, B	—	A, B	A, B
G6	1,600	—	—	—	—	—	—	—	—	B	A, B	—

[1]Maximum sample depth = 200 m.

or more individuals were counted. Abundances of taxa within individual samples and related data are available in a data report (Judkins[3]) and from the senior author. In our treatment of the cross-shelf distribution of zooplankton, we divided the study region into two sectors of equal area, an onshore zone shoreward of the 50 m depth contour and an offshore zone seaward of that contour. Each sector contained 10 zooplankton grid stations (Figure 1). This division yielded approximately equal numbers of onshore and offshore samples and provided an easy test for cross-shelf differences in species abundances.

In Tables 2 and 3, we list abundances as both concentrations (numbers/cubic meter) and standing stocks (numbers/square meter). We calculated concentrations primarily for comparison with the historical data which have been reported almost exclusively in that manner. However, it would be an error to compare concentrations from different locations in the New York Bight because of the wide range of depths of stations and the vertical stratification of zooplankton. Estimates of numbers/cubic meter from oblique tows are average values for the entire water column, and these would be adequate for comparisons of tows from different depths only if zooplankton were evenly distributed throughout the water column. However, if a species is restricted to a narrow depth stratum, then its concentration would be underestimated by deeper tows relative to shallower ones (Peterson and Miller 1977). Vertically discrete samples show that most species in the New York Bight are concentrated in the upper 20 to 30 m (Judkins unpubl. data). To avoid underestimating species abundances in samples that extended below about 30 m, we calculated standing stocks and were then able to obtain mean values for combinations of tows from different depths and to test for significant differences between these means.

[3]Judkins, D. C. Zooplankton sampling program and data. *In* E. Wold (editor), Atlantic coastal experiment survey cruises (July 1974-September 1975) data report Vol. 2. Zooplankton and ichthyoplankton, p. 2-129. BNL 24771. Brookhaven National Laboratory, Upton, N.Y.

RESULTS

Frequency of Occurrence of Zooplankton Taxa

We identified 88 copepod species, 10 chaetognath species, and 26 other holo- and meroplanktonic taxa (Table 4). By season, 100 taxa occurred in samples taken in autumn (September-November) 1974, 68 in samples from winter to spring (February-May) 1975, and 91 in samples from summer (June-September) 1975.

These taxa can be grouped on the basis of seasonal and cross-shelf patterns in occurrence. The taxa in one group occurred commonly during all seasons and included the copepods *Centropages typicus*, *Pseudocalanus* sp., *Calanus finmarchicus*, *Paracalanus parvus*, *Oithona atlantica*, *Metridia lucens*, and *Clausocalanus pergens*, the chaetognaths *Sagitta elegans* and *S. serratodentata*, and pteropods, appendicularians, medusae, polychaete larvae, bivalve veligers, and euphausiid furcilia and calyptopsis stages (Table 4). The copepod *O. similis* was uncommon only during au-

TABLE 2.—Mean abundance (no. /m², no. /m³, and percent total no. /m²), frequency of occurrence (% of samples), average rank, and dominance of the 20 most abundant zooplankton taxa in the New York Bight, September 1974-September 1975. Taxa ranked within each sample on basis of number per square meter (1 = most abundant, ties averaged); ranks for each taxon averaged over all samples (n = 178 for chaetognaths, n = 183 for copepods and others). Dominance: proportion of samples in which taxon was among those making up 50% of the individuals; summation in each sample was begun with the most abundant species (Fager and McGowan 1963).

Taxa	Abundance no./m²	Abundance no./m³	Abundance % total	Frequency %	Average rank	Dominance
Pseudocalanus sp.	25,566	521	13.8	91	15.7	56
Pteropods	25,532	479	13.8	98	11.7	42
Centropages typicus	25,135	655	13.6	97	8.9	57
Paracalanus parvus	15,342	312	8.3	79	28.2	49
Penilia avirostris	14,613	454	7.9	28	82.9	15
Temora longicornis	11,365	373	6.2	61	50.8	11
Calanus finmarchicus	11,245	146	6.1	91	17.3	36
Oithona similis	8,293	146	4.5	81	28.7	9
Appendicularians	7,076	126	3.8	84	27.2	14
Gastropod veligers	4,833	113	2.6	61	52.3	5
Evadne spp.	3,901	91	2.1	46	65.9	9
Doliolids	3,600	90	2.0	32	79.5	6
Metridia lucens	2,498	21	1.4	58	52.4	8
Plutei	2,239	51	1.2	31	80.5	5
O. atlantica	1,979	22	1.1	72	36.7	17
Clausocalanus pergens	1,821	16	1.0	51	59.4	8
Medusae	1,419	27	0.8	74	40.7	0
Acartia tonsa	1,345	43	0.7	24	85.8	0
Sagitta elegans	1,311	26	0.7	96	30.9	3
Polychaete larvae	926	20	0.5	84	33.6	0
Total copepods	114,383	2,406	62.0			
Total chaetognaths	2,222	43	1.2			
Total "others"	67,769	1,511	36.8			
Grand total	184,174	3,960				

tumn 1974, and that may have been due simply to escapement of this small-bodied species through the coarse-mesh (333 μm) net used then. *Metridia lucens, C. pergens,* and euphausiid calyptopsis and furcilia stages were generally common only offshore, but all others in this group tended to be common throughout the Bight.

A number of taxa were common only during portions of the year. The oceanic copepod *Calocalanus tenuis,* cladocerans of the genus *Evadne,* hyperiid amphipods, and doliolids were common in autumn 1974 and again in summer 1975 but were uncommon during the intervening winter-spring period (Table 4). The neretic copepod *Temora longicornis,* ectoproct larvae, and copepod nauplii occurred commonly during autumn 1974 and winter-spring 1975 but were uncommon during summer 1975. The cold-water oceanic copepod *Pleuromamma borealis* occurred commonly only during the winter-spring period and then only offshore. Another oceanic copepod characteristic of warmer waters, *Mecynocera clausi,* was common offshore during winter-spring and summer 1975. Gastropod veligers were common both onshore and offshore during 1975 but were uncommon throughout the Bight in 1974. A large group of taxa were common only during autumn 1974. This assemblage consisted of copepods *Candacia armata, Oncaea venusta, Acartia tonsa, A. danae, Nannocalanus minor, Centropages bradyi, Rhincalanus nasutus, Eucalanus sewelli, Paracalanus aculeatus, Clausocalanus furcatus, C. jobei, Corycaeus clausi, C. speciosus, Temora stylifera, Scolecithrix danae,* and *Oithona plumifera,* the chaetognath *Sagitta enflata,* the cladoceran *Penilia avirostris,* echinoderm plutei, and siphonophores (Table 4). With the exception of the coastal-estuarine species *A. tonsa* and *P. avirostris* (and probably most of the plutei), members of this group typically inhabit the slope region and adjoining warm oceanic waters (Grice and Hart 1962; Owre and Foyo 1967; Bowman 1971).

The majority of copepods (61) and chaetognaths (7) were uncommon or rare in our samples, and most of these (43) were recorded most frequently or exclusively in autumn 1974 and/or summer 1975. Some of these rare and uncommon species are coastal-estuarine forms (e.g., *Centropages hamatus, Acartia longiremis, A. hudsonica, Paracalanus crassirostris, Tortanus discaudatus, Labidocera aestiva, Anomolocera opalus, Sagitta hispida)* and a few inhabit boreal offshore waters (e.g., *Calanus helgolandicus, Heterorhabdus norvegicus),* but the majority typically have

TABLE 3.—Seasonal variations in mean abundance (no./m² and no./m³) and frequency of occurrence (% of samples) of the 20 most abundant zooplankton taxa in the New York Bight, 1974-75. Values in parentheses are percents of total zooplankton (no./m²) during periods. Asterisks indicate significant differences in mean no./m² between periods (* = $P<0.05$, ** = $P<0.01$, NS = not significant, NT = not tested because of different mesh aperatures of nets used in 1974 and 1975).

		1974		1975			
		Sept.	Oct.-Nov.	Feb.-Mar.	Apr.-May	June-July	Aug.-Sept.
No. samples (chaetognaths)		17	26	32	35	34	34
No. samples (copepods, others)		17	26	30	35	37	38
Taxa	Item						
Pseudocalanus sp.	No./m²	1,692 (1.0) NS	507(1.0) NT	116,340 (8.5)**	64,184 (24.1)*	40,855 (18.0)**	9,981 (6.3)
	No./m³	33	11	374	1,163	900	245
	% frequency	71	69	97	100	100	95
Pteropods	No./m²	712 (0.4)**	308 (0.6) NT	81,837 (42.4) NS	43,100 (16.2)**	12,553 (5.6)NS	5,801 (3.7)
	No./m³	13	8	1,215	937	335	149
	% frequency	100	100	100	100	95	97
Centropages typicus	No./m²	16,818 (9.7) NS	19,838 (40.6) NT	30,077 (15.6) **	8,702 (3.3)*	50,801(22.4)NS	18,143 (11.6)
	No./m³	445	606	700	104	1,498	451
	% frequency	100	92	100	97	97	97
Paracalanus parvus	No./m²	2,834 (1.6) NS	6,168 (12.6) NT	17,388 (9.0) NS	5,402 (2.0) NS	13,820 (6.1)**	36,395 (23.2)
	No./m³	74	188	299	41	295	784
	% frequency	94	96	90	31	73	100
Penilia avirostris	No./m²	74,658 (43.0)*	794 (1.6) NT	<1(<0.1) NS	— NS	—*	36,434 (23.2)
	No./m³	2,278	24	<1	—	—	1,152
	% frequency	94	35	3	—	—	63
Temora longicornis	No./m²	139 (0.1) NS	246 (0.5) NT	855 (0.4)**	6,875 (2.6)*	48,173 (21.3)**	529 (0.3)
	No./m³	3	5	30	204	1,605	16
	% frequency	53	62	53	80	84	29
Calanus finmarchicus	No./m²	4,031 (2.3) NS	1,895 (3.9) NT	824 (0.4) NS	26,651 (9.8) NS	16,640 (7.3) NS	9,636 (6.1)
	No./m³	70	32	12	261	231	173
	% frequency	76	81	90	100	95	92
Oithona similis	No./m²	128 (0.1)*	34 (0.1) NT	11,199 (5.8) NS	18,947 (7.1)*	9,836 (4.3)**	3,739 (2.4)
	No./m³	3	<1	221	255	227	68
	% frequency	53	31	83	100	97	95
Appendicularians	No./m²	4,293 (2.5)*	586 (1.1) NT	11,894 (6.2) NS	19,205 (7.2)**	3,136 (1.4) NS	1,623 (1.0)
	No./m³	115	6	204	316	60	39
	% frequency	100	62	60	100	89	92
Gastropod veligers	No./m²	1(<0.1) NS	2(<0.1)NT	6,848 (3.5) NS	13,674 (5.1) NS	5,253 (2.3) NS	159 (0.7)
	No./m³	<1	<1	431	324	149	2
	% frequency	12	4	100	97	70	47
Evadne spp.	No./m²	3,846 (2.2)*	72 (0.1) NT	—**	13,116 (4.9)*	3,884 (1.7) NS	1,156 (0.7)
	No./m³	127	2	—	306	77	23
	% frequency	76	35	—	69	68	34
Doliolids	No./m²	22,022 (12.7)**	65 (0.1) NT	— NS	— NS	389 (0.1) NS	6,191 (4.0)
	No./m³	552	1	—	—	4	183
	% frequency	100	58	—	—	30	39
Metridia lucens	No./m²	221 (0.1) NS	247 (9.5) NT	1,533 (0.8)*	8,195 (3.1)*	1,683 (0.7) NS	1,327 (0.8)
	No./m³	2	4	23	58	15	12
	% frequency	32	62	70	69	47	58
Plutei	No./m²	14,682 (8.5) NS	2,745 (5.6) NT	— NS	1,635 (0.6) NS	48 (<0.1) NS	784 (0.5)
	No./m³	308	90	—	22	1	25
	% frequency	59	54	—	54	14	21
O. atlantica	No./m²	1,354 (0.8) NS	1,742 (3.6) NT	1,498 (0.8) NS	2,350 (0.8) NS	1,963 (0.8) NS	2,497 (1.6)
	No./m³	18	31	27	18	14	24
	% frequency	88	88	100	57	41	76
Clausocalanus pergens	No./m²	142 (0.1) NS	81 (0.2) NT	1,494 (0.8) NS	3,740 (1.4) NS	1,304 (1.4) NS	2,807 (1.8)
	No./m³	1	1	21	27	15	21
	% frequency	41	50	80	29	43	63
Medusae	No./m²	128 (0.1) NS	540 (1.1) NT	511 (0.3)**	4,411 (1.7)*	1,927 (0.9)**	63 (<0.1)
	No./m³	4	16	10	87	33	2
	% frequency	65	85	70	97	78	50
Acartia tonsa	No./m²	4,195 (2.4) NS	435 (0.9) NT	— NS	41(<0.1) NS	—	4,264(2.7)
	No./m³	140	14	—	<1	—	132
	% frequency	71	58	—	6	—	39
Sagitta elegans	No./m²	1,006 (0.6) NS	277 (0.6) NS	478(0.2)**	1,581 (0.6)**	2,850 (1.3)**	1,220 (0.8)
	No./m³	19	5	9	55	61	19
	% frequency	100	100	100	94	91	91
Polychaete larvae	No./m²	140(0.1) NS	71(0.1) NT	227 (0.1)**	2,835 (1.1)*	577 (0.3) NS	1,205 (0.8)
	No./m³	3	1	4	57	12	26
	% frequency	76	81	88	97	85	74
Total copepods	No./m²	49,149(28.3)NS	38,212(78.1) NT	89,074(46.2)*	159,725(60.0) NS	191,772 (84.6)*	96,930(61.8)
	No./m³	1,089	986	1,879	2,260	4,930	2,047
Total chaetognaths	No./m²	1,934(1.1) NS	1,721(3.5) **	797(0.4)**	2,627(1.0) NS	3,502(1.5) NS	2,393(1.5)
	No./m³	34	31	12	53	94	43
Total "others"	No./m²	122,617(70.6)**	8,975(18.4) NT	103,115(53.4) NS	104,226(39.1)**	31,386(13.8) NS	57,401(36.6)
	No./m³	3,441	215	1,582	2,138	733	1,662
Grand total	No./m²	173,697**	49,008 NT	194,238 NS	266,575 NS	226,313 NS	156,472
	No./m³	4,564	1,232	3,473	4,451	5,757	3,752

TABLE 4.—Zooplankton taken in onshore (on) (<50 m) and offshore (off) (>50 m) waters of the New York Bight during period 1 (September-November 1974), period 2 (February-May 1975), and period 3 (June-September 1975). Taxa within the major categories (copepods, chaetognaths, others) listed in order of decreasing overall frequency of occurrence. C = common, occurrence in ≥50% of samples; U = unusual, occurrence in ≤50% of samples; R = rare, occurrence in ≤3 samples.

	Period 1		Period 2		Period 3	
Taxa	On	Off	On	Off	On	Off
Copepods:						
Centropages typicus	C	C	C	C	C	C
Pseudocalanus sp.[1]	C	C	C	C	C	C
Calanus finmarchicus	C	C	C	C	C	C
Oithona similis	U	U	C	C	C	C
Paracalanus parvus	C	C	U	C	C	C
O. atlantica	C	C	C	C	U	C
Temora longicornis	C	C	C	U	U	U
Metridia lucens	U	C	C	C	U	C
Clausocalanus pergens	U	C	U	C	U	C
Mecynocera clausi	U	U	U	C	U	C
Candacia armata	C	C	U	U	U	U
Calocalanus tenuis	C	C	—	U	—	C
Oncaea venusta	C	C	R	U	—	U
Pleuromamma borealis	R	U	U	C	—	U
Acartia danae	C	C	—	—	R	U
Nannocalanus minor	C	C	—	—	R	U
A. tonsa	C	U	R	—	U	U
Centropages bradyi	C	C	R	R	—	U
C. hamatus	R	—	U	U	U	U
Rhincalanus nasutus	U	C	R	U	—	R
Eucalanus sewelli	C	C	R	R	—	R
Paracalanus aculeatus	C	C	—	R	—	—
Clausocalanus furcatus	C	C	—	R	R	R
C. jobei	C	C	—	—	—	R
Corycaeus clausi	C	C	—	—	—	—
Scolecithrix danae	C	C	—	R	R	—
A. longiremis	—	—	U	U	U	U
Corycaeus speciosus	C	C	—	—	—	R
T. stylifera	C	C	—	—	—	—
C. danae	—	—	U	U	—	—
Tortanus discaudatus	—	—	U	U	U	—
Calocalanus styliremis	R	—	R	U	—	U
A. hudsonica	R	—	U	R	R	—
Oithona plumifera	C	R	—	—	—	—
R. cornutus	U	U	—	—	—	—
Oncaea mediterranea	U	U	—	—	—	—
E. pileatus	U	U	R	—	—	R
Labidocera aestiva	U	R	—	—	U	R
Aetideus armatus	—	R	—	R	—	U
Paracalanus crassirostris	R	—	—	—	U	U
Corycaeus venustus	R	U	—	R	—	R
Euchaeta marina	U	U	—	R	—	R
Undinula vulgaris	R	U	—	—	R	—
Calocalunus pavo	—	U	—	—	—	—
Ischnocalanus plumulosus	—	U	—	—	—	—
Calanus tenuicornis	R	R	—	R	R	R
O. conifera	R	U	—	—	—	—
Macrosetella gracilis	R	U	—	—	—	—
Clausocalanus parapergens	—	R	—	R	—	R
Sapphirina angusta	R	U	—	—	—	—
C. paululus	—	—	—	R	—	R
Eucalanus subtenuis	R	U	—	—	—	—
Pleuromamma robusta	—	—	—	—	—	R
Faranula gracilis	—	R	—	—	—	—
Calanus helgolandicus	R	—	—	—	R	R
Paracalanus pygmaeus	—	—	—	R	R	R
E. hyalinus	R	U	—	—	—	—
E. crassus	R	R	—	R	—	R
F. carinata	R	—	—	—	—	R
Clausocalanus lividus	—	R	—	R	—	R
Copila mirablis	—	R	—	—	—	—
Heterorhabdus norvegicus	—	—	—	—	—	R
H. papilliger	—	R	—	—	—	—

	Period 1		Period 2		Period 3	
Taxa	On	Off	On	Off	On	Off
Clausocalanus arcuicornis	—	R	—	—	—	—
L. acutifrons	—	—	—	—	—	R
Corycaeus latus	R	R	—	—	—	—
Anomolocera opalus	—	—	—	—	R	R
Scolecithricella minor	—	—	—	—	—	R
Neocalanus gracilis	—	—	—	—	—	R
O. minuta	—	—	—	R	—	—
Clausocalanus mastigophorus	R	R	—	—	—	—
Corycaeus catus	R	—	—	—	—	—
C. elongatus	R	R	—	—	—	—
Pontella pennata	R	—	—	—	—	—
Sapphririna opalina	—	R	—	—	—	—
Lucicutia flavicornis	—	R	—	—	—	—
Calocalanus pavionius	—	R	—	—	—	—
Scolecithricella vittata	—	R	—	—	—	—
Centropages velificatus	—	—	—	—	—	R
Paracalanus pusillus	—	—	—	—	—	R
Microsetella norvegica	R	—	—	—	—	—
Chiridius obtusifrons	—	—	—	—	—	R
Lubbockia squillimania	—	—	—	—	—	R
S. tenuiserrata	—	—	—	—	—	R
Scottocalanus securifrons	—	—	—	—	—	R
Sapphirina ovatolanceolata	—	—	—	—	—	R
P. quasimodi	—	R	—	—	—	—
Scottocalanus thomasi	—	—	—	—	—	R
Chaetognaths:						
Sagitta elegans	C	C	C	C	C	C
S. serratodentata	C	C	C	C	U	C
S. enflata	C	C	R	U	R	U
Pterosagitta draco	R	U	R	—	—	R
Eukrohnia hamata	—	—	—	R	—	R
S. maxima	—	—	R	R	—	R
S. hexaptera	R	R	—	R	—	R
S. decipiens	—	R	—	—	—	R
S. hispada	—	R	—	—	—	—
E. fowleri	—	R	—	—	—	—
Others:						
Pteropods	C	C	C	C	C	C
Appendicularians	C	C	C	C	C	C
Medusae	C	C	C	C	C	C
Decapod larvae	C	C	U	U	C	C
Polychaete larvae	C	C	C	C	C	C
Bivalve veligers	C	C	C	C	C	C
Euphausiid furcila stages	U	C	C	C	U	C
Gastropod veligers	—	R	C	C	C	C
Ectoproct larvae	C	C	C	C	U	U
Hyperiid amphipods	C	C	U	U	U	C
Copepod nauplii	U	C	C	C	U	U
Evadne spp.	C	U	U	U	C	C
Anthozoan larvae	U	U	U	U	U	C
Euphausiid calyptopsis stages	R	C	U	C	R	C
Doliolids	C	C	—	—	C	C
Plutei	C	U	U	U	U	R
Siphonophores	C	C	R	R	U	U
Penilia avirostris	C	U	—	R	U	U
Conchoecia spp.	U	C	R	U	—	U
Euphausiid nauplii	—	U	R	U	R	U
Barnacle cyprises	—	—	U	U	U	U
Heteropods	U	U	—	—	—	—
Podon spp.	U	—	U	—	R	R
Salps	—	U	—	—	—	U
Barnacle nauplii	—	—	R	U	—	U
Stomatopod larvae	R	—	—	—	R	—

[1]Atlantic representatives of the genus *Pseudocalanus* are not adequately described. They are being studied by B. Frost, Department of Oceanography, University of Washington, Seattle.

warmwater oceanic distributions (Pierce 1953; Grice and Hart 1962; Jefferies 1967; Pennell 1976; Fleminger and Hulsemann 1977).

Mean Abundance, Frequency, Average Rank, and Dominance

We calculated mean abundances for various taxa and found that copepods, on the average, composed 62% of the zooplankton in our samples (Table 2). Pteropods and gastropod veligers together contributed 15% to the total, and cladocerans (*Penilia avirostris* plus *Evadne* spp.) and urochordates (doliolids and appendicularians) yielded another 10 and 6%, respectively. No other group (e.g., echinoderm plutei, medusae, polychaete larvae, chaetognaths), on the average, composed more than about 1% of the zooplankton. At the species level, *Pseudocalanus* sp. and *Centropages typicus* were codominant in 1974-75, their annual mean abundances (number/square meter) each equaling approximatesly 13% of the annual mean for total zooplankton. Pteropods composed another 13% of the zooplankton, and these consisted almost exclusively of one species, *Limacina retroversa* (Wormuth[4]). *Paracalanus parvus, Penilia avirostris, Calanus finmarchicus,* and *Temora longicornis* each composed between 5 and 10% of total zooplankton over the period, and several other taxa had values exceeding 1% (Table 2).

In addition to mean standing stocks and concentrations, we calculated frequency of occurrence, average rank (rank of most abundant taxon in a sample = 1), and an index of dominance (Fager and McGowan 1963) for the 20 taxa having the highest mean abundance in our samples (Table 2). These measures showed similar trends, and, in general, frequency of occurrence and dominance tended to decline and average rank to increase as mean abundance decreased. There were, however, a number of exceptions to this pattern. For instance, the highly seasonal species *P. avirostris* and *T. longicornis* had high mean abundances but disproportionately low frequency and dominance values and high average ranks. Conversely, other taxa, which were seldom abundant, nevertheless occurred frequently (e.g., *S. elegans, O. atlantica,* polychaete larvae, medusae).

[4]J. H. Wormuth, Department of Oceanography, Texas A&M University, College Station, pers. commun. August 1978.

Seasonality in Abundance

Total zooplankton in the New York Bight declined nearly fourfold in mean abundance between late summer (September) and autumn (October-November) 1974 (Table 3), primarily because of a drastic decline in the abundance of *P. avirostris* after September. In 1975, numbers of total zooplankton did not vary as greatly between seasons, and the highest mean value (April-May) differed from the lowest (August-September) by less than a factor of two. Copepods were least numerous in winter (February-March), but increased through spring (April-May) to an early summer (June-July) peak before declining in late summer (August-September). Other zooplankton combined exceeded copepods in mean abundance only during winter, and this primarily was due to the large standing stocks of the pteropod *L. retroversa* present in the Bight during that period.

We calculated mean abundances by season for the 20 taxa having the highest overall mean values in our samples (Table 2) and found that most of these taxa underwent marked and often statistically significant ($P<0.05$) seasonal fluctuations in standing stock (Table 3). *Penilia avirostris*, doliolids, echinoderm plutei, and *Acartia tonsa* reached maximum or near maximum levels of abundance in late summer 1974 and again in late summer 1975. With the exception of echinoderm plutei, these taxa were virtually absent from our samples during the intervening winter and spring. The relatively low numbers of small copepods in 1974 may have been due to escapement through the coarse mesh (333 μm) nets used then. We found that *Paracalanus parvus, Pseudocalanus* sp., *O. similis*, and *Clausocalanus pergens* were significantly less abundant (paired sample *t*-test, $P<0.05$) in collections from 60 cm diameter 333 μm mesh nets than in simultaneous samples from 20 cm diameter 253 and 223 μm mesh nets.

Only 1 taxa (*L. retroversa*) peaked in winter 1975, but 10 taxa (*Pseudocalanus* sp., *Calanus finmarchicus, O. similis, Metridia lucens, Clausocalanus pergens, Evadne* spp., appendicularians, gastropod veligers, medusae, and polychaete larvae) reached their highest levels of abundance during spring 1975. *Centropages typicus, T. longicornis,* and *S. elegans* attained maximum levels of abundance in early summer, and *Paracalanus parvus* peaked in late summer 1975. Among the 20 taxa listed in Table 3, *O. at-*

lantica varied the least in mean abundance during the study, showing only slight increases during spring and late summer 1975.

Onshore-Offshore Distribution

Several of the more abundant zooplankton taxa in the New York Bight showed statistically significant ($P<0.05$) differences in mean standing stocks between the onshore (<50 m) and offshore (>50 m) sectors of the region (Table 5). Taxa which on the average were significantly more abundant onshore during 1974-75 were *C. typicus, Penilia avirostris, T. longicornis, Evadne* spp., *A. tonsa*, and doliolids. Those which were significantly more abundant offshore were *Calanus finmarchicus, O. similis, O. atlantica, M. lucens,* and *Clausocalanus pergens*. Significant onshore-offshore differences on an annual basis were not observed for *Pseudocalanus* sp., pteropods, *Paracalanus parvus*, appendicularians, gastropod veligers, echinoderm plutei, medusae, and *S. elegans*. Neither total copepods nor total chaetognaths differed significantly between the two regions, but other zooplankton combined were significantly more abundant offshore (Table 5).

Substantial seasonal changes occurred in the onshore-offshore distribution of many of the aforementioned taxa (Figure 2). Certain copepod species which peaked or were otherwise very abundant in the offshore region during winter and spring were much less abundant onshore at those times. However, during the summer, onshore stocks of these species increased to levels approaching those in offshore waters. Species exhibiting this pattern were *M. lucens, C. pergens, O. atlantica, Calanus finmarchicus,* and *P. parvus* (Figure 2). Several other taxa which reached maximum levels of abundance during the spring tended to be equally abundant onshore and offshore during most times of the year. This group of ubiquitously abundant taxa included *Pseudocalanus* sp., *O. similis, S. elegans*, medusae, appendicularians, pteropods, gastropod veligers, and polychaete larvae (Figure 2). Doliolids and the coastal-estuarine species *Penilia avirostris, T. longicornis,* and *A. tonsa* all peaked in the onshore environment during summer or autumn and were seldom, if ever, abundant offshore (Figure 2). Although *Centropages typicus* also reached its highest levels of abundance onshore during the summer, it was usually abundant offshore as well, especially during March and April (Figure 2). Echinoderm plutei peaked in onshore waters during autumn 1974 but also exhibited a secondary offshore peak during spring 1975 (Figure 2). *Evadne* spp. exhibited maxima in both the onshore and offshore environments during spring and summer 1975 but were abundant only onshore during autumn 1975 (Figure 2).

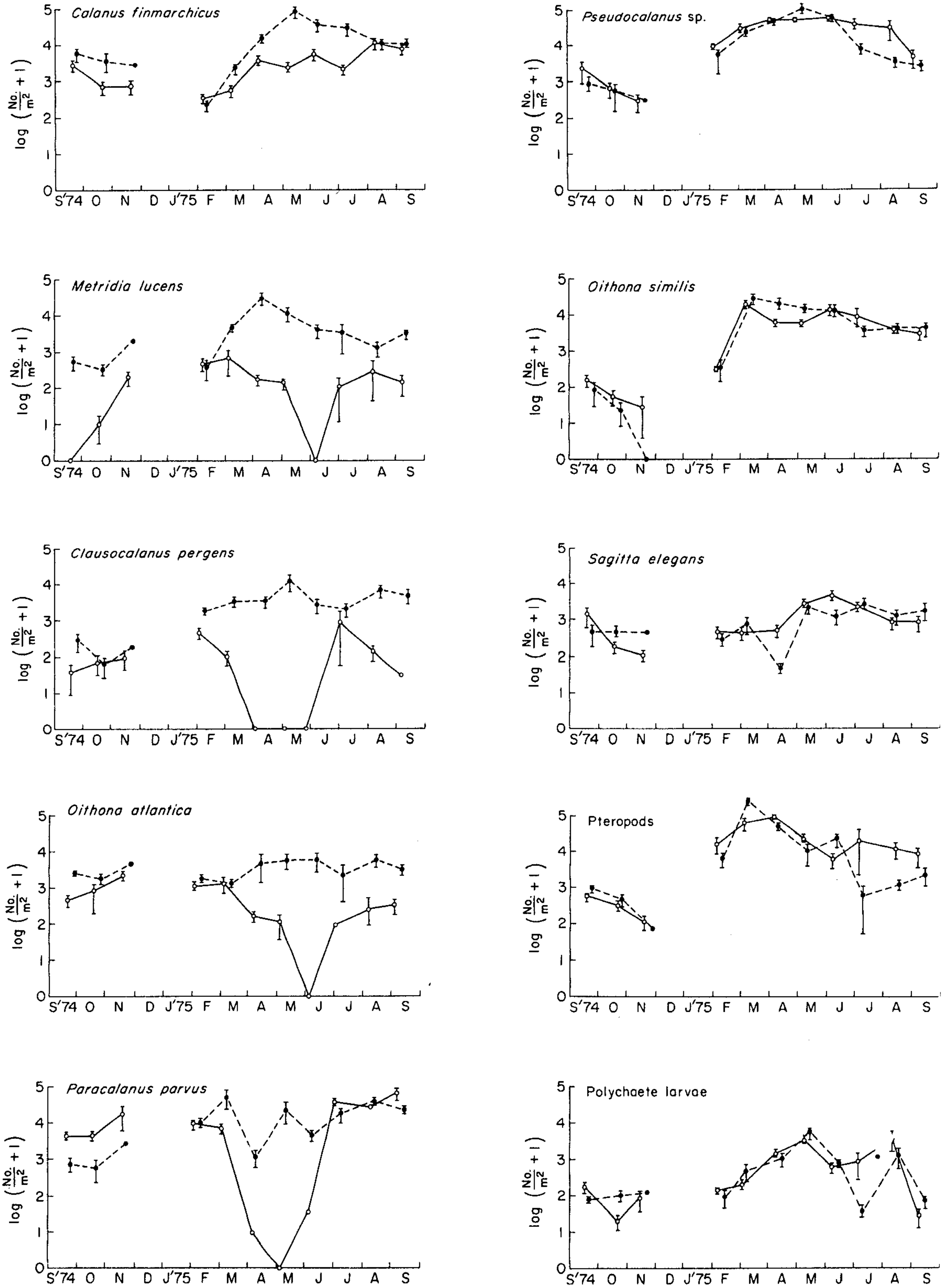
Zooplankton Maxima, Phytoplankton Blooms, and Temperature

We observed distinct peaks in zooplankton abundance in both onshore and offshore environments in 1975 (Figure 3). In the offshore region, there were two maxima, in March and May. The March peak was dominated by *L. retroversa* which composed nearly 60% of all offshore zooplankton during that month. The remaining 40% of offshore zooplankton in March was composed primarily of the copepods *Pseudocalanus* sp., *O. similis, Paracalanus parvus*, and *M. lucens*. The May maximum was dominated by *Pseudocalanus* sp., *Calanus finmarchicus*, and *O. similis*, and these species tended to be most abundant over the outer shelf at the eastern end of the study area (e.g., stations F3, F5, G2, G4). The March pteropod-dominated maximum occurred simiItaneously with the beginning of the spring phytoplankton bloom when chlorophyll *a* standing stock biomass (milligrams/square meters) was high (Figure 3) and discrete depth chlorophyll *a* concentrations exceeded 4 μg/l throughout the water column at virtually all stations. However, during May when copepods peaked in abundance offshore, the phytoplankton bloom was in decline (Figure 3). In the offshore region, water temperatures in the upper 20 m remained low ($\leq 10°$ C) through May.

We observed a single peak in zooplankton abundance in the onshore environment during 1975 (Figure 3). This peak occurred in July and was the result of marked increases in the abundance of *Centropages typicus* and *T. longicornis*. In July, these two species constituted about 67% of all onshore zooplankton and were especially abundant at stations near the apex of the Bight and off the New Jersey coast (e.g., A2, A4, B3, B5). The early summer rise in *C. typicus* and *T. longicornis* stocks occurred during a period when surface water temperatures rose from about 10° to 20° C but when onshore chlorophyll *a* biomass was low (Figure 3). At other times during this study various other taxa were dominant onshore, e.g., *Penilia*

TABLE 5.—Onshore-offshore variations in mean abundance (no./m² and no./m³) and frequency of occurrence (% of samples) of the 20 most abundant zooplankton taxa in the New York Bight, 1975, listed in order of overall mean abundance. Onshore: depth <50 m, offshore: depth >50 m. Values in parenthesis after no./m² values are percents of total zooplankton. Asterisks indicate significant differences (Fisher-Behrens test, Campbell 1967) in mean no./m² between onshore and offshore (* = $P<0.05$, ** = $P<0.01$, NS = not significant).

		Onshore	Offshore
No. samples (chaetognaths)		100	78
No. samples (copepods, others)		99	84
Taxa	Item		
Pseudocalanus sp.	No./m²	26,308(13.1) NS	24,691(14.9)
	No./m³	713	295
	% frequency	91	92
Pteropods	No./m²	21,487(10.7) NS	30,298(18.2)
	No./m³	564	379
	% frequency	99	98
Centropages typicus	No./m²	35,637(17.8)**	12,759(7.7)
	No./m³	1,071	165
	% frequency	98	96
Paracalanus parvus	No./m²	14,668(7.3) NS	16,136(9.7)
	No./m³	400	208
	% frequency	67	89
Penilia avirostris	No./m²	26,829(13.4)**	217(0.1)
	No./m³	836	4
	% frequency	31	24
Temora longicornis	No./m²	20,455(10.2)**	651(0.4)
	No./m³	681	9
	% frequency	76	43
Calanus finmarchicus	No./m²	3,604(1.8)**	20,251(12.2)
	No./m³	82	220
	% frequency	85	98
Oithona similis	No./m²	5,415(2.7)**	11,686(7.0)
	No./m³	151	140
	% frequency	85	77
Appendicularians	No./m²	6,576(3.2) NS	7,666(4.6)
	No./m³	157	89
	% frequency	80	88
Gastropod veligers	No./m²	6,556(3.2) NS	2,804(1.7)
	No./m³	173	41
	% frequency	58	65
Evadne spp.	No./m²	5,891(2.9)**	1,557(0.9)
	No./m³	149	22
	% frequency	49	41
Doliolids	No./m²	6,497(3.2)*	185(0.1)
	No./m³	165	2
	% frequency	29	34
Metridia lucens	No./m²	178(0.1)**	5,232(0.3
	No./m³	4	41
	% frequency	37	83
Plutei	No./m²	3,591(1.7) NS	680(0.4)
	No./m³	86	9
	% frequency	35	25
O. atlantica	No./m²	564(0.3)**	3,646(2.2)
	No./m³	13	31.
	% frequency	57	90
Clausocalanus pergens	No./m²	161(0.1)**	3,777(2.3)
	No./m³	4	31
	% frequency	28	78
Medusae	No./m²	1,454(0.7) NS	1,378(0.8)
	No./m³	35	19
	% frequency	76	73
Acartia tonsa	No./m²	2,432(1.2)*	63(<0.1)
	No./m³	78	1
	% frequency	35	11
Sagitta elegans	No./m²	1,407(0.7) NS	1,187(0.7)
	No./m³	34	17
	% frequency	95	96
Polychaete larvae	No./m²	989(0.5) NS	946(0.3)
	No./m³	26	13
	% frequency	65	68
Total copepods	No./m²	115,284(57.7) NS	113,104(68.2)
	No./m³	3,358	1,284
Total chaetognaths	No./m²	2,175(1.1) NS	2,282(1.4)
	No./m³	52	32
Total "others"	No./m²	82,510(41.3)*	50,396(30.4)
	No./m³	2,663	626
Grand total	No./m²	119,943 NS	165,590
	No./m³	6,073	1,942


Calanus finmarchicus
Pseudocalanus sp.
Metridia lucens
Oithona similis
Clausocalanus pergens
Sagitta elegans
Oithona atlantica
Pteropods
Paracalanus parvus
Polychaete larvae
log (No./m² + 1)
0 1 2 3 4 5
S'74 O N D J'75 F M A M J J A S

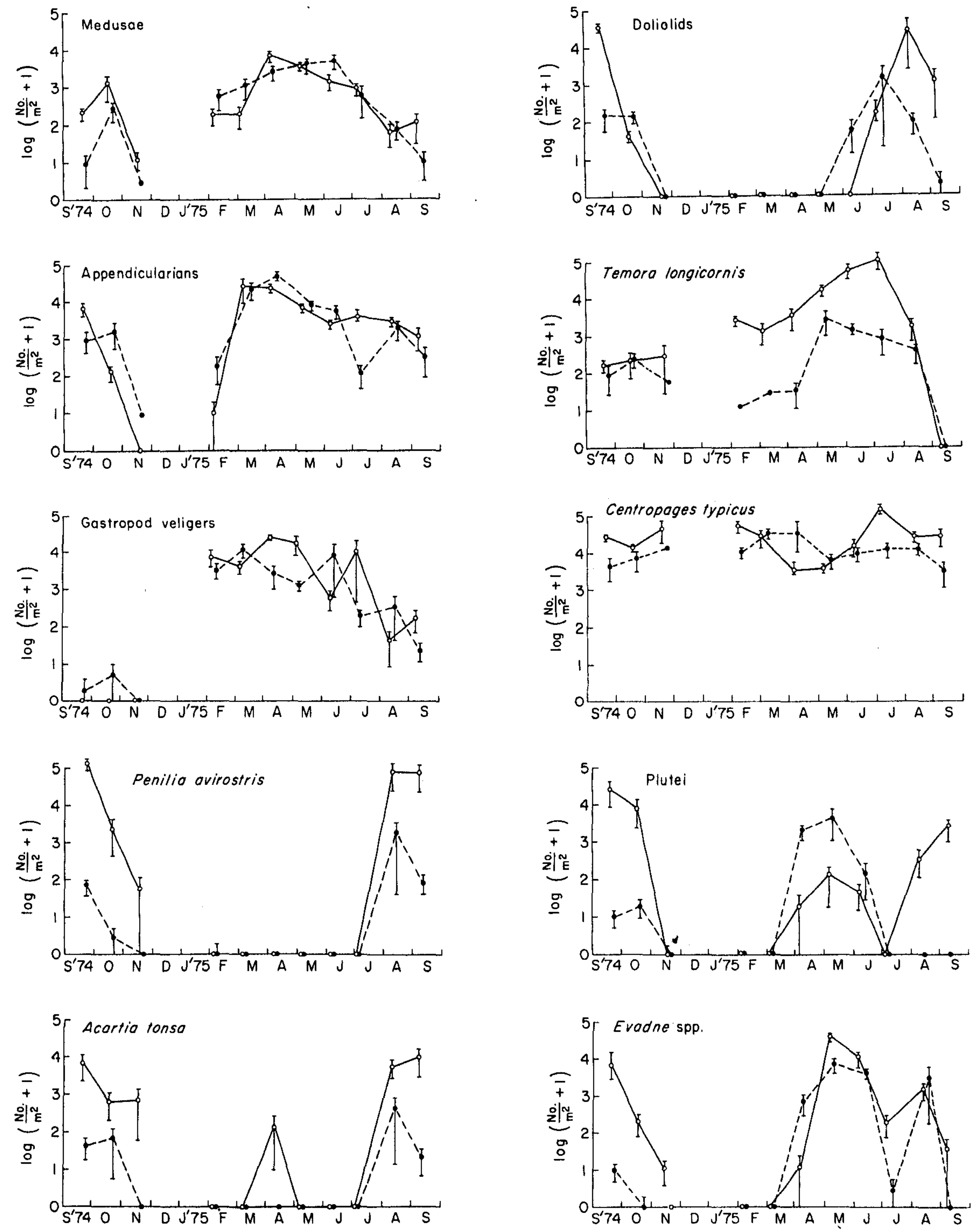


FIGURE 2.—Onshore (<50 m) and offshore (>50 m) monthly mean abundances of 20 most abundant zooplankton taxa in the New York Bight, September 1974-September 1975. Circles = onshore means; dots = offshore means; vertical bars = 1 SE above and below mean.

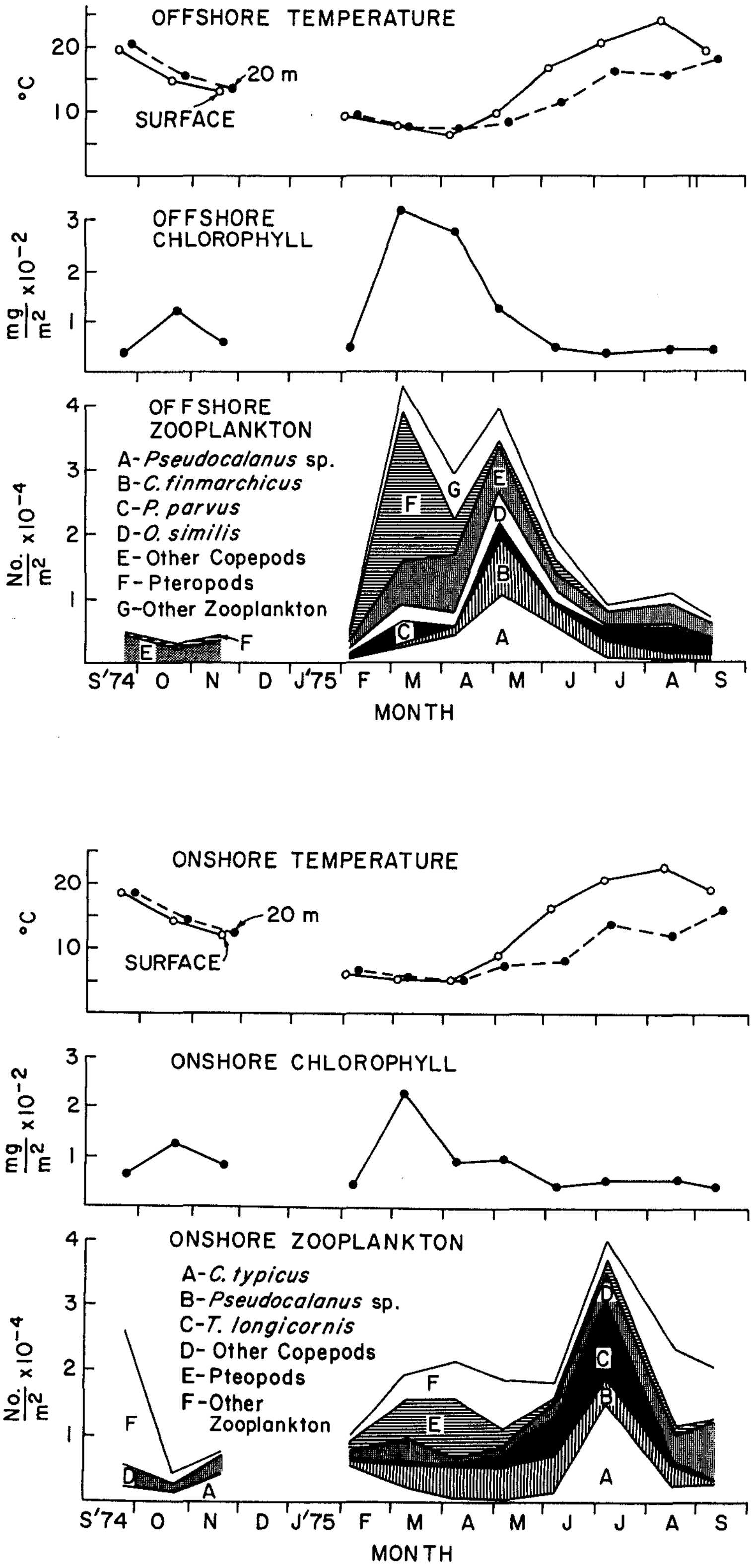


FIGURE 3.—Onshore (<50 m) and offshore (>50 m) monthly means for temperature at surface and 20 m, chlorophyll *a* integrated water column biomass, and zooplankton abundance (showing cumulative contribution of dominant taxa) in the New York Bight, September 1974-September 1975.

avirostris (September 1974), *L. retroversa* (March, April), *Pseudocalanus* sp. (May), and *Paracalanus parvus* (August, September 1975).

DISCUSSION

Previous zooplankton studies in the New York Bight have been based on relatively few samples, usually taken from a restricted area over a limited period of time (cf. review in Malone 1977). Grice and Hart's (1962) study is closest to ours in taxonomic coverage, net mesh size, geography, and quantitative analysis. They collected a total of 14 samples with vertically hauled 230 μm mesh nets from New York Bight shelf waters on cruises in September and December 1959 and March and July 1960. These samples were part of a larger study of zooplankton along a transect between Montauk, N.Y., on eastern Long Island and Bermuda. Comparison of mean concentrations of several abundant species of copepods in their samples (table 4, Grice and Hart 1962) with our mean concentration values (Table 2) is informative. The eight most abundant copepods during 1959-60 (in order of decreasing abundance: *Pseudocalanus* sp., *C. typicus, O. similis, T. longicornis, Paracalanus parvus, Calanus finmarchicus, M. lucens, Candacia armata)* correspond closely with the eight most abundant species in 1974-75 (*Centropages typicus, Pseudocalanus* sp., *T. longicornis, Paracalanus parvus, Calanus finmarchicus, O. similis, Acartia tonsa, O. atlantica)*. Furthermore, the mean densities of the two most abundant copepods in both studies, *Centropages typicus* and *Pseudocalanus* sp., were very similar for both species during the two periods (i.e., the mean density of *C. typicus* was 450/m^3 in 1959-60 and 650/m^3 in 1974-75; the mean density of *Pseudocalanus* sp. was 560/m^3 in 1959-60 and 520/m^3 in 1974-75). This comparison suggests that zooplankton in the New York Bight had not changed substantially in the 15 yr between the two studies. The degree of similarity is somewhat surprising in view of the evidence that considerable year-to-year variations may occur in the timing, duration, and amplitude of abundance maxima in important zooplankton taxa (Bigelow and Sears 1939; Sears and Clarke 1940).

Grice and Hart (1962) observed an influx of warmwater oceanic species into the New York Bight in September 1959, and this is similar to the high incidence of subtropical-tropical species in autumn 1974 and summer 1975. This apparently annual phenomenon is probably associated with intrusions of the Gulf Stream over the continental slope which occur most frequently during the warm seasons (Wright 1976; Bowman 1977). Our hydrographic data reveal the occurrence of salinities (≥36%) characteristic of Gulf Stream water (Wright 1976) in the slope region during September 1974, and in June, August, and September 1975 (Figure 4), and the National Environmental Satellite photos show Gulf Stream water impinging along the outer edge of the study area in August 1974 and in May, July, and August 1975.

A shoreward increase in the abundance of several common offshore copepods (e.g., *Calanus finmarchicus, O. atlantica, Clausocalanus pergens, M. lucens*) also occurred during warm portions of the year. This onshore increase in abundance of common forms and the frequent occurrence over the shelf of less common oceanic species are probably the result of shoreward mixing of slope water with shelf water. Slope water is thought to move onshore along isopycnals during late summer and autumn (Wright and Parker 1976; Gordon et al. 1977), and during September 1974 we observed slope water (35‰ ≤salinity <36‰, Wright 1976) on the shelf (Figure 4).

Limacina retroversa, Pseudocalanus sp., *O. similis*, and *Calanus finmarchicus*, the species responsible for zooplankton abundance maxima in the New York Bight during spring 1975, are low-temperature forms whose distributions are centered north of the region (Fish 1936a, b, c; Redfield 1939; Bigelow and Sears 1939; Fleminger and Hulsemann 1977). Their geographical distribu-

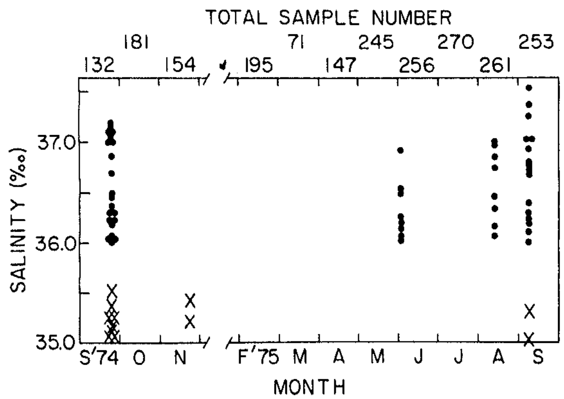


FIGURE 4.—Occurrences of Gulf Stream water (salinity ≥36‰) over slope (≥100 m), and of slope water (35‰<salinity<36‰) over the shelf in the New York Bight, September 1974-September 1975. Dots = Gulf Stream salinities over slope; × = slope salinities over shelf.

tions and the generally southward flow along this sector of the shelf (Bumpus 1973) suggest that a high proportion of individuals occurring in the Bight are advected into the region from the northeast. Irrespective of the origin of these populations, it can be assumed that they were major consumers of the spring phytoplankton bloom in 1975.

Centropages typicus and *Temora longicornis* are warm temperate species (Fleminger 1975), and their abundance in the New York Bight appears to be strongly influenced by temperature. Lawson (1969) found that *C. typicus* eggs failed to hatch when maintained at 5°-6° C, the prevailing water temperature in February through May (Figure 3), and Bigelow and Sears (1939) reported a northward seasonal shift in abundance of *C. typicus* beginning in the Chesapeake Bay-Delaware Bay region in the spring, progressing to the New York area in July, and finally reaching coastal waters off New England in autumn. The geographical distribution of *T. longicornis* corresponds closely to that of *C. typicus* (Fleminger 1975), and it is likely that it exhibits similar seasonal trends in abundance. In the New York Bight in 1975, *C. typicus* and *T. longicornis* increased in abundance from April to July as water temperature rose from about 5° to 20° C (Figure 3). These species appear to be especially well adapted for exploitation of coastal environments where high food levels persist into the warm season. Their peak abundances in 1975 occurred in or near the apex of the Bight where primary production in July can exceed 1-3 g C/m^2 per day (Malone 1976).

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