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**Decadal Plankton Changes on the eastern Nova Scotian Shelf and western
North Atlantic**

D. Sameoto

Department of Fisheries and Oceans,
Ocean Science Division
Biological Oceanography Section
Bedford Institute of Oceanography
Fisheries and Oceans Canada
Dartmouth, Nova Scotia
e-mail: sameotod@mar.dfo-mpo.gc.ca

Abstract

A comparison study of the phytoplankton color index, selected phytoplankton and zooplankton taxa from the eastern Scotian Shelf (CPR E-line) and from the northwest Atlantic (CPR Z- line) showed a significant similarity in yearly abundance changes. It is suggested that environmental changes, influencing both regions, are causing the organisms to respond in a quasi-synchronous manner. Changes in abundance of the population of C. finmarchicus in the northwest Atlantic were correlated with the abundance of C. finmarchicus on the Scotian Shelf. This correlation could be explained if the populations of C. finmarchicus from the northwest Atlantic contribute to the reproducing population of C. finmarchicus on the eastern Scotian Shelf. The period between 1991 and 1998 was a period of high levels of phytoplankton color index and low levels of C. finmarchicus and euphausiids on both CPR lines.

Introduction

There are few data describing the seasonal changes in zooplankton species concentrations on the Canadian northeast continental shelf. Data from the Scotian Shelf Ichthyoplankton Survey program (SSIP) were used to compile seasonal distribution maps during different months of the year for *Calanus* species (Sameoto and Herman 1992). The distribution gradients of various zooplankton species within the central area of the Scotian Shelf were described for August and September using the SSIP data (Tremblay and Roff, 1983). Zooplankton biomass distribution (ml m^{-3}), and total numbers of zooplankton were determined for different seasons on the Scotian Shelf in 1979 using the same SSIP data (O'Boyle et al. 1984). A series of data reports described the vertical distribution of zooplankton along a number of transects across the Scotian Shelf

(Lewis and Sameoto 1988a, 1988b, 1988c, 1989a, 1989b and 1990), however, these data were limited seasonally because sampling was done only once or twice a year.

The longest time series of data describing zooplankton species concentrations on the Canadian eastern continental shelf is the Continuous Plankton Recorder Survey (CPR) collected for The Sir Alister Hardy Foundation (SAHFOS) of Plymouth, England. These data were collected between years 1961 to 1974 and 1991 to the present along a transect line across the Scotian Shelf, the CPR E-line, and between years 1959 to 1986 and 1991 to the present along the Z-line running between Iceland and Newfoundland. The CPR is towed by commercial and weather ships at an average depth of approximately 6.7 m (Hays and Warner 1993) at speeds of up to 20 knots. The CPR has a mouth opening of 1.25 cm² and a filtering mechanism inside the vehicle that collects samples of phytoplankton and zooplankton on a slowly moving band of bolting silk with a mesh size of about 285 x 315 µm. The sample is then covered with a second silk and wound onto a spool in a tank of formalin and preserved. The CPR is towed at regular monthly intervals along generally fixed shipping routes. Myers et al. (1994) analyzed the 1959-1992 data for the Northwest Atlantic and presented seasonal cycles, and long-term trends for zooplankton and phytoplankton for different geographic sub-regions corresponding to the NAFO divisions which included the Scotian Shelf and Gulf of Maine.

Batten et al. (1999) compared zooplankton biomass (mg C m³) estimates from CPR samples with samples taken simultaneously with a Longhurst-Hardy plankton recorder and found the integrated biomass derived from the two samples did not differ significantly. This was the first quantitative experiment that demonstrated the CPR gives an unbiased estimate of the biomass and species composition, in the upper 200 m.

This study examines selected CPR data from the eastern region of E-line, between longitudes 56°W and 61°W and the western Z-line, between longitudes 45°W and 57°W (Fig. 1). The purpose of this study was to detect temporal and spatial differences and similarities in phytoplankton and zooplankton abundance in the two regions. A comparison of changes in the abundance of taxa in the two regions was examined for evidence that eastern Scotian Shelf zooplankton was influenced by changes in zooplankton species abundance in the northwest Atlantic.

Methods

Data from seven taxonomic groups, *C. finmarchicus* stages 1 – 4, *C. finmarchicus* stages 5 – 6, *Paracalanus/Pseudocalanus* spp., total euphausiids, phytoplankton color index, total diatoms and total dinoflagellates were transformed to log₁₀(x+1) to normalize the variance before any

statistical analyses. A least squares spline smoother was calculated, using the program S-plus 2000 (MathSoft, 1999), to demonstrate trends in abundance with time. The smoother relies on the data to specify the form of the model and the curve is fit to data points locally so that any point on the curve depends only on observations at that point and a specified range of neighboring points. The smoother gives a more realistic representation of the data than a polynomial regression.

A robust MM regression (Rousseeuw and Yohai 1984 and MathSoft 1999) was calculated between different variables. Robust regression models are useful for fitting linear relationships when the random variation in the data is not Gaussian and when the data contain significant outliers.

Differences in the climatology were examined for the years 1961 – 1974 and 1991 – 1998 for the E-line and the years 1959 – 1986 and 1991 – 1998 for the Z-line. Climatological monthly means were calculated for all years in the entire data set separately for each line.

The data were contoured using the Kriging method with the program Surfer 7 (Keckler, 1995). The contoured data demonstrate changes in consecutive years against month of the year. Contour plots were calculated for the abundance of zooplankton taxa *Calanus finmarchicus* copepodite stages 1 – 4 and phytoplankton color index. The phytoplankton color index was described by Reid (1998) as: "A visual index of chlorophyll based on the intensity of the green coloration of the CPR filtering silk, which is assigned numerical values in four categories". Net sample estimates of total *C. finmarchicus* per m² from a station in Emerald Basin on the central region of the Scotian Shelf, (Sameoto unpublished) were compared with CPR estimates of total *C. finmarchicus* for the western Scotian Shelf (Fig. 2) to determine if the CPR data accurately reflected zooplankton population changes with time within the entire water column. A robust linear regression analysis showed both data sets had similar negative linear regressions during the years 1991 to 1998 (Fig. 3). Therefore, the evidence suggests that the CPR data are representative of the major trends in the actual abundance of *C. finmarchicus* in the study areas.

Results

Annual means

The annual mean abundance of the various phytoplankton and zooplankton taxa on the E and Z lines showed similar patterns, particularly during the years 1991 - 1998. *C. finmarchicus* stages 1-4, and the total euphausiids had lower annual means than the climatological averages in most years since 1991 (Fig. 4a). The phytoplankton color index, total diatoms and total dinoflagellates all had similar annual mean fluctuations, with the most striking features being a large increase in their annual means during the 1990s (Fig. 4b).

The sequential monthly means for *C. finmarchicus* stages 1-4, *C. finmarchicus* stages 5-6, total euphausiids and phytoplankton color index generally had higher monthly values on the Z-line than on the E-line (Fig. 5).

Taxa Relationships Between Lines

Correlation coefficients were calculated on yearly mean values for all combinations of taxa on the two CPR lines during the 24 years when both lines were sampled together. Only four significant correlations were found. These were between phytoplankton color index, *C. finmarchicus* stages 1 – 4, *C. finmarchicus* stages 5 - 6 and *Para/Pseudocalanus* spp. (Table 1). Robust linear regressions were calculated for these four taxa on the two lines (Fig. 6).

Taxa Relationships Within Lines

The within line relationships were compared with a correlation analysis between all combinations of common taxa. Within the E-line only two taxa showed a significant correlation and a robust linear relationship, these were *C. finmarchicus* stages 5-6 with the phytoplankton color index and *C. finmarchicus* stages 5-6 with *C. finmarchicus* stages 1-4 (Fig. 7). On the Z-line, there were five significant correlation coefficients and robust linear regressions (Fig. 7). These were *C. finmarchicus* stages 1-4 and stages 5-6 with the phytoplankton color index, *Paracalanus/Pseudocalanus* spp. with phytoplankton color index, *C. finmarchicus* stages 5-6 with *Paracalanus/Pseudocalanus* spp. and *C. finmarchicus* stages 5-6 with *C. finmarchicus* stages 1-4. Regressions between *C. finmarchicus* and the phytoplankton color index had a negative slope on both lines, whereas the slope between *Paracalanus/Pseudocalanus* spp. and phytoplankton color index had a positive slope. The slope for the relationship between *C. finmarchicus* stages 5 – 6 and the color index was similar on the two lines, as was the slope between *C. finmarchicus* stages 1 – 4 and *C. finmarchicus* stages 5 – 6 on the two lines.

Abundance of Taxa During 1990s Compared to Climatological Means

The mean monthly abundance for *C. finmarchicus* stages 1-4 and stages 5-6 and the phytoplankton color index for years 1991-1998 from each line were compared to the climatological monthly mean values for the respective lines (Fig. 8,). The phytoplankton color index during 1991-1998 was significantly higher than the climatological mean on both lines and the data from the two lines had similar monthly values and patterns of change. *C. finmarchicus* stages 1-4 and stages 5-6 monthly mean values for years 1991-1998 were lower than the climatological means on both lines. The monthly means for these two taxa on the Z-line were higher than the means on the E-line.

A comparison of the 1998 monthly data for the three above taxa with the climatological monthly means showed that the phytoplankton color index on the E-line in 1998 was higher than on the Z-

line during months 2 and 3. *C. finmarchicus* stages 1-4 values in 1998 were higher during months 6 to 12 on the Z-line than on the E-line, and *C. finmarchicus* stages 5-6 means were higher on the Z-line than the E-line during all months of 1998 (Fig. 9). The monthly means for the two *C. finmarchicus* taxa on the E-line in 1998 were among the lowest values seen during the 1991 to 1998 period. On the Z-line both *C. finmarchicus* stages 1-4 and stages 5-6 had monthly means below the climatological means for most months except for months 8 to 12 when the values were similar to or above the climatological monthly means. The phytoplankton color index monthly means in 1998 on the E-line continued the trend of the 1990s of that being higher than the climatological mean (Fig. 9).

The monthly values for *C. finmarchicus* stages 1-4 and phytoplankton color index from all years were contoured against year separately for the two lines (Fig. 10). These contour plots clearly showed a similarity in seasonal pattern in the phytoplankton color index with year on the two lines, particularly during years 1991 to 1998. The patterns for *C. finmarchicus* stages 1-4 were not as similar to those for the phytoplankton color index, but they did show similar trends on the two lines, particularly during the 1990s.

Conclusions

The eastern Scotian Shelf and the northwest Atlantic regions, as defined by this study, provide strong evidence that the phytoplankton and *C. finmarchicus* populations in the two regions are both influenced by similar physical and /or biological forces that caused the taxa to respond in a similar manner. There was a significant positive correlation between the phytoplankton color index on the Z-line with the phytoplankton color index on the E-line. The significant negative correlations between the phytoplankton color index and the abundance *C. finmarchicus* stages 5-6 suggest a top down control of the phytoplankton. It is possible that the reduced population of *C. finmarchicus*, that graze on diatoms and dinoflagellates, maybe partially responsible for the higher levels of diatoms and dinoflagellates in the 1990s. However, this is only speculation and physical parameters may be contributing to the higher phytoplankton levels seen during the 1990s such as increased stratification (Reid et al. 1998 and Dr. Brian Petrie, personal communication). Z-line *Paracalanus/Pseudocalanus spp.* were negatively correlated with *C. finmarchicus* and positively correlated with the phytoplankton color index. This result may indicate that *Paracalanus/Pseudocalanus spp.* respond favorably to higher levels of phytoplankton concentrations. The coefficient of determination values (Table 1) showed that 46% of the variation on the phytoplankton color index on the E-line could be explained by the changes in phytoplankton color index on the Z-line; however, more than half of the variance is unexplained and was likely the result of local physical and biological influences. The significant correlation between populations of *C. finmarchicus* on the two lines maybe the result of the northwest Atlantic population contributing to the reproducing population of animals on the Shelf in the

spring. There are three sources of reproducing *C. finmarchicus* on the Shelf in the spring, the Gulf of St. Lawrence, by way of the Nova Scotia Current, the population that over winter in the deep basins on the Shelf and copepods in the Labrador Current beyond the Shelf edge (Sameoto and Herman 1992). Recent data suggest that the Gulf of St. Lawrence may have contributed fewer animals in recent years and that the offshore source in the Labrador current may have played a greater role in contributing reproducing *C. finmarchicus* to the Shelf in the spring (Head et al. in press).

C. finmarchicus and the total euphausiids were more abundant on the northwest Z-line than on the eastern E-line during the entire time series. The species composition of the total euphausiid taxa is unknown, since species of euphausiids are not routinely identified by SAHFOS. However, we know from other studies (Sameoto unpublished) that the euphausiid communities in these two areas are dominated by different species. Therefore, abundance changes seen in total euphausiid numbers on the two lines may be due to different species responding to differently to similar biological and physical changes in their environments.

The abundance patterns of the color index and *C. finmarchicus* taxa during 1991 to 1998 period was markedly different from the climatological mean. During 1998, *C. finmarchicus* showed even greater changes than the monthly means for 1991 to 1998. These results showed that the trend for high autumn values of color index and *C. finmarchicus* on the Z-line seen in the early 1990s continued into 1998.

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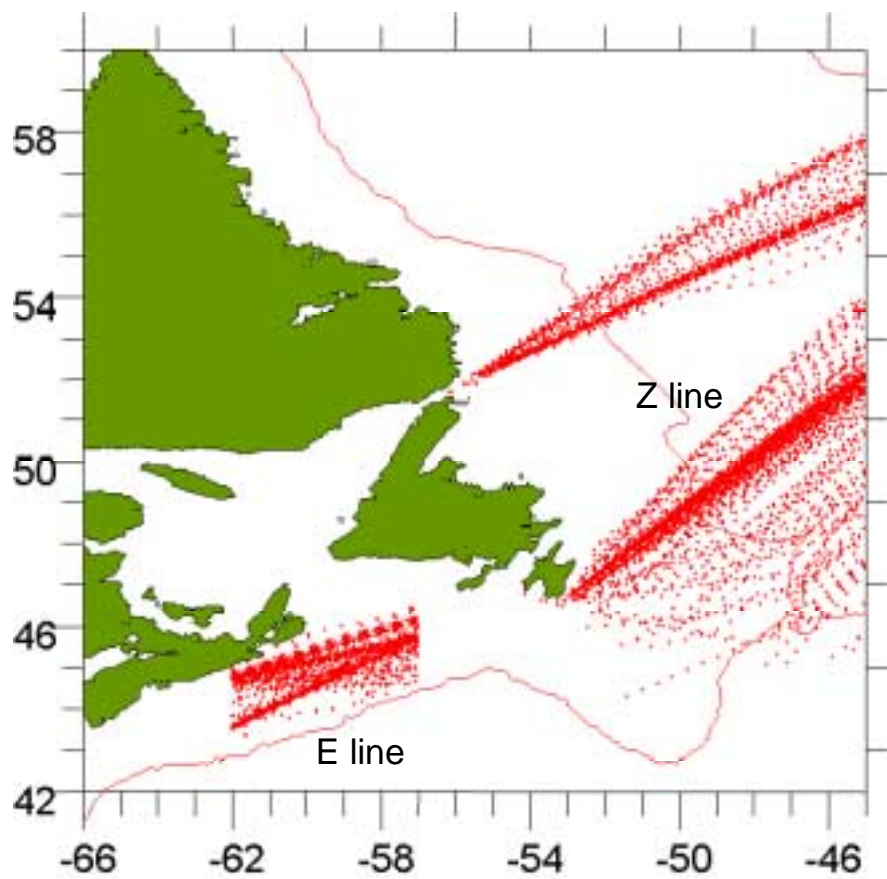


Fig. 1. Positions of CPR stations used in the study.

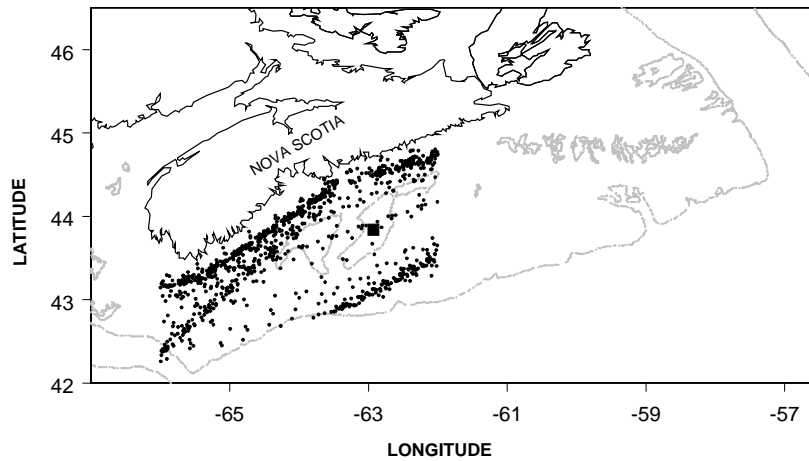


Fig. 2. Location of CPR samples (small dots) and net sample station (large square) collected during 1991 to 1998.

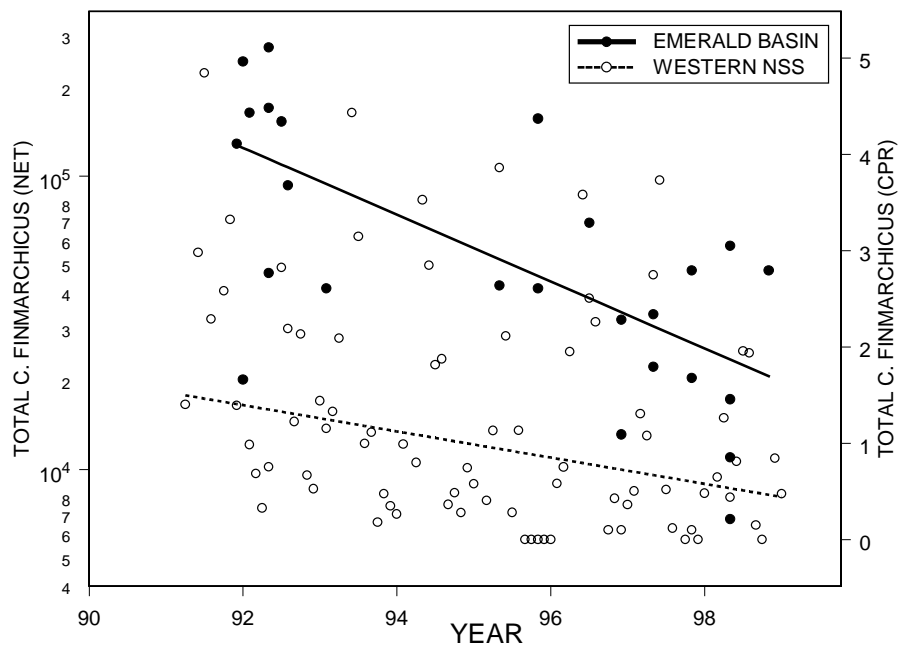


Fig. 3. Sequential monthly means of *C. finmarchicus* in Emerald Basin estimated from net samples (solid dots), and on the western Scotian Shelf estimated from the CPR samples (open circles). Numbers are $\log_{10}(x+1)$ values.

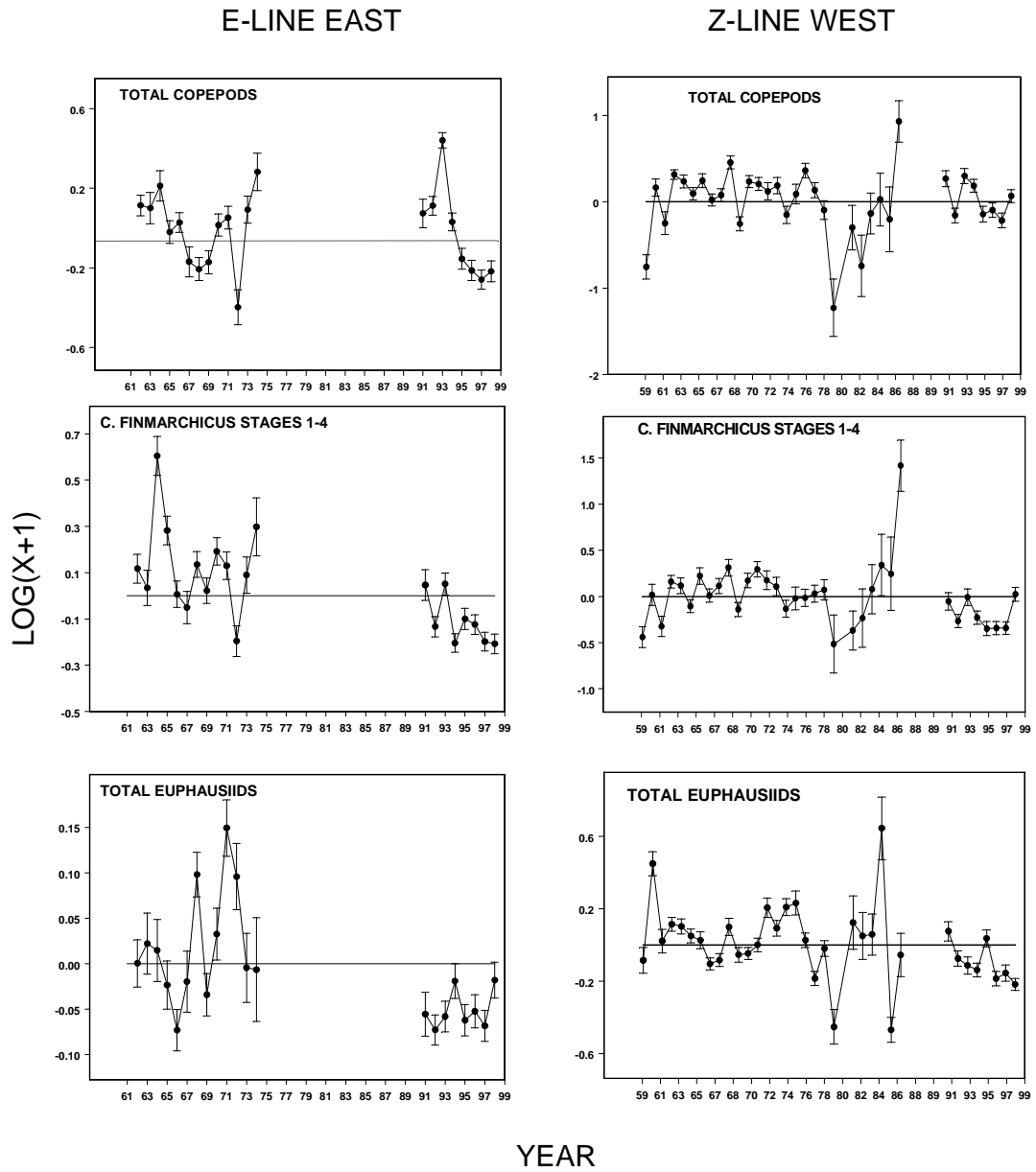


Fig. 4a. Yearly normalized means \pm one standard error plus the long-term mean (horizontal line).

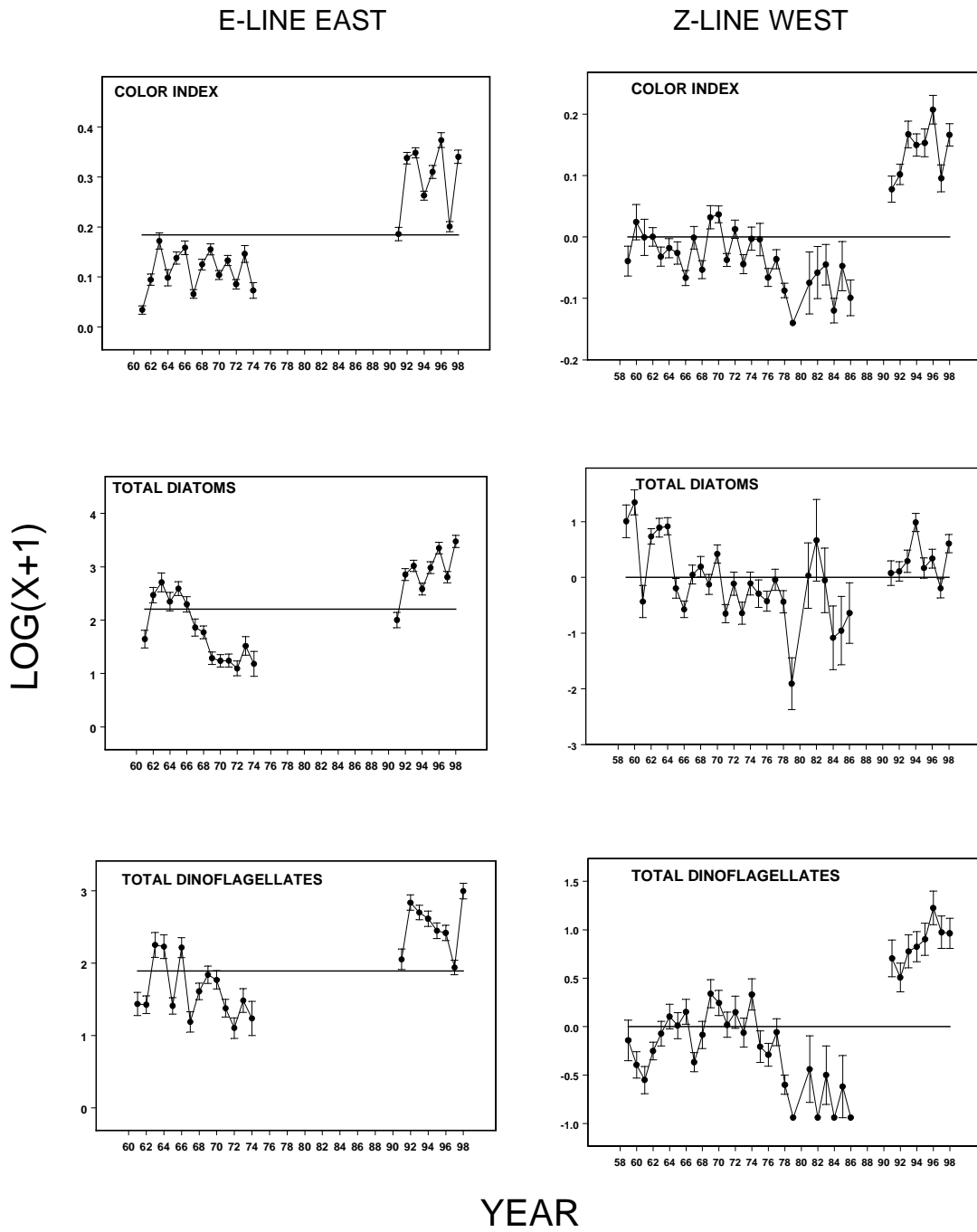
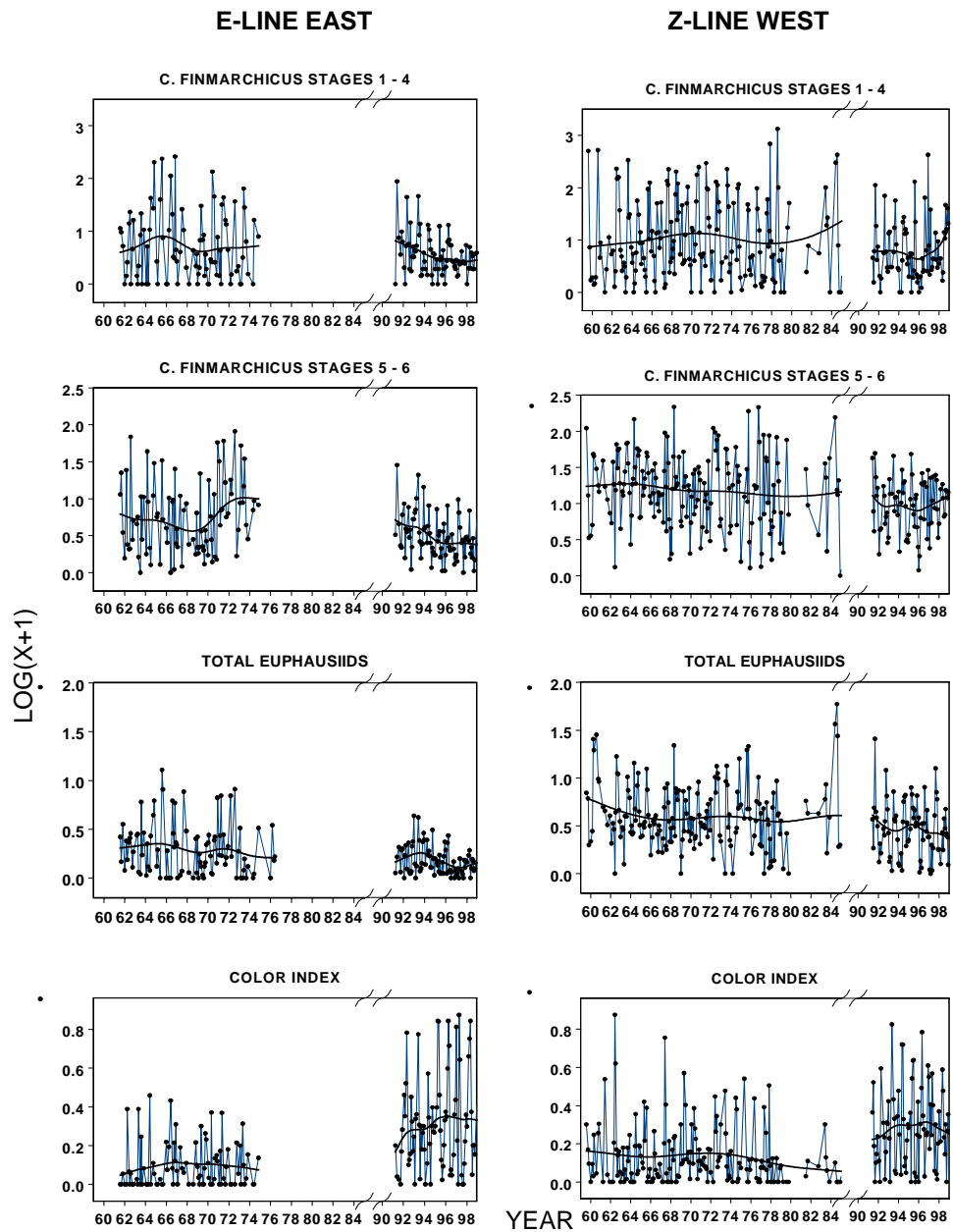


Fig. 4b. Yearly normalized means \pm the one standard error plus the long-term mean (horizontal line).



• Fig. 5. Sequential monthly means plus the cubic spline smoother fitted to the data.

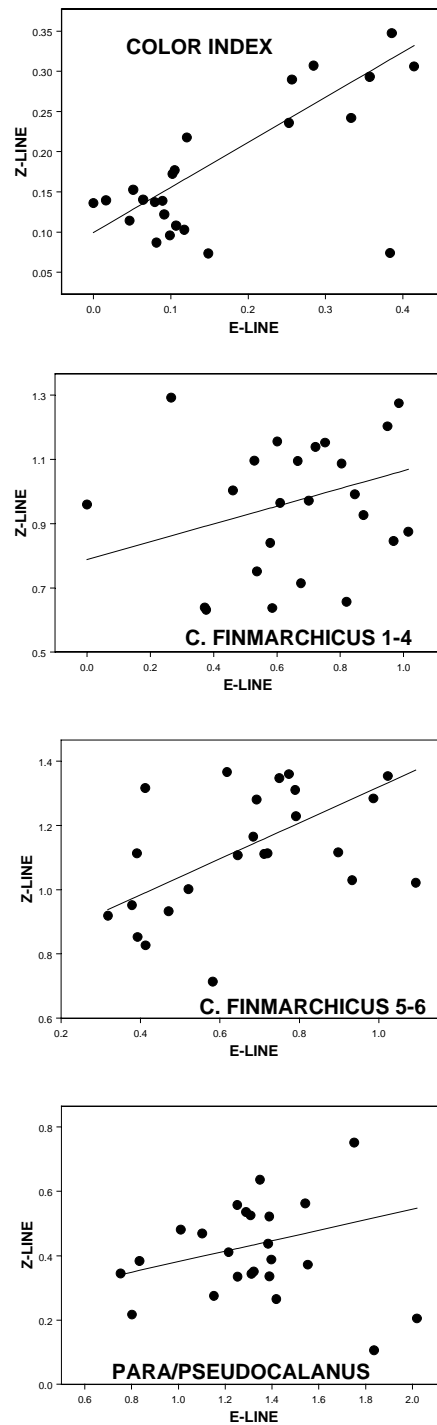


Fig. 6. Robust linear regressions fitted for taxa on the E and Z lines.

E-LINE

Z-LINE

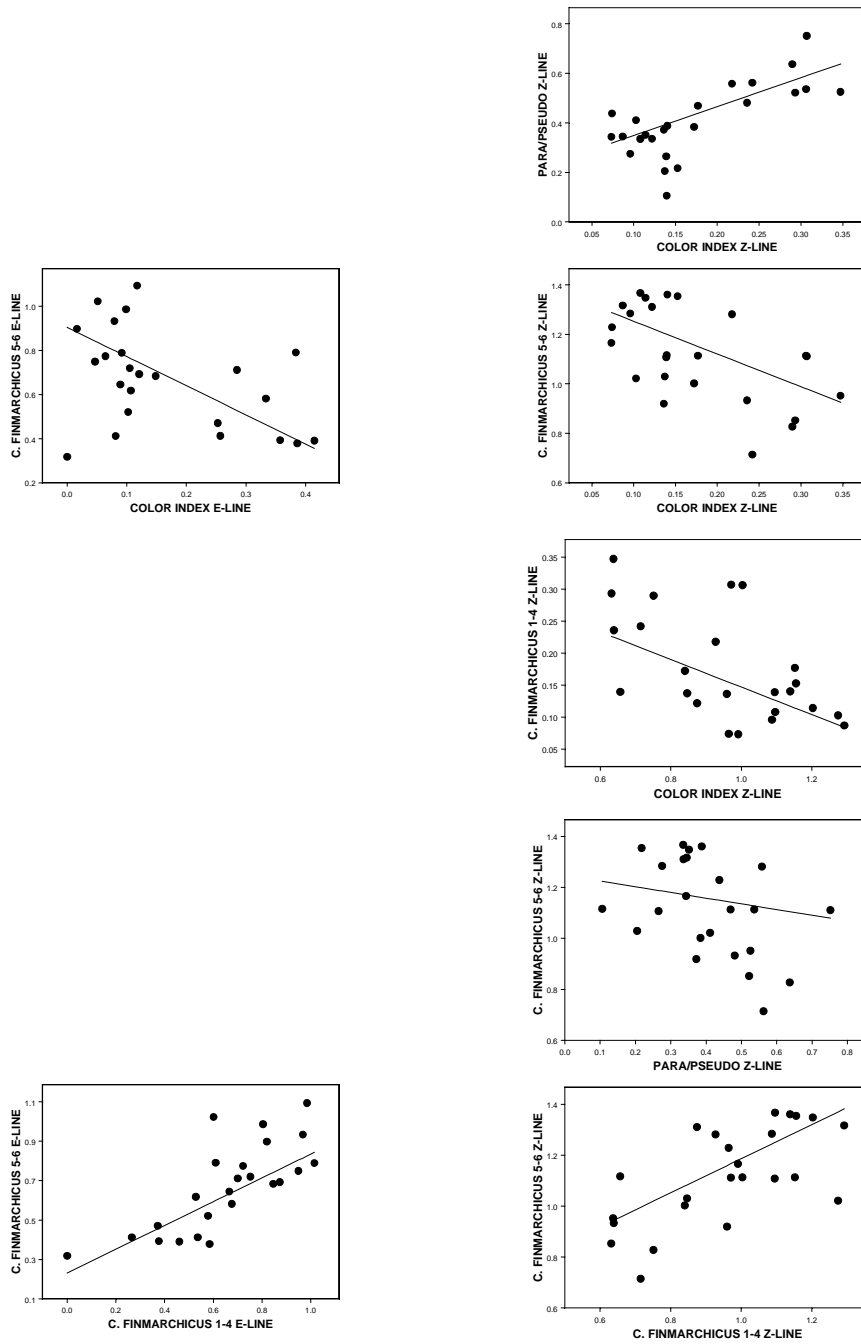


Fig. 7. Robust linear regressions between color index and taxa within the E and Z lines.

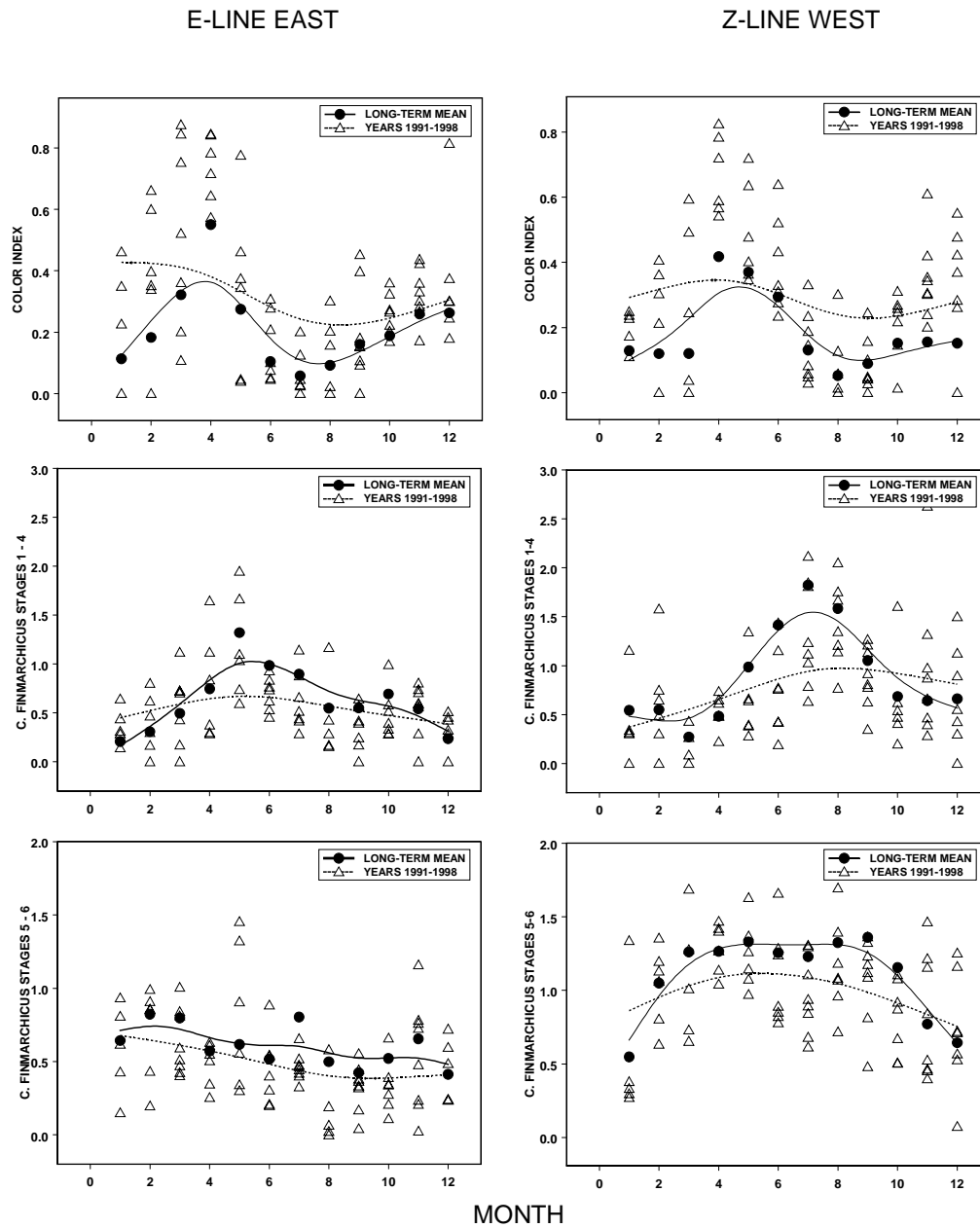


Fig. 8. Spline smoothers fitted to monthly means for years 1991 - 1998 and to the climatological long-term monthly mean values for years 1961-1998 (E-line) and 1959-1998 (Z-line)

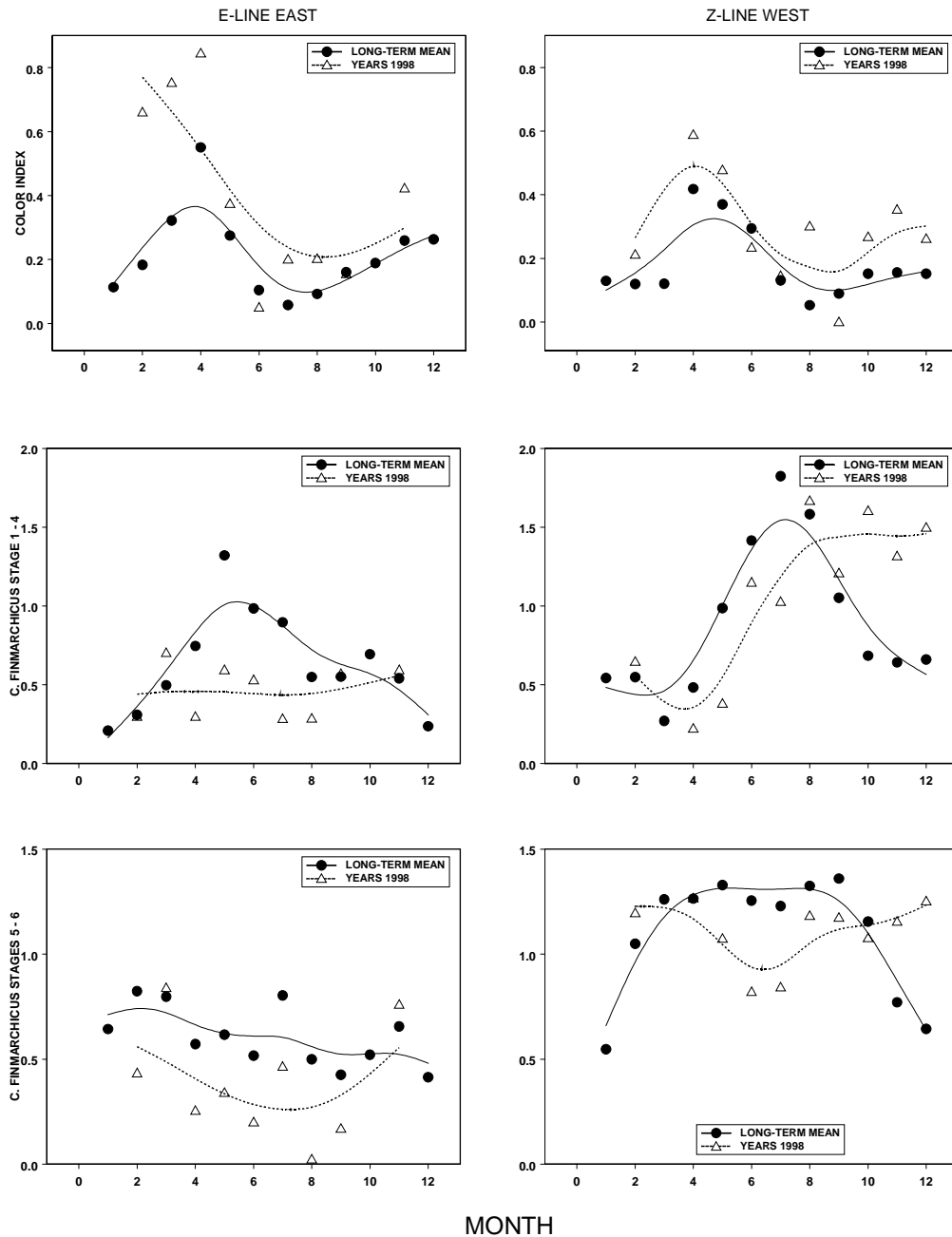


Fig. 9. Spline smoothers fitted to monthly means for 1998 and to the climatological monthly mean values.

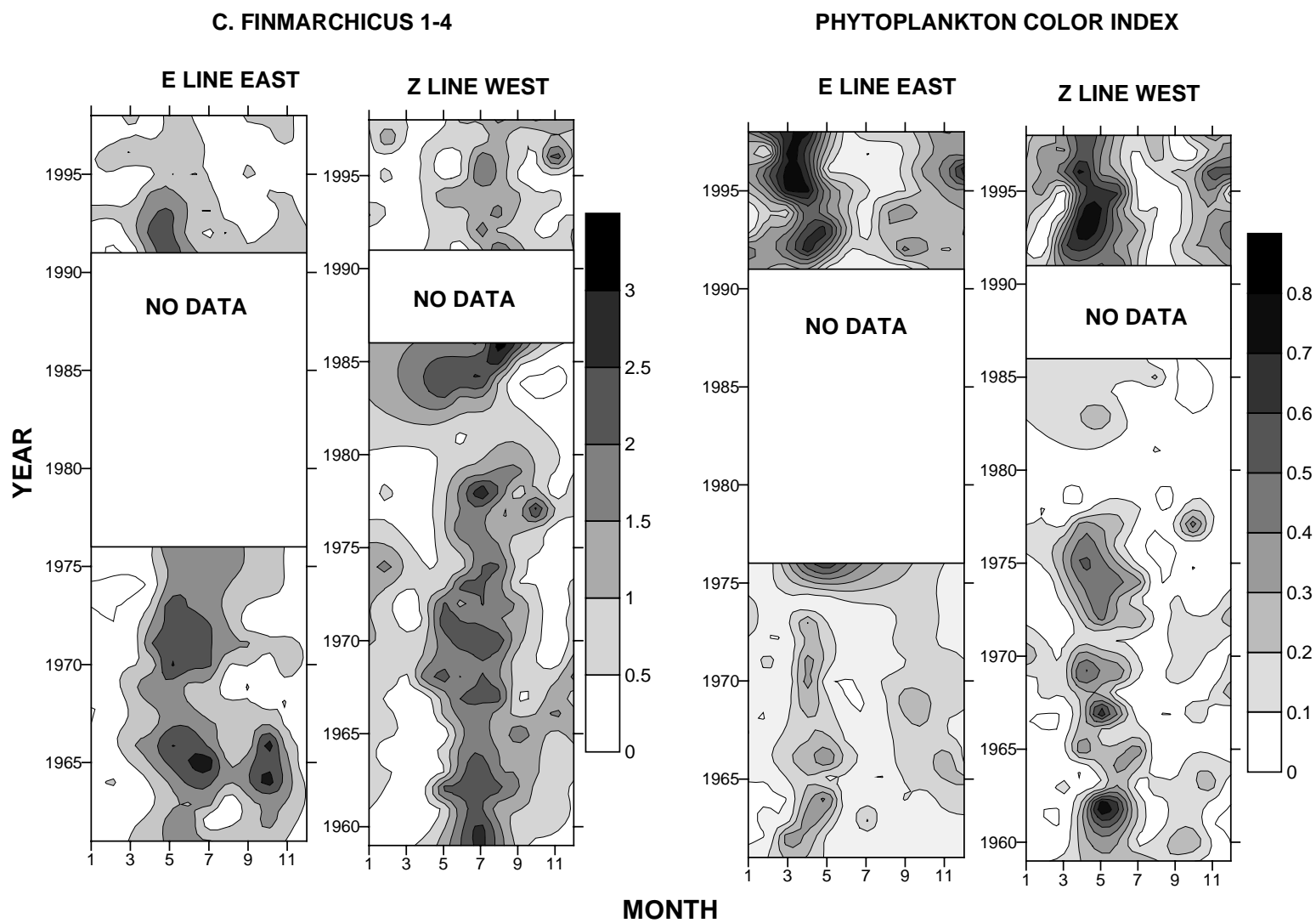


Fig. 10. Contours of *C. finmarchicus* stages 1-4 and phytoplankton color index for months of the year versus year for the E line and Z line. Values are $\log_{10}(x+1)$.

Table 1. Correlation coefficient (r) and coefficient of determination (r^2) between selected taxa from E line east (E) and Z line west (Z). All correlation coefficients are significant at the 0.05 probability level.

| | C. finmarchicus stages 1-4 (E) | | C. finmarchicus stages 5-6 (E) | | Color Index (E) | | C. finmarchicus stages. 1-4 (Z) | | C. finmarchicus stages 5-6 (Z) | | Para/Pseudo (Z) | |
|---------------------------------|--------------------------------|-------|--------------------------------|-------|-----------------|-------|---------------------------------|-------|--------------------------------|-------|-----------------|-------|
| | r | r^2 | r | r^2 | r | r^2 | r | r^2 | r | r^2 | r | r^2 |
| C. finmarchicus stages 5-6 (E) | 0.755 | 0.57 | | | | | | | | | | |
| Color Index (E) | | | -0.433 | -0.19 | | | | | | | | |
| C. finmarchicus stages. 1-4 (Z) | | | 0.393 | 0.15 | -0.472 | -0.22 | | | | | | |
| C. finmarchicus stages 5-6 (Z) | | | 0.462 | 0.21 | -0.470 | -0.22 | 0.666 | 0.44 | | | | |
| Para/Pseudo (Z) | | | -0.489 | -0.25 | 0.696 | 0.48 | | | -0.421 | -0.18 | | |
| Color Index (Z) | | | -0.537 | -0.29 | 0.681 | 0.46 | -0.591 | -0.35 | -0.575 | -0.33 | 0.725 | 0.53 |