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Timing of Plankton Cycles on the Newfoundland Grand Banks: Potential Influence of Climate Change

by

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Abstract

We investigate the seasonality of plankton from the CPR survey in the northwest Atlantic during 1961-2003. Results for the northwest Atlantic show remarkable stability in the timing of seasonal peaks for plankton on the Newfoundland Grand Banks across of broad range of taxa and trophic levels, in contrast to the pattern observed in the central North Sea. Our results suggest the main seasonality of plankton has remained relatively stable throughout the 1960-70's, 1990's and recent years despite comparable trends in ocean warming observed in the northeast Atlantic. The one result that was consistent between the NE and NW Atlantic was the lack of movement in the overall timing of the spring and autumn phytoplankton blooms. Recent studies suggest that day-length and photoperiod may regulate the timing of diatom blooms in general.

Introduction

The Continuous Plankton Recorder (CPR) Survey provides an assessment of long-term changes in abundance and geographic distribution of planktonic organisms ranging from small phytoplankton cells to larger macrozooplankton (Warner and Hays, 1994). CPR collections in the northwest Atlantic began in 1959 and continued with some interruptions during the latter period through till 1986. Collections were renewed in 1991 and continue to present. The recorder is towed by ships of opportunity along a number of standard routes throughout the North Atlantic. The CPR device collects plankton at a nominal depth of 7 m through an aperature and organisms are retained on a moving band of silk material and preserved. Sections of silk representing 18.5 km tow distance and ca. 3m^3 of water filtered[1] are analyzed microscopically. Every second section is analyzed providing a horizontal scale of ca. 37 km. The CPR taxon categories varied from species to subspecies, while others are identified at coarser levels such as genus or family. Throughout this report, we use the same level of identification of each taxon as provided in the original microscopic analysis.

The timing of plankton blooms has important implications for the transfer of energy through various trophic levels consisting of primary, secondary, and tertiary producers (Harrington *et al*., 1999; Cushing, 1990). Recent studies suggest the timing of plankton cycles in temperate marine systems were sensitive indicators of climate change (Edwards and Richardson, 2004). The general trend in rising ocean temperatures in the eastern North Atlantic during the later part of the 1990's and recent years is hypothesized to modify trophic interactions among key planktonic taxa, resulting in the alteration of food web structure, and leading to ecosystem level responses (Beaugrand *et al*., 2003; Edwards and Richardson, 2004). In this paper we investigate the timing of plankton cycles on the Newfoundland Grand Banks derived from the temporal distribution and abundance of major taxa from the CPR

[1] See SAFHOS web site at (http://192.171.163.165/..) for a description of the CPR Program collected for The Sir Alister Hardy Foundation for Ocean Science of Plymouth, England.

survey during 1961-77, and 1991-2003. Our results are compared with the trends recently reported in the central North Sea by Edwards and Richardson (2004) for the period 1958-2002.

Methods

The data analyzed in this report extend from 1961 to 2003 with an intervening gap from 1977 to 1990. The sampling distribution was uneven for both spatial and temporal scales due to the nature of opportunistic sampling with ships of opportunity, variation in shipping routes, and CPR funding (Fig. 1 and 2). The CPR taxa evaluated in this report included the dominant assemblages of phytoplankton, microzooplankton, an important macrozooplankton prey and predator species. We did not differentiate the data based on bathymetry (e.g. shelf versus slope) and included all the data bounded by the NAFO Div. 3L and 3Ps (Fig. 2).

The average seasonal cycle over the period from 1961-77 and 1991-2003 was used to determine the modality of the CPR taxa. In cases where uni-modal peaks occurred, all available monthly data were utilized. In cases where bi-modal peaks were detected, we partitioned the data into the first six months and the last six months of the year. We also excluded data from the analysis when more than two consecutive months were missing to reduce bias when calculating the timing of the seasonal peak. The timing of the seasonal peak in abundance throughout the entire growing season was calculated according to the index given by (Edwards and Richardson, 2004):

$$\mathbf{T} = \left(\sum_{i=1}^{12} \mathbf{M} \cdot \mathbf{x_m}\right) / \left(\sum_{i=1}^{12} \mathbf{x_m}\right)$$

The potential impact of climatic variation and ocean temperatures on the abundance of the CPR taxa were examined. The ocean climate index, the North Atlantic Oscillation (NAO), describing the large-scale atmospheric circulation over the Atlantic, is the difference in winter (Dec.-Feb.) air pressures between the Azores and Iceland. We used the NAO anomaly time series derived for a given year by subtracting by the long-term (1971-2001) climatology (Colbourne, 2004). Ocean temperatures were obtained from Station 27, an inshore coastal region more frequently sampled and representative of much of the Grand Banks Shelf region (Ouellet *et al*., 2003) The temperatures at Station 27 were linearly interpolated for the upper 10m and annual averages calculated during the corresponding CPR time series.

Results

The seasonality of phytoplankton during the 1960-70's indicated that both the spring and autumn peaks were consistent from year to year, with no overall trend apparent during the first two decades of the CPR time series on the Grand Banks (Fig. 3). The seasonality of dominant copepod taxa during the 1960-70's also showed remarkable consistency from year to year (Fig. 4). Interannual variability in seasonality of CPR copepods, particularly for *Paracalanus-Pseudocalanus* spp., can be high, and may mask any long-term trends. Variability in the seasonality of the macrozooplankton was observed during the early part of the time series. Interannual variability in seasonality of Chaetognatha and Euphausiacea revealed abrupt changes from summer to spring occurrence during the early to mid-1960's (Fig. 5). These two plankton groups also show evidence of a systematic and gradual move back to the summer period during the later part of the time series.

The transition to the 1990's and recent years revealed an apparent increase in the number of dominant CPR taxa across all functional groups examined. The seasonality of phytoplankton during the 1990's and recent years showed little change in the annual timing of peak abundance across the Grand Banks (Fig. 6). This period is also characterized by consistent seasonality in timing of occurrence of CPR copepod taxa (Fig. 7). The seasonality for most of the Macrozooplankton taxa was generally consistent throughout the 1990's and recent years but, the overall trend for Chaetognatha and Limacina indicated a shift in peak abundance toward an earlier bloom (Fig. 8). Overall, the results for the NW Atlantic show remarkable stability in the timing of seasonal peaks for CPR plankton on the Grand Banks in contrast to the pattern observed in the central North Sea (Fig. 9). The majority of the values of the slope over the two time periods of interest (1961-77 and 1991-03) indicated that they were not significantly different from zero (P>0.05; 50 out of total of 57 cases). The CPR taxa showing significant (P<0.05) trends in slope were the *Calanus* stages CI-CIV (juvenile copepodite stages) and CV-CVI (adult stages), *Oithona* spp. (a small ubiquitous copepod on the Grand Banks Shelf), *Chaetognatha* (microzooplankton predators) and *Euphausiacea* (important macrozooplankton prey item for higher trophic levels). In general, the pattern in timing differed for these species during the respective time series, with later occurrence during 1961-77, while a shift to earlier timing was observed during 1991-03 (Table 1).

Variability in ocean conditions have been linked to large-scale atmospheric winter circulation, sea ice conditions, local atmospheric forcing and advection reflected in the North Atlantic Oscillation (NAO). Given the large year-year changes in some of the CPR plankton groups, we explored the relationships between seasonality and the annual NAO anomaly and near-surface temperatures. No strong environmental signals were detected in either the NAO or temperature in relation to the seasonality of plankton on the Grand Banks during the study period (Fig. 10 and 11). Corrleation coefficients and significance levels for the relationship between interannual variation in seasonality of plankton and physical indices substantiated the lack of an environmental signal that could be detected (Table 2).

Summary and Conclusions

- Recent results by Edwards and Richardson from the NE Atlantic indicate significant earlier occurrence in seasonality of many phytoplankton and zooplankton taxa collected during the late spring and summer period as part of the CPR Survey over a 45-year time series (1958-2002).

- Edwards and Richardson indicate that the magnitude of changes in the timing of peak occurrence of plankton in the North Sea are greater than previously reported in terrestrial systems and suggest that temperate marine systems are sensitive indicators of climate change.

- In contrast, we did not observe any trends toward the earlier occurrence in the timing of plankton cycles in the NW Atlantic throughout the 1960-70's, 1990's and recent years.

- One consistent result between the NE and NW Atlantic was the lack of movement in the overall timing of the spring and autumn phytoplankton blooms. Recent studies suggest that day-length and photoperiod may regulate the timing of diatom blooms in general.

- The large shifts in timing of plankton cycles reported in the North Sea have occurred over a relatively narrow range of temperature (approximately 2ºC) during the study period 1958-2002.

- In the NW Atlantic over the same time period, the Newfoundland Shelf has experienced comparable temperature anomalies reaching amplitudes of 2-3ºC above and below the long-term mean.

- Despite these marked fluctuations in water temperatures and salinity on the Newfoundland Shelf over the last 4 decades and similar trends in ocean warming with the NE Atlantic since the late 1990's, no environmental signals could be detected in the seasonality of plankton.

Acknowledgements

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TABLE 1. The Continuous Plankton Recorder (CPR) taxa showing significant ($P<0.05$) trend in seasonality of blooms during the respective time series; 1961-77 and 1991-03. The value for slope (regression coefficient), correlation coefficient (r^2), and P-values from linear regression analysis provided.

CPR Taxa	Time Series	Slope	r^2	P-Value	Shift
Calanus CI-IV	1962-77	0.08	0.40	0.01	later
Calanus CV-CVI	1961-77	-0.07	0.22	0.04	earlier
Calanus CV-CVI	1991-03	0.05	0.33	0.02	later
Chaetognatha	1991-03	-0.20	0.41	0.01	earlier
Euphausiacea	1961-72	0.16	0.32	0.04	later
Euphausiacea	1991-03	-0.06	0.32	0.03	earlier
Oithona spp.	1991-03	-0.05	0.27	0.04	earlier

Table 2. Relationship between the Continuous Plankton Recorder (CPR) plankton and the annual North Atlantic Oscillation (NAO) anomaly and upper surface temperature respectively. Correlation coefficient (r^2) and P-values from linear regression analysis provided (NS = not significant at $P<0.05$).

CPR Taxa	r^2	P-Value
Phytoplankton		
Ceratium arcticum	-0.03 / -0.03	NS / NS
C. fusus	-0.02 / -0.04	NS / NS
C. tripos	-0.19 / -0.05	NS / NS
Chaetoceros spp.	-0.03 / -0.03	NS / NS
Coscinodiscus spp.	-0.03 / 0.40	NS / 0.02
Phytoplankton Colour	-0.02 / -0.14	NS / NS
Rhizosolenia spp.	0.10 / -0.08	NS / NS
Silicoflagellates	-0.05 / -0.05	NS / NS
Copepods		
Calanus CI-IV	0.17 / 0.11	0.03 / NS
C. CV-CVI	-0.02 / -0.02	NS / NS
C. finmarchicus	-0.02 / -0.02	NS / NS
Metrida spp.	-0.04 / -0.06	NS / NS
Nauplii	-0.05 / -0.04	NS / NS
Oithona spp.	0.03 / 0.09	NS / NS
Paracalanus/Pseudocalanus spp.	0.10 / -0.03	NS / NS
Paraelongatus spp.	-0.02 / -0.02	NS / NS
Temora longicornis	-0.03 / -0.07	NS / NS
Macrozooplankton		
Chaetognatha	-0.03 / 0.05	NS / NS
Euphausiacea	0.19 / -0.03	0.02 / NS
Hyperiidea	0.08 / 0.00	NS / NS
Larvacea	0.06 / 0.05	NS / NS
Limacina spp.	-0.07 / -0.07	NS / NS
Parafavella spp.	-0.15 / -0.09	NS / NS

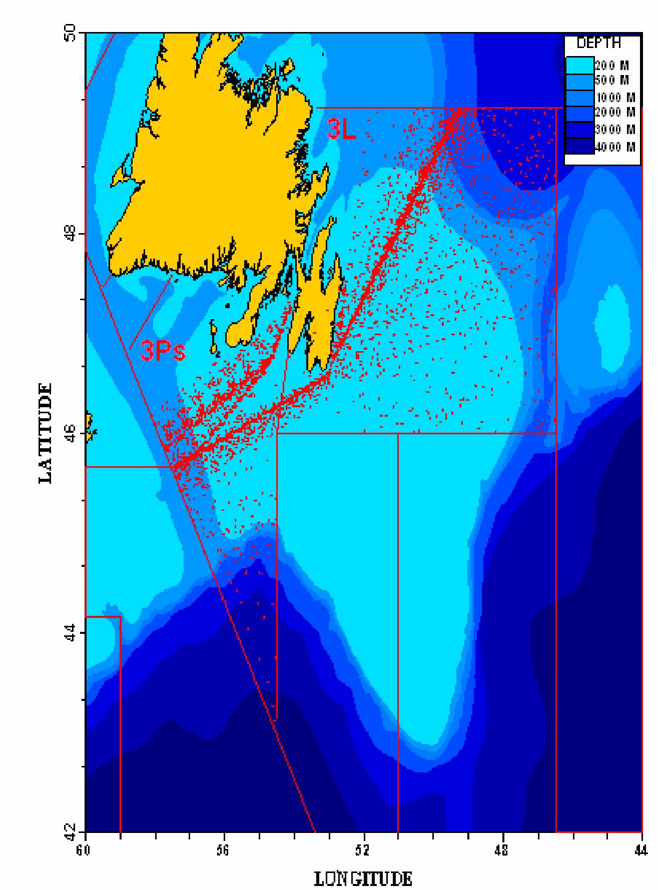

Fig. 1. Overlay of Continuous Plankton Recorder (CPR) stations within NAFO Div. 3L and 3Ps (Newfoundland Grand Banks) during 1961-2003. Note the main commercial shipping lanes across NAFO Divisions 3L and 3Ps.

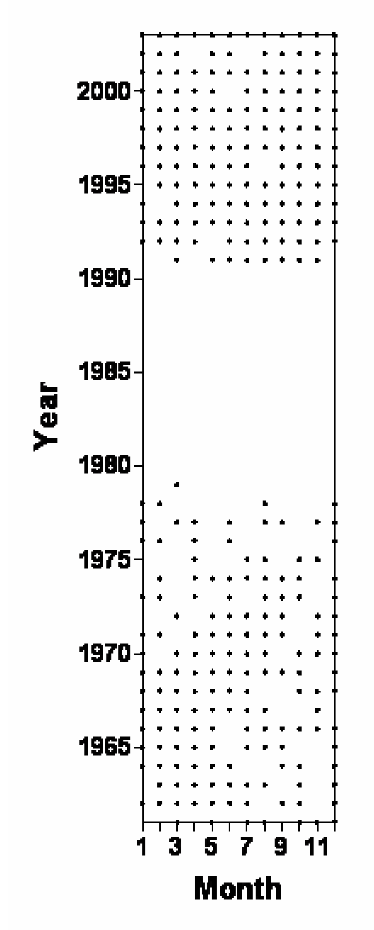

Fig. 2. Temporal coverage of Continuous Plankton Recorder (CPR) stations in NAFO Div. 3L and 3Ps (Newfoundland Grand Banks) during 1961-2003. Note the small monthly data gaps evident during time series and data void between 1978 and 1990.

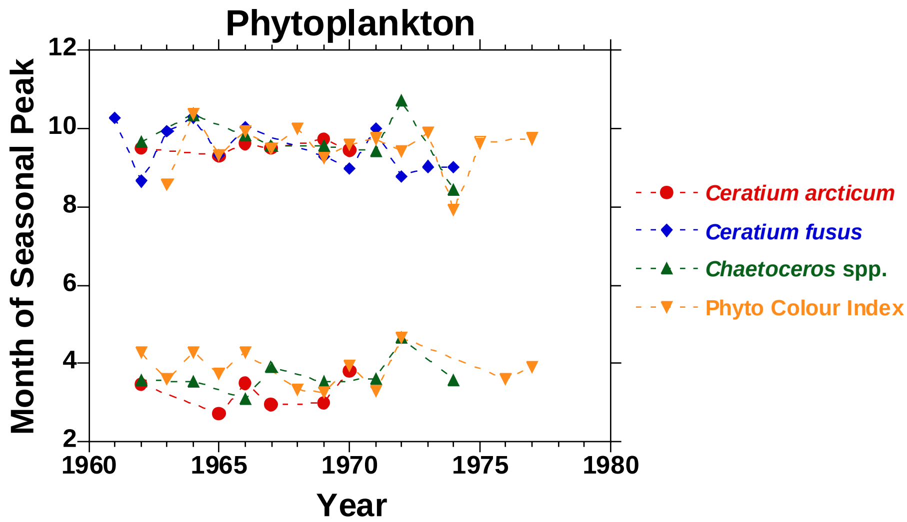

Fig. 3. Seasonality of dominant phytoplankton taxa collected by the Continuous Plankton Recorder (CPR) survey during 1961-77.

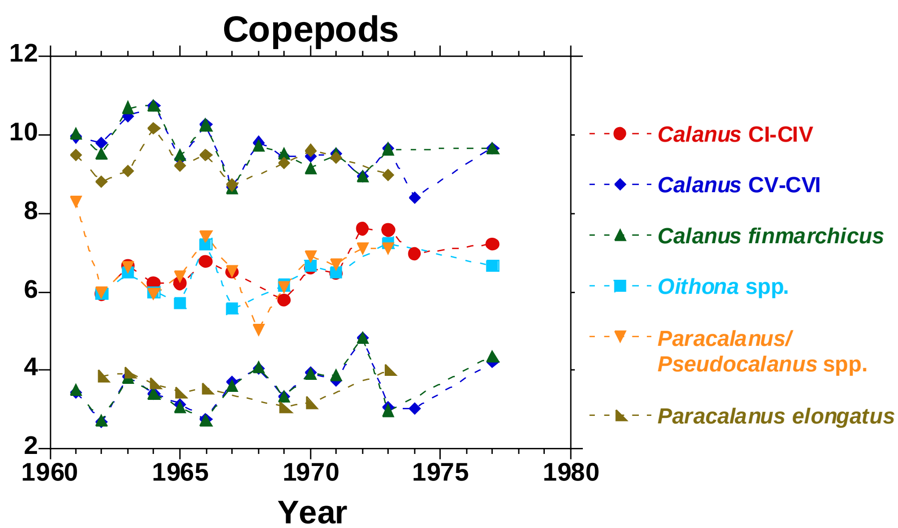

Fig. 4. Seasonality of dominant copepod taxa collected by the Continuous Plankton Recorder (CPR) survey during 1961-77.

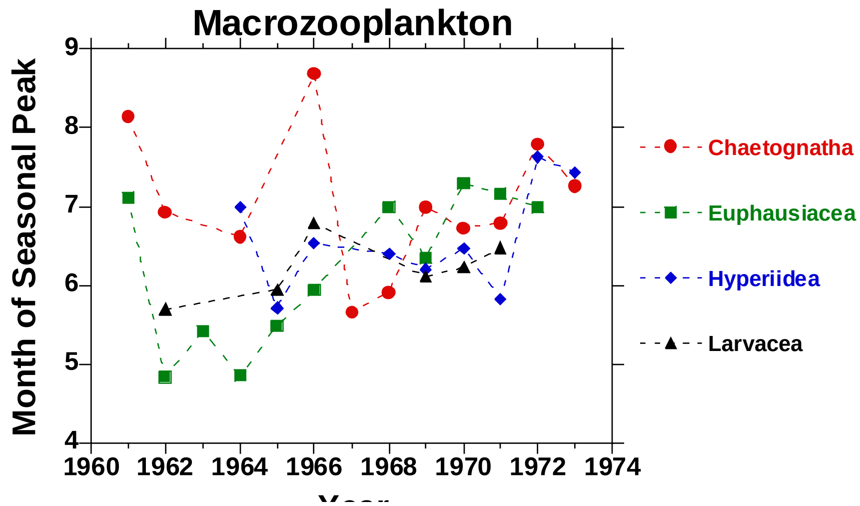

Fig. 5. The seasonality of dominant macrozooplankton taxa collected by the Continuous Plankton Recorder (CPR) survey during 1961-77.

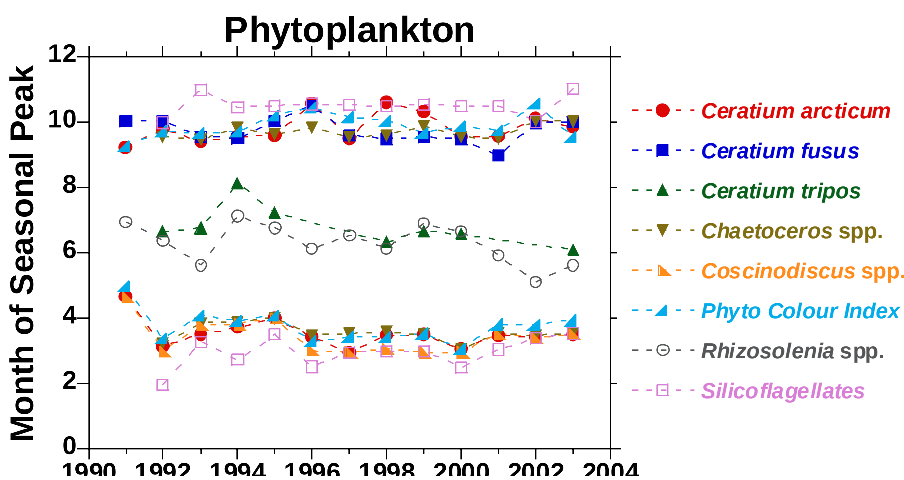

Fig. 6. The seasonality of dominant phytoplankton taxa collected by the Continuous Plankton Recorder (CPR) survey during 1991-03.

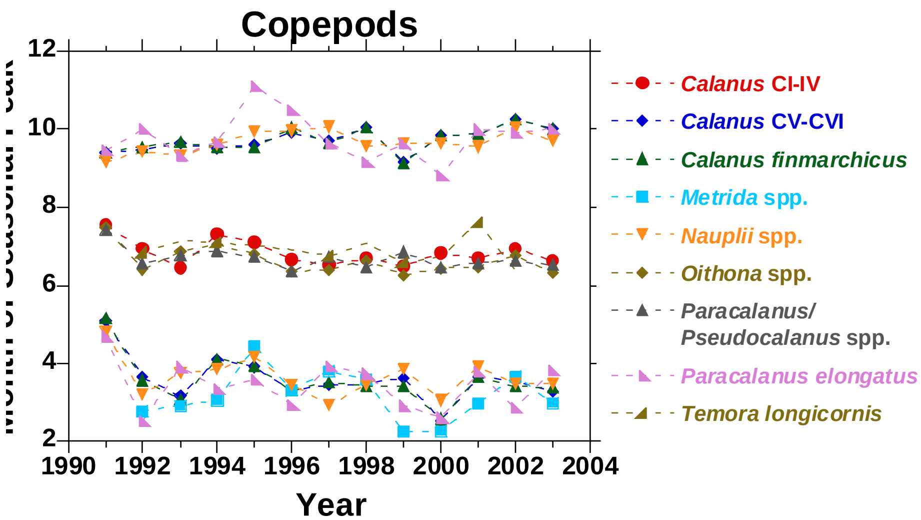

Fig. 7. The seasonality of dominant copepod taxa collected by the Continuous Plankton Recorder (CPR) survey during 1991-03.

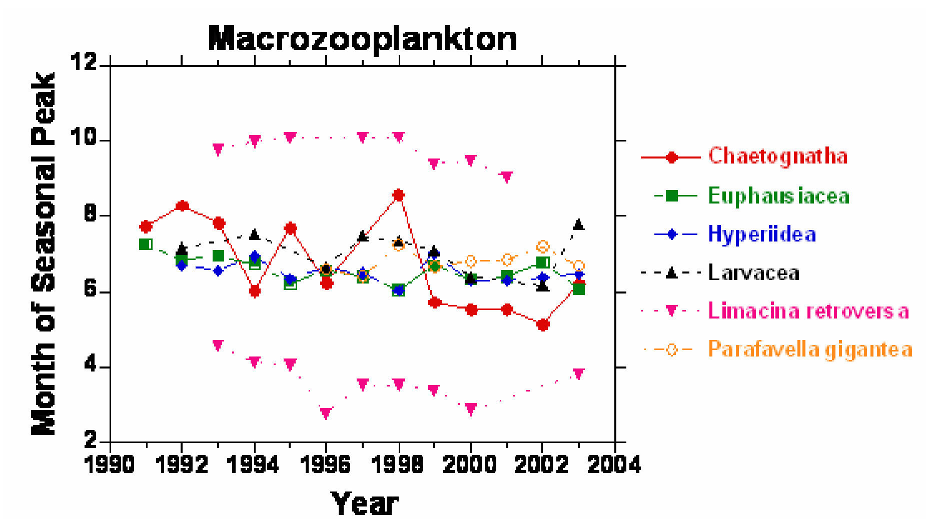

Fig. 8. The seasonality of dominant macrozooplankton taxa collected by the Continuous Plankton Recorder (CPR) survey during 1991-03.

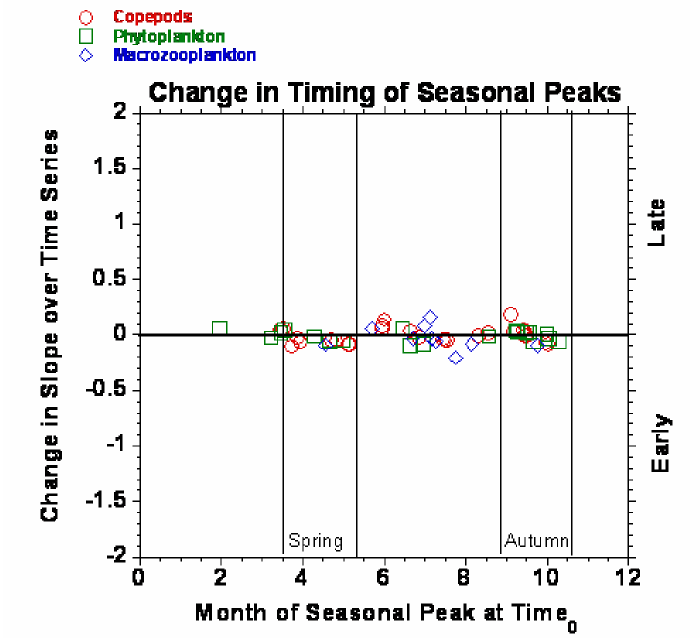

Fig. 9. The change in the timing of the seasonal peaks in months during the respective time series; 1961-77 and 1991-03, *versus* the intiation of the respective time series for each specific taxon. Linear regression analysis was used to estimate the change in slope for each taxon category.

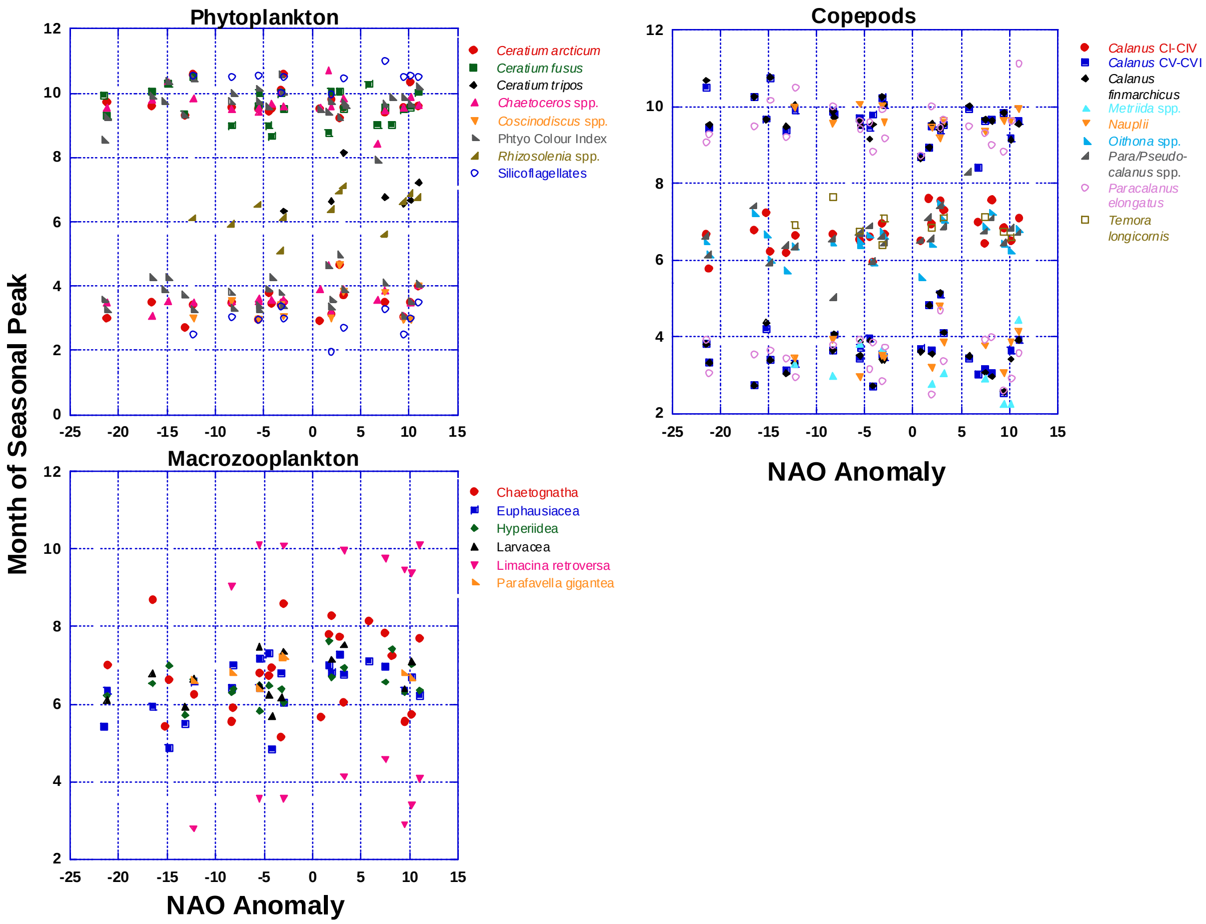

Fig. 10. Relationship between interannual variation in seasonality of plankton collected by the Continuous Plankton Recorder (CPR) survey and the North Atlantic Oscillation (NAO) Index anomaly.

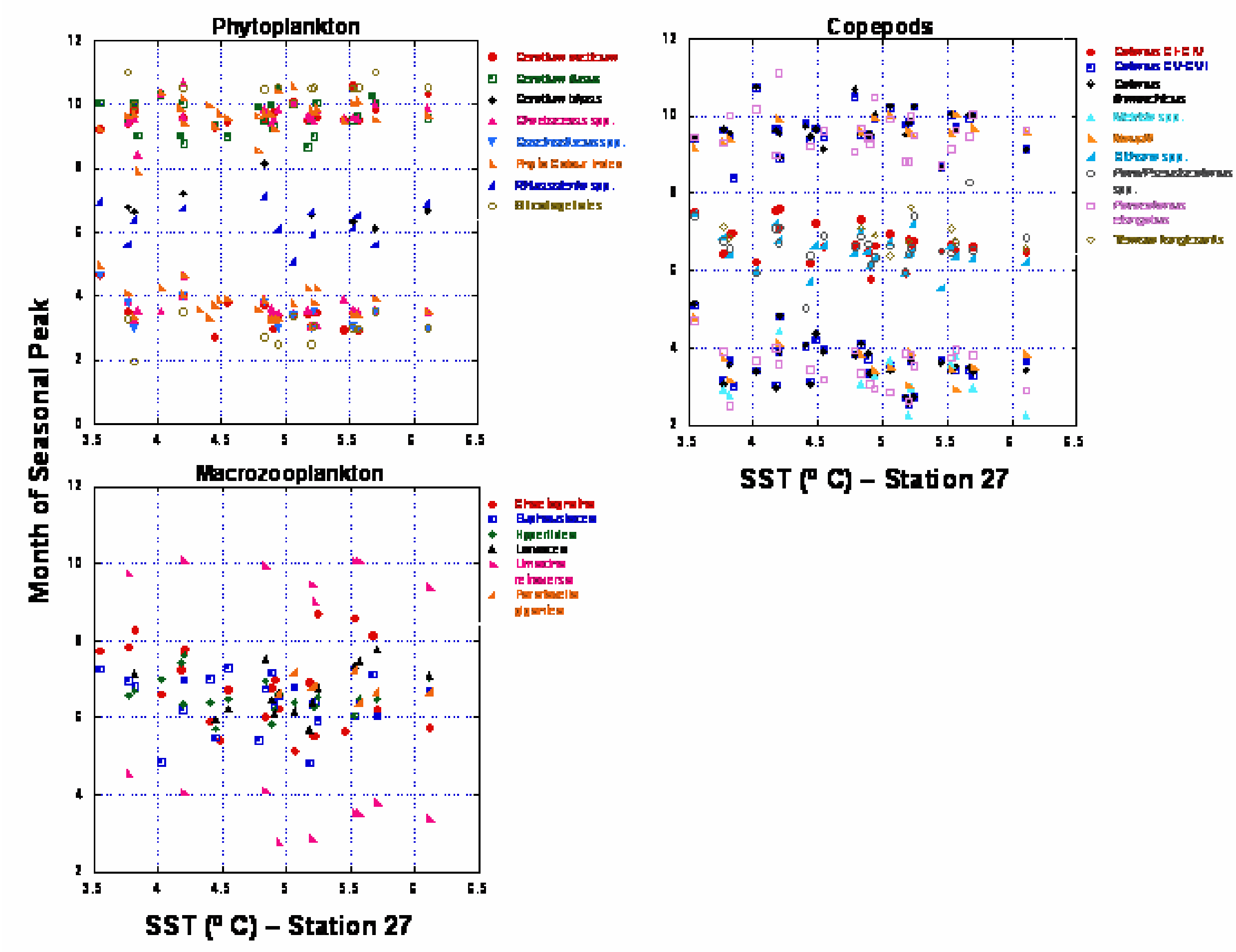

Fig. 11. Relationship between interannual variation in seasonality of plankton collected by the Continuous Plankton Recorder (CPR) survey and the upper water column (10 m integral) temperature at Station 27.