Spring 2007 Update: Annual Condition of the Northeast Shelf Ecosystem

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Spring 2007 Update: Summary of Conditions of the Northeast Shelf Ecosystem

Summary

The Northeast Shelf ecosystem is among the more productive of the world's 64 Large Marine Ecosystems (LMEs). The most recently measured ecosystem wide levels of zooplankton and primary productivity are close to the long term mean (1986 - 2006) of 40 cc $100m^{-3}$ and 337 gC m^{-2} y^{-1}, respectively. However, spatial and temporal variability has been observed among subareas and seasonal pulses of the LME in zooplankton, chlorophyll, and primary productivity are described in this Advisory.

- Sea surface temperature and surface chlorophyll data exhibit a large amount of within and between year variability, but there is an indication in recent years of a warming trend in shelf-wide SST during fall. Inter-annual variability in fall levels of chlorophyll has been large, making it difficult to discern a shelf-wide trend; however, the northern areas of the shelf have had depressed chlorophyll levels in recent years, whereas the southern areas of have shown an increase.
- There is also substantial inter-annual variability in zooplankton biomass, as represented by a biovolume measurement, yet a long-term trend is apparent. Zooplankton biomass during fall is increasing in some areas and decreasing in others.
- Long term trends (1854-2006) in SST show that the NE Shelf Ecosystem is warming, both in terms of annual mean and fall temperatures, but SST has been higher in the past. These same analyses show that the summer to winter range in temperature is at its highest level recorded, suggesting that the ecosystem is experiencing extreme ranges in temperature and rapid heating and cooling rates.
- Ship of opportunity data shows that in situ chlorophyll trends in the Gulf of Maine match those observed in the satellite data, suggesting a decline in fall phytoplankton. The principal fall zooplankton species, Centropages typicus and Oithonia, have also declined in recent years.
- Analysis of regional phytoplankton cycles shows that there is a high degree of year to year variability in seasonal bloom and phytoplankton concentrations. In the northern part of the ecosystem, the fall bloom in the Gulf of Maine and on Georges Bank has declined and even failed to develop in some years. In the southern areas the trends are less well developed.

Data Sources

SST is derived by compositing data from three sources, the Advanced Very-High Resolution Radiometer onboard the Polar Orbiting Environmental Satellite (AVHRR-POES), MODIS Terra and MODIS Aqua, and represents the near-surface ocean temperature, not the temperature of the entire water column.

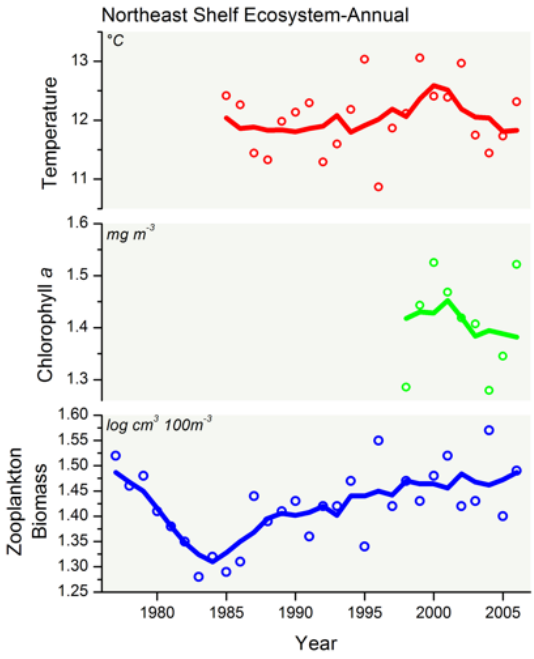
Daily synoptic views of surface concentrations of chlorophyll a are derived from the Sea-viewing Wide Field of View Sensor (SeaWiFS) ocean color sensor onboard the SeaStar spacecraft. Chlorophyll a is considered to be an index of the amount of phytoplankton biomass present in surface water.

Zooplankton biomass is derived from shipboard surveys of the U.S. Northeast Shelf ecosystem - these small animals link the energy produced through primary production to higher trophic levels. From 1977-1987, the MArine Resources Monitoring, Assessment, & Prediction (MARMAP) program conducted intensive surveys from Cape Hatteras, North Carolina to Nova Scotia. These efforts continued at a reduced level through the 1990s and are ongoing today. Currently, 30 plankton samples are taken 6 times a year in each of the four ecosystem subareas: Mid-Atlantic Bight, Southern New England, Georges Bank, and Gulf of Maine (resulting in approximately 720 measures of zooplankton biomass annually).

Phytoplankton and zooplankton also are collected on monthly transects across the Gulf of Maine and the Middle Atlantic Bight using Ships of Opportunity. Phytoplankton abundance is quantified based on the color of the sample. Zooplankton abundance is based on counts of individual species and stages. During the spring and summer of 2006, collections were suspended along the Middle Atlantic Bight transect owing to lack of funding.

Long term SST were extracted from the Extended Reconstructed Sea Surface Temperature (ERSST, version 2) dataset. This dataset is based on the temperature compilation of the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) SST dataset and represents interpolation procedures that reconstructs SST fields in regions with sparse data.

Annual Conditions on the Northeast Shelf Ecosystem

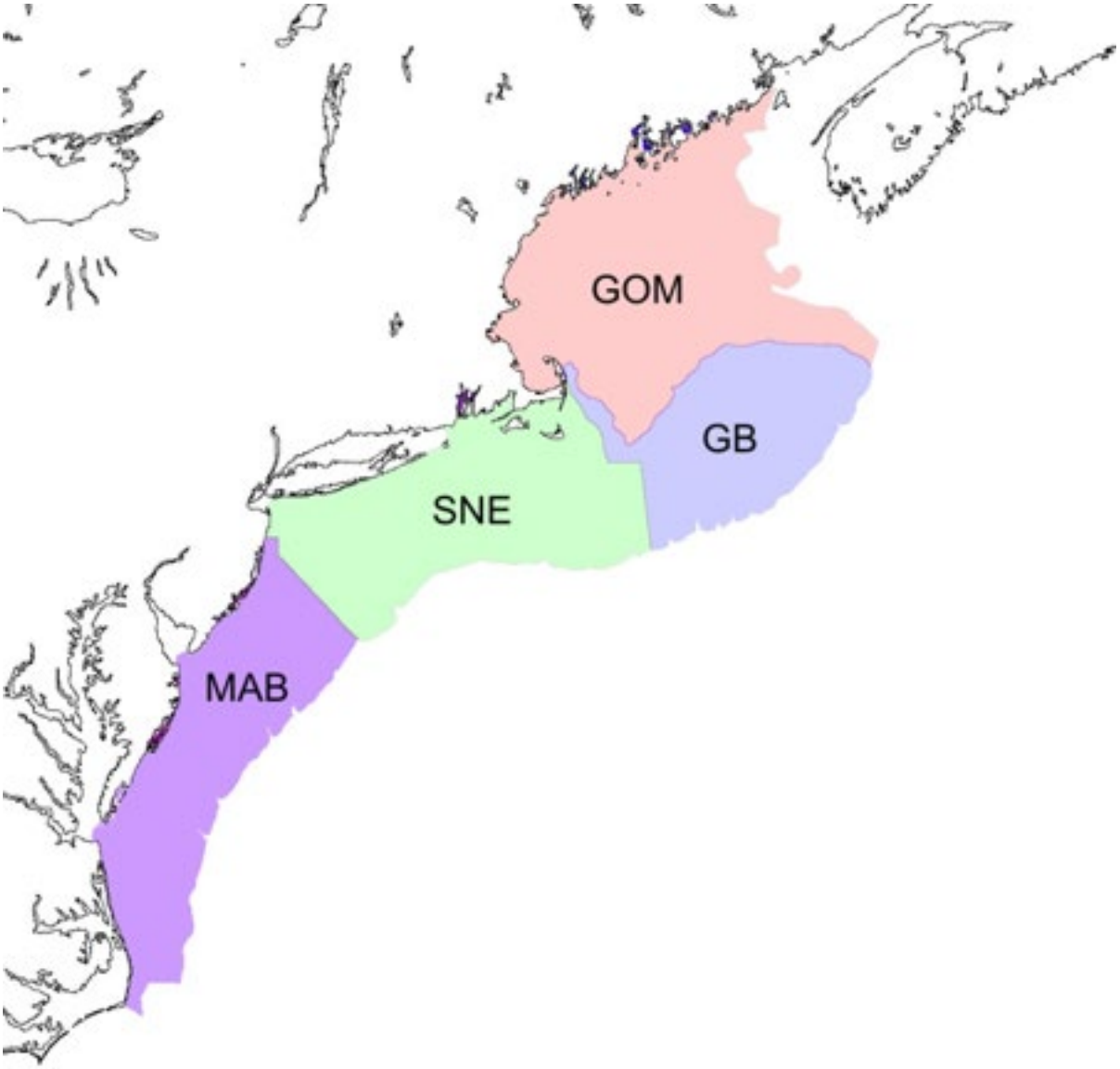


Sea surface temperature and surface chlorophyll data exhibit a large amount of internal variability, but there is an indication in recent years of a cooling trend in shelf-wide SST and a reduction in surface chlorophyll. There was no appreciable trend in SST until the late 1990s, when temperatures began to increase. The data suggest a peak in SST around the year 2000, followed by a decreasing trend through 2006. Estimates of chlorophyll concentration are derived from remotely-sensed measurements made by the SeaWiFS sensor which began operation in September 1997. The available time series in chlorophyll mirrors SST, with a decline evident in the trend line for recent years; however, the measurement in 2006 indicated an increase in shelf chlorophyll.

Data on total zooplankton abundance is available from 1977. There is also substantial variability in zooplankton biomass, as represented by a biovolume measurement, yet a long-term trend is apparent. Zooplankton biomass decreased through the late-1970s and into the 1980's, and has since increased.

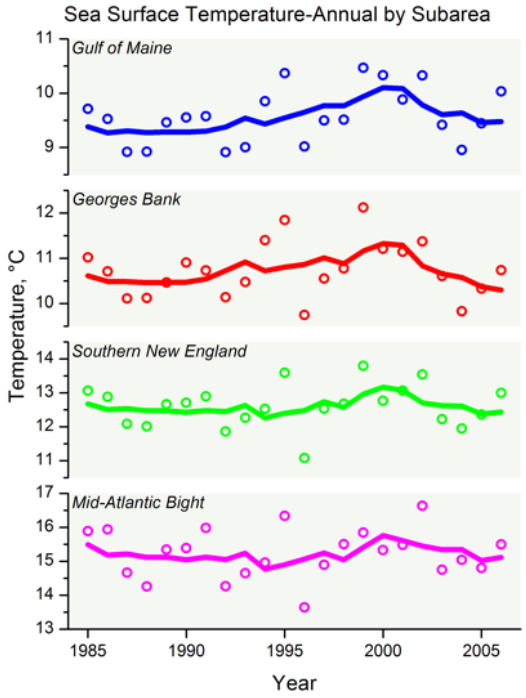
Although these data suggest an overall increase in secondary production and a decrease in temperature and phytoplankton biomass, regional and temporal dynamics must be considered in the assessment of the entire ecosystem.

Annual Conditions on the Northeast Shelf Ecosystem by Subareas



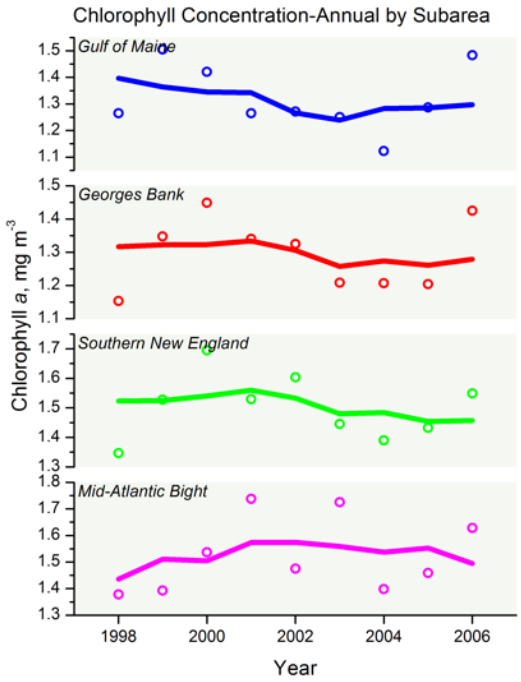
The Northeast Continental Shelf ecosystem can be divided into four major subareas: Gulf of Maine (GOM), Georges Bank (GB), Southern New England (SNE) and the Middle Atlantic Bight (MAB), which reflect different underlying oceanographic conditions and fishery management boundaries. The variations in SST, chlorophyll, and zooplankton biomass in these four subareas are described in the following sections.

Annual Sea Surface Temperature



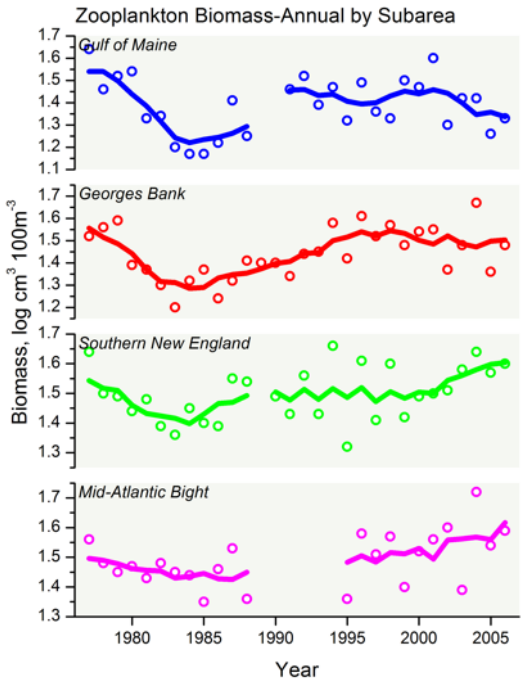
The four shelf subareas show similar temporal trends in SST; however, the temperature levels between subareas are different. SST in the GOM averaged 9.6°C over the period whereas temperature in the MAB averaged 15.2°C; the SSTs on GB and in SNE were intermediate between these values. Though all four subareas show an increase in temperature around the year 2000 and a subsequent decrease during the past five years, the relative magnitude of the change is greatest in the GOM and on GB. The 2000 peak in the temperature represents a 10% increase over SSTs at the beginning of the time series in the GOM whereas it only represents a 4% increase in the MAB. Despite these regional differences in average surface temperature, the general trend in SST, as assessed by satellite sensors for the whole shelf, is representative of the Northeast Shelf Ecosystem.

Annual Chlorophyll



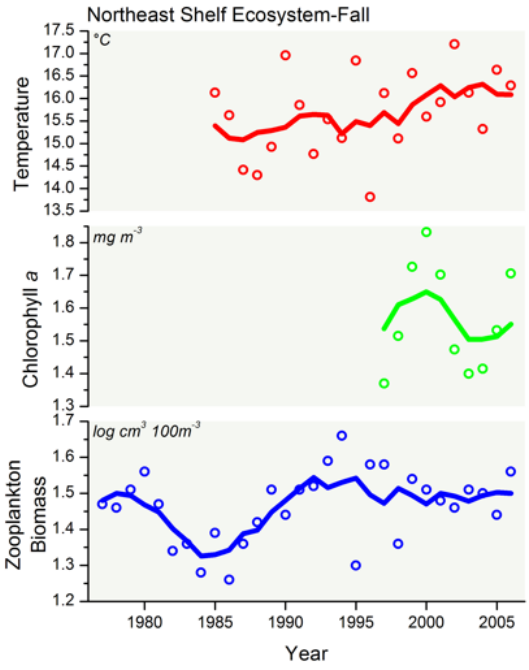
From examination of temporal trends in satellite derived surface chlorophyll for the past eight years, it is evident that there is a high degree of year-to-year variability in the shelfwide chlorophyll index in each of the four subareas. Although this time series of observations is relatively short, the trends for GOM, GB and SNE are similar, showing a down-trend in recent years and a marked increase in 2006. The most northern and southern areas, Gulf of Maine and Mid Atlantic Bight, also have the most variable measurements as indicated by coefficients of variation, which are higher in these areas than in Georges Bank or Southern New England.

Annual Zooplankton



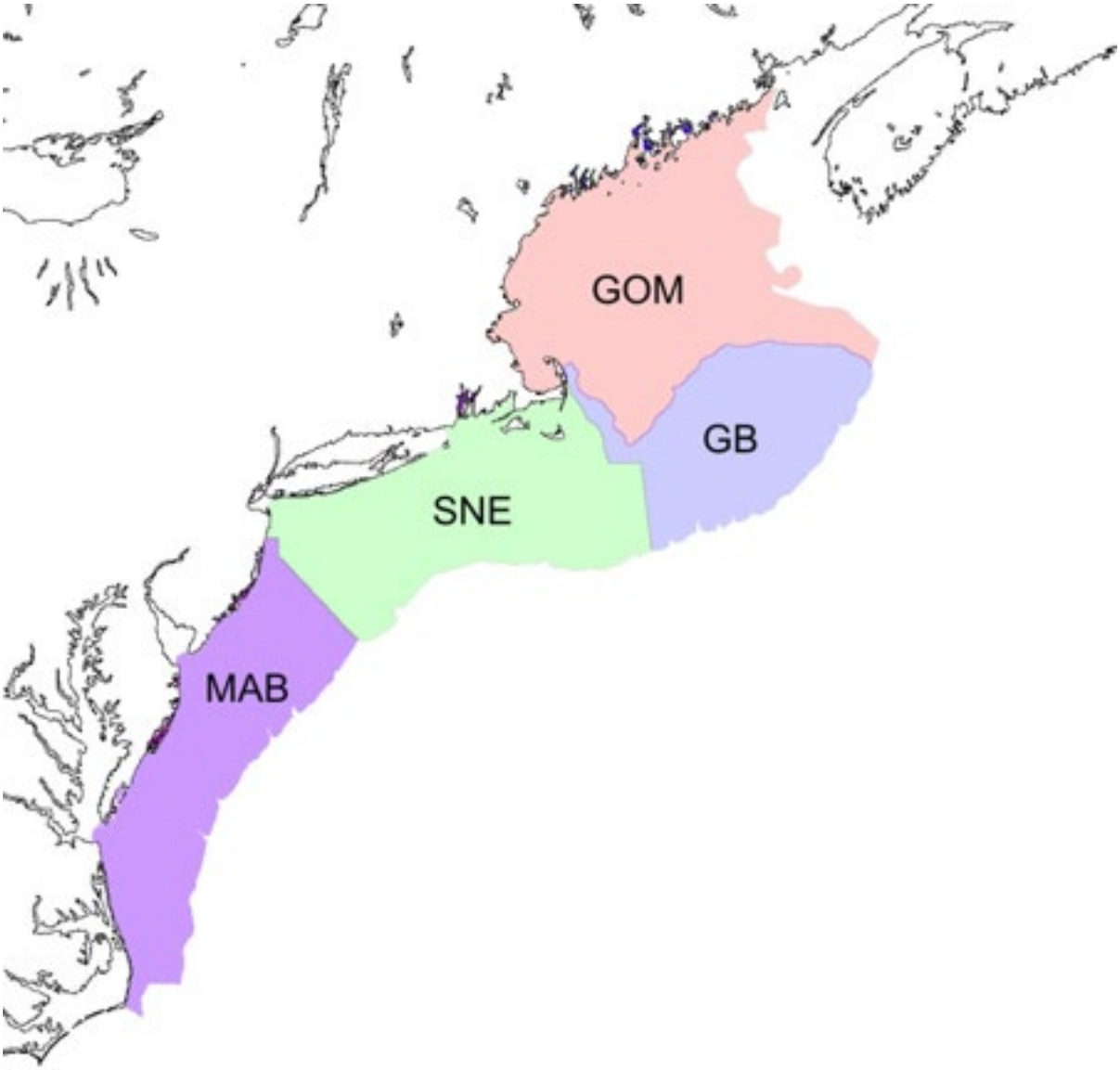
The general trends in zooplankton biomass in all four shelf subareas resemble the shelf-wide average; however, the dynamic pattern of change in biomass level and internal variability in survey results are dramatically different among subareas. The northern subareas, GOM and GB, show a more conservative pattern of interannual change in biomass, suggesting zooplankton are responding to conservative forcing parameters and are well estimated. Zooplankton biomass in SNE and MAB vary widely year to year, which we believe reflects the dynamic nature of the circulation system affecting zooplankton in the region. Generally zooplankton appear to have declined during the early 1980s and have since slowly increased in biomass level. However, this pattern of decline is not the same among the subareas. On GB and in the GOM the decline in zooplankton was most pronounced in the 1980s, resulting in a relative decrease of nearly 50% in zooplankton biomass levels. The biomass in both subareas increased to levels close to 1970s high period between 2000 and 2005. The relative decline in SNE and MAB was more on the order of 20%. Similarly, the recent increase in zooplankton differs in magnitude among subareas. The decrease from 2000 to 2006 in the GOM and GB areas was on the order 10 and 4%, respectively, whereas the increase in SNE and MAB was on the order of 7 and 5%.

Fall Conditions on the Northeast Shelf Ecosystem



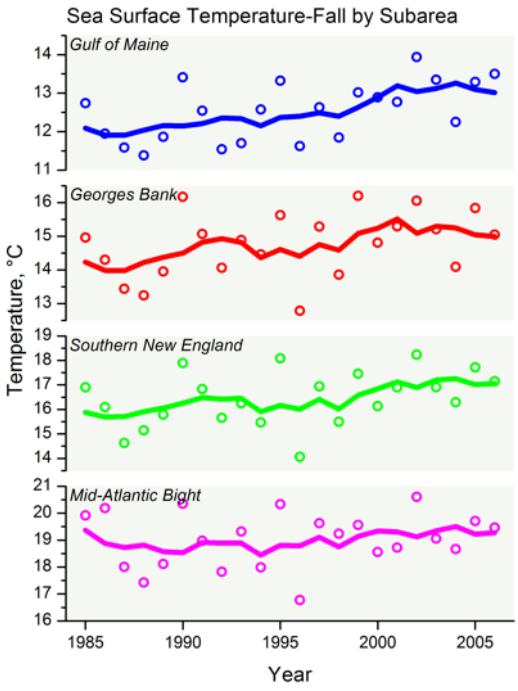
If we consider only the time trend of SST during the fall season then a different pattern emerges from the annual trend in SST for the entire shelf system. Whereas the annual mean suggests surface waters have cooled during the past few years, the fall SST data indicate a continuation of the warming trend that began in the 1990s. Fall chlorophyll levels are slightly higher than the annual mean reflecting the seasonally of fall blooms in some areas. The fall bloom pattern appears to be in synchrony with the overall time series pattern of chlorophyll levels on the shelf. Fall zooplankton biomass suggests a different pattern of decline and increase in zooplankton communities; the decline in zooplankton biomass of the mid 1980s appears to be a more localized event. The recent increase in annual zooplankton abundance is also not seen in the fall, indicating important seasonal dynamics affecting the annual pattern.

Fall Conditions on the Northeast Shelf by Subarea



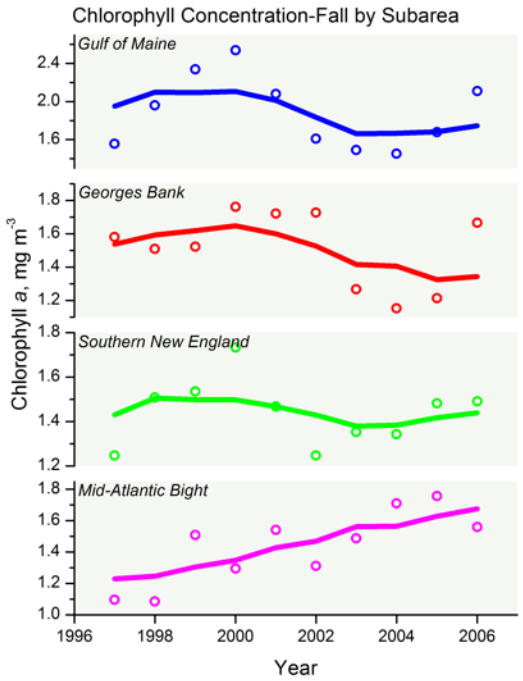
The Northeast Continental Shelf ecosystem can be divided into four major subareas: Gulf of Maine (GOM), Georges Bank (GB), Southern New England (SNE) and the Middle Atlantic Bight (MAB), which reflect different underlying oceanographic conditions and fishery management boundaries. The regional variation in SST, chlorophyll, and zooplankton biomass is evaluated by these subareas.

Fall Sea Surface Temperature



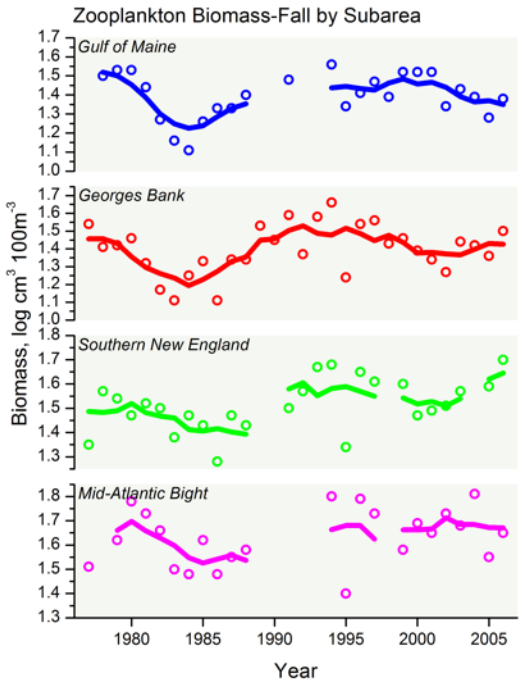
The increase in fall SST is most pronounced in the northern subareas of the shelf. The GOM, GB, and SNE have gone through a 1.1-1.4°C increase in fall SST over the past 21 years. SST has only increased on the order of 0.5°C in the MAB. It should be noted that none of the linear trends in SST were significant

Fall Chlorophyll



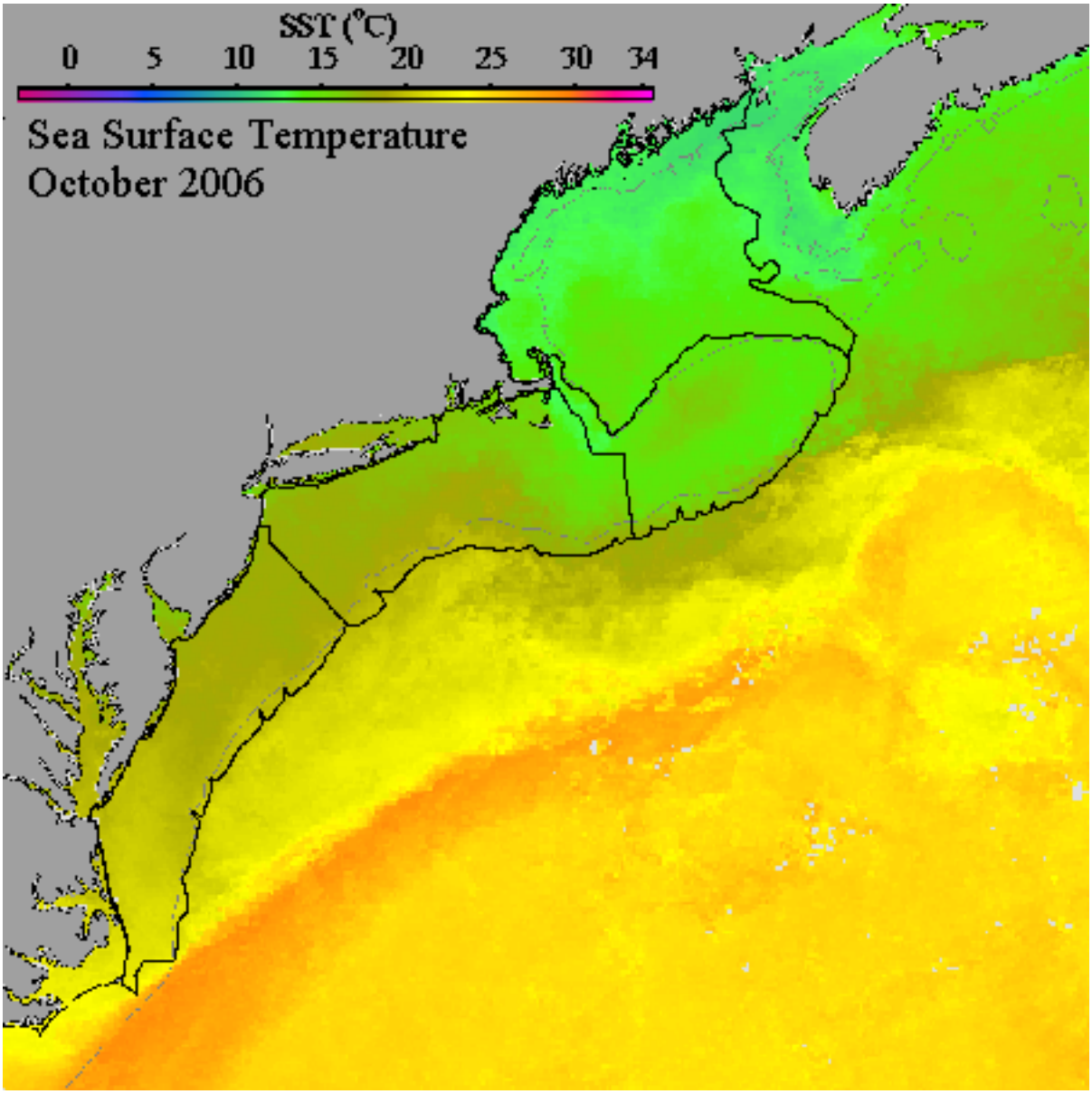
Fall chlorophyll concentrations continue to show a decreasing trend despite the relatively high value observed in 2006. Fall chlorophyll continues to increase in the SNE and MAB areas.

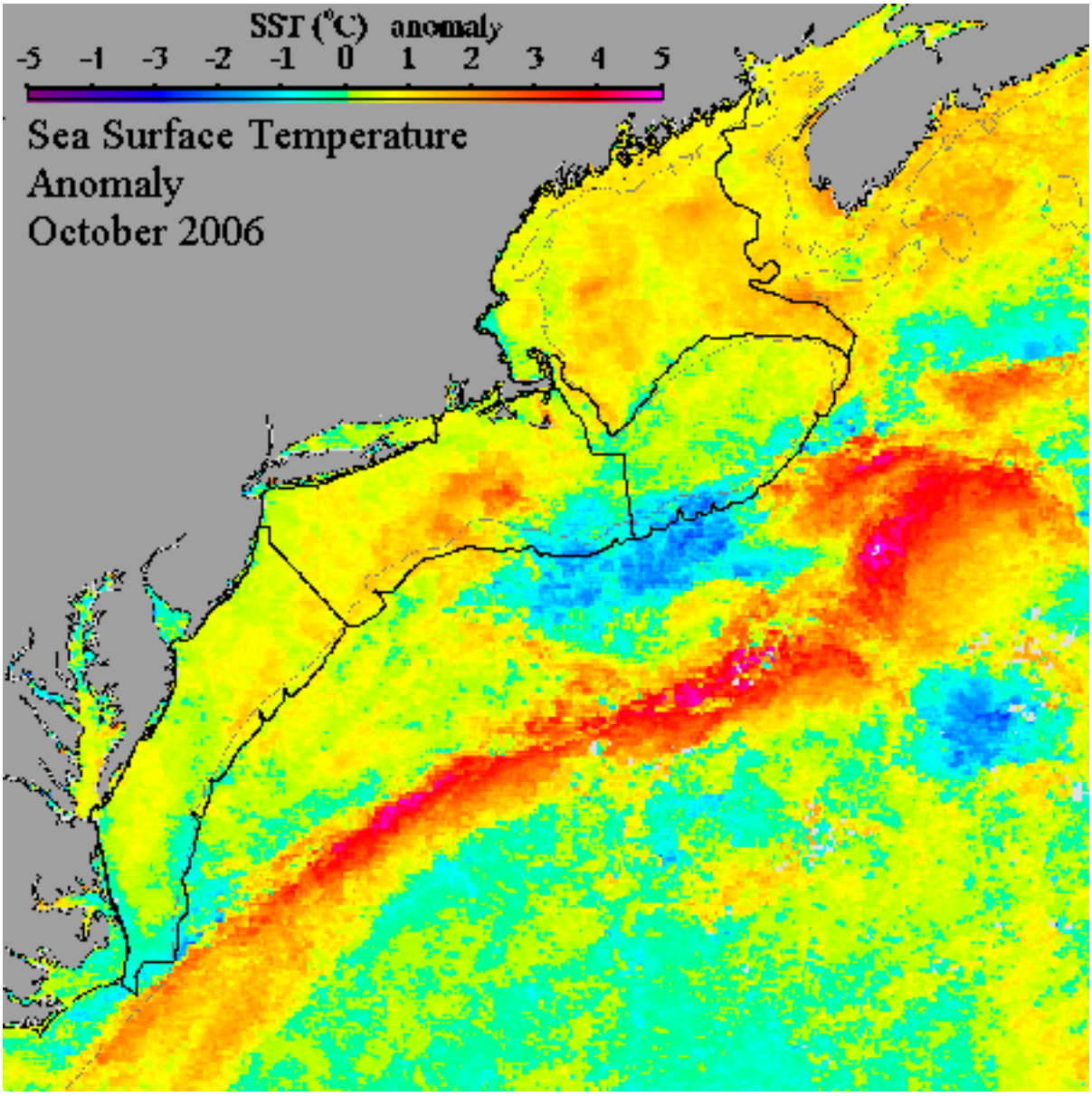
Fall Zooplankton



During September and October, zooplankton biomass is greatest in the MAB and least in the GOM and GB. Zooplankton biomass was near peak through the mid-1990s, but a gradual decline in biomass started in about 2000. Regional declines in fall zooplankton coupled with regional increases in annual zooplankton indicate important regional dynamics affect the shelf-wide annual patterns.

Fall Sea Surface Temperature Distribution

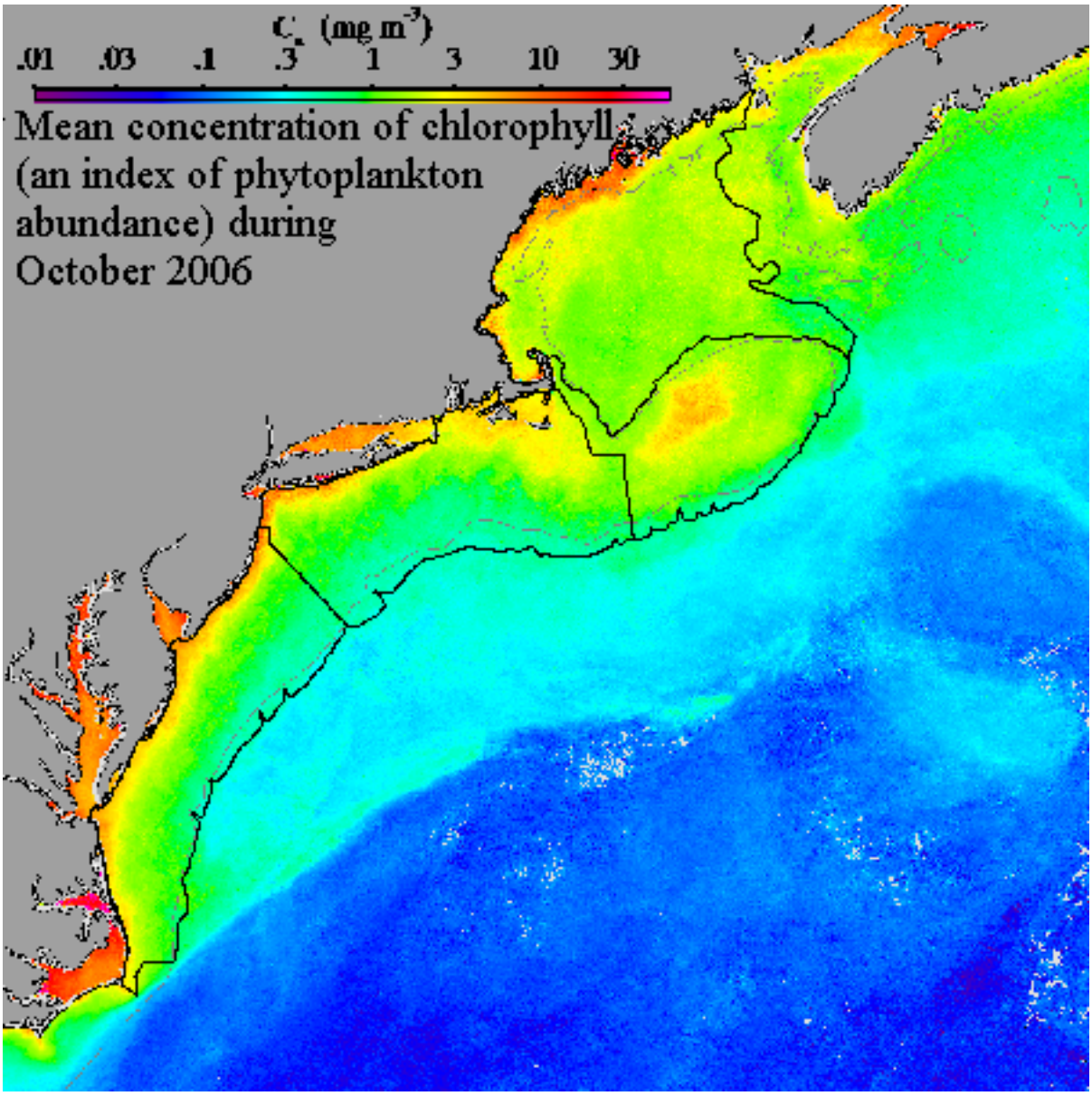


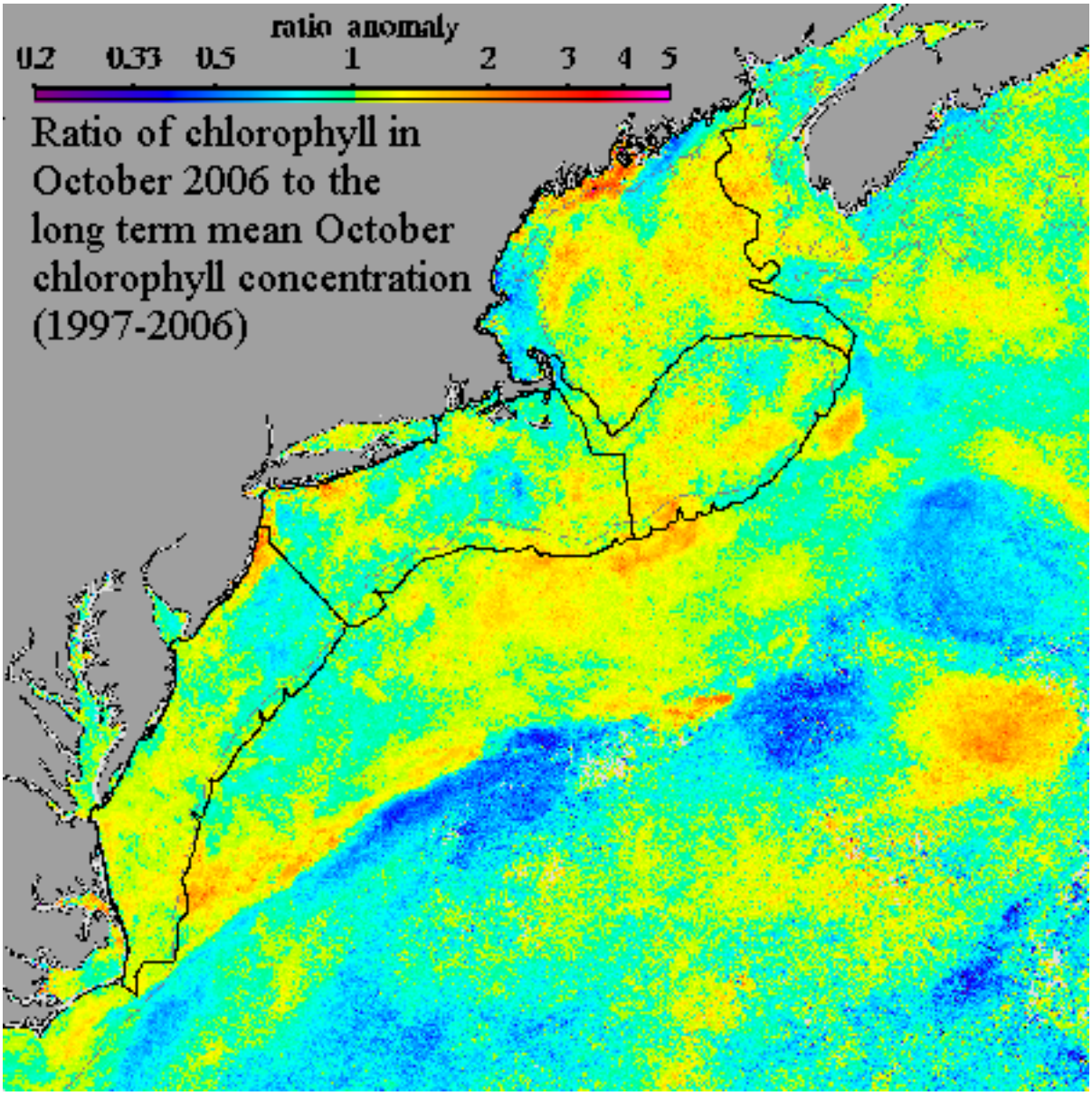


The distribution of sea surface temperature (SST) throughout the Northeast Shelf ecosystem during October 2006 shows a clear separation between the warmer waters in the Southern New England (SNE) / Mid-Atlantic Bight (MAB) subareas, and the cooler surface waters to the north, over Georges Bank and throughout the Gulf of Maine (GOM) (see upper map figure showing the distribution of sea surface temperature in degrees Celsius). The warm waters of the MAB continental shelf and over the western GOM water suggest conditions typical of late summer-early fall where the water column is vertically stratified. In contrast, the cooler surface waters over Nantucket Shoals, parts of Georges Bank, and along the Maine and Nova Scotia coasts reflect the typical conditions of strong tidal mixing and weak vertical thermal stratification throughout the summer. The departures of SSTs during October 2006 from the long-term October mean are shown as a temperature-anomaly map (see lower anomaly map, also in units of degrees Celsius). Surface waters in the GOM and on the SNE shelf and most of the

MAB shelf were about 1-2 degrees warmer during October 2006 than average. SSTs over much of Georges Bank are close to the average values for October. SSTs over the broad axis of the Gulf Stream during October 2006 are 3-4 degrees warmer than the mean SST based on the 22-year (1985-2006) climatology.

Fall Chlorophyll Distribution

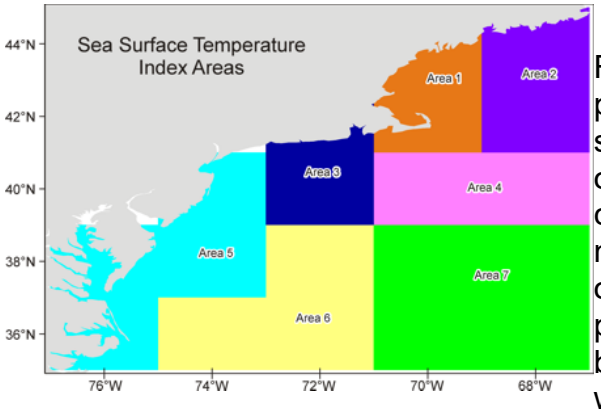




A general pattern is evident where chlorophyll concentration is greatest in continental shelf waters, intermediate over the deeper slope water, and lowest in the vicinity of the Gulf Stream and Sargasso Sea (see upper map figure showing concentration of chlorophyll during October 2006 from Cape Hatteras to Nova Scotia). High levels of chlorophyll occur in the tidally mixed central areas of Georges Bank and Nantucket Shoals, and in the Middle Atlantic Bight estuaries and coastal waters enriched by estuarine plumes. The high chlorophyll values (3-8 mg m-3) in the nearshore northern Gulf of Maine indicate that fall bloom is underway during October. The same geographic range is used to illustrate how chlorophyll conditions during October 2006 compare with the average values for this month, where the average is computed from October data from 1997 through 2006 (see lower map figure showing ratio of chlorophyll concentration). The ratio of October 2006 chlorophyll to the 10-year October mean chlorophyll indicates that each of the four major subareas of the ecosystem have some

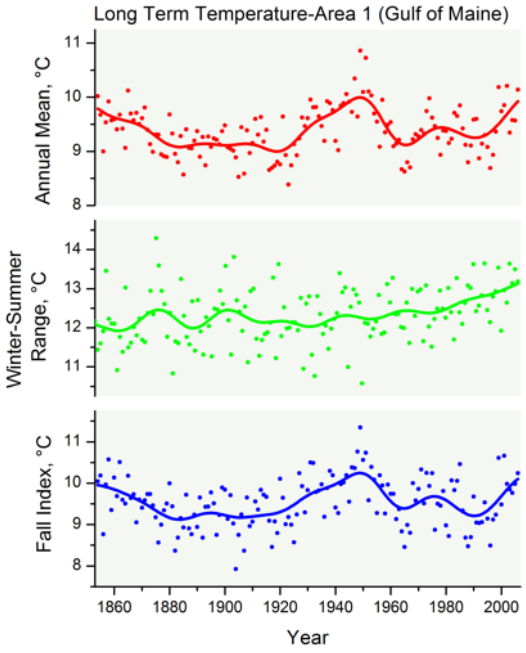
areas above and below the climatological average for October. In the nearshore areas, the phytoplankton fall bloom usually starts in September and peaks during October. These recent data from October 2006 suggest that while the fall bloom is underway it is somewhat above the mean levels only in the nearshore GOM and nearshore waters off New Jersey.

Long Term Temperature Trends



Recruitment of fish stocks is a complex process dependant on both spawning stock size and environmental factors. For a number of stocks, environmental factors appear to be contributing to higher recruitment via transport mechanisms and the role of feeding opportunities for early life stages. The potential role of these and other factors are being explored for stocks on Georges Bank where we have seen improved recruitment over the past decade while zooplankton populations of the Northeast Shelf ecosystem have also increased. The indication of important regional and seasonal dynamics means that temporal and spatially-explicit examinations of zooplankton are required to further examine the link between lower-trophic level production and fisheries production.

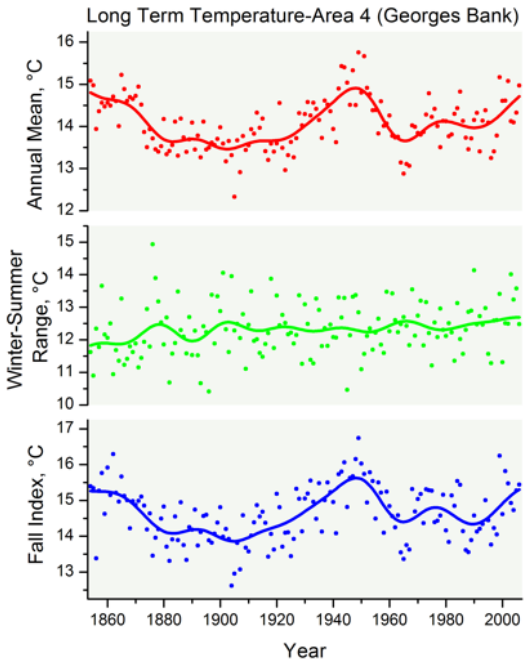
Long Term Temperature-Area 1 (Gulf of Maine)



Index area 1 of the long term ERSST dataset overlaps most of the Gulf of Maine with the exception of the eastern portion of the Gulf. The annual mean SST for area 1 during 2006 was 10.1°C which is greater than the long term mean of 9.4°C, but still less than the maximum of the time series of 10.9°C. SSTs were higher during the mid-century warming period of the 1940s, and nearly as high as the beginning of the time series. Winter-summer temperature difference has been increasing during the last few decades, which has been interpreted as an effect of climate change. The winter-summer difference was 13.2°C in 2006, which is greater than the long term mean of 12.3°C, but still less than the maximum difference of the time series of 14.3°C. Finally, the fall SST index for

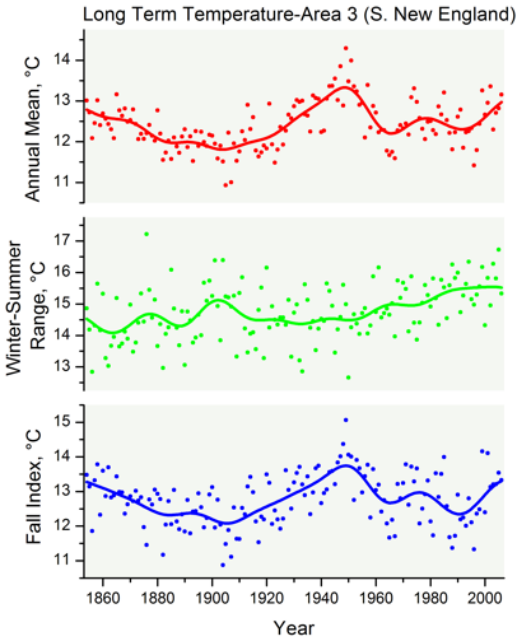
this area is patterned similarly to the annual mean with a value of 10.2°C in 2006, which is greater than the long term mean of 9.5°C, but still less than the maximum of the time series of 11.3°C.

Long Term Temperature-Area 4 (Georges Bank)



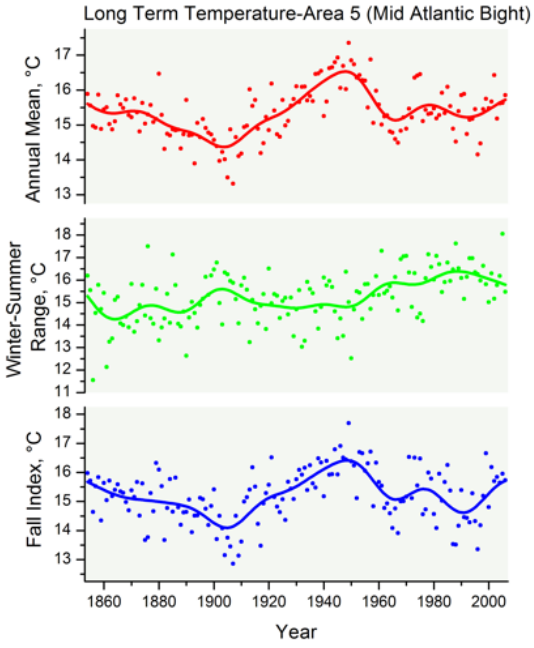
Index area 4 of the long term ERSST dataset overlaps some of Georges Bank, but in looking at the temperatures trends it is obvious that much of area 4 captures SSTs from the Gulf Stream and warmer waters to the south. Since the SST trend between area 4 and Georges Bank correlate well, it was deemed useful to look at this area. The annual mean SST for area 4 during 2006 was 15.0°C which is greater than the long term mean of 14.1°C, but still less than the maximum of the time series of 15.8°C. SSTs were higher during the mid-century warming period of the 1940s, and nearly as high as the beginning of the time series. Winter-summer temperature difference has been increasing at a much slower rate in waters off the shelf and this is reflected in the data for area 4. The winter-summer difference was 12.5°C in 2006, which is only slightly greater than the long term mean of 12.3°C, but still less than the maximum difference of the time series of 14.9°C. Finally, the fall SST index for this area is patterned similarly to the annual mean with a value of 15.4°C in 2006, which is greater than the long term mean of 14.6°C, but still less than the maximum of the time of 16.7°C.

Long Term Temperature-Area 3 (S. New England)



Index area 3 of the long term ERSST dataset overlaps most of the Southern New England area of the shelf. The annual mean SST for area 3 during 2006 was 13.2°C which is greater than the long term mean of 12.4°C, but still less than the maximum of the time series of 14.3°C. SSTs were higher during the mid-century warming period of the 1940s, and nearly as high as the beginning of the time series. Winter-summer temperature difference has been increasing during the last few decades, which has been interpreted as an effect of climate change. The winter-summer difference was 15.3°C in 2006, which is greater than the long term mean of 14.7°C, but still less than the maximum difference of the time series of 17.2°C. However, this maximum was a single point early in the time series, which does not put into perspective how temperature appears to be trending to higher values in recent years. Finally, the fall SST index for this area is patterned similarly to the annual mean with a value of 13.3°C in 2006, which is greater than the long term mean of 12.8°C, but still less than the maximum of the time series of 15.1°C.

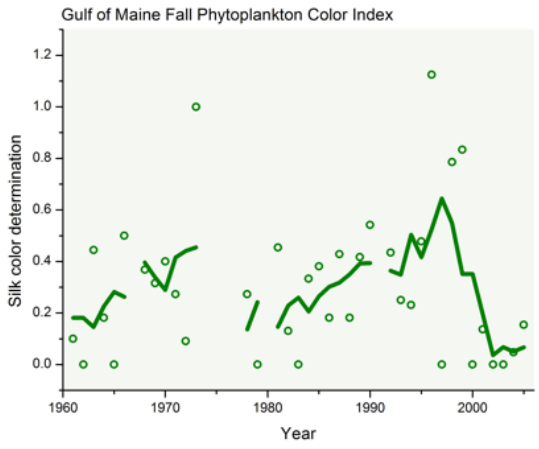
Long Term Temperature-Area 5 (Mid Atlantic Bight)

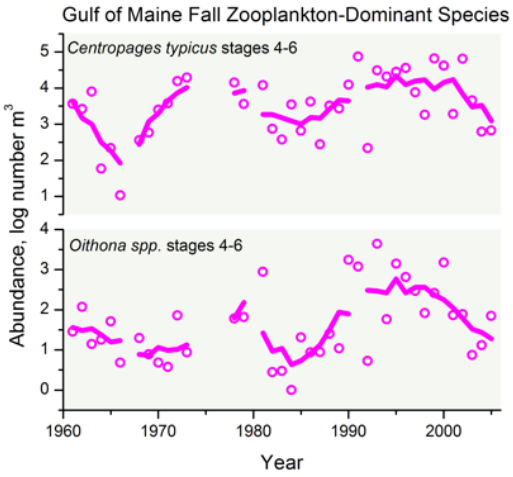


Index area 5 of the long term ERSST dataset overlaps most of the Mid Atlantic Bight area of the shelf. The annual mean SST for area 5 during 2006 was 15.9°C which is greater than the long term mean of 15.4°C, but still less than the maximum of the time series of 17.4°C. SSTs were higher during the mid-century warming period of the 1940s, and nearly as high as the beginning of the time series. Winter-summer temperature difference has been increasing during the last few decades, which has been interpreted as an effect of climate change. The winter-summer difference was 15.5°C in 2006, which is greater than the long term mean of 15.2°C, but still less than the maximum difference of the time series of 18.1°C. The trend curve

suggests that winter-summer temperature difference was elevated during the past few decades but may be decreasing in the most recent decade. Finally, the fall SST index for this area is patterned similarly to the annual mean with a value of 15.7°C in 2006, which is greater than the long term mean of 15.2°C, but still less than the maximum of the time series of 17.7°C.

Ship of Opportunity Data-Dominant Zooplankton Species

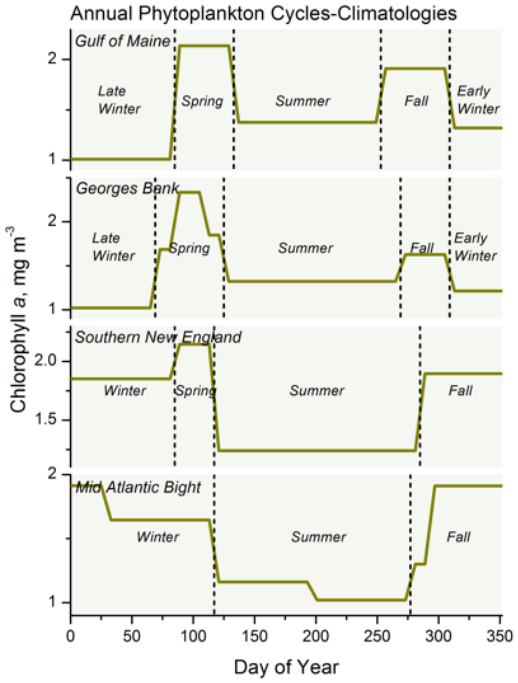




Phytoplankton color index from the Continuous Plankton Recorder transect across the Gulf of Maine is consistent with the chlorophyll a derived measures from satellite - there has been a decline in fall chlorophyll from the mid-1990's to the present. Current fall phytoplankton color index values are near the lowest values observed.

Abundances of two species of copepods from the Gulf of Maine Continuous Plankton Recorder are consistent with the fall biomass estimates - zooplankton biomass and abundances are decreasing in the Gulf of Maine. Two common fall species in the Gulf of Maine both exhibit a decrease in a abundance in recent years after times series highs through the 1990s.

Annual Phytoplankton Cycle

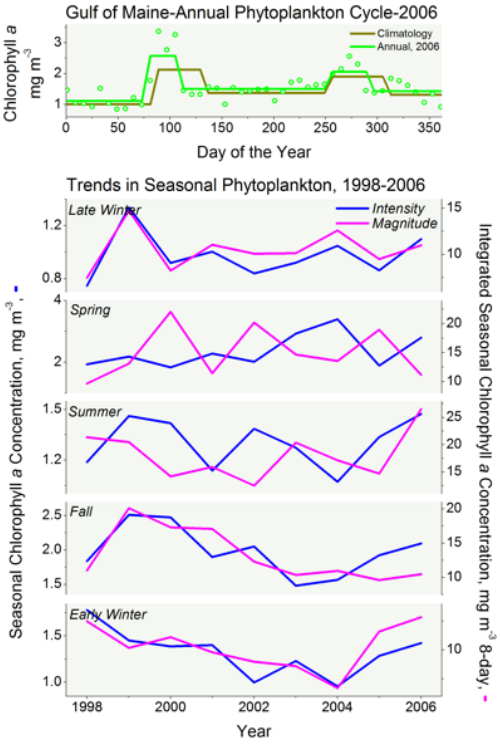


The annual cycle of phytoplankton production varies in different parts of the North Shelf ecosystem. The northern parts of the ecosystem, including the Gulf of Maine and Georges Bank areas, tend to have a spring bloom and usually, but not always, a well developed fall bloom. These two areas can be divided into five seasonal time periods: late winter, spring, summer, fall, and early winter. The five-period cycle is not present in the southern areas of the ecosystem. A spring bloom usually develops in the Southern New England area, but a fall bloom does not consistently develop. This area is divided into four time periods: winter, spring, summer, and fall. The Mid Atlantic Bight can best be characterized with three seasonal time periods: winter, summer, and fall. The 2006 annual cycles for these four regions, and historical data on the chlorophyll concentration during each time period is provided below. Chlorophyll concentration is characterized in two ways:

Seasonal Chlorophyll Concentration: is the mean chlorophyll concentration for the seasonal time period in a region. This is analogous to intensity.

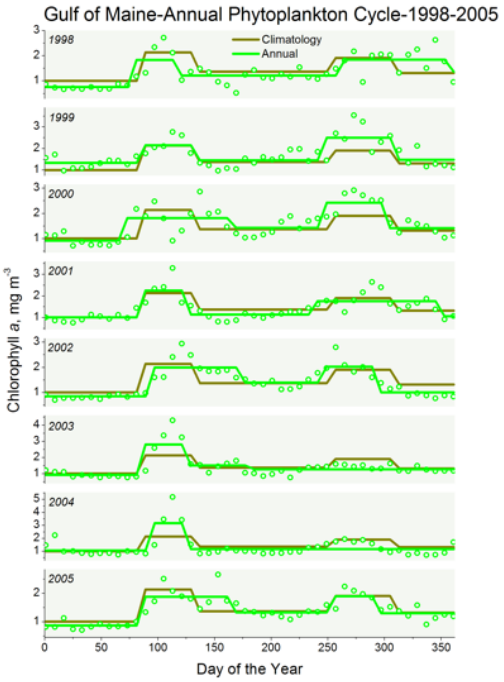
Integrated Seasonal Chlorophyll Concentration: is the mean chlorophyll concentration for a seasonal time period times the length of the time period. This is analogous to magnitude. In some years, the time period start or stop day was not obvious from the annual data, in these cases the climatological time period was used instead.

Annual Phytoplankton Cycle - Gulf of Maine



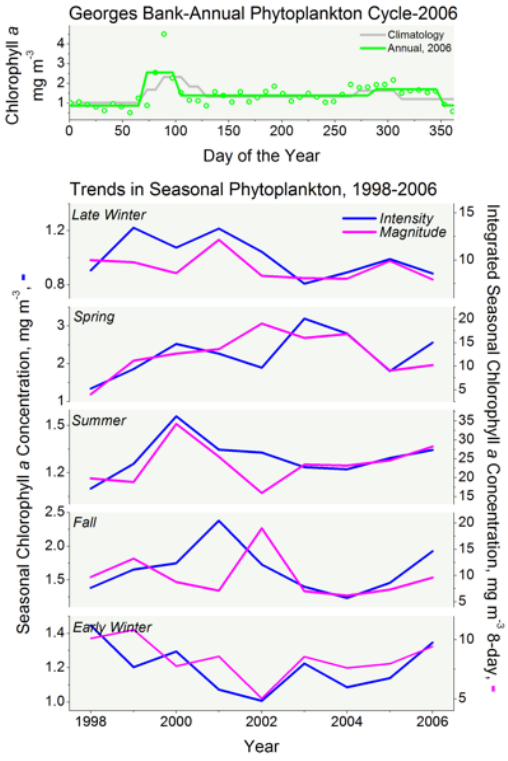
The annual phytoplankton cycle for the Gulf of Maine in 2006 is overlaid on the climatological cycle for comparison (see top panel). The spring bloom was earlier and had a higher than average concentration, where the fall bloom was relatively short and of average concentration. Winter and summer conditions were consistent with the long term average. Seasonal chlorophyll concentration and integrated seasonal chlorophyll concentration are presented for the five time periods used to represent the Gulf of Maine annual phytoplankton cycle (see bottom panel). Concentration showed an increase in all time periods during 2006, however, integrated concentration was extremely low for the spring and fall bloom periods reflecting the short duration of these events. Thought low values of the spring blooms does not suggest a long term trend in spring phytoplankton production, the same cannot be said of the fall bloom which appears to be in decline in terms of both concentration and magnitude over the past decade.

Historic Phytoplankton Cycles - Gulf of Maine



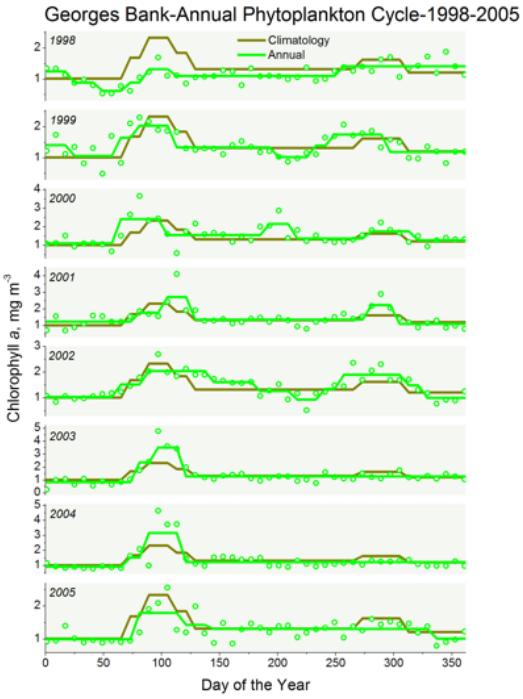
There has been considerable variation in the phytoplankton cycles of the Gulf of Maine. Most notably, the variation in the concentration and duration of the spring and fall blooms. In all years a spring bloom has developed, thought in some years it has been of very short duration (1998, 2001, 2004) versus some years where the bloom was of long duration (2000, 2002, 2005). There is no obvious trend in the development of the spring bloom. The fall bloom has failed to develop in some recent years (2003, 2004), which combined with the evidence of short duration fall blooms (2002, 2005, 2006) suggest the fall bloom has declined over the time period.

Annual Phytoplankton Cycle - Georges Bank



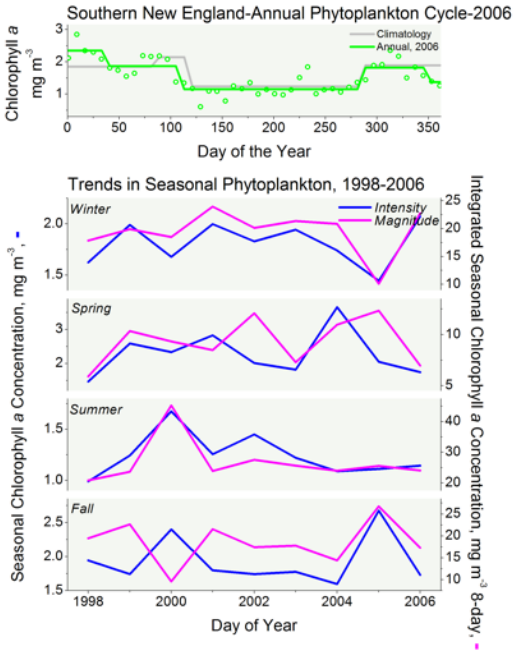
The annual phytoplankton cycle for the Georges Bank in 2006 is overlaid on the climatological cycle for comparison (see top panel). The spring bloom was earlier and had a higher than average concentration, where the fall bloom was of average concentration. The duration of the fall bloom was difficult to estimate, so climatological data was used to estimate the start and end points of the fall and early winters period in 2006. Late winter and summer conditions were consistent with the long term average. Seasonal chlorophyll concentration and integrated seasonal chlorophyll concentration are presented for the five time periods used to represent the Georges Bank annual phytoplankton cycle (see bottom panel). Concentration showed an increase in all time periods except early winter during 2006; however, integrated concentration was low for the spring and fall bloom periods reflecting the short duration of the spring event and the average concentration of the fall event. Spring bloom has gone through a period of relatively increased concentration and magnitude during the period 2000-2004, but has declined in the last few years. Fall bloom has been at low levels since 2003.

Historic Phytoplankton Cycles - Georges Bank



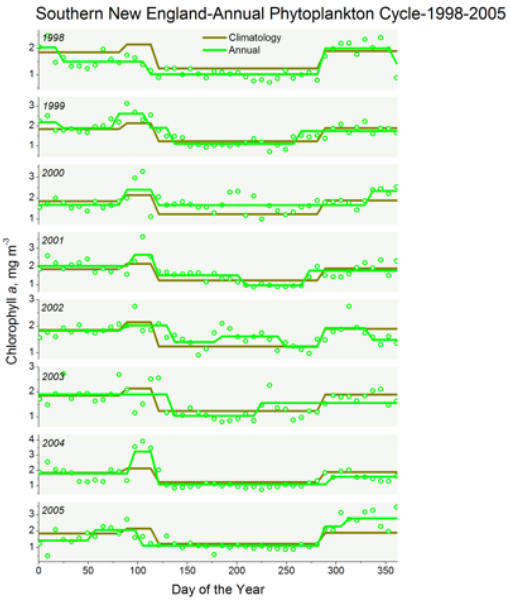
There has been considerable variation in the phytoplankton cycles of the Georges Bank. The timing and intensity of the spring bloom has changed year to year. The concentration was clearly below average in 1998 and 2006 and above average in 2001, 2003, and 2004. There is no obvious trend in the development of the spring bloom. The fall bloom has failed to develop in some recent years (2003, 2004, 2005), which suggests the fall bloom has declined over the time period.

Annual Phytoplankton Cycle - Southern New England



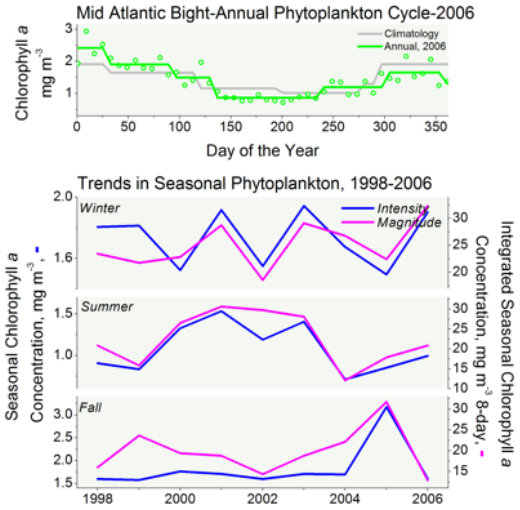
The annual phytoplankton cycle for Southern New England in 2006 is overlaid on the climatological cycle for comparison (see top panel). The spring bloom did not develop in 2006, so the duration of the spring period was taken from climatological estimates. The concentrations of the summer and fall periods appear to be below average. Seasonal chlorophyll concentration and integrated seasonal chlorophyll concentration are presented for the four time periods used to represent the Southern New England annual phytoplankton cycle (see bottom panel). Concentration showed an increase in the winter period and a decline in the spring period during 2006, reflecting the poorly developed spring bloom. There only area showing a trend over time was the summer period where both concentration and magnitude have declined and remain at low levels.

Historic Phytoplankton Cycles - Southern New England



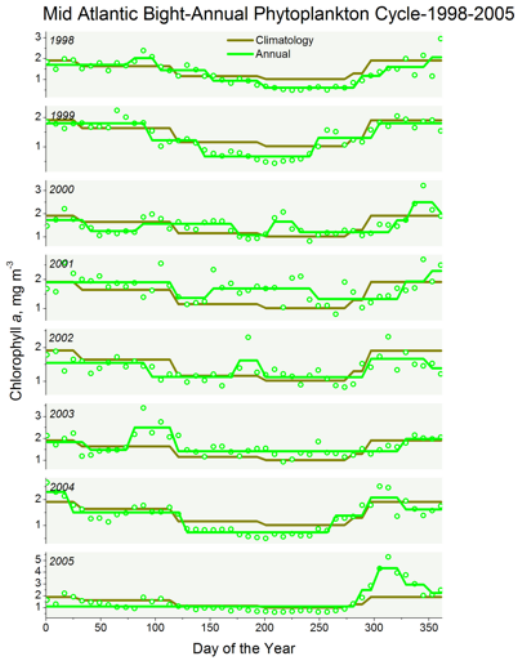
There has been considerable variation in the phytoplankton cycles of the Southern New England, most notably, the variation in the concentration and duration of the spring bloom. Spring bloom failed to develop in 1998, 2003 and 2006, and in some years the spring blooms is barely above background levels. In contrast, some year have produced high concentration spring blooms (2001, 2004). The transition to fall productivity is also highly variable

Annual Phytoplankton Cycle - Mid Atlantic Bight



The annual phytoplankton cycle for the Mid Atlantic Bight in 2006 is overlaid on the climatological cycle for comparison (see top panel). Winter concentration appears to have been above average, where fall concentration was below average. Seasonal chlorophyll concentration and integrated seasonal chlorophyll concentration are presented for the three time periods used to represent the Mid Atlantic Bight annual phytoplankton cycle (see bottom panel). Winter chlorophyll concentration and magnitude changed in a correlated fashion, with no particular time series trends. Summer concentration and magnitude are also highly correlated, but appear to show a trend suggest a localized increase in summer phytoplankton during the period 2000-2003. Fall phytoplankton appears to complement summer production with the highest values observed at the beginning and end of the time series.

Historic Phytoplankton Cycles - Mid Atlantic Bight



There has been considerable variation in the phytoplankton cycles of the Mid Atlantic Bight with evidence of blooms occurring in all time of the years. It is this variation that makes it difficult to characterize any recurring phytoplankton production features.