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Continuous Plankton Records: Massachusetts to Cape Sable, Nova Scotia, and New York to the Gulf Stream, 1988

by

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Abstract

Monthly monitoring of phytoplankton and zooplankton across the Gulf of Maine, and from New York towards Bermuda has been conducted for 28 and 18 years, respectively using the Hardy Continuous Plankton Recorder. Concurrent measurements of surface and water column temperature and surface salinity have been made on these routes for the past thirteen and twelve years, respectively. These features during 1988 are compared to the conditions from 1961 through 1987 for the Gulf of Maine and 1971 through 1987 for the New York Bight. Although departures for the whole of 1988 along the entire transects (or major geographical sections of them) were not significant for either of the variables, numerous highly significant departures were measured at particular time-space locations on both transects. These anomalies were due either to differences in the 1988 abundances or to the timing of the seasonal events. Consistent agreement between the presence of stability inducing conditions and the timing of phytoplankton blooms is demonstrated.

Introduction

From 1961 through 1974 the Oceanographic Laboratory in Edinburgh Scotland conducted monthly monitoring of the zooplankton and larger phytoplankton between Cape Sable, Nova Scotia and the Boston, Massachusetts area using the Hardy Continuous Plankton Recorder (CPR) (Hardy, 1939; Glover, 1967). In 1972, the US National Marine Fisheries Service (NMFS) began a program of cooperation with the Oceanographic Laboratory (now part of the Institute for Marine Environmental Research (IMER) for the extension of the long-term CPR survey into additional areas of the western North Atlantic. The two monthly sampling routes (Fig. 1) reported on here are the results of that effort. The year 1988 marks the 28th and 17th, respectively since sampling began on the Gulf of Maine and the New York Bight transects. Some 170 taxa are routinely identified and enumerated from these samples. This report is meant to present only the major features of the plankton conditions during 1988 and to compare these features with average conditions over the span of the survey. The two features presented are "total phytoplankton" obtained by visual comparison of sample color with a set of color standards (Colebrook and Robinson, 1961), and total Copepoda abundance.

Methods

Plankton, surface and water column temperature (XBT's), and surface salinity sampling using merchant vessels and other ships of opportunity has been conducted along the transects shown in Figure 1 at a desired sampling frequency of once per month.

Net phytoplankton and zooplankton from a depth of 10 m were collected with the CPR. At towing speeds of 10-17 knots a continuous record of the plankton retained by the sampler was obtained along the track of the ship. Water passing through the CPR was filtered with bolting silk having mean aperture dimensions of 225 x 234 microns. The continuous record was cut into 18.5 km (10 nmi) sections (herein termed "samples") with times, dates, and positions calculated for their center points. Prior to taxa identification the green or green-brown color of each sample was compared to a set of four, easily distinguishable color standards (no color, very pale green, pale green, and green;

Colebrook and Robinson, 1961). Assignment of numerical values to these color categories was achieved by dilution of acetone extracts from samples in each category. The average values for the categories were in the ratios of 0 to 1 to 2 to 6.5.

Futher details of the collection and processing methods may be found in Colebrook (1960, 1975). Only methods used by NMFS which differ from those of IMER will be detailed here. They are as follows:

1) Abundance of zooplankton taxa is reported as number of organisms per 100 m^3 of water filtered.

2) Route polygons have been established based on composites of all historical sampling locations for each route. These polygons differ from the IMER's CPR survey standard ecological areas in that they may exhibit considerable environmental variation along their long dimensions. Measured features are assumed to show reasonable similarity crosswise at any point along the polygon. Sample locations were tested against these polygons during data processing, and outliers were excluded from the polygon data base.

3) Distance to each sample from a route-specific reference point is calculated. This same reference distance is calculated for any other biological or environmental data measurements made on the cruise, as well as for any data from non-CPR cruises which could appropriately be combined for analysis.

4) In contrast to previous reports (Jossi et al, 1984, 1985, 1986a and 1986b) where the data from the entire route were lumped for analysis, this report is based on the generation of a standardized time-space matrix with interpolated grid values each 15.23 days along the x, or calendar year axis, and each 17.38 kilometers along the y, or reference distance axis. Full details of the gridding technique are beyond the scope of this paper. However, a brief description is in order.

The time, date, and position each sample is used to determine the sample's julian day, and the radial distance from each transect's reference point. These two values, along with the scalar value of the sample, e.g., log10(abundance + 1) were superimposed on a grid with dimensions given above, resulting in a 3-dimensional time-space-scalar matrix.

The standard grid dimensions were chosen considering a) the average sampling coverage in time (30 days) and space (25 km); b)the size of the grid, i.e., the maximum time period (usually one year) and maximum reference distance (452 km); c) the known rates of change of the scalar values to be gridded; and d) the desire to represent and compare the results in as standard a manner as possible.

The interpolation of each grid point was accomplished by performing an eliptical search of 40 km by 35 days, weighting all the irregularly spaced values found in the elipse according to the inverse square of their distance from the grid point; and calculating the weighted mean.

All calculations of zooplankton abundance were performed on log transformed values, whereas portrayals of abundances show antilogs of such calculated values.

All values for a calendar year were exposed to these techniques to produce annual grids or "maps". Gridding of the combined values for all the years in each series produced long term mean "maps" (1961 through 1987 for the Gulf of Maine; 1971 through 1987 for the New York Bight). Direct calculations of standard deviations for each grid point within such a long term "map" was not possible due to the inability to retain the actual raw values found in each eliptical search. Instead the following method of estimating these standard deviations was employed:

S= sqrt(abs(R − Q) where

S= estimated standard deviation map of the long term grid mean values

sqrt= square root

abs= absolute value

R= multi-year values squared and then gridded

Q= multi-year values gridded and then squared

The ommission of the (n/n-1) term is considered insignificant since n was usually greater than 70 at each grid point.

Annual anomalies and standardized anomalies (anomalies divided by long term standard deviations) were calculated at each grid point where yearly coverage permitted.

5) The conditions during the whole of 1988 for various sections of the two transects have been calculated. In the case of the Gulf of Maine annual means and departures for the areas over Massachusetts Bay, Wilkinson Basin, the central Gulf of Maine ledges, Crowell Basin, the Scotian Shelf, and the entire transect are presented. For the New York Bight annual means and departures are presented for the continental shelf, the area over Deep Water Dump Site 106 (DWDS 106), and the entire transect.

Results

Massachusetts to Cape Sable, N.S.

The time-space distribution of "total phytoplankton" across the Gulf of Maine during 1988 is shown in Figure 2. Two major features of the time-space distribution stand out. A ridge of high values representing the spring bloom extends from Massachusetts to beyond the Crowell Basin. The onset of the event is much earlier in Massachusetts Bay and Wilkinson Basin than elsewhere along the transect and its duration is also longer. Time of the maximum values is late March to early April in Massachusett Bay, but mid-April along the rest of the ridge. By the end of May east of Cashes Ledge and the end of June for the western portion of the transect levels have returned to values comparable with those of the winter with only a small increase over Wilkinson Basin and Massachusetts Bay in the early to mid fall. In contrast the major seasonal event on the Scotian Shelf occurs from the first of June to mid-August, and is centered around mid-July. Maximum values are comparable to those earlier in the year for the rest of the transect. Portions of the Scotian shelf exhibit slightly elevated values during January, and through the fall and early winter.

The standardized anomalies of "total phytoplankton" during 1988 (based on 1961 through 1987 means) are shown in Figure 3. Significant departures from the long term means, in the strictest sense, would be confined to time-space areas in excess of two standard deviations. However, the gridding method offers information on departure trends which have continuity over broader areas. Thus the areas in excess of one standard deviation are portrayed as well. Significant positive departures occurred over the Scotian Shelf in January and February, and again in November and December. Over Massachusetts Bay, Wilkinson Basin and parts of Crowell Basin significant positive anomalies were also observed during the spring bloom period. Some significant, but scattered, negative departures were observed across the Gulf of Maine during the fall.

The 1988, and 1961 thru 1987 means of "total phytoplankton" for sections of the Gulf of Maine (Table 1) show a similar pattern of variation along the transect. For both these statistics Massachusetts Bay yielded the highest values followed by Wilkinson Basin, the Scotian Shelf, the central Gulf ledges, and the Crowell Basin. The 1988 departures were positive, with the exception of those over Crowell Basin, but for no section did they depart by an amount considered significant for 1988 as a whole.

Total Copepoda distribution across the Gulf of Maine during 1988 is shown in Figure 4. Abundances were below the 20,000/100 m^3 level during January and February along the entire transect. The spring increase began over the Scotian Shelf in mid-March and over Massachusetts Bay by the beginning of April. This increase, to values in excess of 20,000 began later over the rest of the transect, especially near Cashes Ledge where this level of abundance was not reached until mid-May. Peak yearly values occurred over Wilkinson Basin in mid-April amounting to >80,000, and over the Scotian Shelf in mid-May amounting to > 100,000. Values from July through September declined to less than 20,000 over Crowell Basin and the outer Scotian Shelf and to below 40,000 over the western Gulf of Maine. A higher abundance ridge reaching > 80,000 just east of the Wilkinson Basin occurred in October. Values dropped back to winter levels along the entire transect by mid-November.

Standardized anomalies of total Copepoda abundance across the Gulf of Maine during 1988 (based on 1961 through 1987 means) are shown in Figure 5. The spring positive anomalies over the Scotian Shelf and Crowell Basin are largely a consequence of differences in timing rather than differences in absolute abundance at any particular time and place, i.e., the increase began nearly one month earlier than usual and the spring high lasted approximately one month longer than usual. On the other hand the positive anomalies in the fall over the Scotian Shelf represent significantly higher abundances in 1988 for this time-space area. The other major area of positive anomalies occurred over Wilkinson Basin from January to mid-February and over Massachusetts Bay during March and April, and November. These abundances are significantly higher than the long term means. One area of negative anomaly occurred from late July into September over parts of Crowell Basin due to the extensive area (Fig. 4) of abundances < 20,000.

The 1988, and 1961 thru 1987 total Copepoda means for sections of the Gulf are listed in Table 2. The pattern of variation between sections mentioned above for "total phytoplankton is seen here, i.e. highest values in Massachusetts Bay followed by Wilkinson Basin, the Scotian Shelf, the central Gulf ledges, and the Crowell Basin. None of the sections exhibited significant departures from the long term annual means for 1988 as a whole.

New York to the Gulf Stream

The time-space distribution of "total phytoplankton" along this mid-Atlantic Bight transect during 1988 is shown in Figure 6. Over the shelf portion of the transect the 1988 seasonal cycle of phytoplankton color falls into three categories: low values occurring during the winter and summer months, a spring high beginning in late February over the outer shelf and continuing towards the inner shelf peaking in May, and a fall increase also following the offshore to onshore time progression during the period July to early December. Offshore localizations of high values occurred at about 400 km reference distance in March and June, but the major area of high values stretched from 250-450 km between mid-July and early November reaching the highest values (2.0) anywhere for the year in August at 300 km offshore.

Standardized anomalies of "total phytoplankton" during 1988 (based on 1971 through 1987 means) are shown in Figure 7. Significant positive anomalies on the shelf occurred at approximately 70 km at the end of Apil and over a large portion of the outer shelf and shelf break during July through September. Scattered negative anomalies occurred on the shelf, especially during the last half of the year, the most significant being in the vicinity of Ambrose Light in September and October. The offshore portion of the transect exhibited scattered departures throughout the year, but the major feature occurred beyond 300 km between August and October where significantly larger values were measured than those of the long term means.

The 1988, and 1971 thru 1987 means of of "total phytoplankton" for the continental shelf section; the DWDS 106 section; and for the entire transect are listed in Table 3. Mean values over the shelf were approximately 1.6 times those at the DWDS 106 both in 1988 and over the 1971 thru 1987 period. For both sections 1988 was 35-40% below the long term mean, but when considering the natural variability neither was shown to be significant.

Total Copepoda distribution along the mid-Atlantic Bight transect during 1988 is illustrated in Figure 8. Over the shelf portion there are two areas of abundance which stand out. They nearly meet at the end of July near Ambrose Light, but are more separated towards the outer shelf. The area of higher abundance in the latter half of the year is itself divided over the outer shelf near mid-October. These 1988 patterns of abundance of total Copepoda on the shelf are basically similar to those seen in the 1978 through 1987 means, although their proportions differ. Abundance reached values > 80,000/ m3 on the mid to outer shelf by March, declined to < 20,000 during late spring and early summer, and then climbed to > 200,000 during August. An August and September high, reaching 180,000, was also measured on the shoreward end of the transect, and finally abundances reached > 120,000 on the midshelf in late November. Offshore abundances were for the most part < 20,000. The two exceptions to this occurred, first at approximately 400 km reference distance in May and June with abundances in excess of 60,000, and second seaward of 375 km during August through October when abundances reached 80,000. Similarities between these total Copepoda time-space abundance patterns and those of the "total phytoplankton" (Fig. 6) should be noted.

Standardized anomalies of total Copepoda abundance across the mid-Atlantic Bight during 1988 (based on 1971 through 1987 means) are presented in Figure 9. For the shelf area positive departures began at 100 km reference distance in January and continued further offshore for most of February and March. This feature resulted from the earlier than usual increase over this area in 1988. In September abundance over much of the shelf was above average. Although long term means were exceeded by less than 2 standard deviations 1988 abundances were over 200,000 compared to the long term mean of approximately 20,000. In late November positive departures occurred over a small area of the mid shelf. Negative anomalies occurred at 50 km at the beginning of the year but the major negative shelf features were in May and July due to the broader than usual duration of the late summer-early spring abundance decline in 1988. At year end the inner and outer shelf exhibited significantly lower abundances than normal. Offshore a major area of negative values occurred from mid-February to the end of April. The spring increase in this area occurred approximately one month later than normal causing this anomaly. A positive anomaly occupied the area near DWDS 106 during the first two and one-half months of the year, but the most unusual positive departure of total Copepoda took place at the outer end of the transect between August and October when abuandances exceeded 80,000 compared to the long term mean of less than 20,000.

The 1988, and 1971 thru 1987 means of total Copepoda for sections of the New York Bight transect are listed in Table 4. Unlike the "total phytoplankton" these anomalies were all positive, yet none produced statistically high departures for 1988 as a whole.

Discussion

Anomalies for the whole of 1988 along the entire transects (or major geographical sections of them) were not significant for either "total phytoplankton" or total Copepoda. However, numerous highly significant departures were measured at particular time-space locations on both transects. The map algebra techniques used here were responsible for identifying these anomalous features.

Phytoplankton seasonal dynamics in the Gulf of Maine and the New York Bight in 1988 were closely related to stability and mixing of the water column. In winter, surface cooling and wind stress mix the water column preventing phytoplankton from remaining in the shallow photic zone. When surface density decreases as a result of vernal warming and/or surface freshening the water column becomes stable enabling phytoplankton in the photic zone to remain there and the bloom to commence. When the phytoplankton exhaust the nutrients the bloom collapses unless some mechanism, e.g., wind mixing, upwelling, advection, etc. occurs to bring additional nutrients into the photic zone to sustain or renew the bloom. By using water column temperature and surface salinity data collected concurrently with the CPR samples we were able to infer density structure which we used in examining the relationships between these physical features and the phytoplankton.

In Massachusetts Bay and Wilkinson Basin the sea surface began to freshen in March, providing the stability needed for the phytoplankton bloom to commence a month earlier than further offshore. By April sea surface warming in the mid-Gulf provided the stability needed for the observed bloom there. The timing of blooms on the Scotian Shelf in 1988 was unusual. Surface salinities show freshening and water column temperature indicated thermal stability in January and during November and December coinciding with the significant positive departures of "total phytoplankton" during these periods. Unstable conditions returned through the usual spring bloom period of April-May. By June and July stability was again in place, solar radiation was near the annual maximum, and a bloom significanly above normal for either this time, or the spring of the year occurred.

Relationships of "total phytoplankton" to stability and mixing in the water column of the New York Bight were similar to those just described for the Gulf of Maine, with the addition of the stability enhancing effect of the photic zone portion of ocean fronts. Within 50 km of shore an increase of "total phytoplankton" coincided with surface freshening in February. The bloom that commences in late February between 125 and 250 km coincided with a spreading of lower salinity water over the outer shelf at that time. The usual spring bloom near shore beginning in late March benefitted from both low salinity and increasing temperature induced stability. An unusual upwelling event in the mid Atlantic Bight during the summer spread large quantities of low salinity water over most of the continental shelf. This event matches the summer to early fall bloom of phytoplankton seen over the entire shelf, one which connected to the usual fall bloom associated with overturn.

Correlations between the timing of stability conditions and the onset of phytoplankton growth and reproduction are being sought using the time series described here as well as density and stability data from other sources. The techniques of map algebra seem especially promising for this purpose where maps can be lagged in time or space, and scalar values can be lumped in a variety of ways to mimic conditions believed to be occurring in nature.

Significantly high total Copepoda anomalies in the Gulf of Maine from January through May occurred during or following significantly high "total phytoplankton" anomalies. From June through December this possible relationship is not readily apparent. On the Scotian Shelf in May to July, and to a lesser extend in October and November, an opposite sequence was observed. In the New York Bight increases of total Copepoda either coincided with phytoplankton highs or occurred just after them in almost all cases. However, the lumped taxa presented here include taxa having a variety of seasonal cycles and trophic interaction characteristics. The phytoplankton-zooplankton interactions suggested above deserve further work where individual taxa or groups of taxa with similar seasonal cycles and trophic characteristics are tested for these relationships using all data in the time series.

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Table 1. "Total Phytoplankton" Means and Departures during 1988 for Sections of the Gulf of Maine Transect. (See test for explanation of relative green units.)

SECTION	1988 MEAN relative green	1971-1987 MEAN relative green	1988 ANOMALY relative green	1988 ZSCORE standard deviation
Massachusetts Bay	1.45	1.13	+0.32	+0.57
Wilkinson Basin	0.79	0.67	+0.12	+0.11
Ledges	0.37	0.34	+0.03	-0.11
Crowell Basin	0.29	0.33	-0.04	-0.16
Scotian Shelf	0.59	0.55	+0.04	+0.25
Entire Transect	0.64	0.57	+0.07	+0.11

Table 2. Total Copepoda Means and Departures during 1988 for Sections of the Gulf of Maine Transect.

SECTION	1988 MEAN no. per 100 m3	1971-1987 MEAN no. per 100 m3	1988 ANOMALY no. per 100 m3	1988 ZSCORE standard deviation
Massachusetts Bay	10,368	13,038	-2,670	-1.21
Wilkinson Basin	11,311	8,111	+3,200	+0.22
Ledges	8,886	6,162	+2,724	+0.20
Crowell Basin	8,238	3,905	+4,334	+0.30
Scotian Shelf	9,908	4,712	+5,196	+0.73
Entire Transect	9,594	6,148	+3,446	+0.15

Table 3. "Total Phytoplankton" Means and Departures during 1988 for Sections of the New York Bight Transect. See text for explanation of relative green units.)

SECTION	1988 MEAN relative green	1971-1987 MEAN relative green	1988 ANOMALY relative green	1988 ZSCORE standard deviation
Continental Shelf	0.67	1.11	-0.44	-0.18
DWDS 106	0.28	0.44	-0.16	-0.22
Entire Transect	0.47	0.73	-0.26	-0.08

Table 4. Total Copepoda Means and Departures during 1988 for Sections of the New York Bight Transect.

SECTION	1988 MEAN no. per 100 m3	1971-1987 MEAN no. per 100 m3	1988 ANOMALY no. per 100 m3	1988 ZSCORE standard deviation
Continental Shelf	22,004	14,438	+7,566	+0.19
DWDS 106	3,388	788	+2,610	+0.46
Entire Transect	5,585	3,255	+2,330	+0.15

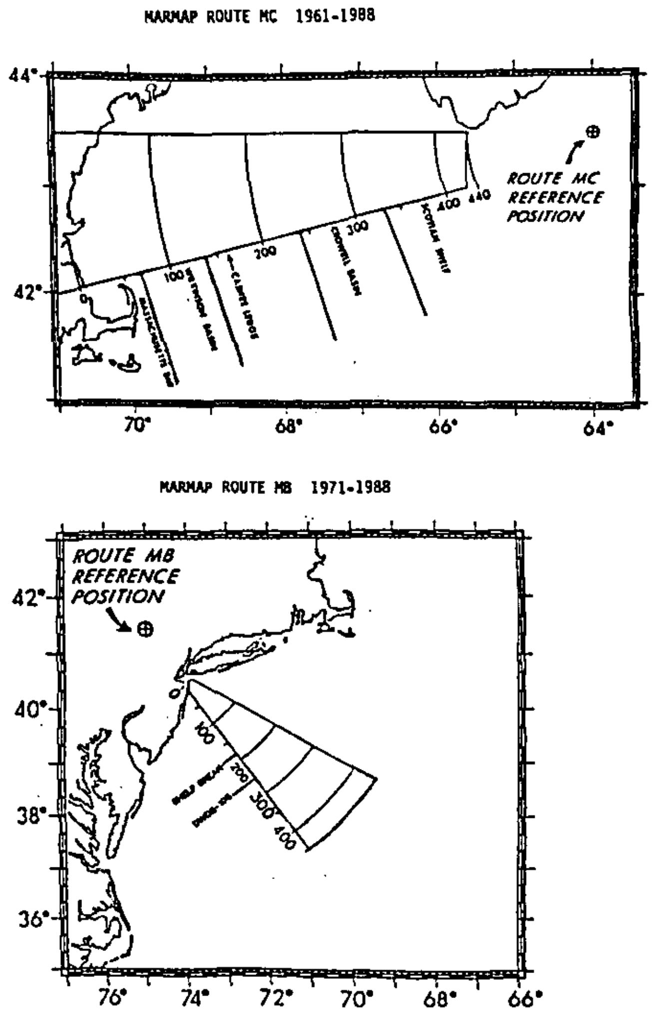

Figure 1. Gulf of Maine (MC) and New York Bight (MB) polygons within which sampling transects are conducted, with standard reference positions and reference distance scales.

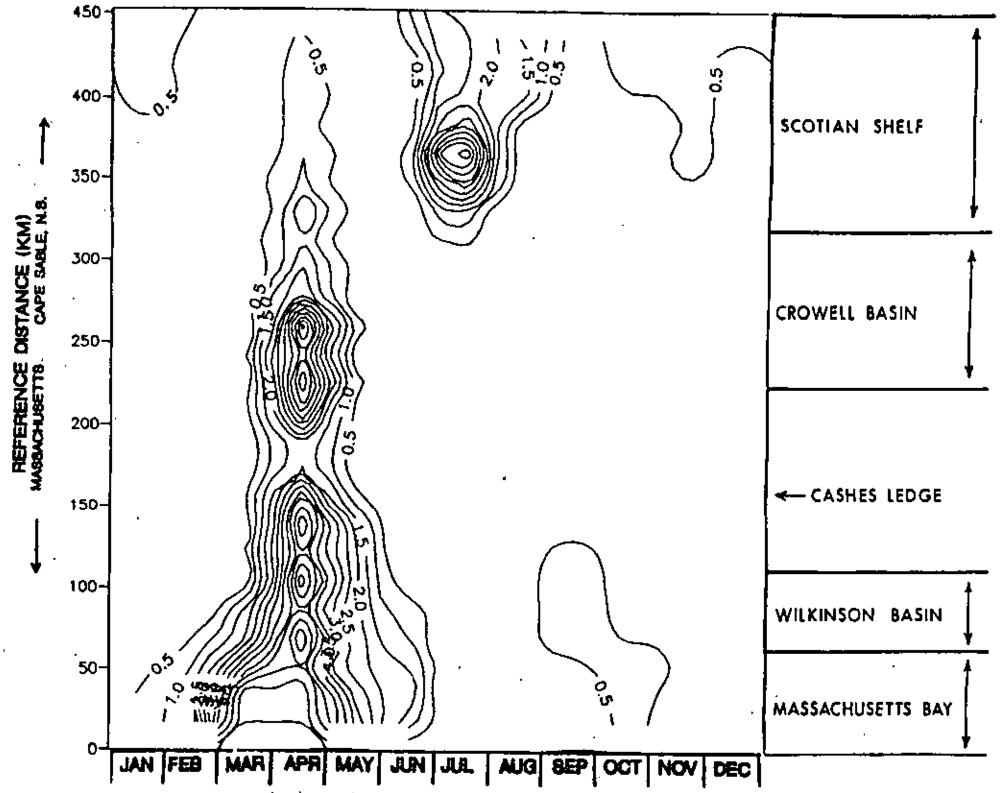

Figure 2. "Total phytoplankton" (relative green) along the Gulf of Maine transect during 1988. Unlabeled contour lines with no hachures enclose elevated values.

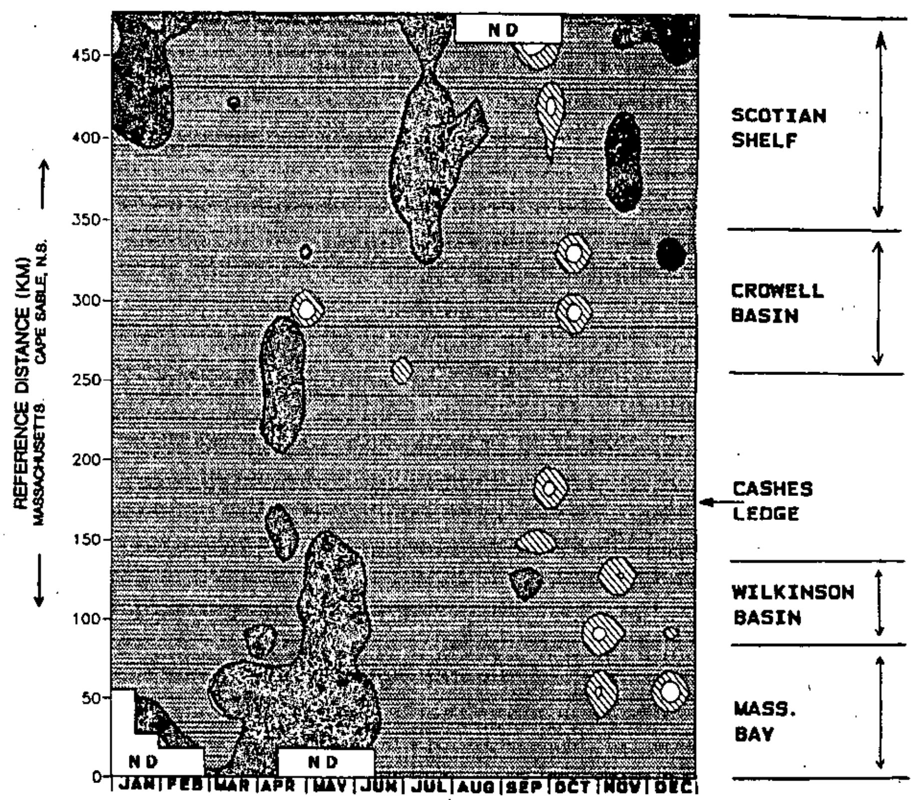

Figure 3. "Total phytoplankton" departures (standard deviation units based on 1961 through 1987 means) along the Gulf of Maine transect during 1988. Positive departures in excess of one standard deviation are shaded dark grey- in excess of positive two shaded black; negative departures in excess of one shown by hatching- in excess of two by white.

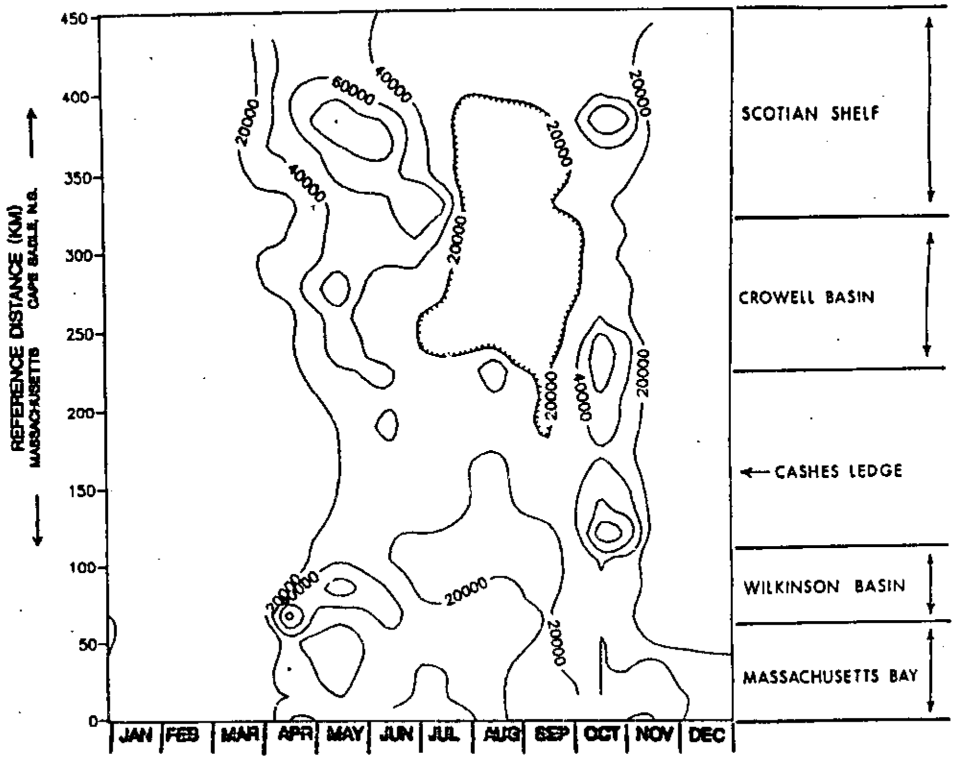

Figure 4. Total Copepoda abundances (no/100m3) along the Gulf of Maine transect during 1988. Abundance declines on those sides of contour lines with hachures. Unlabeled contour lines with no hachures enclose elevated abundances.

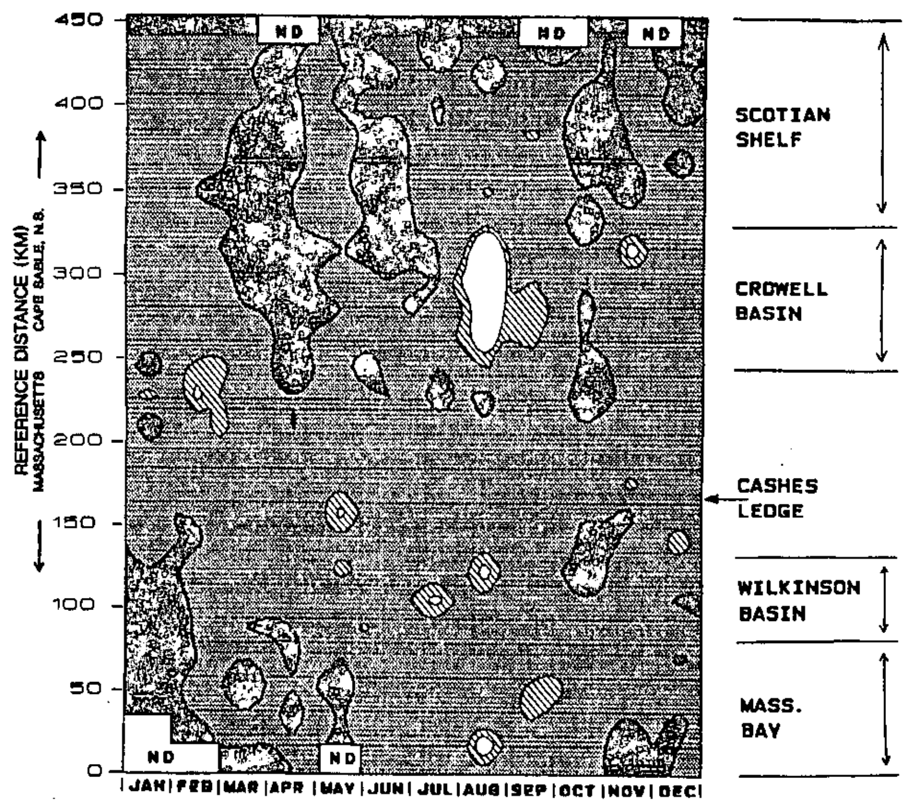

Figure 5. Total Copepoda abundance departures (standard deviation units based on 1961 through 1987 means) along the Gulf of Maine transect during 1988. Positive departures in excess of one standard deviation are shaded dark grey- in excess of positive two shaded black; negative departures in excess of one shown by hatching- in excess of two by white. ND indicates no data in 1988.

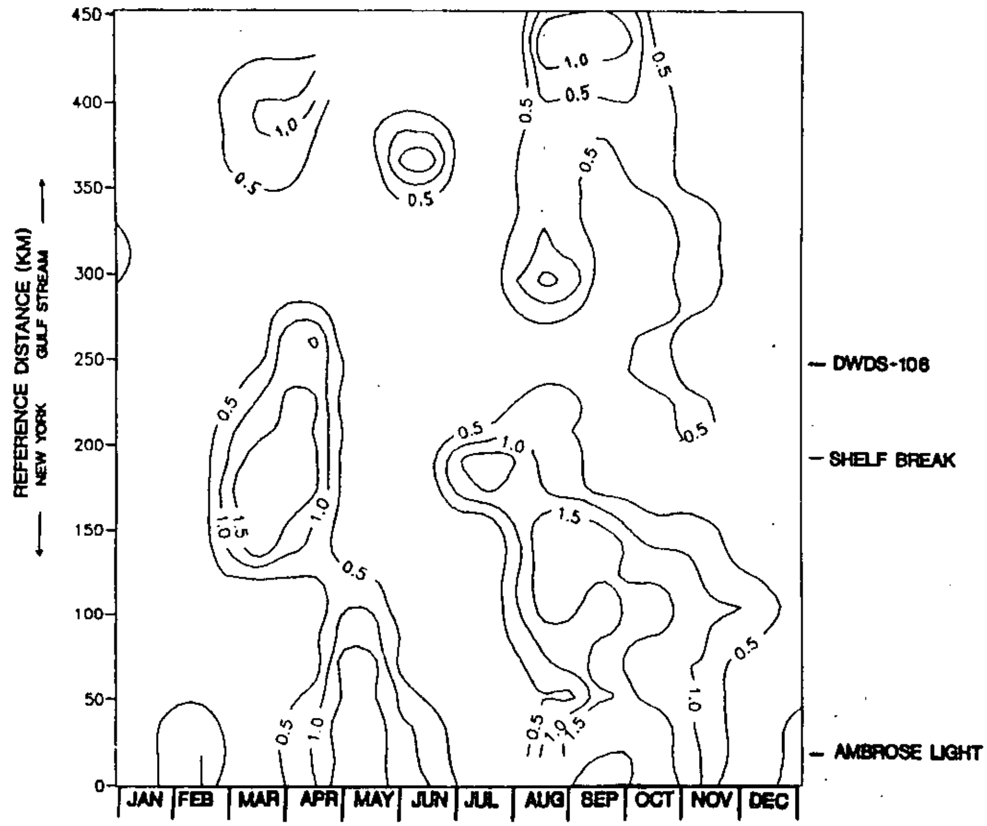

Figure 6. "Total phytoplankton" (relative green) along the New York Bight transect during 1988. Unlabeled contour lines with no hachures enclose elevated values.

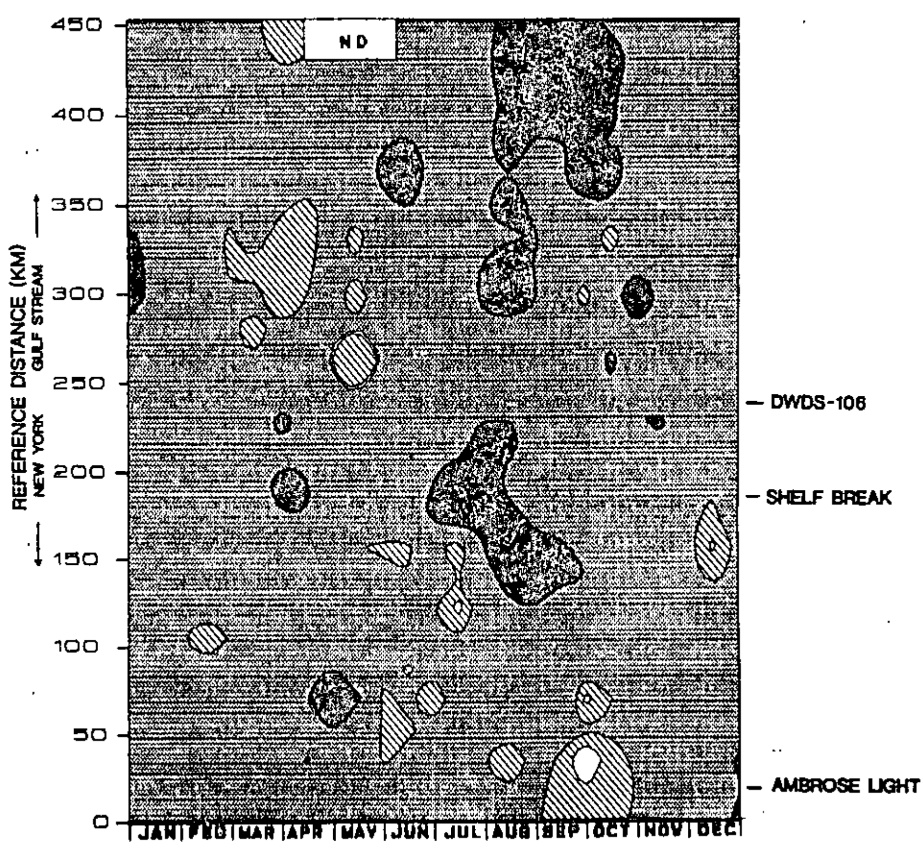

Figure 7. "Total phytoplankton" departures (standard deviation units) along the New York Bight transect during 1988. Positive departures in excess of one standard deviation are shaded dark grey- in excess of positive two shaded black; negative departures in excess of one shown by hatching- in excess of two by white.

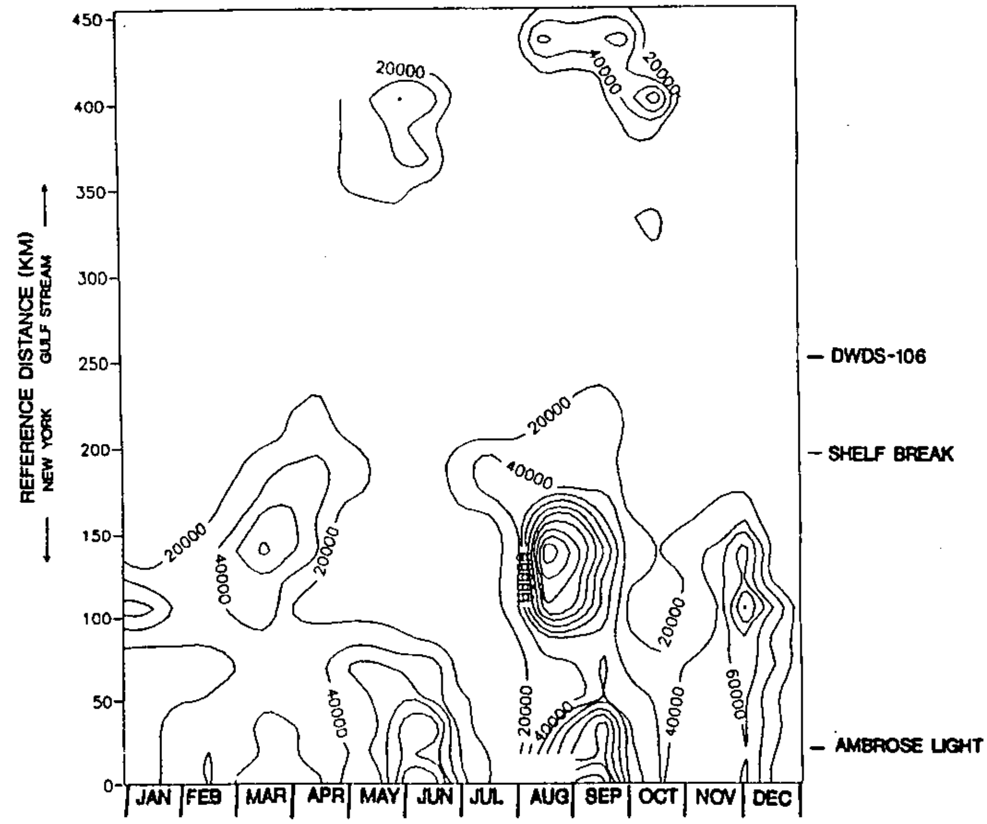

Figure 8. Total Copepoda abundances (no/100m3) along the New York Bight transect during 1988. Unlabeled contour lines with no hachures enclose elevated abundances.

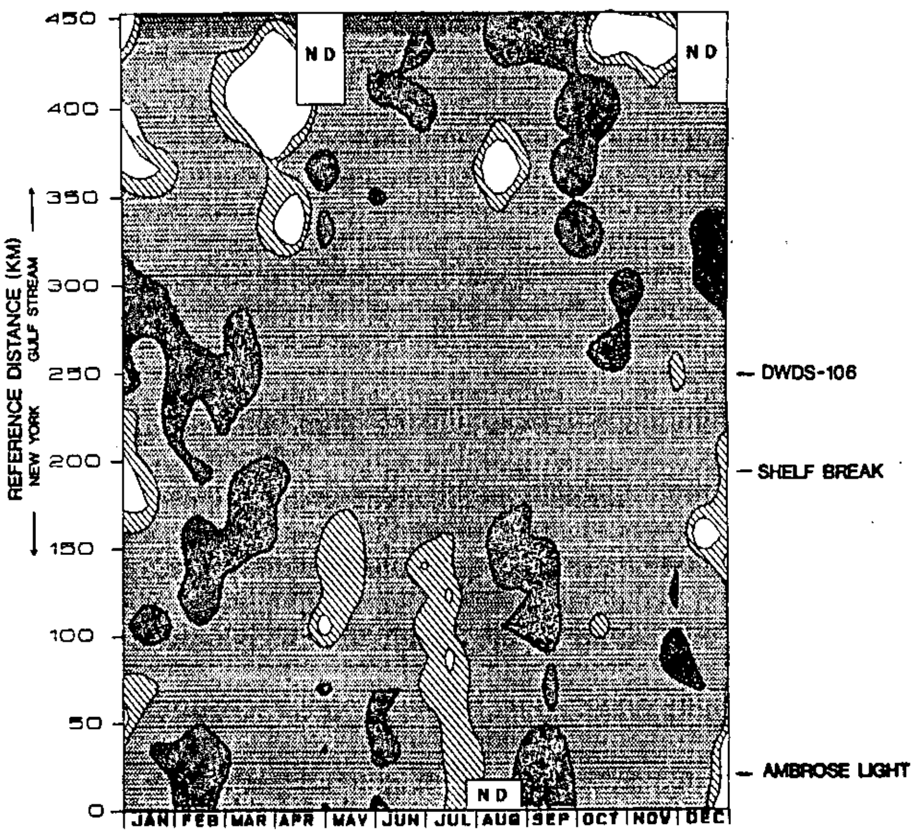

Figure 9. Total Copepoda abundance departures (standard deviation units based on 1978 through 1987 means) along the New York Bight transect during 1988. Positive departures in excess of one standard deviation are shaded dark grey- in excess of positive two shaded black; negative departures in excess of one shown by hatching- in excess of two by white. ND indicated no data in 1988.