ZOOPLANKTON OF WESTERN CAPE COD BAY

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ABSTRACT

The coastal zooplankton of western Cape Cod Bay is described. Copepods were the dominant zooplankters, with two species, *Acartia clausi* and *A. tonsa*, particularly evident. Offshore samples indicated that bivalve larvae originating north of the power station tend to drift south toward the station. During the day copepods and bivalve larvae showed greater densities at depths.

Comparison of Cape Cod Bay zooplankton abundance with that of the more estuarine Mount Hope Bay, a short distance to the south, revealed much higher average densities in the latter area. This differential, in part, is probably attributable to higher nutrient levels and greater phytoplankton food stocks in Mount Hope Bay.

INTRODUCTION

Previous zooplankton studies of coastal New England have centered on the Gulf of Maine and the Georges Bank area southeast of Cape Cod. Anraku (1964) contributed significantly to the knowledge of copepods in Cape Cod Bay with his study combining observations on temperature, salinity, and zooplankton with a comprehensive survey of seasonal and regional distribution patterns for endemic species. His study supplied general background information and concentrated on effects of the Cape Cod Canal, but did not supply sufficient information to define density or distribution along the western shore of Cape Cod Bay. With initiation of Pilgrim Power Station studies, research was undertaken to describe native zooplankton populations and to detect, if present, effects of the power plant on these organisms. From 1973 to 1975, Marine Research, Inc. (MRI) undertook entrainment studies, identified and enumerated resident zooplankton species, assessed the nature of endemic populations, and carried out related entrainment studies.

METHODS

Collections were made from August 1973 to December 1975. Duplicate samples were taken at mid-depth at intake and discharge stations, and at various depths at offshore stations (Figure 1) using a pump-and-hose system. Pump delivery was regulated to produce a water sample of 250 liters. From 1973 to early 1975 pumped

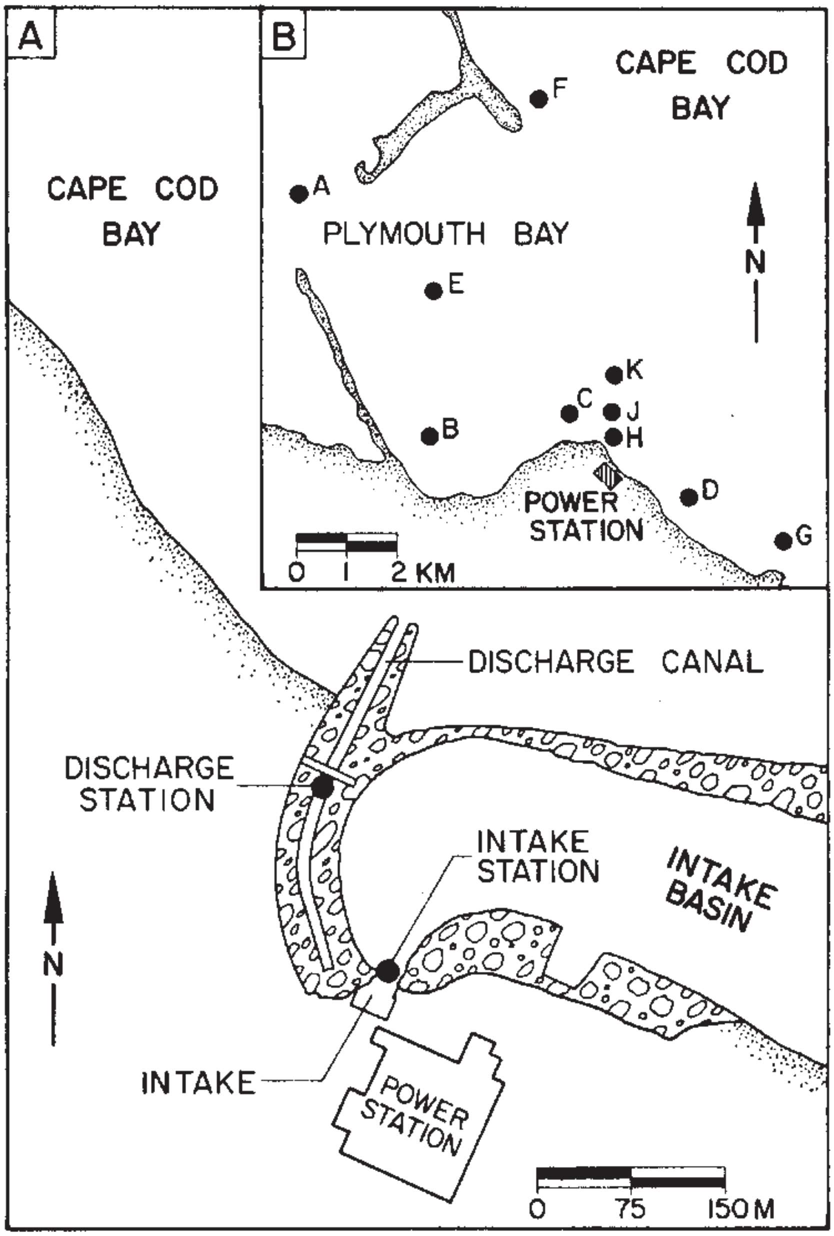

Figure 1. Zooplankton sampling stations at the Pilgrim Nuclear Power Station (A) and in adjacent western Cape Cod Bay (B).

samples were passed through a #20 mesh plankton net (70 μ). From March 1975 to study termination, a #30 mesh net (59 μ) was used to increase retention of smaller organisms. Samples were preserved in glutaraldehyde and analyzed by counting and identifying all organisms in duplicate one-milliliter subsamples in a Sedgwick-Rafter counting cell. Densities were expressed as mean number of organisms per cubic meter of water sampled.

Data were analyzed from the three offshore stations, H, J, and K (Figure 1), to detect vertical distribution of nauplii, bivalve larvae, and selected species of copepods. Samples were collected at depths indicated in Table 1 in duplicate by the methods described above.

A covariance model considered two dependent variables, sampling event and station, and one independent variable, depth. The model took the following form (Bradley 1968):

$$Y_{ijk} = \mu + d_i + S_j + dS_{ij} + \beta Z + \xi_{ijk}$$

where

Y_{ijk} is the $\log_{10}$ transformation of the observation made for the i-th sampling event, j-th station, and k-th replicate of the data set,

μ is the parametric mean,

d_i is the effect attributed to the date of the sampling event,

S_j is the effect attributed to the station,

dS_{ij} is the interaction between the two,

β is a regression coefficient relating density and depth,

Z is the depth, and

ξ_{ijk} is the error (o,σ^2).

Appropriate expectations of the mean squares were derived, and F-tests were conducted for the main effects and interactions.

RESULTS

Composition and Density of Zooplankton

Zooplankton in the vicinity of the Pilgrim Nuclear Power Station contained many copepod species (Table 2). These copepods (particularly nauplii) were moderately abundant, attaining maximum densities in August of each year (Figure 2).

Table 1. Sampling depths for offshore zooplankton stations H, J, and K for various dates, 1975.

	Depths in meters from surface		
	Stations		
	H	J	K
May 7	0, 3, 6	0, 4.5, 9	0, 6, 12
June 3	0, 3, 6	0, 3, 6, 9	0, 3
July 8	0, 3, 6	0, 3, 6, 9	0, 3, 6, 9, 12
August 12	0, 3, 6	0, 3, 6, 9	0, 3, 6, 9, 12
August 19	0, 3, 6	0, 3, 6, 9	0, 3, 6, 9, 12

Table 2. Copepods observed in the Rocky Point vicinity, 1973 - 1975.

Phylum Arthropoda ----- Class Crustacea

Order Calanoida
- Family Acartiidae
  - *Acartia clausi*
  - *A. tonsa*
  - *Acartia* spp.
- Family Calanidae
  - *Calanus finmarchicus*
  - *Calanus* spp.
- Family Centropagidae
  - *Centropages hamatus*
  - *C. typicus*
  - *Centropages* spp.
- Family Temoridae
  - *Eurytemora herdmanni*
  - *E. hirumdoides*
  - *Eurytemora* spp.
  - *Temora longicornis*
  - *Temora* spp.
- Family Paracalanidae
  - *Paracalanus crassirostris*
- Family Pseudocalanidae
  - *Pseudocalanus minutus*
- Family Tortanidae
  - *Tortanus discaudatus*
  - *T. discaudatus* eggs

Order Cyclopoida
- Family Clausidiidae
  - *Hemicyclops* spp.
  - *Saphirella* spp.
- Family Oithonidae
  - *Oithona brevicornis*
  - *O. similis*
  - *O. spinirostris*
  - *Oithona* spp.

Order Harpacticoida
- Harpacticoids

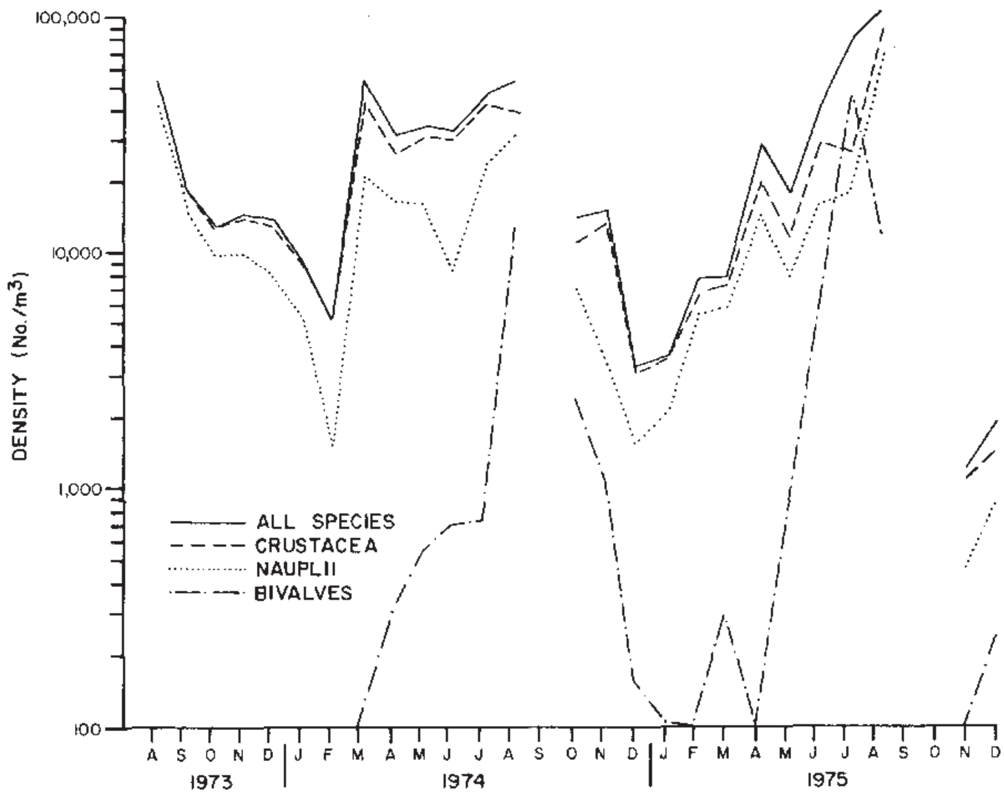

Figure 2. Mean monthly densities per m^3 of zooplankton in western Cape Cod Bay. Intake and discharge densities averaged separately.

Acartia clausi and *A. tonsa* were the dominant copepods. In July 1974, *A. clausi* attained its maximum observed density for the study of 26,697 per m^3, constituting 31% of the zooplankton sampled on that date. On the same occasion *A. tonsa* reached a density of 17,513 per m^3 constituting 20% of the zooplankton sampled. In November and December, *A. tonsa* populations were markedly reduced, and from January through April 1975 *A. tonsa* was absent. *A. clausi* was found every month except November 1975; its abundance frequently exceeded one thousand per m^3.

Oithona similis was present all year, reaching a peak of 4771 per m^3 in July 1975 and constituting 12% of the total collection. This species varied between 300 and 4800 per m^3 with lowest densities in November and December. *O. brevicornis* was relatively scarce, usually numbering in the hundreds per m^3. *Pseudocalanus minutus* occurred in moderate numbers every month. It peaked in June 1974 at 5136 per m^3 and in June 1975 (4810 per m^3), but usually numbered less than 1000 per m^3. *Centropages hamatus* and *C. typicus* were present in small numbers throughout the year. In October, November, and December of 1973 and 1974 both species were present with densities ranging from 100 to slightly over 1000 per m^3; *C. typicus* attained its highest density of 3681 per m^3 in November 1974. Neither species was collected in September of 1973 and 1974.

Calanus spp. was found in limited numbers at both inshore and offshore stations. In 1974 *Calanus finmarchicus* occurred from June through August, ranging from 75 to 140 per m^3. In 1975 *Calanus* spp. was present at inshore stations as early as April 22 and persisted through August with densities in the 100s per m^3. At offshore stations these species appeared as early as April 1 and remained through December. Numbers occasionally exceeded 1000 per m^3; at Station K, 12 m depth, a maximum density of 1665 per m^3 was observed on August 12, 1975. *Calanus* spp. were generally found at a depth of 3 m or greater.

Larval mollusks and annelids were abundant during spring and were present in moderate numbers in summer and fall.

Spatial Distribution of Bivalve Larvae

In April 1975 a study of bivalve larvae distribution began in western Cape Cod Bay. One of its goals was acquisition of information to facilitate entrainment sample studies. Because the net tidal flow in the area was in a southerly direction (see Davis, p. 8), the study focused on bi-monthly sampling at Stations A through H, J, K, Intake, and Discharge (Figure 1).

Percent species similarities for bivalve larvae were computed between all stations for nine dates from May 7 to August 29, 1975, using the method described by Whittaker and Fairbanks (1958). The similarity matrices were clustered using the "nearest neighbor" strategy.

There appeared to be no consistent clustering of stations (MRI 1976). However, when the matrices were pooled and averaged for the entire period, two general groupings appeared (Figure 3). Stations A, E, C, and H composed one group, and it is evident from Figure 1 that these stations lie on a fairly straight line from the mouth of Plymouth Harbor (Station A) to a point one-quarter mile off the Pilgrim Nuclear Power Station (Station H). Stations G, J, and K composed a second group. Station K is one mile offshore; J, one-half mile offshore; and G, to the south near Manomet Point. This analysis suggested that many bivalve larvae probably originate in Plymouth Harbor and drift down the coast

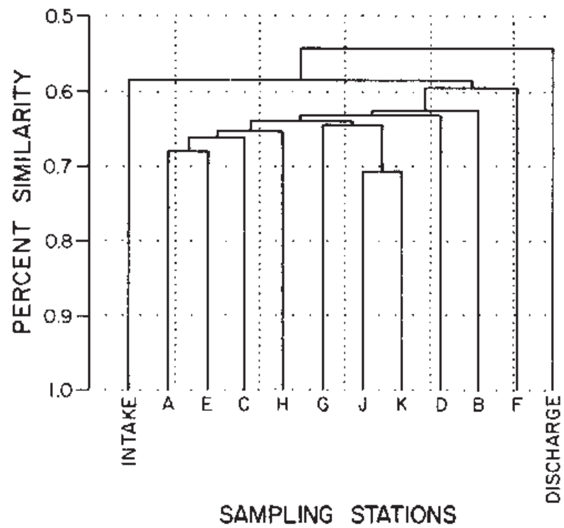

Figure 3. Percent similarities of larval bivalve populations, stations A through H, J, K, Intake and Discharge: May to August, 1975.

toward the power plant; however, their distribution patterns were not well defined.

The Mann-Whitney U test (Sokal and Rohlf 1969) was utilized to determine if various groups of bivalve larvae were more abundant at stations near the power plant (H, J, Intake, and Discharge) than at offshore stations (A - G and K). In 22 of 48 tests (Table 3), a significant difference in abundance developed, indicating lower concentrations of larvae in the immediate vicinity of the plant. It was unclear whether these results were due to entrainment, displacement of coastal water by the discharge flow, or to localized currents.

Among the bivalve larvae, *Spisula solidissima* was the only species showing a significant variation in density among stations (Table 4). Although the test did not rank the densities in order of abundance, total counts for the entire sampling period indicated that density of this species generally increased with proximity to shore. Despite finding no significant variation among stations for *Mytilus edulis*, *Mulinia lateralis*, *Modiolus* spp., and the *Mercenaria/ Modiolus/ Mytilus* group, there was a significant linear regression between density and depth, indicating greater concentration of these larvae in the deeper portions of the water column. In five of the eight cases, i.e., *Mulinia lateralis*, *Mya arenaria*,

Table 3. Results of Mann-Whitney U test, comparing bivalve mollusk larval populations at stations H, J, Intake, and Discharge with populations at stations A through G, and K, 1975. In every case where a significant difference was detected, the first group of stations mentioned above had lower populations of larvae than the second group; statistically significant differences occurred wherever probability levels of $p<0.10$, $p<0.05$, and $p<0.01$ are shown.

Larvae group	1975							
	May 7	May 21	June 3	June 24	July 8	July 22	Aug. 5	Aug. 19
Laevicardium and *Spisula*	n.d.	n.d.	0.10	0.01	n.s.	n.s.	n.s.	n.s.
Mya and *Hiatella*	n.d.	0.05	0.01	0.01	n.s.	0.01	0.01	n.s.
Modiolus and *Mytilus*	n.s.	n.s.	0.05	0.05	0.05	0.01	0.10	0.10
Mercenaria, *Modiolus*, and *Mytilus*	n.s.	n.s.	0.01	0.05	n.s.	0.05	0.01	n.s.
Laevicardium, *Mya*, *Spisula*, and *Hiatella*	n.d.	n.d.	n.s.	0.10	n.s.	0.10	0.05	n.s.
Modiolus demissus and *Modiolus modiolus*	n.s.	0.01	n.s.	n.s.	n.s.	n.s.	0.01	n.s.

n.s. = No significance

n.d. = No data

Ensis directus, *Modiolus* spp., and the group *Laevicardium mortoni*/ *Spisula solidissima*/ *Mya arenaria*/ *Hiatella arctica*, the interaction factor between date and station was significant, making any tests of differences among dates or stations invalid.

Table 4. F-ratios of analysis of covariance for various species or groups of bivalve larvae.

	F-ratio		
	Date	Station	Date-Station Interaction
Ensis directus	5.96**	0.43	8.08**
Laevicardium mortoni *Spisula solidissima* *Mya arenaria* *Hiatella arctica*	0.15	1.51	5.99**
Mercenaria mercenaria *Modiolus* spp. *Mytilus edulis*	2.52	1.72	1.66
Modiolus spp.	35.72	0.75	4.04**
Mulinia lateralis	6.74*	1.57	4.20*
Mya arenaria	25.10**	0.68	10.17**
Mytilus edulis	17.29**	2.74	2.36
Spisula solidissima	2.05	11.86*	1.93

* Significant

** Highly significant

Statistical Interaction for Copepod Samples

For nauplii, *Acartia tonsa*, *A. clausi*, *Pseudocalanus minutus*, and *Oithona similis* (Table 5), the interaction differences among sampling events and stations were sufficient to prevent comparisons between stations. In other words, mean densities at each station varied widely from one sampling event to the next, masking possible intrinsic differences between stations.

In most cases, a pooled linear regression correlating density to depth indicated a significantly higher density of *O. similis*, *A. clausi*, *P. minutus*, and nauplii in deeper portions of the water column. *A. tonsa* did not follow this pattern of distribution, although in a study of Narragansett Bay during the summer of 1971 (MRI 1972) adult *A. tonsa* were relatively more abundant near the bottom during the day and more abundant near the surface at night. Cape Cod Bay samples were collected only during the day.

Table 5. F-ratios of analysis of covariance for copepods.

	F-ratio		
	Date	Station	Date-Station Interaction
Acartia clausi	74.11**	133.14**	15.03**
Acartia tonsa	286.90**	7.06*	7.15**
Nauplii	693.44**	0.45	19.34**
Oithona similis	171.22**	1.62	21.20**
Pseudocalanus minutus	43.61**	1.56	21.28*

* Significant

** Highly significant

DISCUSSION

Both *Acartia clausi* and *A. tonsa* were abundant in Cape Cod Bay. *A. clausi* was relatively abundant year-round, and especially common in the summer; Bertrand (1976) made the same observation in Penobscot Bay, Maine. Also occurring similarly in Cape Cod Bay and Penobscot Bay were the year-round copepod populations of *Oithona similis* and *Pseudocalanus minutus*. *Calanus* spp. were observed every month in Penobscot Bay but were absent from Cape Cod Bay samples in January through March. Bertrand (1976) found *Centropages hamatus* particularly abundant in summer and autumn in Penobscot Bay; Cape Cod Bay densities were comparatively high from October to December. *C. typicus* was found in relatively small numbers in both areas; however, Bigelow and Schroeder (1953) found this to be one of the most abundant fall copepods in the Gulf of Maine. As would be expected, the composition of the copepod population in western Cape Cod Bay is not too dissimilar from that in the Gulf of Maine.

Comparison of copepod populations from Cape Cod Bay and waters directly south of Cape Cod was possible as a result of studies conducted about forty miles off the coast of Martha's Vineyard in November 1974 (MRI 1975). Results showed both areas with somewhat similar composition at that time of year. The dominant copepod in both was *O. similis*; also common in the two areas were *A. clausi*, *A. tonsa*, *C. hamatus*, *C. typicus*, and *P. minutus*.

When the composition of the Cape Cod Bay zooplankton is compared with that in an estuarine environment such as Mount Hope Bay, Massachusetts, similarities are also apparent. As in Cape Cod Bay, *A. clausi* and *A. tonsa* are dominant (Toner 1981), but in Mount Hope Bay, *A. clausi* is generally a winter and spring inhabitant while in Cape Cod Bay it is usually found year-round. In both areas this species may make up over 30% of the zooplankton. *A. tonsa*, a summer and fall resident of Mount Hope Bay, is less abundant than *A. clausi* in both areas. *Oithona* spp. and *P. minutus* also are prevalent in Mount Hope Bay although densities vary.

However, comparison of zooplankton densities between the two regions also revealed interesting differences. The estuarine environment seems much more productive. As an example, the Pilgrim Power Station entrainment total ranged from 1000 to 90,000 per m^3, with an overall mean of 23,000 per m^3. In Mount Hope Bay, the average density of zooplankton entrained was 94,500 per m^3, based on 148 separate observations from eight years of study. These figures underscore the important difference often existing between a highly productive estuarine area and a more oceanic environment with lower nutrient levels.

The differences in abundance between these two areas may be attributed, in large part, to the availability of phytoplankton for sustaining the generally herbivorous zooplankters. The average zooplankton density in Cape Cod Bay was 24% of that for Mount Hope Bay, while the Cape Cod Bay phytoplankton density was 20% of that for Mount Hope Bay (Toner 1981), illustrating the strong link between phytoplankton and zooplankton communities.

In western Cape Cod Bay, the depth-related distribution of copepods and bivalve larvae was difficult to discern because of the limited observations. It is generally agreed that the immediate stimulus to diel migration, i.e., daily vertical movement of zooplankters to deep water during daytime and towards the surface at night, is illumination (Marshall and Orr 1972), perhaps modified in extreme cases by temperature. Because our collections offshore were made during daylight hours, it is reasonable that greater densities at depths were a reflection of this negative response to light and not a response to thermal gradients. The station nearest the power plant was one-quarter mile offshore, and the thermal plume was not detectable at this distance.

The data also suggested that bivalve larvae, originating north of the station, perhaps in the region of Plymouth Harbor, drift in a southerly direction along the coast; although their drift patterns are not well defined, their general routes follow the flow patterns described in Davis (p. 8).

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