Seasonal and Areal Distribution of Zooplankton in Coastal Waters of the Gulf of Maine, 1967 and 1968

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By

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CONTENTS

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ABSTRACT

The abundance, composition, and seasonal variations in the distribution of zooplankton are described. Thirteen taxa were among the more abundant zooplankters in the samples: 6 were holoplanktonic, and 7 were meroplanktonic. Copepods were the dominant zooplankters during all seasons in both years. Zooplankton volumes were highest in the western area (Cape Ann to Cape Elizabeth), intermediate in the central area (Cape Elizabeth to Mt. Desert Island), and lowest in the eastern sector (Mt. Desert Island to Machias Bay). The differences in zooplankton abundance among areas and between years were caused by variations in the timing of vernal warming and coastal differences in water column stability and circulation.

INTRODUCTION

In 1963 the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, began studying zooplankton in coastal waters of the Gulf of Maine. Sampling was designed to monitor seasonal changes in the composition, distribution, and abundance of large zooplankton, particularly calanoid copepods, the predominant food of juvenile Atlantic herring, *Clupea harengus harengus* L. The studies are part of an investigation of how the environment affects the abundance of herring and their availability to the commercial fishery. This is the fourth in a series of reports on the coastal zooplankton assemblage in the Gulf of Maine (see also Sherman 1965, 1966, and 1968).

METHODS

As in previous years, four stations in each of three Gulf of Maine coastal areas--western (Cape Ann to Cape Elizabeth), central (Cape Elizabeth to Mt. Desert), and eastern (Mt. Desert to Machias Bay)--were sampled seasonally on cruises of the research vessel *Rorqual* (see fig. 1 for station locations and cruise dates). In each of the seasons in 1967, and in the winter, spring, and summer of 1968, collections were made with a Gulf III sampler, fitted with a 20-cm. nose cone and metal netting (aperture width 0.366 mm.). Step-oblique tows of 30 minutes--10 minutes each at 20 m., 10 m., and the surface--were made during daylight. Recent experimentation has shown, however, that the Gulf III undersamples the smaller copepods when towed at 6 knots (Sherman and Honey, in press). To reduce this sampling bias, a bongo-type sampler (Posgay, Marak, and Hennemuth, 1968) was substituted for the Gulf III in autumn 1968. The towing method, mesh apertures, and mouth openings of the bongo net were identical to those of the Gulf III, except that nylon was substituted for the metal netting used in the Gulf III. The volumes of zooplankton and counts of copepods obtained from the bongo tows were adjusted by reducing them to Gulf III values, using data obtained from comparisons of the bongo and Gulf III samplers made in autumn 1967 (Sherman and Honey, 1968).[1] A calibrated flowmeter was mounted in the tail section of the Gulf III and in the mouth opening of one of the bongos. Each tow covered about 5.6 km. and filtered about 200 m.^{3} of water. Towing speed was 6 knots (308 cm. per second).

Zooplankton volumes were measured in the laboratory by the mercury immersion method of Yentsch and Hebard (1957). Ctenophores, large coelenterates, other large organisms

[1] The correction factor used was the ratio of the average difference between volumes obtained with the Gulf III and with the bongos and between smaller copepod species--*Centropages hamatus*, *Pseudocalanus minutus*, *Temora longicornis*, *Acartia longiremis*, and *Acartia clausii*--obtained by both samplers in 10 simultaneous tows.

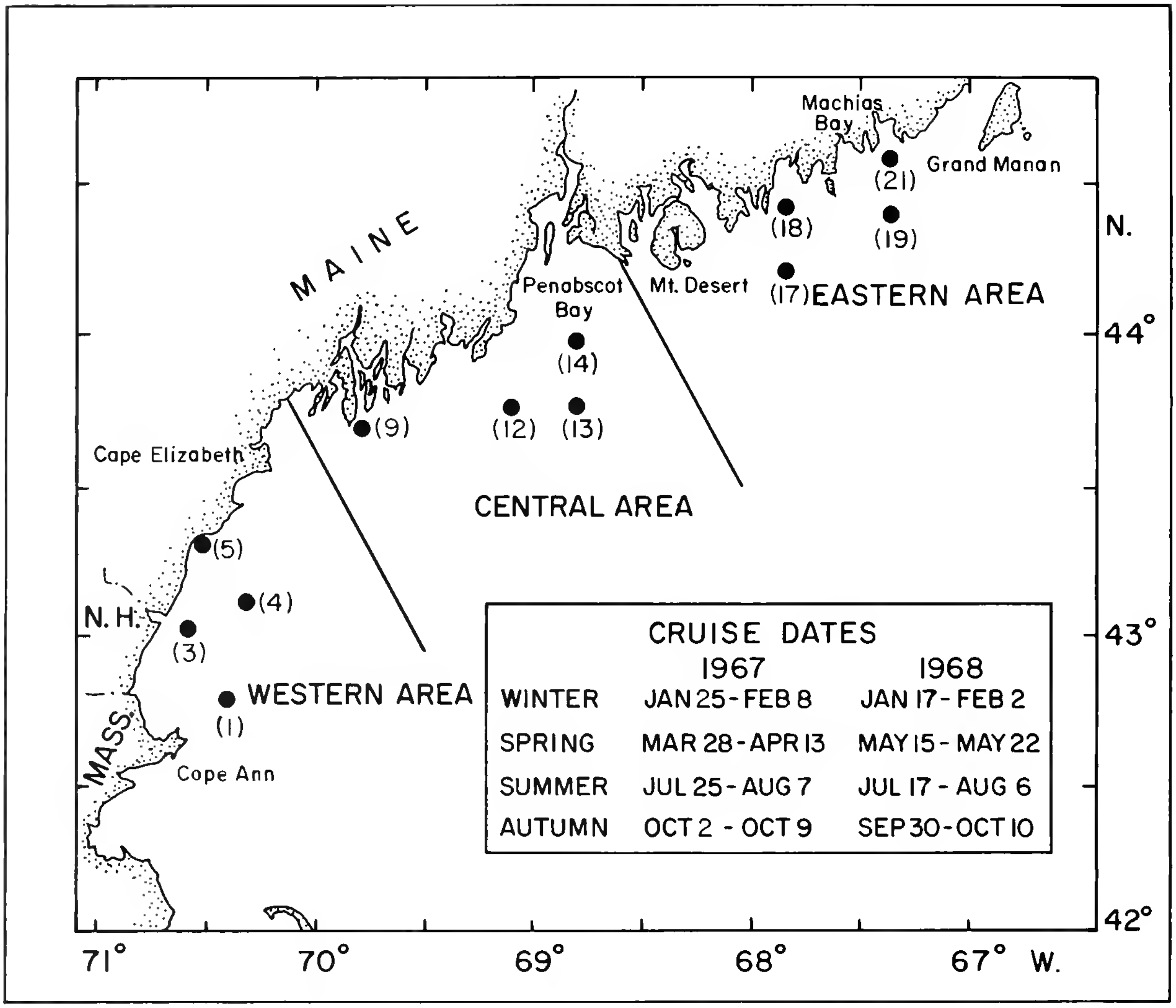

Figure 1.--Zooplankton sampling stations, Gulf of Maine coastal waters, 1967 and 1968. Station numbers are shown in parentheses.

greater than 2 cm. in their broadest dimension, and all fish larvae were excluded. Zooplankton samples were divided into aliquots, 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 numbers of copepods and other zooplankters per 100 m.^{3} were calculated.

ABUNDANCE, COMPOSITION AND DISTRIBUTION OF ZOOPLANKTON

Observations were made of the seasonal and annual changes in zooplankton abundance, composition, and distribution in 1967 and 1968.

Zooplankton Volumes

Seasonal trends in zooplankton volumes were similar in the 2 years with one exception (fig. 2). Volumes increased from winter to a spring peak and declined in summer in both years; from summer to autumn, however, they decreased in 1967 and increased in 1968. These volumes are considered minimal estimates of abundance as sampling was done only in daylight in the upper 20 m. of water with relatively large-mesh netting (0.366 mm. apertures).

Volumes at each station were examined for differences among areas with the Kruskal-Wallis analysis of variance (Siegel, 1956). Differences in station values among the areas were significant ($P < 0.05$) in winter, spring, and autumn 1967 and in spring 1968. Volumes generally decreased from west to east. Differences among the areas were not significantly different in autumn and winter 1968, and in the summer of both years (table 1).

Trends in zooplankton abundance were similar along the coast in 1967 and 1968; mean annual volumes for each of the areas declined

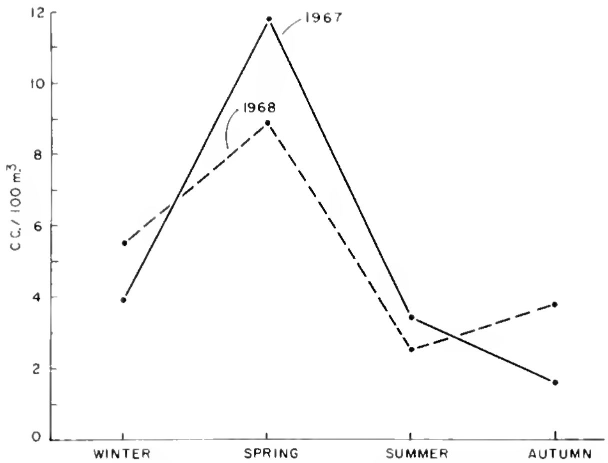

Figure 2.--Mean seasonal volumes of zooplankton in Gulf of Maine coastal waters, 1967 and 1968. Solid line is for 1967, and dotted line for 1968.

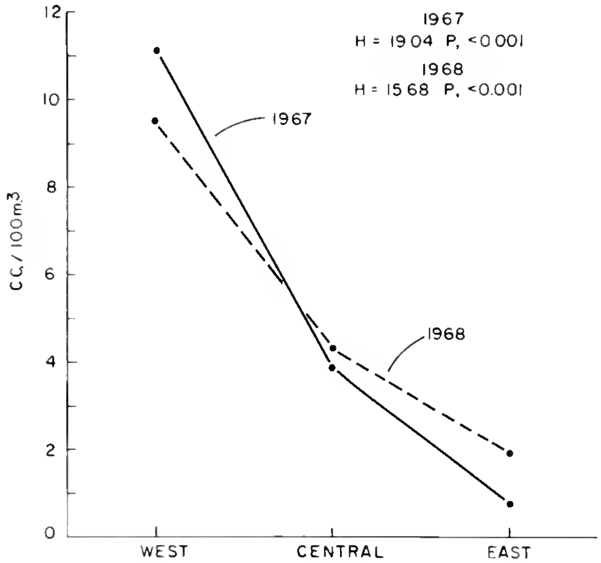

Figure 3.--Mean annual volumes of zooplankton for each of the areas investigated in Gulf of Maine coastal waters in 1967 (solid line) and 1968 (broken line). Kruskal-Wallis H values given are for among-area comparisons.

from a high in the west to a low in the east (fig. 3). Differences in station volumes among the areas were tested with the Kruskal-Wallis analysis of variance, and in each of the years the areal decrease in abundance was significant ($P < 0.001$).

Group and Species Composition

Copepods are the predominant zooplankters in coastal waters. In different seasons they constituted from 98 percent of the total zooplankton (winter 1968) to 41 percent (summer 1967). Twelve other groups (taxa) constituted more than 1 percent of the zooplankton in each

Table 1.--Sample volumes per 100 m.[3] of water strained at each sampling station in three areas along the coast of the Gulf of Maine, 1967 and 1968

[Kruskal-Wallis H and probability values are listed for each area by season. See figure 1 for location of stations and areas]

Year, area, and station number	Winter	Spring	Summer	Autumn
1967:				
West:				
1.......	0.91	9.08	3.73	5.81
3.......	2.44	63.28	1.42	2.87
4.......	4.34	5.69	12.45	2.67
5.......	[1]33.56	21.81	5.21	1.47
Central:				
9.......	0.57	9.91	1.26	0.19
12.......	0.28	4.36	8.00	1.98
13.......	0.70	11.22	1.49	0.87
14.......	([2])	10.72	0.09	2.50
East:				
17.......	0.15	1.48	0.89	0.38
18.......	0.01	0.88	0.48	0.24
19.......	0.62	0.39	2.94	0.11
21.......	0.29	2.73	0.57	0.16
H value.....	7.48	7.94	3.96	7.54
P value.....	<0.010	<0.008	>0.104	<0.011
1968:				
West:				
1.......	10.32	42.18	1.31	2.92
3.......	4.12	22.10	1.98	2.55
4.......	9.94	9.80	3.07	7.77
5.......	7.71	16.05	2.43	3.99
Central:				
9.......	0.55	8.94	4.22	6.43
12.......	4.33	4.11	4.40	5.29
13.......	10.12	1.11	2.74	1.66
14.......	1.72	1.13	0.90	6.23
East:				
17.......	1.33	0.45	0.93	([2])
18.......	3.06	0.40	2.43	0.83
19.......	9.75	0.31	1.97	([2])
21.......	3.62	0.48	0.97	0.76
H value.....	2.88	9.84	2.19	4.42
P value.....	>0.104	<0.008	>0.104	>0.103

[1] Mostly euphausiids.
[2] No sample obtained.

year (table 2); five were holoplanktonic (appendicularians, chaetognaths, cladocerans, euphausiids, and pteropods) and seven were meroplantonic (brachyuran larvae, cirriped larvae, crustacean eggs, crustacean nauplii, decapod larvae, fish eggs, and gastropod larvae). The seasons of abundance of these groups varied between years. The holoplankters were most numerous in spring 1968, when all except the cladocerans were at their annual peak in abundance. In 1967, in contrast, four of the six groups--appendicularians, chaetognaths, cladocerans, and euphausiids--were most abundant in summer. Among the meroplankters, cirriped larvae were most numerous in spring

Table 2.--Mean numbers and percentage composition of zooplankton groups per 100 m.^{3} of water strained in each season, Gulf of Maine coastal waters, 1967 and 1968

Year and group	Winter		Spring		Summer		Autumn	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1967:								
Holoplankton:								
Amphipoda	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1
Appendicularia(*)	30	7	0	0	1,441	14	90	2
Chaetognatha(*)	14	3	14	< 1	26	< 1	81	2
Cladocera(*)	7	2	0	0	723	7	411	9
Copepoda(*)	322	73	4,645	78	4,228	41	2,802	62
Euphausiacea(*)	42	10	84	1	797	8	47	1
Medusae	< 1	< 1	3	< 1	26	< 1	5	< 1
Pteropoda(*)	< 1	< 1	3	< 1	0	0	0	0
Siphonophora	0	0	0	0	0	0	1	< 1
Meroplankton:								
Annelida larvae	0	0	7	< 1	50	< 1	< 1	< 1
Brachyura larvae(*)	< 1	< 1	47	< 1	186	2	149	3
Cirripedia larvae(*)	3	< 1	842	14	29	< 1	4	< 1
Crustacean eggs(*)	0	0	32	< 1	576	6	755	16
Crustacean nauplii(*)	0	0	0	0	104	1	77	2
Decapoda larvae(*)	9	2	211	4	49	< 1	25	< 1
Fish eggs(*)	8	2	18	< 1	1,928	19	17	< 1
Gastropoda larvae(*)[1]	0	0	0	0	50	< 1	38	< 1
Pelecypoda larvae	4	< 1	5	< 1	28	< 1	12	< 1
Pycnogonoida	0	0	< 1	< 1	0	0	< 1	< 1
1968:								
Holoplankton:								
Amphipoda	0	0	< 1	< 1	2	< 1	0	0
Appendicularia(*)	0	0	7,960	21	1,323	12	30	< 1
Chaetognatha(*)	11	< 1	16	< 1	11	< 1	3	< 1
Cladocera(*)	0	0	1,484	4	1,608	14	617	13
Copepoda(*)	3,710	98	23,829	62	5,434	47	3,306	72
Euphausiacea(*)	0	0	412	1	186	2	32	< 1
Isopoda	0	0	< 1	< 1	0	0	0	0
Medusae	0	0	24	< 1	54	< 1	0	0
Pteropoda(*)	62	2	232	< 1	39	< 1	37	< 1
Siphonophora	1	< 1	0	0	0	0	0	0
Meroplankton:								
Annelida larvae	0	0	122	< 1	1	< 1	11	< 1
Brachyura larvae(*)	0	0	19	< 1	149	1	53	1
Cirripedia larvae(*)	0	0	2,026	5	226	2	0	0
Crustacean eggs(*)	0	0	145	< 1	1,023	9	6	< 1
Crustacean nauplii(*)	0	0	5	< 1	509	4	362	8
Decapoda larvae(*)	0	0	1,856	5	318	3	57	1
Echinodermata larvae	0	0	28	< 1	0	0	0	0
Fish eggs(*)	4	< 1	298	< 1	479	4	104	2
Gastropoda larvae(*)	0	0	12	< 1	141	1	1	< 1

(*) Constituting greater than 1 percent of the zooplankton in a season.
[1] Larval decapods other than brachyuran larvae.

of both years, and decapod larvae in peak numbers in spring 1968. The remaining groups were at an annual maximum in summer (table 2).

Copepod Abundance and Distribution

The samples had 19 species and groups of copepods; 5 were common (>50/100 m.^{3}/year) in 1967, and 11 in 1968 (table 3). The most numerous species were Calanus finmarchicus in winter, spring, and summer, and Centropages typicus in autumn. The abundance of copepods generally decreased from west to east. Notable exceptions were the high concentrations of C. finmarchicus, Pseudocalanus minutus, Tortanus discaudatus, and Temora longicornis, in

Table 3.--Total species composition and mean number of the dominant copepods per 100 m.^{3} of water in different seasons in each of the coastal Gulf of Maine areas, (W) western, (C) central, and (E) eastern in 1967 and 1968

Year and species	Mean no./station	Winter			Spring			Summer			Autumn		
		W	C	E	W	C	E	W	C	E	W	C	E
	Number/100 m.^{3}												
1967:													
Common species (>50/100 m.^{3}):[1]													
Calanus finmarchicus	2,010	330	322	148	10,543	2,985	226	5,528	1,565	1,309	518	217	10
Centropages typicus	500	2	35	23	0	0	0	62	105	0	5,377	274	12
Pseudocalanus minutus	94	13	16	7	133	7	19	1,616	395	178	394	277	53
Temora longicornis	85	11	2	1	2	0	0	400	324	4	159	89	5
Oithona spp.	50	18	4	5	0	0	< 1	137	40	7	362	17	5
1968:													
Common species (>50/100 m.^{3}):[2]													
Calanus finmarchicus	7,127	4,891	2,627	2,561	59,295	5,207	152	2,256	1,069	2,274	700	823	217
Centropages typicus	3,832	0	3	84	91	0	< 1	2,413	79	72	26,170	14,634	1,055
Centropages hamatus	1,468	0	0	0	475	33	0	144	596	64	1,489	2,338	[3] 133
Pseudocalanus minutus	763	16	39	38	1,247	246	23	1,114	504	1,451	21	77	[3] 51
Temora longicornis	644	17	< 1	0	913	18	2	635	763	625	137	657	[3] 120
Acartia longiremis	153	0	0	6	342	240	6	0	351	80	15	18	[3] 25
Calanoid spp. immature	152	0	0	0	1,538	42	0	0	154	9	0	0	0
Oithona spp.	134	14	0	0	1,210	1	< 1	0	33	5	174	100	5
Acartia clausii	89	0	0	0	0	0	1	0	93	13	23	25	[3] 16
Eurytemora herdmani	78	0	0	0	89	0	0	5	760	42	0	0	9
Tortanus discaudatus	71	0	0	0	244	56	0	14	22	181	117	106	160

[1] Less numerous species (<50/100 m.^{3}) and no./100 m.^{3}, in 1967, were: Acartia longiremis, 34; Metridia lucens, 29; Eurytemora herdmani, 21; Acartia clausi, 14; Centropages hamatus, 14; Tortanus discaudatus, 6; Calanoid spp. immature, 3; and Paracalanus parvus, 2. Species representing a mean of less than 1 per season in each area were: Metridia longa, Acartia spp. immature, Cyclopoid spp., Euchaeta norvegica, Harpacticoid spp., and Anomalocera pattersoni.

[2] Less numerous species (<50/100 m.^{3}) and no./100 m.^{3}, in 1968, were: Metridia lucens, 41; Acartia spp. immature, 11; Metridia longa, 3. Species representing a mean of less than 1 per season in each area were: Euchaeta norvegica and Harpacticoid spp.

[3] Values adjusted to Gulf III equivalents for the smaller copepod species collected in the bongo samplers in autumn 1968.

the eastern area and Eurytemora herdmani in the central area in summer 1968 (table 3).

HYDROGRAPHY AND ZOOPLANKTON

Observations were made of the seasonal changes in the temperature and salinity of the coastal waters and the effects of temperature changes on zooplankton abundance.

Surface Temperature and Salinity

Surface temperatures and salinities in each of the areas varied seasonally. In the western and central areas temperatures increased from a winter low to a summer high and decreased in autumn; in the eastern area the annual maximum was reached in autumn. The salinity maximum was in autumn in the eastern area and during winter in the central and western sections. Surface conditions were similar in all three areas in winter. In other seasons temperatures decreased and salinities increased from west to east along the coast (fig. 4).

The areal differences in temperature and salinity are a result of local environmental conditions, rather than of large-scale advection of waters. The low temperatures and high salinities of the eastern area are produced through vertical mixing by tidal stirring; the higher temperatures and lower salinities of the western region result from increased stability of the water column, reduced tidal mixing, and large-scale runoff from rivers (Bigelow, 1927; Sherman, 1966). Bathythermograph traces made along the coast support earlier reports of vertical mixing in the east and stratification in the west (fig. 5). Large-scale seasonal changes in the temperature of coastal waters of the Gulf of Maine are controlled by the seasonal variations in solar radiation, prevailing wind patterns, and river runoff (Bigelow, 1927). The long-term annual changes in temperature appear to depend on shifts in the relative position of coastal and oceanic water masses along the edge of the Continental Shelf (Colton, 1968a, b, and c).

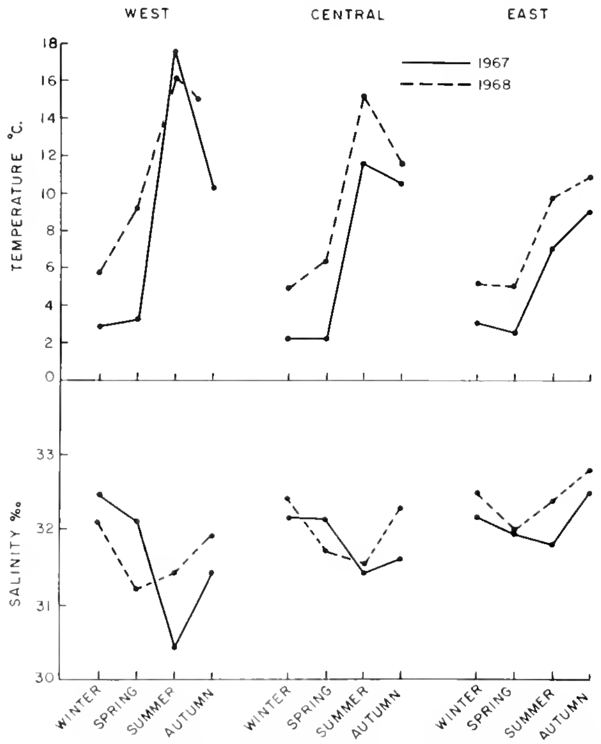

Figure 4.--Mean seasonal surface temperature and salinity for the western, central, and eastern areas of the coastal Gulf of Maine in 1967 and 1968.

Variations in Temperature and Zooplankton Abundance

Thermal stratification of coastal waters begins in spring and is most pronounced in summer. With the onset of vernal warming, the overwintering populations of adult zooplankters produce swarms of nauplii, copepodites, and other young forms. The timing of the spring swarming, however, varies with temperature. In spring 1967, when sampling was earlier (March 28 to April 13) than in 1968 (May 15-22), the coastal waters were cool ($<3^{\circ}$ C.) and vertically mixed from Cape Ann to Machias Bay. In spring 1968, the waters were warmer and a thermocline was developed in the western and central areas (fig. 6); eastern waters were also warmer, although vertically mixed because of tidal stirring. Zooplankton volumes in spring were not significantly different between the two years ($U = 56$, $P > 0.05$), but the size composition of the dominant zooplankter--Calanus finmarchicus--showed the effects of the earlier sampling in 1967; the adult overwintering form was dominant in 1967, whereas copepodite stages three and four predominanted in 1968.

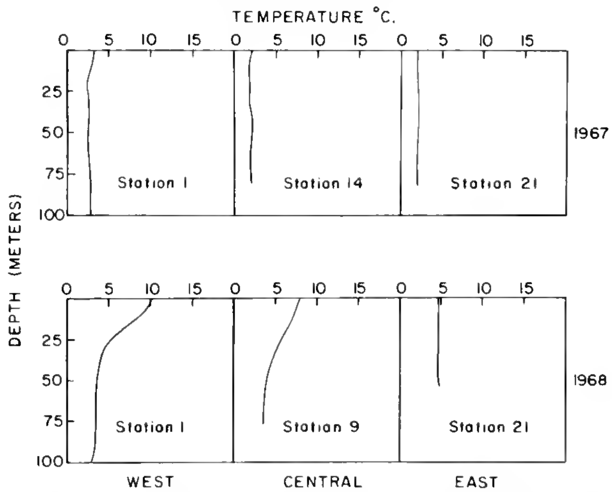

Figure 5.--Bathythermograph traces for selected stations in the western, central, and eastern areas of the coastal Gulf of Maine in spring 1967 and 1968.

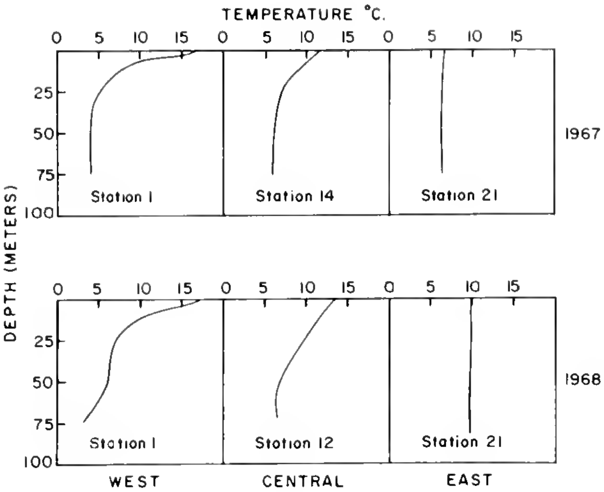

Figure 6.--Bathythermograph traces for selected stations in the western, central, and eastern areas of the coastal Gulf of Maine in summer 1967 and 1968.

The displacement volume of individuals is considerably less for copepodites than for adults but since the copepodites were more numerous in 1968 than the adults in 1967, the standing crop estimates in spring were not significantly different in the 2 years.

The between-year difference in the timing of the spring sampling was also reflected in the abundance of other zooplankton commonly eaten by juvenile herring. Decapod larvae, cladocerans, and cirriped larvae were more numerous in the spring samples in 1968 than in 1967 (table 2).

The seasonal peak in zooplankton abundance in 1963-66 was in summer (Sherman, 1965, 1966, 1968). Whether the low summer standing crop in 1967 and 1968 is a result of a timing gap in sampling, which missed a period of swarming, or an actual low in biomass is not known. Several of the copepod species abundant in coastal waters of the Gulf produce a new generation within 30 days during spring and summer (Fish, 1936a, b, and c), and it would be possible to miss an entire generation in sampling limited to a single 10-day cruise in each season. A semimonthly series of zooplankton samples are now obtained from waters near Boothbay Harbor to supplement coastal monitoring and provide information on seasonal succession in the plankton.

Previous investigators have observed the general decline in zooplankton abundance from west to east and reported that this decline is a result of dissimilar hydrography along the coast (Bigelow, 1926; Fish and Johnson, 1937). In the east, the unstable water column and the lack of appreciable influx of zooplankton from the north and east lead to relatively poor conditions for population growth. The higher spring and summer temperatures in the western and central areas, where the water column is relatively stable and stratified, provide an increasingly favorable environment for growth and development of zooplankton from Mt. Desert to Cape Ann (Bigelow, 1926; Fish and Johnson, 1937; Sherman, 1968).

Circulation and Zooplankton Abundance

The intensity and duration of river discharge influence the annual development of nontidal drift in the Gulf of Maine (Bigelow, 1927; Bumpus, 1960; Bumpus and Lauzier, 1965). Runoff in the eastern half of Maine was less in 1968 than in 1967 (Anonymous, 1969). This difference could have contributed to the apparent anomalous concentrations of three of the more numerous copepod species in summer 1968. Concentrations of Calanus finmarchicus, Pseudocalanus minutus, and Termora longicornis were similar in the eastern and western areas of the coast in summer 1968, when the reduction in runoff would have advected less zooplankton out of the eastern area in the dominant southwesterly drift along the coast. These species followed the more usual pattern of declining abundance from west to east in the summer of 1967 following the spring freshets.

The annual differences in the abundance of zooplankton from west to east along the coast (fig. 3) corroborate similar differences found both in the early decades of the century, and more recently in each year in 1963-68. Although the annual trend in zooplankton abundance is well established, the seasonal differences among the three coastal areas are more variable (table 1). Significant variations in abundance can occur between 2 years at the same season of the year, depending on the timing of sampling--as evidenced by the differences in the spring abundance estimates of 1967 and 1968. Local differences in circulation can affect the areal abundance of zooplankton, as observed in summer of 1968. The holoplankters found in coastal waters are widely distributed--particularly the dominant copepods. Concentrations of the predominant species, Calanus finmarchicus and Centropages typicus, occur in offshore waters (Bigelow, 1926; Fish, 1936a), and offshore waters are advected periodically into the coastal region to compensate for estuarine discharge (Graham, in press). The influence of the offshore populations on the abundance of zooplankters along the coast is being investigated.

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