Spring 2010 Update: Annual Condition of the Northeast Shelf Ecosystem

Produced by the Ecosystem Dynamics and Assessment Branch

Published by Northeast Fisheries Science Center

February 14, 2010

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Spring 2010 Update: Summary of Conditions of the Northeast Shelf Ecosystem

Summary

- Sea surface temperature (SST) in the Northeast Shelf Large Marine Ecosystem during the second half of 2009 alternated between moderately warm and cool conditions.
- There were exceptional spring and fall phytoplankton blooms on the Northeast Shelf. As a result, 2009 has the highest chlorophyll *a* concentrations recorded in the satellite data time series. This is a clear indication that productivity of the ecosystem is at a very high level.
- Zooplankton biomass levels were average or above during most of the year.
- Analyses of thermal conditions from multiple data sources indicate that the ecosystem is warming and affecting the distribution of species and biological communities. This warming trend is not uniform across the entire system, resulting in a constriction of thermal habitats on the shelf.
- The ecosystem has undergone a freshening trend caused by changes in source waters, which has affected community patterns in the lower trophic levels.
- The trophic level of fish landed has declined precipitously over the past three decades, reflecting changes in the biological community and metrics related to diversity and stability.
- There has been a shift in fish condition, which will most likely impact individual species seasonal reproductive capacity and thus recruitment.

Data Sources

SST was derived by combining data from three sources: the Advanced Very-High Resolution Radiometer onboard the Polar Orbiting Environmental Satellite (AVHRR-POES); the MODIS Terra sensor; and the MODIS Aqua sensor. The data represent the surface ocean temperature, not the temperature of the entire water column.

Synoptic views of surface concentrations of chlorophyll *a* were derived from the Sea-viewing Wide Field of View Sensor (SeaWiFS) and the Moderate Resolution Imaging Spectroradiomater on the Aqua satellite (MODIS-Aqua). Data from these ocean color sensors were obtained from the NASA Ocean Biology Processing Group. The data sources were combined to represent trends in chlorophyll *a* during 2009. Chlorophyll *a* is considered a proxy of phytoplankton biomass present in the near-surface water.
Zooplankton biomass was derived from shipboard surveys of the U.S. Northeast Shelf ecosystem. Zooplankton provide the link from primary producers 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 as the Ecosystem Monitoring program (EcoMon). Currently, 30 plankton samples are taken 6 times a year in each of four ecosystem subareas: Middle Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine (resulting in approximately 720 zooplankton biomass samples annually). Zooplankton are identified to the lowest taxonomic level possible, resulting in taxon specific data on abundance and distribution.

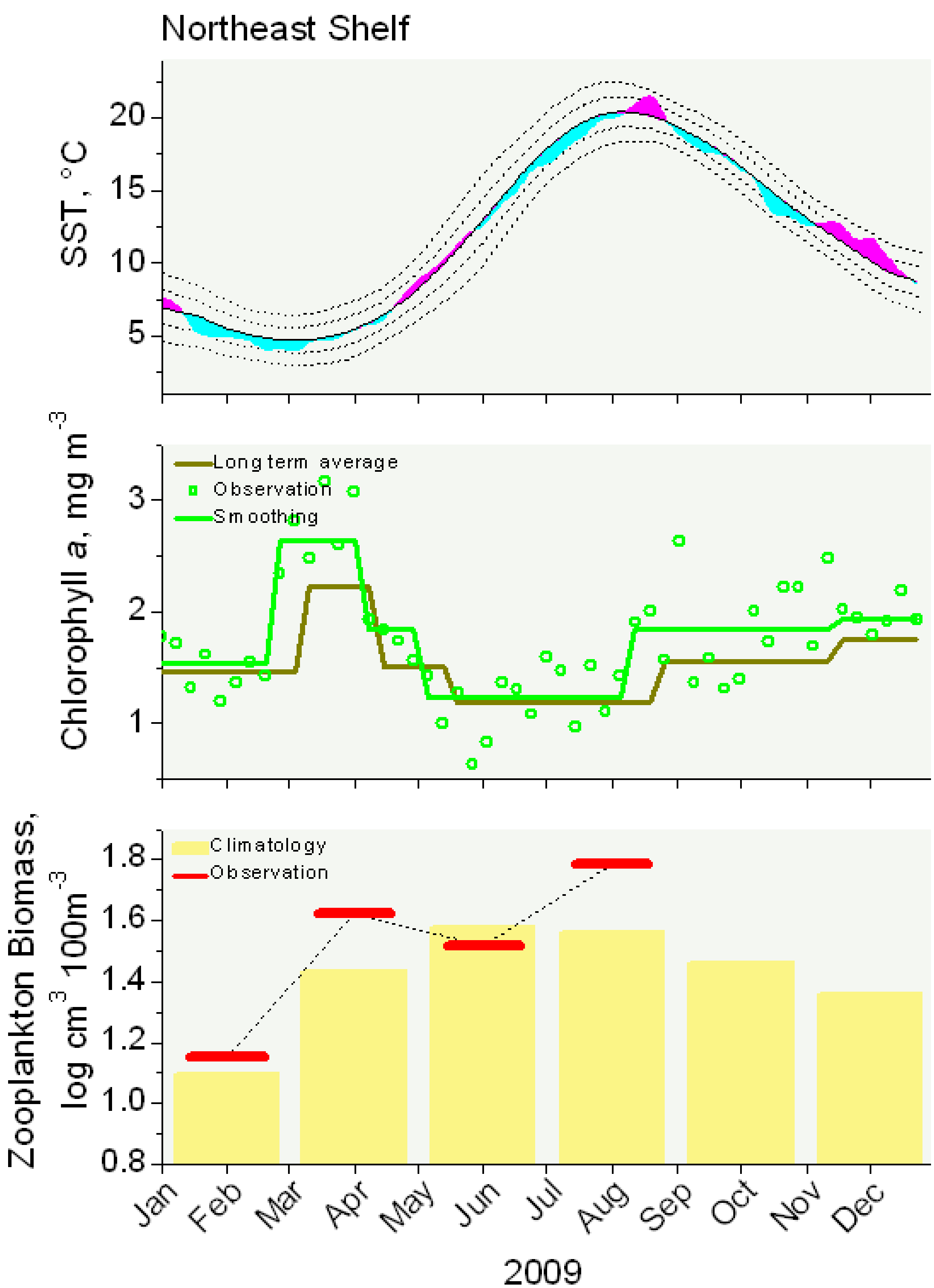
Thermal habitats were computed using the NOAA Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature Analysis.

Species assemblage data were constructed using the stratified mean biomass of the top fifty species caught during the NEFSC bottom trawl surveys. The spring data presented are from 1968-2008.

Long term SSTs were extracted from the Extended Reconstructed Sea Surface Temperature (ERSST, version 3) dataset. This dataset is based on the temperature compilation of the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) SST dataset, and contains reconstructed SST fields (obtained by interpolation) in regions with sparse data.

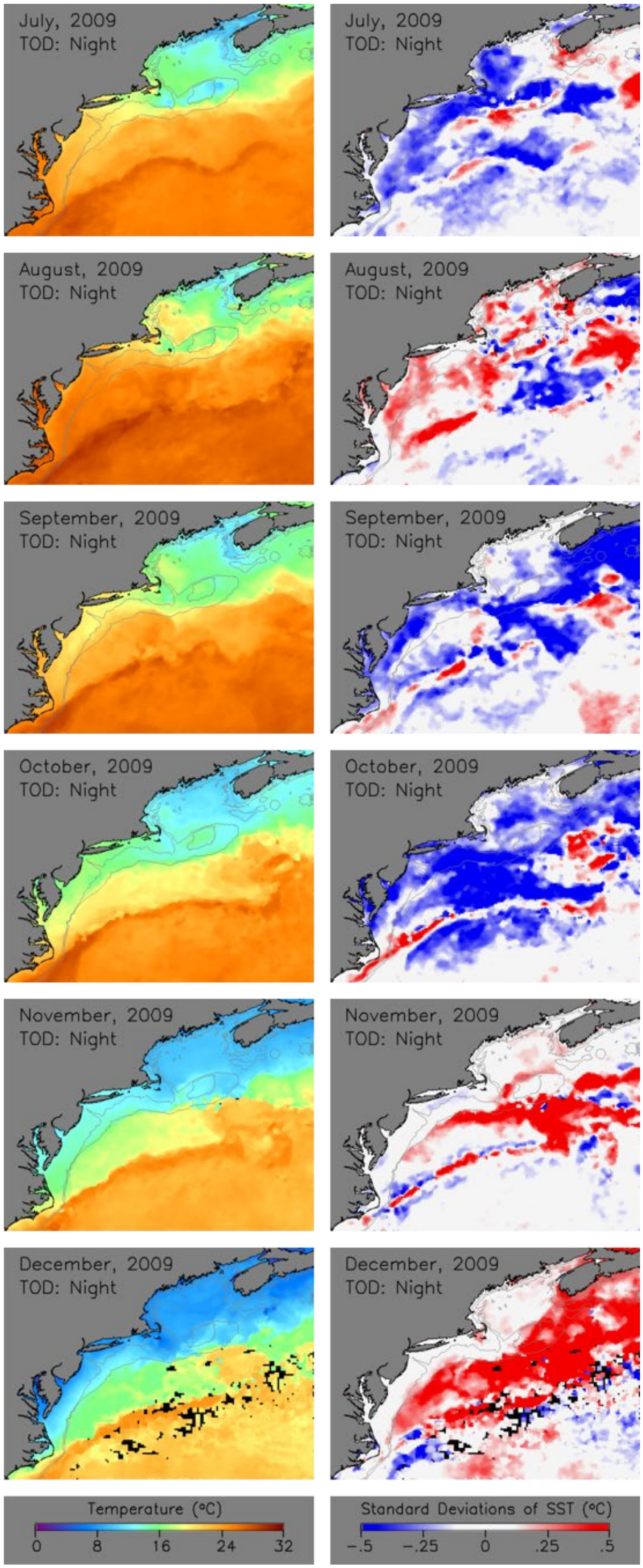
The percent diet composition of ctenophores in spiny dogfish was derived from the Food Habits Database, collected from shipboard fishery independent surveys of the U.S. Northeast Shelf ecosystem.

Fall Conditions - Northeast Shelf Ecosystem



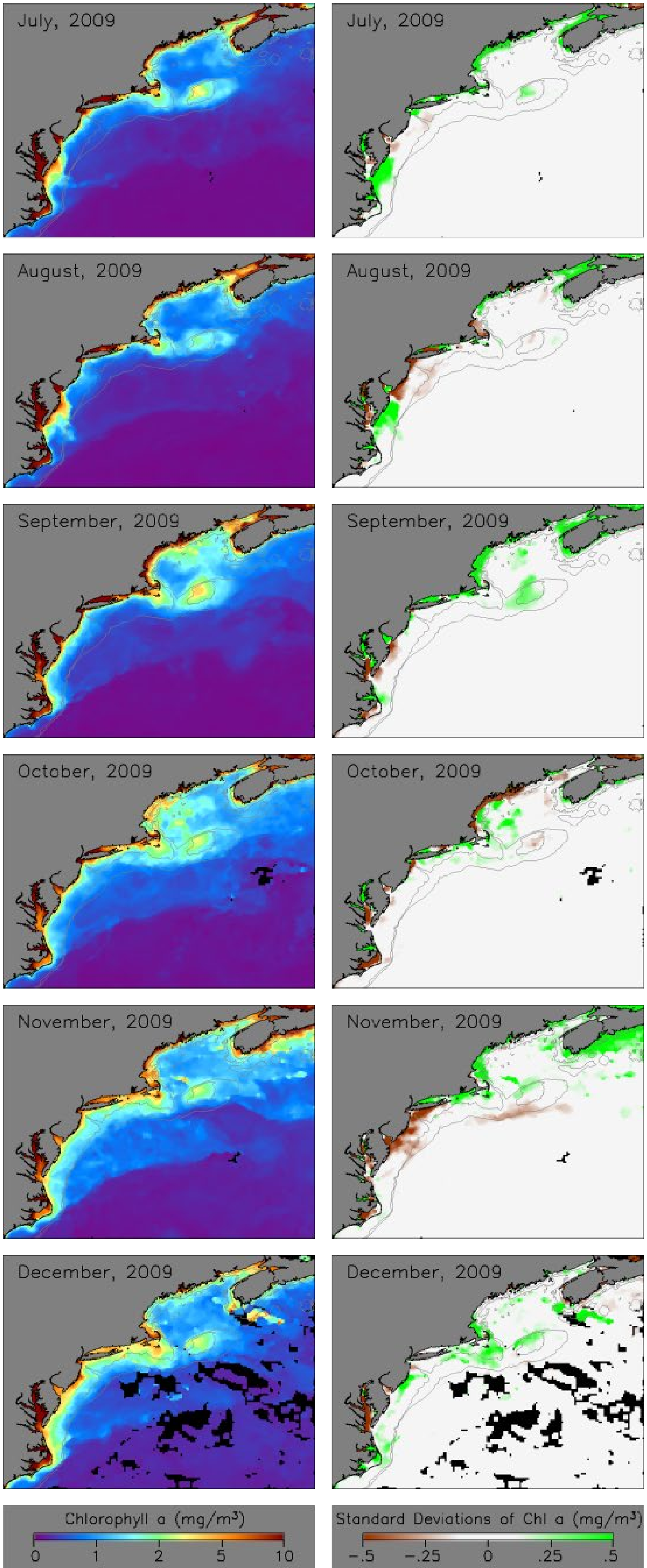
The Northeast Shelf Large Marine Ecosystem experienced minor fluctuations in sea surface temperatures (SSTs) during the fall of 2009. SSTs during the second half the year were generally below average with the exception of August temperatures and November into December temperature, which were above average. The high level of phytoplankton biomass (represented by the high chlorophyll *a* concentrations in the adjacent figure) observed in the first half of 2009 also continued into the second half of the year. Integrated estimates of chlorophyll concentration were at high levels by late summer, approximately a month in advance of the typical time frame that fall blooms usually develop on the shelf. This analysis was based on the most up to date version of the chlorophyll data; the revised data reaffirms the conclusion that 2009 continues the trend over the past few years that both spring and fall phytoplankton productivity are at high levels. Zooplankton biomasses were at or above average levels throughout the summer and into the fall of 2009 (late fall data is still be processed).

Sea Surface Temperature Distribution


July, 2009
TOD: Night
July, 2009
TOD: Night
August, 2009
TOD: Night
August, 2009
TOD: Night
September, 2009
TOD: Night
September, 2009
TOD: Night
October, 2009
TOD: Night
October, 2009
TOD: Night
November, 2009
TOD: Night
November, 2009
TOD: Night
December, 2009
TOD: Night
December, 2009
TOD: Night
Temperature (°C)
0
8
16
24
32
Standard Deviations of SST (°C)
-.5
-.25
0
.25
.5

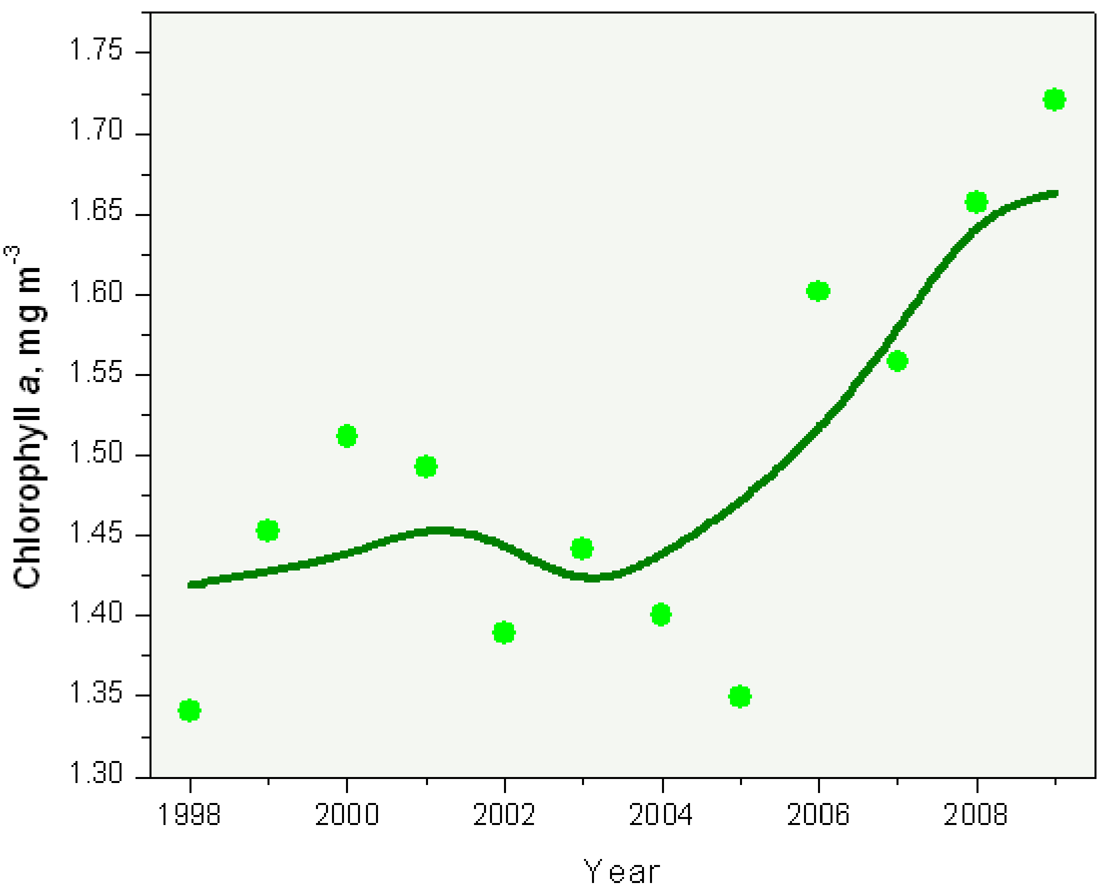
The progression of fall sea surface temperatures (SSTs) during the months of July through December are shown in the left hand set of panels. Higher SSTs appear as warm shades whereas low SSTs appear as cool shades. The right hand set of panels show SST anomalies, those tending to exceed plus or minus one quarter of a standard deviation of the overall SST for the field. The anomaly figures highlight above (red shades) and below (blue shades) average SSTs in a given area. Above average fall SSTs were observed during the months of August, November and December; during August all regions of the shelf were at higher temperatures whereas during November and December elevated temperatures were restricted to the shelf break and the eastern portion of Georges Bank. The alternate cool months involved lower temperatures in the Middle Atlantic Bight and in Southern New England, whereas not all parts of the Gulf of Maine were particularly cool. Offshore patches of warming and cooling are typically due warm and cold core rings associated with the Gulf Stream. The Scotian Shelf, which is a source of water for the Northeast Shelf, was very cool this past fall. Inflows of Scotian Shelf water may have contributed to a moderation of SSTs in the Gulf of Maine.

Chlorophyll Distribution


July, 2009
July, 2009
August, 2009
August, 2009
September, 2009
September, 2009
October, 2009
October, 2009
November, 2009
November, 2009
December, 2009
December, 2009
Chlorophyll a (mg/m³)
0
1
2
5
10
Standard Deviations of Chl a (mg/m³)
−.5
−.25
0
.25
.5

The progression of fall chlorophyll *a* concentrations during the months of July through December are shown in the left hand set of panels. Higher chlorophyll a concentrations appear as warm shades whereas low concentrations appear as cool shades. The right hand set of panels show exceptional anomalies of chlorophyll concentration, those tending to exceed plus or minus one quarter of a standard deviation of the overall concentration for the field. The anomalies highlight strong blooms in an area (i.e., the green shades) as well as significantly below-average concentrations (i.e., the brown shades). Given the provisional nature of these data, it would be imprudent to make definitive inferences on the intensity of regional bloom activity on the shelf. However, the only exceptional phytoplankton bloom appeared to be localized in the Middle Atlantic Bight during August and September. It is likely that this bloom contributed to the apparent early onset of fall bloom activity. In most other areas of the shelf, phytoplankton bloom levels were near the long-term mean.

Chlorophyll Concentration at New Heights



The integrated mean annual chlorophyll concentration for the Northeast Shelf Ecosystem was the highest in the time series, which continues a trend of increasing chlorophyll concentrations seen in recent years. The production features that appear to be driving this trend are intense, early developing spring blooms that begin in the Nantucket Shoals/Southern New England areas and continue to develop in the Gulf of Maine and on Georges Bank, and by a fall bloom associated with the coastal waters of the Middle Atlantic Bight. This pattern of variation in chlorophyll concentration has the potential of affecting higher trophic levels by providing higher energy inputs, depending on the type of phytoplankton species comprising the bloom - not all contribute equally to energy transfer to upper trophic levels.

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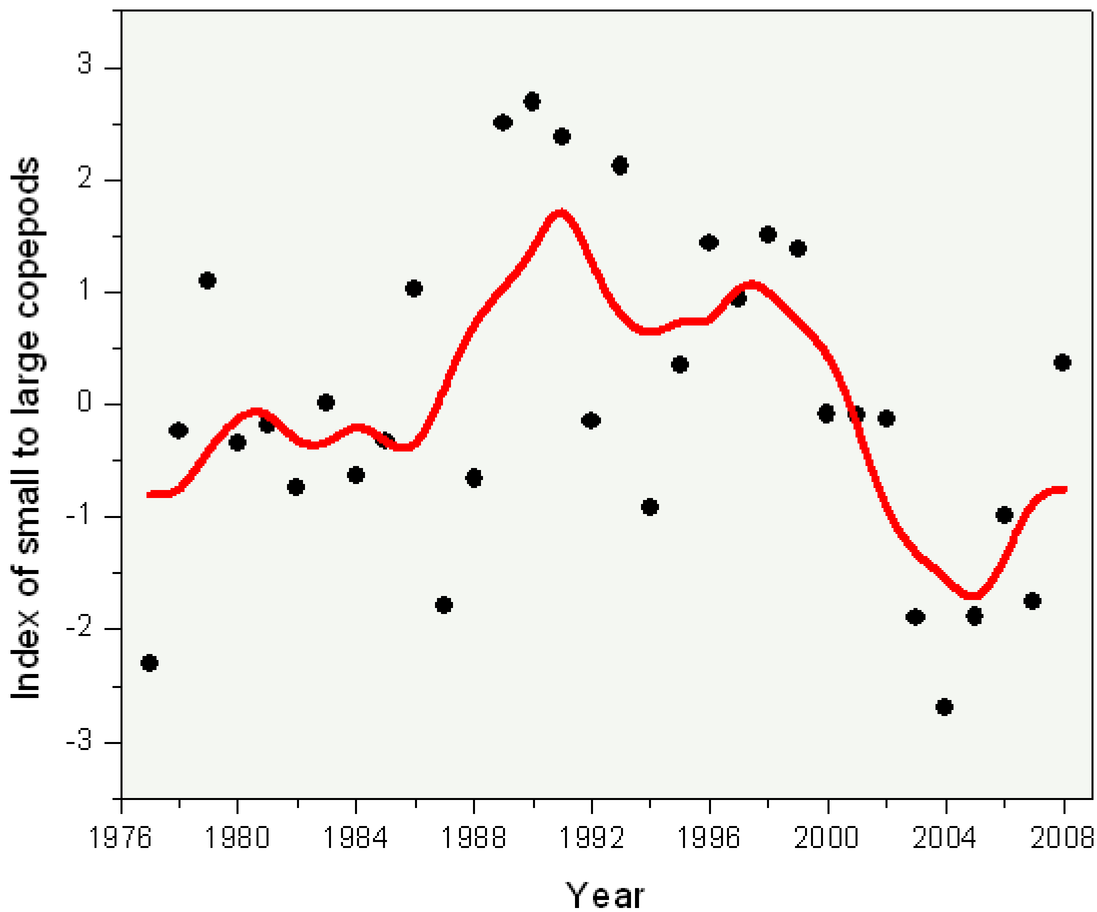
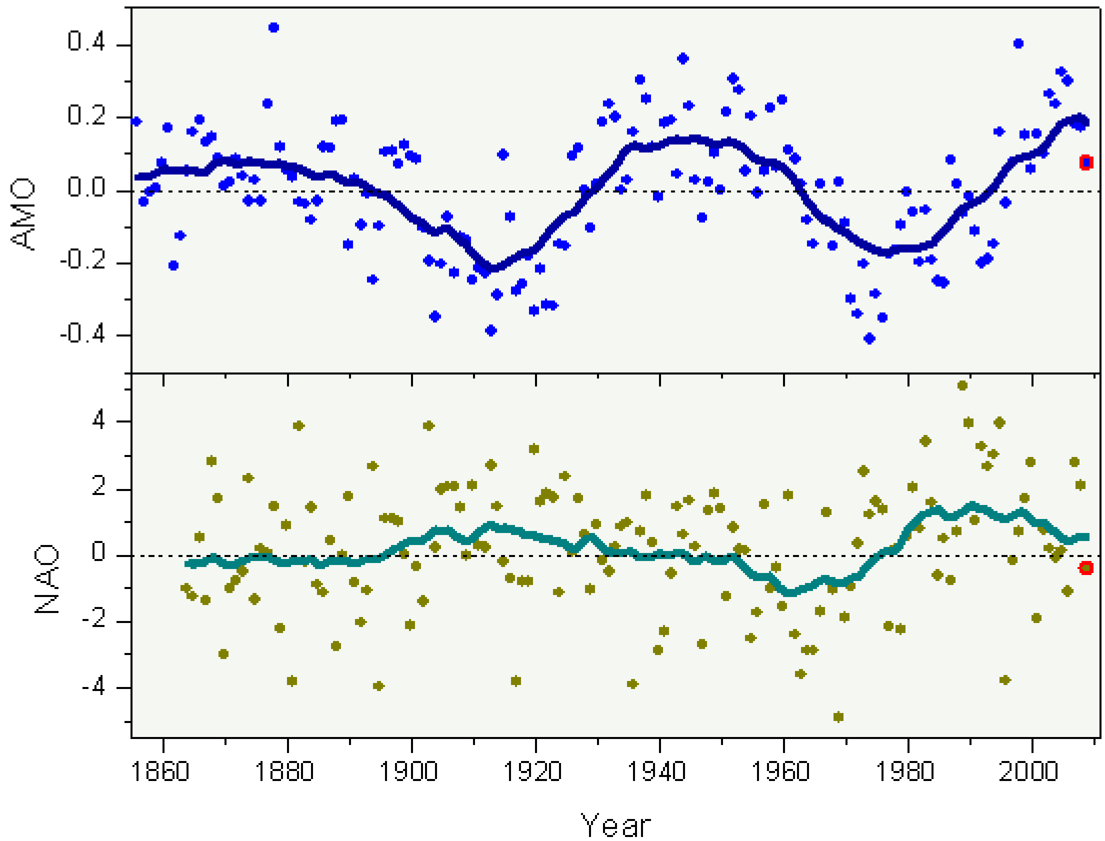
ystematic Shifts in Zooplankton Species Composition



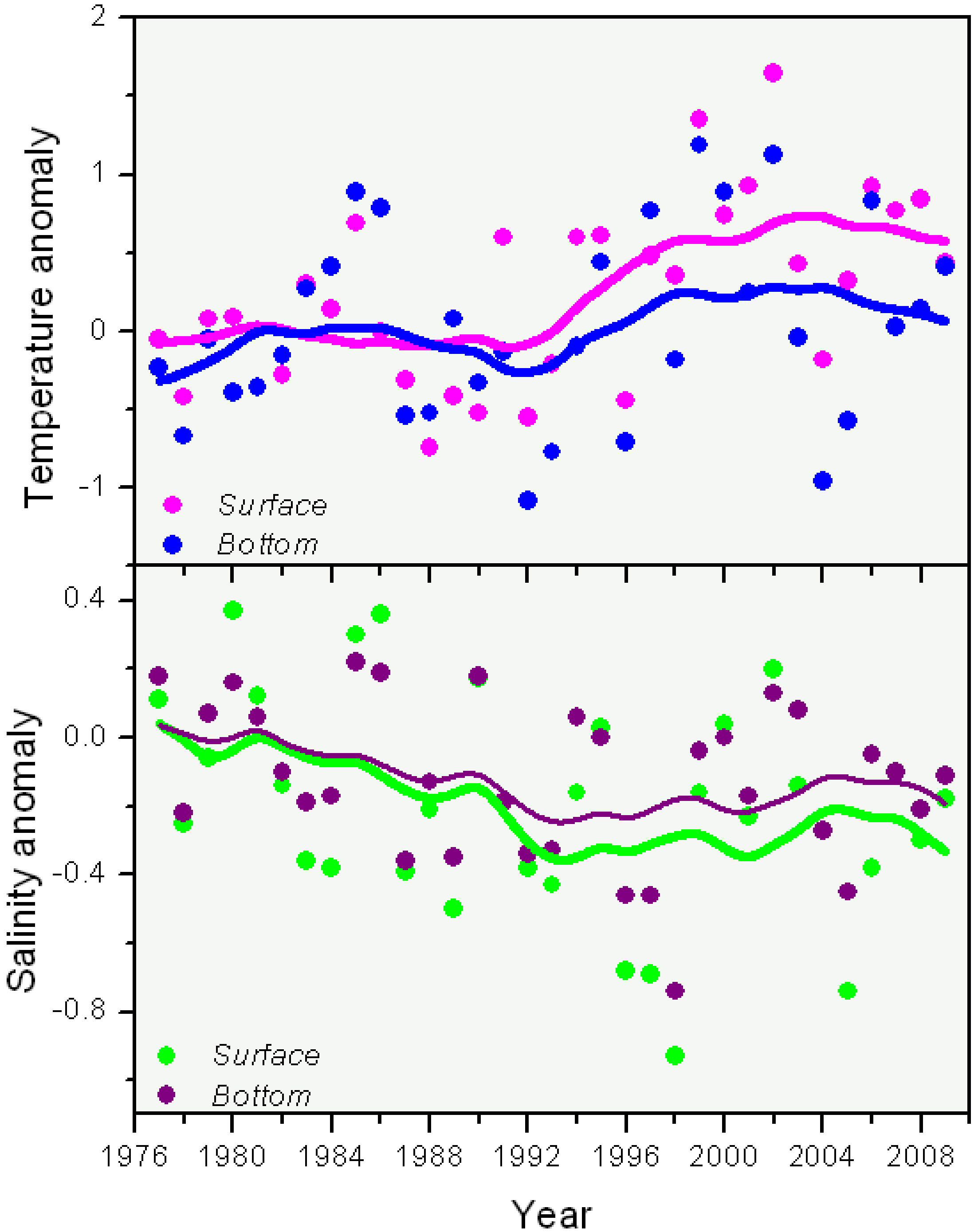
The flow of energy through the pelagic food web and the success of many species of fish is dependent on the types of zooplankton comprising the phytoplankton grazing community. One of the most responsive indicators of the nature of that community is the body size of the dominant zooplankton species, since size is associated with the feeding dynamics of zooplankton and their suitability as prey. An index of small to large copepods provides a simple indicator of these ecosystem functions. This index is calculated as the difference in abundance of small copepods (*Pseudocalanus* spp. *Centropages typicus, Centropages hamatus, Temora longicornis*) minus the abundance of the large copepod *Calanus finmarchicus*. This index was mostly negative through the 1970's and 1980's. The index became positive in 1989 and remained mostly positive through 1999. In 2000, the index again became negative and was negative through 2007. In the most recent year of data (2008), the index is positive again, indicating a relative increase in the abundance of small copepods and a decrease in *Calanus finmarchicus*.

Key Climate Drivers



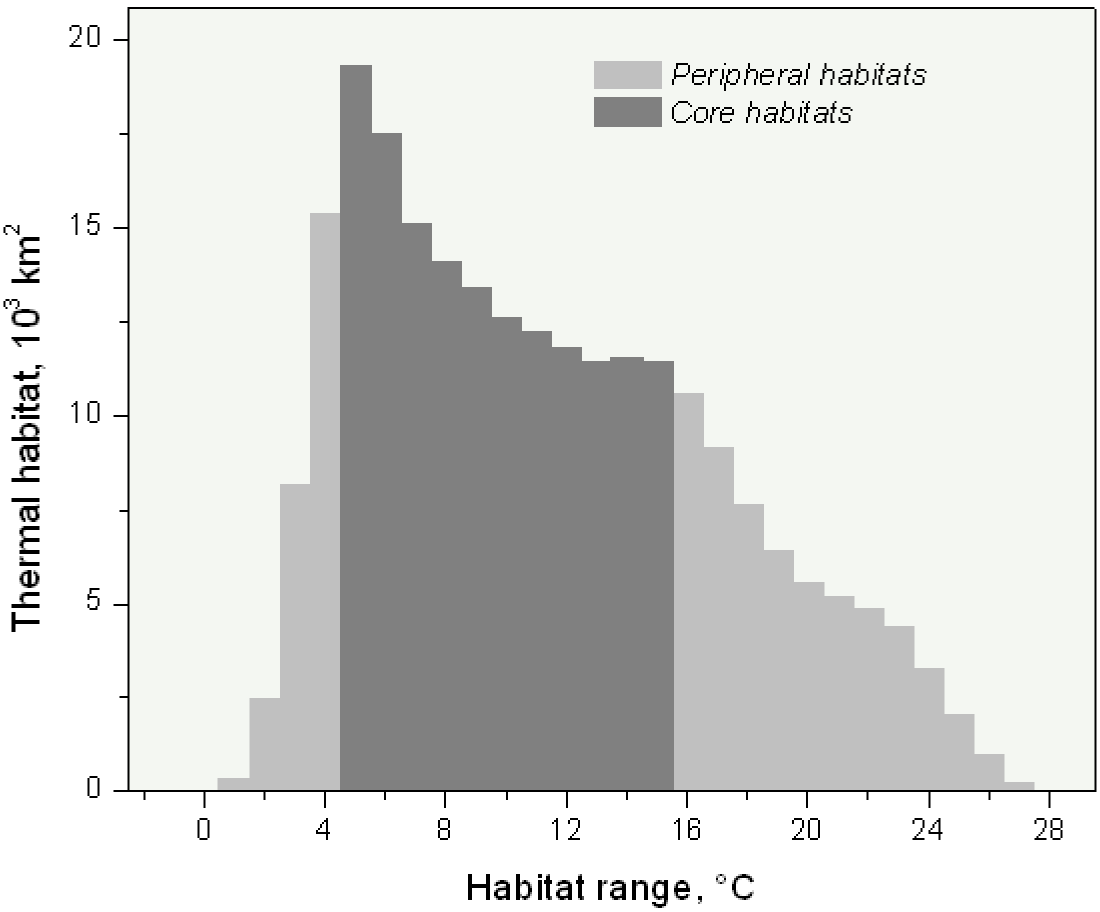
Two key climate drivers affecting the oceanography of the Northeast Shelf Ecosystem are the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO). Multidecadal patterns in sea surface temperature (SST) in the North Atlantic are represented by the Atlantic Multidecadal Oscillation (AMO) index, which has been linked to the poleward shifts of fish distributions on the northeast U.S. shelf. The AMO has been in a warm phase (positive) since 1997; however, the 2009 level was well below the recent trend. The warm phase is expected to continue for the next 10-20 years. This (NAO) index has been related to key oceanographic and ecological processes in the North Atlantic basin and is associated with alternate states of wind and weather in regions associated with the North Atlantic Basin. Since 1972, the NAO has primarily been in a positive state, although one-year reversals to a negative state have occurred. Changes in the NAO have been linked to changes in plankton community composition in the North Atlantic, reflecting changes in both the distribution and abundance of warm and cold-temperate species. In 2009, the winter NAO index was weakly negative; this is only the fourth negative NAO value since 1990 and the sixth since 1980.

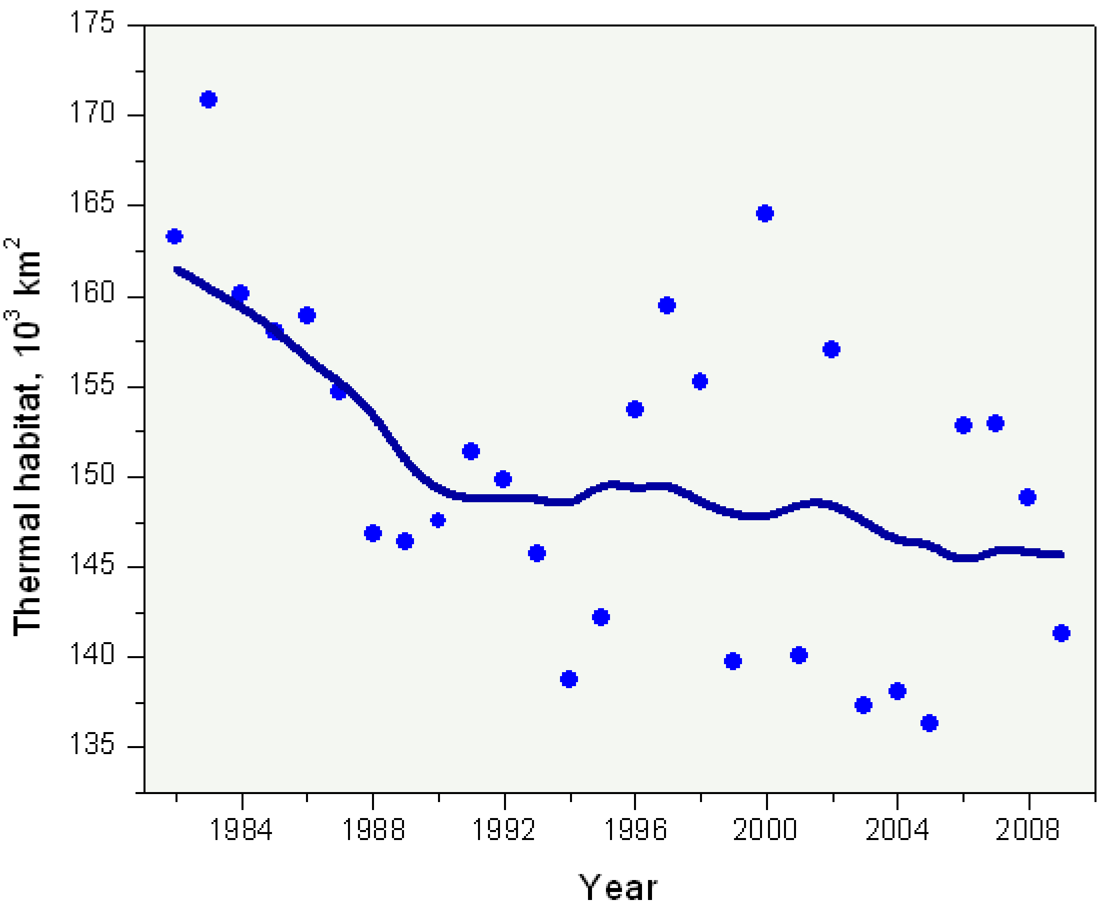
A Warmer and Fresher Ecosystem



As part of its survey program, the Northeast Fisheries Science Center (NEFSC) has measured water temperatures and salinities on the shelf since the mid-1970's. Over the time series, surface and bottom temperatures have increased, with the trend in the surface water being more clearly developed. Salinity shows a reciprocal pattern to temperature, providing evidence that there has been a general freshening pattern also in both the surface and bottom waters. The overall warming of the ecosystem has been visualized in a number of different ways and has been associated with shifts in the distribution of many species. The freshening has been associated with variation in the nature of sources waters into the ecosystem originating in the Arctic. The freshening effect is associated with changes in the dynamics and distribution of the lower levels of the food chain.

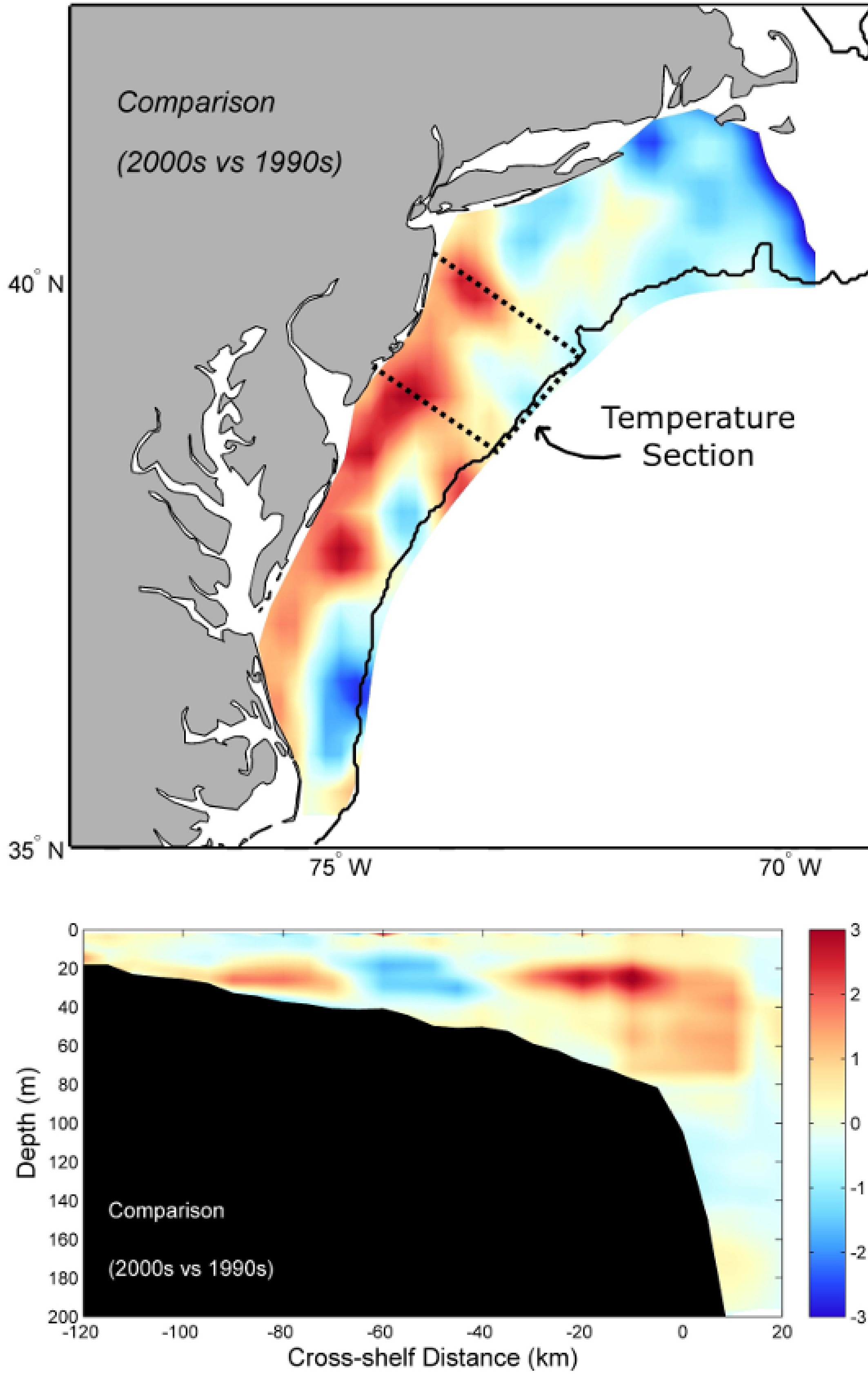
Ecosystem Shift in Thermal Habitat


Peripheral habitats
Core habitats
Thermal habitat, 10³ km²
Habitat range, °C
0
5
10
15
20
0
4
8
12
16
20
24
28



Temperature is one of the most important factors defining the habitat of marine organisms. Thermal conditions affect the growth and development of fish and shellfish, and differentially affect the survival of different life stages. Recent analyses of the amount of surface thermal habitat on the Northeast Shelf over the past 27 years reveal a trend of constriction of the core thermal habitats of the Northeast Shelf ecosystem. Core thermal habitats represent year round habitats ranging from 5 to 15°C (see top figure), whereas peripheral thermal habitats are only available during parts of the years, i.e. the winter and summer. Core thermal habitats have been declining over time (see bottom figure), with the 2009 estimate of approximate 142,000 km2 being one of the lower values in the time series. The ecosystem appears to have been affected simultaneously by both cooling and warming effects; cooling was most likely actuated by inputs from the Labrador Current and warming by increased temperatures observed in the Middle Atlantic Bight.

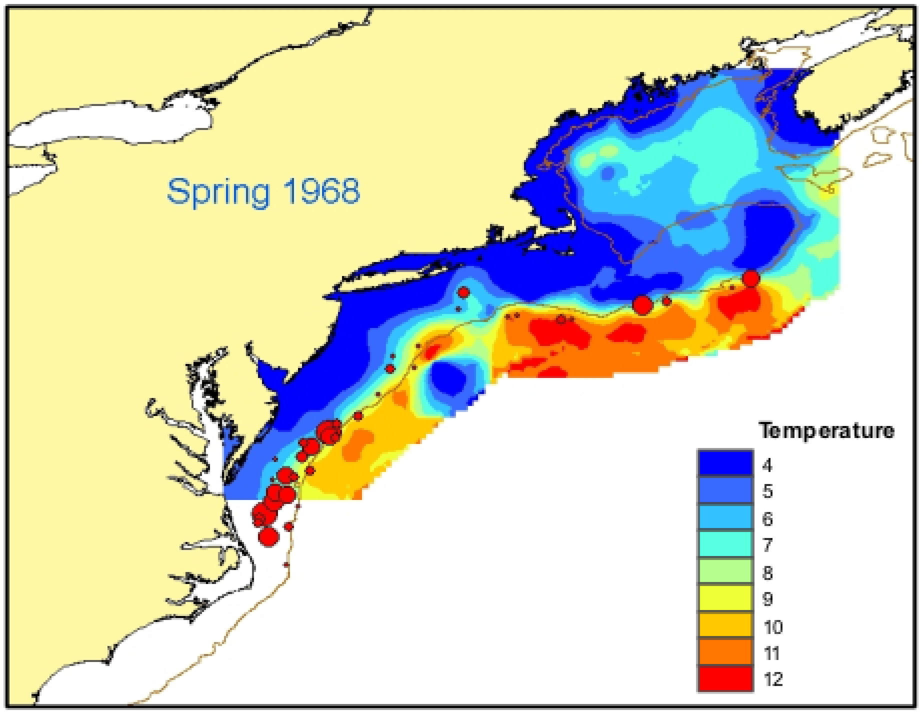
Shrinking Refugium for Cold Water Species

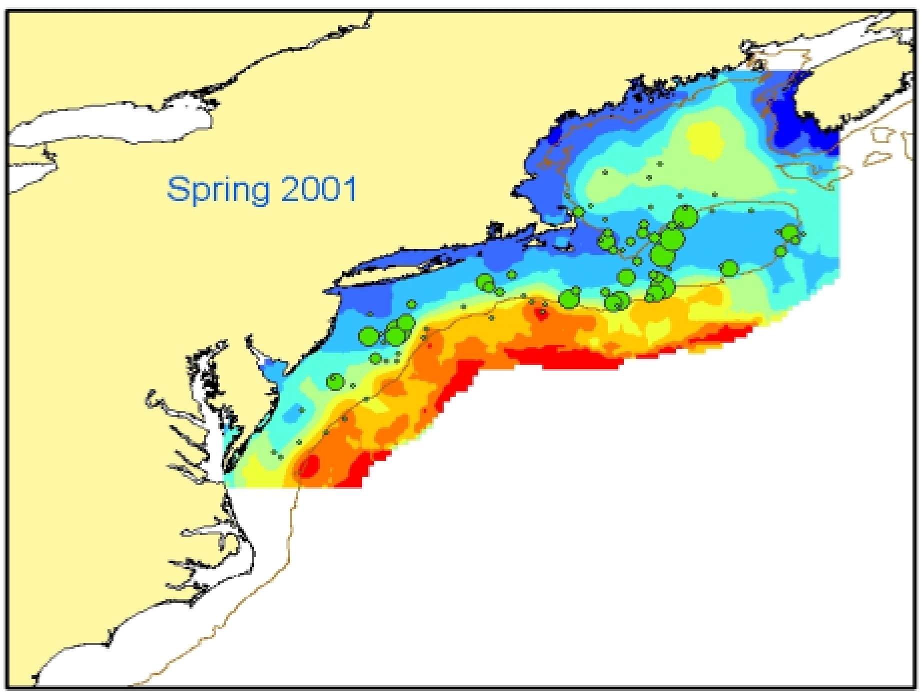


Comparison
(2000s vs 1990s)
40° N
35° N
75° W
70° W
Temperature
Section
0
20
40
60
80
100
120
140
160
180
200
Depth (m)
Comparison
(2000s vs 1990s)
-120
-100
-80
-60
-40
-20
0
20
Cross-shelf Distance (km)
3
2
1
0
-1
-2
-3

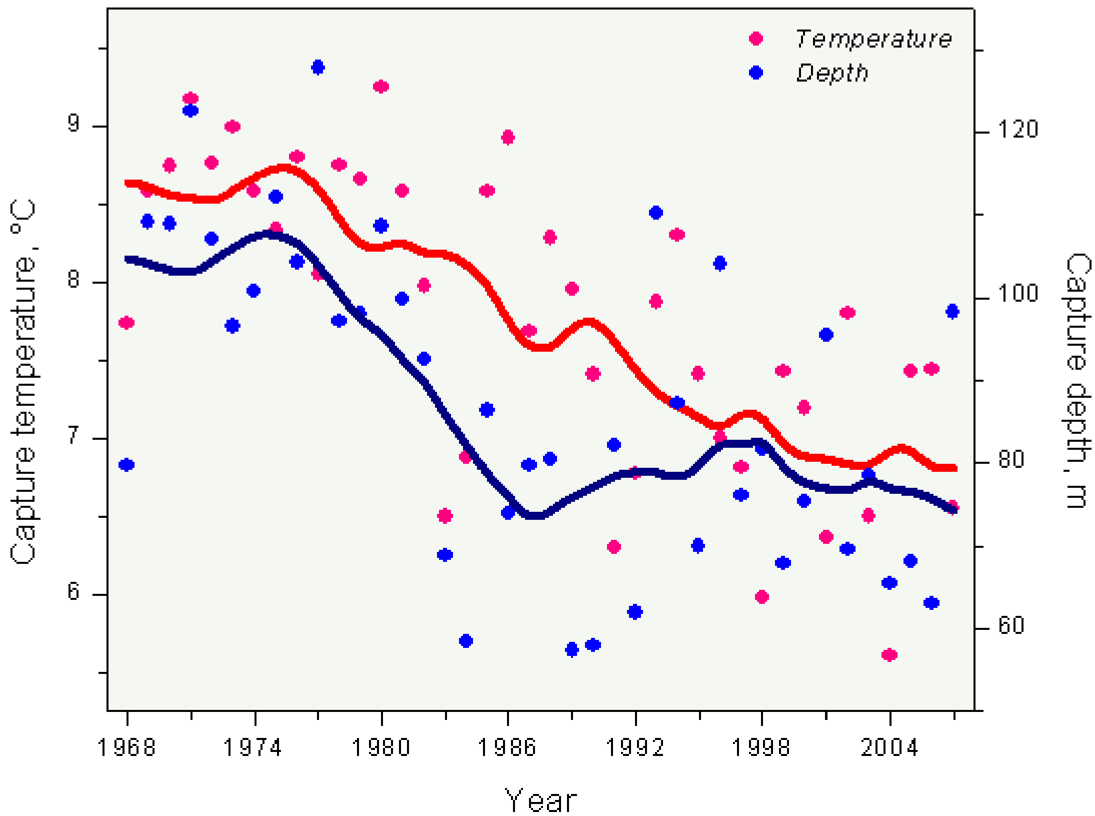
The Mid-Atlantic cold pool is an area of remnant winter water that exists on the northeast U.S. shelf in summer and fall and serves as the southern habitat limit for a number of cold-temperate species. This feature is separated from the surface by a seasonal thermocline, and is surrounded in the along-shelf and cross-shelf directions by warmer waters. A newly initiated study will develop indicators of cold pool strength and use these indicators in the assessments of several commercially harvested species. Preliminary analyses show dramatic changes in the cold pool. Off the coast of New Jersey, the cold pool has constricted at both the onshore and offshore edges. This constriction has resulted in a dramatic warming of the inner shelf waters in the 3-5°C range from pre-1995 to post-1995. The impact of these changes on fisheries will be examined over the next 2 years.

Mackerel Habitat Redefined


Spring 1968
Temperature
4
5
6
7
8
9
10
11
12

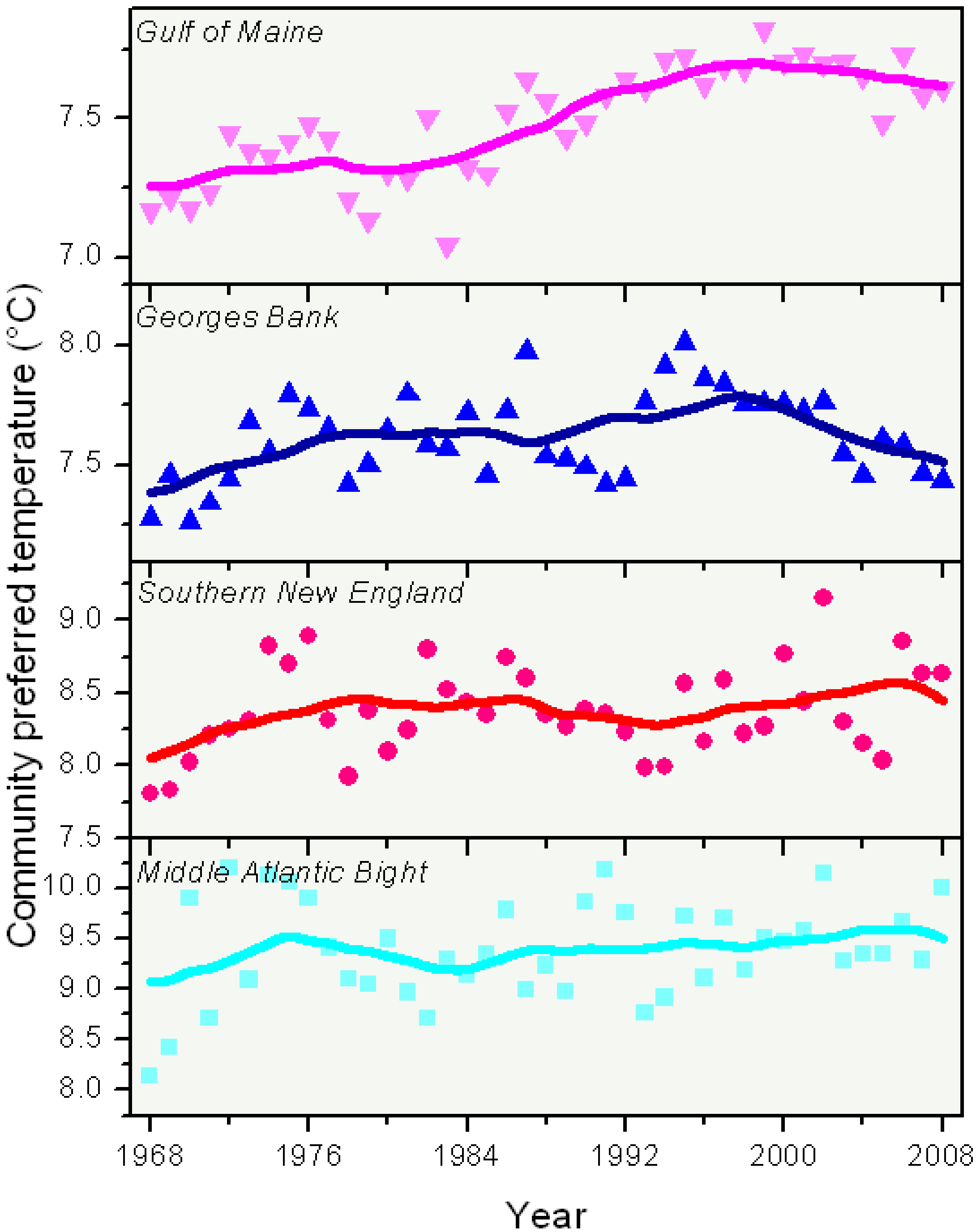

Spring 2001

-



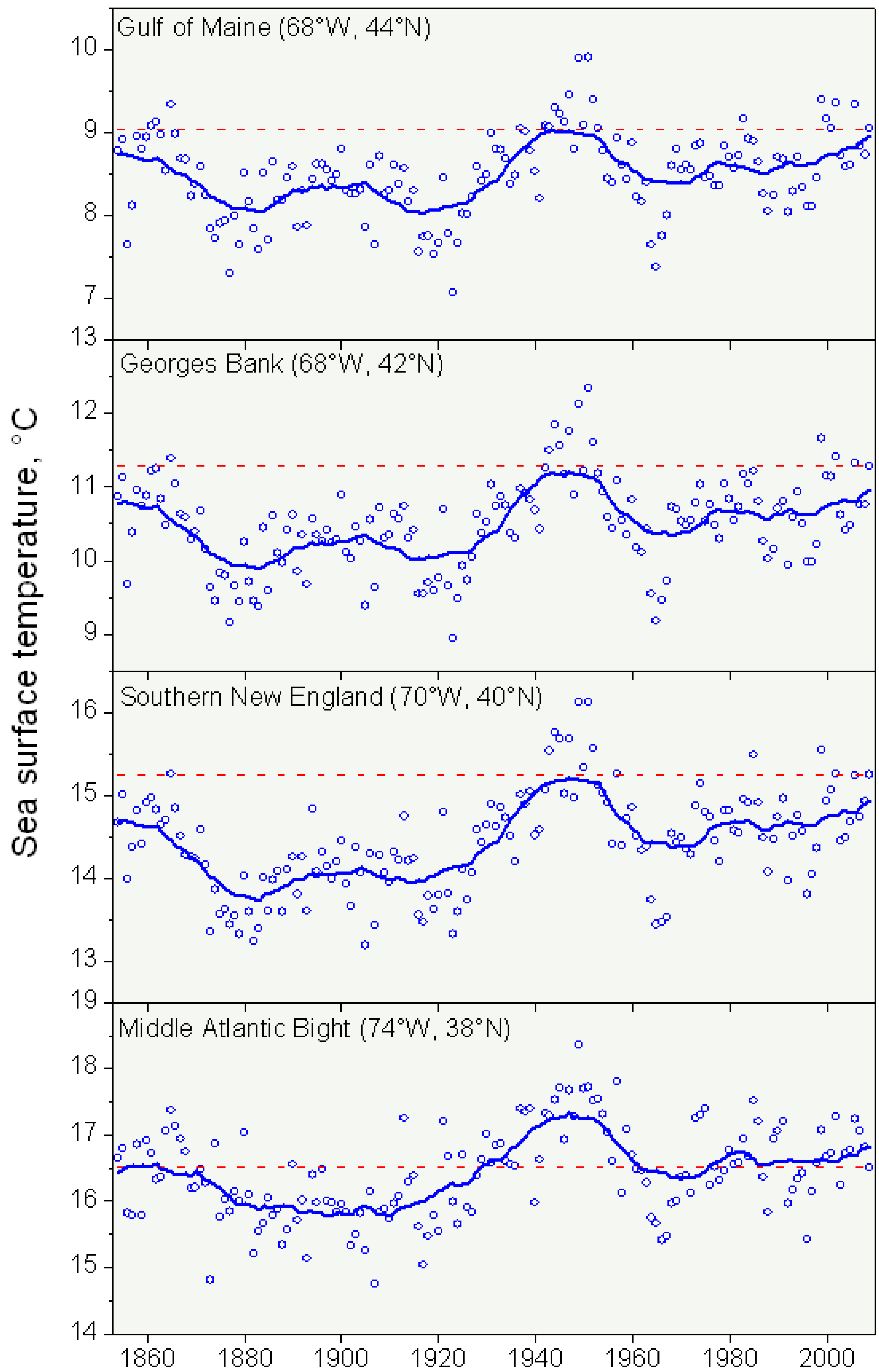
The Northwest Atlantic stock of Atlantic mackerel is distributed from Cape Hatteras North Carolina to Newfoundland Canada and migrates great distances on a seasonal basis, overwintering off the Northeastern USA. Mackerel are sensitive to changes in temperature, preferring water greater than 5°C. Comparing mackerel distribution and bottom temperature profiles during a cold year and a warm year, 1968 and 2001, illustrates the importance of temperature in affecting distribution. In 1968, a cold year, mackerel were found offshore and far to the south off Cape Hatteras, whereas in 2001, a warm year, mackerel occurred much farther north on the shelf, and well out on Georges Bank (see top set of figures). Analysis suggests that during the past 40+ years (1968-2008), the distribution of the stock has shifted about 250 km to the north and east. Major changes have also occurred in the mean temperature and the mean depth occupied by the mackerel stock. Mean capture temperatures have decreased from about 9 to 6°C (see bottom figure). Mean capture depths have changed from greater than 100 m to less than 70 m. The center of distribution of the stock on the shelf is related to a change in temperature selectivity, with mackerel found in relatively cooler waters in recent years. This is not because the temperature preference of mackerel has changed, but because much more habitat is now available at temperatures within the preferred range of the species. These areal and bathymetric changes in distribution are likely related to inter-annual variability in atmospheric forcing and long-term warming.

Species Reflect Shifting Thermal Conditions



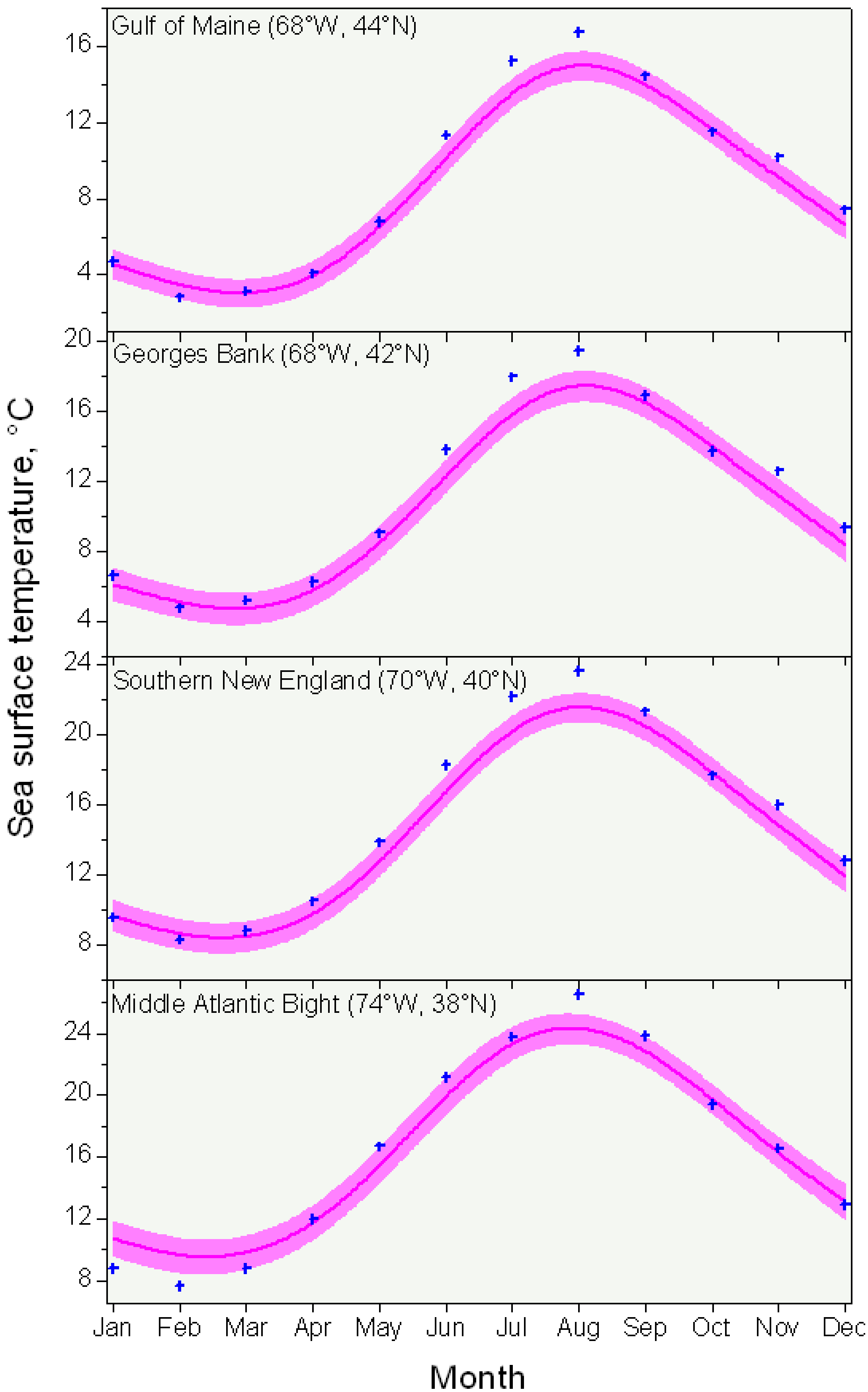
Community preferred temperature is calculated by weighting the preferred temperature of each species by its biomass in the spring trawl survey in each year. Increases in community preferred temperature indicate a shift in community structure from one dominated by cold water species to one dominated by warm water species. Warm water species may be more abundant and/or have shifted their distribution north to remain within their preferred temperature range. The trend in community preferred temperature is very similar to the physical measures of temperature observed on the Northeast U.S. continental shelf. There have been statistically significant increases in community preferred temperature over the 40-year spring bottom trawl survey time series in all 4 ecoregions. However, in the most recent years community preferred temperature has decreased, particularly in the Georges Bank region.

Long Term Temperature Trends


Gulf of Maine (68°W, 44°N)
Georges Bank (68°W, 42°N)
Southern New England (70°W, 40°N)
Middle Atlantic Bight (74°W, 38°N)
Sea surface temperature, °C
Month
10
9
8
7
13
12
11
10
9
16
15
14
13
19
18
17
16
15
14
1860
1880
1900
1920
1940
1960
1980
2000

The Northeast Shelf Ecosystem is warming; however, this warming trend is still below the temperatures the system experienced during the 1940s and 1950's. The Extended Reconstructed Sea Surface Temperature (ERSST) dataset includes temperature records back to 1854. Monthly mean SSTs in 2009 in four subregions of the ecosystem (Gulf of Maine, Georges Bank, Southern New England, and the Middle Atlantic Bight) were compared to long term trends in SST (dashed magenta line marks 2009, blue line is smoothed trend). The northern subareas of the ecosystem were at or above the recent trends in the data, whereas the annual mean 2009 SST for the Middle Atlantic Bight was below this trend.

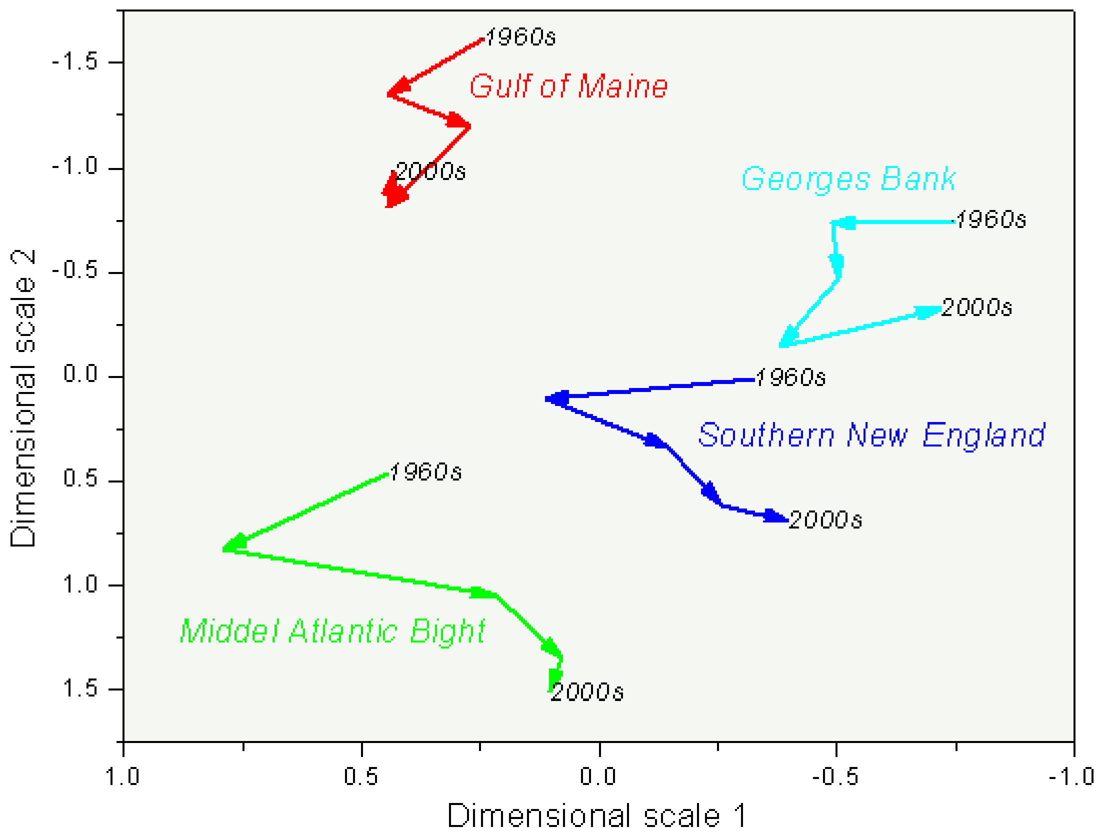
Long Term Monthly Temperature Trends



Gulf of Maine (68°W, 44°N)
Georges Bank (68°W, 42°N)
Southern New England (70°W, 40°N)
Middle Atlantic Bight (74°W, 38°N)
Sea surface temperature, °C
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

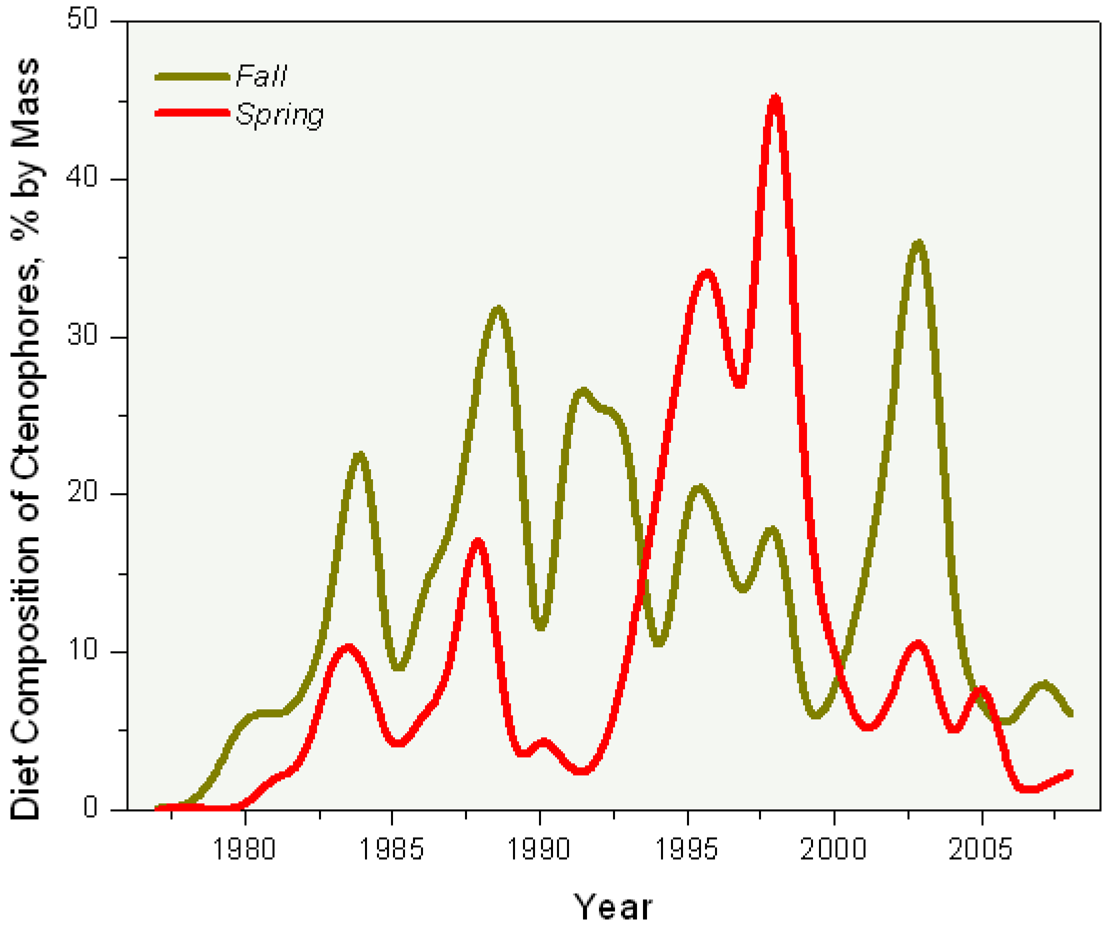
All subregions of the shelf ecosystem showed warmer than average summer temperatures; however, winter temperatures were below average in the southern end of the ecosystem. The Extended Reconstructed Sea Surface Temperature (ERSST) dataset includes temperature records back to 1854. Monthly mean SSTs in 2009 in four subregions (Gulf of Maine, Georges Bank, Southern New England, and the Middle Atlantic Bight) were compared to long term means bounded by confidence bands (magenta line in light magenta region, respectively). In 2009, monthly SSTs for the Gulf of Maine were close to the long-term average in most months, with the most notable exception being the July and August SSTs, which were well above average. A similar pattern can be seen in the monthly temperature data for Georges Bank and Southern New England. In the Middle Atlantic Bight subregion, only the August mean is significantly above the long term mean and SST were below average in January, February and March. These data underscore how thermal properties within the ecosystem are not uniform.

Shifting Fish Communities



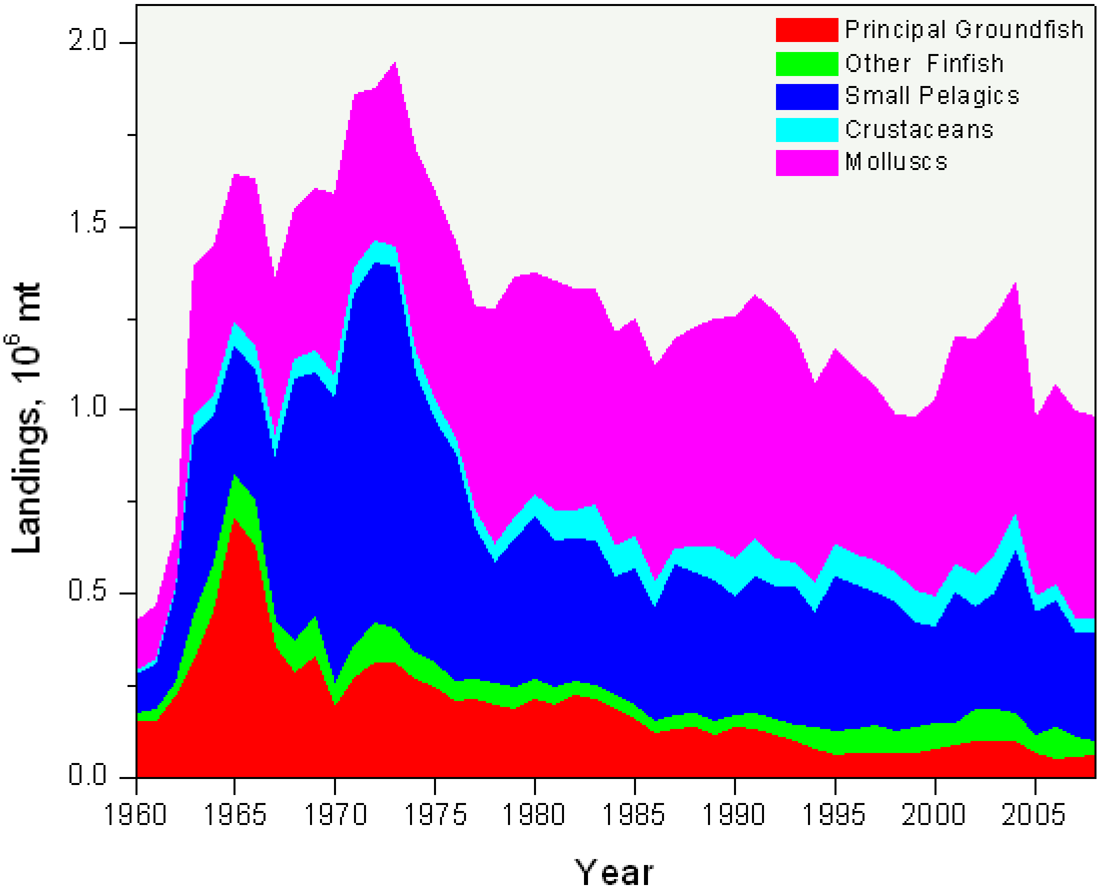
A combination of shifting climate conditions and time-area changes in fishing pressure has resulted in changes in species ranges as well as changes in species assemblages on the Northeast Shelf. A recent analysis by Center scientists shows that species assemblages in the standard subregions of the Northeast US Continental Shelf Large Marine Ecosystem now more closely resemble the species assemblage of adjacent areas to the south. We can visualize these changes along two axes or dimensions oriented roughly to latitude where the time course of species composition in each area can be plotted. The community statistics now (2000s) show an overall trend of subregions shifting towards species assemblages more like the assemblages found in their adjacent subregion to the south at the beginning of the time series (1960s). The trajectory of the Georges Bank statistic appears to be somewhat anomalous suggesting a reversion to the assemblages found in the 1960's, most likely due to the recovery of haddock, *Melanogrammus aeglefinus*. The Gulf of Maine, being the highest latitude eco-region, was relatively stable in species assemblage and the most distinct from the other three regions. Because of its deep waters, the Gulf of Maine experiences a narrower range of temperature variation than the rest of the shelf.

Spiny Dogfish Rely on Ctenophores



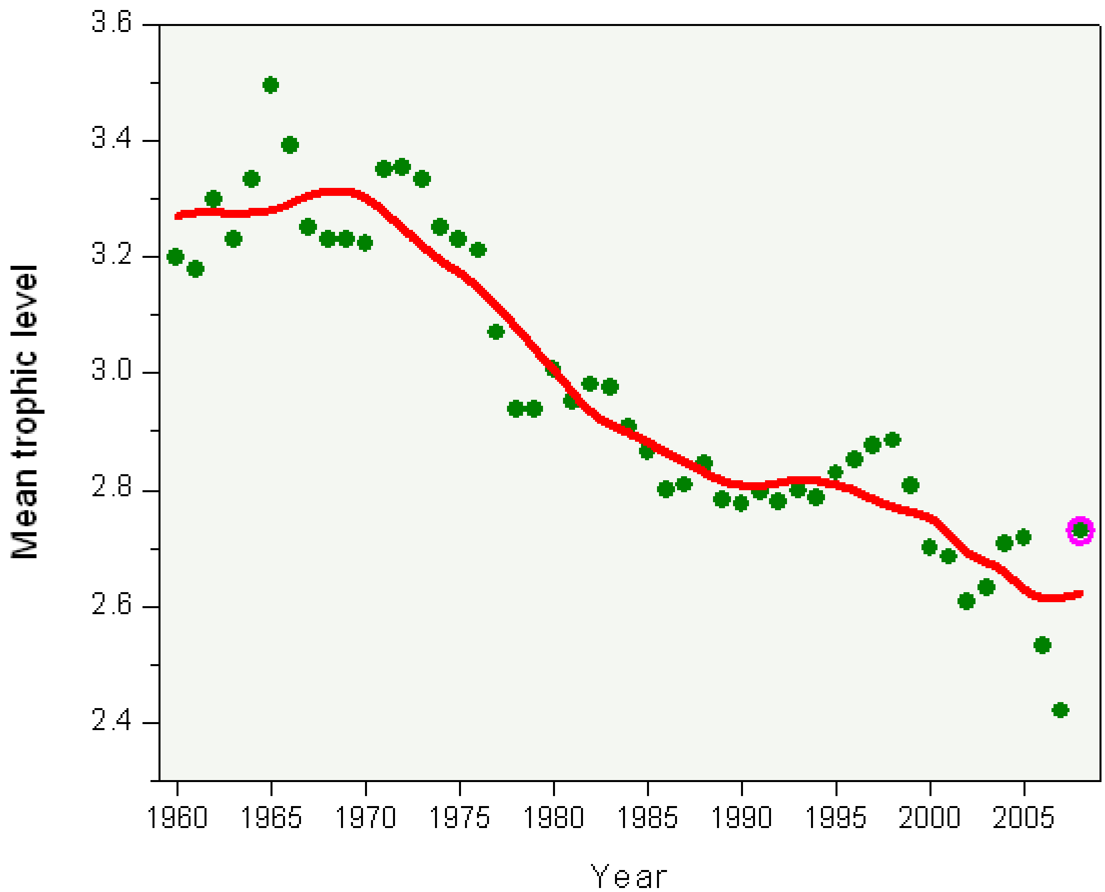
Ctenophores, more commonly known as comb jellies, are an important prey item for many fish species within the U.S. Northeast Shelf ecosystem. Their presence and importance as food for spiny dogfish (*Squalus acanthias*) can be quite variable composing in excess of ~20-50% of the diet by mass for some years as shown here. This variability is seen in the diet data for both fall and spring surveys. This temporal pattern in diet proportions of ctenophores for spiny dogfish remains unexplained, though it is suspected that seasonal oceanographic processes may influence diet composition.

Landings by Major Species Group



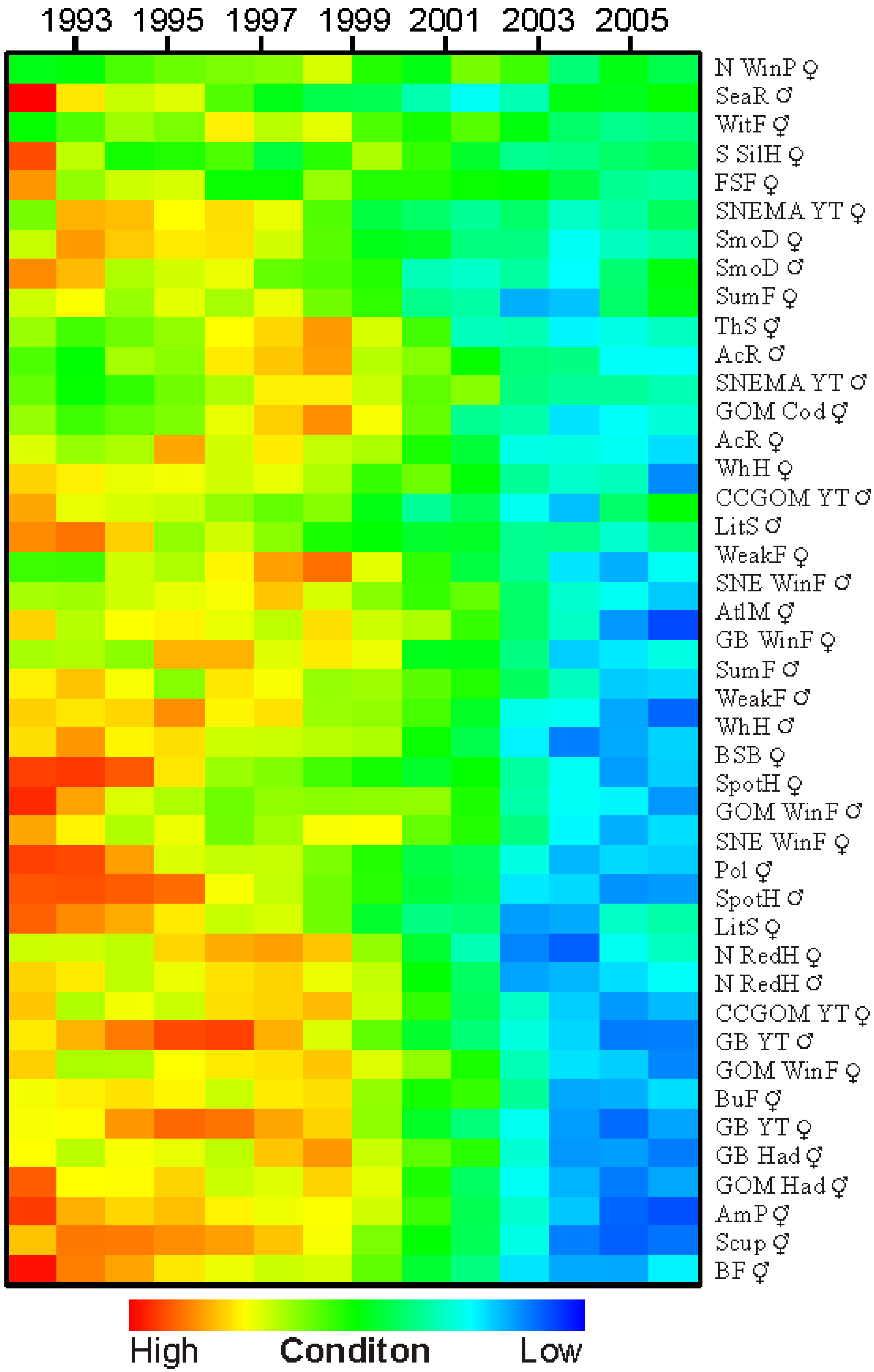
Total landings trends for major groups of fishes and invertebrates from the NES LME continue the trend of declining yields from the ecosystem over recent years. The combined landings for all species categories in 2008 were the second lowest since the late 1960s (see figure). Landings of groundfish (Atlantic cod, haddock, etc.) increased slightly in 2008 over the previous year. Groundfish landings have continued to remain relatively low since the mid 1970s due to severe overfishing and, more recently, to regulatory intervention to rebuild depleted stocks; currently they are still a minor component of total system removals. Landings of other finfish (redfish, Atlantic croaker, black sea bass etc.) and crustaceans (primarily American lobster) have been relatively stable during 1960-2008. Landings of molluscs increased during the early 1980s due to a rapid expansion of the surfclam and ocean quahog fishery by the U.S. industry. With the recovery of the sea scallop resource in the mid to late 1990s, this category of landings (molluscs) along with small pelagic fishes, still accounts for the largest proportions of current landings.

Trophic Level of the Landings



The mean trophic level of landings (TLL) (1960-2008) for the NES LME was updated in 2008 to continue to monitor possible changes in the trophic structure in the region. This method accounts for the trophic level of each species in the landings weighted by the total landings of each species in a given year. The TLL for the system declined steadily since 1960, but increased slightly in 2008 (see figure). This increase was due to increased landings of cod, haddock, and goosefish. Recent landings have been dominated by molluscs and small pelagic fishes and this was still the case in 2008 (see **Landings by Major Species Group**). Continued monitoring of TLL will indicate whether the long-term trend in this important variable has begun to change.

Condition Factors of Fish


1993
1995
1997
1999
2001
2003
2005
N WinP ♀
SeaR ♂
WitF ♀
S SilH ♀
FSF ♀
SNEMA YT ♀
SmoD ♀
SmoD ♂
SumF ♀
ThS ♀
AcR ♂
SNEMA YT ♂
GOM Cod ♀
AcR ♀
WhH ♀
CCGOM YT ♂
LitS ♂
WeakF ♀
SNE WinF ♂
AtlM ♀
GB WinF ♀
SumF ♂
WeakF ♂
WhH ♂
BSB ♀
SpotH ♀
GOM WinF ♂
SNE WinF ♀
Pol ♀
SpotH ♂
LitS ♀
N RedH ♀
N RedH ♂
CCGOM YT ♀
GB YT ♂
GOM WinF ♀
BuF ♀
GB YT ♀
GB Had ♀
GOM Had ♀
AmP ♀
Scup ♀
BF ♀
High
Conditon
Low

Declines in condition factor, or individual fish weight in relation to fish length, have been noted for numerous fish stocks in the Northeast US. Recently, trends in condition factor were analyzed for 40 finfish stocks caught in the NEFSC autumn bottom trawl survey (1992-2007), and sexes were analyzed separately for species whose growth rate differ by sex. Most of fish stocks and sexes (43 of the 66 combinations) were found to have significant trends in condition factor over the time series, and of these, only females of the Northern windowpane flounder stock showed a significant increase in condition factor. Changes in condition factor can be due to fishing pressure, competition, or environmental changes. However, further analysis showed that abundance or bottom temperatures did not appear to be driving the observed decreases in fish weight. Similar changes in condition have been noted for fish in Atlantic Canada. The overall change in fish condition is important because the productivity of fish stocks and expected yield depend on growth and condition. Further, the reproductive output of fish stocks is linked to their condition, potentially affecting egg production and recruitment.