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ZOOPLANKTON AND FISHERIES OF THE NORTHEAST SHELF LARGE MARINE ECOSYSTEM

by

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ABSTRACT

Since 1961 the Northeast Fisheries Science Center of the National Marine Fisheries Service has conducted a study of the zooplankton of the U.S. Northeast Shelf Large Marine Ecosystem. The objective of the study was to investigate possible linkages between the long-term trends in macrozooplankton and variations in the abundance and distribution of economically important demersal and pelagic fish stocks. Two sampling strategies have been used in the study: (1) collections with Continuous Plankton Recorders (CPR's) in collaboration with the Sir Alister Hardy Foundation for Ocean Science (1961 to the present); and (2) collections with bongo nets on spring and autumn bottom trawl surveys from the early 1970's to the present and during the decade of Marine Resources Monitoring, Assessment, and Prediction surveys (1977-1987) of the ecosystem. The dramatic downward trend in demersal fish stocks seen during this period is not mirrored in the zooplankton series. The emergent zooplankton patterns are dominated by interannual variability. In at least two subareas, a statistically significant upward trend was observed. These patterns of variability are different from those reported from the North Sea, and most recently from the California Current ecosystems, and do not appear to be in phase with the changing structure of the fish community of the NE Shelf ecosystem.

Comparative Studies of Large Marine Ecosystems

The Northeast Shelf Large Marine Ecosystem is one of the 49 Large Marine Ecosystems (LMEs) around the margins of the ocean basins for which analyses are underway to determine the principal driving forces affecting the long-term sustainability of biomass yields (Sherman, et al., 1993). The plankton component of marine ecosystems provide useful information on the biofeedback from environmental changes in relation to the natural production of fish stocks. (Aebischer et al., 1990).

It has recently been reported that the average global fisheries yields of the past several years that can be supported by present levels of primary production of aquatic ecosystems has been reached, and any further large-scale expansion of unmanaged biomass yields from the world's oceans will likely be at levels lower than fish in the marine food chains (Pauly and Christensen 1995; Beddington 1995). Recent observations are in agreement with this hypothesis. In the East China Sea LME, changes in the patterns of fish yields show an increase in catches of lower food chain species. Since the mid-1980's the preferred, relatively large demersal species have been depleted by excessive fishing mortality and replaced in the catches of the fisheries of the region by species at the lower end of the food chain including squid, shrimp, and relatively small fish species (Chen and Shen 1995). This trend appears to have occurred in other Asian marine ecosystems where the need for fish protein in the maritime countries adjacent to the LMEs is especially acute. (Piyakarnchana 1989; Tang 1993). The impact of this trend on the zooplankton communities of LMEs is unclear, particularly with regard to the effects of global climate change on marine ecosystems (Bakun 1993).

Although experimentation is the preferred strategy for isolating cause and effects of environmental change on species abundance in ecosystems, (Roush 1995), with a few exceptions (Carpenter et al., 1995) it is not as yet practical to experimentally manipulate large-scale marine ecosystems. However, observations of the causes for changes among several ecosystems can provide useful insights to the major driving forces of change (Bakun, 1995).

Northeast Shelf Fisheries Patterns

Since 1960 major changes have occurred within the finfish community of the Northeast Shelf ecosystem. The principal demersal species, haddock, cod, and flounder have declined to unprecedented low levels. Two other fish components have also changed. Small elasmobranchs have increased in abundance, whereas pelagic mackerel and herring have recovered from low levels of abundance in the 1970's to an historical high level of approximately 5 million metric tons in 1994 (Fig. 1, a and b).

Northeast Shelf Zooplankton Patterns

Since 1961 the pattern of macrozooplankton (≥0.250 mm. in broadest dimension) has been monitored within the NE Shelf ecosystem using Hardy Continuous Plankton Recorders. To augment the CPR data, which is taken at the 10m depth, approximately 12,000 oblique hauls from near bottom to the surface, were made on the shelf using 0.333 mm. mesh bongo nets from 1973 through 1993. Detailed methods of CPR and bongo collections and areas sampled are given in Jossi and Goulet (1993) and Sibunka and Silverman (1989), respectively.

Comparative LME Zooplankton Patterns

To provide initial insights into the driving forces controlling the emergent patterns of zooplankton we compared our results to recent studies of the California Current LME and the North Sea LME. The zooplankton of the California Current LME has declined significantly from the 1950's through the 1990's apparently in response to a basin-wide warming signal in the Pacific (Roemmich and McGowan 1995). The long-time series of zooplankton for the North Sea ecosystem displays a decadal pattern that decreases from the 1950's to the late 1970's, and then increases in abundance (NSTF 1993). Aebischer et al, (1990) attributed the decreasing pattern in zooplankton, marine birds and fish to ecosystem level effects of the Northeast Atlantic marine climate.

The "climate" of the NE Shelf ecosystem is influenced on the seaward boundary by the warm water of the Gulf Stream, and the cold water flowing southwestward from Scotian shelf ecosystem. The dominant atmospheric influences are the winter cold air from central North America, the warm moist air from the Gulf of Mexico, and the position of the predominant westerly jet stream across eastern North America (Hertzman, in press). These conditions lead to distinct seasonal pulses in plankton in each of the four subareas of the shelf ecosystem (Fig. 2). The maximum zooplankton biomass (as measured by displacement) on Georges Bank is in spring, followed by a secondary pulse in summer, and a decline to a winter annual low level. The annual cycle of abundance in the Gulf of Maine is characterized by an extended spring bloom that is maintained between 30 and 40 cc/100m^3 through summer, followed by a decline in autumn and a winter low. A similar plateau is reached in spring and persists through summer in Southern New England prior to an autumn decline and a winter low. The annual maximum in zooplankton abundance is not reached until late summer and early autumn in the Middle Atlantic Bight, where it is followed by a decline to a winter low. However, dominance in zooplankton taxa among the four subareas differs. The number of species reaching dominance levels is greater in the southern half of the ecosystem, from the monotypic copepod dominance in the Gulf of Maine to the more varied taxonomic assemblages in the Southern New England and Middle Atlantic Bight subareas (Sherman et al., 1983). In the northern half of the ecosystem, the Gulf of Maine and Georges Bank are the principal spawning areas for cod and haddock within the NE Shelf ecosystem (Smith et al., 1979, Morse et al., 1987). Two of the most important prey species of cod and haddock larvae, the copepods <u>Calanus finamarchicus</u> and <u>Pseudocalanus</u> spp. (Kane 1984) are among the dominant species of the zooplankton community on Georges Bank and in the Gulf of Maine (Sherman et al., 1983). They have remained among the most numerous species in these two subareas from the first two decades of the century (Bigelow), through the MARMAP decade (Sherman et al.) and during our 1992 (Table 2) survey of the NE Shelf ecosystem.

The zooplankton of the subareas of the Northeast Shelf ecosystem undergoes considerable interannual variability. Two of the patterns show increases in the zooplankton abundance time series. Based on sampling with the bongo nets from 1977-1993 in spring and autumn a significant upward trend was found for spring in Southern New England subarea. (Fig. 3 and Table 1.) Within the 1961-1990 CPR time series for the Gulf of Maine total numbers of zooplankton also showed a significant upward trend (Fig. 4 and Table 1.).

The long-term bottom temperature signal for the Northeast Shelf ecosystem shows considerable interannual variability but no statistically significant upward or downward trend (Fig. 5) (Holzwarth and Mountain 1990). In both the California Current and North Sea ecosystems the change in zooplankton abundance has been attributed to large-scale change on the ocean basin-wide climate scales rather than the result of localized perturbations. However, the emergent pattern of the NE Shelf zooplankton abundance does not appear related to the basin-wide climatic effects reported for the Northeast Atlantic and North Sea zooplankton abundance patterns of the past forty years.

Fish Stocks and Zooplankton

Unlike the California Current ecosystem and the North Sea ecosystem, the Northeast Shelf ecosystem appears to be affected less by large-scale marine induced environmental signals and more by the large-amplitude seasonal signal which is driven principally by the heating and cooling trends of the continental air masses. Recent evidence, however, suggests that the observed interannual changes in zooplankton abundance, particularly on the Georges Bank subarea, could be influenced by cool water from the Scotian Shelf that is periodically advected over Georges Bank (Bisagni et al., submitted). The studies of GLOBEC now underway under the joint sponsorship of the National Science Foundation and NOAA, are focused on the influence of the seasonal and interannual changes in oceanographic and planktonic conditions on the recruitment recovery of depressed cod stocks on Georges Bank (GLOBEC 1991). Available evidence indicates that the depleted state of cod, haddock, and flounder populations are the result of extensive recruitment overfishing rather than from any persistent large-scale environmental signal affecting the fish stocks and their zooplankton prey field (Anthony, in press; Murawski, in press).

The statistically significant trends detected from our present analysis of the zooplankton component of the ecosystem are the increasing levels of abundance in the Gulf of Maine subarea, and the Southern New England subarea in spring. The increasing trend in zooplankton abundance in spring in two of the subareas on the shelf ecosystem, and absence of a significant downward trend elsewhere suggests that the large biomass of zooplanktiverous mackerel and herring are not a dominant control on the zooplankton of the ecosystem. In relation to the potential for the recovery of depressed haddock and cod stocks, neither the important zooplankton prey species of cod and haddock larvae or the abundance levels of total zooplankton have undergone persistent downward trends within the ecosystem. Nor has any evidence of depensation been found for haddock or cod stocks within the NE Shelf ecosystem (Meyers et al 1995, Barinaga, 1995). It would appear, therefore, that any good production and survival of incoming year-classes of cod and haddock larvae would not be adversely impacted from any reduction of their zooplankton prey-field by the high biomass of zooplanktiverous herring and mackerel stocks inhabiting the NE Shelf ecosystem.

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Table 1. Test of linear trends, by area and season for zooplankton displacement volumes, total zooplankton abundances, and bottom temperatures over the Northeast Shelf ecosystem.

Area[1]	Season	Years	Variable	Significance (p)
GBK	Spring	1971-1994	Zooplankton Displacement Volume	.280
GBK	Autumn	1971-1993	"	.948
GOM	Spring	1977-1994	"	.112
GOM	Autumn	1977-1993	"	.413
SNE	Spring	1977-1994	"	**.010**
SNE	Autumn	1977-1993	"	.301
MAB	Spring	1977-1990	"	.277
MAB	Autumn	1977-1993	"	.454
GOM	All	1961-1990	Total Zooplankton Numbers	**.032**
MAB	"	1972-1990	"	.701
GOM	Spring	1968-1990	Bottom Temperature	.667
GOM	Autumn	1963-1990	"	.888
GBK	Spring	1968-1990	"	.203
GBK	Autumn	1963-1990	"	.605
SNE	Spring	1968-1990	"	.769
SNE	Autumn	1963-1990	"	.806
MAB	Spring	1968-1990	"	.468
MAB	Autumn	1963-1990	"	.223

[1]GBK=Georges Bank
GOM=Gulf of Maine
SNE=Southern New England
MAB=Middle Atlantic Bight

Table 2. Relative abundance of zooplankton taxa in percentage composition by subarea of the Northeast Shelf ecosystem, spring 1992.

	TAXA	PERCENT
GEORGES BANK	Harpacticoida	36.1552
	Calanus finmarchicus	22.7600
	Pseudocalanus minutus	14.1997
	Metridia lucens	9.9333
	Temora longicornis	2.1304
	Centropages typicus	2.0989
	Oithona ssp.	1.3096
	Alteutha depressa	0.8016
	Centropages hamatus	0.5190
	Nannocalanus minor	0.4934
	Clausocalanus arcuicornis	0.2624
	Paracalanus parvus	0.1397
GULF OF MAINE	Calanus finmarchicus	18.4826
	Acartia longiremis	14.1235
	Pseudocalanus minutus	14.0866
	Metridia lucens	8.9908
	Temora longicornis	4.8608
	Oithona ssp.	2.3798
	Centropages typicus	1.6181
	Centropages hamatus	0.8519
	Candacia armata	0.8475
	Clausocalanus arcuicornis	0.4517
	Calanoida	0.2016
SOUTHERN NEW ENGLAND	Pseudocalanus minutus	26.1990
	Calanus finmarchicus	24.5633
	Temora longicornis	12.4209
	Metridia lucens	6.0706
	Centropages typicus	5.1116
	Clausocalanus arcuicornis	5.0070
	Centropages hamatus	3.6824
	Paracalanus parvus	0.2832
	Nannocalanus minor	0.1828

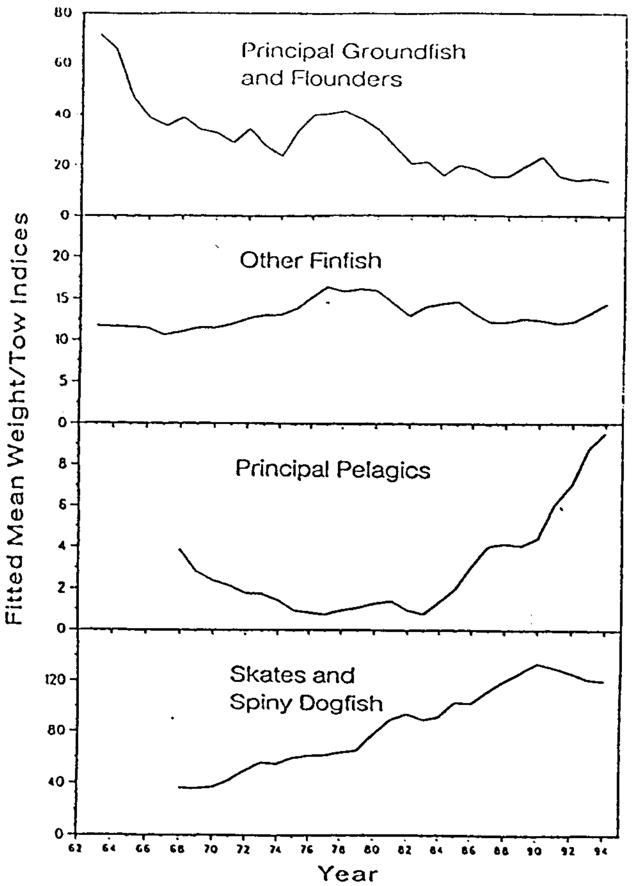

Figure 1 (a).

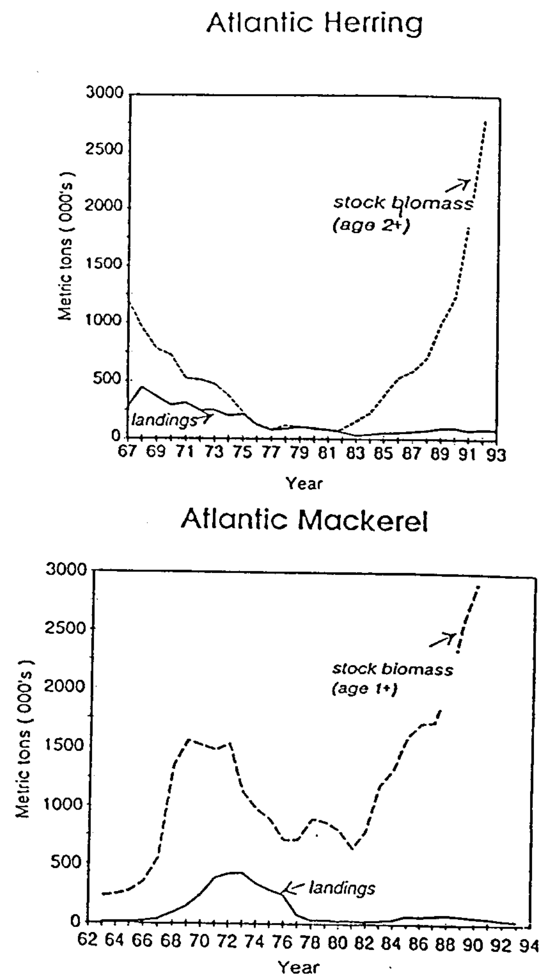

Figure 1 (b).

Figure 1 (a). Trends in indices of aggregate abundance reflecting changes in fisheries resources based on bottom trawl surveys of the Northeast Shelf ecosystem 1963-1994;
(b). Fish catch and estimated biomass of Atlantic herring and Atlantic mackerel stocks inhabiting waters off the Northeast coast of the United Stated, 1963 to 1994. (From NEFSC, 1995).

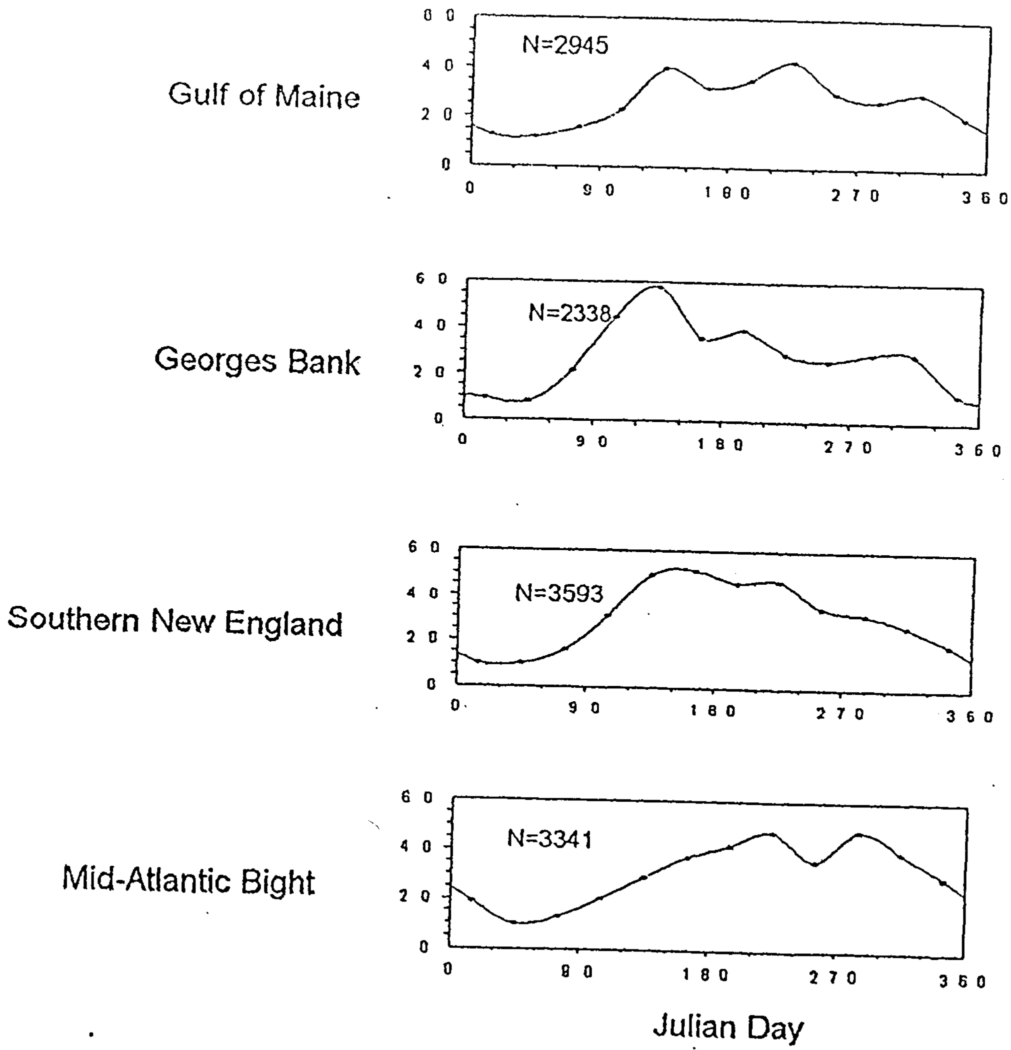

Figure 2. Seasonal variation of zooplankton displacement volume (median cc/100m^3) from Bongo net collections over four subareas of the Northeast Shelf ecosystem, based on 1977-1993 data.

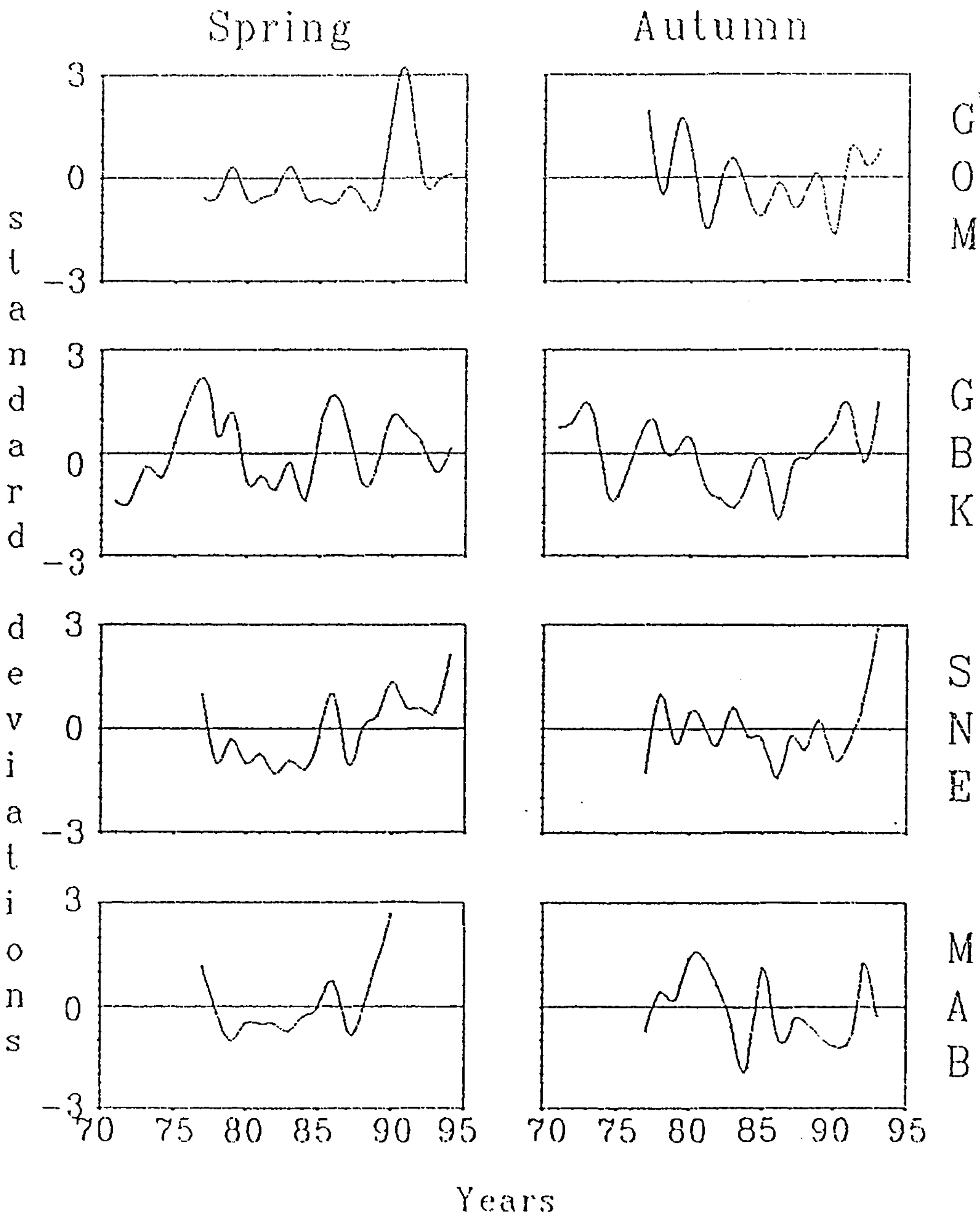

Figure 3. Standardized time series of spring and autumn zooplankton displacement volumes from Bongo net collections over four subareas of the Northeast Shelf Ecosystem: Gulf of Maine (GOM); Georges Bank (GBK); Southern New England (SNE), and Middle Atlantic Bight (MAB).

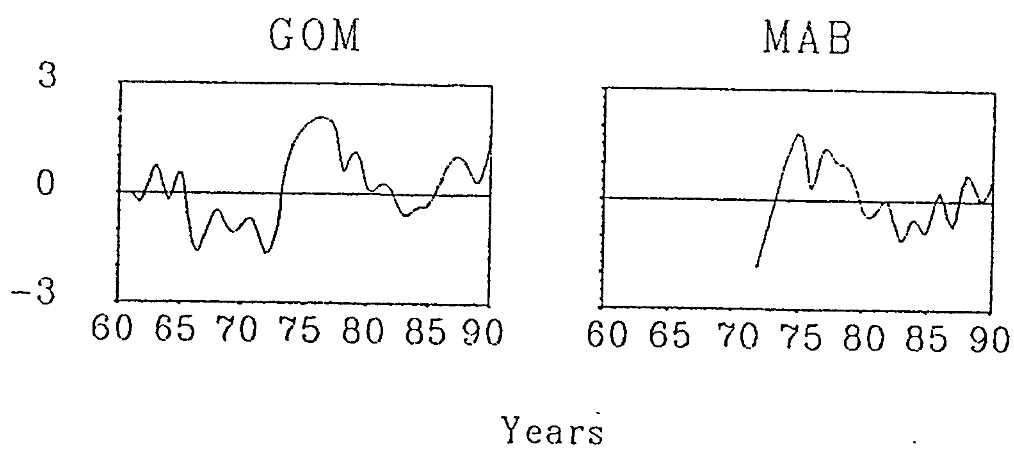

Figure 4. Standardized time series of annual abundances of zooplankton from continuous plankton recorder transects crossing two subareas of the Northeast Shelf Ecosystem: Gulf of Maine (GOM); and Middle Atlantic Bight (MAB).

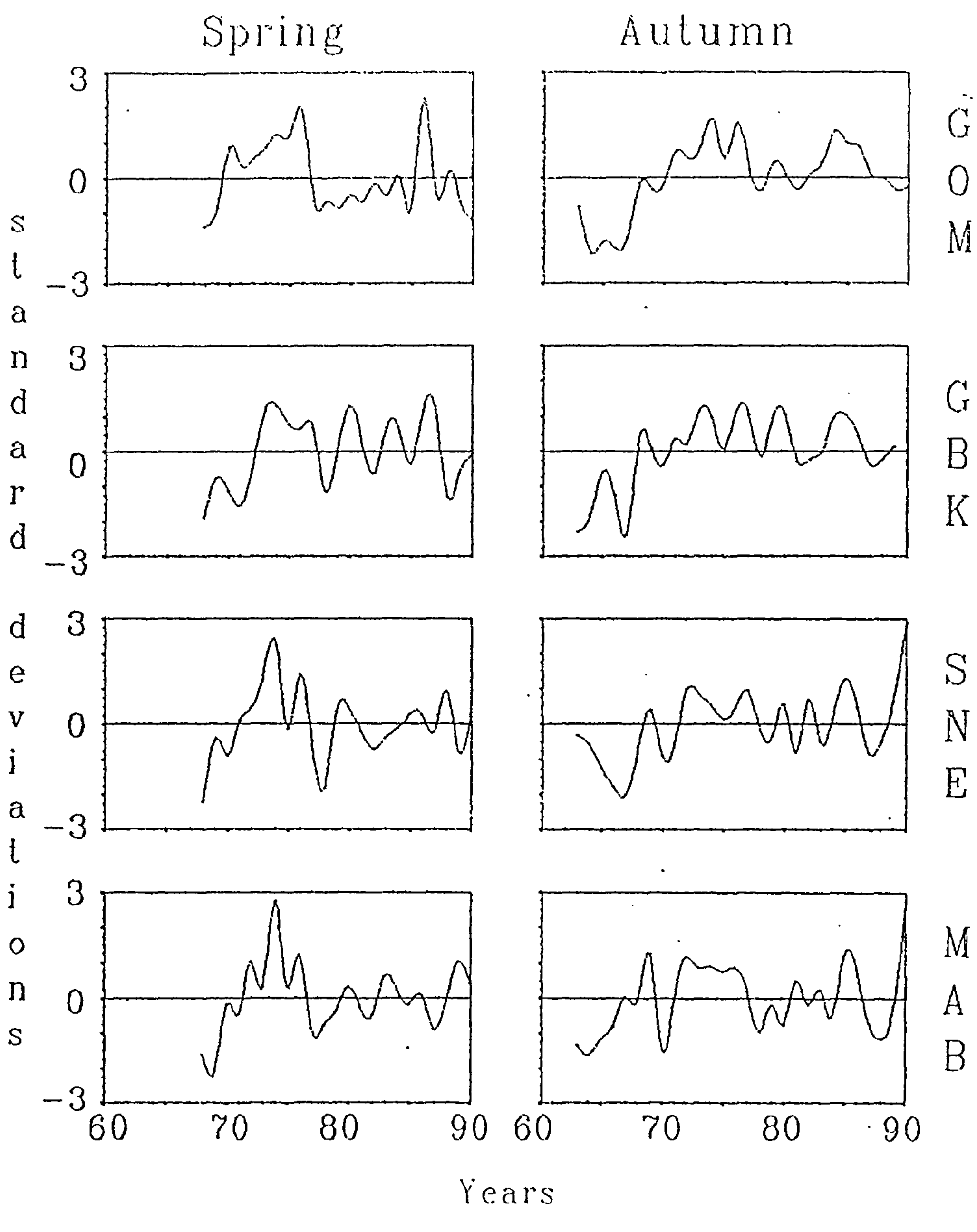

Figure 5. Standardized time series of spring and autumn bottom temperatures over four subareas of the Northeast Shelf Ecosystem: Gulf of Maine (GOM); Georges Bank (GBK); Southern New England (SNE); and Middle Atlantic Bight (MAB). Modified from: Holzwarth and Mountain, 1990).