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Seasonal and Areal Distribution of Zooplankton in Coastal Waters of the Gulf of Maine, 1964

By Kenneth Sherman

SPECIAL SCIENTIFIC REPORT–FISHERIES No. 530

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

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Washington, D.C.

May 1966

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ABSTRACT

A description is given of the composition and seasonal variations of zooplankton in coastal waters of the Gulf of Maine during 1964, and comparisons are made between 1963 and 1964. Twelve zooplankton groups (major taxa) were represented in the samples. Five occurred as holoplanktonic forms and seven were meroplanktonic. Copepods were the dominant zooplankters during all seasons. Zooplankton volumes for both years followed similar areal trends. Mean annual volumes were highest in the western area (Cape Ann, Mass., to Cape Elizabeth, Maine); moderate in the central area (Cape Elizabeth to Mt. Desert Island, Maine); and low in the eastern sector (Mt. Desert Island to Machias Bay, Maine). Zooplankton volumes were generally lower in 1964 than in 1963. Seasonal and annual variations in abundance of zooplankters are discussed in relation to hydrography. Local hydrography appears to influence the abundance and distribution of coastal zooplankters more directly then does the cyclonic-eddy system of the Gulf proper.

INTRODUCTION

An expanded program of biological and environmental sampling of Gulf of Maine coastal waters was begun in 1963 by the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine. The program was designed to provide information on the relations between the environment and the availability and abundance of immature herring, Clupea harengus L. This report is the second of a series describing the zooplankton assemblage in Gulf of Maine coastal waters. The relative abundance, composition, and areal distribution of the zooplankton in 1963 was described previously (Sherman, 1965). Sampling in 1964 was directed at determining seasonal, annual, and areal variations of the larger zooplankters, particularly calanoid copepods and herring larvae. This report presents results of the 1964 coastal survey and a description of between-year differences (1963-1964).

METHODS

Four stations in each of three Gulf of Maine coastal areas--western (Cape Ann to Cape Elizabeth), central (Cape Elizabeth to Mt. Desert Island), and eastern (Mt. Desert Island to Machias Bay)--were sampled seasonally on single quasi-synoptic cruises of the research vessel Rorqual: winter, January 21-February 14; spring, May 21-28; summer, August 10-20; and fall, October 1-13 (fig. 1). As in 1963, samples were collected with a Gulf III sampler, fitted with a 20.4-cm. nose cone and monel netting (aperture width, 0.37 mm.). Step-oblique tows from 20 m. to the surface lasting 30 minutes each were taken during daylight. The net was towed for approximately 10 minutes at each tow--at the surface, at 10 m., and at 20 m. The amount of water strained was determined from a calibrated flow meter mounted on the tail section of the Gulf III. The average 30-minute tow covered 3 nautical miles and filtered about 200 m.^{3} of water. Towing speed was 6 knots.

In the laboratory, displacement volumes were determined by the mercury-immersion method (Yentsch and Hebard, 1957). Ctenophores, large coelenterate remains (>2 cm. long), and all fish larvae were removed in advance of the volume determinations. Zooplankton samples were split into aliquots

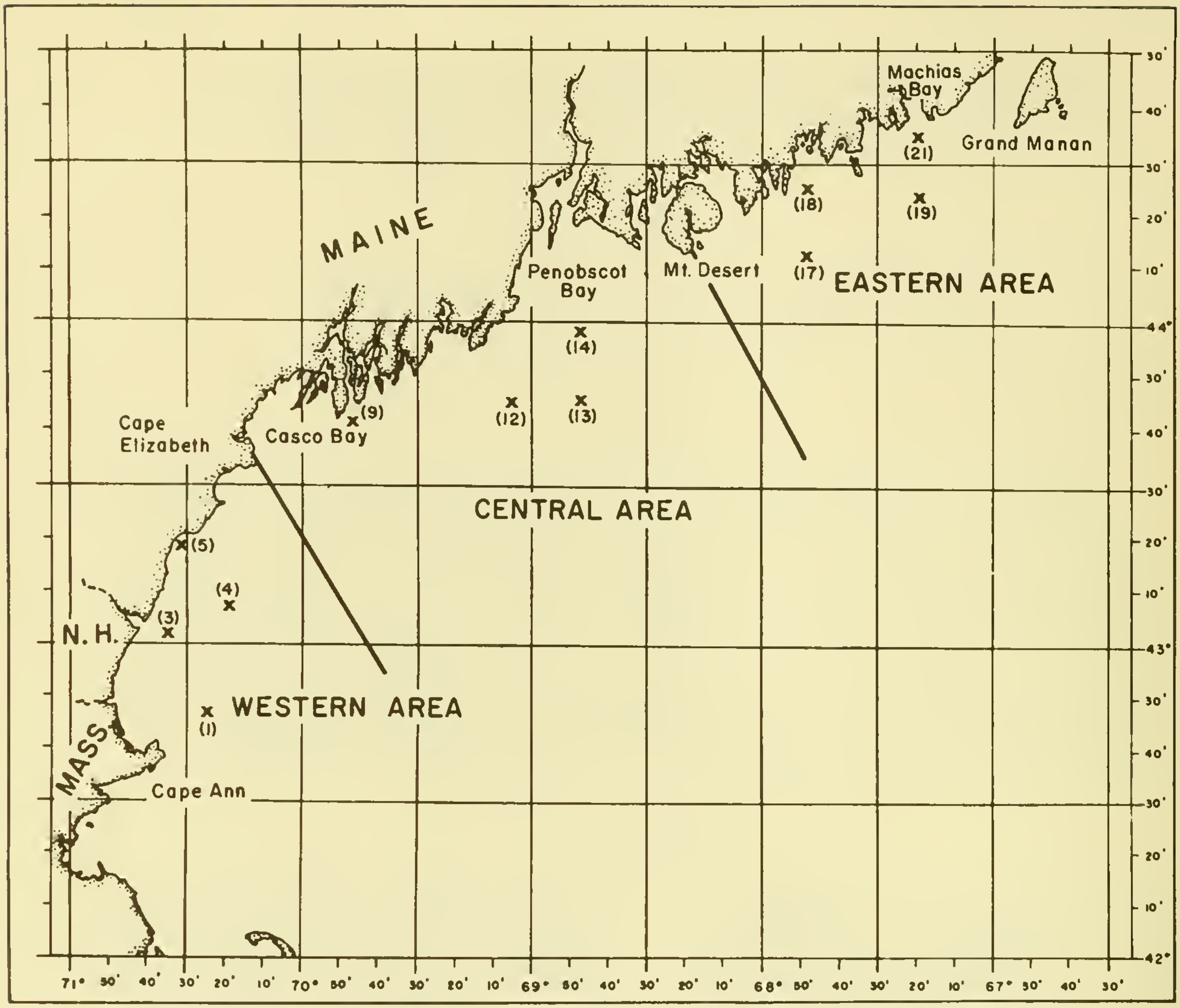

Figure 1.--Zooplankton sampling stations, Gulf of Maine coastal waters, 1964. Station numbers are shown in parentheses.

ranging from a half to a sixty-fourth, depending on the mass of the sample, and sorted into major taxonomic groups. Copepods were identified to species, and the numbers of copepods and other zooplankters per 100m.^{3} of water were calculated.

ABUNDANCE, COMPOSITION, AND DISTRIBUTION OF ZOOPLANKTON

Zooplankton volumes

Comparison of mean seasonal volumes of zooplankton shows that seasonal variation differed among the three coastal areas. All areas had their lowest volumes of zooplankton in the winter; the eastern area had its zooplankton peak in spring; the central area, in fall; and the western area, in summer (fig. 2). Seasonal variation was greatest in the western area, where the summer high exceeded values for winter, spring, and fall by a ratio of 3:1. These values are considered to be minimal estimates of zooplankton abundance because the 0.37-mm. mesh aperture confined sampling to the larger zooplankters, particularly calanoid copepods.

The nonparametric Mann-Whitney U-test (Siegel, 1956) was used to test for differences between areas. Western volumes were significantly higher ($P < 0.05$) than central or eastern volumes in the spring, and higher than eastern volumes in the summer (table 1). Sample volumes are given for each Gulf of Maine coastal area in table 2.

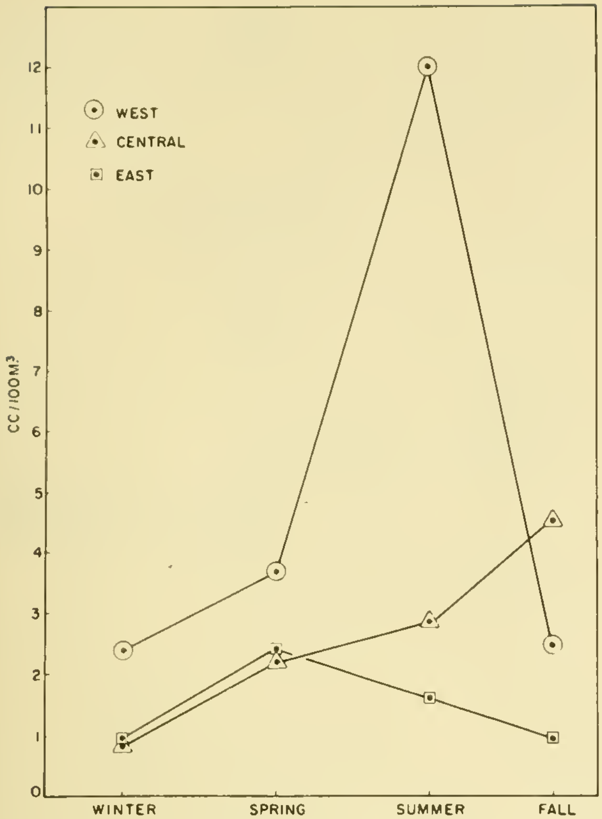

Figure 2.--Mean zooplankton volumes by area and season, Gulf of Maine coastal waters, 1964. Locations of the areas are shown in figure 1.

Group and species composition by season and area

Twenty zooplankton groups (taxa) were represented in the samples. Of these, 12 constituted more than 1 percent of the total zooplankton: copepods, chaetognaths, pteropods, amphipods, decapod larvae, cirriped larvae (nauplii and cyprids), gastropod larvae, cladocerans, appendicularians, fish eggs, crustacean eggs, and brachyuran zöea. Copepods were dominant, ranging from 80 percent in winter to 45 percent in spring (fig. 3).

Areal distributions of dominant zooplankton groups (seasonal mean $>100/100m.^3$ of water) were determined by season for each of the three Gulf areas (fig. 4, A-D). During winter, zooplankters were at the annual numerical minimum. Copepods were dominant; lowest numbers were in the central area. Chaetognaths and pteropods were most numerous in the western sector (fig. 4A). In the spring, numbers in each of the major groups, with the exception of cirriped larvae, decreased from west to east. Larval cirripeds were most plentiful in the eastern area of the coast (fig. 4B). Distribution was more variable during summer and fall.

Table 1.--Mann-Whitney one-tailed test (U) values for comparing zooplankton volumes of main coastal areas, 1964

Areas compared	Winter		Spring		Summer		Fall	
	U	P[1]	U	P	U	P	U	P
Central-East...	7	0.443	4	0.171	3	0.100	2	0.057
Central-West...	4	.171	1	.029	3	.100	7	.443
West-East...	5	.243	1	.029	1	.029	2	.057

[1] P is probability, which is significant at less than .05.

Table 2.--Sample volumes (cc./100 m.3) for each of the Gulf of Maine coastal areas, 1964

Area	Station number	Season			
		Winter	Spring	Summer	Fall
West	1	2.28	3.66	9.71	1.31
Do...	3	4.24	4.38	1.60	2.93
Do...	4	0.27	2.91	26.60	1.62
Do...	5	2.82	3.97	10.05	3.85
Central	9	1.34	1.94	5.78	13.48
Do...	12	0.35	1.07	2.14	1.48
Do...	13	0.33	3.50	1.06	2.17
Do...	14	1.32	1.90	2.00	0.88
East...	17	1.32	2.03	0.54	1.44
Do...	18	1.76	3.13	0.36	1.48
Do...	19	0.31	2.29	4.93	0.10
Do...	21	0.16	2.02	0.52	0.55

Copepods dominated in the western area and fish eggs and crustacean eggs in the central area in summer (fig. 4C). Copepods, crustacean eggs, brachyuran larvae, and appendicularians were most numerous in the central area during fall. Numbers of each of the major taxa were smaller, however, in the eastern area (fig. 4D).

The collections contained 23 species of copepods, of which 8 were classified as common (>50 per $100m.^3$ per station). The dominant species was Calanus finmarchicus, followed by Pseudocalanus minutus, Centropages typicus, Temora longicornis, Metridia lucens, Oithona similis, Acartia longiremis, and Tortanus discaudatus (table 3). Five of the

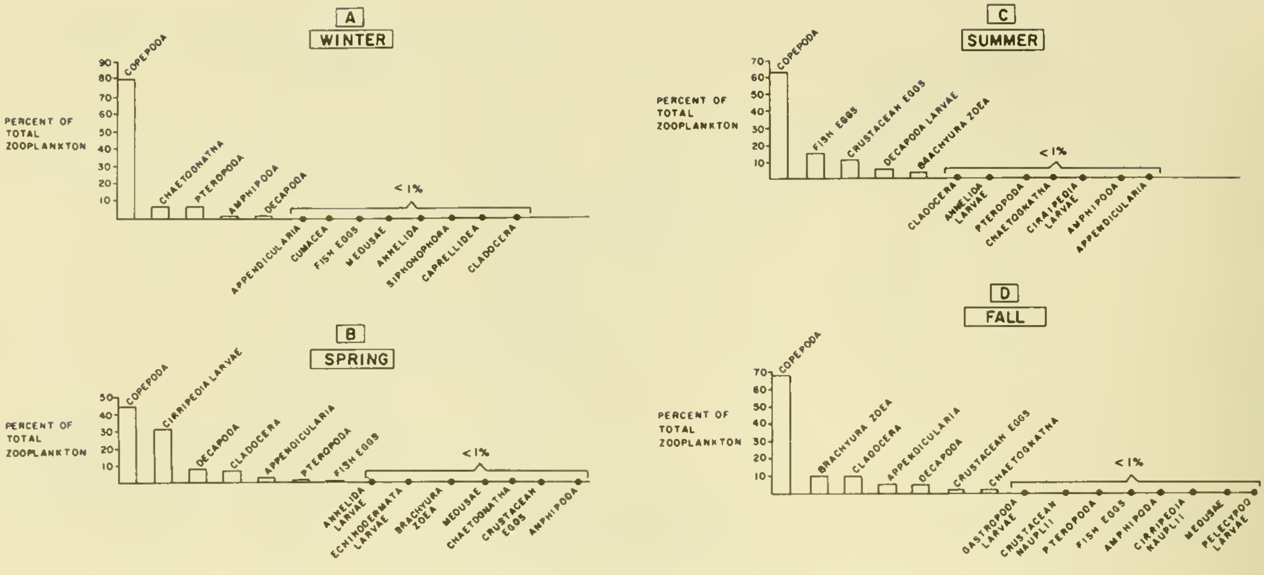

Figure 3.--Percentage composition of zooplankton groups in Gulf of Maine waters in each season, 1964.

Figure 4.--Mean number of the dominant zooplankton groups per 100m.^{3} of water in western (W), central (C), and eastern (E) Gulf of Maine coastal waters.

eight species--P. minutus, C. typicus, T. longicornis, O. similis, and T. discaudatus--declined in abundance from west to east. Three species had different patterns of seasonal and areal occurrence: in the fall C. finmarchicus was most numerous in the central area; in winter M. lucens was found in greatest numbers in the eastern area; and in summer A. longiremis increased in numbers from west to east (fig. 5).

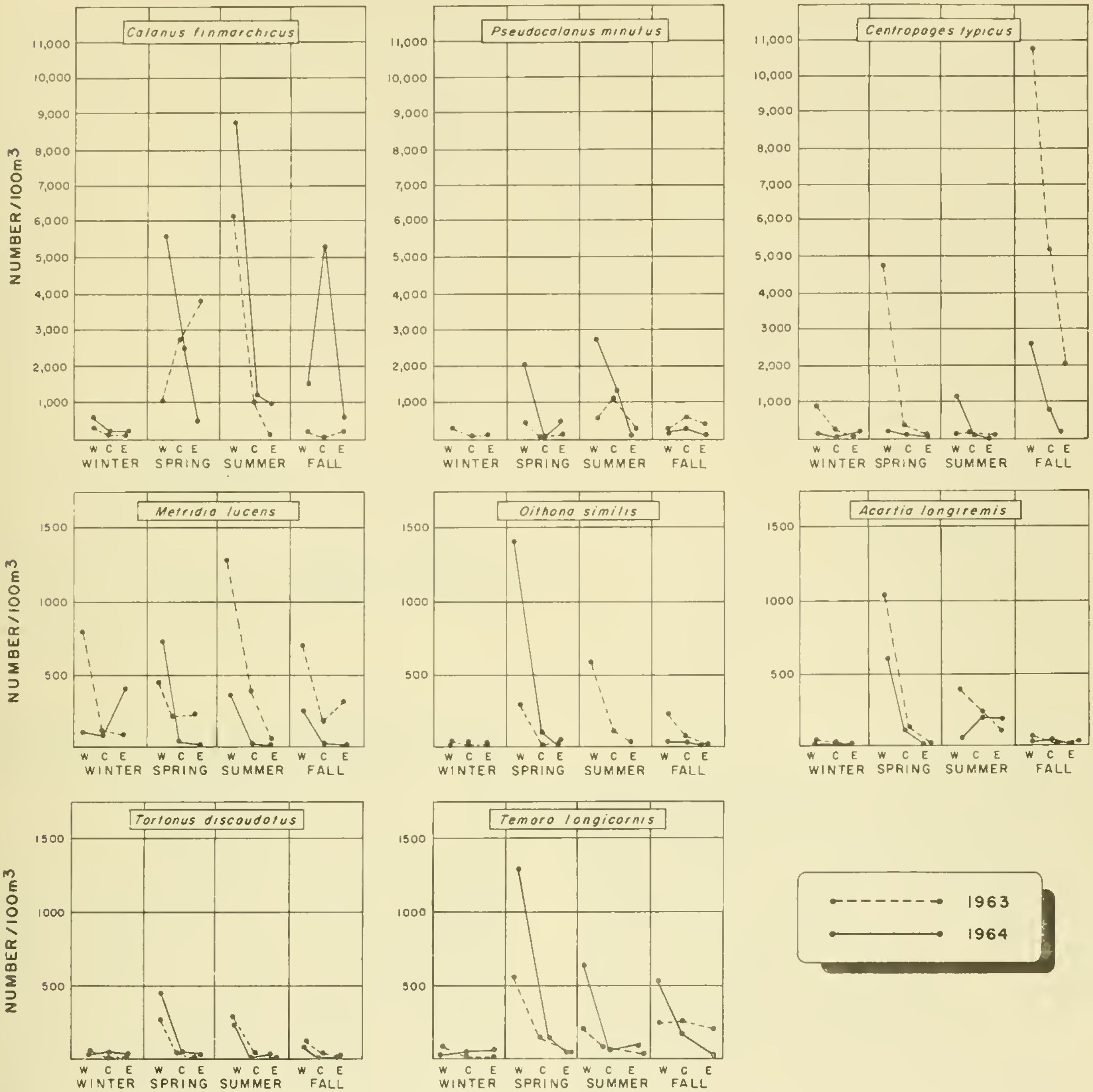

Figure 5.--Seasonal variations of dominant copepods by Gulf of Maine coastal areas for 1963 and 1964.

Table 3.--Copepod species in zooplankton samples, Gulf of Maine coastal waters, 1964

Species	Mean number/ 100m.^{3}/ station
Common species (>50/100m.^{3})	
Calanus finmarchicus (Gunnerus)..	2,368
Pseudocalanus minutus (Kroyer)...	618
Centropages typicus Kroyer.......	407
Temora longicornis (Muller)......	242
Metridia lucens Boeck............	163
Oithona similis Claus............	136
Acartia longiremis (Lilljeborg)..	106
Tortanus discaudatus (Thompson & Scott)......................	65
Less numerous species (<50/100m.^{3})	
Centropages hamatus (Lilljeborg).	25
Calanoid sp. immature............	12
Eurytemora herdmani Thompson and Scott........................	10
Less numerous species--Cont.	
Metridia longa (Lubbock).........	6
Acartia clausi Giesbrecht........	5
Eurytemora affinis (Poppe).......	4
Acartia sp. immature............	3
Cyclopoid sp.....................	2
Oithona spinirostris Claus.......	1
Diaptomus minutus Lilljeborg.....	0.73
Euchaeta norvegica Boeck.........	0.48
Candacia armata (Boeck)..........	0.42
Anomalocera patersonii Templeton.	0.29
Harpacticoid sp..................	0.17
Undinopsis similis Sars..........	0.04

BETWEEN-YEAR COMPARISONS, 1963 and 1964

Zooplankton volumes

Areal trends in zooplankton volumes were similar in 1963 and 1964 (fig.6). Volumes were compared between areas within each year by the Mann-Whitney U-test. In both years volumes were significantly higher ($P<0.05$) in the western areas than in the central and eastern areas. Significant differences were found between central and eastern volumes in 1963, but not in 1964 (fig. 6). This between-year difference may have been related to the transitional character of the central sector, located between areas with high and low volumes.

Mean seasonal volumes are plotted by area in figure 7 for both years. Seasonal trends were similar in the western and eastern areas: in the western area volumes increased from a winter low to a summer peak and declined in the fall; in the east, volumes reached a spring peak from a winter low and declined in summer. The trend was reversed in the central sector, where winter-fall volumes decreased in 1963 and increased in 1964. Comparison of volumes between years by the Mann-Whitney U-test revealed significantly lower seasonal values ($P < 0.05$) in 1964 in the west (spring and ~~summer~~ fall), and in the central areas (winter and summer). Volumes in the eastern area were similar in those years (fig. 7).

Zooplankton groups and species

During the 2 years, 12 major groups (seasonal mean >100/100m.^{3}) of zooplankton were collected. Five of them--copepods, cladocerans, appendicularians, pteropods, and chaetognaths--were holoplanktonic forms; seven were meroplanktonic--cirriped larvae, fish eggs, crustacean eggs, decapod larvae, brachyuran larvae, annelids, and gastropod larvae. Large swarms of meroplanktonic forms occurred during the spring (cirriped larvae), summer (decapod larvae and fish and crustacean eggs), and fall (brachyuran larvae). This swarming occurs during the breeding periods of these forms, the onset of which is largely under the influence of local environmental conditions. Copepods were the dominant forms during all seasons in both years. The curves of copepod abundance were similar for winter and spring, but differed during summer and fall (fig. 8). These differences were related to variations in abundance of the dominant species. During summer 1964, C. finmarchicus and P. minutus showed large (>500/100m.^{3}) mean seasonal increases in abundance over the previous summer (fig. 5). In contrast, the decline in copepod abundance in the fall of 1964 was caused by the sharp decrease in mean seasonal numbers of C. typicus (ca. 6,000/100m.^{3}) and to a lesser degree by reductions in numbers of P. minutus and M. lucens (ca. 300/100m.^{3}).

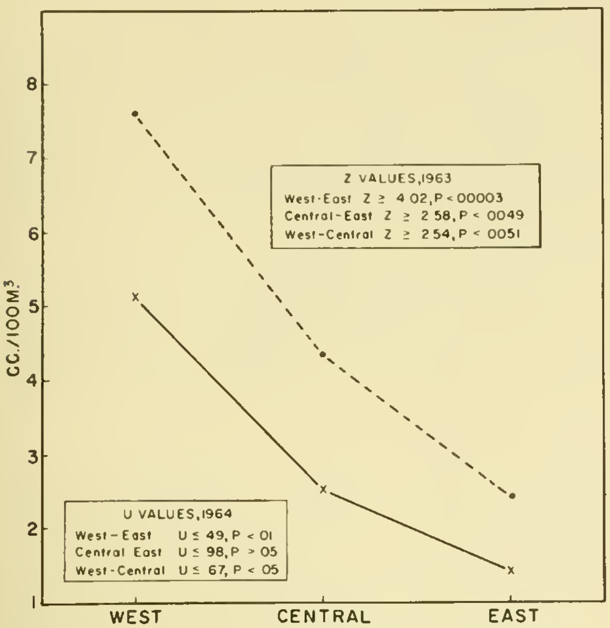

Figure 6.--Mean annual zooplankton volumes by Gulf of Maine coastal areas for 1963 (broken line) and 1964 (solid line). Mann-Whitney U and Z values are given for between-area comparisons.

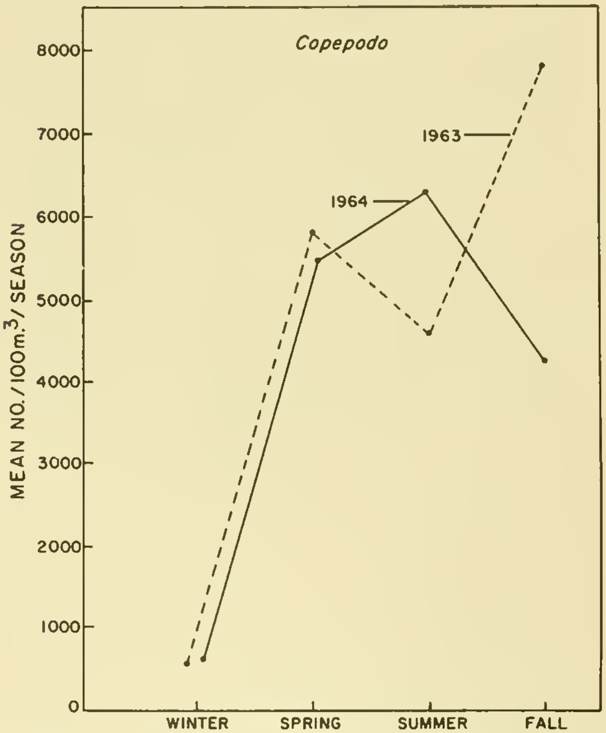

Figure 8.--Seasonal curves of copepod abundance, Gulf of Maine coastal waters, 1963-64.

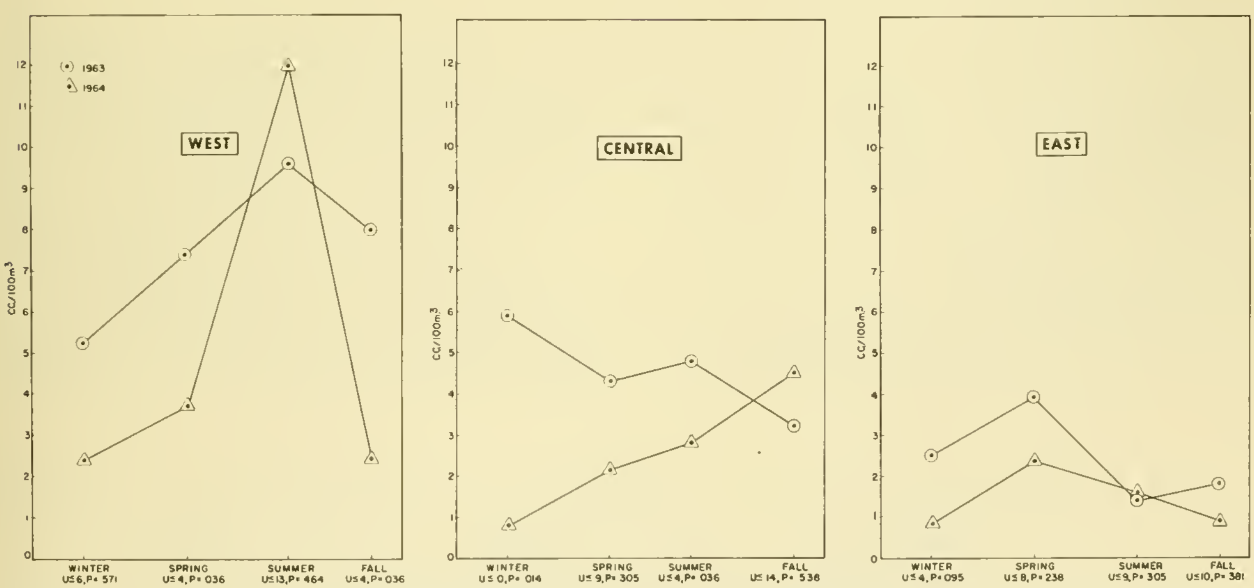

Figure 7.--Mean seasonal zooplankton volumes by Gulf of Maine coastal areas in 1963 and 1964. Mann-Whitney between-year U values and probabilities are given by season.

Variations of temperature and salinity

Hydrographic data showed seasonal and annual variations along the coast. The curves of mean seasonal surface temperature and salinity for each of the Gulf areas are given in figure 9, A-C. Curves for 1963 and 1964 were similar; temperatures increased from a winter minimum to a summer maximum, and then declined in the fall. Salinities rose to a fall-winter maximum from a spring low. Similar seasonal variations of temperature and salinity have been reported for Gulf waters by Bigelow (1927), Gran and Braarud (1935), and Graham and Boyar (1965).

Ranges of temperature and salinity among the three coastal areas differed seasonally and annually. Temperatures were cooler and salinities higher in the eastern area for spring, summer, and fall. Winter conditions of low temperature and high salinity were similar in all areas. The greatest between-year temperature difference occurred in the western area during spring, where temperatures were 4.8° C. lower in 1964 than in the preceding year. Salinity values were higher in 1964 during all seasons. Seasonal changes of salinity were similar in the central and eastern areas during both years, increasing from a spring minimum to a fall maximum. In the western area salinity reached a maximum in the fall in 1963, but the maximum was in winter in 1964. Spring runoff for major rivers emptying into the Gulf was much reduced in 1964 (table 4); this decreased river drainage apparently was responsible for the higher salinities of 1964. The importance of river discharge on the salinity and circulation characteristics of the Gulf has been reported by Bigelow (1914, 1927), Bumpus (1960), and Bumpus and Lauzier (1965).

Areal differences in surface temperature and salinity in coastal waters of the Gulf of Maine have been shown to reflect local conditions rather than advection of waters (Bigelow, 1914).

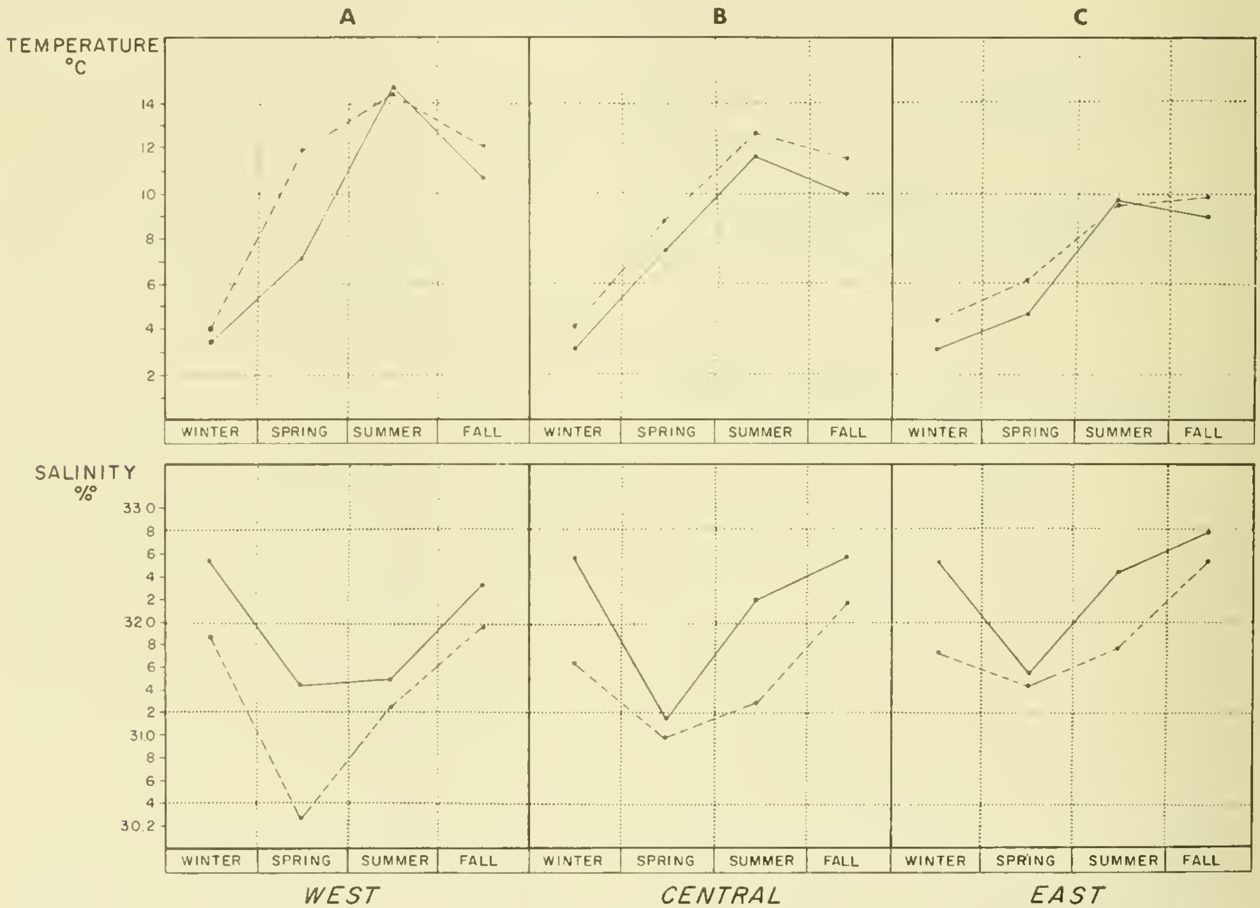

Figure 9.--Mean seasonal surface temperature and salinity for the western, central, and eastern areas of the coastal Gulf of Maine in 1963 (broken line) and 1964 (solid line).

Table 4.--Mean monthly discharge (in cubic feet per second) of the major rivers emptying into the Gulf of Maine, April and May 1963 and 1964[1]

River	Year	
	1963	1964
St. Croix................	10,255	6,697
Machias..................	6,180	3,025
Penobscot................	64,520	33,470
Sheepscot................	1,756	788
Androscoggin.............	28,530	19,107
Sacc.....................	13,067	10,307
Total................	124,308	73,394

[1] Data from the U.S. Geological Survey, District Engineer, Surface Water Branch, Vickery-Hill Building, Augusta, Maine.

Bigelow attributed the higher salinities and cooler waters of the eastern Gulf to vertical mixing. Lower salinities and warmer waters of the western sector were related to river discharge and thermal stratification. During winter, one would expect wind-induced vertical mixing and cool air moving from the land to produce relatively homogeneous hydrographic conditions. This situation existed during the winters of 1963 and 1964. Profiles of temperature and salinity corroborate Bigelow's conclusions regarding vertical mixing in the eastern Gulf and stratification of water in the western area during the warmer months (fig. 10).

Distribution of copepods and circulation

The general decrease in zooplankton volumes from west to east, differs from the areal distribution which would be expected from the cyclonic drift theory applied to the calanoid community of the offshore Gulf of Maine by Redfield (1941). He showed a progressive west-to-east seasonal increase in the Gulf calanoid population from a low in winter to a high in late summer and early fall. This change occurred during an annual circuit of the Gulf in the cyclonic nontidal drift. If the circulation theory presented by Redfield for offshore Gulf waters were applicable in the coastal region, one would expect an increase in the density of the calanoid population along the coast from west to east; maximum volumes should occur off Mt. Desert Island in early fall. The generally decreasing volumes from west to east in 1963 and 1964, and similar areal decline in numbers of the eight dominant calanoid copepods suggest that local hydrography exerts a greater influence on the abundance and distribution of the coastal zooplankton than does the cyclonic-eddy system of the Gulf proper. Periodic offshore-inshore incursions of calanoid species and other zooplankters from outer Gulf waters have been reported, however (Bigelow, 1926; Fish, 1936a, 1936b; Fish and Johnson, 1937; Redfield, 1939, 1941; Redfield and Beale, 1940). During 1964 two calanoid species known to breed in both inshore and offshore waters were responsible for apparently anomalous west-to-east distributions of copepods. During the winter Metridia lucens accounted for the eastern-area peak in copepod numbers, and during the fall Calanus finmarchicus was responsible for the central-area peak. These anomalous occurrences may have resulted from incursions of outer Gulf waters.

Areal differences in zooplankton volumes (low in the eastern area, moderate in the central area, and high in the western area) may be caused by dissimilar hydrography. In the eastern area the unstable water column, minimal runoff (J. J. Graham, unpublished data), and lack of appreciable influx of zooplankton from the north and east (Bigelow, 1926; Redfield, 1941) lead to minimal conditions for population growth. In contrast, optimal conditions of maximum runoff and associated nutrient effluent, increased stability of the water column, and higher spring and summer water temperatures in the western area provide a favorable environment for growth and development of coastal zooplankton; conditions in the central area are transitional between the two extremes. Preliminary information indicates that coastal eddies form along the periphery of the Gulf coast under the interaction of river discharge and nontidal drift (J. J. Graham, unpublished data). Little is known about the seasonal permanence of these eddies. They may be of prime importance, however, in the maintenance of populations of coastal zooplankton.

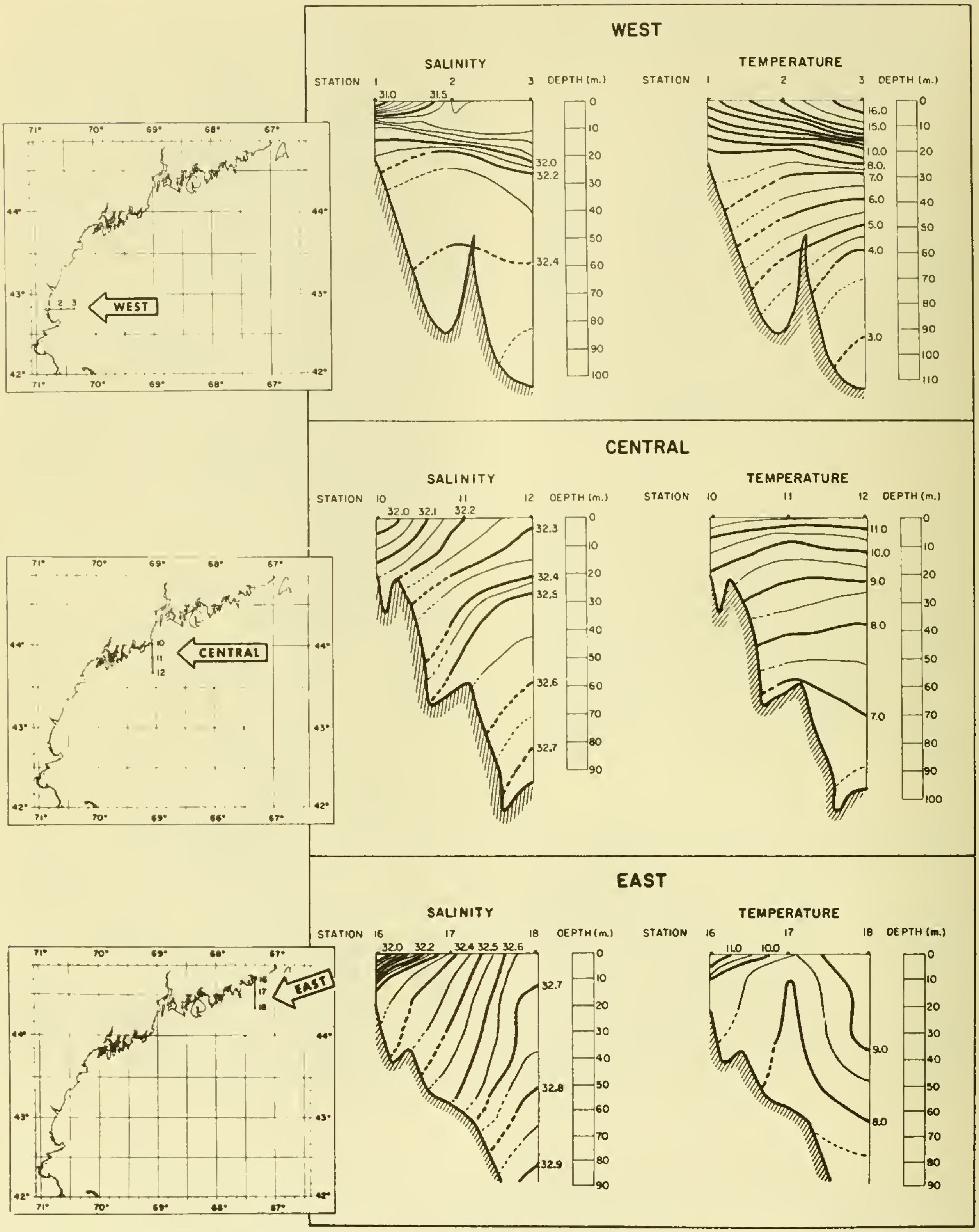

Figure 10.--Inshore-offshore vertical profiles of temperature (°C.) and salinity (p.p.t.), Gulf of Maine coastal waters, summer 1964. Insets at left show station locations.

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