# Massachusetts Bay zooplankton communities: a historical retrospective

Massachusetts Water Resources Authority

Environmental Quality Department
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**Massachusetts Bay Plankton Communities:**
**A Historical Retrospective**

**Task 337**
**MWRA Harbor and Outfall Monitoring Project**

**submitted to**

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## EXECUTIVE SUMMARY

This report characterizes historical data on zooplankton communities in the Massachusetts Bay and Cape Cod Bay system (and adjacent Gulf of Maine waters) in order to enhance the baseline of information prior to relocation of the Massachusetts Water Resources Authority (MWRA) effluent discharge. Available zooplankton data were examined to identify seasonal, interannual, and regional variability in zooplankton abundance and the potential relationship of this variability to zooplankton structure in Cape Cod Bay.

The scope of this retrospective was developed by a Focus Group convened by the Outfall Monitoring Task Force (OMTF) to discuss issues surrounding MWRA's monitoring of the zooplankton communities in the Bays, and their importance as a forage resource for the Northern right whale. Three main issues were to be addressed: 1) identification of all relevant zooplankton data from the region, 2) use of all comparable data to distinguish Cape Cod Bay from other areas, if possible (i.e. identify any regional differences), and 3) establish a longer and broader baseline data set for both Massachusetts Bay (MB) and especially Cape Cod Bay (CCB) than is presently available from only the MWRA monitoring. A zooplankton retrospective was initially recommended to be undertaken during an initial assessment of plankton issues associated with the outfall relocation (Cibik *et al.* 1998).

**Data Sources.** Several historical data sets on the zooplankton of Massachusetts and Cape Cod Bays were identified during the focus group meeting. Examination of these data sets formed the basis of the present study. The sources include: MWRA Harbor and Outfall Monitoring Program baseline data collected between 1992-1996; Center for Coastal Studies (CCS) data collected between 1984-1996; Marine Resources Monitoring, Assessment, and Prediction (MARMAP) Surveys conducted by the National Marine Fisheries Service (NMFS) from 1977-1987; Ship of Opportunity Continuous Plankton Recorder (SOOP-CPR) Surveys conducted by NMFS from 1961-1990; Pilgrim Power Plant Monitoring conducted from 1973-present; Seabrook Power Plant Monitoring conducted from 1978-1983, and the open literature. Sampling methods used in these studies varied widely and included integrated net tows (MWRA and MARMAP), bottle casts and pump sampling (CCS), and continuous sampling (CPR). Various mesh sizes were used, making comparisons between studies difficult. In making quantitative comparisons in this report, an attempt was made to standardize the data to the extent possible, including water column averaging of pump data and basing comparisons on similar-sized life stages of the various species to compensate for mesh size differences.

**Results**

MARMAP zooplankton data (0.333 mm mesh size) from the entire NW Atlantic Shelf, from Cape Hatteras to Nova Scotia, (see review in Sherman *et al.* 1983) document that twelve taxa account for 85% of total zooplankton dominance: *Calanus finmarchicus, Pseudocalanus* spp., *Centropages typicus, Centropages*

*hamatus, Metridia lucens, Temora longicornus, Acartia hudsonica, Acartia tonsa, Acartia* spp. (*A. clausi – A. longiremis*), *Oithona* spp., *Calanus* spp., and *Paracalanus parvus*. Three of these species, *Calanus finmarchicus, Pseudocalanus,* and *Centropages typicus,* typically constituted 75% of the total dominance (Sherman *et al.*1983). Analysis by Davis (1982, 1984a, and 1987b) of finer-mesh net tows (0.165 mm mesh) concurrently conducted on the MARMAP surveys revealed that, in addition to the latter three species, the smaller copepods *Oithona similis*, *Paracalanus parvus*, and *Centropages hamatus* also were numerical dominants, and that *Calanus, Pseudocalanus, Paracalanus*, and *Centropages* spp. accounted for most of the zooplankton production. Sherman *et al.* (1983) also documented that the N.E. shelf has not encountered any large scale changes in species composition or abundance in the past seventy years.

Results from this retrospective indicated that the species composition and abundance patterns of zooplankton in MB and CCB mirror those in the offshore regions of the continental shelf, with the primary exception that *Acartia hudsonica* and *Acartia tonsa* make up the bulk of the zooplankton in Boston Harbor and typically are dominant within a few kilometers from shore. As in the offshore areas, the zooplankton of MB and CCB are characterized by pronounced shifts in species composition both regionally and seasonally, with copepods being the dominant group. In general, zooplankton abundance and species composition also exhibit apparent inter-annual variation, including long term trends.

The different data sets were used in this present study in different ways based on their sampling methodologies and data structure. The CCS data were used to investigate natural variability in the zooplankton community in Cape Cod Bay including surface zooplankton distributions. To the extent possible, the spatial structure of surface distributions were documented and compared with zooplankton distributions on a broader scale in Cape Cod Bay. Significant differences were often detected in the surface distributions, and in comparison with the vertical distributions.

Both the MARMAP and MWRA datasets were used to define whether CCB and MB assemblages are different. MARMAP also provided data from an earlier decade to compare with the MWRA data collected during the 1990's. No significant differences were found between MB and CCB within the MARMAP samples. Analysis of MWRA data revealed no significant differences between the two CCB stations or within MB for most taxa. However, significant nearshore/offshore differences were found in MB for *Acartia, Oithona,* and *Centropages hamatus*. *Calanus finmarchicus* was found to be significantly more abundant in MB than CCB. No significant differences were found between MB and CCB in the MWRA data for the other taxa. CCB was found to be statistically similar to nearshore MB samples, whereas offshore MB samples were demonstrated to be significantly different from CCB.

**Conclusions**. Based on extensive graphical and statistical analyses in this study, four main conclusions can be made.

1) Observed patterns in Mass Bay and Cape Cod Bay zooplankton were similar to those seen in other regions of Gulf of Maine/Georges Bank (e.g., Georges Bank, Davis 1987a) with some subtle

differences. For example, Massachusetts Bay appears to be comprised of two regions resulting from coastal-offshore water quality characteristics. In addition, it appears the waters of northern Cape Cod Bay may exhibit some seasonal differences in successional patterns compared with waters of southern Cape Cod Bay (e.g. *Acartia* spp.)

2) Massachusetts Bay was similar to Cape Cod Bay with regard to species composition and population assemblage. This was confirmed through separate statistical investigations of both the MARMAP dataset and the MWRA dataset. However, Cape Cod Bay is more similar to the Coastal Mass Bay assemblage than the offshore Mass Bay assemblage.

3) Similarities were displayed between the MWRA and MARMAP datasets. Consistencies between the MWRA and MARMAP datasets support the use of the MARMAP data to augment the MWRA baseline. This should be further evaluated by studying the connection between the 1988 to present dataset (which has been recently made available) with the MWRA 1992-1997 baseline.

4) The existing broad-scale zooplankton abundance data do not demonstrate a uniqueness to Cape Cod Bay zooplankton communities. The dense patches of zooplankton observed in the Bay (documented in the CCS database) on which whales feed therefore appear not to result from a unique background zooplankton community, but rather on the interaction of physical and behavioral factors within the Bay itself, acting to locally concentrate a widespread resource.

The seasonal patterns for the dominant taxa from each study are similar to those found in shelf regions along the eastern U.S. The nearshore/offshore affinities of the various species are also common to other eastern shelf areas. Published data suggest that *Acartia* is food limited in nature and thus is restricted to eutrophic nearshore environments. It is reasonable then to hypothesize for the purpose of MWRA contingency planning that the discharge of effluent in the nearfield region could cause local eutrophication that will lead to a shift in the zooplankton species composition towards an *Acartia* spp. dominated system. This *Acartia* hypothesis for the MWRA program is substantiated further by the SOOP-CPR dataset analysis.

**Recommendations.** The retrospective has brought together invaluable baseline data sets which have contributed immensely to the understanding of zooplankton dynamics in Massachusetts Bay and Cape Cod Bay. The basic structure of the zooplankton monitoring should be continued prior to outfall relocation to further define the extent of spatial and temporal variability. Post-relocation monitoring should continue so that potential changes in community structure can be identified. Also, the 1988-present MARMAP data which have recently been made available should be used to augment the MWRA baseline.

In order to determine the relative effects of natural and outfall-induced perturbations to the dominant zooplankton species, correlation of environmental variables with the dominant zooplankton species is recommended. Although interannual variations were observed in both environmental conditions and zooplankton abundance, the connections between them are not obvious and should be further explored.

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# 1.0 INTRODUCTION

## 1.1 Background

The Massachusetts Water Resources Authority (MWRA) is currently in the process of relocating its treated wastewater discharge from its present location in Boston Harbor to a site approximately 15 km offshore in Massachusetts Bay. Beginning in late 1999, effluent will be dispersed at the new location through a series of 55 8-port diffusers on the sea floor. Together with other engineering improvements in both the wastewater treatment process and in the control of combined sewer discharges to Boston Harbor, the configuration of nutrient loading to adjacent offshore waters will change (Galya *et al.* 1996).

The environmental planning process associated with the permitting of this new outfall required baseline monitoring of the Massachusetts Bay ecosystem, which will continue as post-discharge monitoring once the new outfall is commissioned. The post-discharge monitoring will provide the basis to evaluate threshold criteria developed for contingency planning purposes (MWRA 1997).

One issue subject to the contingency review will be assessment of the potential for eutrophication in the nearfield water column resulting from the change in nutrient loading. The seasonal physical structure of the water column (summer stratification, seasonal overturn and mixing) influences the manner in which eutrophication might be manifest. Both annual and seasonal chlorophyll concentrations will be used to assess whether an increase in biomass has occurred relative to the baseline data record (MWRA 1997). However, changes in the phytoplankton community may potentially occur without a significant change in chlorophyll biomass (see Cura 1991, Cibik *et al.* 1998). Such a scenario would entail a change in species composition and successional patterns which might alter the trophic structure in the water column. Furthermore, it is also possible that increased primary productivity would not be manifest in changes in phytoplantkon standing stock due to grazing by zooplankton.

Changes in phytoplankton production, biomass, or species composition could potentially lead to shifts in zooplankton production, biomass, or species composition, with the further potential for alterations in higher trophic levels such as fish, shellfish, and other organisms that feed on zooplankton (including the endangered northern right whale, *Eubalena glacialis*). As discussed in Cibik *et al.* (1998), it should be recognized that increased primary and secondary production are not necessarily detrimental to the ecosystem. However, changes in carbon production and utilization patterns could result in subtle changes in carbon flow through the food web. In order to assess the potential for post-relocation impacts, adequate characterization of the pre-relocation zooplankton communities in the ecosystem is required.

Impact assessments performed by the U.S. Environmental Protection Agency (EPA), which considered all potential impacts associated with the discharge of MWRA's effluent discharge into Mass Bay, concluded that there would be no adverse physical or biological impacts associated with the new outfall (U.S. EPA 1988). The assessment of potential impacts to endangered species (Section 7 Consultation) performed by the EPA and National Marine Fisheries Service (NMFS), which included a detailed assessment of potential impacts to the right whale, concluded that the outfall may affect but would not jeopardize endangered species (U.S. EPA 1993). Nevertheless, concerns remain about the effects of outfall relocation upon marine life, most specifically the endangered right whale which feeds on calanoid copepods (in particular *Calanus finmarchicus)* in the Mass Bay region.

While commercial whaling was the historic reason for the decline of the northern right whale, one of the major current causes of death for right whales seems to be collisions with ships as well as entanglements in fishing gear (USEPA 1993). In addition to the losses associated with ship collisions, loss of inshore habitat due to environmental alterations may be a major factor in the poor recovery of North Atlantic right whale populations (Gaskin 1987). Zooplankton density and distribution in the water column appear to be important factors in the appropriateness of particular areas for use by whales. Habitat degradation can have a major impact on plankton populations by altering species composition, biomass, and productivity. The right whale has such a small breeding population size and long reproductive cycle that even a few incidental deaths have a profound negative effect on the rate of increase in population (Best 1987). The humpback whale is another endangered species which utilizes the study area, and its food organisms, planktivorous fish, are influenced by zooplankton abundance and distribution.

Right whales are often seen skim feeding on zooplankton patches near the water surface in Cape Cod Bay (Kraus *et al.* 1989; Mayo and Marx 1990). During skim feeding, the whale swims slowly at the surface, its body submerged, with its upper jaw out of the water and with its mouth wide open, filtering dense swarms of zooplankton (Mayo and Marx 1990). These patches typically consist of calanoid copepods and euphausiids from surface waters (Watkins and Schevill 1976; Mayo and Marx 1990). Right whales filter zooplankton through baleen plates that line each side of the upper jaw while swimming at a speed of about 4.5-km per hour (Watkins and Schevill 1979).

There are strong indications as to the importance of the relationship between whale behavior and the density and composition of a given region's zooplankton assemblage. Sightings of past feeding occurrences indicate that whales search for dense zooplankton assemblages, often avoiding unsuitable foraging locations (Mayo and Marx 1990). Such preferential behavior has been exhibited in the past, most notably during 1986 and again in 1997. During 1986, a system-wide decrease occurred in the distribution and abundance of the planktivorous fish *Ammodytes americanus* (sand lance), an abundant prey species of humpback whales, which was followed by a subsequent rise in the abundance of Calanoid copepods (Payne *et al.* 1986). Payne *et al.* (1986) described the connection between the abundance of sand lance and *C. finmarchicus* during the 1980's as an inverse relationship. Subsequently, a large number of right whales were sighted during 1986, possibly as a result of the increase in calanoid copepods. Past observations of feeding in Cape Cod Bay (Mayo and Goldman 1996) indicate that right whale sightings in the region coincided with the density of calanoid copepod assemblages (in particular *C. finmarchicus*) and subsequently, as these densities decreased, the whales vacated the area.

During 1997, right whales vacated their usual feeding area in Cape Cod Bay at an unusually early time. A Video Plankton Recorder (VPR) survey of the Bays (Davis, unpublished data; Mayo *et al.* 1997) revealed that there had been an unusually dense outbreak of the alga *Phaeocystis pouchetii* during the 1997 early spring bloom which gave large areas of the bay a murky brown appearance. The concurrent timing of these events raised concerns among local environmentalists that the food supply of the right whale was somehow disrupted (Mayo, unpublished data). However, *Phaeocystis* has been observed in Cape Cod Bay since at least the early 1900's. *Phaeocystis* forms mucilaginous colonies during such blooms; densities vary by several orders of magnitude from year to year. This variability, as well as the relationship between *Phaeocystis* and other environmental parameters, is currently being investigated by MWRA.

Given the issues surrounding the right whale, a Focus Group was convened on December 5, 1996 by the Outfall Monitoring Task Force (OMTF) to discuss monitoring of the zooplankton community in Cape Cod Bay and its importance as a forage resource for the northern right whale. The recommendations of the group included performance of a retrospective study:

> "Effort should be made to identify all relevant sources of plankton data from the region of interest and to use these historical data (Mayo, MARMAP, the Plymouth Nuclear Power Plant Siting Study, others) to establish interannual variability in the abundance and relative proportions of selected zooplankton taxa. These should then be compared with existing data and to relate them to trends for whale presence and behavior as an integral step in developing testable hypotheses concerning the right whale, its food resources, and the patchiness structure which appears to play such a prominent role in its feeding behavior. This step is clearly needed to provide insight on composition of patches and to corroborate the results from high-resolution studies, both past and future."

The Focus Group explained their recommendation by stating that:

> "...we feel it is important to examine the historical record to determine the interannual variation of zooplankton species composition and abundance. The focus would include copepods as well as non-copepods (e.g. barnacle larvae) which right whales have been observed feeding upon. In such efforts, we recommend further analysis of the data collected around feeding whales to determine the species abundance and composition in relation to regional sampling (like that undertaken by the monitoring program)."

In essence, the charge from the OMTF was to:

- determine if the retrospective analysis broadens the existing MWRA baseline;

- establish if special qualities exist in CCB which make whale foraging attractive; and
- identify issues raised relative to measurement and detection of change given the context of space-time variability apparent in the various datasets.

## 1.2 Objectives

The objective of this report was to characterize the historical data on zooplankton communities in the Massachusetts Bay and Cape Cod Bay system (and adjacent Gulf of Maine waters) in order to enhance the baseline of information prior to relocation of the MWRA effluent discharge. Available zooplankton data from the MWRA Harbor and Outfall Monitoring (HOM) Program, together with unpublished data and data from the literature, were examined to identify seasonal, interannual, and regional variability in zooplankton abundance and the potential relationship of this variability to zooplankton patches in Cape Cod Bay.

With regard to the latter, data collected in the vicinity of feeding whales were compared with regional results to provide the means to assess potential post-discharge effects to the right whale's food source in the Bays. By considering available data on zooplankton patch composition relative to abundance and distribution on a broader scale, potential hypotheses for evaluating post-discharge effects on the zooplankton community could be developed.

To achieve these goals, four areas of statistical investigation were undertaken: 1) statistically analyze differences in "patch" vs. "background" data in CCS sampling 2) characterize assemblage composition on a regional basis and to statistically analyze differences in regional assemblages 3) characterize the long-term variability in abundance in Mass Bay and Cape Cod Bay and 4) compare variability across sampling programs, to the extent possible. Based on these results, recommendations were developed to strengthen the zooplankton post-relocation monitoring program.

## 1.3 Report Organization

The following sections provide an overview of the information obtained from each data source, a rationale and approach to treatment of the data for the retrospective, and the graphical and statistical investigations undertaken.

Following this introductory section, Section 2 presents the overview of the zooplankton record in the Gulf of Maine (specifically Massachusetts Bay and Cape Cod Bay systems), including the MWRA data. Trends identified in the literature pertaining to the zooplankton community are highlighted. Section 3 presents the graphical and statistical investigations for the CCS, MARMAP (conducted by NMFS), CPR (also conducted by NMFS), and MWRA databases. Section 4 includes conclusions from this retrospective study. Finally, recommendations for post-discharge monitoring are given in Section 5.

# 2.0 REVIEW OF GULF OF MAINE ZOOPLANKTON DATA SOURCES

The Plankton Issues Report (Cibik *et al.* 1998) included a recommendation that a comprehensive historical review and analysis of unpublished and published zooplankton data be performed for Cape Cod Bay and Massachusetts Bay to provide a multi-decadal context on which the MWRA monitoring data can be interpreted. This section provides a description for the areas of concern, an overview of the data sources, and a summary of trends previously documented within the datasets.

## 2.1 Geographic Location of Research (Area of Review)

For purposes of this report the following geographic regions are defined. The NW Atlantic shelf (N.E. U.S.) ecosystem extends from the Gulf of Maine south to Cape Hatteras, and from the coast seaward to the edge of the Continental Shelf. This ecosystem includes Georges Bank, western areas of the Gulf of Maine, including Massachusetts and Cape Cod Bays, and southern New England to the Mid Atlantic Bight (Sherman *et al.* 1996).

## 2.2 Data Source Summary

A literature search was conducted to identify relevant data for Massachusetts and Cape Cod Bays. Abstracts were reviewed for relevance, and selected papers obtained. Conclusions and comparable data were summarized and discussed below for the following data sources.

1 Center for Coastal Studies (CCS)
2 Marine Resources Monitoring, Assessment, and Prediction (MARMAP) bongo collections
3 Ship of Opportunity Program-Continuous Plankton Recorder (SOOP-CPR) surveys
4 Massachusetts Water Resource Authority (MWRA)
5 Open literature

The open literature reviewed consisted primarily of Pilgrim Nuclear Power Plant and Seabrook Station Monitoring Programs as well as some of the major zooplankton studies of the century as identified by Sherman *et al.* (1996). Such studies include: Bigelow (1926), Bigelow, and Sears (1939), Fish (1936a, b), Clarke and Zinn (1937), Clarke (1940), Redfield (1941), Clarke *et al.* (1943), Riley and Bumpus (1946), Deevey (1952, 1956, 1960a, b), Grice and Hart (1962), Judkins *et al.* (1980), Dagg and Turner (1982), Davis (1984a,b), Townsend and Cammen (1988), Durbin and Durbin (1996), Sherman *et al.* (1983) and Sherman *et al.* (1995). In addition, selected other major zooplankton studies of relevance were reviewed. Such studies include: Toner *et al.* (1984), Davis (1987a, b), Mayo and Marx (1990), and Turner (1994), Jossi and Goulet (1993), and NAESC (1996).

Due to the different sampling methodologies and other potential biases inherent in the various programs, comparisons between the data sets were largely qualitative. The comparisons focused on the results for larger dominant taxonomic forms (that would be captured similarly by the various mesh sizes). Annual or seasonal means and 95 percent confidence intervals were used for comparative purposes among and within databases. This approach allowed categorization of results by region (Cape Cod Bay, Massachusetts Bay, and Gulf of Maine waters representative of the Massachusetts Bay study area boundary condition) and by time frame (often on a decadal scale).

Taxonomic technique issues were also considered in this study. CCS reported *Pseudocalanus* and *Paracalanus* combined as a complex, while the MWRA, MARMAP and CPR databases reported both taxa. *Centropages* species were also not separated within the CCS database. Therefore for the statistical comparisons between CCS and MWRA datasets, results for these taxa were combined within the MWRA database. In addition, accounting for the difference in mesh size, only adult populations of *Centropages*, *Calanus finmarchicus*, and *Pseudocalanus/Paracalanus* were compared. Figure 2-1 displays the size relationships of *Calanus finmarchicus*, *Centropages typicus*, *Centropages hamatus*, *Pseudocalanus* spp., *Paracalanus parvus*, and *Oithona* spp. in relation to zooplankton net mesh size (Davis 1987b). Finally, life stage information is present in the MWRA and CPR datasets but is not listed for either the data from CCS or the dominant MARMAP taxa.

All data were log transformed by adding a value of one to the reported densities (individuals/$m^3$) and then taking the log10 of that value for use in statistical and graphical evaluations. The addition of one to the values was done to eliminate negative numbers after the log transformation and for consistency with the NMFS assessments (MARMAP and CPR datasets). However, NMFS typically reports organisms in individuals/100$m^3$ prior to transformation. To account for this in the CPR dataset, the proper transformations were performed first to reflect individual/m3, then log-transformation of the data occurred.

### 2.2.1 Center for Coastal Studies

Center for Coastal Studies (CCS) collected zooplankton data from conical surface tows (471 µm mesh) taken in Cape Cod Bay and adjacent waters of Massachusetts Bay (Mass Bay) from 1984 to the present. Data through 1995 were made available by CCS for the retrospective and compiled into an Access®database. Data consist of samples taken in: 1) the path of feeding whales, 2) locations where whales were present but not feeding, and 3) locations where no whales were present (see section 3.1 for details). Sampling months varied from year to year depending on the periods of whale residency. Samples consisted of routine transect sampling and targeted surface patch sampling in the vicinity of feeding whales.

The majority of the CCS work has been focused on 471 µm and 333 µm conical net tows, aimed at mimicking right whale baleen filtration. Anything smaller than 333 µm was considered too small to be retained in their baleen. However, over time CCS attempted other sampling methods in an effort to more efficiently characterize the near-whale zooplankton conditions. These other methods included:

- forward vertical arrays (1987-88);
- continuous surface transects (1989);
- four-depth sampler pump series (1991) ;
- phytoplankton sampling (1991-1993);
- midwater vertical profiles, horizontal in-path feeding, and micro-scale sampling (1994-1996); and
- other miscellaneous protocols (1987 only).

During most sampling activities, whale behavior was recorded by CCS. There were several types of whale behavior codes in the database (e.g., skim feeding right whale, subsurface activity, non feeding traveling whale, social activity, other baleen whale, no whale present). Details regarding sampling and analysis can be found in a report submitted to the Cape Cod Commission for presentation to the MWRA Outfall Taskforce Review Committee (Mayo and Goldman 1996).

### 2.2.2 Marine Resources Monitoring, Assessment, and Prediction

The Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program was conducted between 1977 and 1987, and included surveys performed on the northeast continental shelf of the U.S. Survey results from Massachusetts and Cape Cod Bays (between 41°45'N and 42°00'N, and westward of 70°00'W-excluding Gulf of Maine proper), comprising data from 182 tows, were obtained from the NMFS Northeast Fisheries Science Center. Samples consisted of double vertical oblique tows (from the surface to within 5m of the bottom and return to surface). The towing apparatus consisted of two bongos, a 64 cm diameter set and a 20 cm diameter set. The larger set had 505 µm mesh net on one side and a 333 µm mesh on the other. The smaller set had a 253 µm mesh net on one side and a 165 µm mesh net on the other. The 333 µm mesh samples are the ones routinely processed for zooplankton and were the ones evaluated in this study. As part of an independent study completed by Davis (1982, 1984a, 1987a), some of the 165 µm mesh MARMAP samples were sorted as well as some 165 µm mesh samples from the ICNAP Larval Herring Study. MARMAP sampling has continued since 1988 to present, with sampling conducted six-times per year using a 333 µm and 253 µm mesh. The 333µm data were released in March 1998, but were not available in time for this retrospective.

### 2.2.3 Ship of Opportunity Program – Continuous Plankton Recorder Surveys

The Ship of Opportunity Program – Continuous Plankton Recorder Surveys (SOOP-CPR) used ships of opportunity traversing the North Atlantic out of Boston between 1961 and the present as platforms for collection of plankton data using the continuous plankton recorder. The CPR was typically towed behind the vessel at a standardized depth of 10m, and used silk bolting cloth with an effective wet mesh size of around 240µm. The silk cloth was advanced by impeller-driven gears, which resulted in a continuous record of plankton encountered as the vessel progressed along its course track. Samples were examined to yield a relative color index for autotrophs and for zooplankton abundance and taxonomy. Data reviewed as part of this retrospective were restricted to the 1961-1990 period of record.

### 2.2.4 Massachusetts Water Resources Authority Harbor and Outfall Monitoring Program

The Massachusetts Water Resources Authority (MWRA) Harbor and Outfall Monitoring Program (HOM) typically included analysis of the zooplankton community in Boston Harbor, Massachusetts Bay, and Cape Cod Bay during eleven nearfield and six combined nearfield-farfield surveys conducted from February to December each year from 1992 to present. Between 1992-1994, sampling was performed at six nearfield stations (N01, N04, N07, N10, N16, and N20) during the nearfield surveys, while an additional four locations were sampled during the combined events (F01, F02, F13, and F23). During 1995 sampling was performed at two nearfield stations (N10 and N16), while an additional ten locations were sampled during the combined events (F01, F02, F06, F13, F23, F24, F25, F27, F30, and F31). During 1996 this protocol was slightly altered in that the nearfield stations were changed to N04 and N10, while N16 was sampled during the combined events. Zooplankton samples were collected at each station by 102μm mesh oblique tow. Details regarding sampling and analysis can be found in Section 3.5 and in the Combined Work Plan/Quality Assurance Project Plan for water column monitoring (Bowen *et al.* 1997).

### 2.2.5 Open Literature

Two studies of interest for reference data were Seabrook Station (Seabrook, NH) and Pilgrim Power Plant Monitoring Programs (Plymouth, MA). ENSR was not able to obtain the individual datasets, but was able to obtain all relevant and available literature. In addition, selected major zooplankton studies of relevance were also reviewed.

#### 2.2.5.1 Seabrook Station

Seabrook Station data results include pre-operational monitoring results from 1978 to August 1990, and post-operational data collection from August 1990 to present. Post-operational data were available for the retrospective through 1995. Sampling included microzooplankton (surface and bottom pump and screened using a 76μm mesh), bivalve larvae (oblique tows using 76μm mesh net), and macrozooplankton (nighttime oblique tows in quadruplicate using 505μm mesh). Most copepod taxa were reported from the microzooplankton (76 μm mesh) sampling, whereas *Calanus finmarchicus* results were reported from the macrozooplankton (505 μm mesh) samples.

Seabrook data have most recently been synthesized in an annual report which evaluates data through 1995 (NAESC 1996). Included were graphical presentations of monthly abundance and variability (log abundance and 95% confidence intervals) for nauplii, copepodites, and adults of *Oithona, Pseudocalanus* and *Eurytemora*. Copepodites and adults of *Calanus finmarchicus* were similarly reported from the macrozooplankton data set. These results were compared in the present report with similar graphics prepared from the other data sets to compare seasonal patterns in abundance and variability. In addition, seasonal assemblages of dominant taxa (>5% of total group abundance) were characterized for offshore waters. The Seabrook results provide insight into the "upstream" Gulf of Maine zooplankton assemblage.

#### 2.2.5.2 Pilgrim Monitoring Data

Zooplankton surveys were conducted by Boston Edison in western Cape Cod Bay between August 1973 and December 1975. Sampling included assessments of zooplankton at the cooling water intake and in the discharge canal. Pump-delivered samples (250L) were initially passed through a 70μm mesh (August 1973-March 1975); after that time the samples were screened using a 59μm mesh. Near-shore ambient samples also were collected on a monthly basis between May and August 1975, consisting of three locations out to approximately 1.5 km offshore of the intake. These ambient samples were collected at 3-meter intervals throughout the water column.

These results were summarized by Toner *et al.* (1984) who provided graphical results for total zooplankton, larval crustaceans, nauplii, and larval bivalve species, and seasonal maxima for dominant taxa. The seasonal progression of dominant copepod taxa was reported, with *Acartia hudsonica* and *Acartia tonsa* dominating the assemblage. *A. hudsonica* was reported to be present year-round, as were *Oithona similis* and *Pseudocalanus minutus*. *A. tonsa* had a summer/fall distribution. *Calanus* spp. were not present in January through March. *Centropages hamatus* was abundant in summer and fall, while *Centropages typicus* was found in relatively small numbers during that period.

### 2.3 Patterns in Zooplankton Abundance and Distribution Evident in Literature

Extensive research has been completed in the U.S. Northeast shelf ecosystem. The literature was examined to identify documented temporal and spatial patterns in zooplankton populations in the Mass Bay and more generally in the U.S. Northeast shelf ecosystem as a whole.

**Species composition** - Literature from the past seventy years identifies twelve taxa, which account for 85% of the zooplankton population: *Calanus finmarchicus, Pseudocalanus* spp., *Centropages typicus, Centropages hamatus, Metridia lucens, Temora longicornus, Acartia hudsonica, Acartia tonsa, Acartia spp. (A. hudsonica -A. longiremis), Oithona* spp., *Calanus* spp., and *Paracalanus parvus*. Three of these species, *Calanus finmarchicus*, *Pseudocalanus*, and *Centropages typicus*, typically constituted 75% of the total abundance (Sherman *et al.* 1983). Analysis by Davis (1982, 1984a, 1987a) of finer-mesh net tows (0.165 mm mesh) concurrently conducted on the MARMAP surveys revealed that, in addition to the latter three species, the small copepods *Oithona similis*, *Paracalanus parvus*, and *Centropages hamatus* also were numerical dominants. Sherman *et al.* (1983) also documented that the N.E. shelf has not encountered any large scale changes in composition or abundance in the past seventy years.

**Seasonal and regional patterns** – The most pronounced patterns in zooplankton abundance on the NE shelf are seasonal and regional. The NE shelf is characterized by large seasonal changes in sea surface temperature (SST), due to prevailing westerly winds bringing continental air mass over the adjacent shelf waters (i.e. continental climate). The annual range in SST is one of the largest on earth, with similar ranges seen in the northern Japan Sea, northern North Sea, and the Argentinian shelf (Davis 1987b). The large annual range in temperature in these areas leads to large changes in the zooplankton community composition, with the boreal copepods, *Calanus* and *Pseudocalanus*, dominant during the winter/spring and warm-water copepods, *Paracalanus* and *Centropages*, dominant during the summer/fall (Davis 1987b). It also has been estimated that most of the zooplankton production occurs during the warm half of the year when biomass is lower but is turning over much faster due to higher temperatures and predation (Davis 1987b). Regionally, the larger *Calanus* are more abundant in waters where the bottom depth is greater than 70-100 m, while the smaller Pseudocalanus is more abundant in the shallower areas (Davis 1987a, Sherman *et al.* 1987). *Centropages hamatus* is typically orders of magnitude more abundant in regions where the bottom depth is shallower than 60 m, a distribution postulated to result from hatching of bottom resting eggs (Davis 1987a). During the summer/fall, *Centropages typicus* and *Paracalanus* are found mainly within the warm surface layer (Davis 1987a). The genus *Acartia* is dominant in coastal areas, especially harbors and bays, and its abundance falls off sharply offshore due to some combination of salinity intolerance and food-limitation.

**Long-term trends** - The literature includes a series of publications on the MARMAP and CPR data. NMFS investigators have produced graphical demonstrations of abundance and variability in dominant zooplankton taxa over large geographic regions (e.g. Mass Bay, Gulf of Maine, Georges Bank). These investigators have demonstrated substantial interannual variability in zooplankton abundance including some significant long-term trends in abundance. Data from the mid-1970's revealed a significant increase in *C. finmarchicus* abundance in the Gulf of Maine during that decade (Jossi and Goulet 1993). Other trends also were evident. For example, MARMAP data revealed a shift from co-domination by *C. typicus* to an increasing proportion of *C. hamatus* in the Gulf of Maine and Georges Bank (Sherman *et al.* 1994). Short -term declines seen in the abundance of *C. finmarchicus* were attributed to a complex inter-relationship between zooplankton dynamics and the abundance of planktivorous fish (sand lance, herring and mackerel) (Sherman *et al.* 1996). The intra-generic shift in *Centropages* was not considered to be due to planktivorous fish pressure, but possibly to other environmental influences (Sherman *et al.* 1994). Important to the retrospective is the demonstration that significant trends in decadal time scales do occur within the system, and that these must be taken into account when evaluating post-relocation effects.

## 2.4 Factors which Control Zooplankton Abundance

Alteration in nutrient loading and potential changes in phytoplankton populations resulting from outfall relocation could possibly lead to changes in zooplankton abundance. Other environmental factors which are not associated with the outfall (non-outfall influences) could potentially cause shifts in zooplankton abundance. These include effects from seasons, winds, tides, ocean circulation, light intensity, temperature, freshwater influxes and anthropogenic nutrient input from sources other than the MWRA outfall. Biological factors such as predation can affect zooplankton population abundance as well (e.g., Davis 1984b, 1987b). The North Atlantic Oscillation is also believed to affect regional zooplankton populations.

In general, zooplankton abundance in any given location is determined by a combination of in situ population growth and immigration/emigration via lateral exchange. Population growth is determined by development rate, somatic growth, egg production, and mortality. Development, growth and fertility are all affected by temperature and food availability. Mortality is caused largely by predation, which in turn is affected by predator abundance and consumption rates (also temperature-dependent). Immigration/emigration is determined by physical transport of the animals in and out of the area by advection and diffusion. Each of these factors is influenced by variability in environmental forcing.

### 2.4.1 Temperature, Food Availability, Wind, and Physical Transport

Changes in temperature can have both direct and indirect effects on zooplankton population abundance. Direct effects include limitations in the rates of egg production and survival. Indirect effects include limitations to growth and development rates which in turn affect final adult size and generation time. Adult size is related to egg production rate and generation time determines the turnover rate of the population. Colder temperatures will lead to slower growth of the population but will also slow predatory consumption rate.

Seasonal changes in temperature are very pronounced in the Massachusetts Bay region due to the continental climatic conditions. As discussed above, the changes in sea surface temperature (0-20°C) are very large compared to other regions of the world ocean (Davis 1987b). These large seasonal changes cause pronounced shifts in the species composition of the zooplankton, from boreal species during winter/spring to warm water species in summer/fall. The seasonal succession of offshore species composition mirrors that found on Georges Bank (Davis 1987b).

Unlike temperature, changes in salinity, within the tolerance range of a given species, typically have little effect on their reproduction or growth rates. Outside this tolerance range, however, salinity can adversely affect vital rates such as the observed negative impact of high salinity on *Acartia* recruitment (Tester and Turner 1991). Likewise the amount of ambient light has little direct impact on zooplankton vital rates. These factors, however, can be associated indirectly with patterns of zooplankton abundance. Temperature and light can affect the vertical distribution of zooplankton which in turn can affect feeding rate and advective transport. During the stratified period, a subsurface phytoplankton maximum occurs, within which turbulence is low and zooplankton species can migrate to feed at elevated rates. This food-rich environment enhances growth and reproductive rates. Ambient light levels and cycles serve as cues for vertically migrating zooplankton. Vertical migration may be diel, ontogenic, or seasonal. Some species stay near the surface or in the chlorophyll maximum both day and night, while others migrate between different depths to maximize food intake but avoid visual predators.

Food availability can limit the overall distribution of certain species of zooplankton such as *Centropages typicus* (Davis and Alatalo 1990), whereas within certain areas such as Georges Bank, food may not be limiting (e.g. *Pseudocalanus* spp., Davis 1984a, b). The role of food limitation versus predation in controlling zooplankton populations is an active area of research in marine zooplankton ecology (Kleppel *et al.* 1996). It is generally known that protozoans are the dominant grazers of phytoplankton in the sea, but that at certain times such as during the spring diatom bloom, copepods (the dominant zooplankton taxa) are the dominant grazers. It is also well established that copepods feed on protozoans as well as on phytoplankton, and that protozoans provide an important nutritional source for copepods. The traditional view that temperate marine zooplankton production is tied to the spring diatom bloom no longer holds, rather the highest production occurs during the warmer months when turnover rates are higher and zooplankton biomass is lower (Davis 1987b, Cibik *et al.* 1998).

Episodic events such as upwelling and freshwater plumes can lead to phytoplankton blooms that provide food-rich environments for the zooplankton. Such events would be most beneficial to the zooplankton during the warmer stratified period when nutrients are limiting. In the nearfield region of the future outfall site, nutrients are supplied to the surface waters by lateral advection from Boston Harbor (Kelly and Turner 1995). Once the outfall goes on line, it is possible that the surface waters in the nearfield region will have lower nutrients during the stratified period. There may be a stronger subsurface chlorophyll maximum due to a larger nutrient gradient at the pycnocline. Possible changes in phytoplankton cell size distribution due to changes in the nutrient regime are not likely to affect zooplankton production, since zooplankton are generalist feeders and can consume a wide range of cell shapes and sizes. Zooplankton production would be reduced if the nutritional quality of the food species becomes poor.

Food availability is actually determined by the encounter rate of an organism with its prey (Davis *et al.* 1991). Encounter rate is a function of prey and predator concentrations as well as their swimming speeds and the microscale turbulent motions that bring them together. At low turbulence levels, encounter rates can be high since micropatches of food are able to form, and the consumer can forage within these patches. At intermediate levels of turbulence, the patches are dissipated and encounter rate is reduced. At higher levels of turbulence the encounter rate may increase again due to the rapid rate at which the physical motions bring predator and prey together. If turbulence is too high, feeding behavior may be disrupted.

Strong wind events during the stratified period thus may have several effects. Existing micropatchiness would be destroyed and encounter rate would first decrease. This rate then would increase with wind speed and possibly decrease again if the winds become too strong. Vertical mixing of the water column, or the possible occurrence of upwelling, would result in nutrient enrichment of the surface layer. Following the wind event, stratification would return and the subsurface phytoplankton maximum would reform, again creating a food-rich environment for the zooplankton. Enhancement of these mixing events by increased bottom water nutrients from the future outfall could result in pronounced increases in phytoplankton biomass and creating an even richer feeding environment for the zooplankton. Opportunistic food-limited zooplankton species, such as *Acartia* spp., may benefit greatly from such events.

Physical transport is a dominant factor affecting zooplankton abundance. On Georges Bank, the greatest range in zooplankton biomass from year to year appears related to retention associated with seasonal formations and decay of the Georges Bank gyre (Sherman *et al.* 1983). Within the Massachusetts and Cape Cod Bays, the generation times of zooplankton are long enough that the populations can be significantly affected by physical transport through the region. During winter/spring for example, the generation time of the dominant copepod *Calanus finmarchicus* is about two months. Since the transit time for particles through the Bays region is of similar order, the distribution of this species is clearly affected by advection. During the warmer months, the generation times of the warmer water species is on the order of two weeks, so that *in situ* growth in the region may be relatively more important for these species. Wind-forced intrusions of Gulf of Maine water into Massachusetts Bay, as well as coastal freshwater plumes moving into the region, are expected to be important sources of zooplankton to the Massachusetts Bay standing stock. Further biological/physical modeling work is needed to determine the relative importance of lateral exchange versus *in situ* growth in determining the size of zooplankton populations in the Bay. (Excerpted from Cibik *et al.* 1998).

### 2.4.2 Predation Pressure

Davis (1984a, b) used a combination of laboratory experiments, field data, and modeling to show that the seasonal cycles of the dominant copepod species on Georges Bank can be effectively controlled by invertebrate predation: chaetognaths, ctenophores, and carnivorous zooplankton. This study revealed that food levels on Georges Bank were high enough throughout the year that food was not a limiting factor in population growth of these copepod species.

In addition to invertebrate predation, fish predation has been found to influence zooplankton population size. An inverse relationship between the abundance of sand lance and *Calanus finmarchicus* during the 1980's is one of the first documented examples of predatory control of zooplankton by a marine fish (Durbin and Durbin 1996). Fish predation is also thought to be a dominant factor influencing diel vertical migration in zooplankton (Bollens and Frost 1991).

By contrast, other studies have found the relationship between fish and zooplankton populations to be less obvious. Zooplankton have interannual variability that is not in phase with alterations in fish-structured communities (Sherman *et al.* 1995). Fishing mortality has resulted in greater distress on fish populations of the NE Shelf than any of the relatively moderate changes in the abundance of their zooplankton prey (Sherman *et al.* 1995). The 50% decline (1968-1975) in fish biomass cannot be ascribed to zooplankton abundances (Sherman *et al.* 1983). In the MARMAP data, the significant increasing trend in zooplankton abundance in Southern New England and the Gulf of Maine and the absence of significant trends elsewhere suggest the large biomass of zooplanktivorous herring and mackerel are not a dominant control on the zooplankton of the ecosystem (Sherman *et al.* 1995). Likewise, larval fish are generally thought to be too dilute to affect their prey populations (Cushing 1986).

### 2.4.3 North Atlantic Oscillation

The North Atlantic Oscillation (NAO) is an indicator of a large-scale mode of variability in our climatic system. The NAO is confined to the North Atlantic Ocean basin. The NAO is defined as "the tendency for pressure to be low near Iceland in winter when it is high near the Azores and south-west Europe" (Van Loon and Rogers, 1978). The NAO generally exists in one of two extreme states, positive or negative. A positive (negative) NAO refers to an intensified (weakened) poleward pressure gradient resulting from a synchronous strengthening (weakening) of the Azores High (AH) and deepening (shallowing) of the Icelandic Low (IL) on the order of 15mb (Hurrell 1995). The NAO index is described as the difference between the normalized mean winter sea-level pressure (SLP) anomalies at various locations (representative of the relative strengths of the Azoric Highs and the Icelandic Lows.)

The NAO causes changes in monthly and seasonally averaged wind speeds and directionality over the ocean, and changes in the paths of winter storms and their effect over the ocean and Europe. Using a multivariate linear regression to quantify the temperature variability associated with the NAO, Hurrell (1996) showed that the NAO accounts for 31% of Northern Hemisphere interannual temperature variance.

Cayan (1992) has shown that the NAO is responsible for generating systematic, large-amplitude patterns in the anomalies of wind speed, latent and sensible heat fluxes, and hence sea surface temperature over much of the North Atlantic. The NAO exerts a controlling influence on winter temperatures and precipitation throughout the North Atlantic basin and impacts marine and terrestrial ecosystems. Multi-decadal weather related decline reported for zooplankton for the NW North Sea appears to be related to the N. Atlantic Oscillation (Sherman *et al.* 1996).

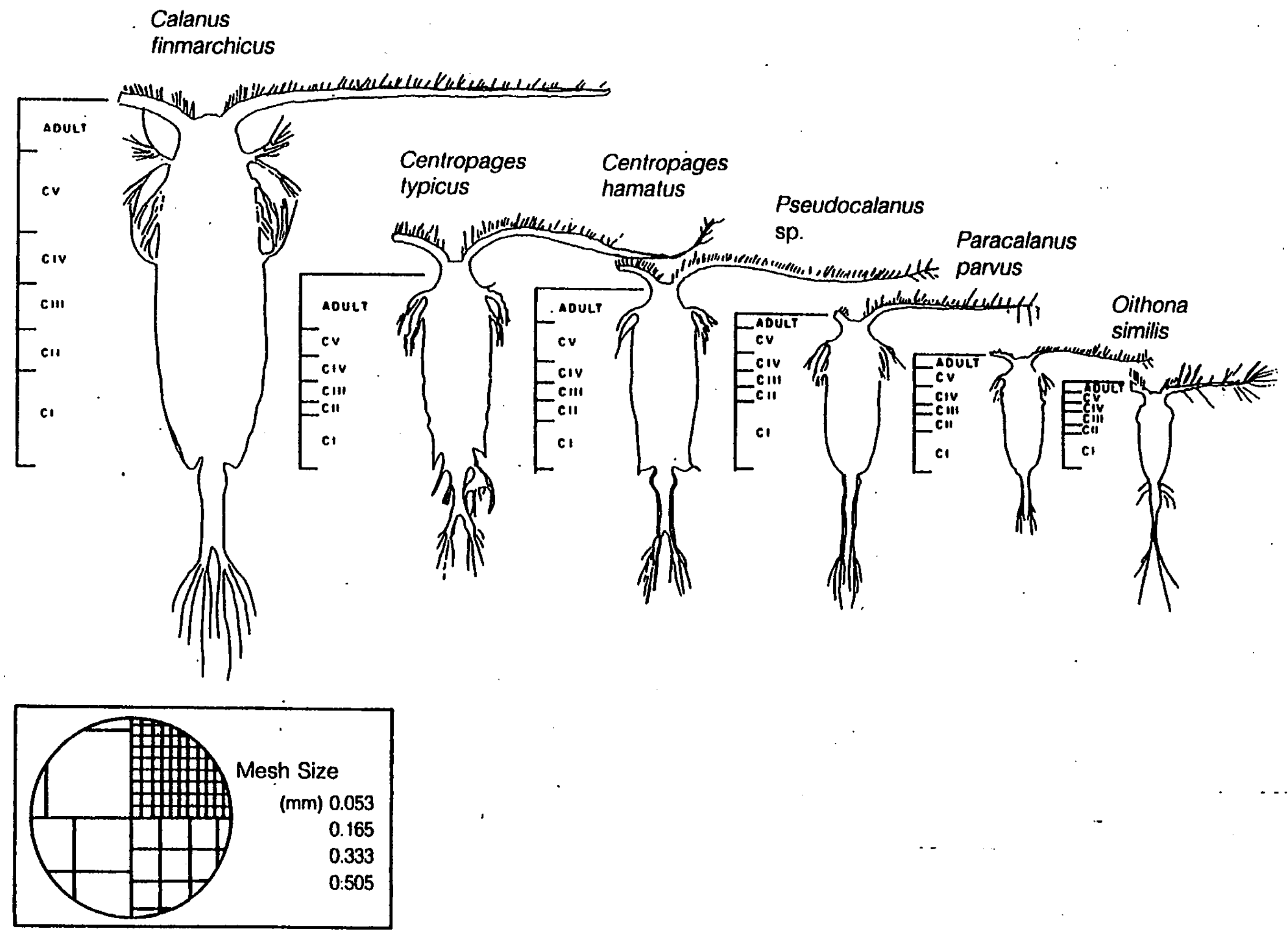



**FIGURE 2-1**
**Six Dominant Zooplankton Species and Associated Net Mesh Sizes**
**The six developmental stages, from top to bottom, are adult and fifth through first copepodites (CV-CI)**
**(From Davis, 1987a)**

# 3.0 STATISTICAL INVESTIGATIONS

## 3.1 Overview of Methodology

Various types of ANOVAs were used throughout the evaluations to determine significance. Since an ANOVA assumes the data are from a normally distributed zooplankton population and variances are homogeneous, preliminary tests were applied to check these assumptions. Zooplankton data are typically log normally distributed, thus the first assumption is accounted for by log transforming the data. In order to check for homogeneity of variance, a F-test or Bartlett's homogeneity of variance would typically be performed, but both tests are perhaps overly sensitive to non-normality. Thus an alternative method of comparability was used based on guidance from Dr. Andrew Solow of the Woods Hole Oceanographic Institution (WHOI). Standard deviations were considered for all samples (for which n>6) to evaluate if a parametric test could be performed. If standard deviations were within a factor of 2, the data were considered acceptable to use for parametric testing. If they were not found to be within a factor of two, another data transformation would have been performed, but this was not necessary in this study. All of the data fit within these parameters, making the use of the parametric ANOVA test acceptable. To account for the sampling nature of specific datasets, we analyzed the data according to an unbalanced design.

The four data sets for statistical investigation are based on different methodologies, sampling sizes, and objectives. An attempt to characterize each dataset and suggestions for each statistical approach follows.

## 3.2 Center for Coastal Studies

The Center for Coastal Studies (CCS) provided zooplankton data for this retrospective from surveys they conducted between 1984 and 1995. These surveys predominately performed surface tows using a 471 µm mesh conical plankton net (Section 2.2.1), thus the data used in this retrospective and reported in Section 3.2.1 were largely from these surface samples. Additional consideration was given to a series of vertical profiles conducted between 1994 and 1996 (Section 3.2.2).

### 3.2.1 Surface Tows

The CCS sampling results were separated into three sample-type categories according to recorded whale behavior: 1) no whales present (Figure 3-2), 2) whales present but not feeding (Figure 3-3) and 3) whales present and feeding (Figure 3-4). Analysis of the data was limited to Cape Cod Bay, specifically to points south of 42.40° N and west of 70.20°W. The feeding-whale samples were mostly concentrated near Provincetown (Wood End) and Billingsgate shoal, whereas the no-whale and the nonfeeding-whale samples were more widespread around Cape Cod Bay.

Table 3-1 presents the general distribution of sample types by year relative to sampling transects. The majority of the no-whale samples were taken at predetermined sampling stations, while feeding-whale and nonfeeding-whale samples were irregularly distributed. The most frequently sampled station was 6M, followed by 6N and 6S (Table 3-1). Overall, ambient, no-whale samples greatly outnumbered the whale-present samples (619 versus 150 samples). Throughout the program, 35 of the 255 samples taken in March and 54 of the 233 samples taken in April were feeding-whale samples (Figure 3-1). Feeding-whale samples were most numerous in 1986 (16 samples) and 1987 (18 samples) (Figure 3-5). The largest sampling efforts occurred in 1988 (118 samples) and 1993 (117 samples).

Both graphical and statistical investigations were undertaken using the CCS data. Due to the CCS program emphasis on zooplankton as a seasonal resource to the right whale during its migration through the study area, the bulk of the surface sampling over the period of record occurred between January and June (Figure 3-1). Samples collected in the presence of feeding whales were almost exclusively from the months of March and April. Therefore, results presented in Section 3.2.1 incorporate varying subsets of data available from CCS to minimize seasonal bias. Investigations involving CCS data included graphical depictions of:

- seasonal (January to June) total zooplankton abundance by sample type;
- seasonal (January to June) zooplankton assemblage composition by sample type;
- monthly distribution of dominant taxa; and
- annual variability in dominant taxa.

**Rationale and Approach for Retrospective.** CCS data offer the means to compare zooplankton densities and composition in the presence of feeding whales with other samples taken in Cape Cod Bay over a twelve-year time frame. Such long-term comparisons provide insights into the natural variation in the zooplankton community, and potentially into the effects of this variability on the composition of zooplankton patches formed in the Bay. Additionally, the locations of samples taken in the vicinity of feeding whales served to document the spatial distribution of patch occurrences. This may help assess whether CCB exhibits unique qualities that attract foraging right whales.

The emerging relationships discerned from CCS data for the Cape Cod Bay zooplankton community were used for regional comparisons with other data to help define whether the Cape Cod Bay assemblage is unique or follows larger scale regional patterns. Direct quantitative comparisons with MWRA data and other data sources were largely constrained due to the surface-oriented sampling and large mesh size, but comparisons for important larger taxa nonetheless yielded useful information.

Statistical analysis was performed on the 471 $\mu$m mesh conical surface tows. Sample sizes varied with the two sample types analyzed in depth, feeding-whale (FW) versus no-whale (NW):

| | March | | April | |
|---|---|---|---|---|
| | FW | NW | FW | NW |
| Total abundance | 23 | 172 | 51 | 142 |
| *Calanus finmarchicus* | 21 | 129 | 49 | 122 |
| *Pseudocalanus/Paracalanus* | 21 | 153 | 42 | 113 |
| *Centropages* | 15 | 148 | 28 | 93 |
| *Cyprids* | 16 | 115 | 35 | 121 |
| *Nauplii* | 15 | 84 | 33 | 68 |

Statistical comparisons of feeding-whale (FW) vs. no-whale samples (NW) were restricted to March and April (months of available data for feeding whales) of each year. Non-feeding whale samples were excluded from detailed analysis because of uncertainty whether whales were feeding. The focus of this study was to determine significant differences using extreme cases of whales feeding and whales-not-present.

#### 3.2.1.1 Total Zooplankton Abundance

The average annual zooplankton abundances (January to June) for feeding-whale, non-feeding whale and no-whale samples are presented in Figure 3-6. Some assessments were restricted from January through June data as the majority of CCS sampling occurred from January through June. The graphs are set to the same scale in order to see the magnitude of difference in abundance between feeding-whale samples and the other two types. In most years, there is a ten-fold difference between the abundance of zooplankton in the feeding-whale samples and that in the non-feeding-whale and no-whale samples. The highest average densities of total zooplankton were reported during 1988 and 1989 in the feeding-whale samples. Zooplankton abundance in the feeding-whale samples was substantially lower during 1985 and 1990, below 5,000 individuals/m$^3$. The lowest zooplankton abundances were found in the no-whale samples (Figure 3-6).

Focusing on Cape Cod Bay, Figure 3-7 displays the average annual zooplankton abundance (January to June) in Cape Cod Bay for feeding-whale and no-whale samples. Zooplankton densities are substantially greater in the feeding-whale samples (typically by an order of magnitude). The highest average densities of total zooplankton when whales were feeding in Cape Cod Bay occurred in 1988, 1989 and 1992.

Differences in total abundance between feeding-whale vs. no-whale samples over the twelve-year baseline were investigated. A two-way Analysis of Variance (ANOVA) was performed. The main effect of the analysis was the presence or absence of whales and the second effect was the year. Separate tests were performed for data from March and from April. Results with $p<0.05$ were considered significant. Feeding-whale samples had a significantly higher abundance of total zooplankton during both March ($p \sim 0.0000$) and April ($p \sim 0.0000$) than the no-whale-present samples. The year effect was not significant for March or April, p = 0.8008 and p = 0.2635, respectively. These analyses support previous conclusions (Mayo and Marx 1990) that whales feed only in areas above a certain threshold.

#### 3.2.1.2 Zooplankton Assemblage Composition

CCS concluded that the dense micro-scale aggregation of copepods which comprise the patches consist of six dominant taxa: *Calanus finmarchicus, Pseudocalanus minutus /Paracalanus* complex, *Centropages* spp., *Acartia, Temora,* and larval Cirripedes (late pre-settlement barnacle stages) (Mayo 1997). Four of these taxa are investigated in the retrospective: *Calanus finmarchicus, Pseudocalanus/Paracalanus* complex, *Centropages* spp., and barnacle cyprids; and nauplii (predominantly barnacle nauplii) are also included. Other taxa found in the samples were not enumerated consistently throughout the CCS study and thus were not included here. A full taxonomic listing is included in Appendix A. Dominant taxa and percent contribution for the month of March are depicted in Figure 3-8 and 3-9, respectively, and for April in Figures 3-10 and 3-11.

The *Pseudocalanus/Paracalanus* complex (Figure 3-8) numerically dominated the majority of both feeding-whale and no-whale samples taken in March from 1984 to 1995. The overall densities varied greatly among years, with relatively large densities occurring in 1988 for feeding-whale samples and in 1987 for no-whale samples. The only years in which the *Pseudo/Para* complex did not dominate the zooplankton population were 1995 (feeding-whale samples) and 1991 (no-whale samples). *Calanus* was dominant in 1995, while 1991 was dominated by barnacle cyprids (Figure 3-9). In addition, although the 1986 total zooplankton density in the no-whale samples is small compared in to other years, it was also dominated by nauplii, not the *Pseudo/Para* complex. The relative contribution of other identified taxa, which were not part of the five selected dominant species, varied among years. In 1991, "other" zooplankton represented 40% of the total zooplankton population in the feeding-whale samples (Figure 3-9). In several cases, the dominant taxon in the "other" category was the copepod *Temora longicornis*. However, the "other" category may be comprised of taxa included in the top dominant list, as some samples within the CCS data record were not consistently keyed to the same taxonomic level.

*Calanus finmarchicus* was an important dominant in April relative to March (Figure 3-10). Average densities of *C. finmarchicus* were highest in late 1980's. With the exception of 1993 and 1995, *Pseudocalanus/Paracalanus* were more prevalent in the samples from the 1990's. "Other" taxa were important, especially in no-whale samples in 1990-1992 (Figure 3-11). *Centropages* was important in feeding-whale samples in 1991. Cyprids were important in 1984 and 1994 no-whale samples. Potential artifacts may arise from the number of samples per year (Table 3-1). For example, in 1989 sampling was such that only 1 feeding-whale sample occurred, three in 1990 and two in 1992-1993 compared to 1986 and 1987 which had 16 and 18 samples, respectively. Even fewer samples than those shown in Table 3-1 occurred within the geographic confines of this report.

#### 3.2.1.3 Seasonal Distribution of Dominant Taxa

Monthly mean densities of dominant taxa ($\log_{10}$ (individuals/$m^3$+1) for *Calanus finmarchicus*, *Pseudocalanus/Paracalanus* complex, *Centropages* spp., barnacle cyprids, and nauplii), along with their 95% confidence intervals, were plotted for the period 1984-1995 to illustrate their seasonal distributions (Figures 3-12 through 3-16). If less than three samples were available for statistical analyses errot bars were not calculated for that time interval. For each taxon, results for both feeding-whale and no-whale were plotted to demonstrate the relationship between "patch" and "ambient" densities, respectively. Note that the CCS database had a greater relative number of no-whale-present samples due to the sporadic presence of the right whales in Cape Cod Bay.

CCS surface tow results between 1984 and 1995 indicated that *Calanus finmarchicus* began its seasonal increase in abundance in Cape Cod Bay around March, reaching its annual peak during May (Figure 3-12). Mean densities between January and March in the no-whale samples were less than 10 individuals/$m^3$, but densities peaked at a few hundred individuals/$m^3$ in May samples. From July through October, densities were similar to that seen during the winter. During its seasonal increase in April, results from feeding-whale samples were between one and two orders of magnitude higher than samples taken where whales were not present.

CCS surface tow results indicated that *Pseudocalanus/Paracalanus* complex began its seasonal increase in abundance in Cape Cod Bay during winter, reaching its annual peak during the spring (Figure 3-13). Mean densities between January and April in the no-whale samples were fairly steady 10-30 individuals/$m^3$, but densities peaked at a 60 individuals/$m^3$ in May samples. From August through December, densities decreased with the lowest densities occurring in December. During its seasonal increase in the spring, results from feeding-whale samples were between one and two orders of magnitude higher than samples taken where whales were not present. *Pseudocalanus* is a boreal species and *Paracalanus* is a warm water species, so that the abundances for the first half of the year are expected to be nearly all *Pseudocalanus*, whereas abundances in the second half of the year are a mix of the two species (Davis 1987a, Cibik *et al.* 1998). It is likely that transitions between the two species occurred during August.

Results for *Centropages* indicated that its seasonal increase in abundance in Cape Cod Bay began in early fall, reaching its annual peak during October and minima in March/April (Figure 3-14). Mean densities between January and July in the no-whale samples were less than 100 individuals/$m^3$, but densities peaked at a few hundred individuals/$m^3$ in October samples. Results from feeding-whale samples were approximately one order of magnitude higher than samples taken where whales were not present.

Cyprid abundance began increasing in Cape Cod Bay around March, reaching its annual peak during April (Figure 3-15). Barnacle cyprids appear to be found only in the first half of the year (Jan – May), likely corresponding to the life history of the barnacle. (*Semibalanus*) *Balanus balanoides* eggs (the common barnacle in this area) are fertilized in the autumn and are usually brooded until March, thereby explaining why cyprids and barnacle nauplii are only present in the beginning of the year (Ruppert 1997). Mean densities between January and March in the no-whale samples were less than 10 individuals/m$^3$, but densities peaked at a 25 individuals/m$^3$ in April samples. Lowest densities occurred during January and February. During its seasonal peak in April, results from feeding-whale samples were approximately one order of magnitude higher than samples taken where whales were not present.

CCS surface tow results between 1984 and 1995 indicated that nauplii began increasing in abundance in Cape Cod Bay around March, reaching an annual peak during April (Figure 3-16). This pattern is similar to that of the cyprids, and was likely attributable to the dominance of barnacle and copepod nauplii in this category. This pattern matches the life histories of the barnacles and the larger copepod *Calanus finmarchicus,* both of which have nauplii large enough to aggregate and be captured by the relatively coarse mesh nets used in the CCS surface tows. Mean densities between January and February in the no-whale samples were less than 10 individuals/m$^3$, but densities peaked at a few hundred individuals/m$^3$ in April feeding-whale samples. During its seasonal increase in April, results from feeding-whale samples were approximately one order of magnitude higher than samples taken where whales were not present.

#### 3.2.1.4 Annual Abundance and Inter-Annual Variability of Dominant Taxa

Having examined the seasonal distribution of dominant taxa documented by the CCS program (Section 3.2.1.3), interannual variability was next evaluated for these same dominants to illustrate fluctuations in abundance and to identify whether any trends could be detected over the 12-year period of record (Figures 3-17 through 3-21). Given the CCS sampling emphasis on presence of the right whale in Cape Cod Bay, interannual comparisons were restricted to the months of March and April.

Interannual plots for *Calanus finmarchicus* also showed the higher densities in April seen in the seasonal plots (Figures 3-17a and b). Overall mean densities from samples taken during April were typically an order of magnitude higher than March. Overall, densities of feeding-whale samples were also at least an order of magnitude higher than those taken when whales were not present. Highest mean densities for both sample types were typically found in the late 1980's, and again in 1995. Minimum densities appeared to have occurred between 1992 and 1994. Sampling effort was quite low during these years in which there appears to be a downward trend.

Interannual plots for *Pseudocalanus/Paracalanus* for the most part, displayed a similar pattern to that of *Calanus finmarchicus*. *Pseudocalanus/Paracalanus* had higher densities in March, as seen in the seasonal plots (Figures 3-18a and b). Overall mean densities from feeding-whale samples taken during April were typically an order or two of magnitude higher than March. Overall, densities of feeding-whale samples were also at least an order of magnitude higher than those taken when whales were not present. Highest mean densities for both sample types were typically found in the late 1980's. Minimum densities appeared to have occurred during the early 1990's.

Interannual plots for *Centropages* displayed that March and April were the lowest part of a seasonal cycle and indicated lower densities in general compared to *Calanus* and *Pseudo/Para* complex. (Figures 3-19a and b). Overall mean densities from feeding-whale samples were typically an order of magnitude higher than no-whale samples. Overall, densities of no-whale samples in March were similar to those taken in April. Highest mean densities for both sample types were typically found in 1991. Minimum densities for both March and April appeared to have occurred between 1992 and 1994.

Interannual plots for cyprids had a similar pattern to that of the copepods (but not as pronounced), with highest densities occurring in the late 1980's and minimum densities during the early 1990's (Figures 3-20a and b). Interannual variation is lower however. There is little difference between feeding-whale and no-whale samples in March. The maximum mean abundance of cyprids in March occurred in 1995 for feeding-whale samples and in 1991 for no-whale samples. The difference between feeding-whale and no-whale samples is more apparent in April. Maximum densities occurred in 1988 for feeding-whale samples and in 1994 for no-whale samples (Figure 3-20).

Interannual plots for nauplii also had higher densities in April as seen in the seasonal plots (Figures 3-21a and b). In March, nauplii were found in feeding-whale samples in only four of the years. This may be attributable to taxonomic inconsistencies. Maximum densities in March occurred in 1991 for feeding-whale samples and in 1987 for no-whale samples. Overall mean densities from samples taken during April were typically an order of magnitude higher than March. There is little difference between feeding-whale and no-whale samples in March. Overall, densities of feeding-whale samples were an order of magnitude higher than those taken when whales were not present during April. However, there is large overlap in the 95% confidence intervals. The maximum mean abundance occurs in 1987 and 1994 for feeding-whale samples and in 1989 for no-whale samples (Figure 3-21).

Two-way ANOVA was used to quantitatively assess differences in abundance between years and between feeding-whale and no-whale samples. Tests were run separately for the five taxonomic groups: *Calanus finmarchicus*, *Pseudocalanus/Paracalanus* complex, *Centropages* spp, cyprid larvae, and nauplii. Tests were performed on abundance data for feeding-whale and no-whale samples throughout the period of record. This analysis was performed separately for each of the months of March and April as the taxonomic composition may vary from month to month. The results were evaluated for significance at an alpha = 0.05, with the main effect being the presence or absence of whales and the second effect being year. *Calanus finmarchicus*, *Pseudocalanus/Paracalanus* complex and *Centropages* spp. had significantly higher abundances in the feeding-whale samples than in the no-whale-present samples during both March and April ($p < 0.05$). The abundance of cyprids in feeding-whale samples exceeded those in no-whale-present samples in March and April but only to a significant extent in April ($p \sim 0.0000$). The same pattern was observed for nauplii in which the abundance of nauplii in feeding-whale samples exceeded that in no-whale-present samples significantly in April ($p = 0.0004$). The year effect was not significant for March but was for April for all taxa, with the exception of *Centropages* for which year was neither significant in March nor April.

### 3.2.2 Vertically Stratified Samples

Although the majority of the CCS work has been focused on the standard 471 μm conical net surface tow samples, over time CCS attempted other sampling methods in an effort to more effectively characterize the near-whale zooplankton conditions (detailed in section 2.2.1). In particular, vertical pump samples (333 μm) were taken between 1994 and 1996 throughout Cape Cod Bay and adjacent waters of Massachusetts Bay, which to a certain degree coincided with spatial and temporal patterns in MWRA's Cape Cod Bay sampling (Figure 3-22). The "whales present" symbols in this figure include both whales-present-but-not-feeding as well as whales-feeding. The vertical profile data were considered for the potential to augment the MWRA baseline (1992-1997) during the overlapping period. Of particular interest was comparison of ambient (no-whale) samples from CCS with MWRA samples. If comparable, the CCS whale-present samples then could be combined with the MWRA data to further examine the nature of zooplankton distributions.

Vertical samples were statistically analyzed for differences in zooplankton abundance between whale-present and no-whale samples within the CCS dataset and externally with the MWRA data. Total zooplankton, *Calanus finmarchicus, Pseudocalanus/Paracalanus* and *Centropages* spp. were included in the analysis. The analysis of the vertical data was constrained because it only consisted of data from a three year period and required various assumptions (i.e. mathematical compositing for comparison with oblique tow method and size mesh differences which required only selected taxa be used).

Evaluation of the vertical data was limited to the late winter/spring, from January to June, again due to the CCS program emphasis on the seasonal presence of the right whale. A total of 69 vertical pump samples were taken between January and June over the period from 1994 to 1996. The largest sampling efforts occurred in 1994, in which 30 vertical pump samples were taken (10 whale and 20 no-whale) (Figure 3-22). Whale-present samples outnumbered the ambient, no-whale samples (41 to 28 samples). Whale-present samples were most numerous in 1996 (20 samples).

Sample sizes varied with each sample analyzed:

| | W | NW |
|---|---|---|
| Total abundance | 41 | 28 |
| *Calanus finmarchicus* | 37 | 15 |
| *Pseudocalanus/Paracalanus* | 31 | 9 |
| *Centropages* | 29 | 7 |

For quantitative comparisons between CCS and MWRA results, a method of normalizing data for differences between MWRA (102 $\mu$m, oblique tows) and CCS (333 $\mu$m, 2-m interval pump samples) sampling protocols was necessary. CCS values were averaged over the water column with respect to the volume pumped for each depth within each sample. Analysis was also restricted to the larger taxa such as adult *Calanus finmarchicus, Centropages* spp. and *Pseudocalanus/Paracalanus* in order to minimize errors due to difference sin mesh size between CCS and MWRA. Refer to Figure 2-1 for size relationships between dominant taxa and zooplankton net mesh.

Densities of total zooplankton, *Calanus finmarchicus, Pseudocalanus/Paracalanus* and *Centropages* spp. were examined using the annual mean abundance (with 95% confidence intervals) for whale-present and no-whale samples (Figure 3-23).

Even in the depth-integrated vertical sampling, mean abundances for total zooplankton and the three taxa examined were greater in the whale-present samples than in the no-whale samples for each year (Figure 3-23 a through d). The one exception was the mean value for *Centropages* spp. during 1995 (Figure 3-23d). Note that the *Pseudocalanus/Paracalanus* complex was not reported in whale-present samples during 1994. *Centropages* spp. was not reported from either type of sample during that year, as it was not enumerated by CCS in 1994.

Statistical tests using a two-way ANOVA (with sample type the main effect and year the second effect, Section 3.2.2) indicated that total zooplankton abundances were significantly higher in the whale-present samples than the no-whale-present samples ($p = 0.0004$). *Calanus* and *Pseudocalanus/Paracalanus* also had larger assemblages in the whale-present samples but not to a significant extent ($p = 0.0811$ and 0.5320). No significant difference was found for *Centropages* spp ($p = 0.0667$). The year effect was not significant over the three year sampling period.

The two-way ANOVA also was used to compare results from MWRA samples (again, January to June) for 1994 to 1996 with the CCS vertical data. For this comparison, only the no-whale results from the CCS database were used because they most closely resemble the routine sampling characteristic of MWRA sampling protocol. It was found that abundance in the MWRA samples exceeded that in the CCS samples for total zooplankton and the three taxa, but only to a significant extent for total zooplankton ($p \sim 0.0000$), *Calanus finmarchicus* ($p = 0.043$) and *Centropages* ($p = 0.0017$). Again, year was not significant. Perhaps because the CCS vertical sampling was done primarily in March-April it should be expected to have lower abundances than in May-June.

## 3.3 Marine Resources Monitoring, Assessment, and Prediction

Marine Resources Monitoring, Assessment, and Prediction (MARMAP) data from NMFS provide a decade-long record of coverage in both Massachusetts and Cape Cod Bays from 1977-1987. The sampling methodology was similar to that used by MWRA except for the larger mesh size in the MARMAP program (333$\mu$m). Results can be quantitatively compared by restricting comparisons to larger taxa. Details regarding sampling and analysis can be found in a NOAA Technical Memorandum (Sibunka *et al.* 1984).

Rationale and Approach for Retrospective. The MARMAP 1977-1987 sampling provides an extension of the MWRA baseline data (1992 – 1997) for the abundance and variability of selected dominant zooplankton taxa. Comparisons performed within the MARMAP database between Massachusetts Bay and Cape Cod Bay results provide further assessment of regional differences in zooplankton assemblages. To meet such objectives, mesh size and geographic area were taken into consideration. First, the sampling methodology was similar to that used by MWRA except for the smaller mesh size in the MWRA program (102 µm), which can be compensated for by restricting comparisons to larger taxa. Second, the MARMAP sampling results were segregated into Massachusetts Bay and Cape Cod Bay by drawing an east-west line of demarcation at 42°07'N (approximately 3.5 km north of Race Point). All data points south were considered to be Cape Cod Bay samples and all data points north were considered to be Massachusetts Bay samples (analyses did not include data from the Gulf of Maine proper). The MARMAP sampling locations are presented in Figure 3-24 and are identified as either Massachusetts Bay or Cape Cod Bay samples. Typically, two samples were collected randomly over Massachusetts and Cape Cod Bays at bimonthly intervals during this period.

In the following section, MARMAP zooplankton data are presented through an assessment of their seasonal and regional characteristics. Total abundance and species succession of dominant taxa are examined during a typical annual cycle. The mean $\log_{10}$ (individuals/$m^3$+1) with 95% confidence intervals were calculated for *Calanus finmarchicus, Pseudocalanus* spp. *Paracalanus parvus, Centropages hamatus, Centropages typicus, Acartia* spp., and *Oithona* spp. for each region over the period of record. Regional zooplankton abundance was statistically analyzed to assess differences and/or similarities in species composition. A full taxonomic listing is included in Appendix A.

### 3.3.1 Total Zooplankton Abundance

In general, monthly means for total zooplankton densities during the MARMAP decade appeared to increase throughout the year in both Massachusetts and Cape Cod Bays (Figure 3-25a and b). A modest bimodal appearance could be discerned, with maxima evident in spring and fall in both Massachusetts and Cape Cod Bay samples. Lowest densities in both regions occurred during late winter. In most instances, monthly mean values in Cape Cod Bay were slightly higher than in Massachusetts Bay, particularly in the month of January.

### 3.3.2 Zooplankton Assemblage Composition

Zooplankton collections from the MARMAP sampling program were typically dominated by copepods, larvaceans, cladocerans, and cirripedes (Figure 3-26). Dominant copepod taxa were: *Calanus finmarchicus, Pseudocalanus* spp, *Paracalanus parvus, Centropages hamatus, Centropages typicus,, Oithona* spp., *Acartia* spp., *Metridia lucens*, and *Temora longicornis*.

The numerically dominant species among the copepods were *Pseudocalanus* sp and *Centropages typicus* throughout the MARMAP decade. *Pseudocalanus* spp. dominated the zooplankton assemblage throughout spring into early summer peaking in March (85%) (Figure 3-27). *Centropages typicus* dominated the autumn/early winter assemblage of zooplankton, with peak dominance (75%) in October. Subdominants included *Calanus finmarchicus* and in spring and *Centropages hamatus* and *Paracalanus parvus* in autumn. Copepods account for the majority of total zooplankton abundance (83% to 97%) in October, November, December, and January, with *Centropages typicus* and *Pseudocalanus* as the dominant organisms. However, in Cape Cod Bay during February and March (60%), April (80%), May and June (50%), other taxa (i.e. larvaceans (appendicularia), cirripedes, and cladocerans) were dominant contributors to total zooplankton (Figure 3-27). In Mass Bay during April (78%), May (45%) and June (62%), "others" seem to be dominant contributors to total zooplankton (Figure 3-26).

In summary, the seasonally dominant copepods were *Centropages typicus* (fall/late winter), *Metridia lucens* and *Pseudocalanus* sp (spring), and *Temora longicornis (summer).*

### 3.3.3 Seasonal Distribution of Dominant Taxa

Monthly mean densities of dominant taxa ($\log_{10}$ (individuals/$m^3$+1) for *Calanus finmarchicus, Pseudocalanus* sp, *Paracalanus parvus, Centropages hamatus, Centropages typicus, Oithona* spp., and *Acartia* spp. along with their $95^{th}$ percentiles, were plotted for the period of record (1977-1987) to illustrate their seasonal distributions. For each taxon, results for both Cape Cod Bay and Massachusetts Bay were plotted to demonstrate any potential regional relationships. Variability was higher in Cape Cod Bay due the lower number of samples taken.

MARMAP results indicated that *Calanus finmarchicus*, which is present in all months, began its steady seasonal increase from an annual minimum in winter to a peak in the spring (Figure 3-28). Mean densities in both Massachusetts Bay and Cape Cod Bay, between January and March were around 10 individuals/$m^3$, but densities peaked at a few hundred individuals/$m^3$ in April samples. From July through December, densities followed a steady decrease in density, similar to that seen during the winter. Results from Massachusetts Bay and Cape Cod Bay samples were similar in density.

MARMAP results indicated that *Pseudocalanus* sp displayed peaks during late spring/early summer, with minima occurring in January and February, respectively (Figure 3-29). Mean densities for both Massachusetts Bay and Cape Cod Bay, for the year varied around 200 individuals/$m^3$. From August through December, densities remained constant in both Cape Cod Bay and Mass Bay. Results from Massachusetts Bay and Cape Cod Bay samples were similar in density.

*Paracalanus parvus,* a small warm water species (undersampled by the 333 µm mesh net used), began its seasonal increase in abundance in late summer (August), reaching its annual peak during November in both Massachusetts Bay and Cape Cod Bay (Figure 3-30). Mean densities between January and July were less than 10 individuals/$m^3$, but densities peaked at a few hundred individuals/$m^3$ in November samples. Minima occurred in late spring and early summer where no individuals were reported. Results from Massachusetts Bay and Cape Cod Bay samples were similar in density.

*Centropages hamatus* began its seasonal increase in abundance in Massachusetts Bay around June, reaching its annual peak during August (Figure 3-31). Densities remained consistent from July through December and were similar to that seen during the winter. Mean densities for the year in Massachusetts Bay were less than 10 individuals/$m^3$, but densities were slightly greater in the Cape Cod Bay samples. There were no occurrences of *Centropages hamatus* during March in Mass Bay or Cape Cod Bay. Low abundances were typical during February and April in Cape Cod bay and January through May in Mass Bay.

MARMAP results for both Massachusetts Bay and Cape Cod Bay indicated that *Centropages typicus* began a steady seasonal increase in July reaching its annual peak around November, while minima occurred during April through June (Figure 3-32). In general, results indicated that *Centropages typicus* abundance is an order of magnitude greater than that of *Centropages hamatus. Centropages typicus* follows the same general patterns of abundance in both Bays. The maximum mean abundance occurs during early fall and continues throughout the winter months. Mean densities between July and December peaked at a few hundred individuals/$m^3$, but densities during the minima were typically around than 10 individuals/$m^3$.

*Oithona* spp. (a small cyclopoid that also is undersampled by the 333 µm mesh net) began its seasonal increase in abundance in the late winter/early spring months, reaching its annual peak during March in Cape Cod Bay (Figure 3-33). Mean densities ranged around 10 to 100 individuals/$m^3$. Abundance dropped in April in both Mass Bay and Cape Cod Bay and then peaked again during May. There is a significant drop in abundance during the summer months of June and July with a general rise in abundance again which lasts through December, peaking in November in Massachusetts Bay (Figure 3-33).

*Acartia* spp. (*A. tonsa* and *A. hudsonica* combined) began increasing in abundance around April, reaching an annual peak during May (Figure 3-34). Mean densities between January and March were less than 10 individuals/$m^3$, but densities peaked slightly higher in May samples. Both Mass Bay and Cape Cod Bay display peak abundances in May, however the early months tend to be greater in abundance than in Mass

Bay (Figure 3-34). From the MWRA data for 1995-1997, we know that *A. hudsonica* dominates during the cold half of the year and is present in the warmer months as well, when *A. tonsa* becomes a dominant.

Statistical comparison of MARMAP data was performed using a paired t-test to contrast results from Massachusetts Bay and Cape Cod Bay, taking into consideration the lack of stations in eastern Cape Cod Bay. The tests concentrated on comparisons of total abundance and the distribution of dominant species (*Calanus finmarchicus*, *Pseudocalanus* sp, *Paracalanus parvus*, *Centropages hamatus*, *Centropages typicus, Acartia* spp. and *Oithona* spp.). Where synoptic sampling was unavailable, the pairing was isolated to the same month and year (the closest in time) for the samples. Fortunately, all pairs occurred on the same day and month within the year with few exceptions. This should eliminate temporal variability. No significant difference in abundance ($p < 0.05$) between Massachusetts Bay and Cape Cod Bay were found for any of the species. However, greater assemblages of *Calanus finmarchicus*, *Paracalanus parvus* and *Oithona* spp. were found in Massachusetts Bay while Cape Cod Bay had larger assemblages of total zooplankton, *Pseudocalanus* sp., *Centropages hamatus*, *Centropages typicus* and *Acartia* spp.

## 3.4 Ship of Opportunity Continuous Plankton Recorder Record

Ship of Opportunity Continuous Plankton Recorder (SOOP-CPR) data collected by ships of opportunity provide a long-term historical baseline of zooplankton abundance and variability in northern Massachusetts Bay. The data also provide insight into the horizontal distribution in abundance and species composition, allowing the potential role of the CPR data to support investigations of potential eutrophic response to the outfall relocation.

The mean $\log_{10}$ (individual/$m^3$+1) with 95% confidence intervals were calculated (in this study) for *Calanus finmarchicus, Pseudocalanus spp., Centropages typicus, Acartia* spp., and *Oithona* spp. for the nearfield over the period of record. Further statistical analyses were not conducted on the CPR data (in this study) due to the interpolation method (kriging) of sample values between data points in space and time. Values were interpolated across space and time by NMFS only when sufficient data existed to warrant the interpolation. Details regarding this kriging/interpolation method can be found in Benway *et al.* (1993). Regional analysis was also not performed on the CPR data (in this study) as the Ship of Opportunity sampling approach does not lend itself to easy demarcation and division of very specific regional areas. Data were evaluated in a polygon transect as only the longitude of the samples was used as a reference in our graphics. The CPR sampling locations are displayed in Figure 3-35.

In the following section, zooplankton are presented through an assessment of their seasonal characteristics and species succession. Total abundance is examined during a typical annual cycle to assess community assemblages. Zooplankton taxa were assessed for species dominance within the plankton community. *Acartia* was also assessed for the potential inshore/offshore gradient typically seen within the MWRA dataset.

**Rationale and Approach for Retrospective.** CPR data provide a long-term historical baseline of zooplankton abundance and variability in northern Massachusetts Bay. The data also provide insight into the horizontal distribution in abundance and species composition, thus the potential role of the CPR data in supporting the zooplankton hypothesis proposed to assess potential eutrophication in the nearfield is being investigated. This role is being considered only qualitatively in this report.

### 3.4.1 Total Zooplankton Abundance

In general, monthly means for total zooplankton densities during the CPR sampling period appeared to increase through early spring, peaking between May and June in the nearfield (Figure 3-36). A modest bimodal pattern could be discerned, with maxima evident in spring and fall and minima during late winter in Massachusetts Bay.

### 3.4.2 Zooplankton Assemblage Composition

The CPR zooplankton collections typically were dominated by copepods, cirripedes (barnacles), and Euphausiacea (krill). The following organisms were identified as the dominants and are ranked by abundance: *Calanus finmarchicus* (Stage 1 through 4), *Centropages typicus* (unstaged), *Calanus finmarchicus* (Stages 5 and 6), *Pseudocalanus* spp. (adults), *Oithona* spp. (copepodite stages 4 through 6), *Acartia* spp. (unstaged), *Temora longicornis* (unstaged), *Metridia lucens* (copepodite stages 5 and 6), Cirripedia (nauplius), *Euphausiacea* (larva), *Euphausiacea* (adults). Included in this retrospective are *Calanus finmarchicus* (Stage 1 through 4 and 5,6), *Centropages typicus*, *Pseudocalanus* spp., *Acartia* spp., and *Oithona* spp., which are consistent with the dominant species identified in the MARMAP study as well as the MWRA study. A full taxonomic listing is available in Appendix A.

*Calanus finmarchicus* (stage 1 through 4) dominated the zooplankton assemblage throughout the spring peaking in April and May (approximately 60%) (Figure 3-37). *Calanus finmarchicus* (stage 1 through 4) densities decreased throughout the summer. However, *Calanus finmarchicus* adults continued to flourish throughout the summer months. Densities of the spring and summer dominants decreased as *Centropages typicus* densities increased and dominated the fall bloom, with peak dominance in November (60%). *Pseudocalanus* spp. and *Oithona* species exhibited slight increases in the fall, but were relatively small contributors in comparison to *Centropages typicus*. During February (50%), March (75%) and June (85%), "others" seem to be dominant contributors to total zooplankton (Figure 3-37).

### 3.4.3 Seasonal Distribution of Dominant Taxa

Monthly mean densities of dominant taxa ($\log_{10}$ (individuals/$m^3$+1) for *Calanus finmarchicus, Pseudocalanus* spp., *Centropages typicus, Oithona* spp., and *Acartia* spp. along with their $95^{th}$ percentiles, were plotted for the period of record (1961-1990) in the nearfield to illustrate their seasonal distributions.

CPR results between 1961 and 1990 for the nearfield indicated that *Calanus finmarchicus* copepodite population began its seasonal increase in abundance around March, reaching its annual peak during May (Figure 3-38a). Mean densities between January and March were less than 10 individuals/$m^3$, but densities peaked slightly higher in May samples. From July through December, densities were similar to those seen during the winter. Results indicated that the *Calanus finmarchicus* adult population began its seasonal increase in abundance around March with peak densities occurring in July (Figure 3-38b). Monthly mean abundance of adults typically was less than 10 individuals/$m^3$. From October through January, *Calanus finmarchicus* adults were typically an order of magnitude more abundant than the younger copepodite stages.

Figure 3-39a details *Calanus finmarchicus*, (copepodite stages 5 and 6) mean seasonal abundances for the 1961-1990 base period along the transect shown in Figure 3-35 between 70-50 W (Boston Harbor) and 69-50W (Stellwagen Bank). Peak densities are seen during the summer months in all areas, however maximum densities appear to encompass a greater period at the more seaward stations. Densities were low during the winter months and into early spring in the more seaward stations. In the more coastal stations abundance appears to start increasing slightly during February. The progression toward the Stellwagen Bank area displays higher abundances of *Calanus*. *Calanus* abundance at the more seaward stations is consistently greater than that at the more coastal stations. Figure 3-39b details the mean abundance of *Calanus* expressed as percentage of total copepod abundance. The percentage of *Calanus* ranged from 80 - 100% near Stellwagen Bank during January and February and again during the summer months. The percentage of *Calanus* near the coast peaked during July and August.

*Pseudocalanus* spp. abundance decreased from January to April and then increased until June, after which it remained relatively stable for the remainder of the year (Figure 3-40). Monthly mean densities were typically less than 10 individuals/$m^3$ year round, with minima in March and April. It should be noted that in analyzing CPR gauze samples, *Pseudocalanus* and *Paracalanus* are often grouped together. This may account for the relatively high abundance during late summer and fall, a period typically dominated by *Paracalanus parvus*.

*Centropages typicus* began its pronounced seasonal increase in abundance around July, reaching its annual peak during October (Figure 3-41). Mean densities between January and July were less than 10 individuals/$m^3$, but densities peaked at a few hundred individuals/$m^3$ in October samples. Minimum densities occurred during late spring early summer, with very low occurrences of *Centropages* during April. *Centropages typicus* in the CPR samples showed similar patterns to that of the MARMAP samples.

*Oithona* spp. began its seasonal increase in abundance around April, reaching its annual peak during May and June and a secondary smaller peak in density occurred during September (Figure 3-42). Mean densities for the year varied about 10 individuals/$m^3$. Densities remained relatively constant during the winter months of November through February.

*Acartia* spp. began its seasonal increase in abundance around April, reaching its annual peak during June (Figure 3-43). Mean densities for the year were well under 10 individuals/$m^3$, even during peaks. Minima occurred from December to March, during which no individuals were reported in January or February. *Acartia* spp is dominated by *A. hudsonica* during winter/spring and by both *A. tonsa* and *A. hudsonica* during summer/fall.

### 3.4.4 *Acartia* Hypothesis

MWRA is developing monitoring threshold parameters to evaluate potential environmental effects from the outfall relocation. A proposed threshold would consider changes in zooplankton assemblage in the nearfield. A shift toward an *Acartia*-dominated assemblage would be indicative of localized enrichment.

Zooplankton assemblages vary with location in the Massachusetts Bay system. *Acartia, Eurytemora*, and *Centropages hamatus* dominate the species composition of inshore communities, while the species composition of offshore communities is dominated by *Calanus, Pseudocalanus, Centropages typicus*, and *Oithona*. The nearfield region currently represents a transition between the two communities (Table 3-2).

The zooplankton species in inshore communities are known to require the high concentrations of carbon that are found in Boston Harbor for maximal growth and reproduction. Once the new outfall is online, the nutrient concentrations in both the Boston Harbor and the nearfield region may change, potentially altering both phytoplankton and zooplankton community composition. The zooplankton community in the nearfield may change. The zooplankton community in Boston Harbor may change toward that presently in Massachusetts Bay. The proposed caution level is intended to detect a shift in assemblage composition in the nearfield toward a more eutrophic "harbor" assemblage dominated by *Acartia* spp.

Figure 3-44a details *Acartia* spp. mean seasonal abundances for a 1961-1990 base period along a transect between 70-50W (Boston Harbor) and 69-50W (Stellwagen Bank) which provides information on the horizontal distribution of *Acartia*. Peak abundances are seen during the summer months in all areas, however maximum densities appear to span a greater portion of time at the more coastal stations. The progression toward the Stellwagen Bank area displays brief peaks in abundance. Abundance is low during the winter months and into early spring. In the more coastal stations abundance appears to start increasing slightly during the months of February and March and more consistently from May until August. In the more seaward stations, *Acartia* spp. begins to increase from May through June followed by short peaks during the summer months. In summary, the long-term CPR data set shows that *Acartia* spp. abundance is higher and less sporadic nearshore than offshore. Figure 3-44b details the mean abundance of Acartia spp. expressed as percentages of total copepod abundance. The percentages of Acartia peaked throughout the summer with higher percentages occurring in the coastal areas.

## 3.5 Massachusetts Water Resources Authority

Figure 3-45 displays the locations of Massachusetts Water Resources Authority (MWRA) zooplankton sampling locations for 1997. Selected stations were used for this retrospective: "Cape Cod Bay" stations are identified as F01 and F02 and "Massachusetts Bay" plankton stations are identified as N01, N04, N07, N10, N16, and N20. Other 1997 plankton station locations are also shown in enlarged text (Figure 3-45) but were not used for this retrospective. Table 3-3 presents a detailed account of the baseline sampling of the selected stations from two perspectives. First, sample size by station and year is presented, providing a spatial and inter-annual perspective. Then, sample size by year and month is presented, providing a seasonal and inter-annual perspective (Table 3-3).

**Rationale and Approach for Retrospective.** Comparisons performed within the MWRA database between Massachusetts Bay and Cape Cod Bay results provided further assessment of the "uniqueness" of the Cape Cod Bay assemblages. Further, dominant taxa were compared qualitatively to results from other sampling programs.

### 3.5.1 Total Zooplankton

In general, monthly means of total zooplankton densities in Massachusetts Bay began to increase by April and continued throughout the summer and fall, with peaks in June, August, and October (Figure 3-46). In general, monthly means of total zooplankton densities in Cape Cod Bay appeared to increase throughout the year. Lowest densities in both regions occurred during the winter. Both Bays were similar in the range of densities displayed throughout the year.

### 3.5.2 Zooplankton Assemblage Composition

Zooplankton collections from the MWRA sampling program typically were dominated by *Oithona similis*. and unidentified copepods (predominantly copepod nauplii) in both Massachusetts and Cape Cod Bay (Figure 3-47) Subdominants included *Centropages typicus*, *Pseudocalanus newmani*, and bivalves during most of the year. *Calanus finmarchicus* was seen in greatest densities during spring in April and May. There were substantial contributions in Massachusetts Bay from "other" taxa during the first part of the year, in February (36%), March (40%), and April (44%) (Figure 3-48). In Cape Cod Bay, "other" taxa contributed substantially to the total during the first part of the year in February (22%), March (44%), and April (34%). A full taxonomic list for the baseline is given in Appendix A.

### 3.5.3 Seasonal Distribution of Dominant Taxa

The mean $\log_{10}$ (individuals/$m^3$+1) with 95% confidence intervals were calculated for *Calanus finmarchicus, Pseudocalanus newmani, Paracalanus parvus, Centropages hamatus, Centropages typicus, Oithona* spp. and *Acartia* spp, for the each region over the period of record.

MWRA results between 1992 and 1996 indicated that *Calanus finmarchicus* (copepodite and adult populations) began its seasonal increase in abundance in Massachusetts Bay around March, reaching its annual peak during July (Figure 3-49a&b). *Calanus finmarchicus* adults were not observed during the month of May in Massachusetts Bay. Adult *Calanus finmarchicus* in Cape Cod Bay increased in density beginning in March, with a peak in August (Figure 3-49d). There were no occurrences of *C. finmarchicus* adults in February in Cape Cod Bay. There appears to be more variation in the copepodite populations in Cape Cod Bay likely due to the few stations sampled (n=2). Densities of copepodites decreased in March, increased in April and declined again during June (Figure 3-49c) although these patterns are unlikely to be significant. Mean densities for copepodite populations in both Massachusetts Bay and Cape Cod Bay were typically an order of magnitude higher than the adult populations. Figure 3-49e&f displays the similarities between the two Cape Cod Bay stations F01 and F02.

*Pseudocalanus newmani* began its seasonal increase in abundance in Massachusetts Bay and Cape Cod Bay around April, reaching its annual peak during May and August respectively (Figure 3-50). (Note however that for the period 1992-1994 the bulk of the fall "*Pseudocalanus newmani*" were likely *Paracalanus parvus*, Cibik *et al.* 1998) Mean densities between February and April reaching densities around 100 individuals/$m^3$, but densities peaked around 2500-3000 individuals/$m^3$ in May in Massachusetts Bay.

*Paracalanus parvus* began its seasonal increase in abundance in Cape Cod Bay around April, reaching its annual peak during August (Figure 3-51). Mean densities throughout the year ranged between a few 100 and 1000 individuals/$m^3$. Maximum densities of *Paracalanus parvus* in Massachusetts Bay occurred in early spring/late fall, with peaks in March and August. While *Pseudocalanus newmani* is a year round species, *P. parvus* was not observed in the months of May and July and November in Massachusetts Bay (Figures 3-50 & 3-51). (Note however that for the period 1992-1994 the bulk of the winter/spring "*Paracalanus parvus*", was likely *Pseudocalanus newmani* Cibik *et al.* 1998).

MWRA results indicated that *Centropages hamatus* began its seasonal increase in abundance in both Massachusetts Bay and Cape Cod Bay around June, reaching its annual peak during late summer/early fall (Figure 3-52). Mean densities throughout the year ranged between 50 to a few hundred individuals/$m^3$ for both Massachusetts Bay and Cape Cod Bay. Minimum densities in Massachusetts Bay and Cape Cod Bay occurred in March and April, respectively. Densities in both Massachusetts Bay and Cape Cod Bay were similar in magnitude.

*Centropages typicus* began its seasonal increase in abundance in Massachusetts Bay and Cape Cod Bay around August, reaching its annual peak October (Figure 3-53). Mean densities throughout the year ranged around a few hundred individuals/$m^3$ with peak densities at 1000 individuals/$m^3$. Minimum densities occurred from January to April in both Massachusetts Bay and Cape Cod Bay.

*Oithona* spp. began its seasonal increase in abundance in Massachusetts Bay and Cape Cod Bay around April, reaching its annual peak during August and October, respectively (Figure 3-54). Mean densities from February through April were around 300-500 individuals/$m^3$, but densities peaked around two thousand individuals/$m^3$ in August in Massachusetts Bay. *Oithona* spp. was abundant throughout the entire year in both Massachusetts Bay and Cape Cod Bay.

*Acartia* spp. began its seasonal increase in abundance in Massachusetts Bay and Cape Cod Bay in April, reaching its annual peak during September and August, respectively (Figure 3-55). Mean densities between February and April were less than 100 individuals/$m^3$, but densities peaked at several hundred individuals/$m^3$ in August and September samples. Densities began to decline during October and continued to decline throughout the winter into February.

Statistical comparisons of MWRA data were performed using a three-way ANOVA to contrast results within Massachusetts and Cape Cod Bays. The three effects tested for in this ANOVA were station, month and year. These tests concentrated on comparisons of total abundance and the distribution of dominant species (*Calanus finmarchicus, Pseudocalanus newmani, Paracalanus parvus, Centropages hamatus, Centropages typicus,* and *Acartia* spp., and *Oithona* spp.). The station effect within Cape Cod Bay was not significant for any of the above species, including total zooplankton ($p < 0.05$). The station effect within Massachusetts Bay was not significant for *Calanus finmarchicus* ($p = 0.1118$), *Centropages typicus* ($p = 0.35$), *Paracalanus parvus* ($p = 0.4503$), *Pseudocalanus newmani* ($p = 0.2803$)and total zooplankton ($p = 0.3977$). Consequently, the stations within each region were grouped together and used in another three-way ANOVA comparison of Cape Cod Bay to Massachusetts Bay for *Calanus finmarchicus, Centropages* spp., *Paracalanus parvus, Pseudocalanus newmani* and total zooplankton. The three effects tested in this ANOVA were region, month and year. The abundance of *Calanus finmarchicus* was significantly greater in Massachusetts Bay than in Cape Cod Bay ($p = 0.0138$). The abundance of total zooplankton and *Paracalanus parvus* were also greater in Massachusetts Bay than Cape Cod Bay but not to a significant extent. The abundance of *Pseudocalanus newmani* and *Centropages typicus* were higher in Cape Cod Bay than Massachusetts Bay, but not to a significant extent.

Since *Acartia* spp. ($p = 0.0004$), *Oithona* spp ($p = 0.0006$). and *Centropages hamatus* ($p \sim 0.0000$) displayed significant station effects in the former ANOVA, further tests were performed. A three-way ANOVA (station, month and year) was used to determine that the Massachusetts Bay stations could be grouped into nearshore (N01, N20, N10) and offshore (N04, N16, N07) regions. Farfield stations within the nearfield were not used in this assessment. Each Massachusetts Bay region then was compared to Cape Cod Bay.

Nearshore Mass Bay and the Cape Cod Bay regions for all three species were found to be similar ($p > 0.05$). When the offshore Mass Bay stations were compared with Cape Cod Bay, it was found that both *Acartia* spp. ($p = 0.0015$) and *Centropages hamatus* ($p \sim 0.0000$) were significantly more abundant in Cape Cod Bay. Alternatively, *Oithona* spp. was significantly more abundant at the offshore stations ($p = 0.0054$).

| | Feeding Whale | | | | | | | | | | | | No Whale | | | | | | | | | | | | | Whale Not Feeding | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station/Year | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 97 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 |
| 5N | | | | | | | | | | | | | | 1 | 4 | 4 | 4 | 4 | 4 | 1 | 6 | 6 | 4 | 2 | | | | | | | | | | | | | |
| 5M | | | | | | | | | | | | | | | | | | | 1 | | | 1 | | | | | | | | | | | | | | | |
| 5S | | | | | | | | | | | | | | | 1 | 2 | 6 | 4 | 2 | | 6 | 8 | 7 | 1 | | | | | | | | | | | | | |
| 6N | | | | | | | | | | | | | | | | 8 | 12 | 9 | 3 | 3 | 4 | 11 | 7 | 3 | 1 | | | | | 1 | | | | | 1 | | 1 |
| 6M | | | | | | | | | | | | | | 1 | 3 | 7 | 7 | 11 | 4 | 5 | 5 | 9 | 8 | 4 | 1 | | | | | | | | | | | | |
| 6S | | | | | | | | 1 | | | | | | | | 8 | 7 | 10 | 5 | 2 | 3 | 9 | 10 | 4 | 3 | | | | | | | | | 1 | | | |
| 7N | | | | | | | | | | | | | | | | 2 | 3 | 6 | 2 | | 1 | 3 | 1 | | | | | | | | | | | | | | |
| 7M | | | | | | | | | | | | | 1 | | 4 | 4 | 6 | 7 | 3 | | 1 | 4 | 2 | 6 | | | | | | | | | | | | | |
| 7S | | | | | | | | | | | | | 1 | 2 | 3 | 5 | 4 | 10 | 2 | 1 | 3 | 3 | | 2 | 1 | | | | | | | | | | | | |
| 8N | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | | | |
| 8M | | | | | | | | | | | | | | | | 1 | 1 | | | | 1 | | | 2 | 1 | | | | | | | | | | | | |
| 8S | | | | | | | | | | | | 1 | | | | 1 | 2 | 2 | | | 1 | 1 | 1 | 1 | 2 | | | | | | | | | | | | |
| other | 12 | 9 | 16 | 18 | 9 | 1 | 3 | 6 | 2 | 2 | 4 | 9 | 12 | 13 | 28 | 33 | 49 | 28 | 12 | 1 | 6 | 51 | 8 | 10 | 27 | 2 | 2 | 1 | 10 | 7 | 3 | 4 | 5 | 5 | 8 | 2 | 4 |
| total | 12 | 9 | 16 | 18 | 9 | 1 | 3 | 7 | 2 | 2 | 4 | 10 | 14 | 17 | 43 | 75 | 101 | 91 | 38 | 13 | 37 | 106 | 48 | 36 | 36 | 2 | 2 | 1 | 10 | 8 | 3 | 4 | 5 | 6 | 9 | 2 | 5 |

**TABLE 3-1**
**CCS Surface Tow Sampling by Year and Location**

| Harbor/Coastal | Offshore/Boundary/CCbay |
|---|---|
| *Acartia tonsa* | *Oithona similis* |
| *Acartia hudsonica* | *Pseudocalanus newmani* |
| *Centropages hamatus* | *Centropages typicus* |
| *Eurytemora herdmani* | *Calanus finmarchicus* |
| Polychaete Larvae | *Oikopleura dioica* |
| *Podon* spp. | *Microsetella norvegica* |
| | *Paracalanus parvus* |

**TABLE 3-2**
**Geographical Affinity of Zooplankton Taxa**

MWRA sample size by station and year

| | | Station | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | N01 | N04 | N07 | N10 | N16 | N20 | F01 | F02 |
| Year | 1992 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| | 1993 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| | 1994 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| | 1995 | 0 | 0 | 0 | 16 | 17 | 0 | 6 | 6 |
| | 1996 | 0 | 16 | 0 | 16 | 6 | 0 | 6 | 5 |

MWRA sample size by year and month

| | | Year | | | | |
|---|---|---|---|---|---|---|
| | | 1992 | 1993 | 1994 | 1995 | 1996 |
| Month | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 8 | 8 | 8 | 8 | 10 |
| | 3 | 8 | 8 | 8 | 2 | 2 |
| | 4 | 8 | 8 | 8 | 6 | 4 |
| | 5 | 0 | 0 | 0 | 2 | 2 |
| | 6 | 8 | 8 | 8 | 4 | 5 |
| | 7 | 0 | 0 | 0 | 4 | 4 |
| | 8 | 8 | 8 | 8 | 6 | 7 |
| | 9 | 0 | 0 | 0 | 3 | 4 |
| | 10 | 8 | 8 | 8 | 4 | 7 |
| | 11 | 0 | 0 | 0 | 4 | 2 |
| | 12 | 0 | 0 | 0 | 2 | 2 |

**TABLE 3-3**
Selected MWRA Samples (1992-1996)
(a) Station and Year, (b) Year and Month

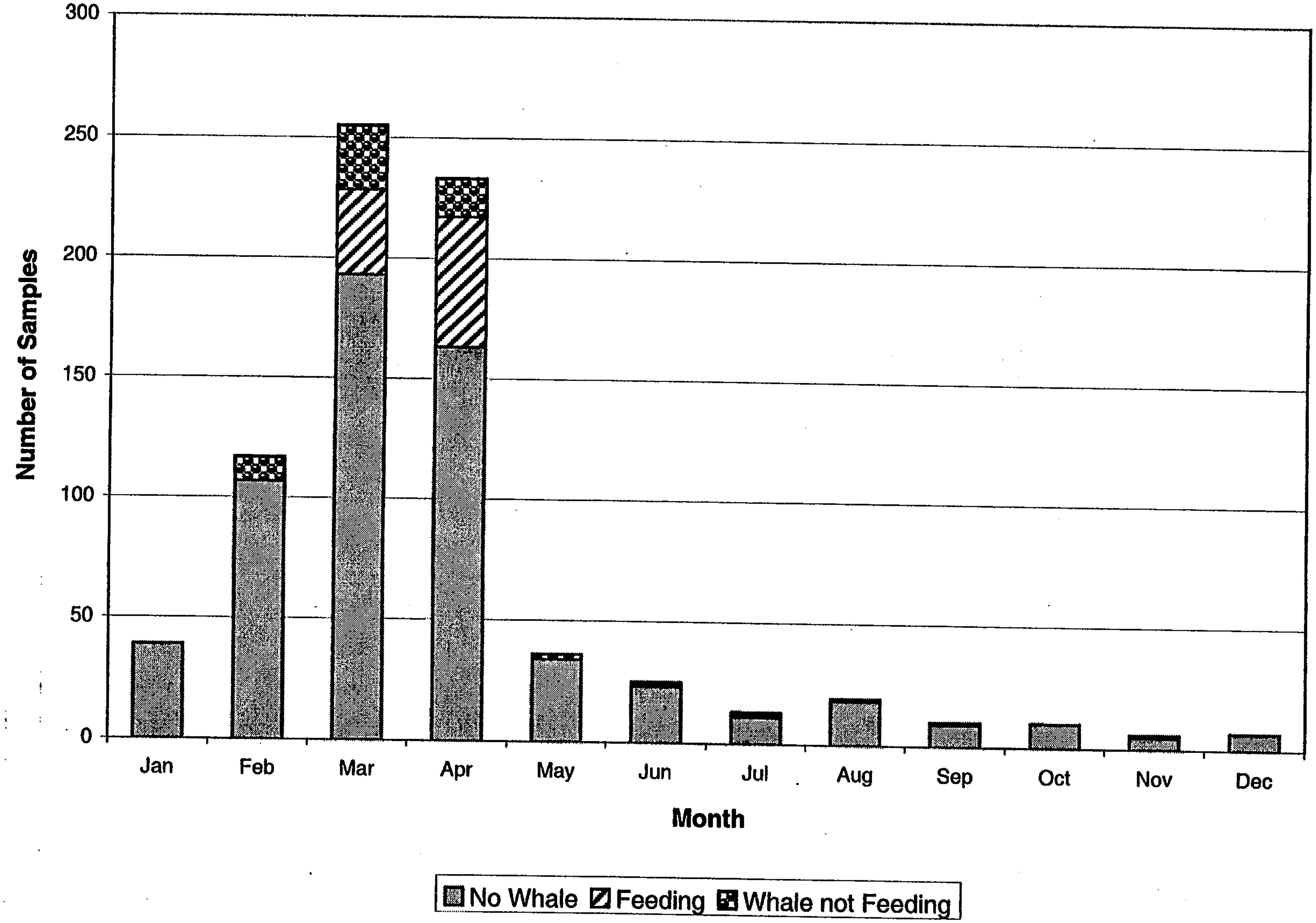



**FIGURE 3-1**
Monthly Distribution of CCS Sampling - 1984-1995

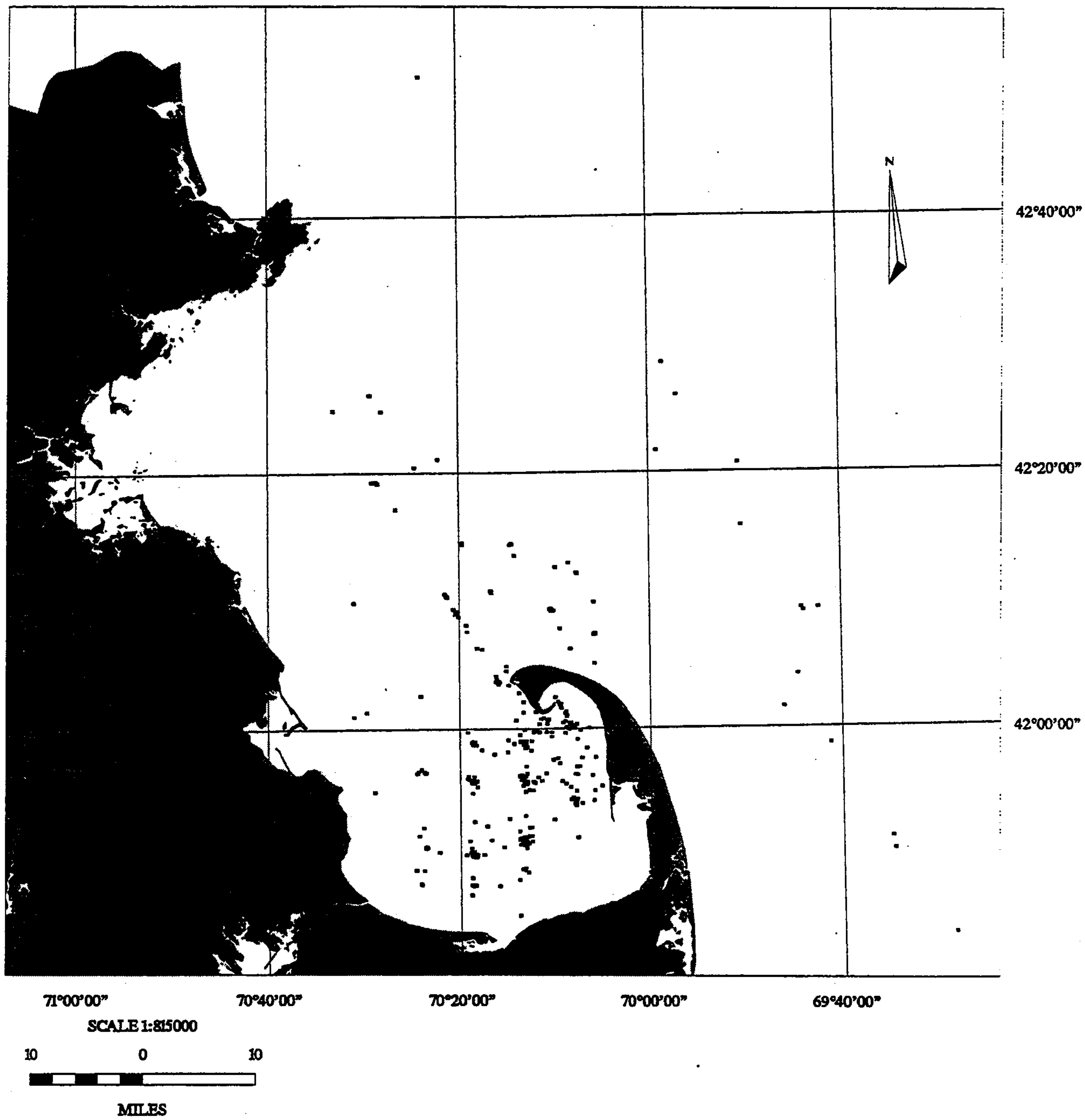



**FIGURE 3-2**
**CCS Conical Surface Tow Sampling Locations (1984-1997)**
**No whales present**

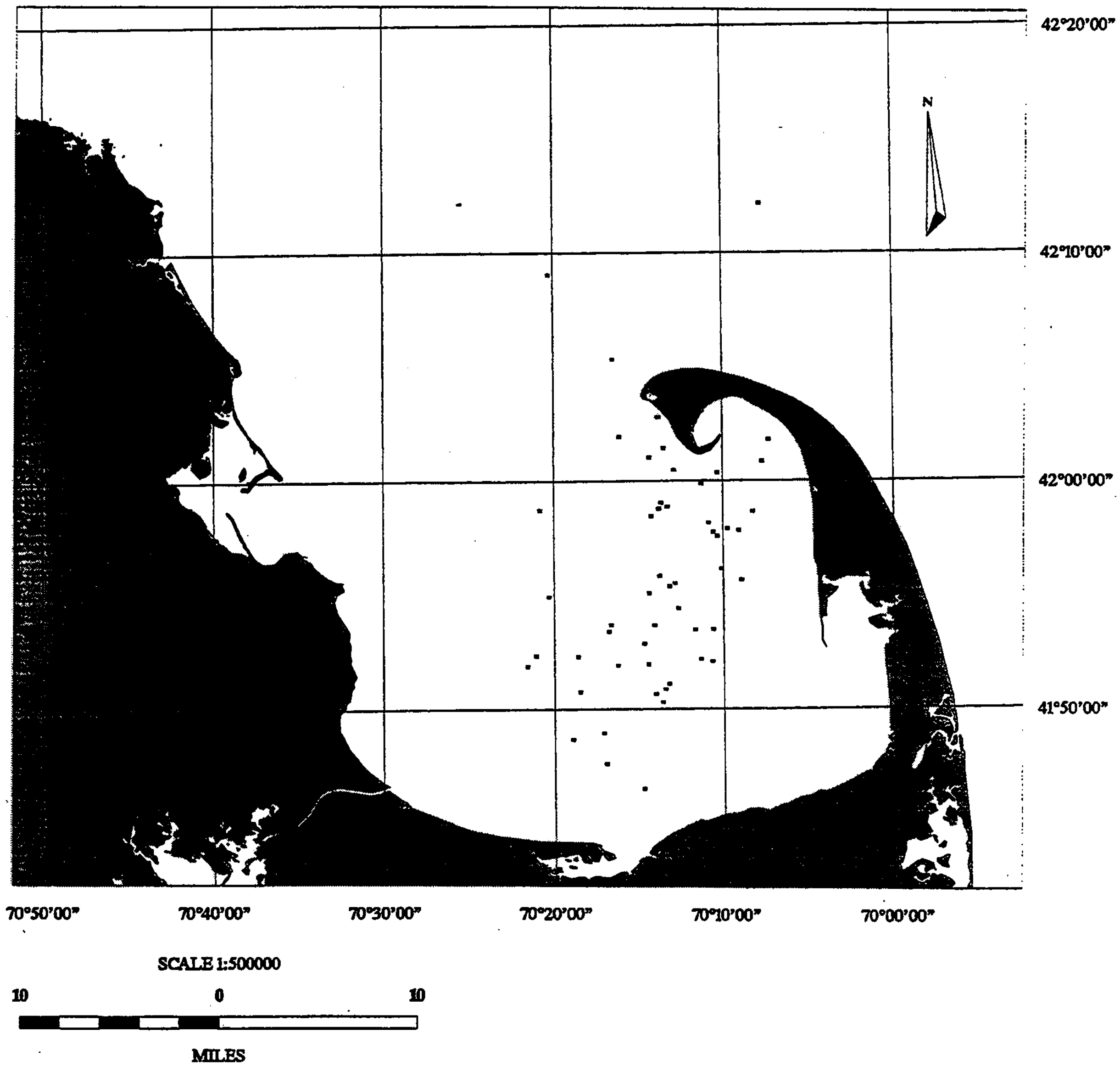



**FIGURE 3-3**
**CCS Conical Surface Tow Locations (1984-1995)**
**Whales present, not feeding**

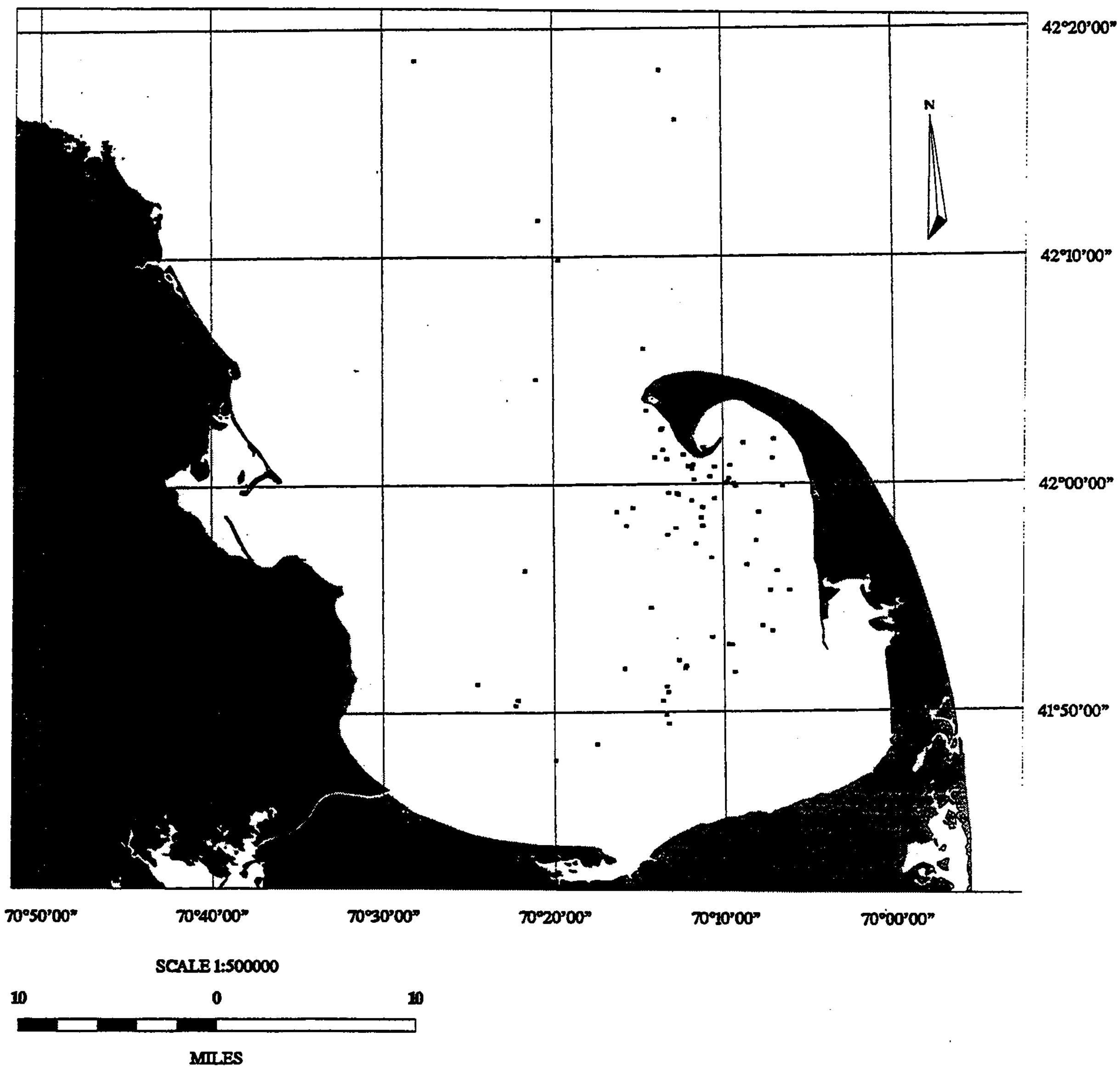



**FIGURE 3-4**
**CCS Conical Surface Tow Locations (1984-1995)**
**Whales feeding**

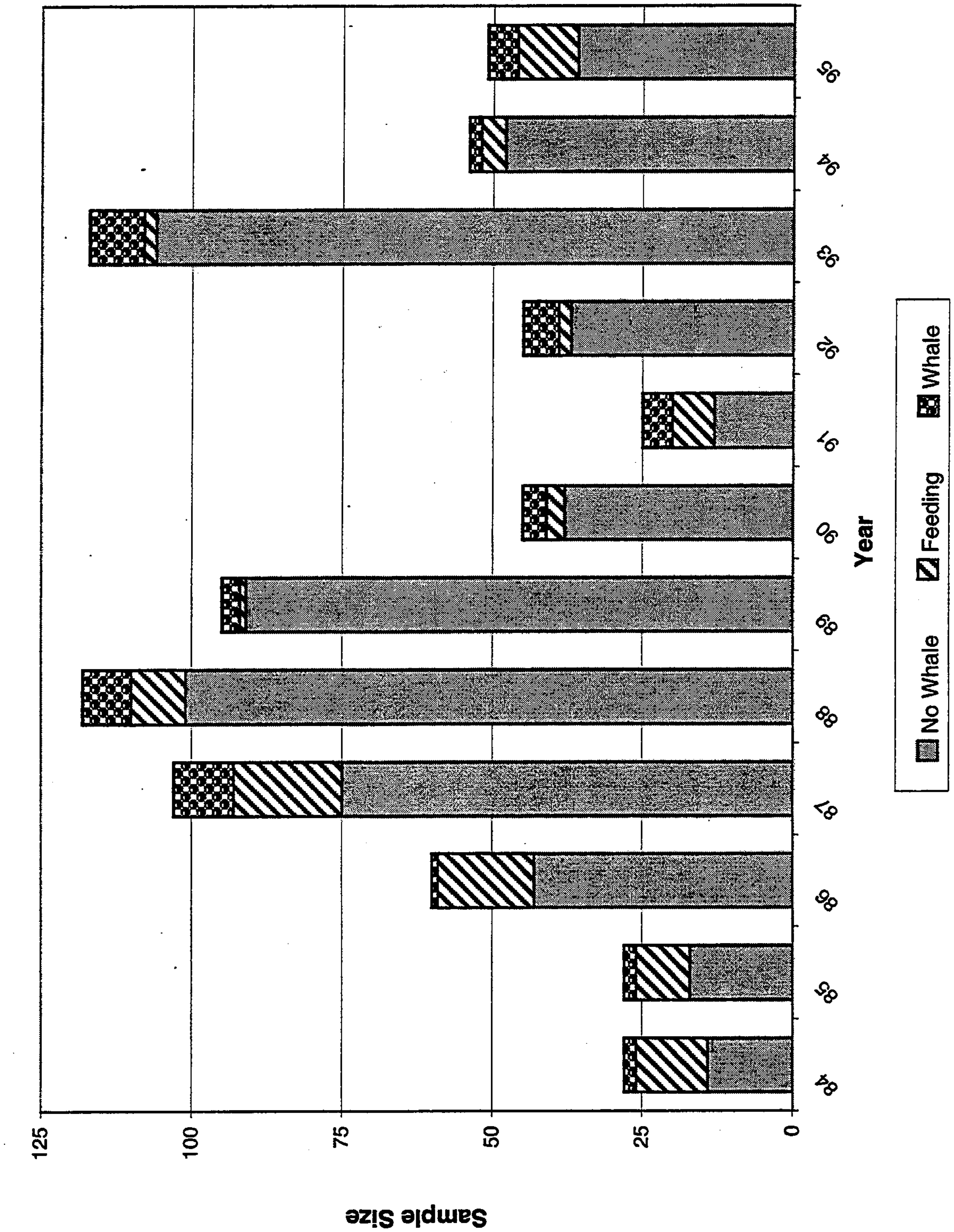



**FIGURE 3-5**
**CCS Sampling by Year**

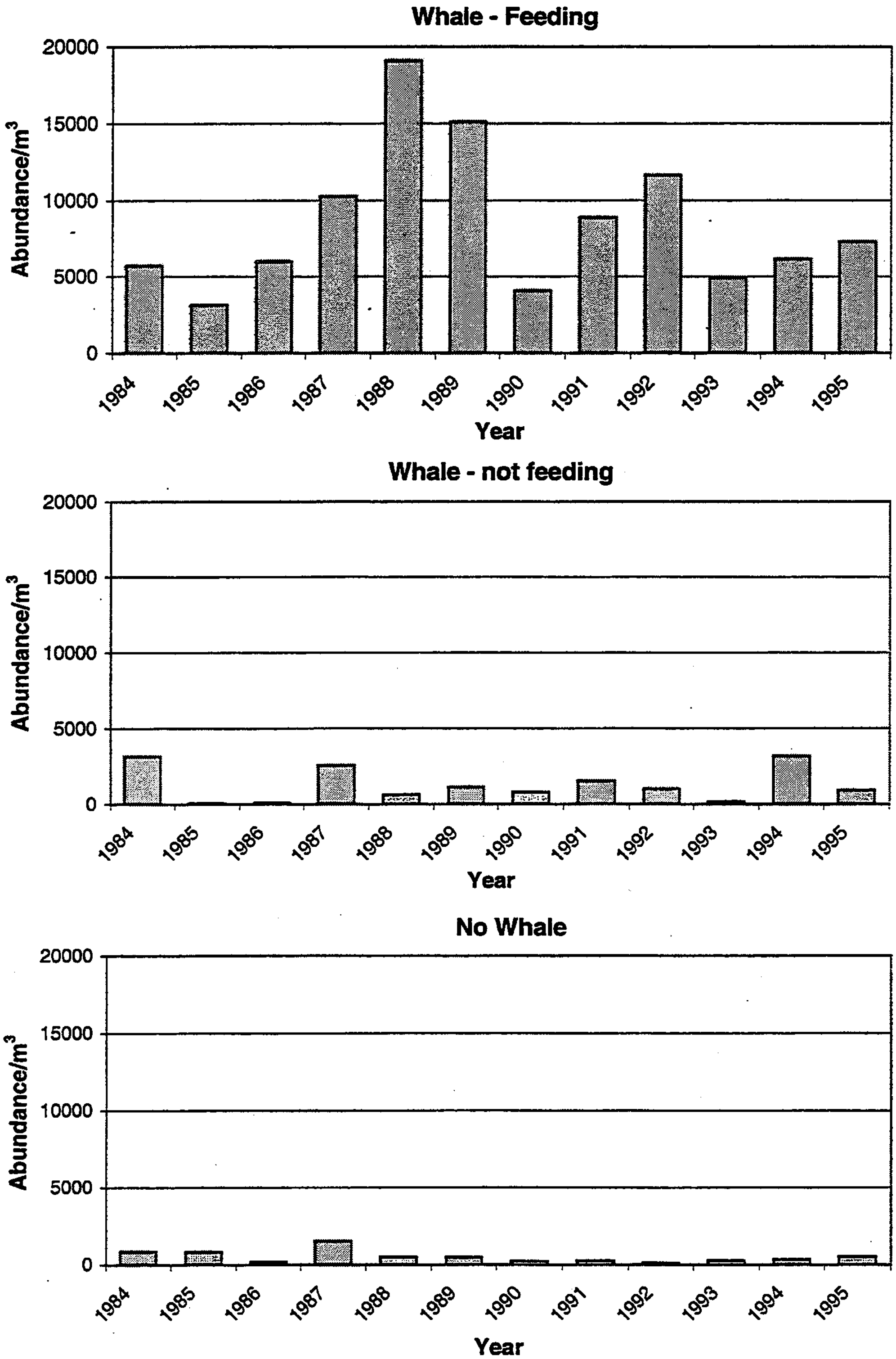



**FIGURE 3-6**
**Average annual zooplankton abundance (January - June)**
**1984-1995 CCS feeding-whale, non-feeding-whale and no-whale-present samples**

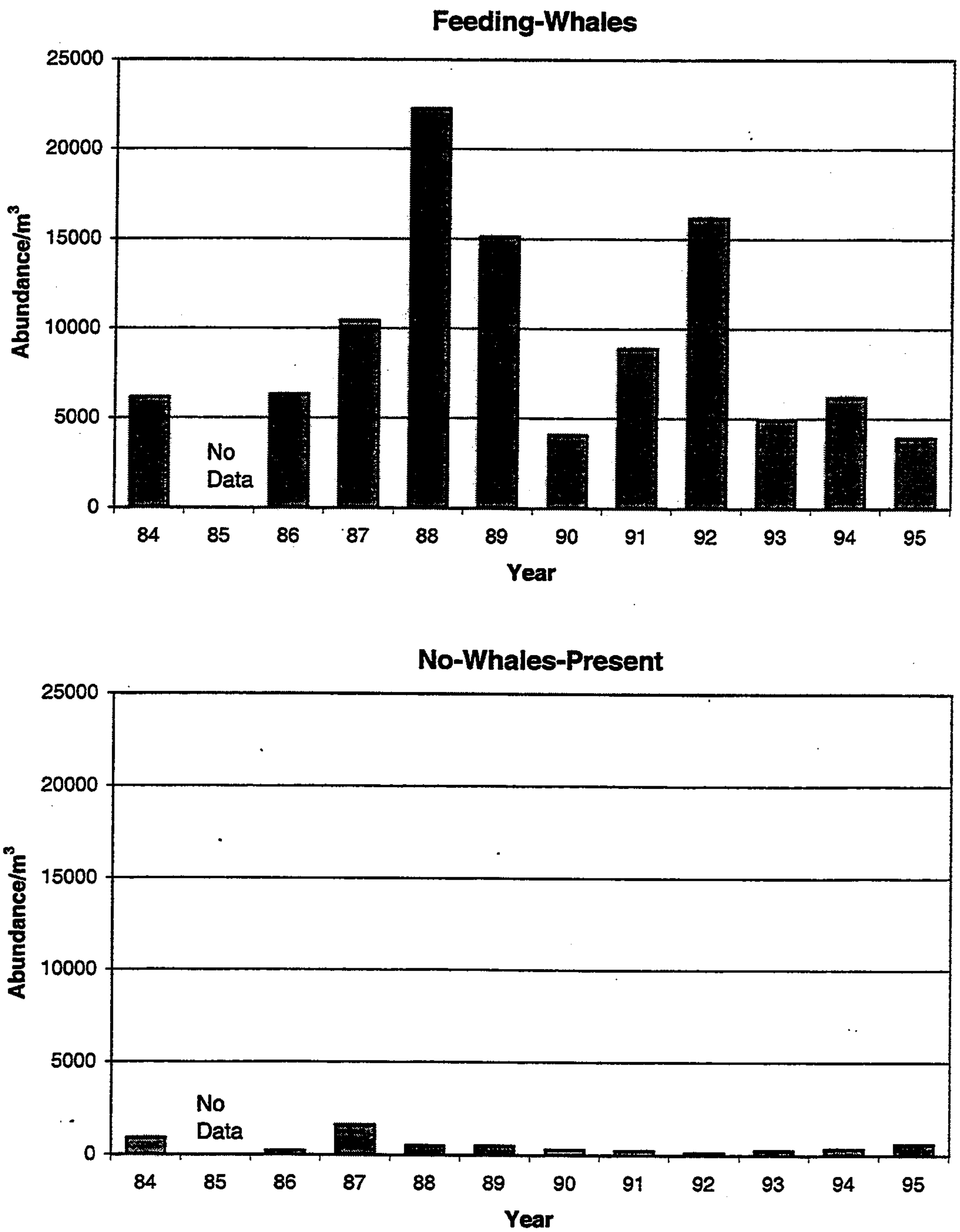
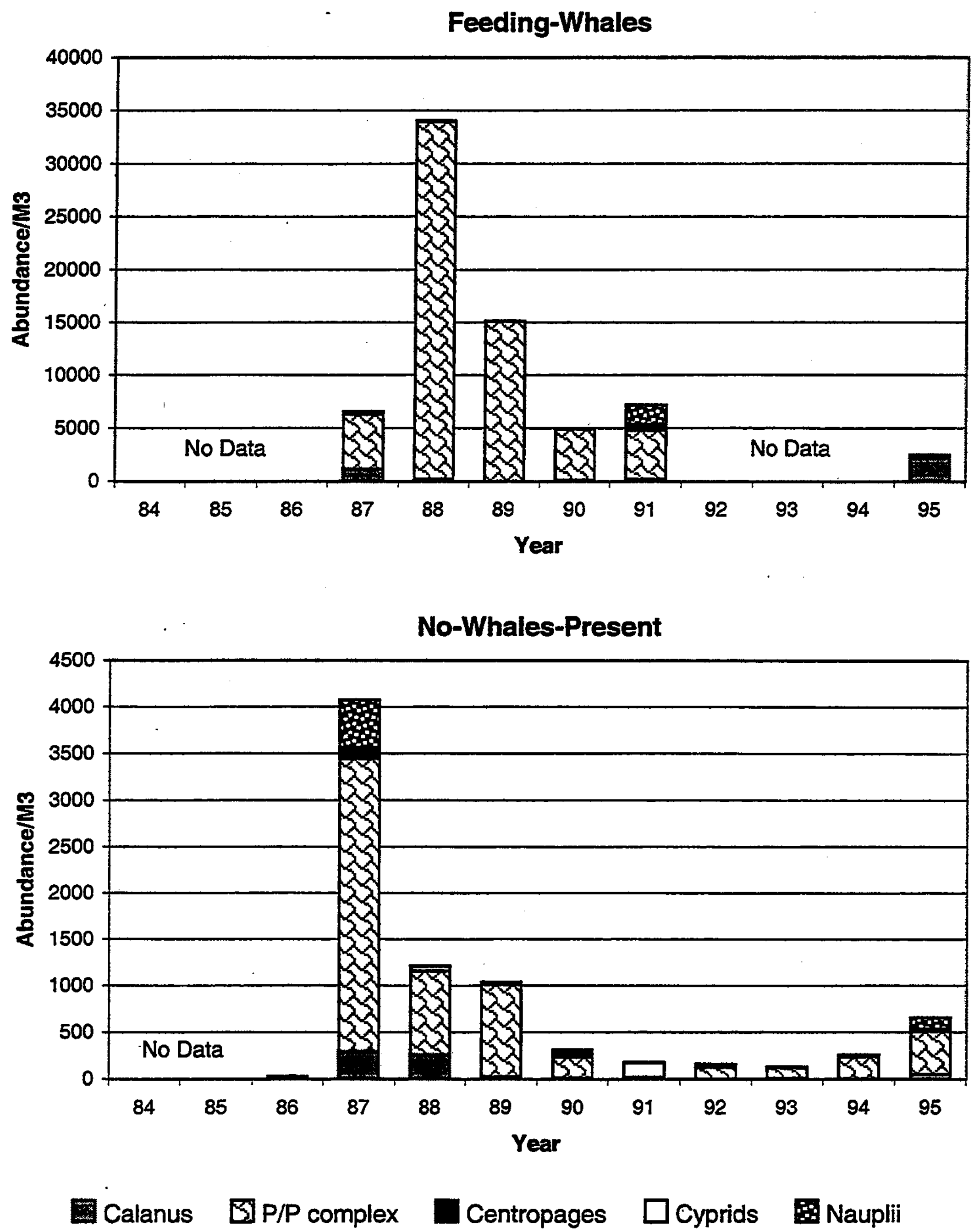



**FIGURE 3-7**
**Average annual zooplankton abundance (Janury - June) in Cape Cod Bay**
**1984-1995 CCS feeding-whale and no-whale-present samples**




*note scale difference

**FIGURE 3-8**
Annual variation in dominant zooplankton taxa during March 1984-1995 CCS feeding-whale and no-whale-present samples

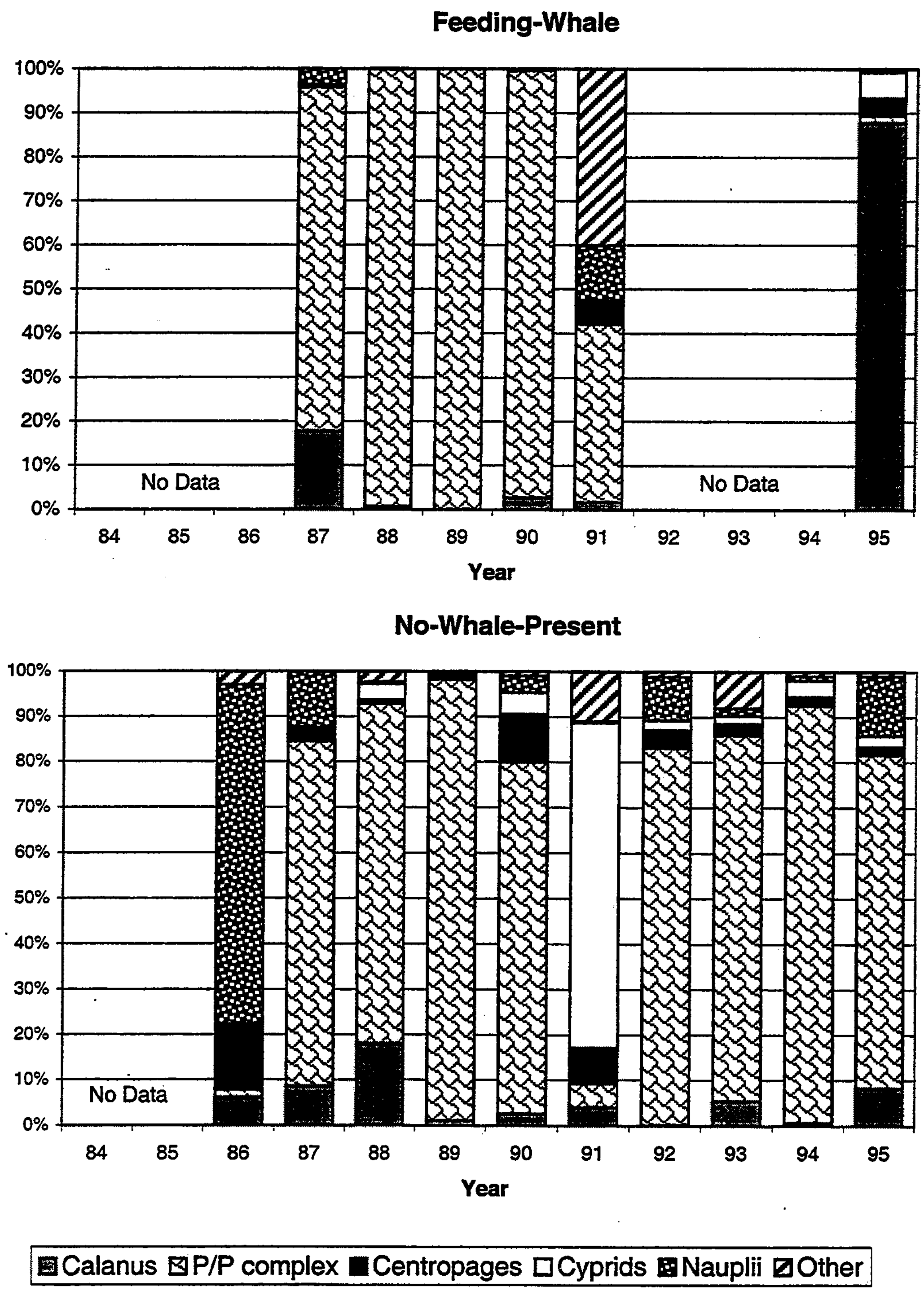



**FIGURE 3-9**

Percent contribution of dominant taxa during March
1984-1995 CCS feeding-whale and no-whale-present samples

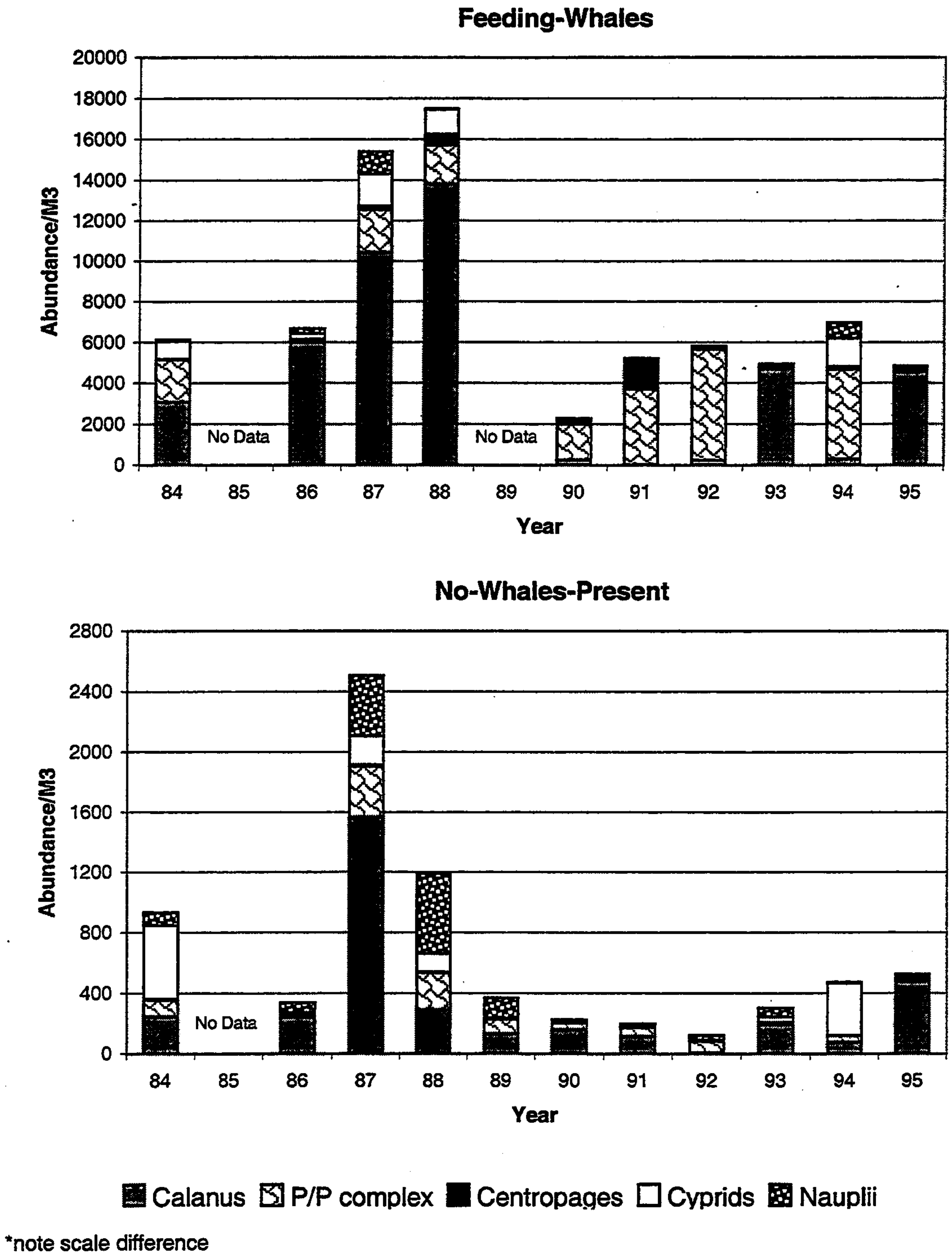



**FIGURE 3-10**
Annual variation in dominant zooplankton taxa during April
1984-1995 CCS feeding-whale and no-whale-present samples

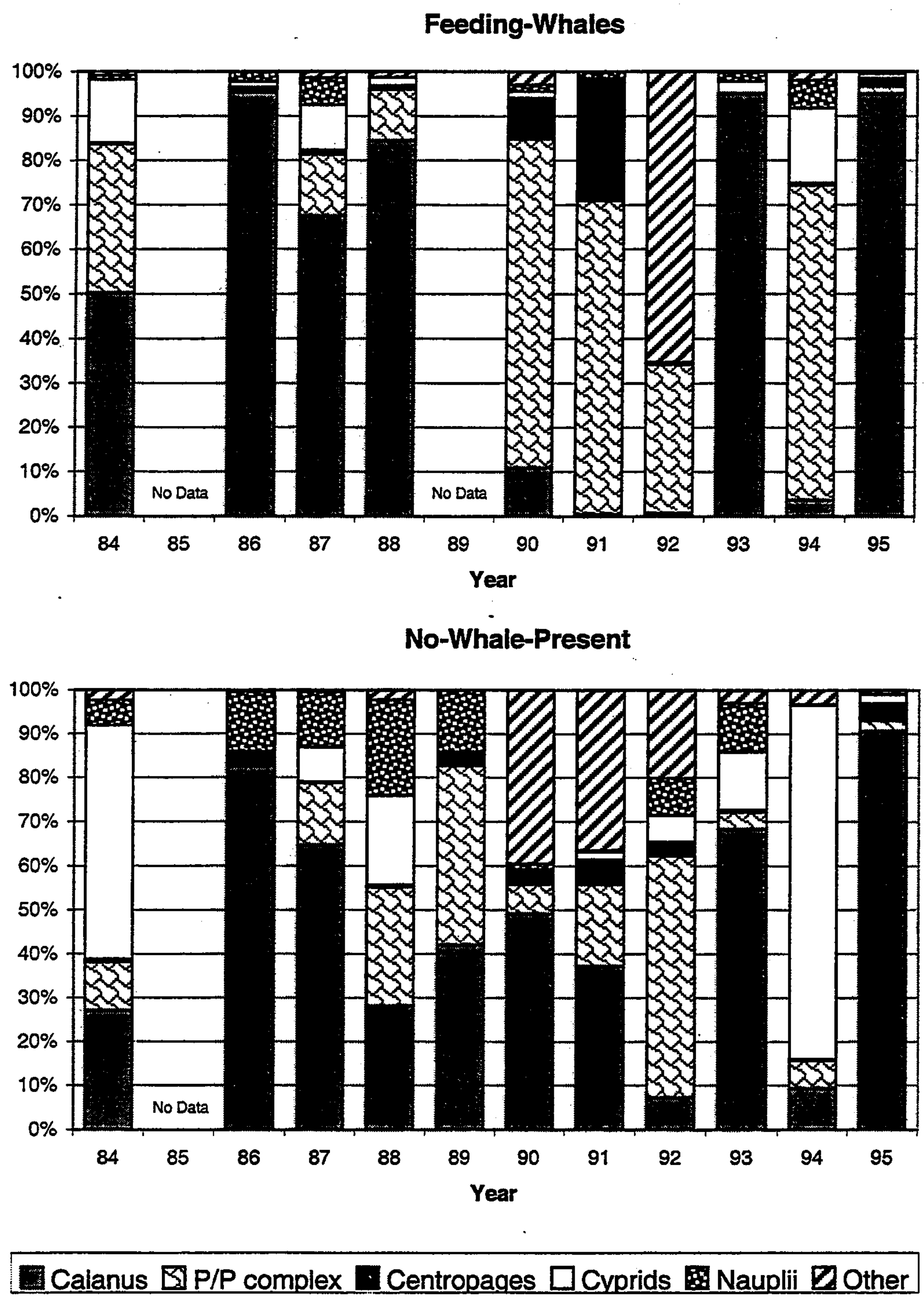



**FIGURE 3-11**
Percent contribution of dominant taxa during April
1984-1995 CCS feeding-whale and no-whale-present samples

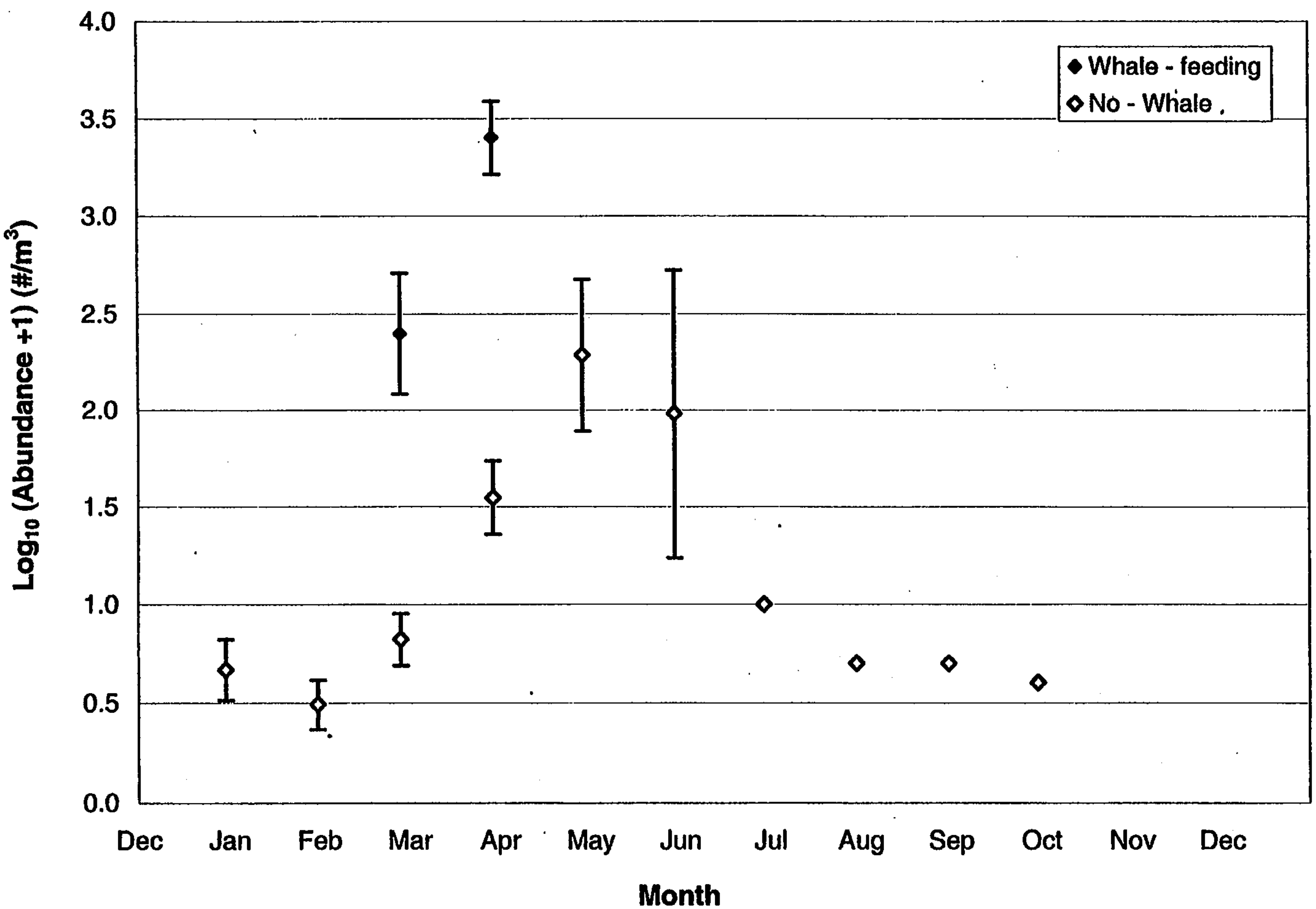



**FIGURE 3-12**
**Monthly mean abundance with 95% confidence intervals for *Calanus finmarchicus***
**CCS Cape Cod Bay survey results (1984-1995)**

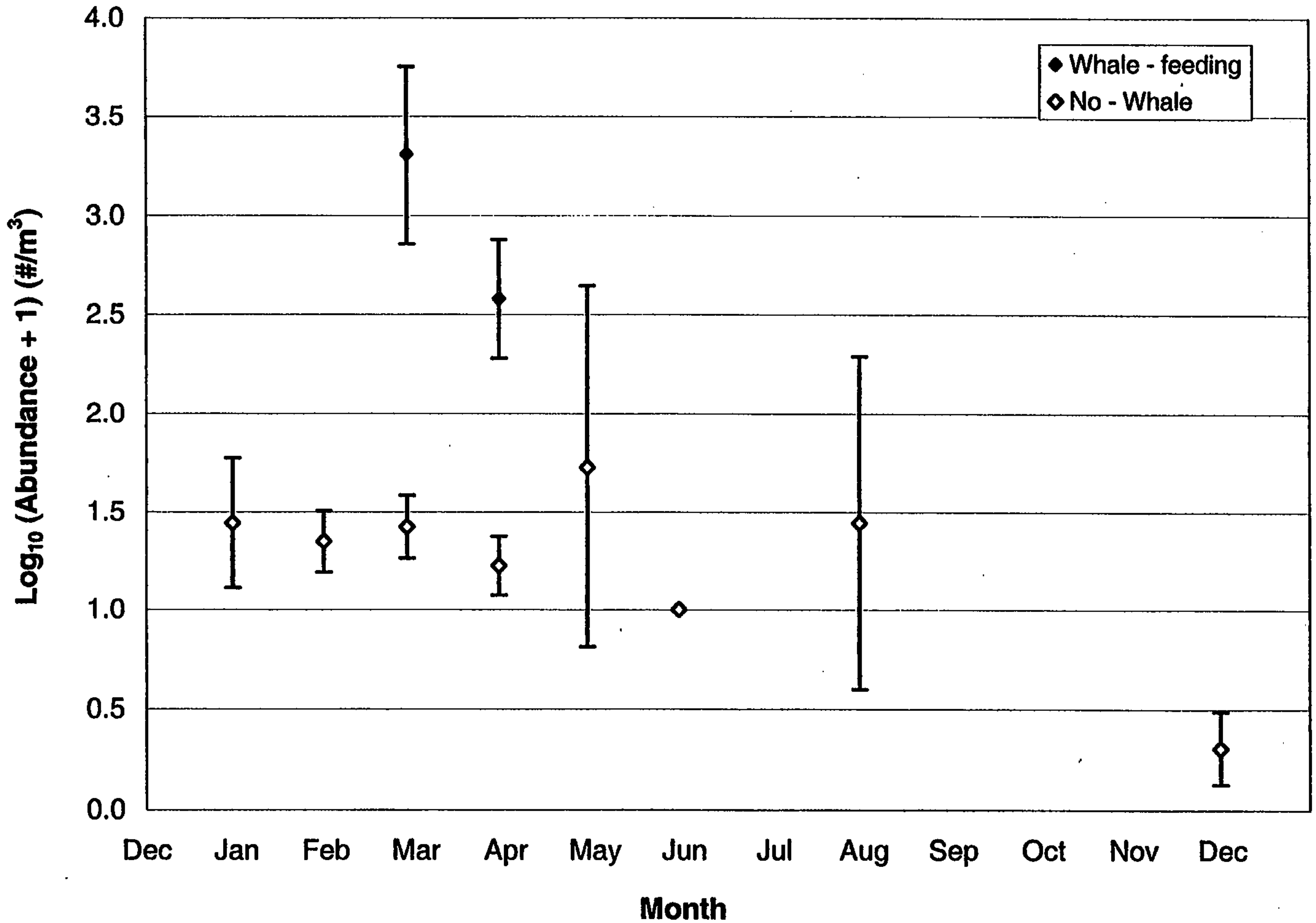



**FIGURE 3-13**
**Monthly mean abundance with 95% confidence intervals for *Paracalanus/Pseudocalanus***
**CCS Cape Cod Bay survey results (1984-1995)**

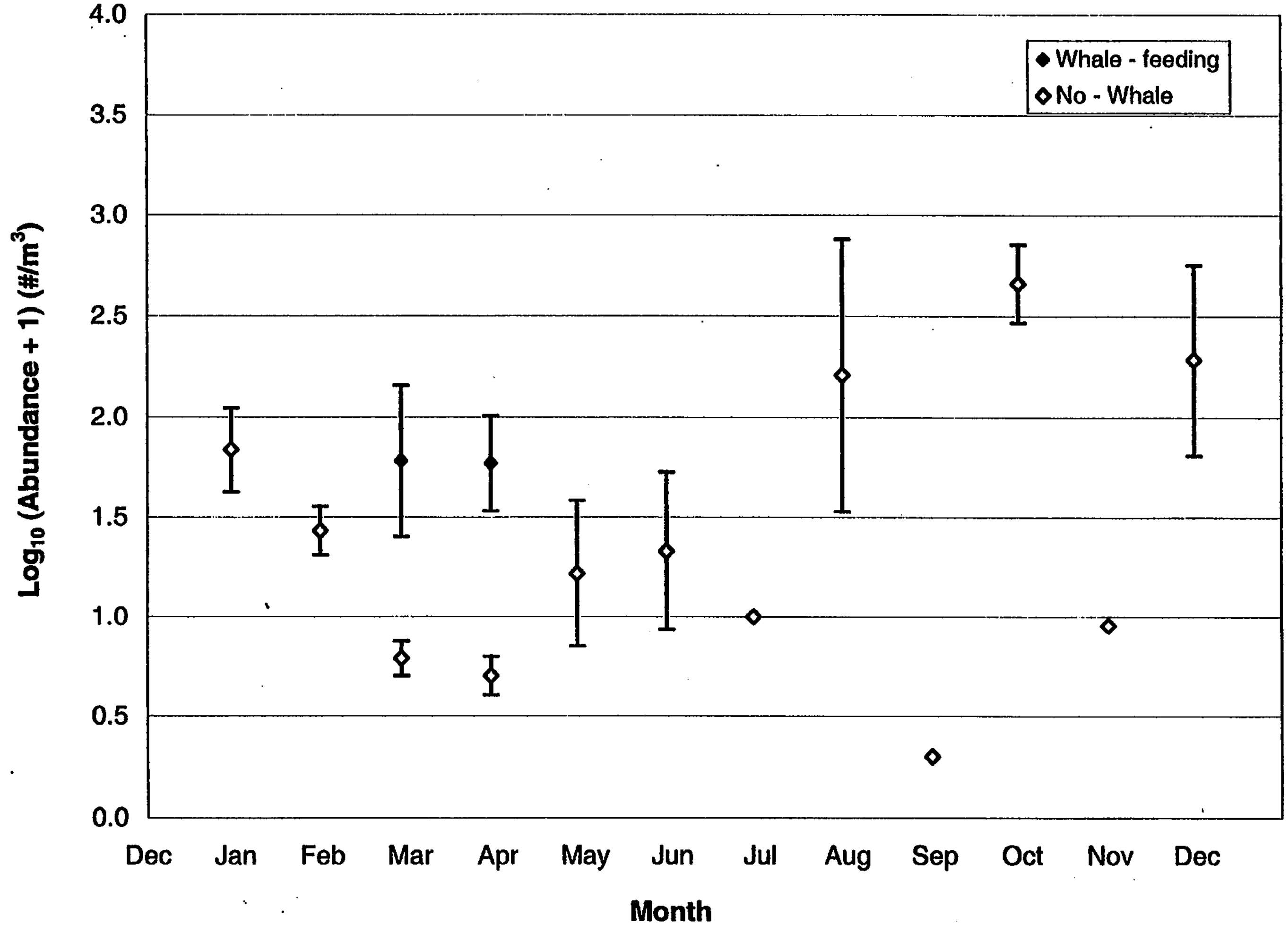



**FIGURE 3-14**
**Monthly mean abundance with 95% confidence intervals for *Centropages* sp.**
**CCS Cape Cod Bay survey results (1984-1995)**

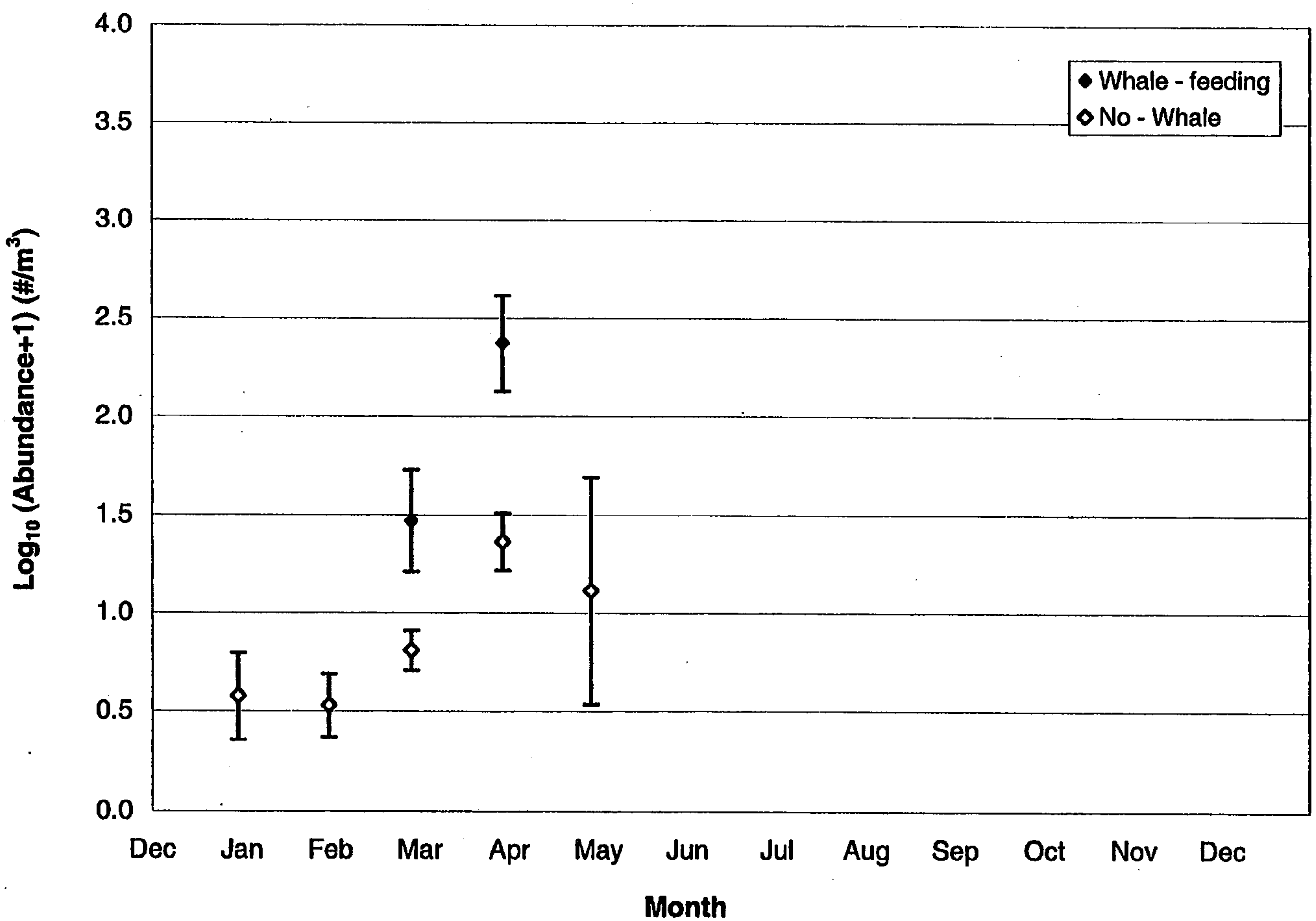



**FIGURE 3-15**
**Monthly mean abundance with 95% confidence intervals for Cyprids**
**CCS Cape Cod Bay survey results (1984-1995)**

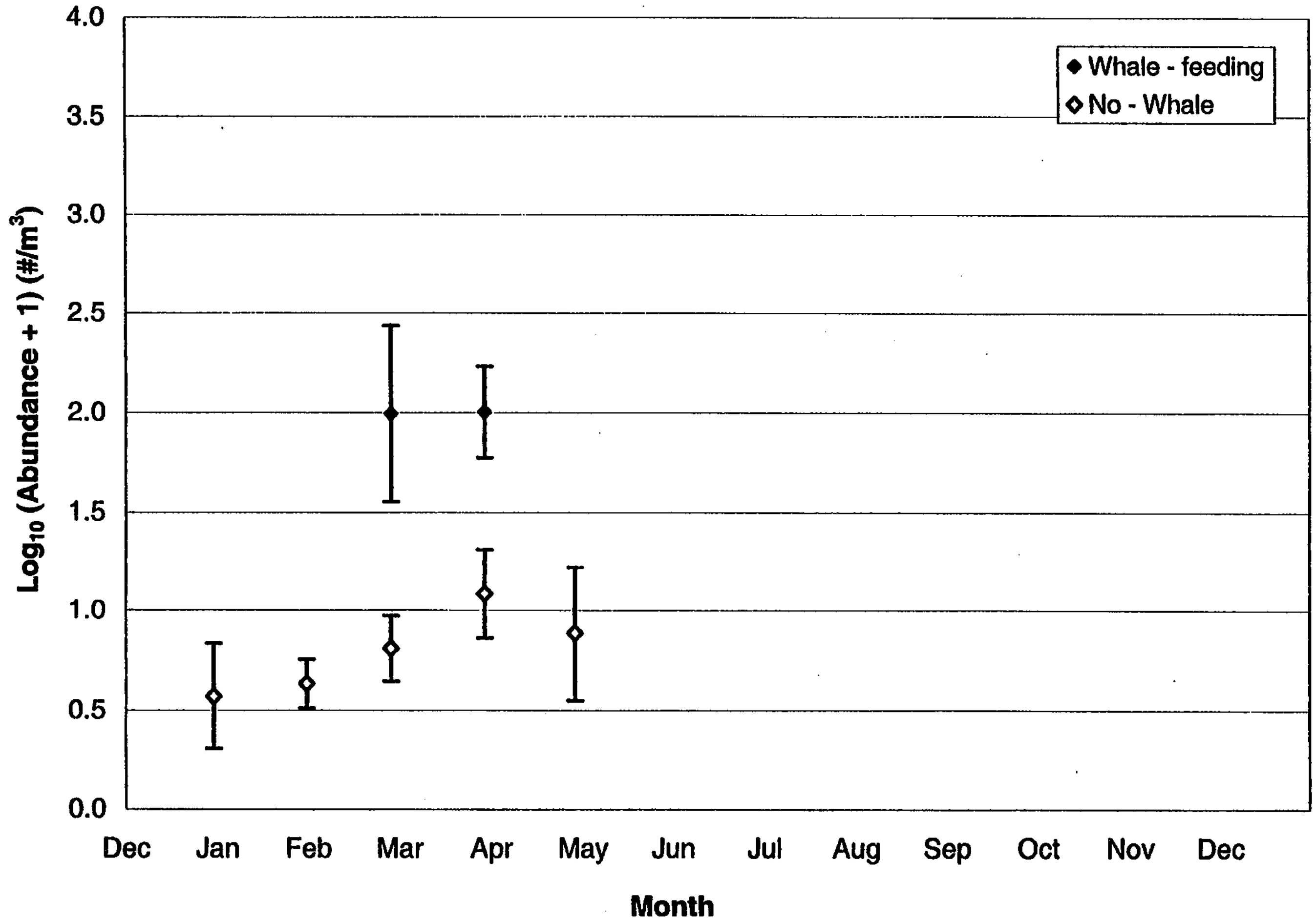



**FIGURE 3-16**
**Monthly mean abundance with 95% confidence intervals for Nauplii**
**CCS Cape Cod Bay survey results (1984-1995)**

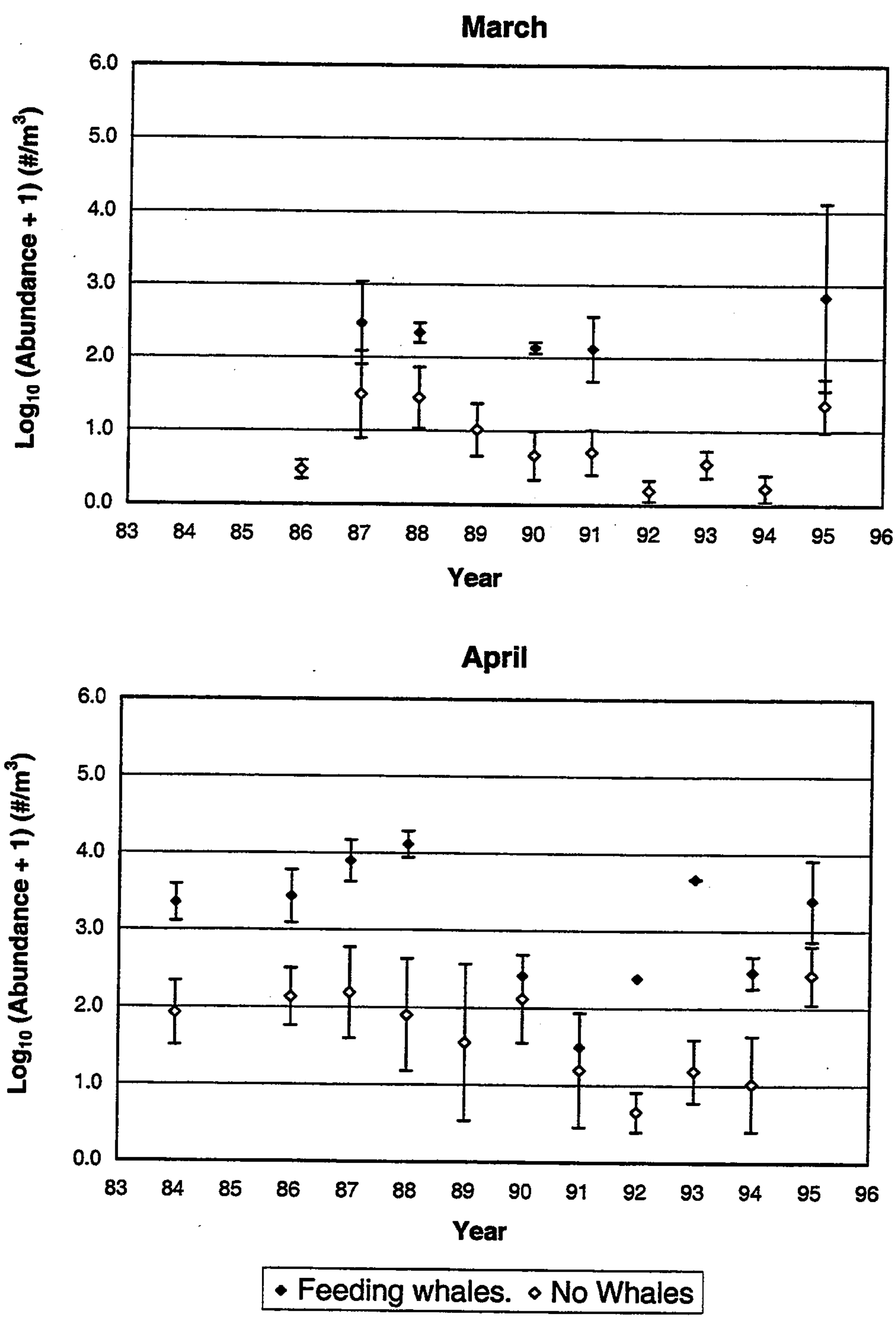



**FIGURE 3-17**
**Mean abundance with 95% confidence intervals for *Calanus finmarchicus* during March and April CCS Cape Cod Bay survey results (1984-1995)**

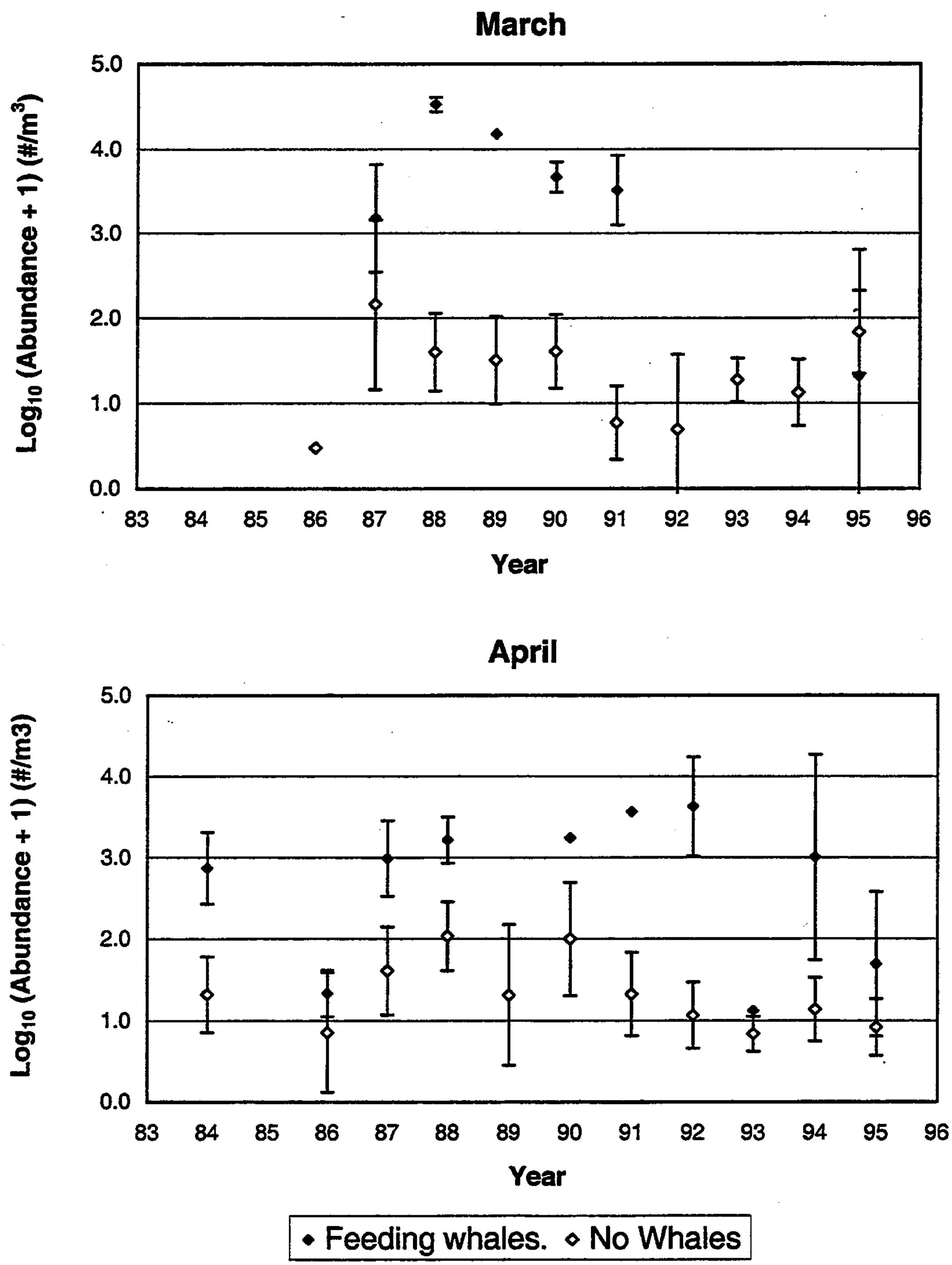
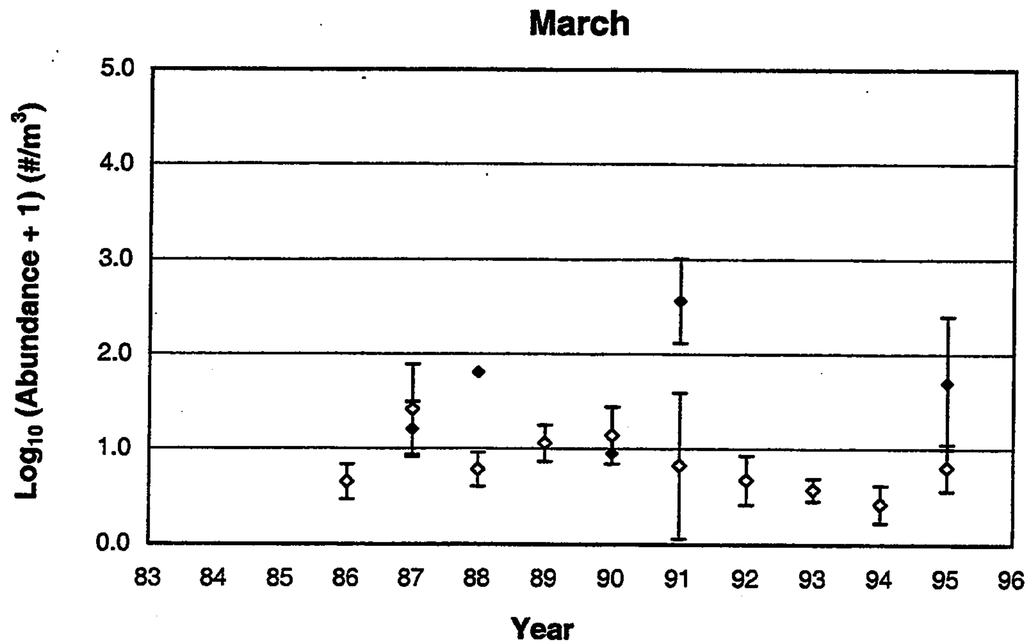



**FIGURE 3-18**
**Mean abundance with 95% confidence intervals for *Paracalanus/Pseudocalanus* during March and April CCS Cape Cod Bay survey results (1984-1995)**



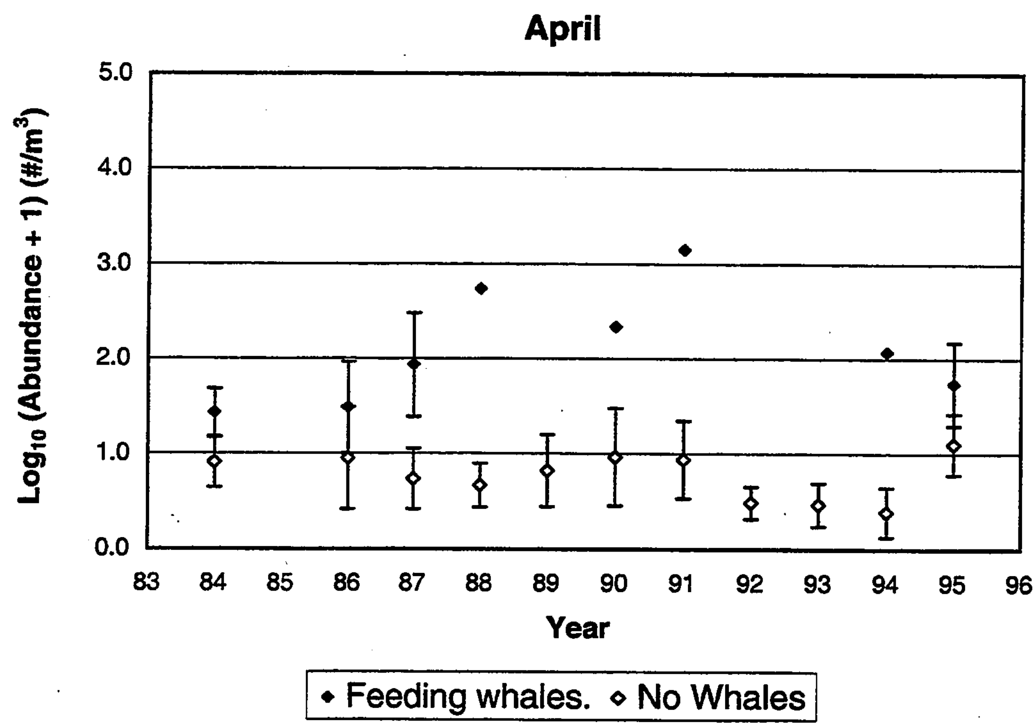




**FIGURE 3-19**
**Mean abundance with 95% confidence intervals for *Centropages* sp. March and April CCS Cape Cod Bay survey results (1984-1995)**

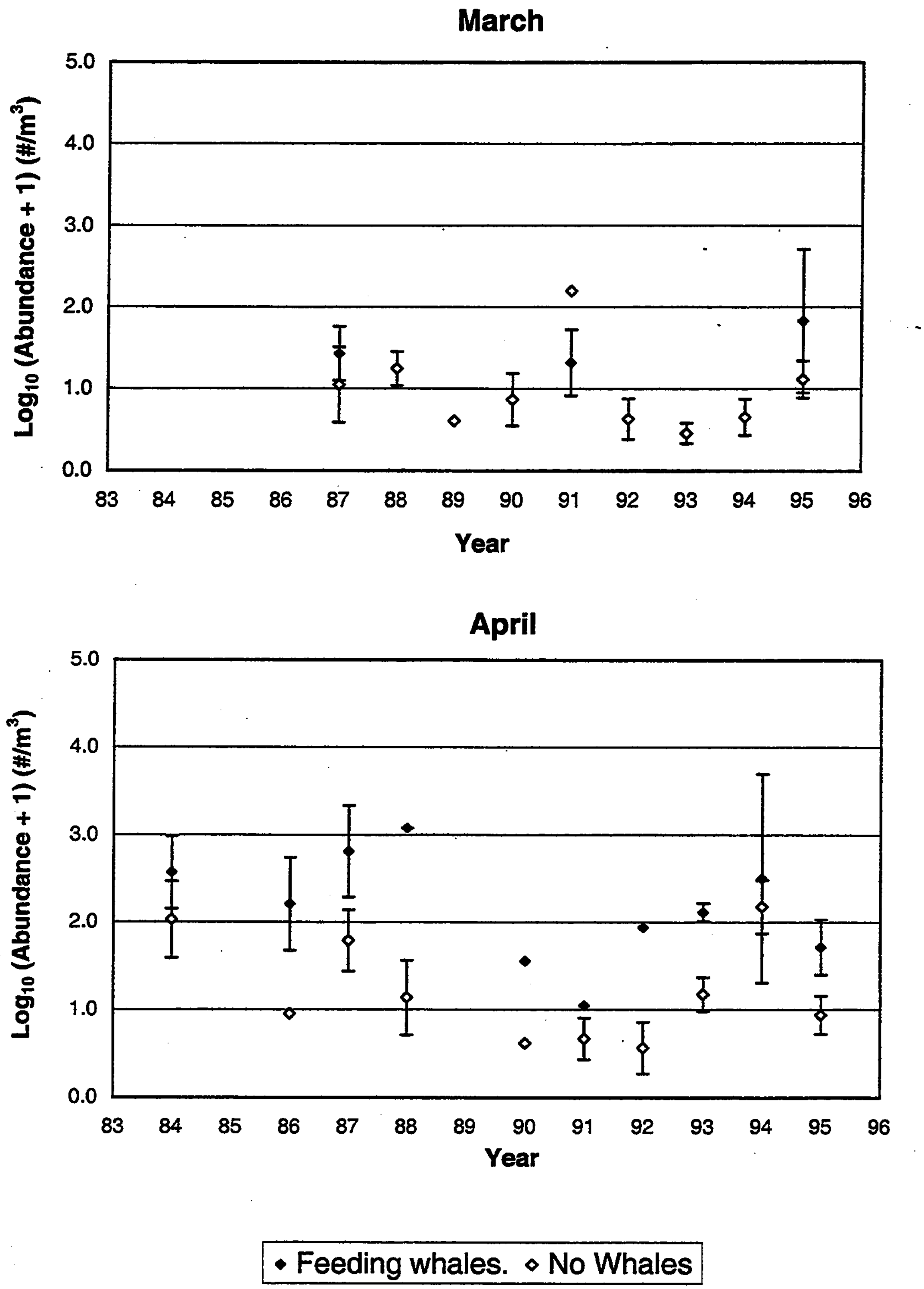



**FIGURE 3-20**
**Mean abundance with 95% confidence intervals for Cyprids during March and April**
**CCS Cape Cod Bay survey results (1984-1995)**

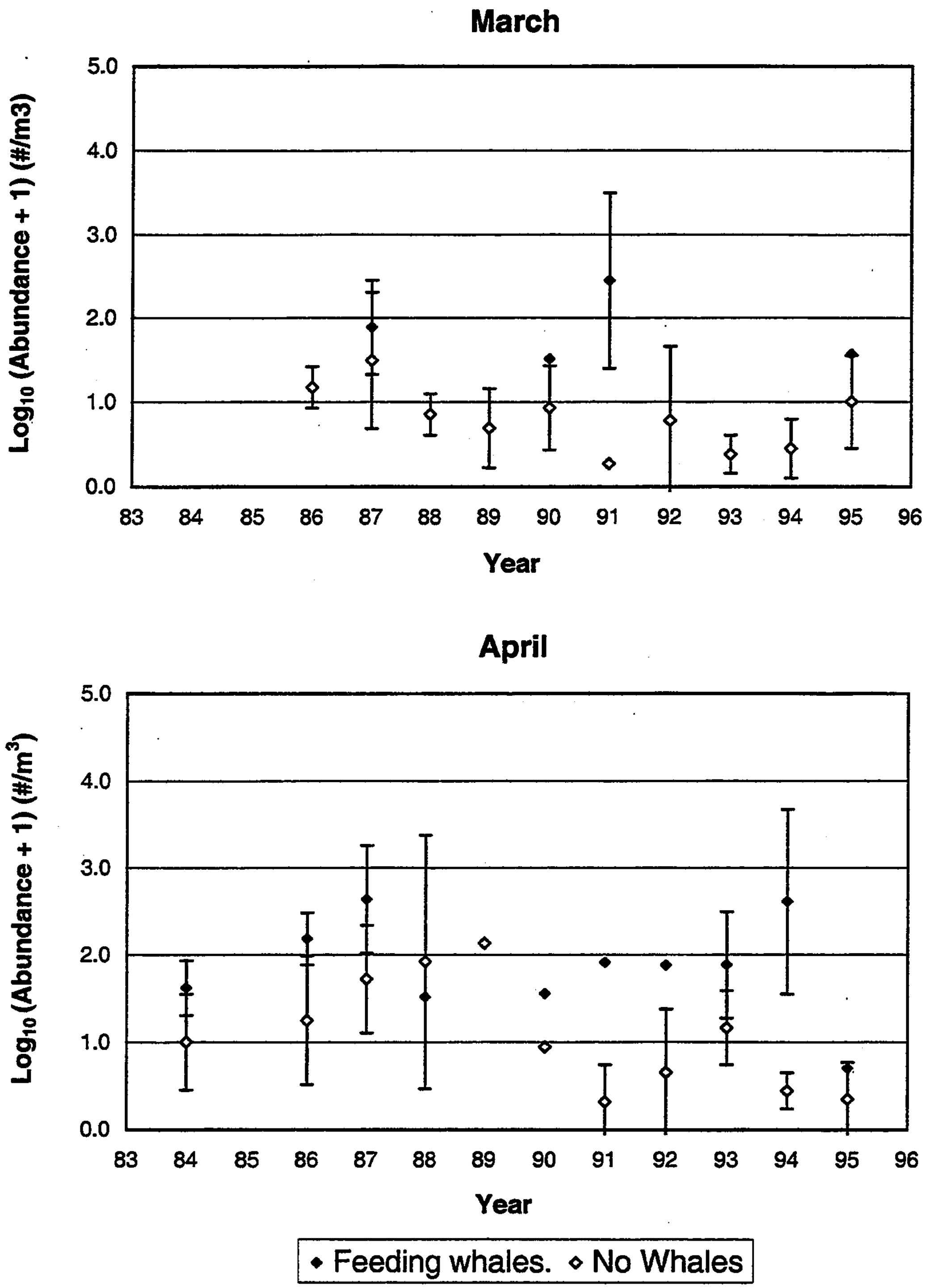



**FIGURE 3-21**
**Mean abundance with 95% confidence intervals for Nauplii during March and April CCS Cape Cod Bay survey results (1984-1995)**

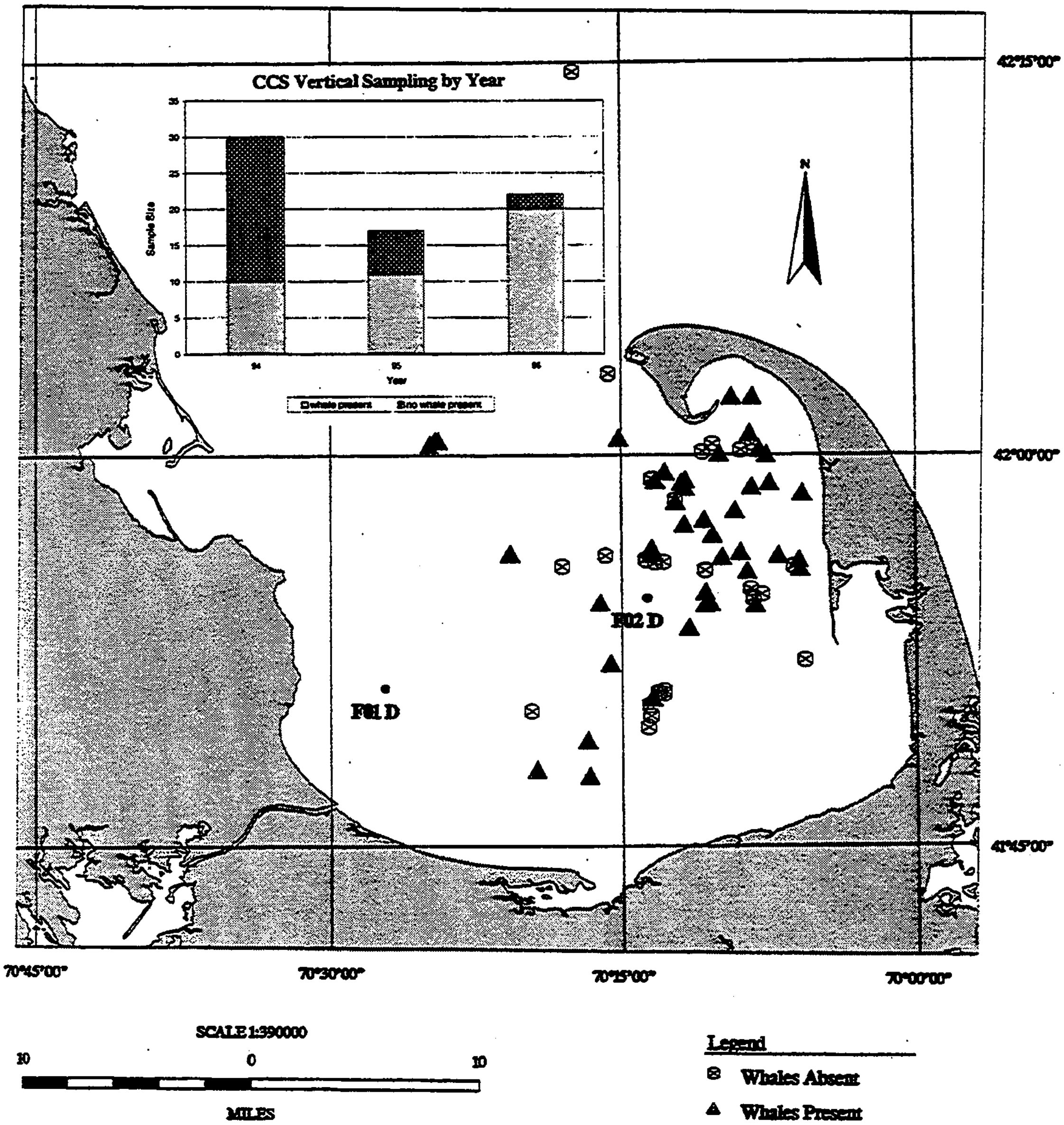



**FIGURE 3-22**
**1994-1996 CCS Vertical Profile Sampling Locations**
**Relative to MWRA Sampling Stations (F01 and F02)**

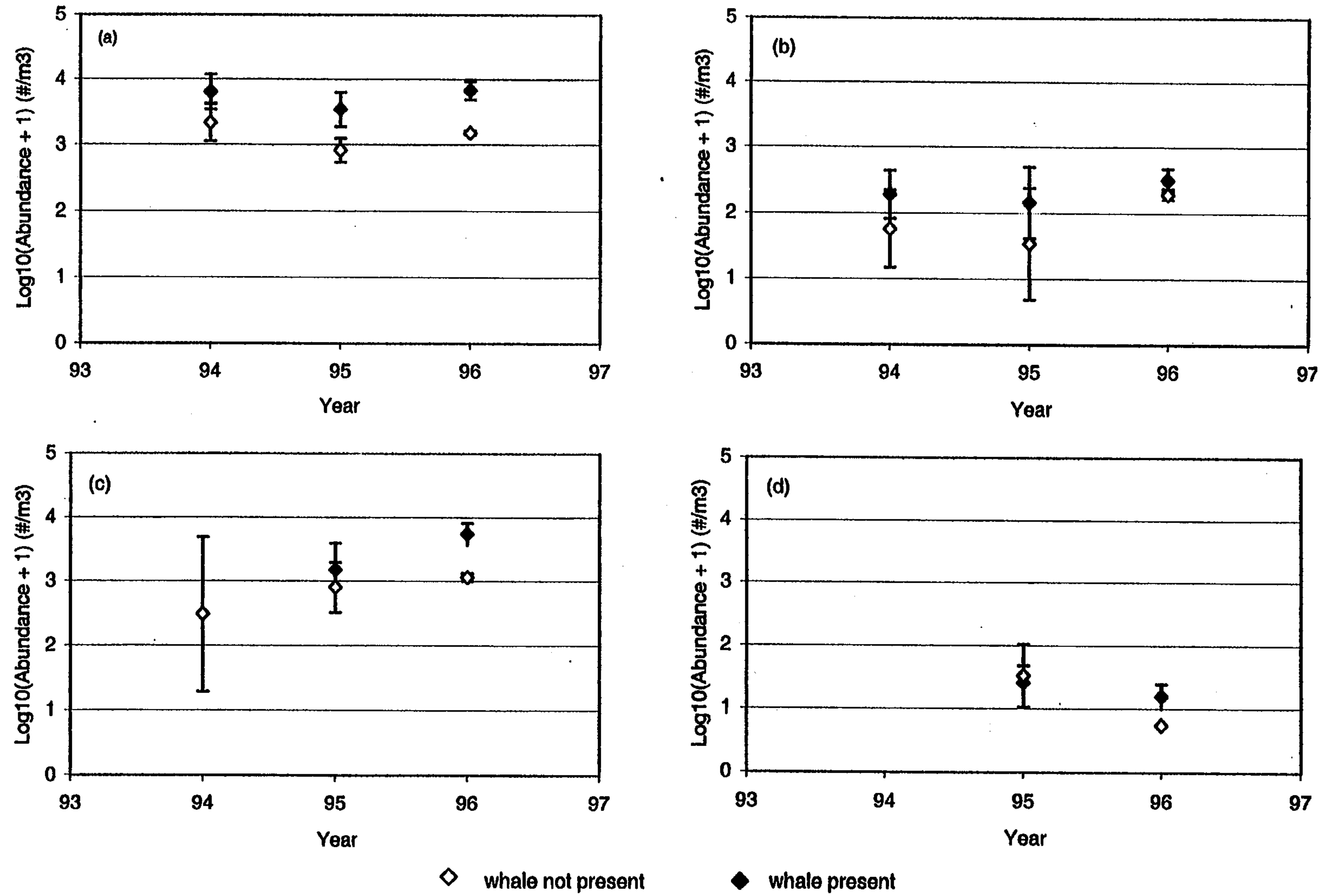



**FIGURE 3-23**
**Mean abundance with 95% confidence intervals for a) total zooplankton, b) *Calanus finmarchicus*, c) *Paracalanus/Pseudocalanus*, and d) *Centropages* sp**
**CCS vertical survey results (1994-1996)**

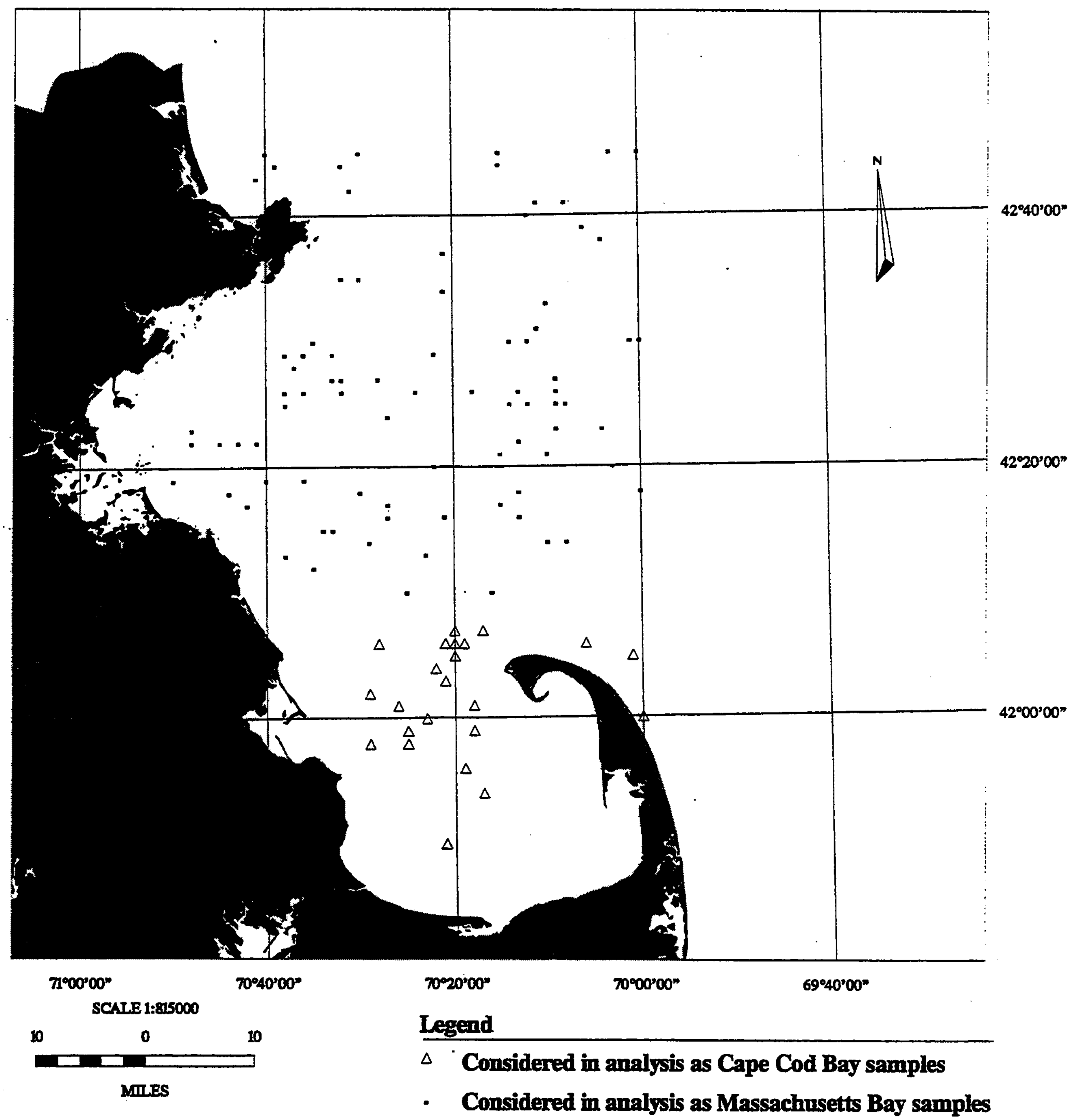



**FIGURE 3-24**
**MARMAP Sampling Locations 1977-1987**

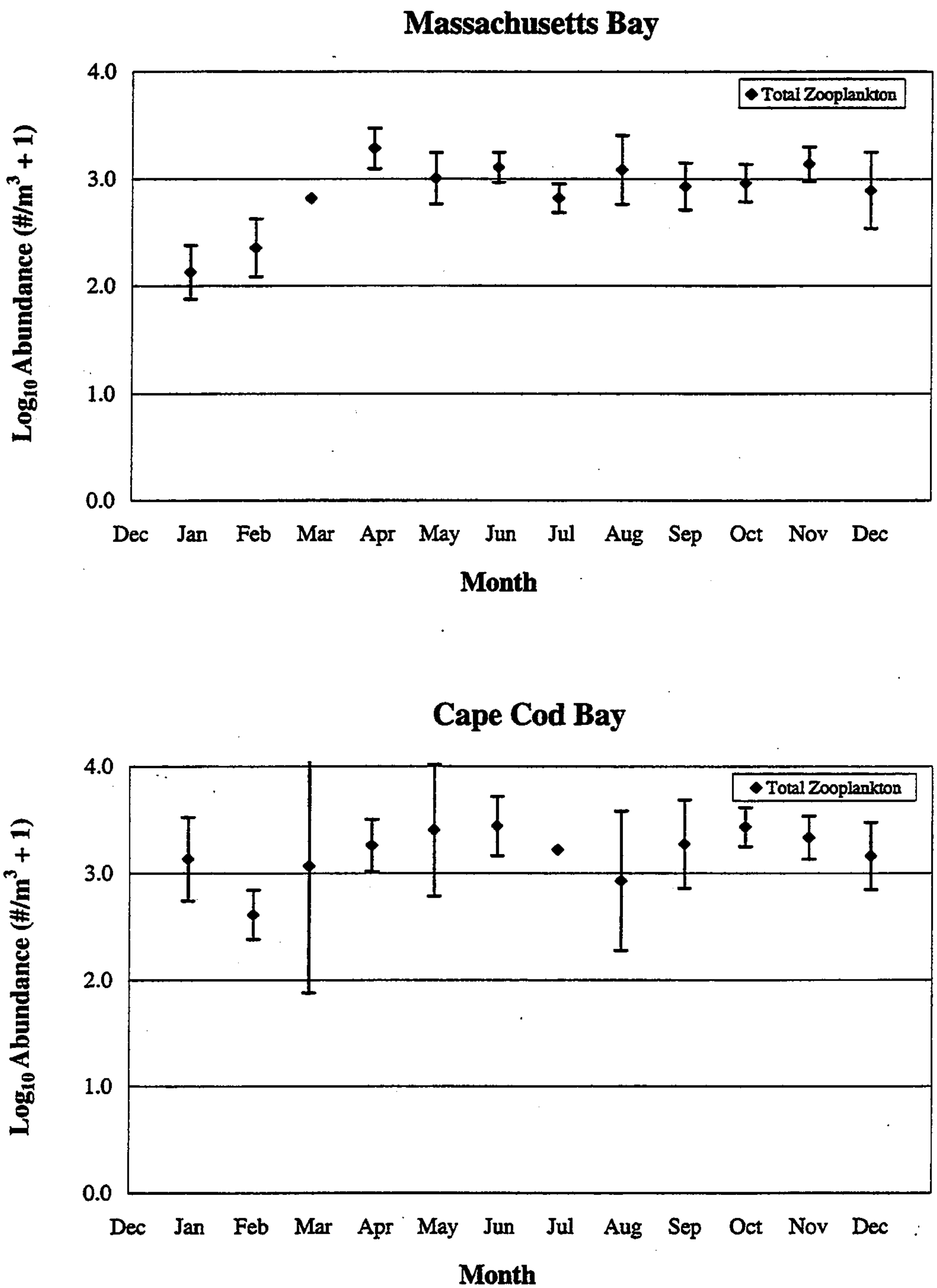



**FIGURE 3-25**
**Total Zooplankton - monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**

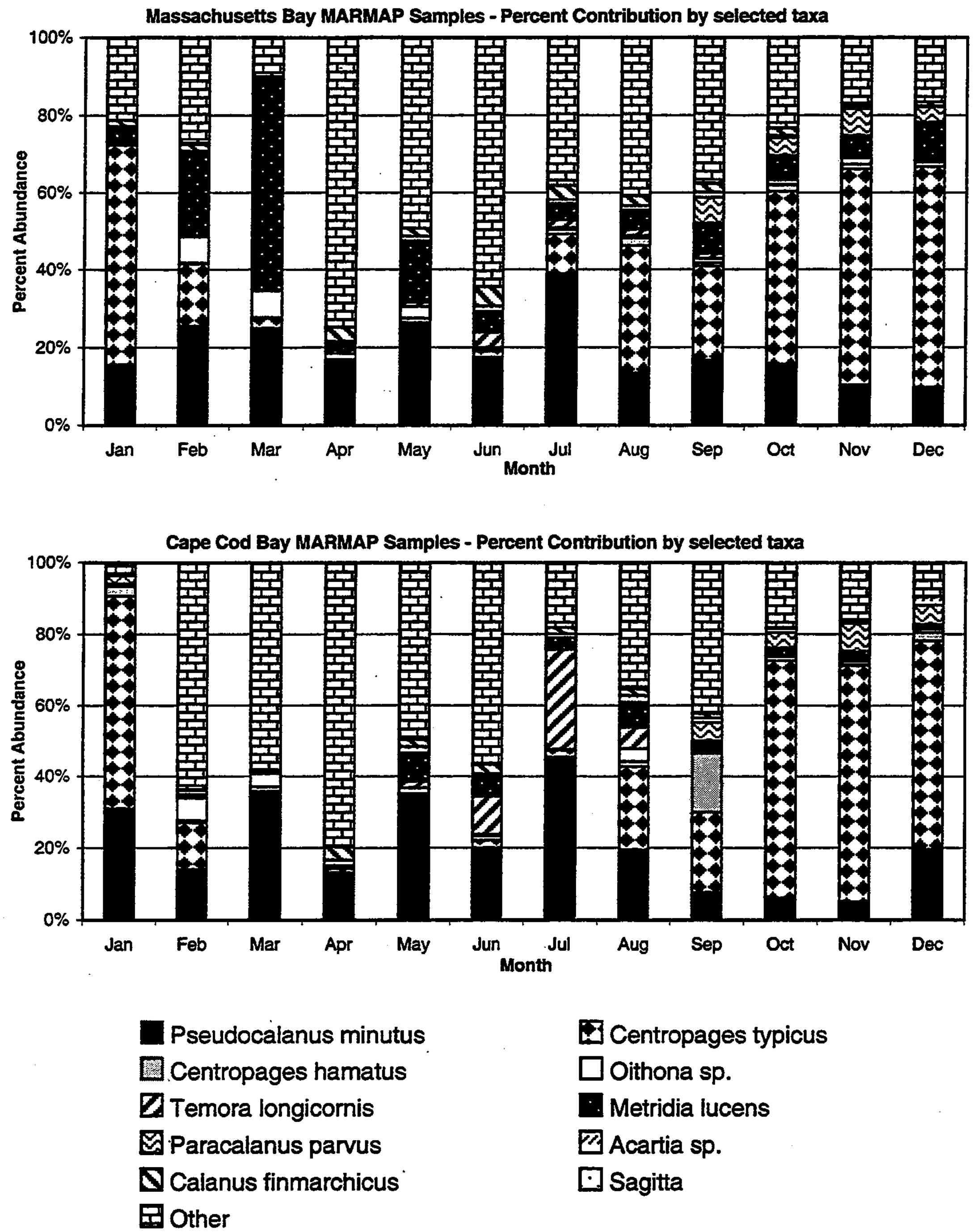



**FIGURE 3-26**
Percent contribution of all taxa in Massachusetts and Cape Cod Bays
MARMAP survey results

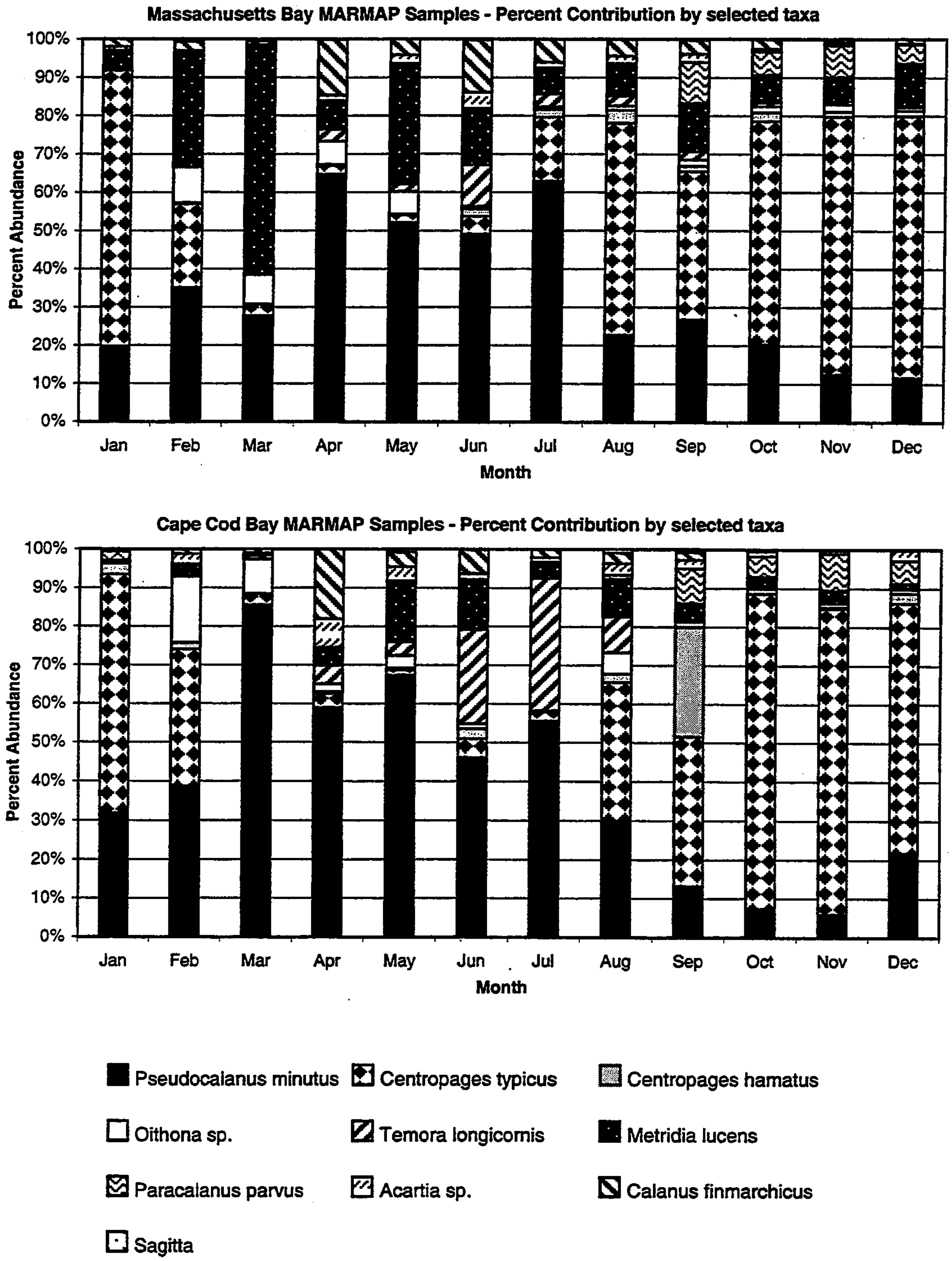
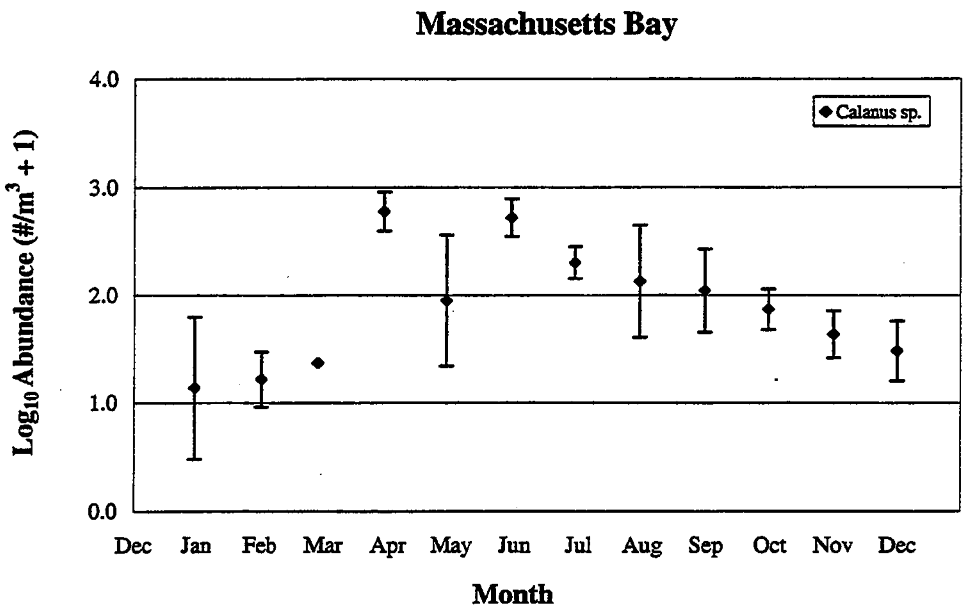



**FIGURE 3-27**

**Percent contribution of selected taxa for Massachusetts and Cape Cod Bays MARMAP survey results**



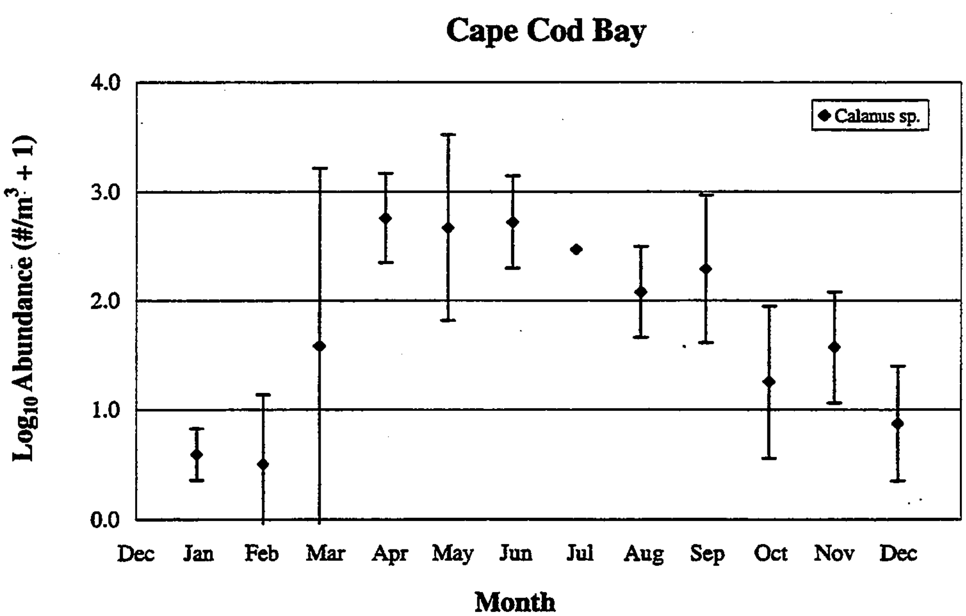




**FIGURE 3-28**
***Calanus finmarchicus*** **- monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**

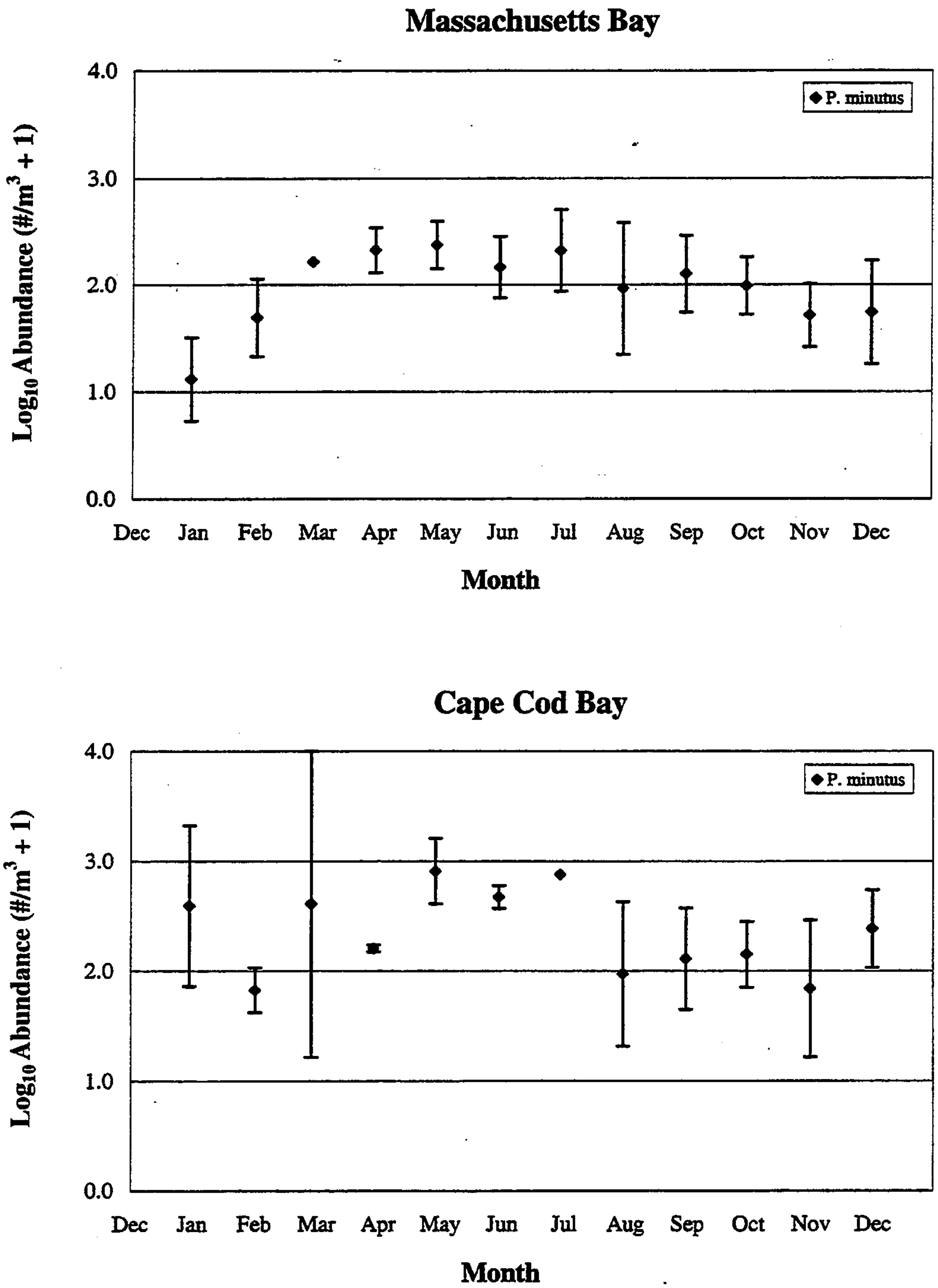
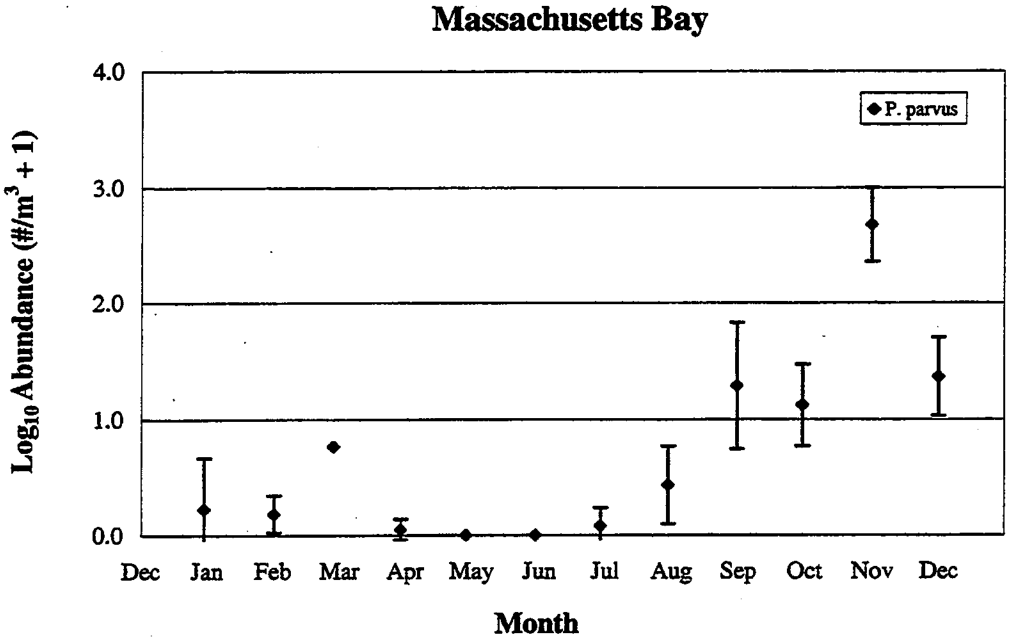



**FIGURE 3-29**
***Pseudocalanus minutus*** **- monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**



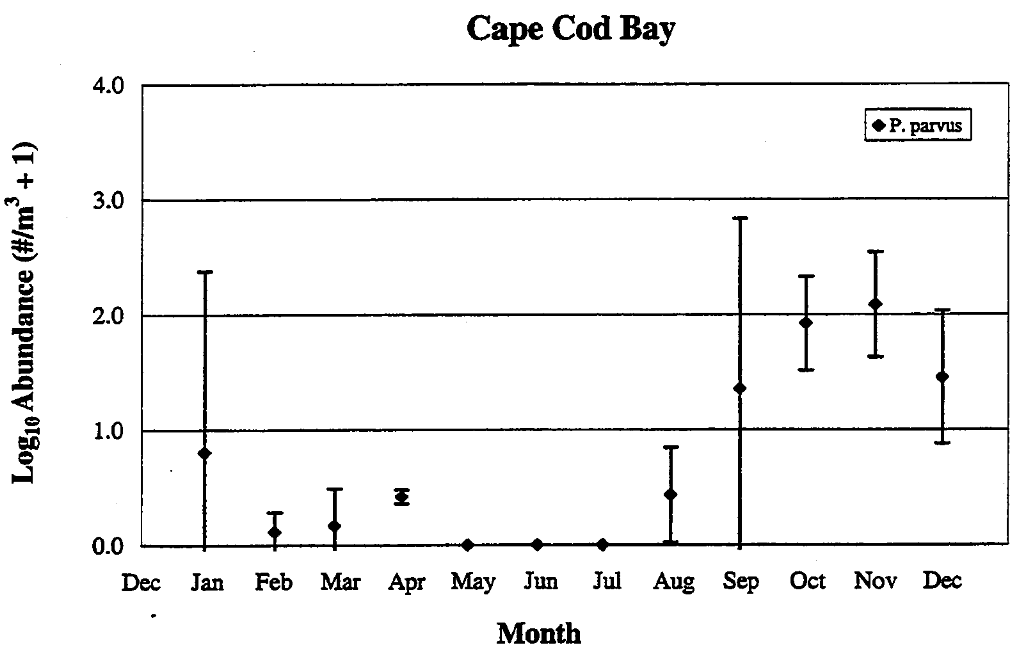
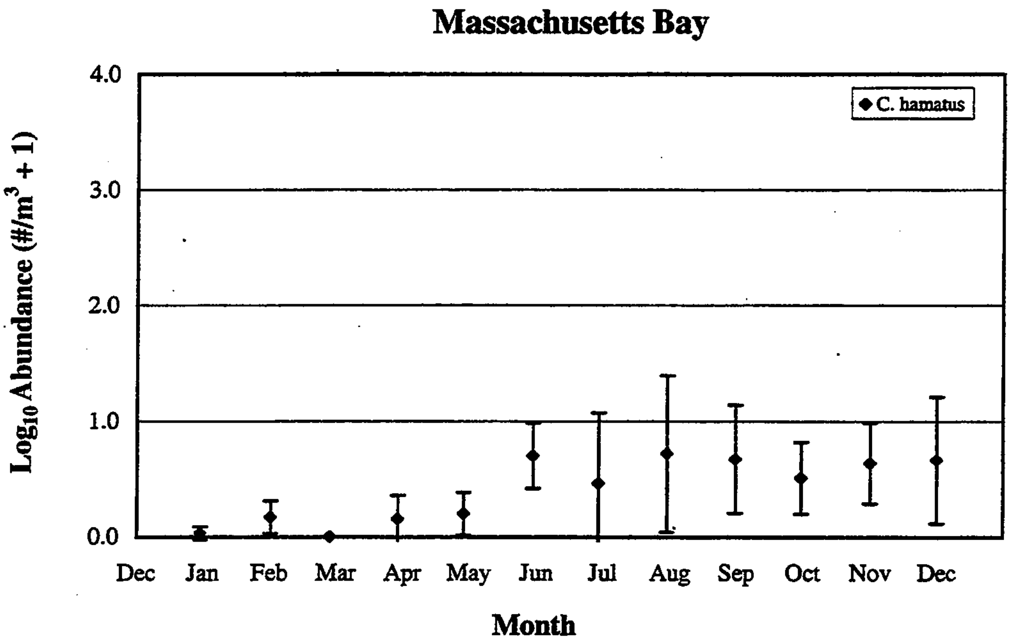




**FIGURE 3-30**
***Paracalanus parvus* - monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**



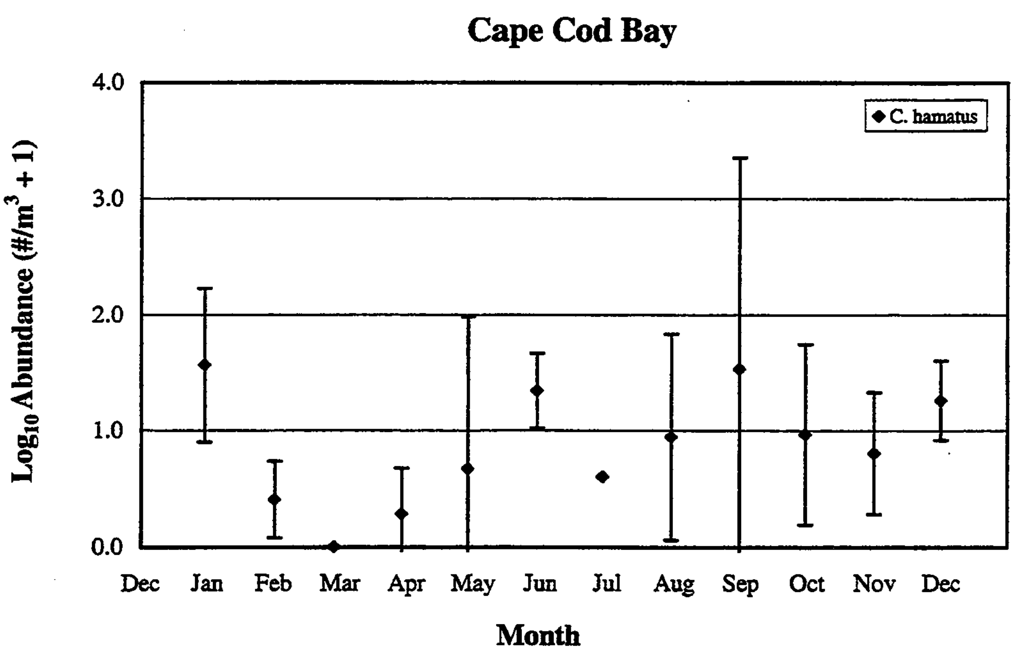
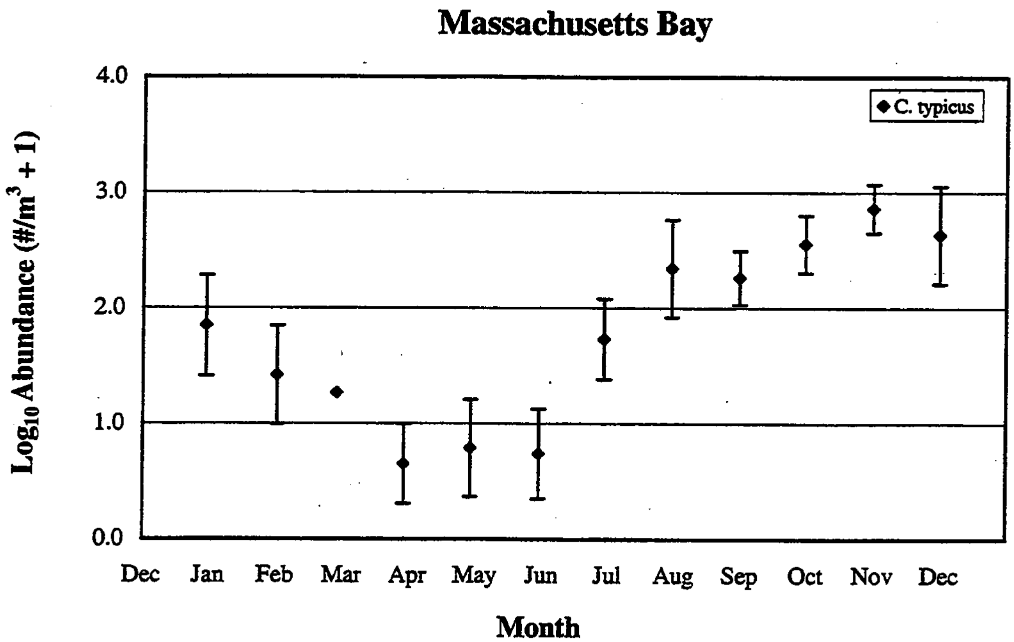




**FIGURE 3-31**
***Centropages hamatus*** **- monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**



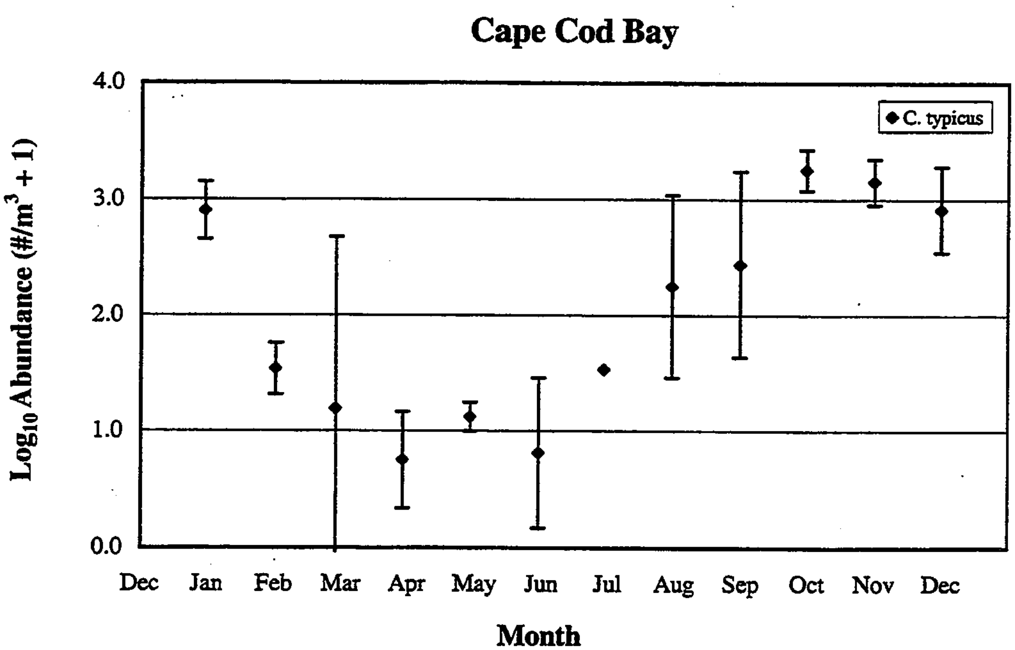
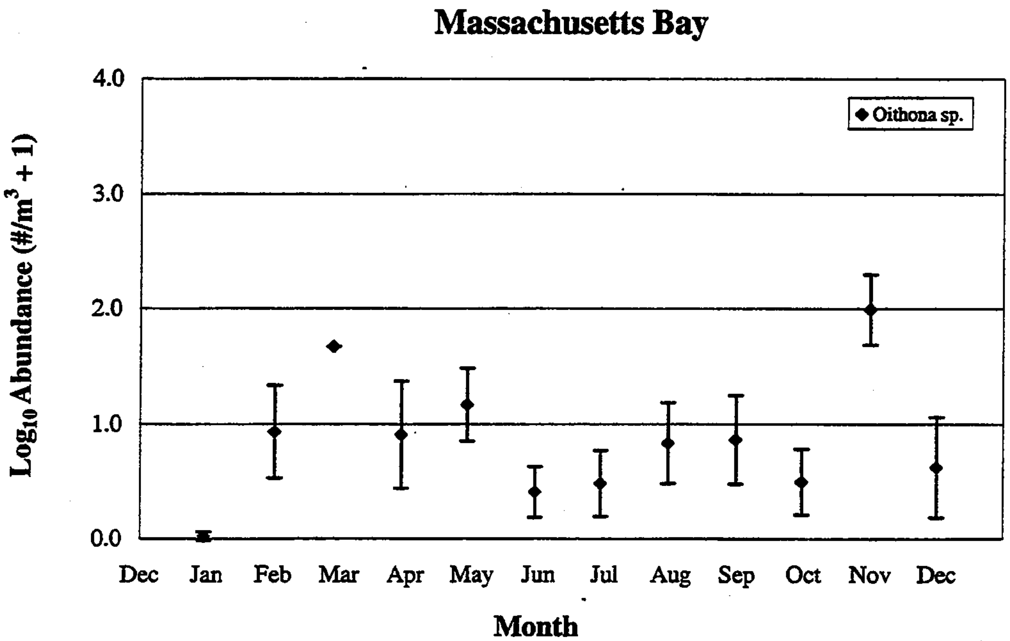




**FIGURE 3-32**
***Centropages typicus*** **- monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**



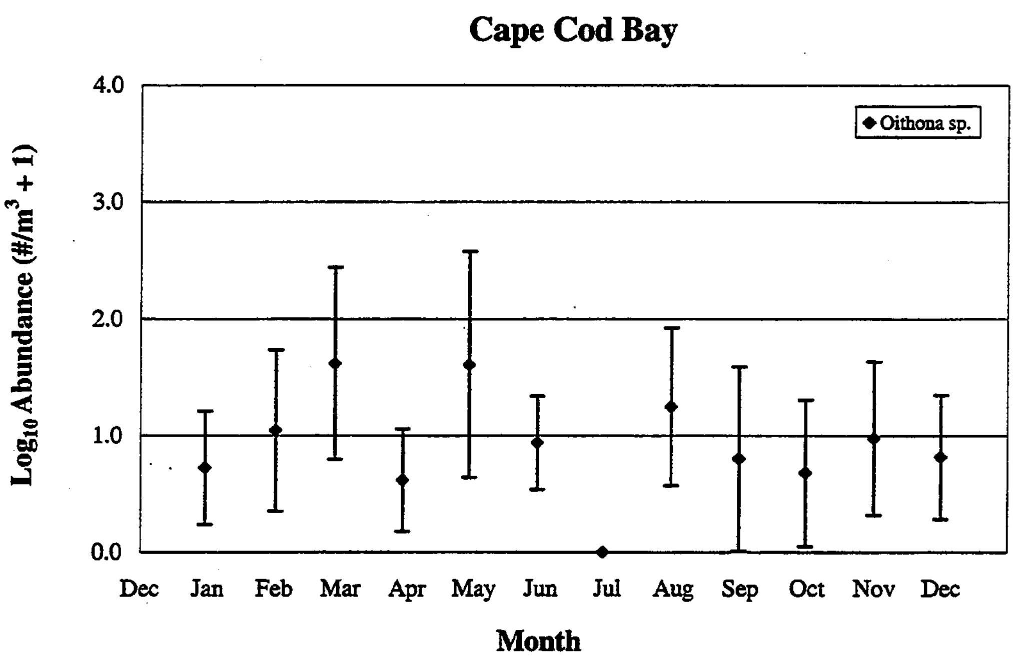
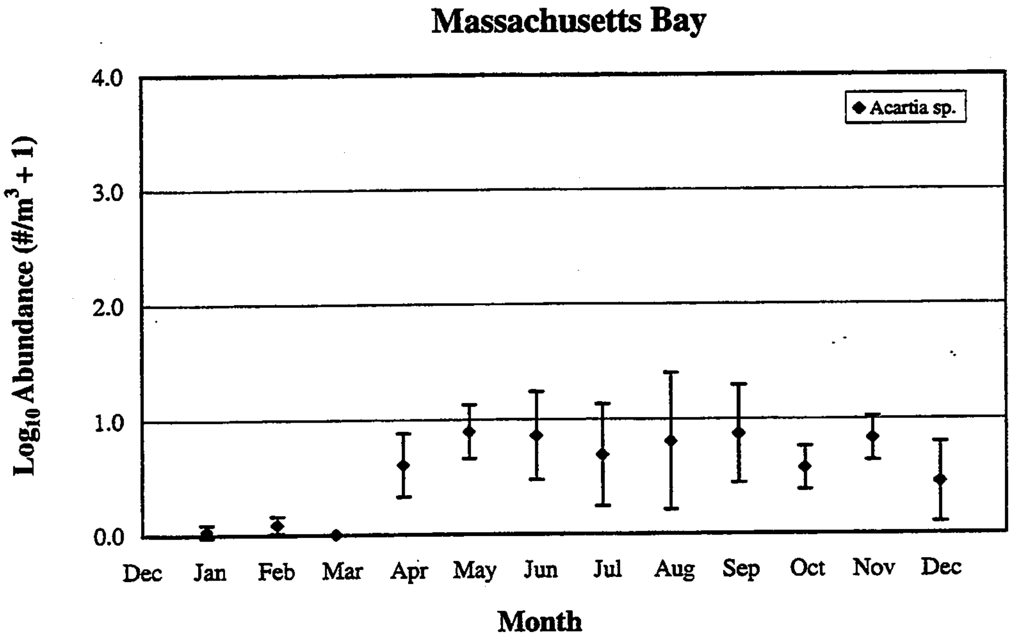




**FIGURE 3-33**
***Oithona* sp. - monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**



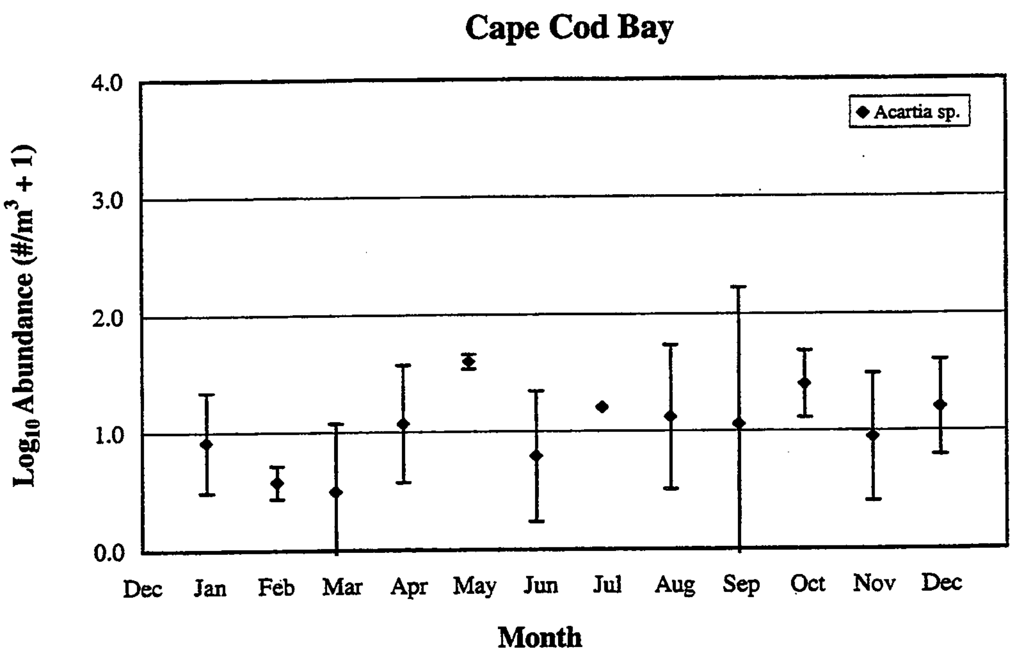




**FIGURE 3-34**
***Acartia* sp. - monthly means with 95% confidence intervals**
**MARMAP survey results - February 1977 through October 1987**

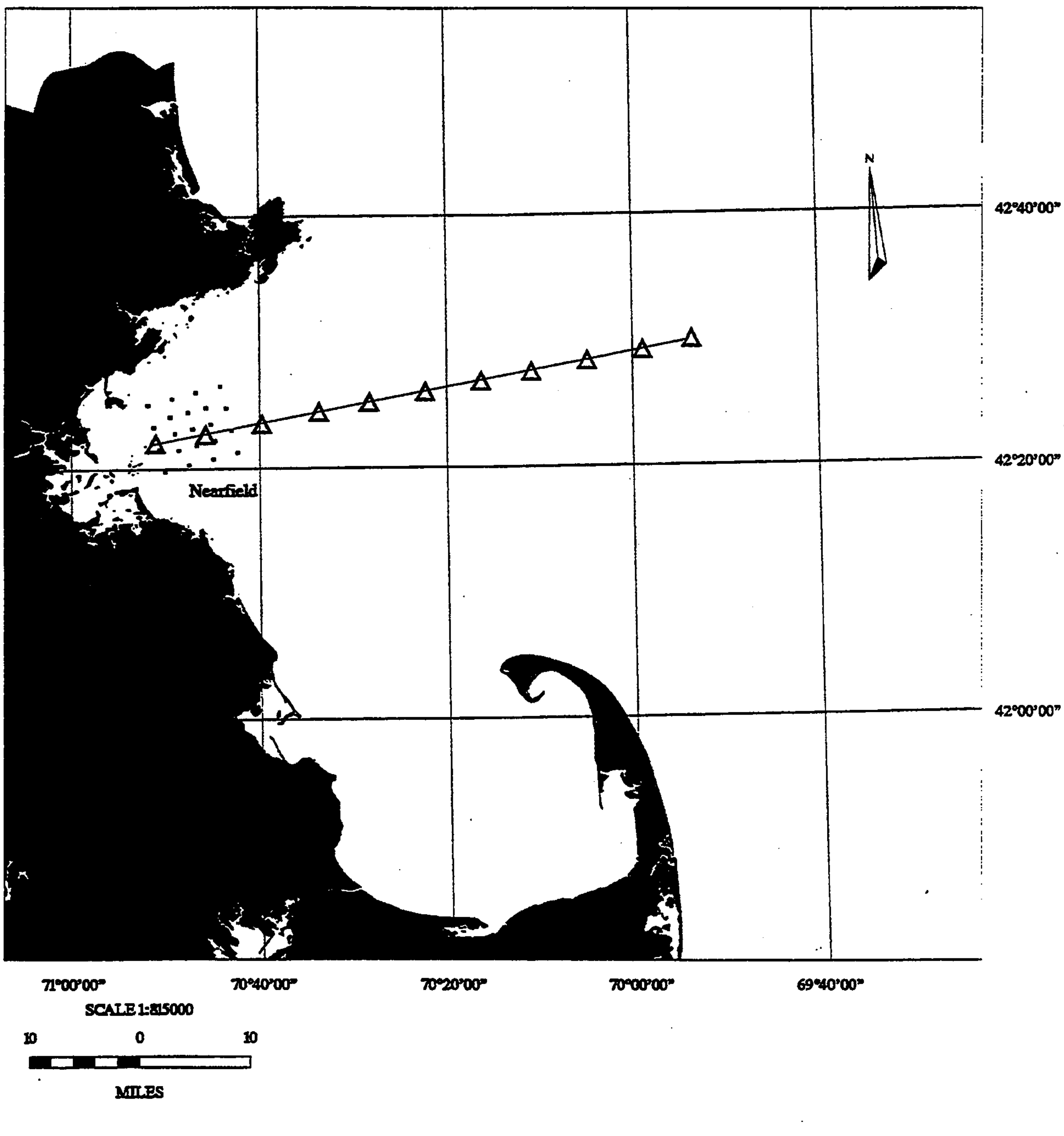



**FIGURE 3-35**
**Approximate Location of Continuous Plankton Recorder Sample Intervals**
**1961-1990**

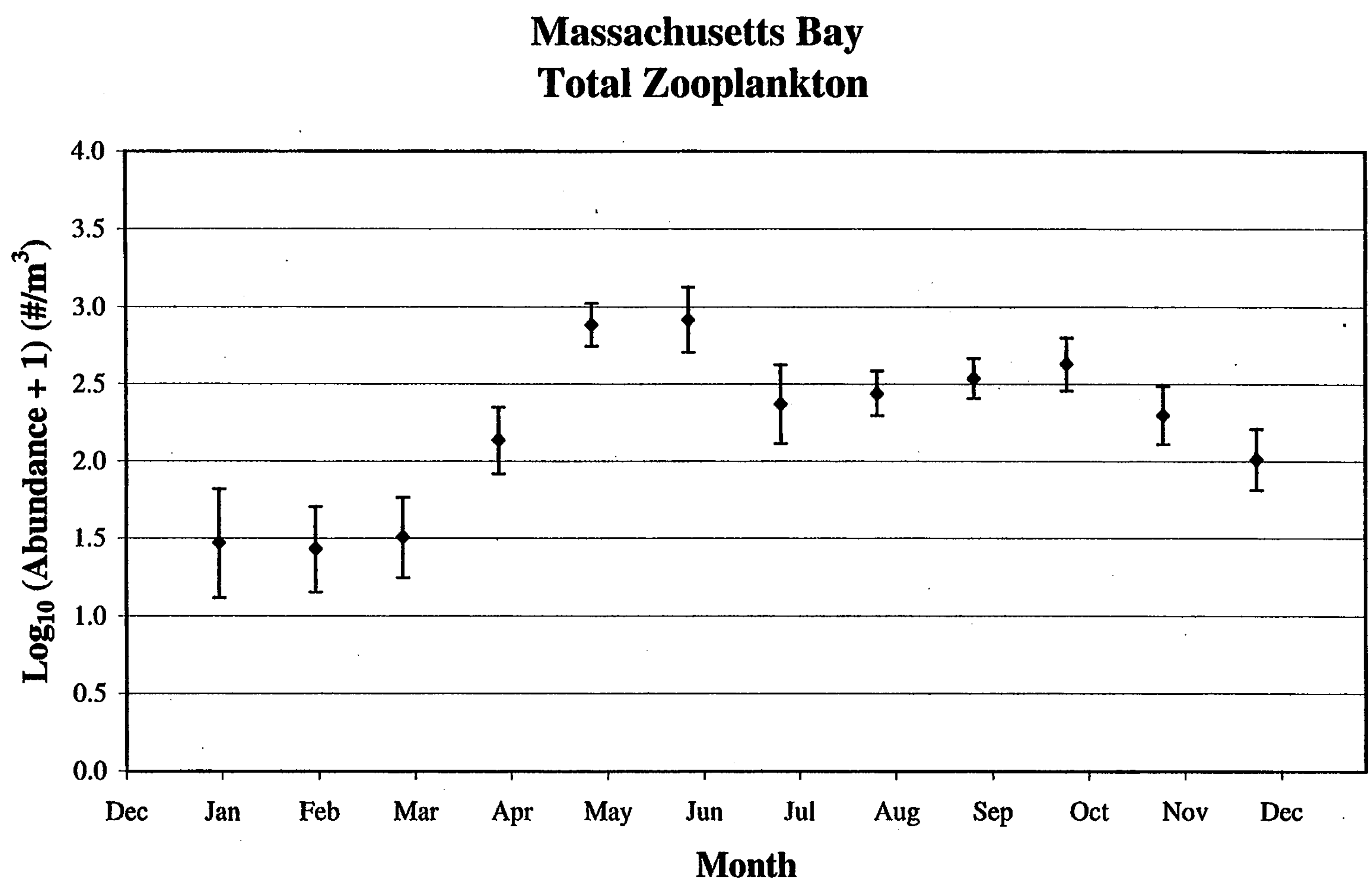



**FIGURE 3-36**
**Total Zooplankton – Monthly mean abundance with 95% confidence intervals**
**CPR survey results – January 1961 through December 1990**

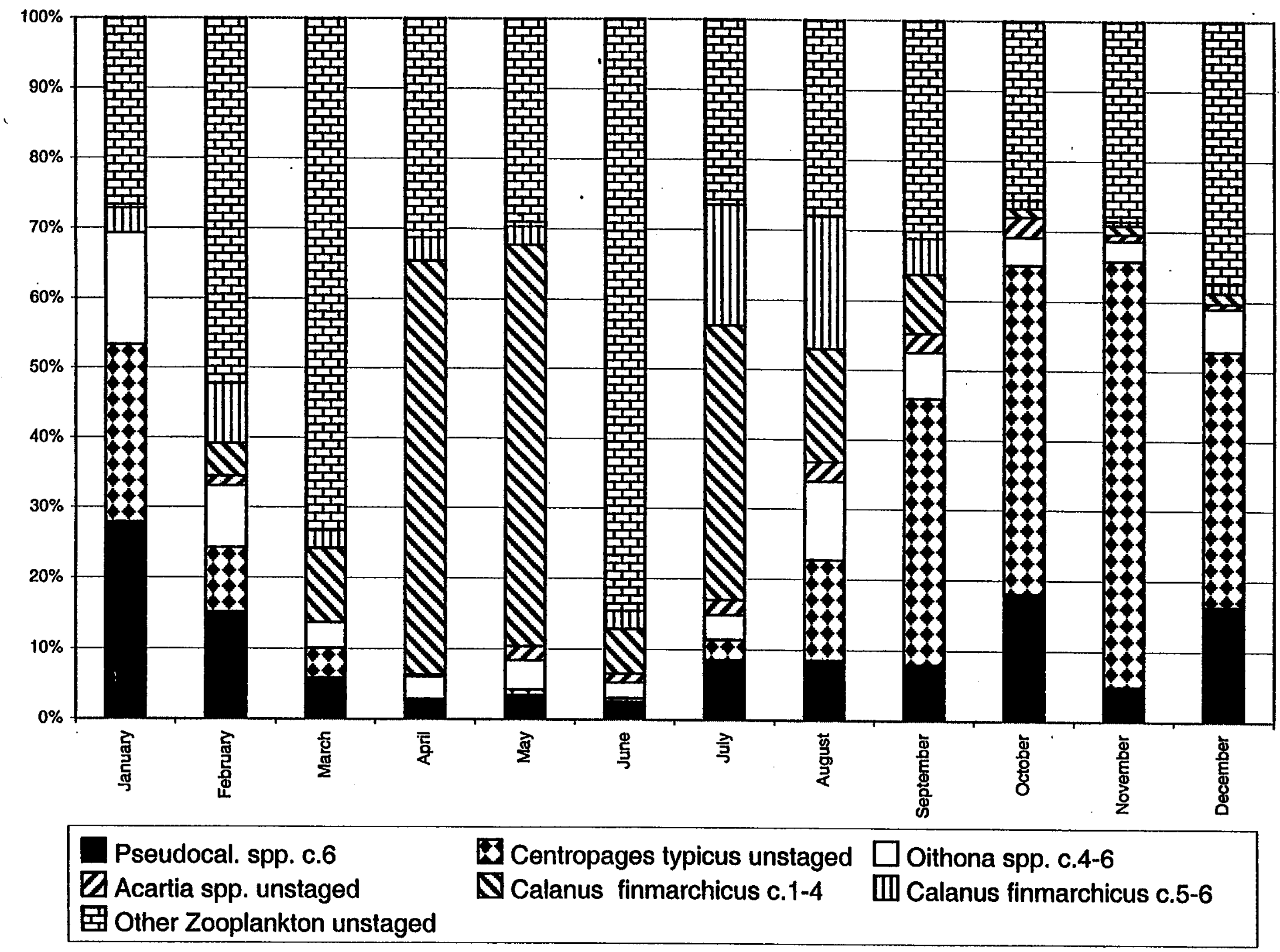
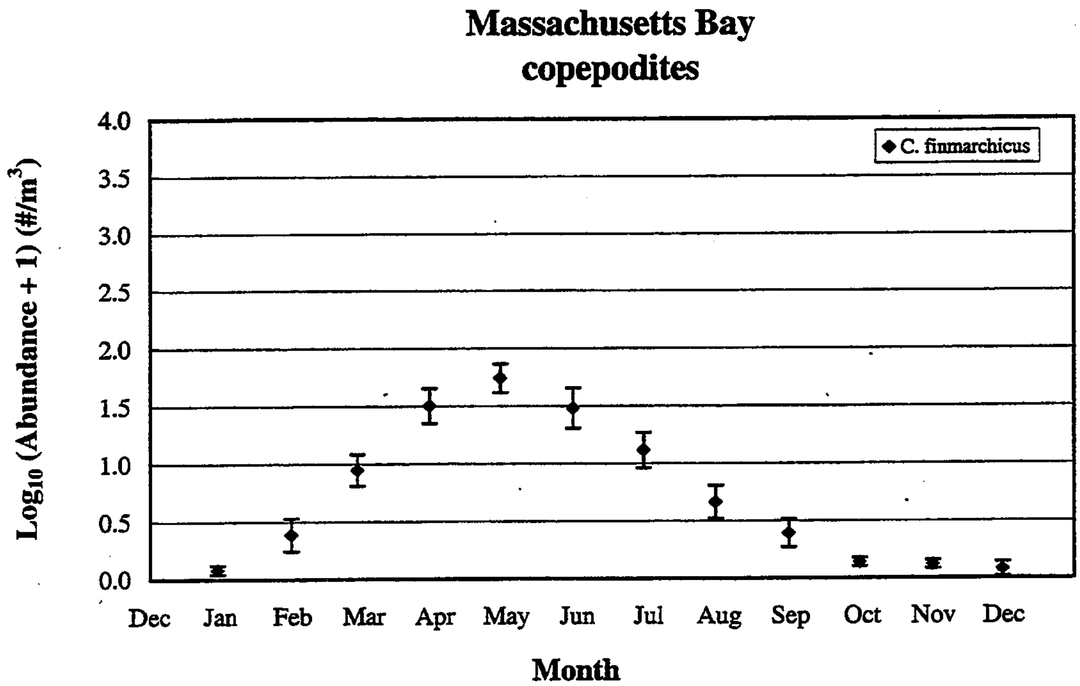



**FIGURE 3-37**
Percent Contribution of Selected Taxa for Massachusetts Bay
CPR Survey Results



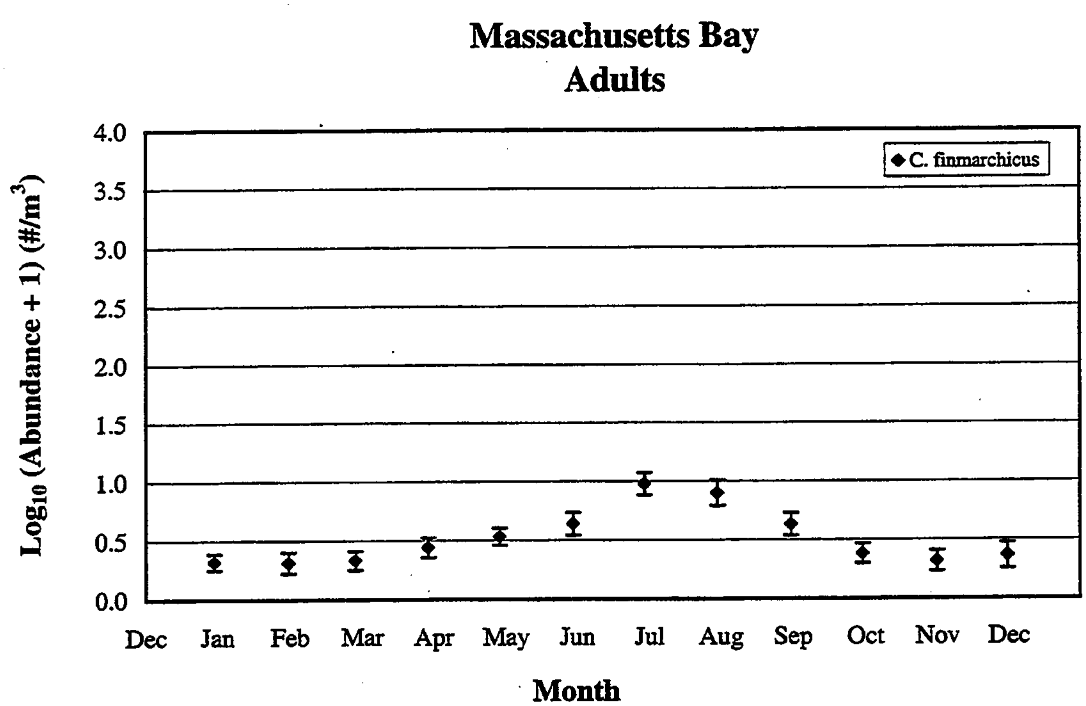




**FIGURE 3-38**
***Calanus finmarchicus* – Monthly mean abundance with 95% confidence intervals**
**CPR survey results – January 1961 through December 1990**

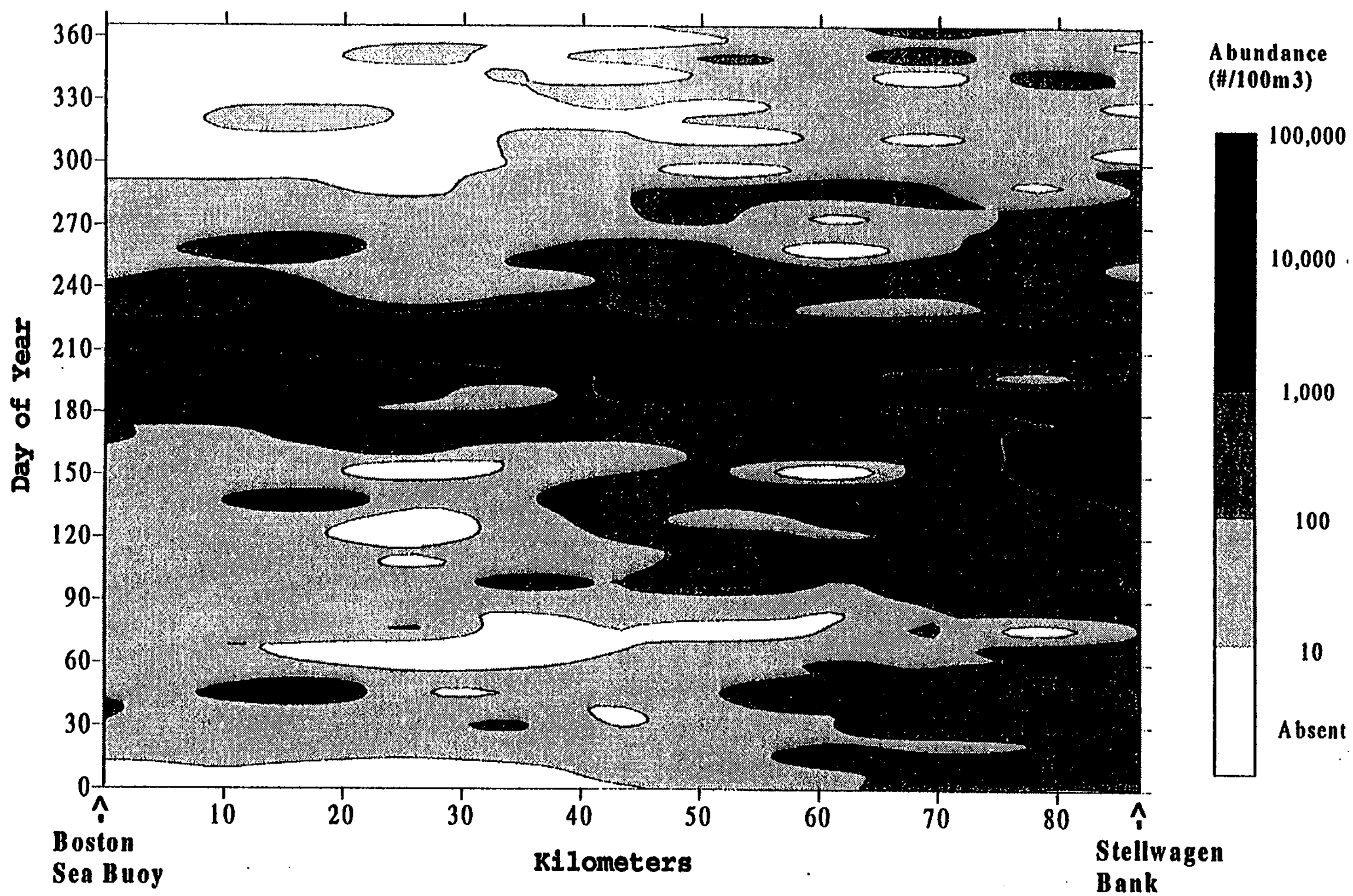



**FIGURE 3-39a**
**Gridded, mean (1961-1990) abundances of Calanus finmarchicus, c.5-6, between Boston Harbor and Stellwagen Bank. Data collected at 10 m depth with the Hardy Continuous Plankton Recorder.**

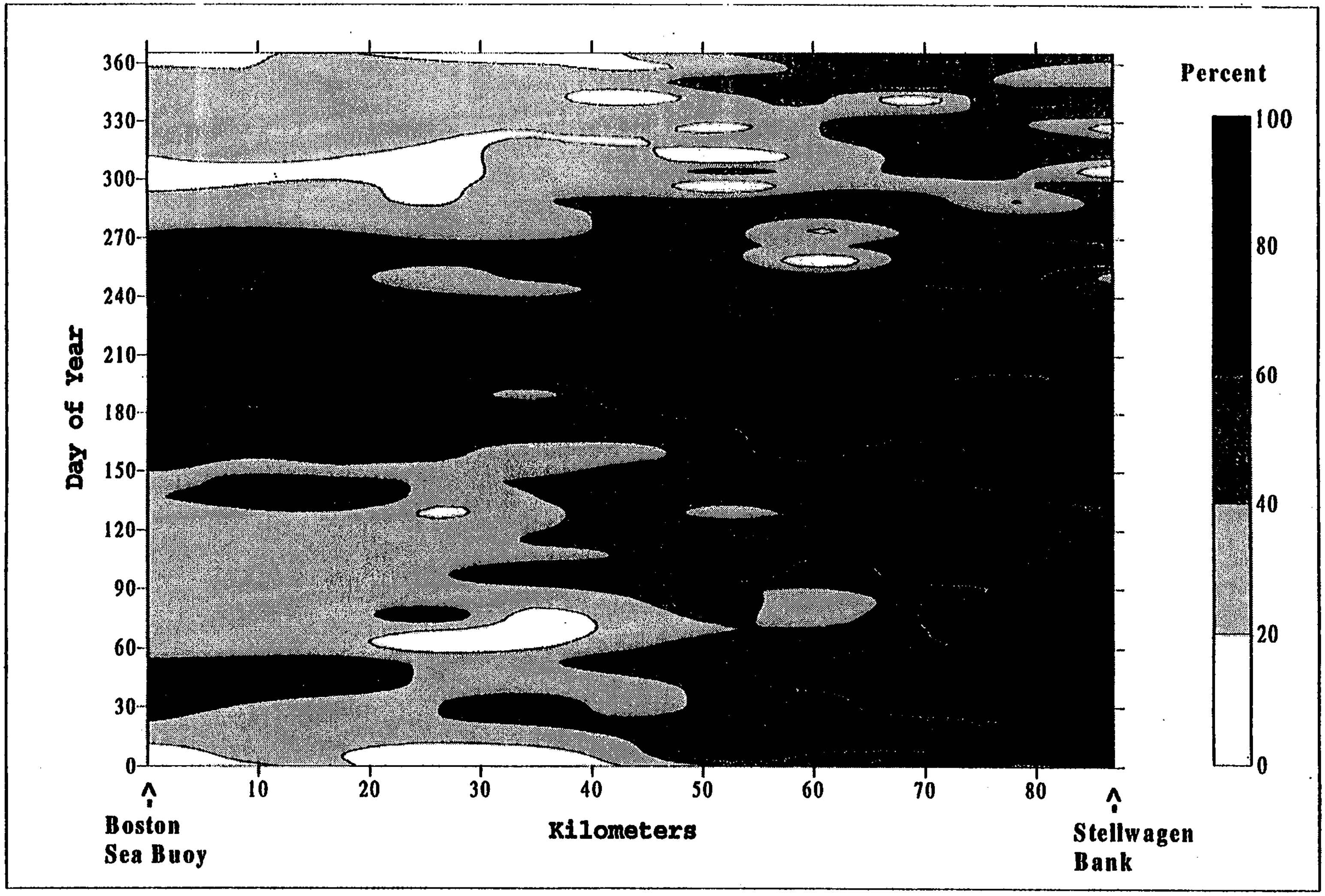



**FIGURE 3-39b**
Gridded, mean (1961-1990) abundances of Calanus finmarchicus, c.5-6, between Boston Harbor and Stellwagen Bank, expressed as percentage of total copepod abundance. Data collected at 10 m depth with the Hardy Continuous Plankton Recorder.

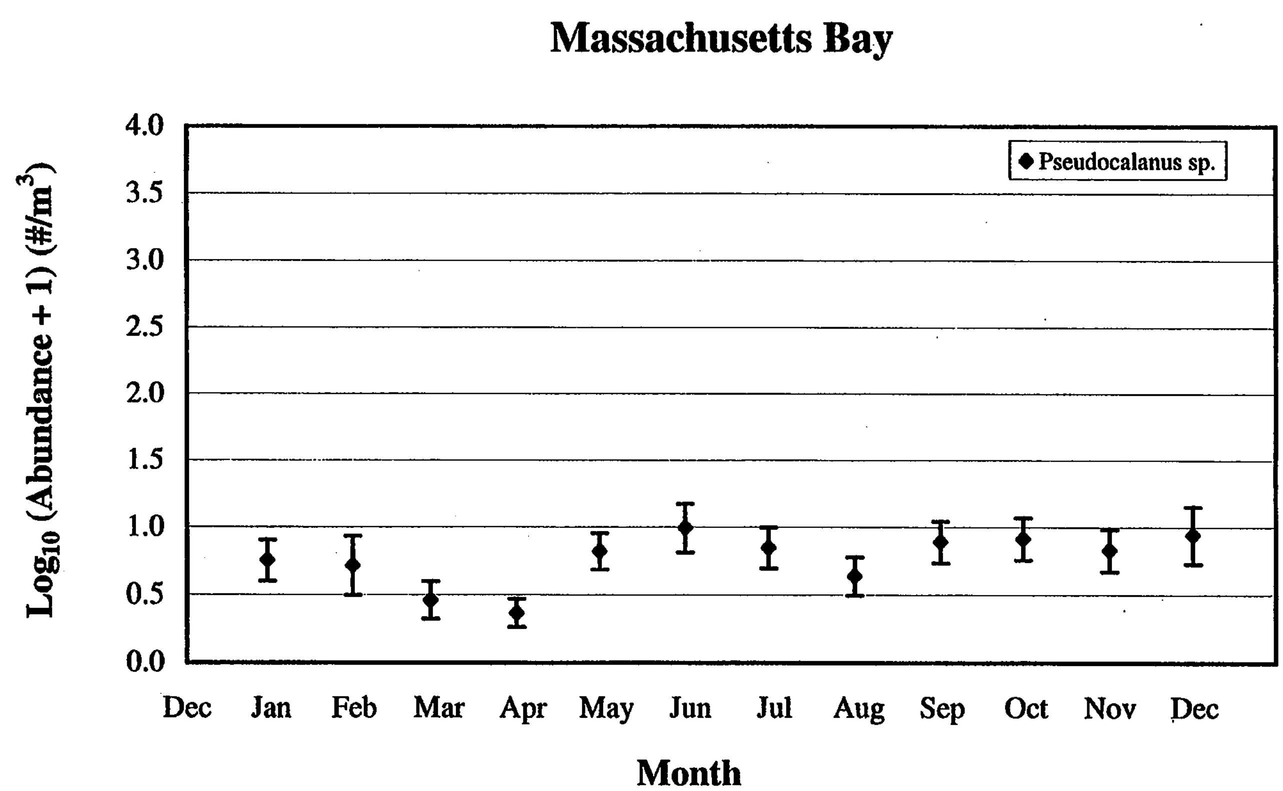



**FIGURE 3-40**
***Psuedocalanus* spp. – Monthly means with 95% confidence intervals**
**CPR survey results – January 1961 through December 1990**

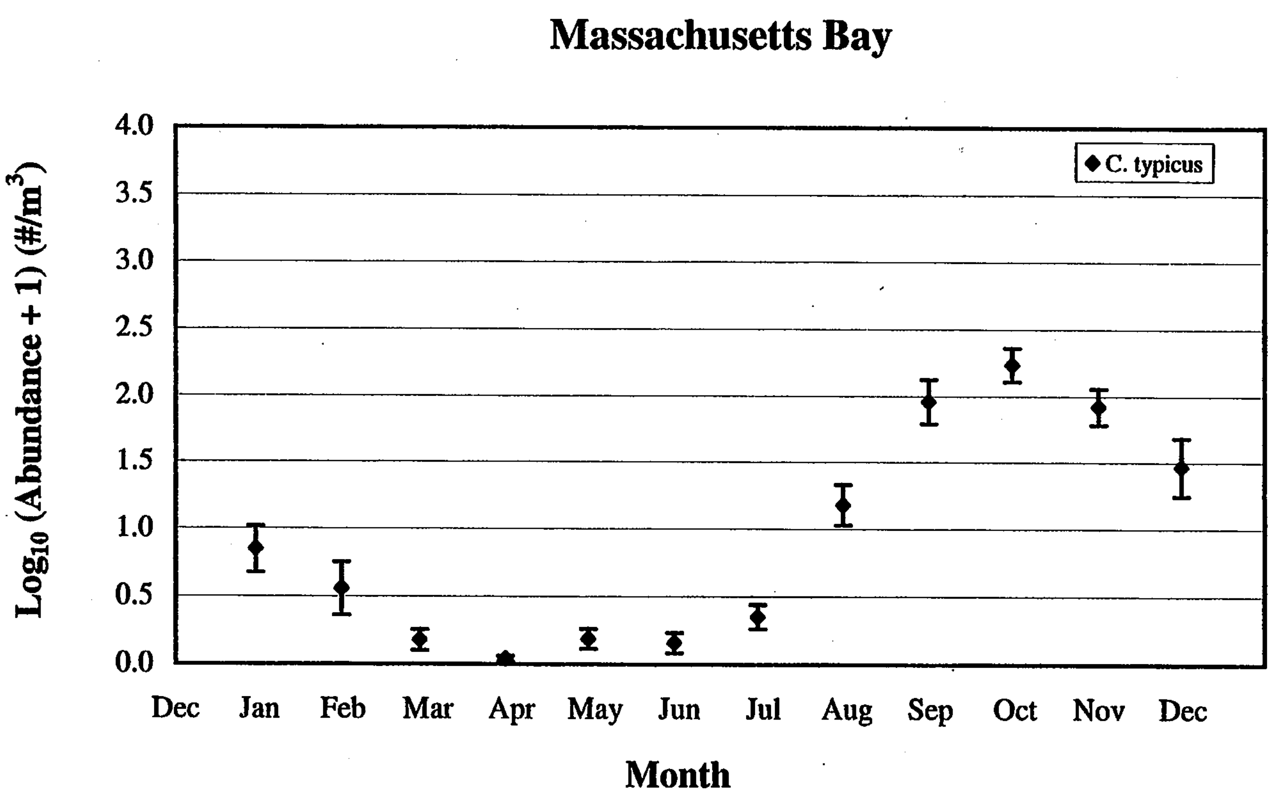



**FIGURE 3-41**
***Centropages typicus* – Monthly mean abundance with 95% confidence intervals**
**CPR survey results – January 1961 through December 1990**

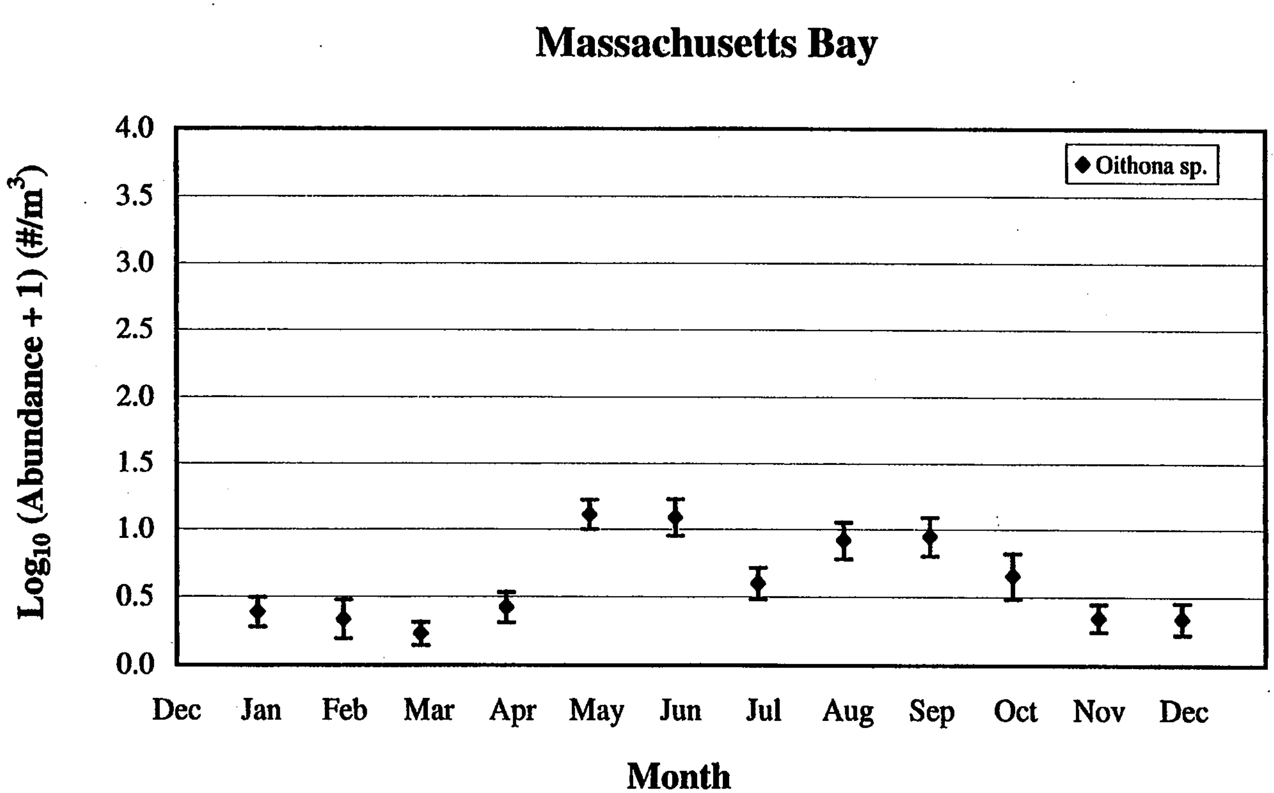



**FIGURE 3-42**
***Oithona* spp. – Monthly mean abundance with 95% confidence intervals**
**CPR survey results – January 1961 through December 1990**

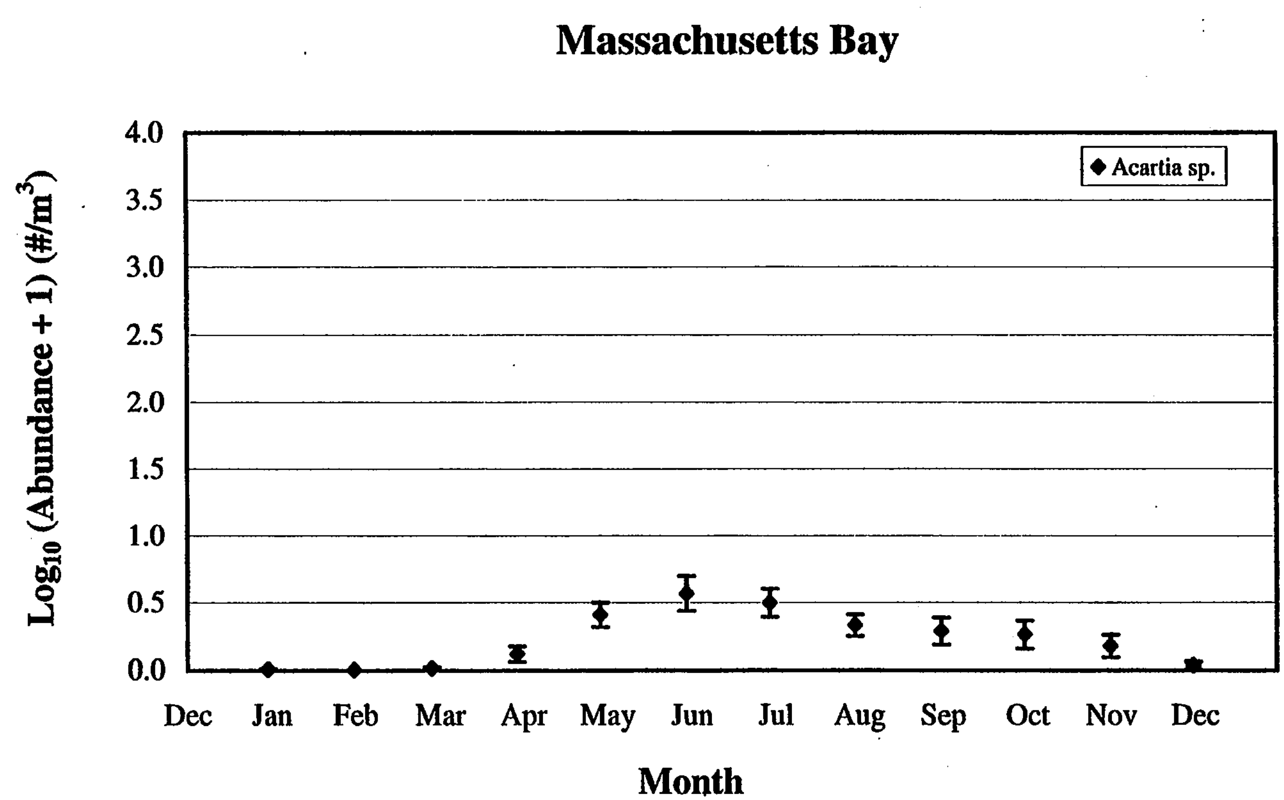



**FIGURE 3-43**
***Acartia* spp. – Monthly mean abundance with 95% confidence intervals**
**CPR survey results – January 1961 through December 1990**

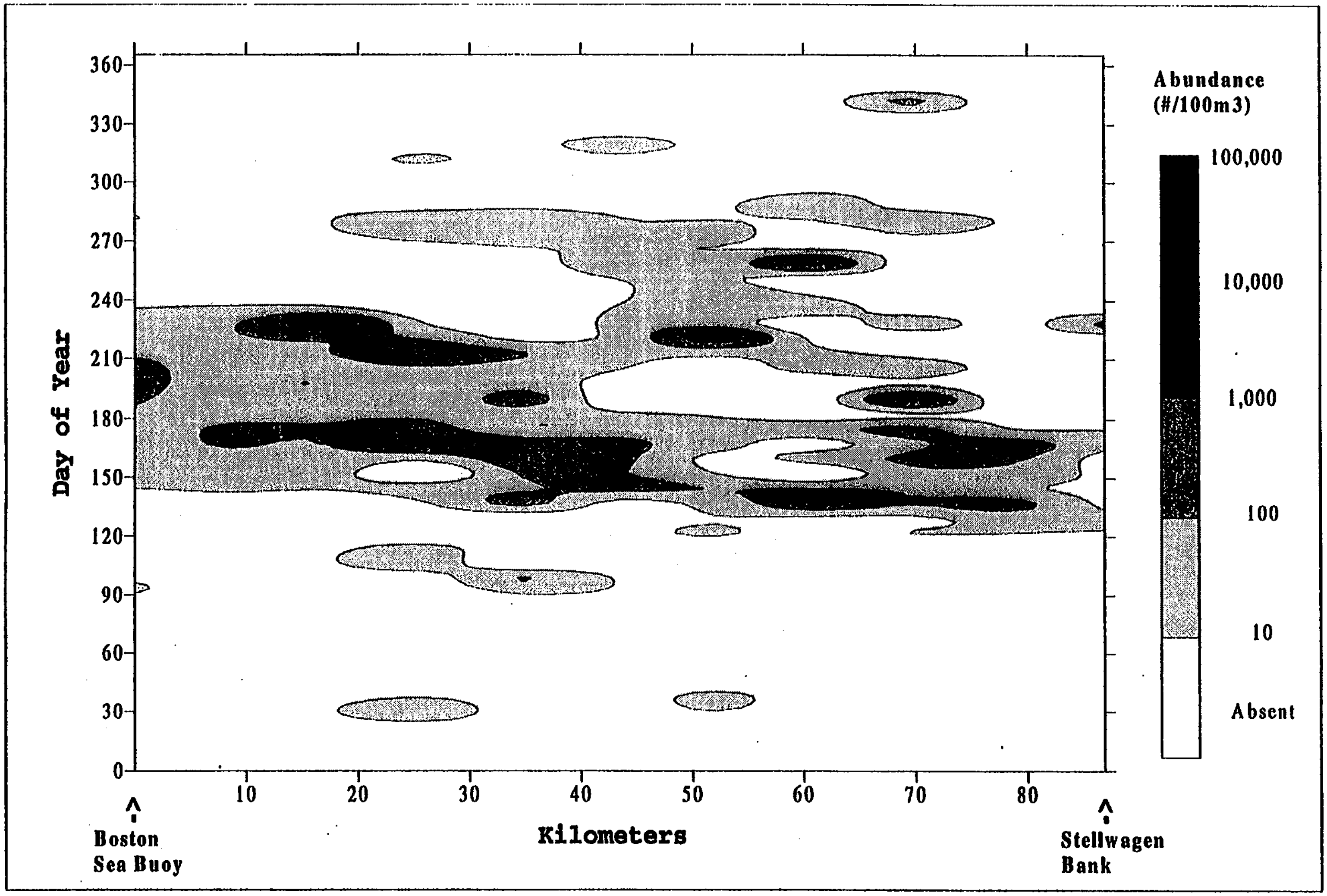



**FIGURE 3-44a**
**Gridded, mean (1961-1990) abundances of Acartia spp., unstaged,between Boston Harbor and Stellwagen Bank. Data collected at 10 m depth with the Hardy Continuous Plankton Recorder.**

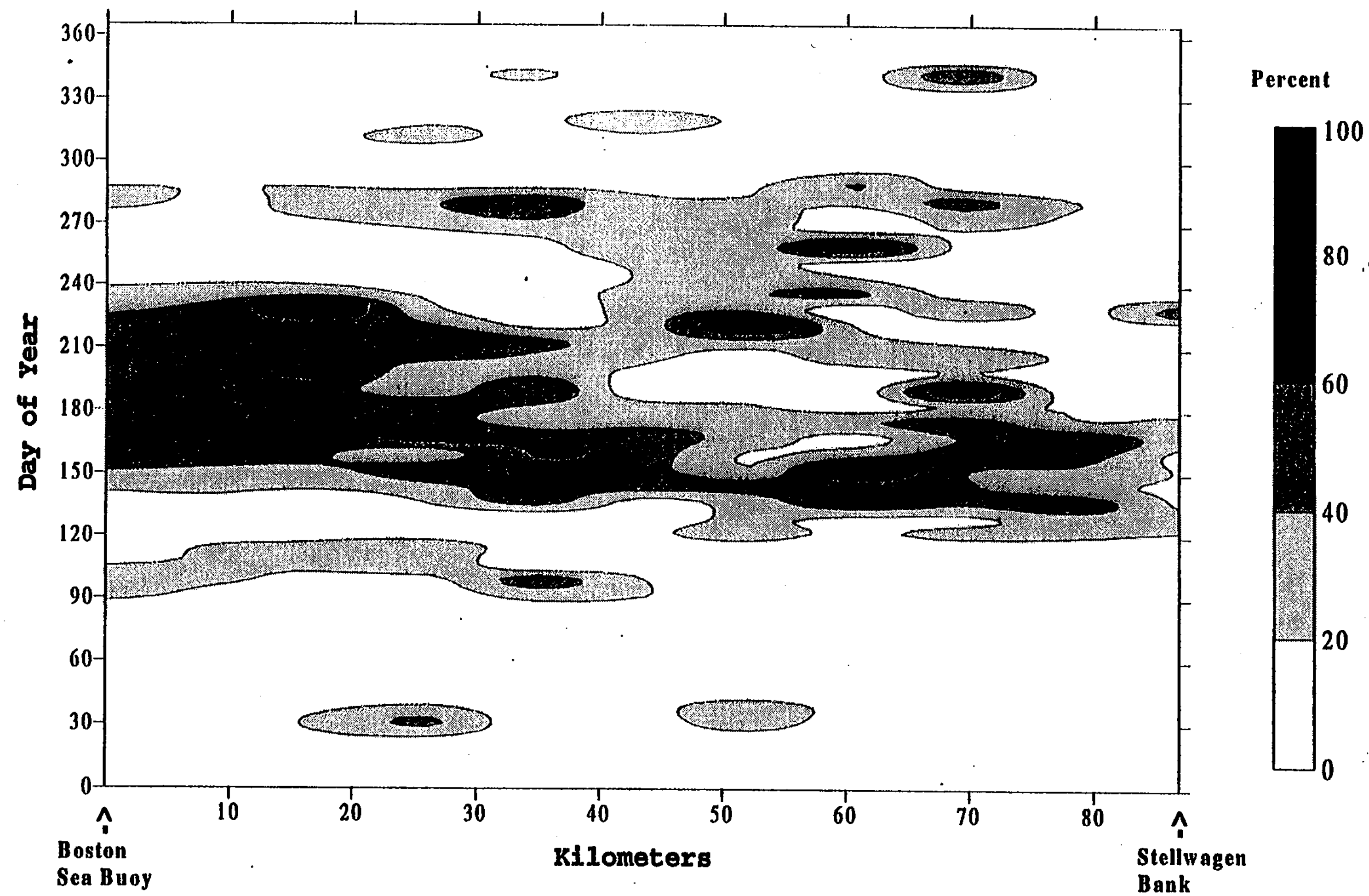



**Figure 3-44b**

**Gridded, mean (1961-1990) abundances of Acartia spp., unstaged, between Boston Harbor and Stellwagen Bank, expressed as percentage of total copepod abundance. Data collected at 10 m depth with the Hardy Continuous Plankton Recorder.**

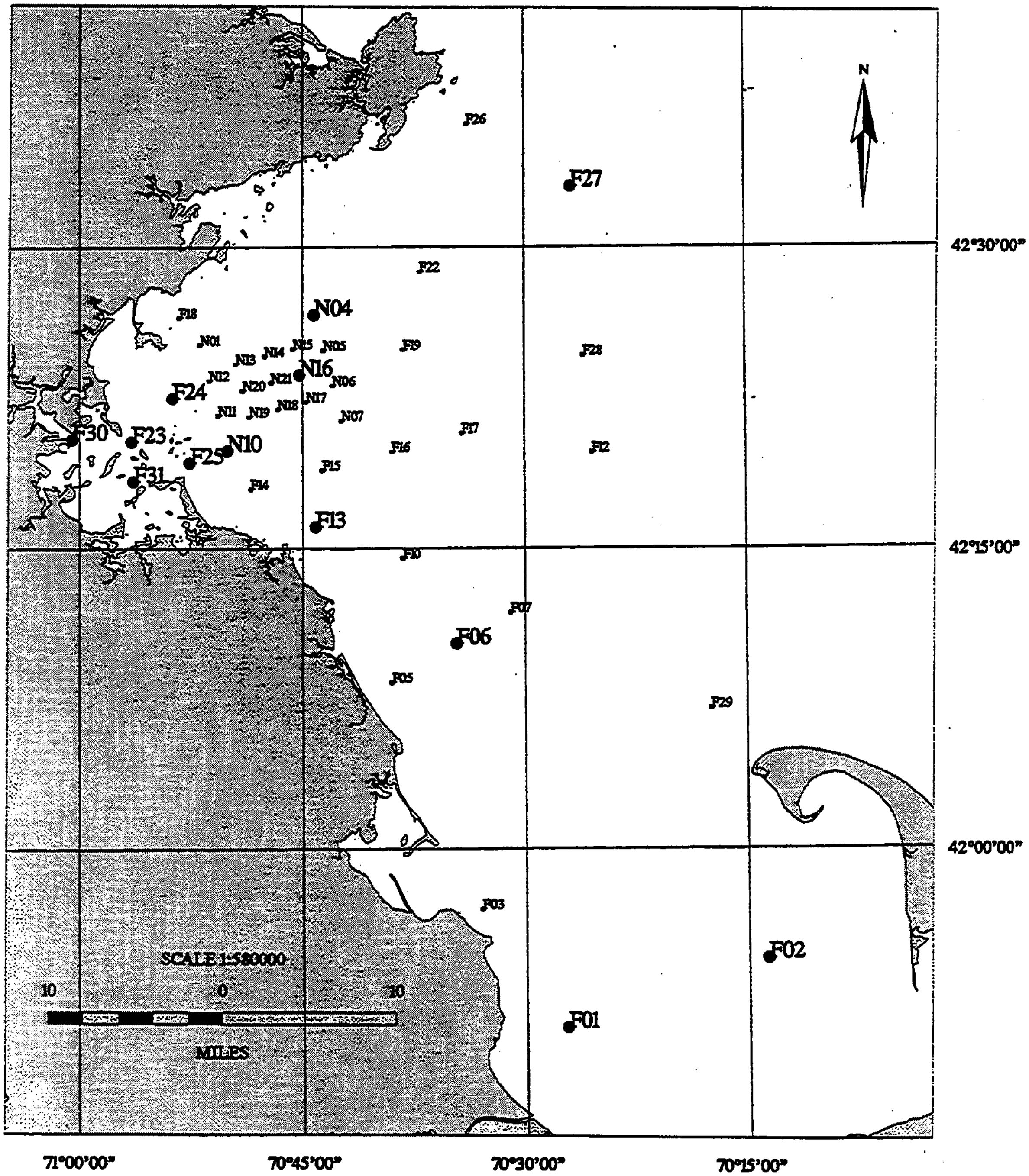
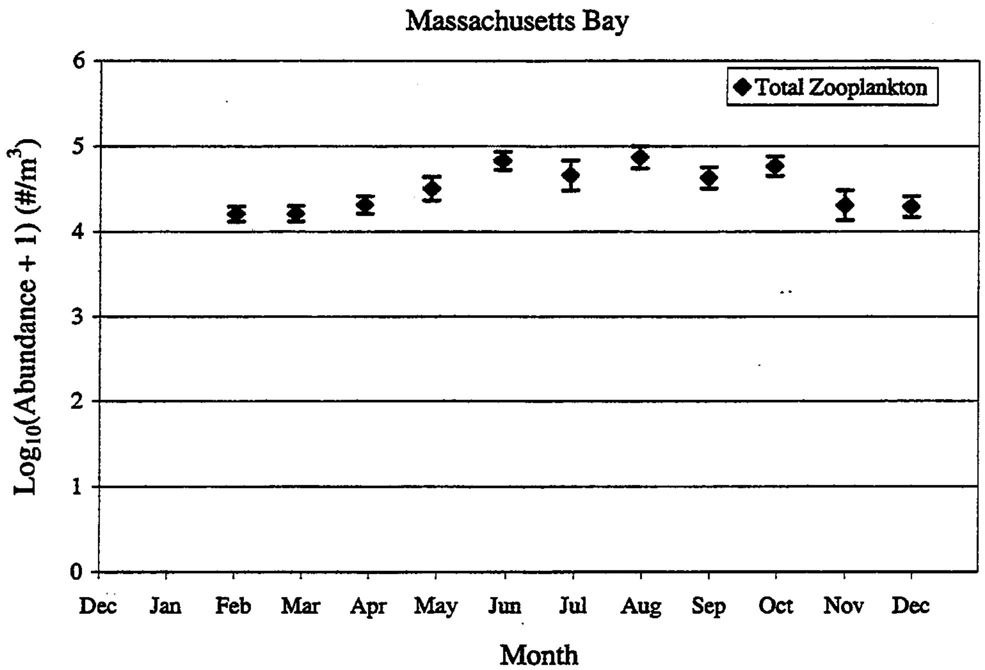



**FIGURE 3-45**
**HOM Plankton Station Locations**
**(Enlarged Text)**



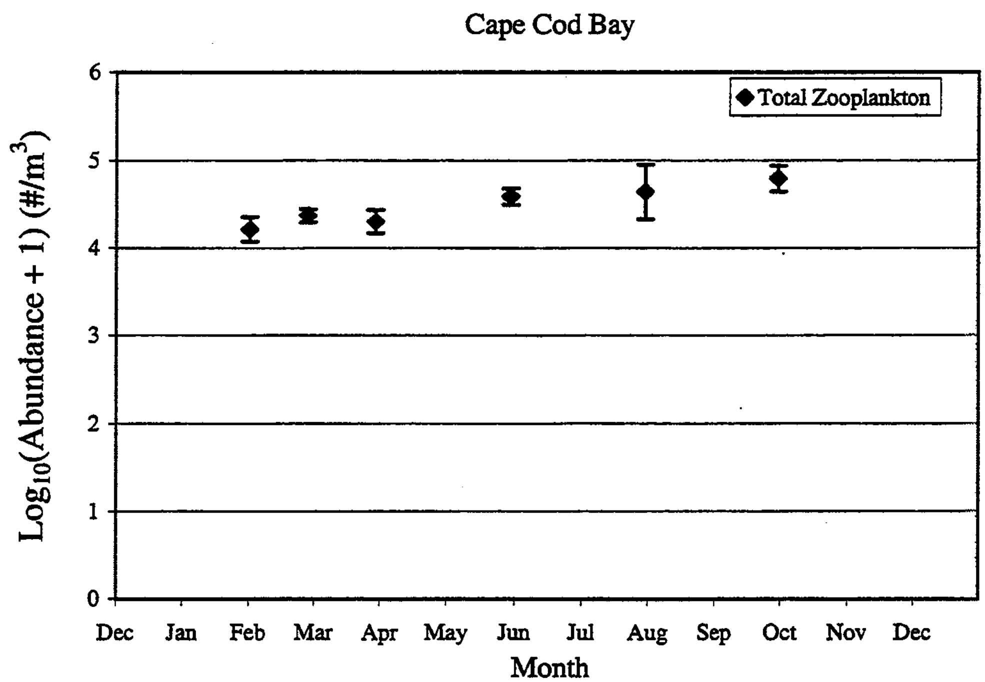




**FIGURE 3-46**
**Total Zooplankton - monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**

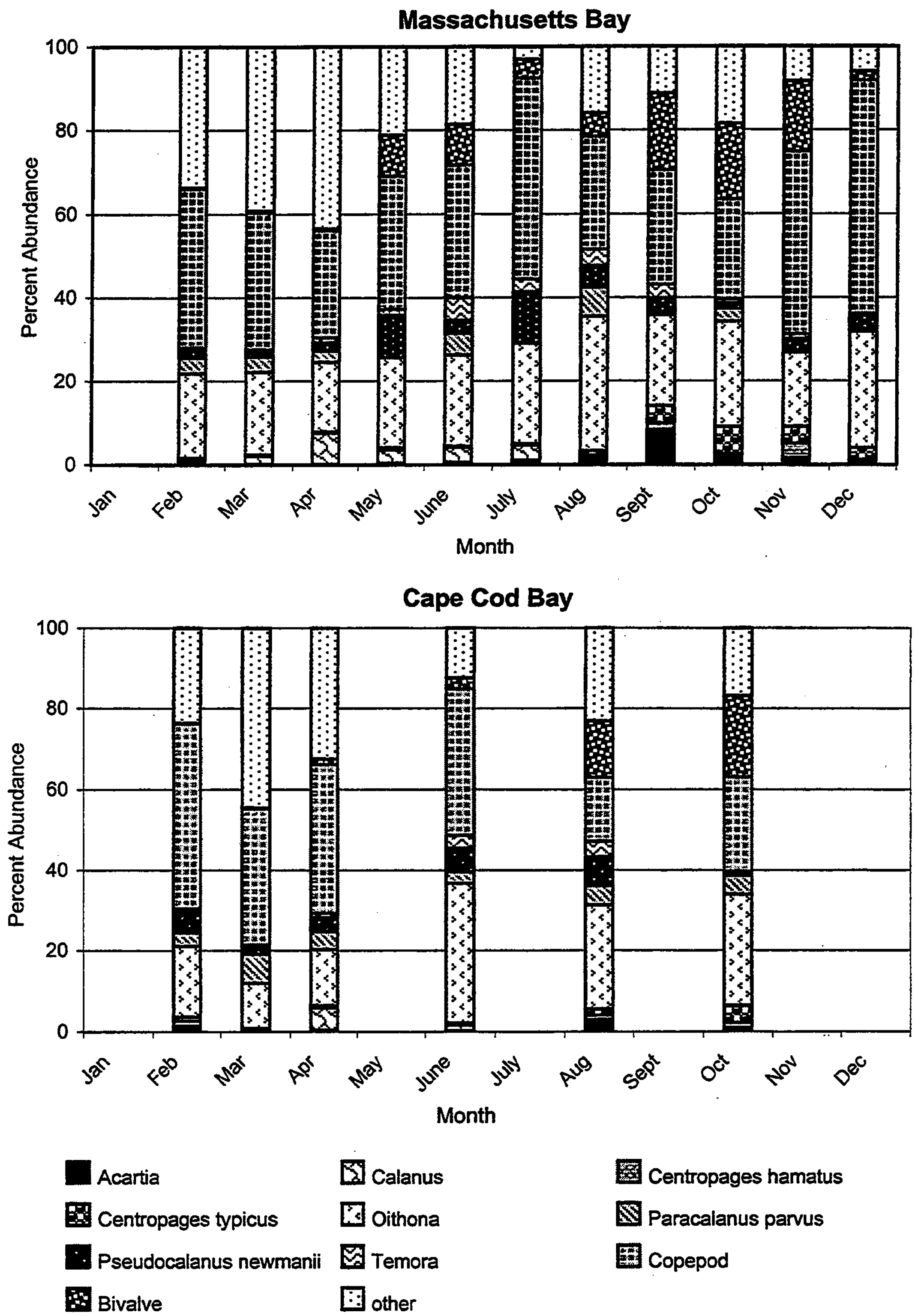



**FIGURE 3-47**

Percent Contribution of All Taxa During the MWRA Baseline 1992-1996 Data

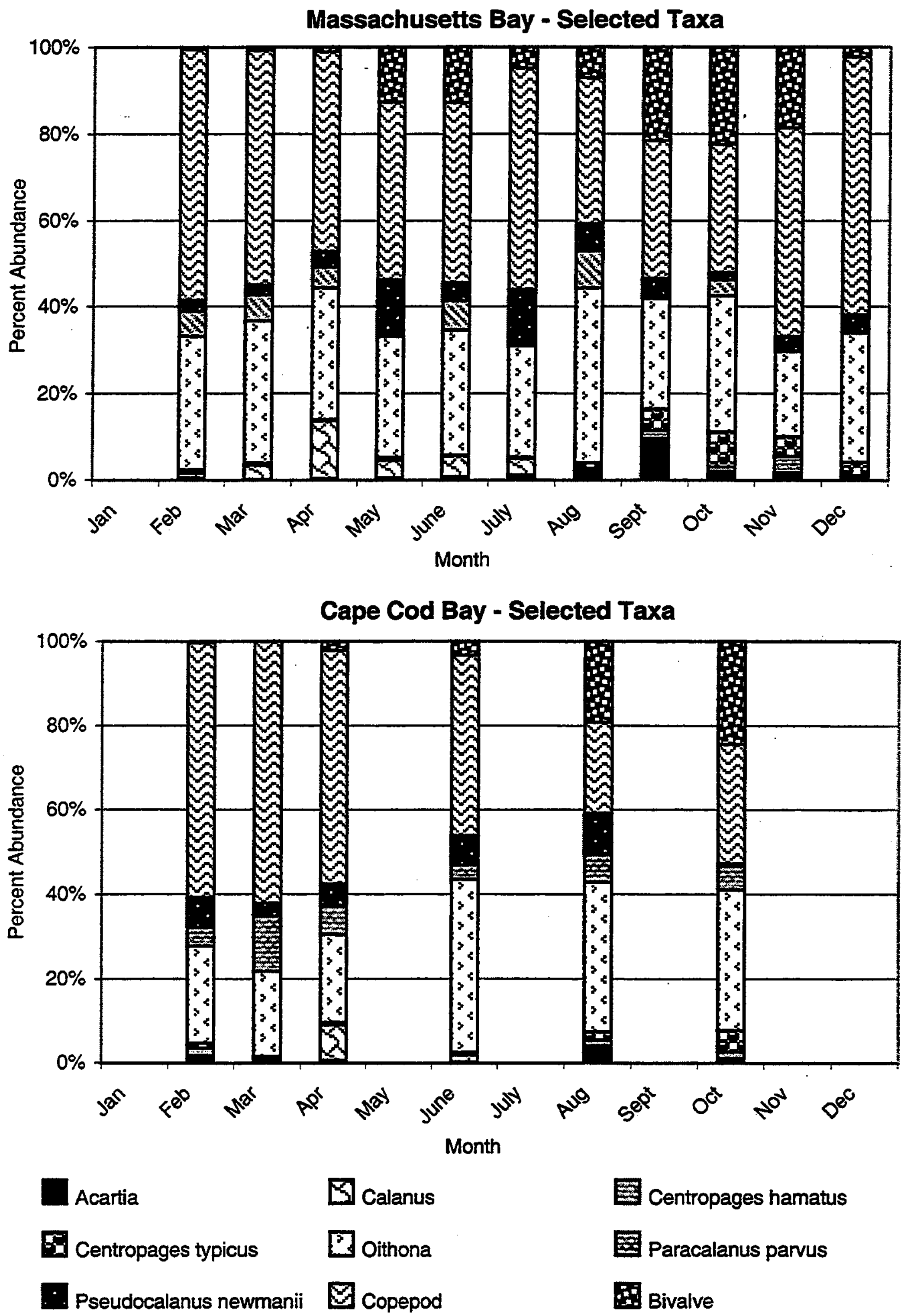



**FIGURE 3-48**

Percent Contribution of Dominant Taxa During the MWRA Baseline 1992-1996 Data

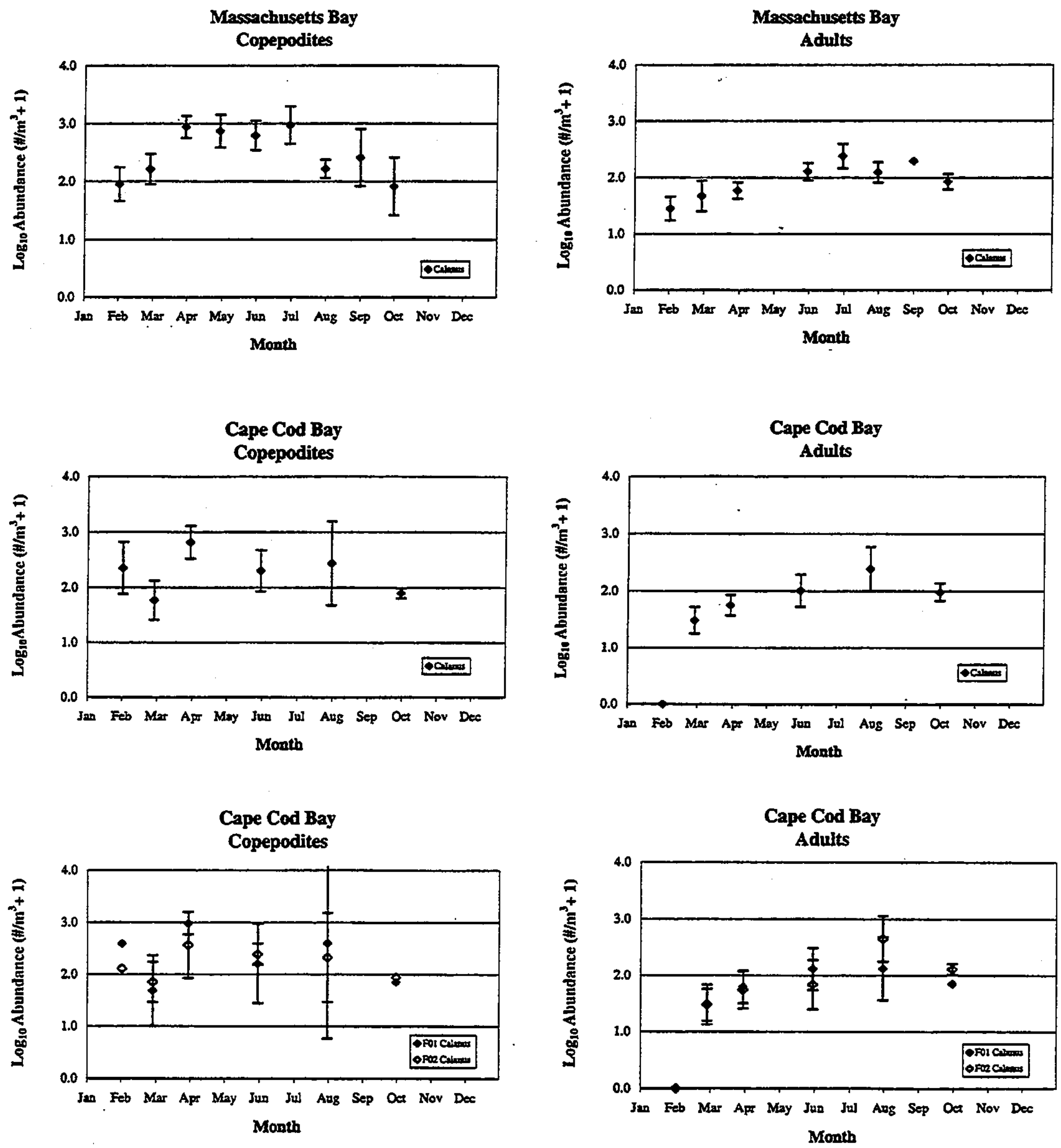
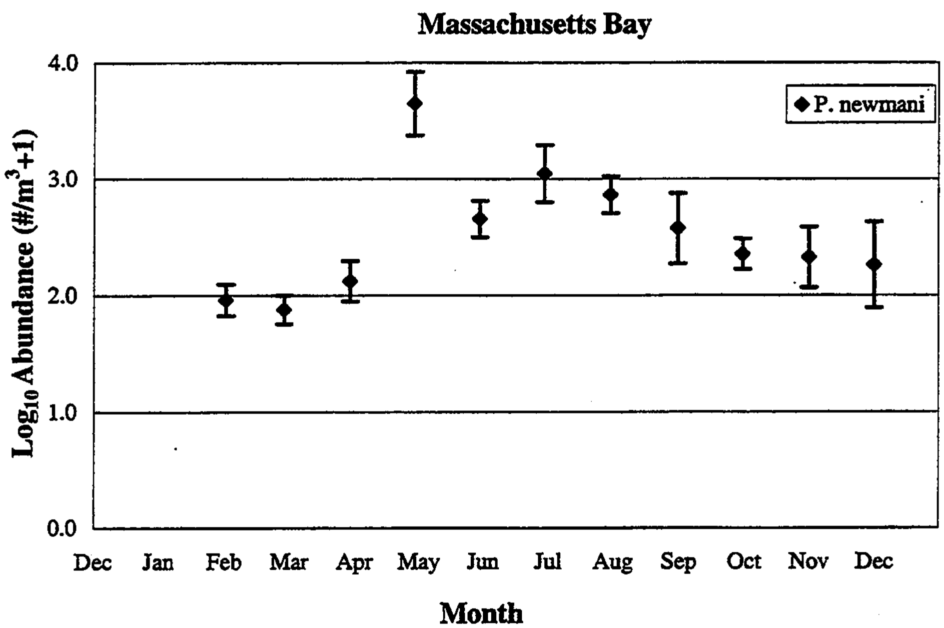



**FIGURE 3-49**
***Calanus finmarchicus* copepodites and adults - monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**



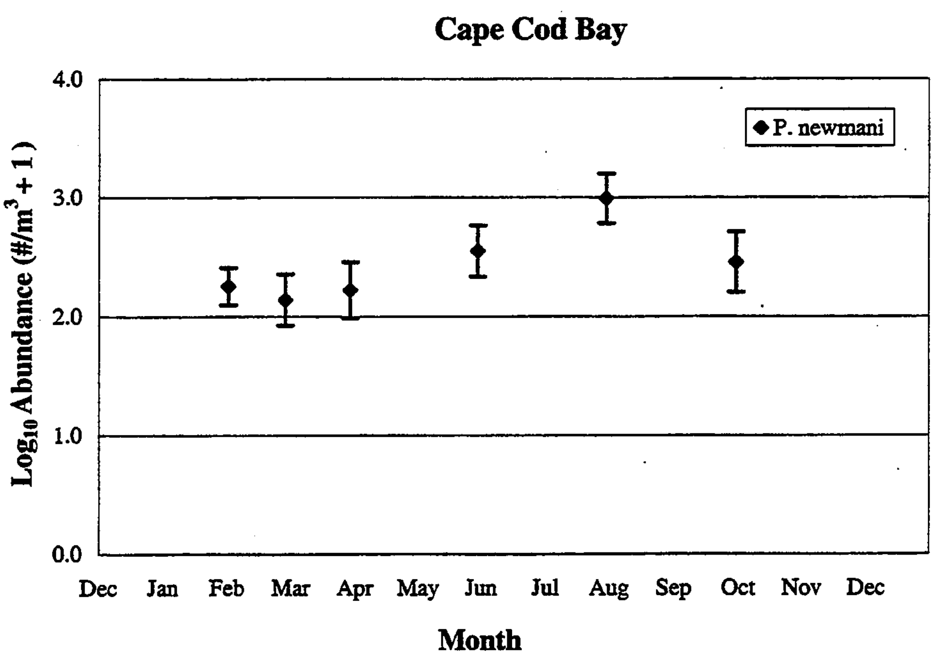




**FIGURE 3-50**
***Pseudocalanus newmani* -monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**

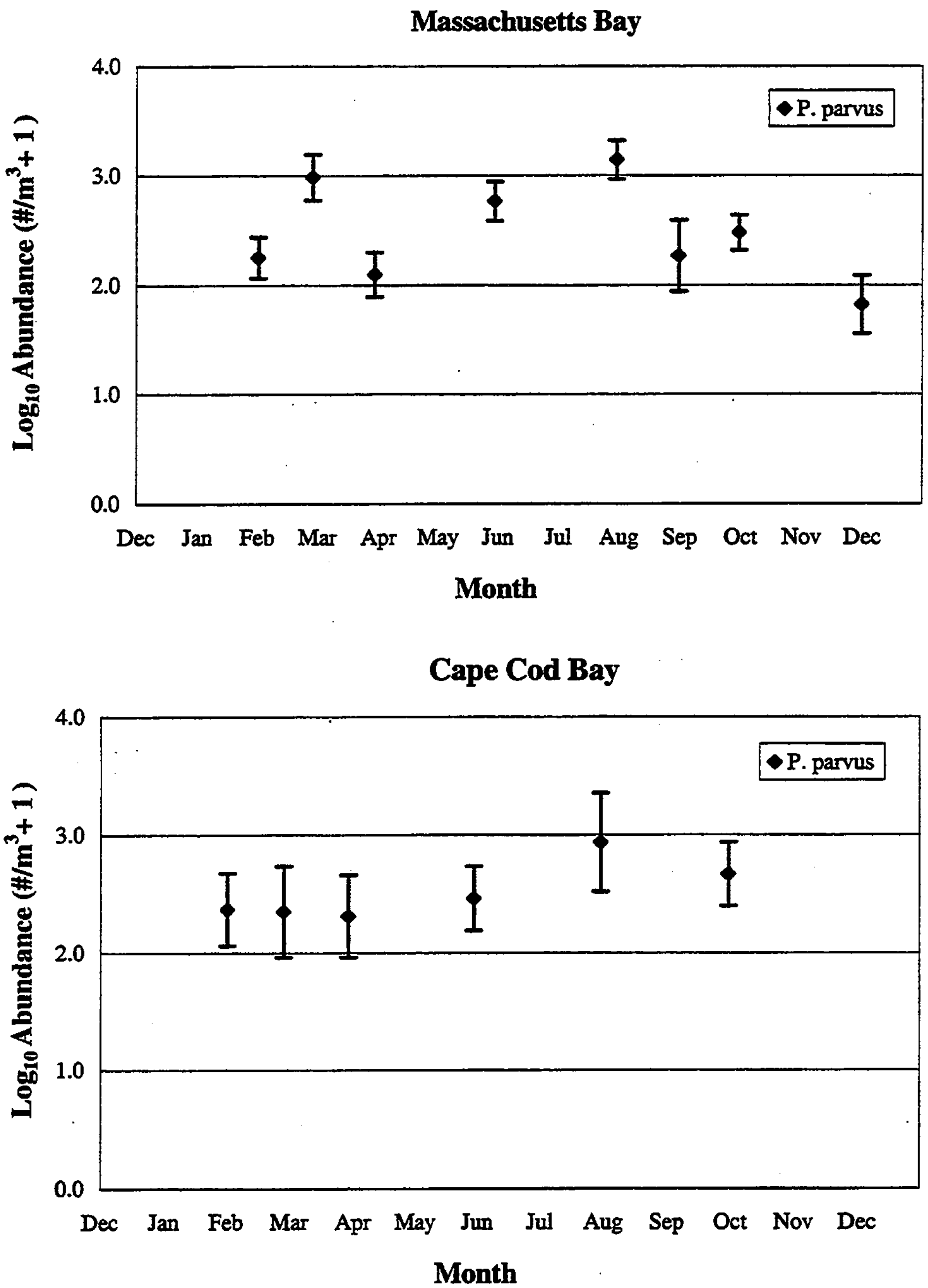



**FIGURE 3-51**
***Paracalanus parvus*** **-monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**

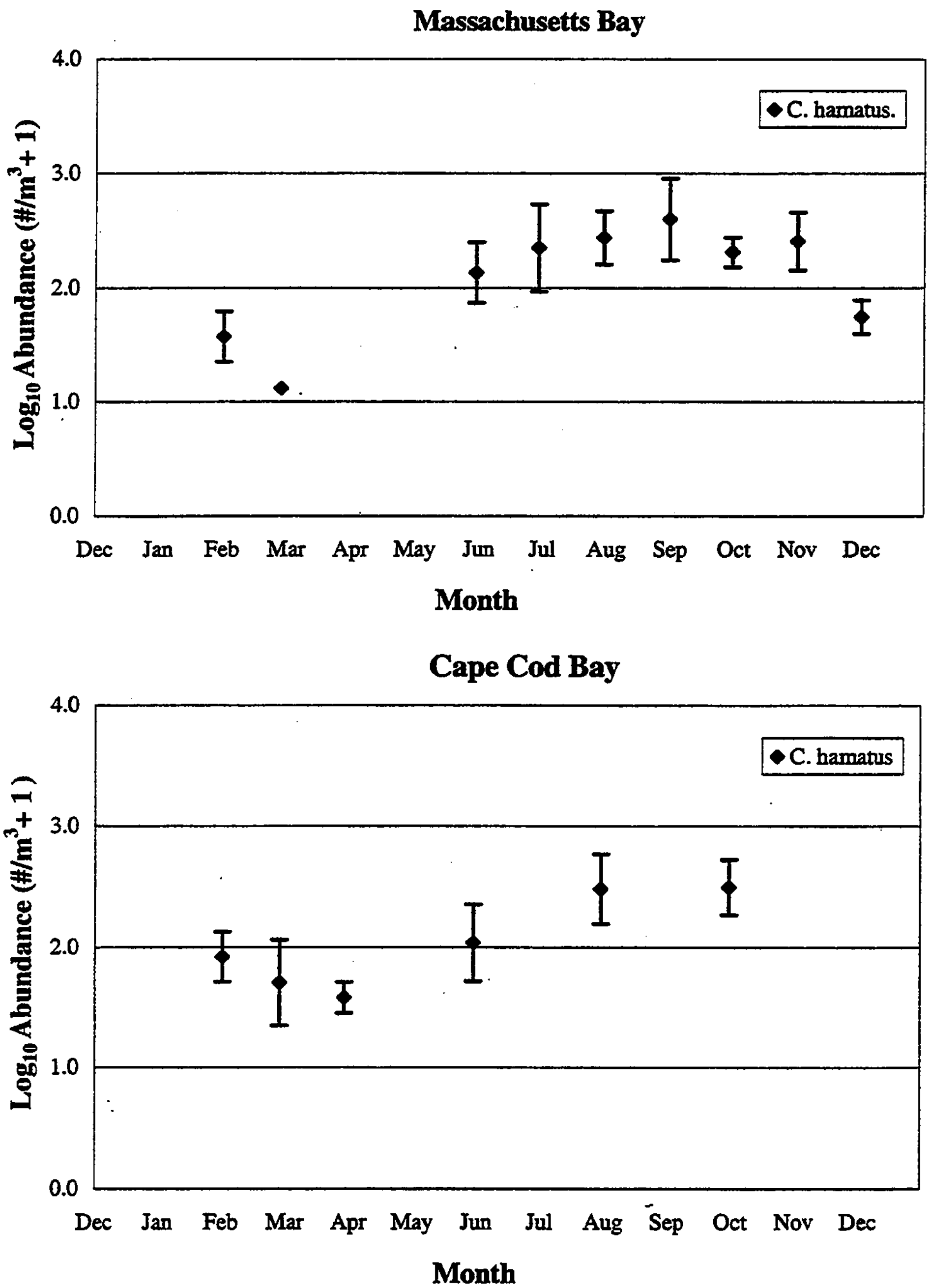
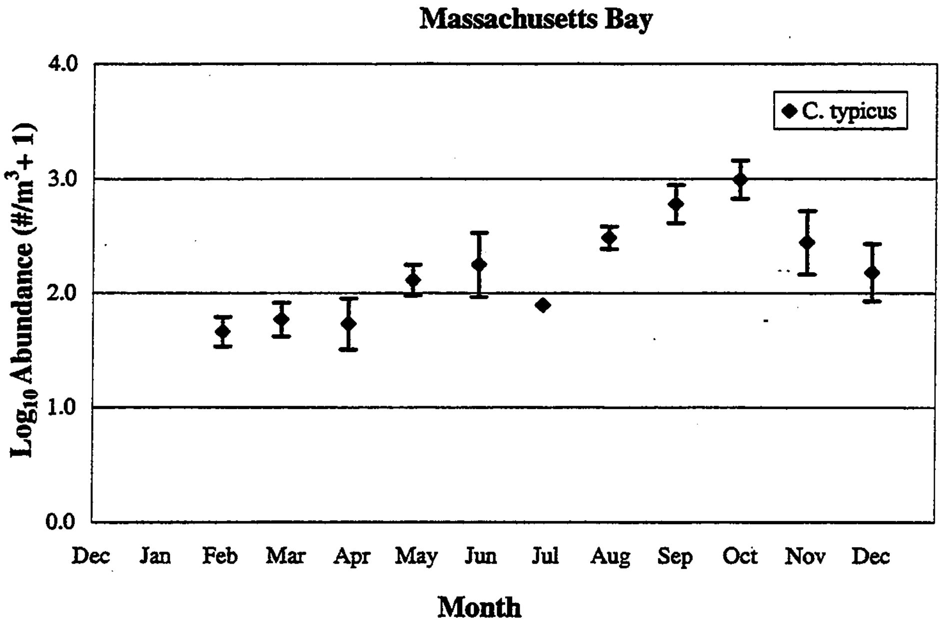



**FIGURE 3-52**
*Centropages hamatus* -monthly means with 95% confidence intervals
MWRA Baseline Results - February 1992 through June 1997



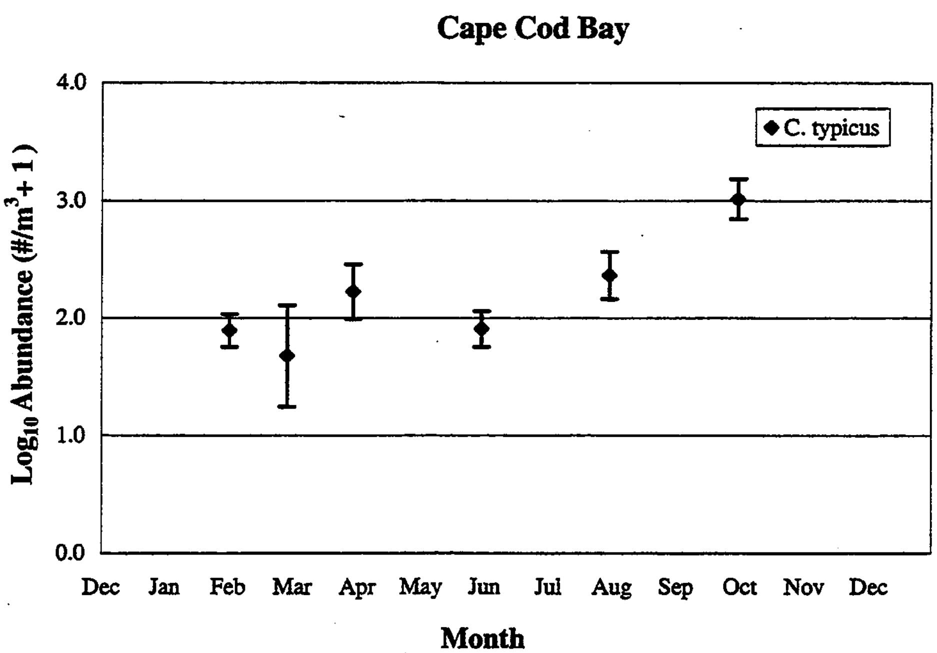
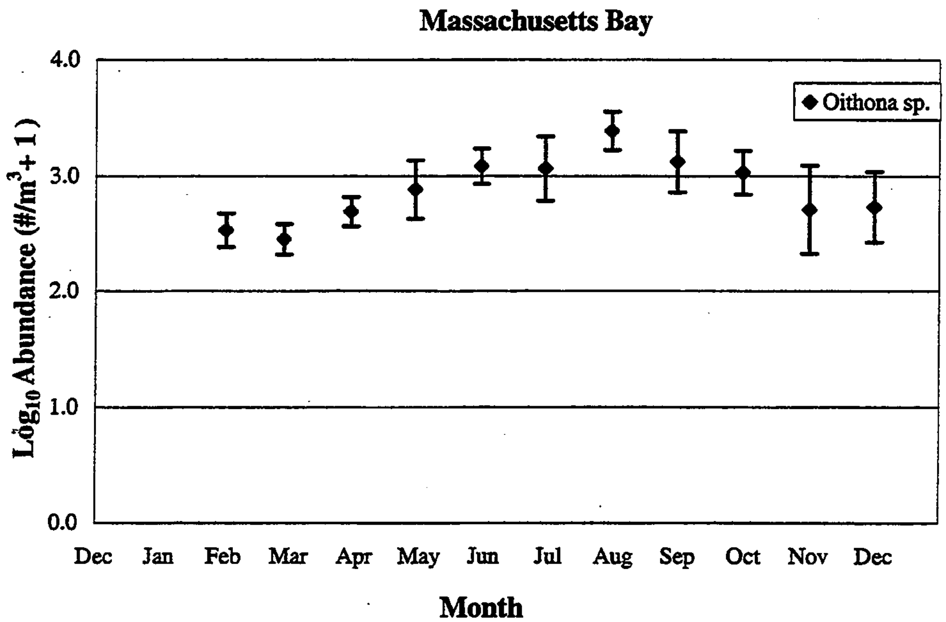




**FIGURE 3-53**
***Centropages typicus*** **-monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**



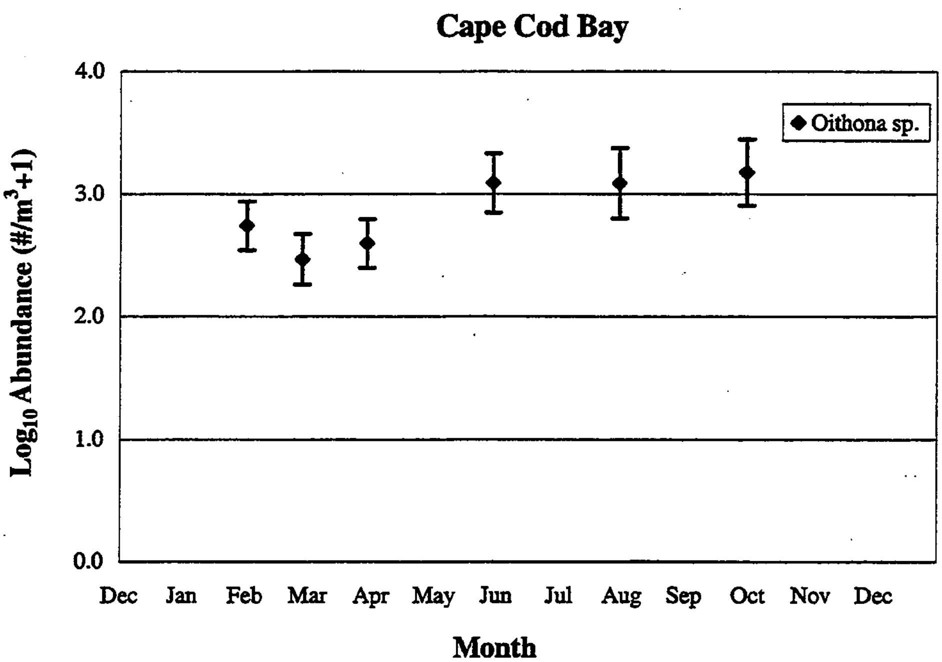
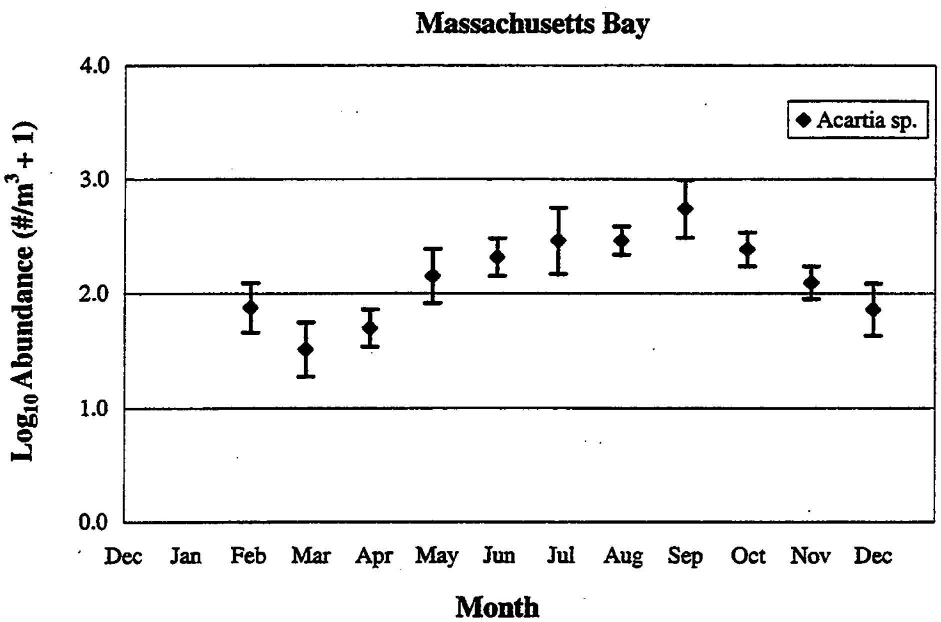




**FIGURE 3-54**
***Oithona* sp. -monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**



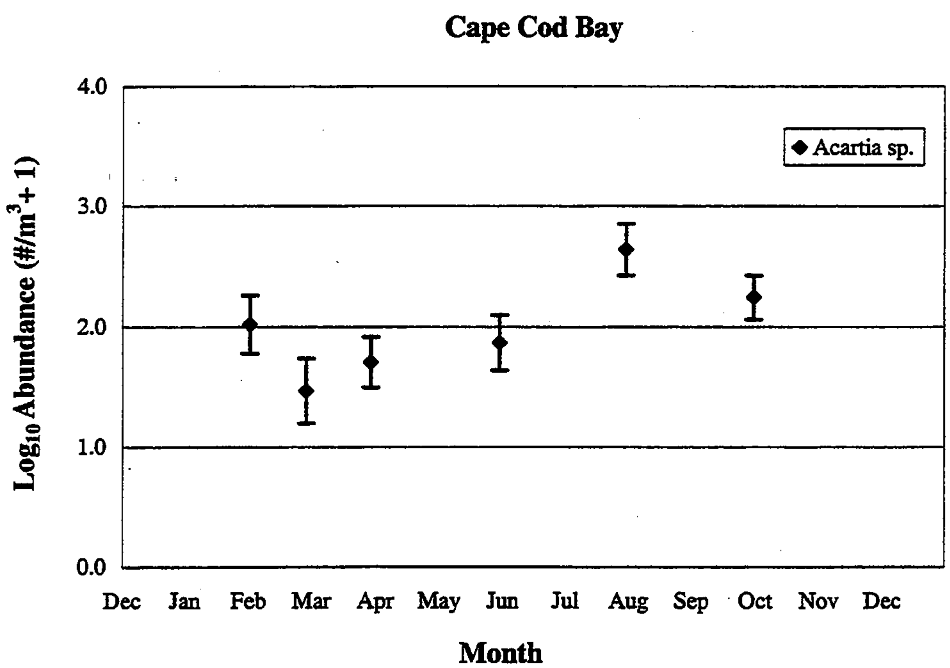




**FIGURE 3-55**
***Acartia* sp. -monthly means with 95% confidence intervals**
**MWRA Baseline Results - February 1992 through June 1997**

# 4.0 CONCLUSIONS

Despite limitations due to methodological differences and sampling bias within the studies reviewed, this retrospective has provided a more comprehensive understanding of the seasonal and annual patterns of zooplankton assemblages in Massachusetts Bay and Cape Cod Bays. The benefits of the information assembled herein, as well as its limitations, are summarized below.

## 4.1 Overview of results

The graphical and statistical investigations have produced the following conclusions:

1) Observed patterns in Mass Bay and Cape Cod Bay zooplankton were similar to those seen in other regions of Gulf of Maine/Georges Bank (e.g., Georges Bank, Davis 1987a) with some subtle differences. For example, Massachusetts Bay appears to be comprised of two regions resulting from coastal-offshore water quality characteristics. In addition, it appears the waters of northern Cape Cod Bay may exhibit some seasonal differences in successional patterns compared with waters of southern Cape Cod Bay (e.g. *Acartia* spp.) In general strong regional, seasonal, and interannual variation in zooplankton abundance was found within the literature as well as the individual data assessments performed for this report. This can be largely attributed to pronounced annual temperature cycle (0-20° annual range) and patterns in primary production. Also, literature from NMFS MARMAP surveys identified twelve taxa which account for 85% of zooplankton dominance in the entire NW Atlantic shelf: *Calanus finmarchicus, Pseudocalanus* spp., *Centropages typicus, Centropages hamatus, Metridia lucens, Temora longicornus, Acartia hudsonica, Acartia tonsa, Acartia* spp (*A. clausi – A. longiremis*), *Oithona* spp., *Calanus* spp., and *Paracalanus parvus*. However, three of these species, *Calanus finmarchicus, Pseudocalanus,* and *Centropages typicus typically constituted* 75% of the dominance (Sherman *et al.* 1983).

2) Massachusetts Bay was similar to Cape Cod Bay with regard to species composition and population assemblage. This was confirmed through separate statistical investigations of both the MARMAP dataset and the MWRA dataset. However, Cape Cod Bay is more similar to the Coastal Mass Bay assemblage than the offshore Mass Bay assemblage. The spatial distributions of the zooplankton taxa reveal two distinct groups with affinities for nearshore or offshore regions. The *Acartia* spp. are thought to be restricted to nearshore environments due to some combination of food limitation and possibly salinity intolerance of their nauplii (Cibik *et al* 1998). *Centropages hamatus* is restricted to shallow regions where tidally induced resuspension of bottom sediment prevents their bottom resting eggs from becoming buried (Davis 1987a), thus supporting the nearshore affinities displayed within the MARMAP and MWRA datasets.

3) Similarities were displayed between the MWRA and MARMAP datasets. Consistencies between the MWRA and MARMAP datasets support the use of the MARMAP data to augment the MWRA baseline. This should be further evaluated by comparing the 1988 to present dataset (which has been recently made available) with the MWRA 1992-1997 baseline.

4) The existing broad-scale zooplankton abundance data do not demonstrate a uniqueness to Cape Cod Bay zooplankton communities. The dense patches of zooplankton observed in the Bay (documented in the CCS database) on which whales feed therefore appear not to result from a unique background zooplankton community, but rather on the interaction of physical and behavioral factors within the Bay itself, acting to locally concentrate a widespread resource.

## 4.2 Sources of uncertainty

The limitations of our understanding of the zooplankton in Mass Bay and Cape Cod Bay center on the trophic relationship which form the basis for the observed results, including recruitment and losses from predation (GLOBEC 1989).

### 4.2.1 Recruitment

Recruitment variability is the single most important natural event controlling population size in marine animal populations (eg. GLOBEC 1989). Recruitment can be defined as the number or mass of individuals passing into a given life stage, age-class, or size-class over some time interval. In fisheries ecology, recruitment is used to mean the number of young fish entering the catchable portion of the population. In benthic ecology, recruitment is used to mean the number of individuals settling successfully from the planktonic larval stage into the adult population. For holozooplankton such as copepods, recruitment is also important in determining population size, and the term is used to mean the number of young making it to the adult stage per unit time. In essence, recruitment is a measure of survivorship during the pre-adult stages. This survivorship is determined by food availability, predation mortality, and emigration via advective transport. Given the wide array of interacting physical, chemical, and biological variables that determine recruitment, understanding these dynamics well enough to adequately explain the abundance patterns described in this report is difficult. Mere statistical description and comparisons of the data, while a necessary first step, are inadequate for understanding the underlying dynamics controlling the patterns. The objective of this report was to characterize the data. Further work is needed, including process-oriented modeling to examine specific components of the system.

### 4.2.2 Grazing

Another limitation is the difficulty in examining food web interaction. There is much debate as to whether systems are controlled by "top-down" or bottom-up" factors (Sommer 1989). No discussion is provided in this report regarding grazing pressure for zooplankton/phytoplankton, nor planktivorous fish/zooplankton predators, since adequate data are not present in the MWRA, CPR, and MARMAP datasets. Related data are available in the CCS dataset (e.g., whale feeding), but such a task was beyond the scope of this report.

## 5.0 RECOMMENDATIONS

The zooplankton component of the MWRA monitoring program should focus on the potential alteration of community structure in the nearfield, where the greatest likelihood of impact exists. However, a more comprehensive understanding of the causes of the observed variability in the baseline data will be required in order to interpret significant change in the zooplankton assemblage should it be demonstrated. Statistical analysis of relationships between physical and biological variables (including potential effect of temperature, salinity, wind forcing, fluorescence and nutrients on the variability of zooplankton abundance in time and space) is necessary, despite the sources of uncertainty described in section 4.2. The baseline monitoring data are sufficiently robust to support the analyses of these first-order relationships.

In addition, hydrodynamic modeling being undertaken under HOM3 should examine specific process-oriented dynamics such as the transport of particular copepod species (e.g. *Calanus* and *Pseudocalanus*) through the Bays. These efforts should examine the relative importance of in- situ growth of the populations in the Bays versus advective transport through the system to help understand the potential effects of the altered nutrient loading regime.

Given the importance of Cape Cod Bay as a critical habitat for the northern right whale and the whale population's tenuous status, studies outside of the MWRA monitoring program should be promoted to address these concerns. Since neither the MWRA station (F02) or NMFS MARMAP stations are located in eastern Cape Cod Bay, comparison of the historical data from CCS samples in this region with recent high resolution zooplankton sampling should be pursued. Such comparisons may help bridge the gap between the historic zooplankton record and the dynamics of patch formation in eastern Cape Cod Bay. High resolution automated surveys quantifying plankton taxa throughout MB and CCB is also recommended to enhance our understanding of the significant temporal and spatial variability which exists within the Bays. These surveys should at a minimum include the well-mixed and stratified periods of the year which encompass the seasonal utilization of the region by the whales.

### 5.1 Acknowledgments

The authors wish to acknowledge the people who contributed to the synthesis of this report. We would like to acknowledge Julien Goulet and Ken Sherman of National Marine Fisheries (NMFS), and David Stevenson of Maine Department of Marine Resources, Jude Wilber of Capella Consulting Group (WHOI), and Ron Sher of North Atlantic for providing some of the literature and data for this paper and to Andrew Solow of Woods Hole Oceanographic Institute (WHOI) for providing statistical advice.

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# APPENDIX A

# TAXA LIST

| APPENDIX A – TAXA LIST | | | | |
|---|---|---|---|---|
| **MWRA** | **MARMAP** | | **CPR** | **CCS** |
| *Acartia hudsonica* | *Acartia clausi* | **Con't** | *Acartia* spp. | *Acartia* |
| Bivalvia spp. | *Acartia danae* | *Limacina* spp. – Secondary Name | Anomura | *Calanus finmarchicus* |
| Bryozoa spp. | *Acartia longiremis* | *Mecynocera clausi* | Appendicularia | *Calanus* tails |
| *Calanus finmarchicus* | *Acartia* spp. | *Meganyctiphanes norvegica* | Brachyura | *Centropages* |
| *Centropages hamatus* – C4+C5 | *Acrocalanus longicornis* | *Metridia longa* | Bryozoa | chaeto |
| *Centropages* spp. | Aetideidae | *Metridia lucens* | *Calanus finmarchicus* | Copepods |
| *Centropages typicus* | *Alteutha depressa* | *Metridia* spp. | *Calanus glacialis* | Cyprid |
| Cirripede spp. | Amphipoda | *Microcalanus pusilus* | *Calanus helgolandicus* | Decapod larvae |
| Copepod spp. | Appendicularia | *Microcalanus* spp. | *Candacia armata* | *Eurytemora* |
| Crustacea: Unidentified Crustacean | Asteroidea | *Microsetella* spp. | Cavoliniidae | Fish eggs |
| Decapoda spp. | Balanidae | *Monstrilloida* spp. | *Centropages hamatus* | Gastropoda larvae |
| *Echinoderm plutei* | *Brachyscelus crusculum* | Mysidacea | *Centropages typicus* | Nauplii |
| *Eurytemora herdmani* | Brachyura | *Mysidopsis bigelowi* | Chaetognatha Hpr Eyecount | Non-cal copepods |
| *Evadne nordmanni* | Bryozoa | *Nanocalanus minor* | Chaetognatha Hpr Traverse | *Paracalanus/Pseudocalanus* complex |
| *Evadne* spp. | Calanidae | *Nanomia cara* | Cirripedia | *Paracalanus/Pseudocalanus* complex tails |
| Fish spp. | Calanoida | Nematoda | *Clausocalanus* spp. | Raw *Pseudocalanus minutus* |
| Gastropoda; Mollusca | *Calanus finmarchicus* | *Neomysis americana* | Coelenterata | Raw tails |
| Harpacticoida spp. | *Calanus minor* – Secondary Name | *Oikopleura* spp. | Copepoda | *Temora* |
| Medusa | *Calanus* spp. | *Oithona spinirostris* | Corycaeus spp. | *Temora longicornis* |
| *Metridia lucens* | *Calocalanus* spp. | *Oithona* spp. | Decapoda - Arthropoda | *Tornatus* |
| *Microsetella norvegica* | *Candacia armata* | *Oncaea* spp. | Echinodermata | Total zooplankton |
| *Oikopleura dioica* | *Candacia* spp. | Ophiuroidea | *Eucalanus* spp. | Unidentified copepods |
| *Oithona atlantica* | Caridea | Ostracoda | *Euchaeta norvegica* | Unidentified non-copepods |
| *Oithona similis* | *Centropages bradyi* | Paguridae | Euphausiacea | |
| *Paracalanus parvus* | *Centropages furcatus* | *Paracalanus parvus* | *Eurytemora americana* | |
| *Podon polyphemoides* | *Centropages hamatus* | *Paracalanus* spp. | *Eurytemora herdmani* | |
| Polychaete spp. | *Centropages* spp. | *Paraeuchaeta norvegica* – Secondary Name | *Evadne* spp. | |
| *Pseudocalanus newmani* | *Centropages typicus* | Pelecypoda | Fish | |
| *Temora longicornis* | Cephalopoda | *Penilia avirostris* | Foraminifera | |
| *Tortanus discaudatus* | Chaetognatha | Phoronida | Gammaridea | |
| Unidentified Larvae | Cladocera | *Pleuromamma* spp. | Harpacticoida | |
| | *Clausocalanus arcuicornis* | *Podon intermedius* | Heteropoda | |
| | *Clausocalanus furcatus* | *Podon* spp. | Hyperiidea | |
| | *Clausocalanus* spp | Polychaeta | Invertebrate | |
| | *Clytemnestra* spp. | Pontellidae | *Lucicutia* spp. | |
| | Cnideria – Secondary Name | Pseudocalanidae | *Metridia longa* | |
| | Coelenterata | *Pseudocalanus minutus* | *Metridia lucens* | |
| | Copepoda | *Pseudocalanus* or *Calanus* | *Metridia* spp. | |
| | Corycaeidae | *Pseudocalanus* spp. | Mysidacea | |
| | *Crangon septemspinosa* | Pycnogonida | *Nanocalanus minor* | |
| | Crangonidae | *Rhincalanus nasutus* | Natantia | |
| | *Ctenocalanusvanus* | *Sagitta elegans* | Nematoda | |
| | Ctenophora | *Sagitta serratodentata* | *Oithona* spp. | |
| | Cumacea | *Sagitta* spp. | Ostracoda | |
| | Cyclopoida | Salpidae | *Paracalanus* or *Pseudocalanus* | |
| | Decapoda-Arthropoda | *Scolecithricella* spp. | *Paracalanus* spp. | |
| | Echinodermata | Scolecithricidae | Pelecypoda | |

## APPENDIX A – TAXA LIST (Con't)

| MWRA | MARMAP | | CPR | CCS |
|---|---|---|---|---|
| | *Eucalanus* spp. | Siphonophora | *Pleuromamma piseki* | |
| | *Euchaeta norvegica* | *Spiratella retroversa* | *Pneumodermopsis paucidens* | |
| | Euchaetidae | *Spiratella* spp. | *Podon* spp. | |
| | *Euchirella* spp. | *Temora longicornis* | Polychaeta | |
| | Euphausiacea | *Temora* spp. | *Pseudocalanus* spp. | |
| | *Eurytemora hirundoides* | *Temora stylifera* | *Scina* spp. | |
| | *Eurytemora* spp. | Thalassinidea | Sergestidae | |
| | *Evadne nordmanni* | Thecosomata | Siphonophora | |
| | *Evadne spinifera* | *Thysanoessa inermis* | *Spiratella retroversa* | |
| | *Evadne* spp. | *Thysanoessa longicaudata* | *Spiratella* spp. | |
| | Fish | *Thysanoessa raschii* | *Temora longicornis* | |
| | Foraminifera | Tomopteridae | *Temora turbinata* | |
| | *Fritillaria* spp. | *Tomopteris helgolandica* | Thecosomata | |
| | Gammaridae | *Tomopteris* spp. | Tintinnidae | |
| | Gastropoda | *Tortanus discaudatus* | *Tortanus discaudatus* | |
| | Gymnosomata | *Tortanus* spp. | | |
| | *Halithalestris croni* | Unidentified Zooplankton and Fragments | | |
| | *Halithalestris* spp. | | | |
| | Harpacticoida | | | |
| | Heteropoda | | | |
| | Heterorhabdidae | | | |
| | Hydrozoa | | | |
| | Hyperiidae | | | |
| | Invertebrate | | | |
| | Isopoda | | | |
| | *Labidocera aestiva* | | | |
| | Larvacea – Secondary Name | | | |
| | *Limacina retroversa* – Secondary Name | | | |

# APPENDIX B

# STATISTICAL RESULTS

**Tests for significance**
**Center for Coastal Studies**
**Feeding Whale vs No Whale Present Samples**
**(Conical Surface Samples)**

| What to test?[1] | Time frame | Two-way ANOVA Year Effect | p Value Year | Two-way ANOVA Main Effect | p Value Main | Area of Greater Assemblage |
|---|---|---|---|---|---|---|
| Total abundance | March | not significant | 0.8008 | significant | 0.0000 | Feeding Whale populations |
| | April | not significant | 0.2635 | significant | 0.0000 | Feeding Whale populations |
| Calanus finmarchicus | March | not significant | 0.2530 | significant | 0.0000 | Feeding Whale populations |
| | April | significant | 0.0002 | significant | 0.0000 | Feeding Whale populations |
| Pseudocalanus/Paracalanus | March | not significant | 0.1000 | significant | 0.0000 | Feeding Whale populations |
| | April | significant | 0.0001 | significant | 0.0000 | Feeding Whale populations |
| Centropages spp. | March | not significant | 0.4415 | significant | 0.0023 | Feeding Whale populations |
| | April | not significant | 0.0986 | significant | 0.0000 | Feeding Whale populations |
| Cyprids | March | not significant | 0.2041 | not significant | 0.7490 | Feeding Whale populations |
| | April | significant | 0.0000 | significant | 0.0000 | Feeding Whale populations |
| Nauplii | March | not significant | 0.7579 | not significant | 0.0542 | Feeding Whale populations |
| | April | significant | 0.0316 | significant | 0.0004 | Feeding Whale populations |

Notes:
[1]All statistics were run on Feeding whale samples vs No whale samples with an alpha = 0.05

**Tests for significance**
**Center for Coastal Studies**
**Whale Present vs No Whale Present Samples**
**(Vertical Pump Samples)**

| What to test?[1] | Time frame | Two-way ANOVA Year Effect | p Value Year | Two-way ANOVA Main Effect | p Value Main | Area of Greater Assemblage |
|---|---|---|---|---|---|---|
| Total abundance | January - June | questionable | 0.0797 | significant | 0.0004 | Whale present samples |
| Calanus finmarchicus | January - June | not significant | 0.2654 | not significant | 0.0811 | Whale present samples |
| Pseudocalanus/Paracalanus | January - June | not significant | 0.0737 | questionable | 0.5320 | Whale present samples |
| Centropages spp. | January - June | questionable | 0.1610 | not significant | 0.0667 | Whale not present samples |

Notes:
[1] All statistics were run on Feeding whale samples vs No whale samples with alpha = 0.05

**Tests for significance**
**Center for Coastal Studies**
**No Whale Present vs MWRA Baseline Dataset**
**(1994 - 1996)**

| What to test?[1] | Time frame | Two-way ANOVA Year Effect | p Value Year | Two-way ANOVA Main Effect | p Value Main | Area of Greater Assemblage |
|---|---|---|---|---|---|---|
| Total abundance | January - June | questionable | 0.0738 | significant | 0.0000 | MWRA samples |
| Calanus finmarchicus | January - June | not significant | 0.7002 | significant | 0.0431 | MWRA samples |
| Pseudocalanus/Paracalanus | January - June | not significant | 0.9815 | not significant | 0.1470 | MWRA samples |
| Centropages spp. | January - June | not significant | 0.3088 | significant | 0.0017 | MWRA samples |

Notes:
Alpha level = 0.05

## Tests for significance between Cape Cod Bay and Massachusetts Bay
## MARMAP Samples
## 1977-1987

| What to test?[1] | Time frame | Two-tailed P-values | P value (Alpha Level) | Calculated T statistic | Critical T statistic | Area of Greater Assemblage | Paired T-test |
|---|---|---|---|---|---|---|---|
| Total zooplankton | baseline | 0.437 | 0.05 | 0.786 | 2.024 | Cape Cod Bay | not significant |
| Calanus finmarchicus | baseline | 0.576 | 0.05 | -0.564 | 2.024 | Massachusetts Bay | not significant |
| Pseudocalanus minutus | baseline | 0.642 | 0.05 | 0.467 | 2.024 | Cape Cod Bay | not significant |
| Paracalanus parvus | baseline | 0.908 | 0.05 | -0.115 | 2.024 | Massachusetts Bay | not significant |
| Centropages hamatus | baseline | 0.741 | 0.05 | 0.333 | 2.024 | Cape Cod Bay | not significant |
| Centropages typicus | baseline | 0.913 | 0.05 | 0.109 | 2.024 | Cape Cod Bay | not significant |
| Acartia sp. | baseline | 0.061 | 0.05 | 1.92 | 2.024 | Cape Cod Bay | not significant |
| Oithona sp. | baseline | 0.957 | 0.05 | -0.053 | 2.024 | Massachusetts Bay | not significant |

Notes:

[1]All statistics were run on baseline data, 1977 - 1987 (NMFS)

Sample size for all analyses (N= 39)

**Tests for significance between Cape Cod Bay and Massachusetts Bay**
**MWRA Samples**
**1992-1996**

| What to test?[1] | Area | Three-way ANOVA Station Effect | p Value Station | Three-way ANOVA Month Effect | p Value Month | Three-way ANOVA Year Effect | p Value Year | Three-way ANOVA Region | p Value Region | Area of Greater Assemblage |
|---|---|---|---|---|---|---|---|---|---|---|
| Total zooplankton | Cape Cod Bay | not significant | 0.9451 | significant | 0.0000 | significant | 0.0032 | | | |
| | Mass Bay | not significant | 0.3977 | significant | 0.0000 | significant | 0.0000 | | | |
| Calanus finmarchicus | Cape Cod Bay | not significant | 0.9669 | significant | 0.0008 | not significant | 0.0844 | | | |
| | Mass Bay | not significant | 0.1118 | significant | 0.0000 | not significant | 0.5236 | | | |
| Pseudocalanus minutus | Cape Cod Bay | not significant | 0.9221 | significant | 0.0234 | significant | 0.0088 | | | |
| | Mass Bay | not significant | 0.2803 | significant | 0.0000 | significant | 0.0000 | | | |
| Paracalanus parvus | Cape Cod Bay | not significant | 0.7364 | not significant | 0.4370 | significant | 0.0000 | | | |
| | Mass Bay | not significant | 0.4503 | significant | 0.0000 | significant | 0.0000 | | | |
| Centropages hamatus | Cape Cod Bay | not significant | 0.6476 | significant | 0.0230 | significant | 0.0094 | | | |
| | Mass Bay | significant | 0.0000 | significant | 0.0000 | not significant | 0.4561 | | | |
| Centropages typicus | Cape Cod Bay | not significant | 0.4611 | significant | 0.0000 | significant | 0.0009 | | | |
| | Mass Bay | not significant | 0.3500 | significant | 0.0000 | significant | 0.0000 | | | |
| Acartia | Cape Cod Bay | not significant | 0.2260 | significant | 0.0007 | significant | 0.0022 | | | |
| | Mass Bay | significant | 0.0004 | significant | 0.0000 | significant | 0.0002 | | | |
| Oithona | Cape Cod Bay | not significant | 0.9713 | significant | 0.0000 | significant | 0.0227 | | | |
| | Mass Bay | significant | 0.0006 | significant | 0.0000 | significant | 0.0001 | | | |
| Total zooplankton | MB to CCB | | | | | | | not significant | 0.4768 | Mass Bay |
| Calanus finmarchicus | MB to CCB | | | | | | | significant | 0.0138 | Mass Bay |
| Pseudocalanus minutus | MB to CCB | | | | | | | not significant | 0.2338 | Cape Cod Bay |
| Paracalanus parvus | MB to CCB | | | | | | | not significant | 0.6878 | Mass Bay |
| Centropages typicus | MB to CCB | | | | | | | not significant | 0.7766 | Cape Cod Bay |
| Centropages hamatus | Nearshore to CCB | | | | | | | not significant | 0.1931 | Cape Cod Bay |
| | Offshore to CCB | | | | | | | significant | 0.0000 | Cape Cod Bay |
| Acartia | Nearshore to CCB | | | | | | | not significant | 0.8048 | Nearshore |
| | Offshore to CCB | | | | | | | significant | 0.0015 | Cape Cod Bay |
| Oithona | Nearshore to CCB | | | | | | | not significant | 0.8547 | Cape Cod Bay |
| | Offshore to CCB | | | | | | | significant | 0.0054 | Offshore |

Notes:
[1] All statistics were run on baseline data, 1992-1996 with alpha = 0.05

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