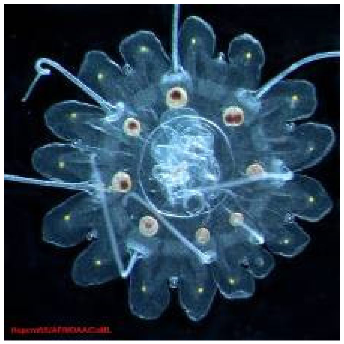
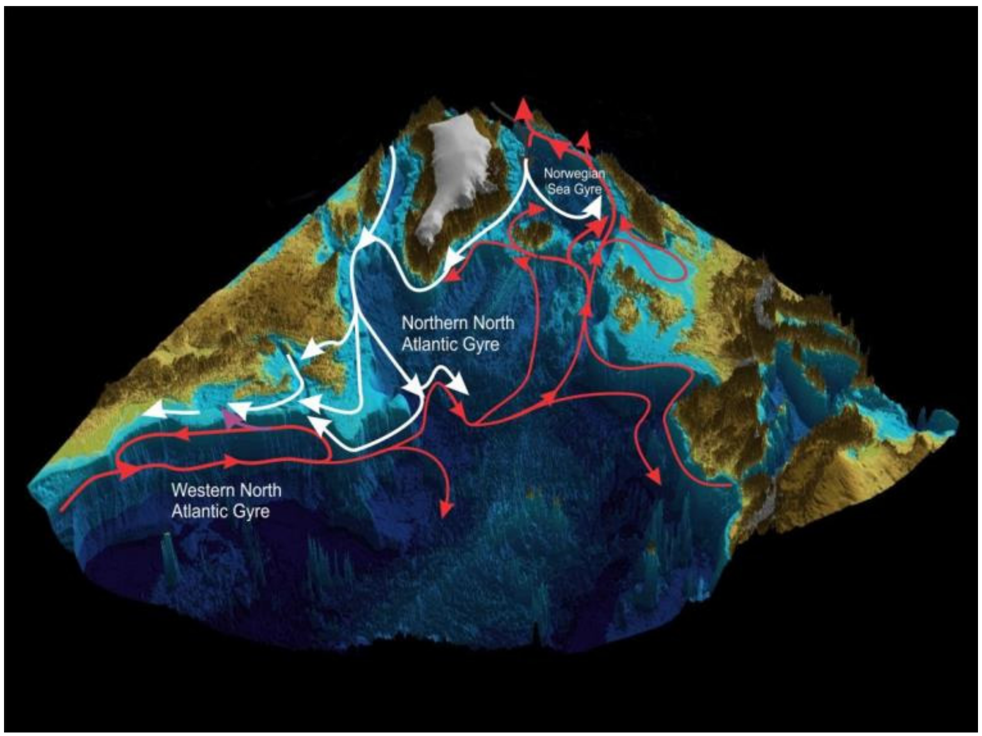
Response of North Atlantic zooplankton populations to environmental forcing

Peter H. Wiebe
Woods Hole Oceanographic Institution
Woods Hole, MA
&
Todd D. O'Brien
NOAA - NMFS - Office of Science & Technology
Marine Ecosystems Division





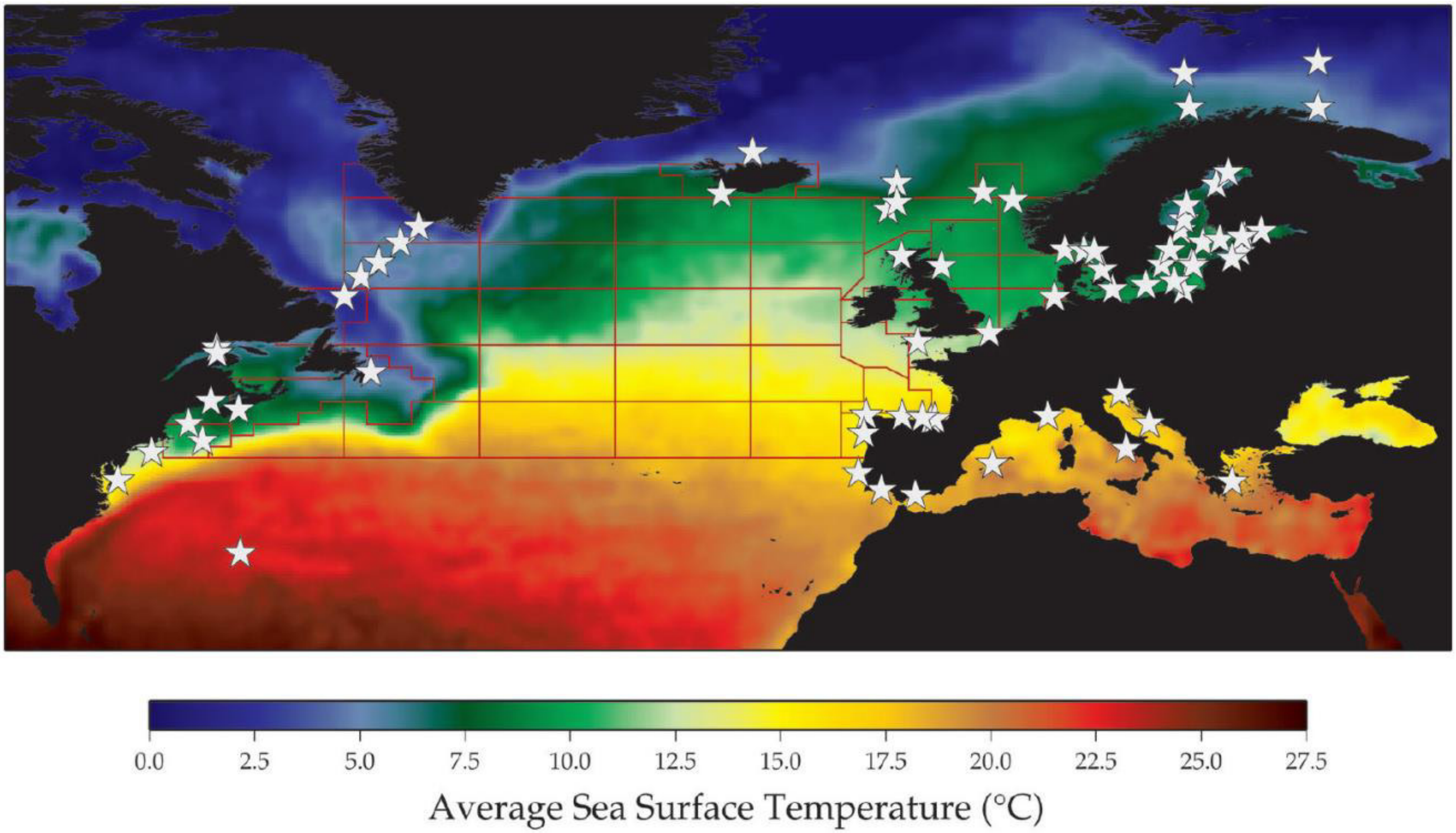
Ocean Carbon and Biogeochemistry (OCB) Summer Workshop, Woods Hole, MA 21 July 2015.
An International Group for Marine Ecological Time Series (IGMETS) Contribution.

Response of North Atlantic Zooplankton Populations to Environmental Forcing

Outline

- Zooplankton monitoring sites in the N Atlantic
- Driving Forces Related to Biological Change on decadal Time Scales.
- Patterns of change in N Atlantic regions based on ICES status reports.
- The view from the NE Atlantic.
- A closer look at change in NW Atlantic.
- Summary.
- Closing thoughts.

Zooplankton Monitoring Sites in the N Atlantic



Monitoring sites (62 white stars) and Continuous Plankton Recorder (CPR) standard areas (red outlined boxes). Seven Areas: The NW Atlantic, the Nordic and Barents seas, the Baltic Sea, the North Sea and English Channel the NW Iberian peninsula, the Mediterranean Sea, the North Atlantic Basin.

O'Brien, Wiebe, and Falkenhaug, 2013.

Driving Forces Related to Biological Change on Decadal Time Scales.

Directional – Anthropogenic Changes

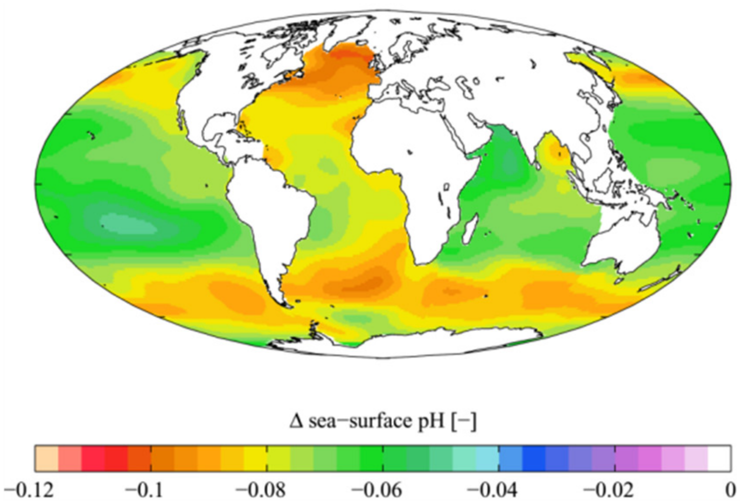
- Ocean Acidification (OA)
- Wind Speed and Wave Height ?
- Sea Surface Temperature (SST)

Aperiodic / Periodic Oscillations

- Atlantic Multidecadal Oscillation (AMO)
- North Atlantic Oscillation (NAO)
- Arctic Oscillation (AO) – Arctic Ocean Oscillation (AOO)
- Anthropogenic Impacts (Eutrophication, Fishing)
- Volcanic Eruptions

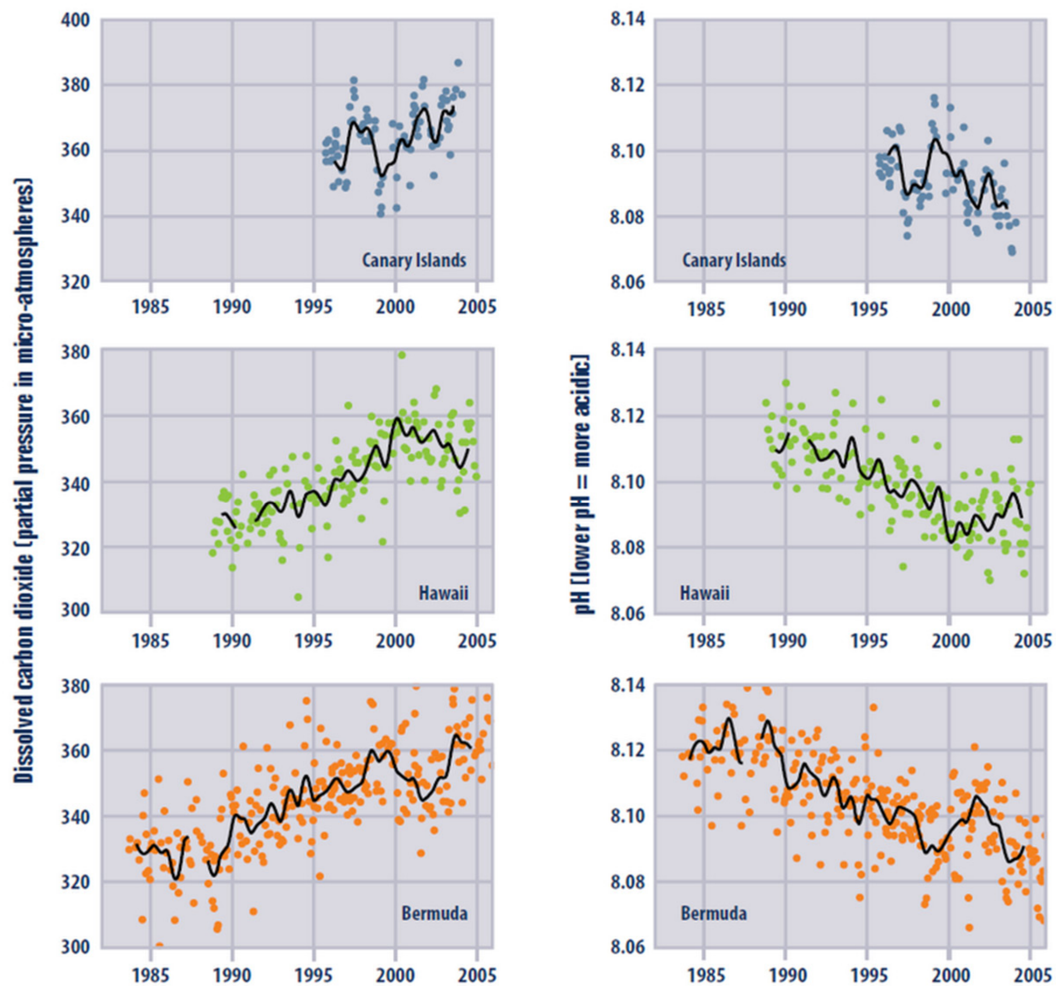
Directional Change: Ocean Acidification

Historical Changes in Ocean Acidity, 1700s–1990s based on modeled data



Changes in CO_2 and pH are important; impacts are just beginning to be understood.

Changes in Ocean CO_2 Levels and Acidity, 1983–2005



From: Yool, A. 2007; Bindoff, N.L et al. 2007

Directional Change? - Wind Speed and Wave Height

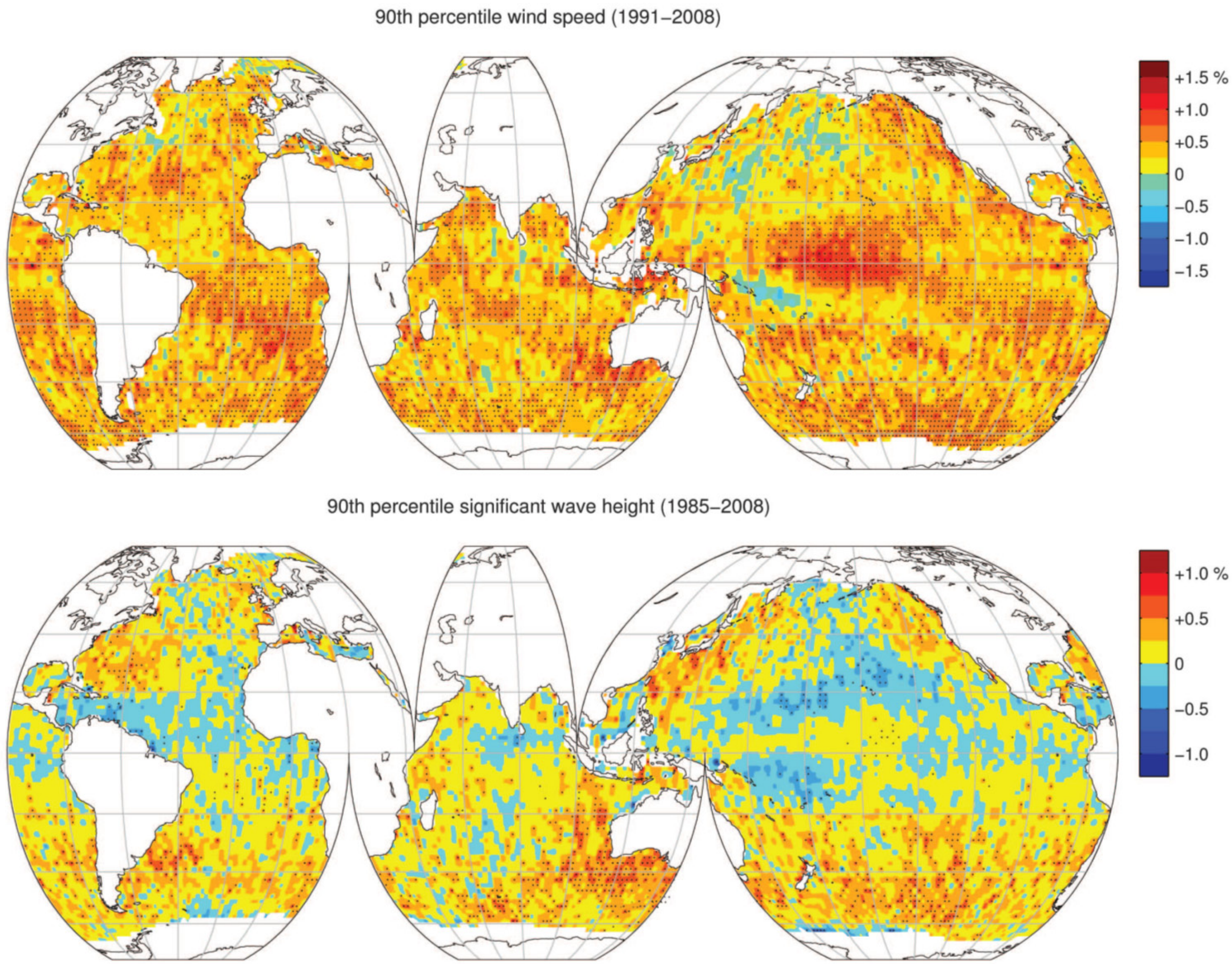
Global Trends Satellite Derived Wind Speed and Wave Height

Consistent trend of increasing wind speeds over past 2 decades.

Significant trend of increasing wave height at high latitudes.

Not possible to distinguish between directional trend, versus multidecadal oscillation.

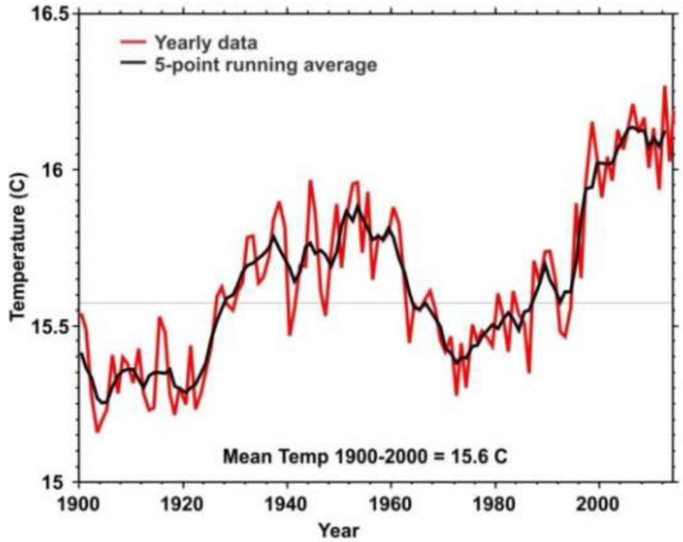
Biological Consequence:
Impact on Upper Ocean Mixing and advection



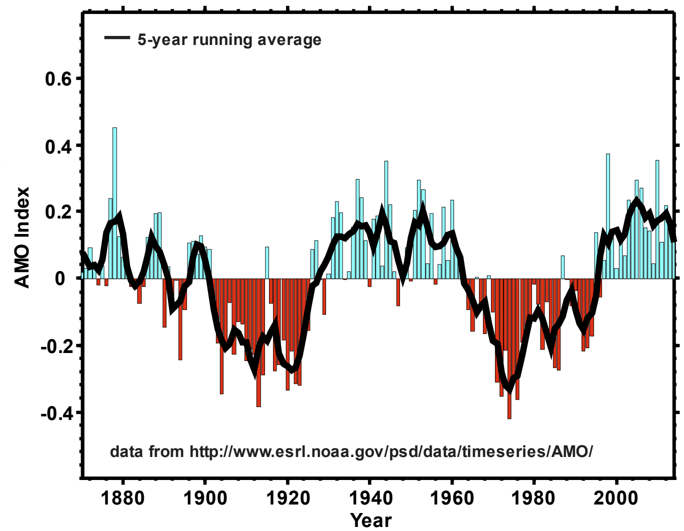
From: Young,et al. 2011

SST and AMO, AO, NAO Indices – 1870 / 1900-2014

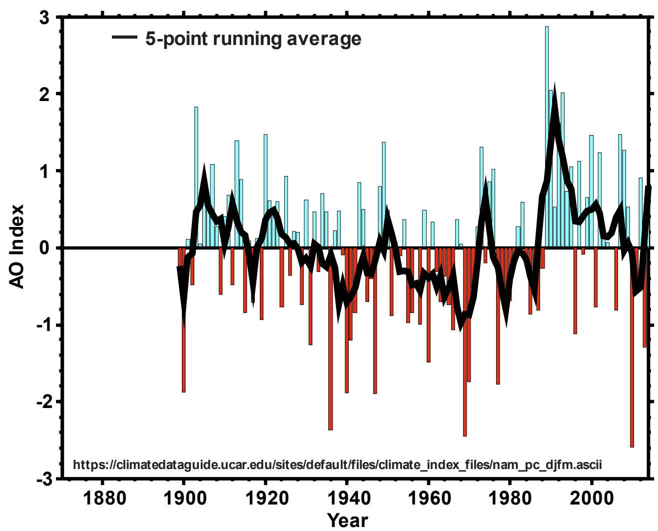
Sea Surface Temperature



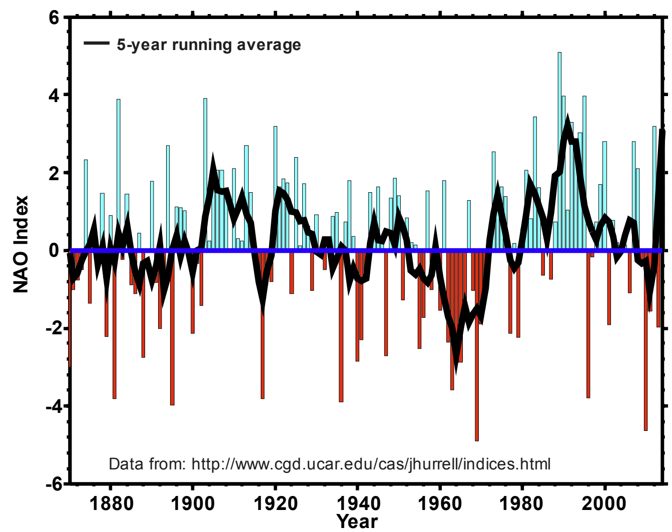
Atlantic Multidecadal Oscillation (AMO)



Arctic Oscillation (AO)

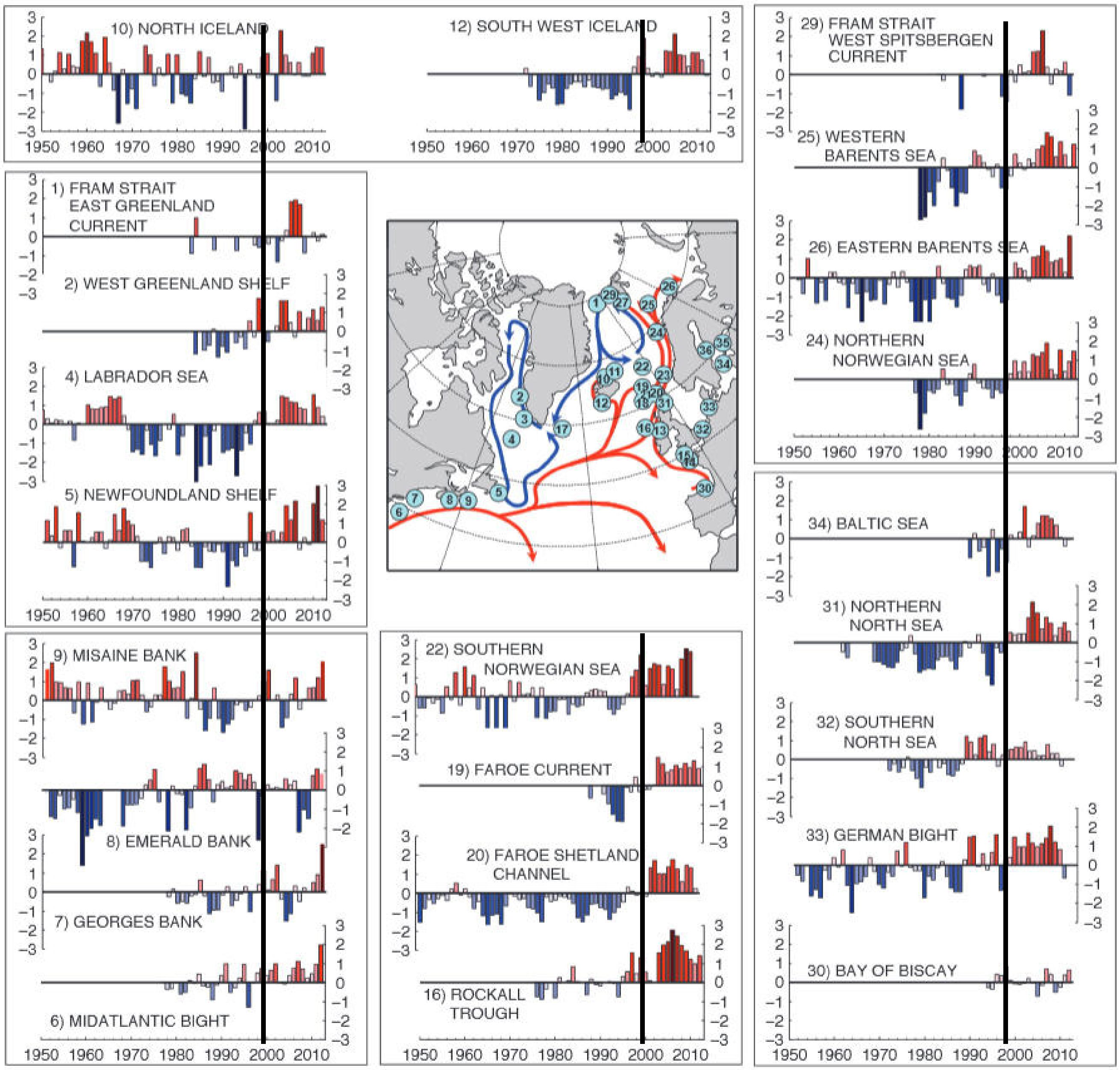


North Atlantic Oscillation (NAO)



- **Atlantic Multidecadal Oscillation** (AMO): oscillatory mode of variability computed from de-trended N. Atlantic SST.
- **Arctic Oscillation** (AO) or **Northern Hemisphere Annular Mode** (NAM): index of the dominant pattern of non-seasonal sea-level pressure variations north of 20N latitude.
- **North Atlantic Oscillation** (NAO): difference of atmospheric pressure at sea level between the Icelandic low and the Azores high.

Upper Ocean N Atlantic Temperature Anomalies



ICES 2012 Ocean Climate Report

Time-series of temperature anomalies normalized with respect to S.D. Color intervals 0.5 S.D..; reds = positive / warm; blues = negative / cool.

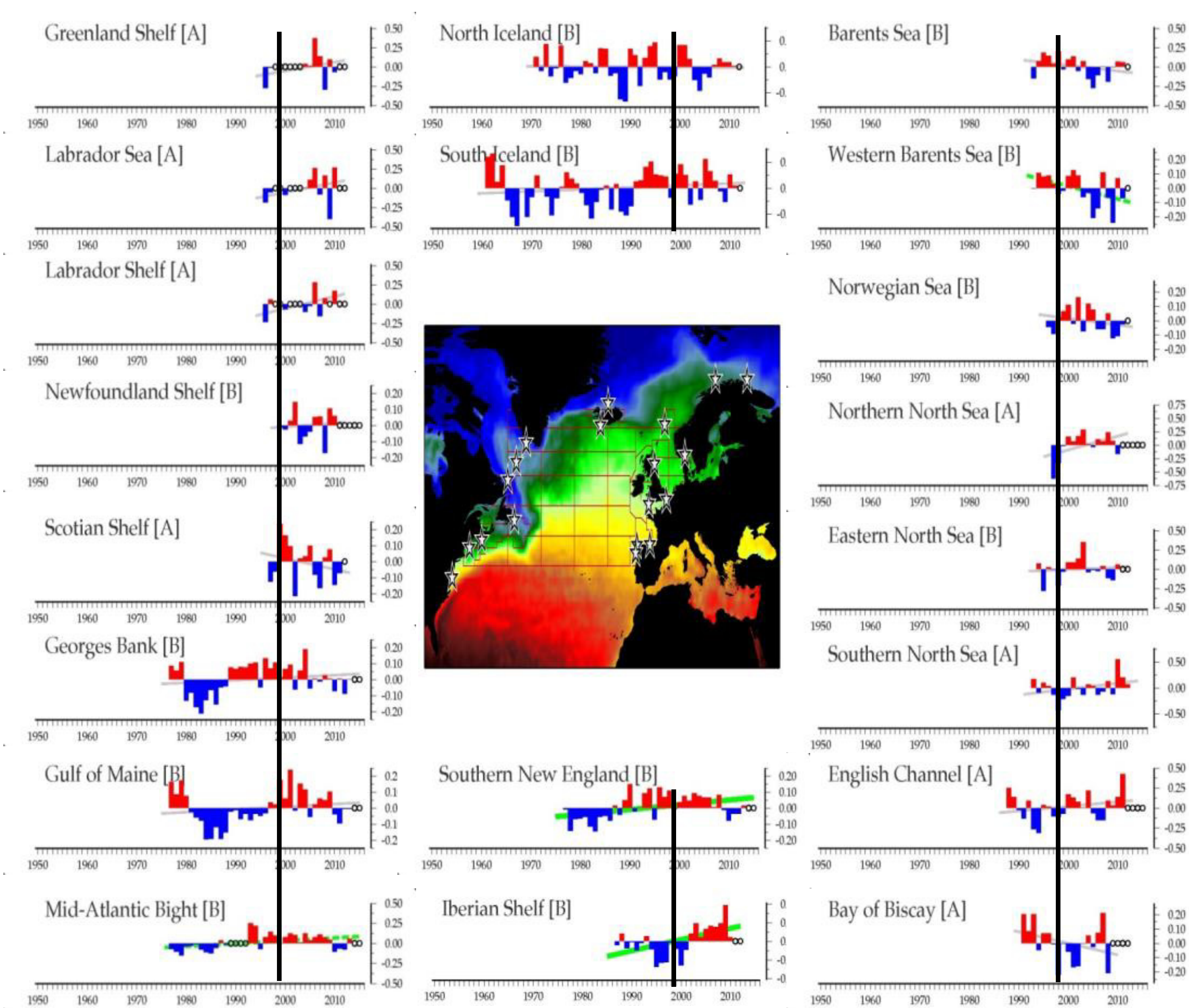
Vertical line indicates a regime shift around 2000 and warming that is coherent over most of North Atlantic.

Exception: NW Atlantic

Biological Consequence:
Increased stratification;
More warm-water species

Beszczynska-Möller,and Dye, (Eds.) 2013.

Upper Ocean Zooplankton Anomalies



ICES 2013 Zooplankton Status Report

Time-series of zooplankton anomalies normalized with respect to S.D. Color intervals 0.5 S.D..; reds = positive / warm; blues = negative / cool.

Vertical line marks the temperature regime shift around 2000.

Most time series too short;

Lack of consistent measurement type.

No coincident coherent basin-scale pattern;

O'Brien, Wiebe, and Falkenhaug, 2013.

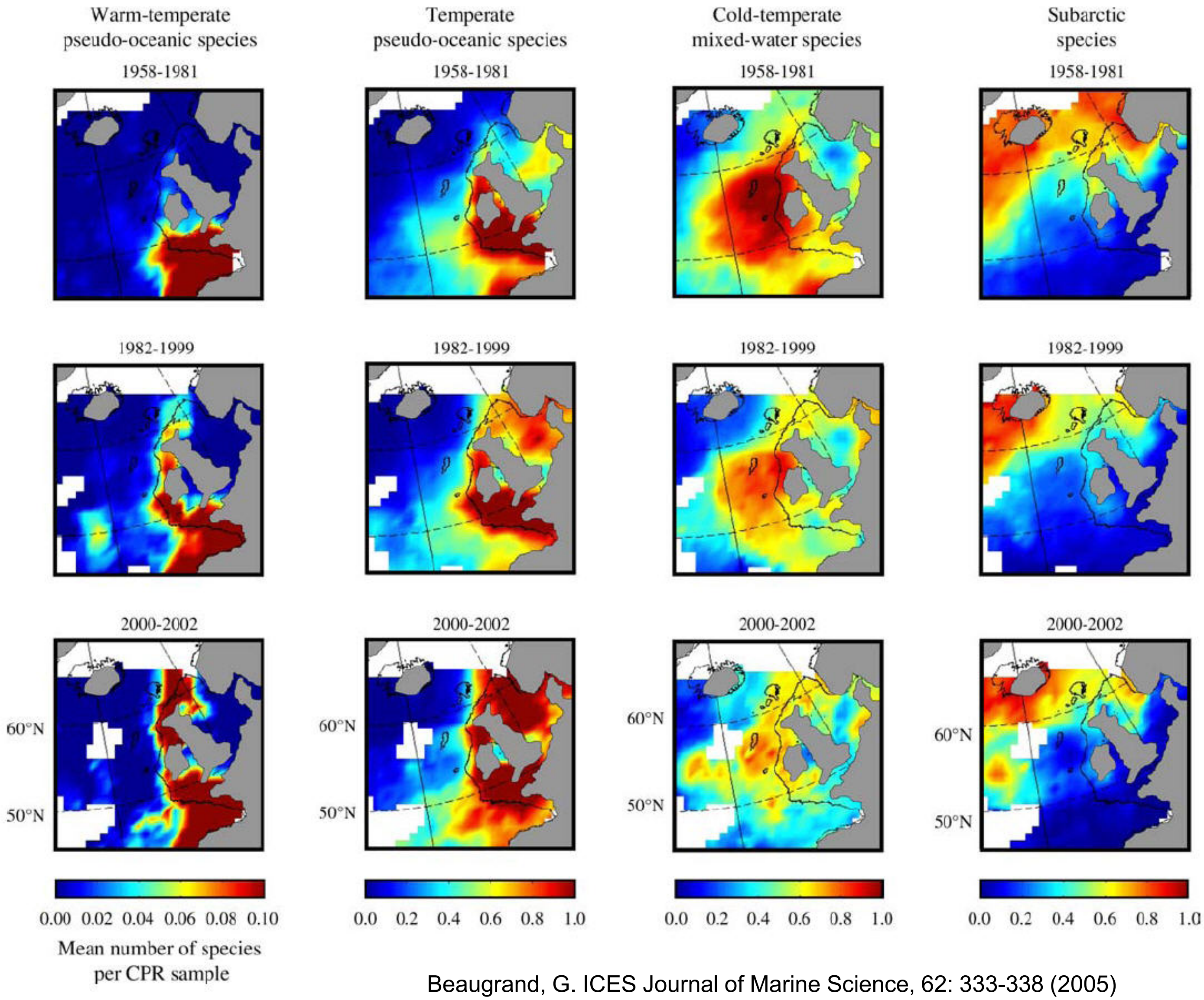
Biological Consequences of Climatic Warming
Or Changes in Water Mass Structure.

Changes in:

- **Range and spatial distribution of species.**
- **Location of biogeographical boundaries, provinces, and biomes.**
- **Phenology of species (e.g. earlier reproductive season).**
- **Dominance (e.g. a key species can be replaced by another one).**
- **Biodiversity.**
- **Structure and dynamics of ecosystem with possible regime shifts.**

Expected Results: Major impacts on exploited marine resources and biogeochemical processes (e.g. sequestration of CO_2).

Long-term Changes in Species Abundances for 1958-1981, 1982-1999, and 2000-2002



Abundances based on Continuous Plankton Recorder (CPR) surveys.

Warm-water species distributions extended north by >10° latitude.

Cold-water species decreased in abundance and range.

Changes coincident with NE Atlantic warming.

Beaugrand, G. ICES Journal of Marine Science, 62: 333-338 (2005)

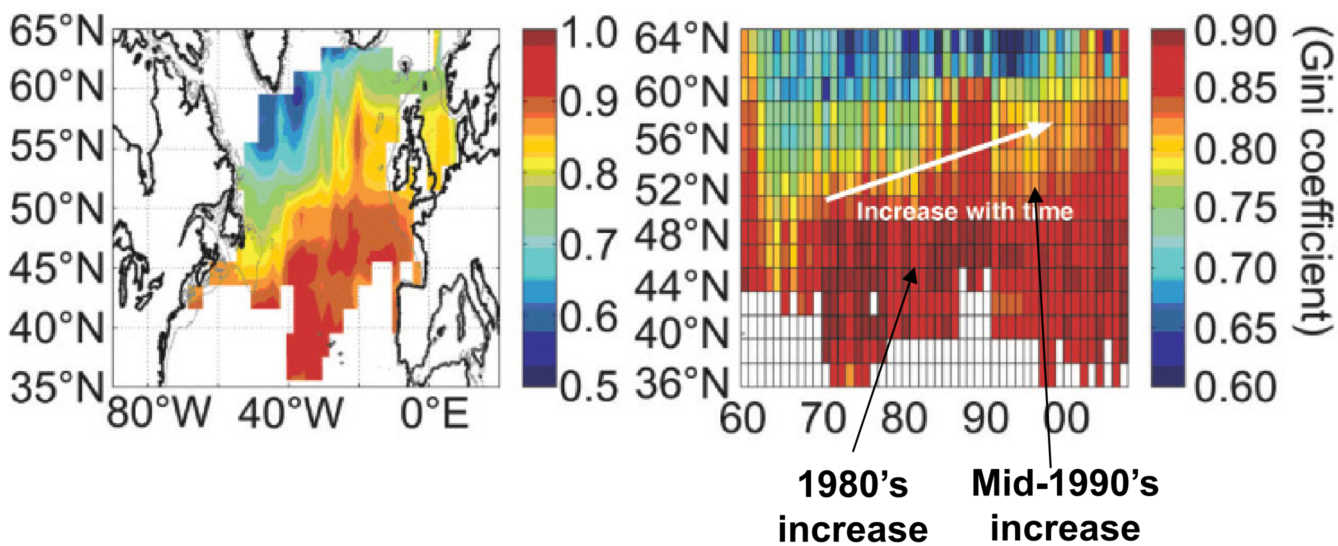
Changes in Copepod Diversity and Particulate Flux

Multi-decadal northward shift in copepod biodiversity coincided with increased SST at high latitudes and decrease in copepod sizes.

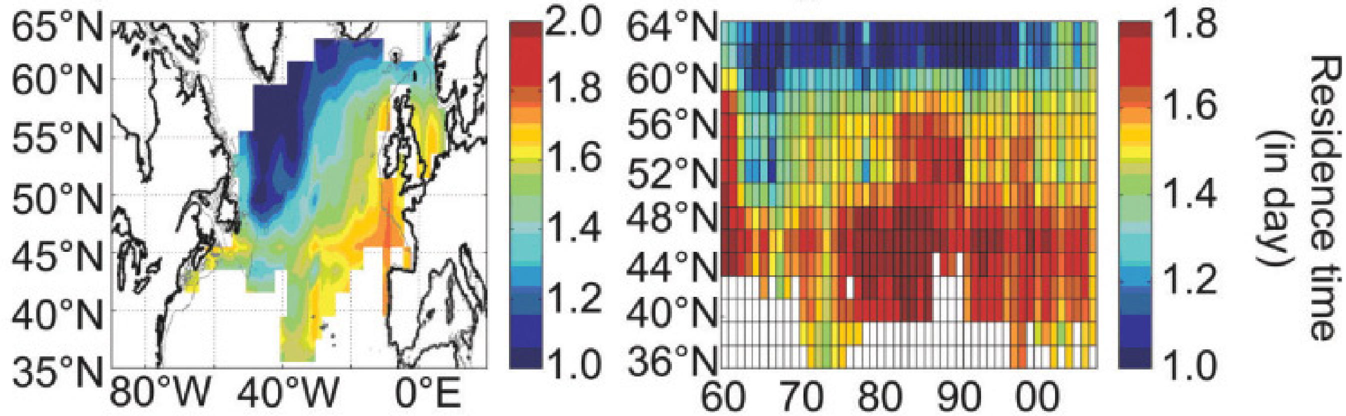
As animal body size decreases, increase in residence time of particles they produce; decrease in downward flux (based on allometric equations; Legendre & Michaud, 1998) *

Biological Consequence: **Decreased CO_2 input into Deep-Sea**.

Mean copepod biodiversity **Latitudinal change in biodiversity**



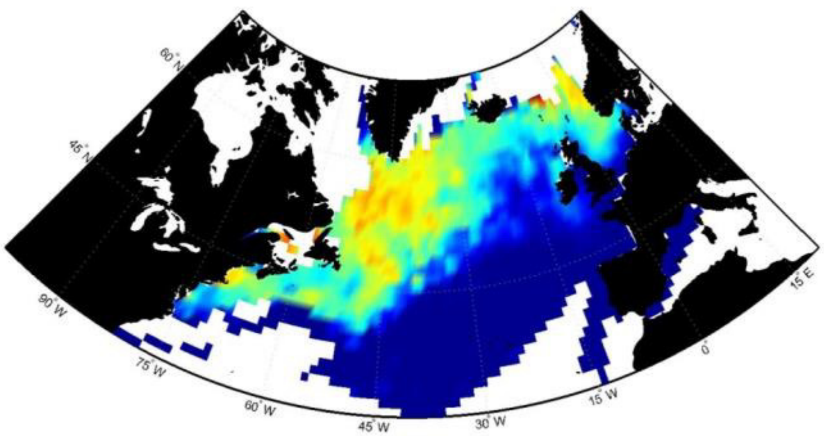
Mean residence time of particulate carbon **Latitudinal changes in residence time**



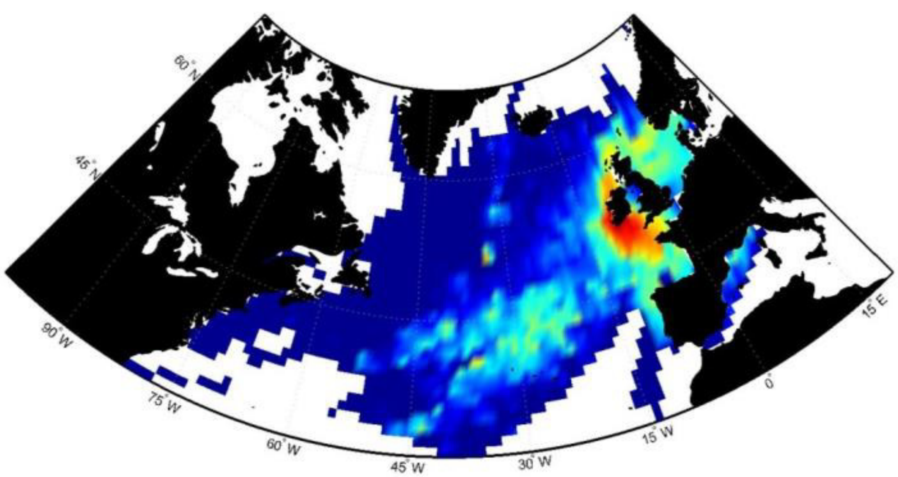
Beaugrand, et al., 2010. PNAS.107(22):10120–10124

Copepod Species Relationships: *Calanus finmarchicus* versus *C. helgolandicus*

Mean spatial average for the last 50 years
Calanus finmarchicus



Calanus helgolandicus



Dramatic shift in ratio of two copepod species in North Sea:

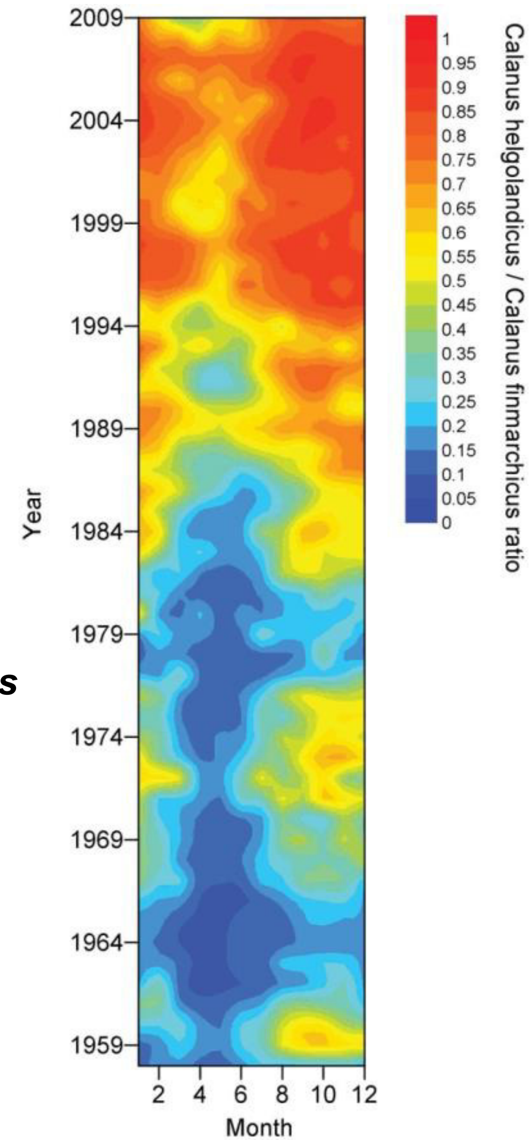
C. helgolandicus **increases;**

C. finmarchicus **decreases.**

What will be fate of *C. finmarchicus* in NW Atlantic with warming?

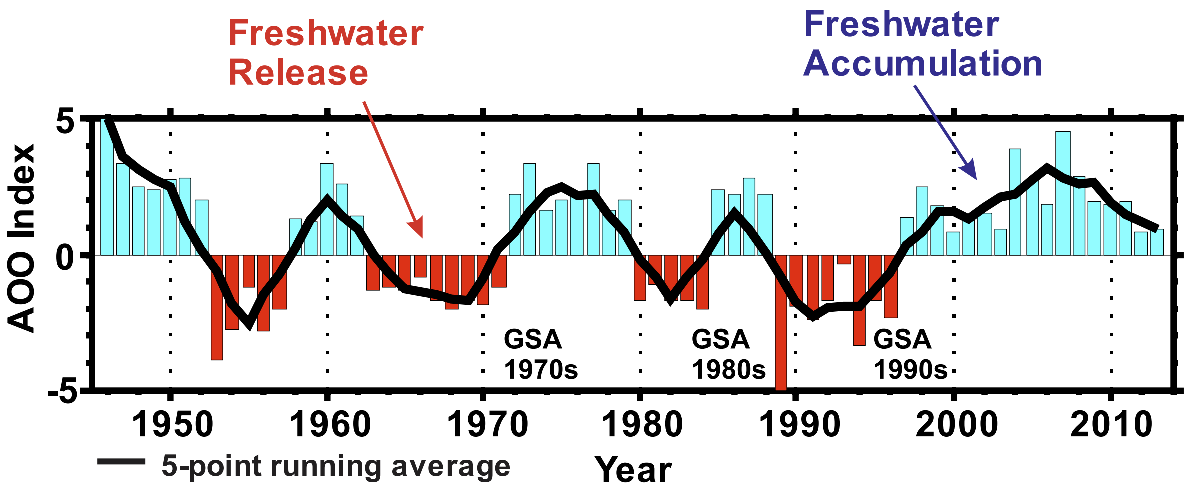
Why is *C. helgolandicus* rare in NW Atlantic?

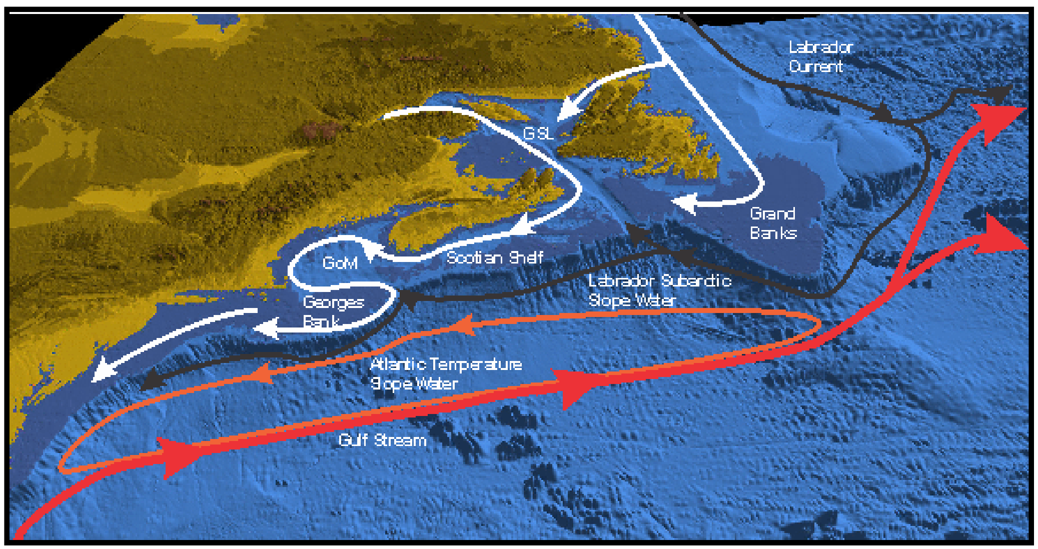
North Sea *Calanus*



From: SAHFOS Marine Ecological Status Report 2010

AOO Index – 1946-2013





Sources to Gulf of Maine / Georges Bank:

- Canadian Archipelago via Labrador shelf / Labrador Current.
- Fram Strait, east of Greenland Current, Labrador Current via Northeast Channel
- St Lawrence Seaway via Scotian Shelf

The Arctic Ocean Oscillation (AOO): based on sea surface height in barotropic ocean model**.**

Positive index anticyclonic wind forcing accumulates freshwater in the Beaufort Gyre; not released to the N Atlantic.

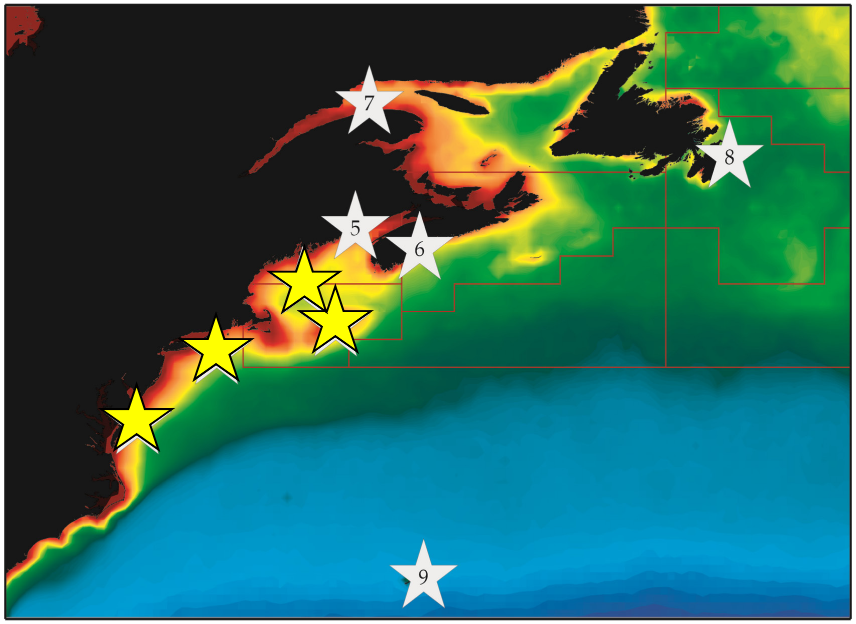
Negative index - cyclonic forcing releases fresh water to N Atlantic.

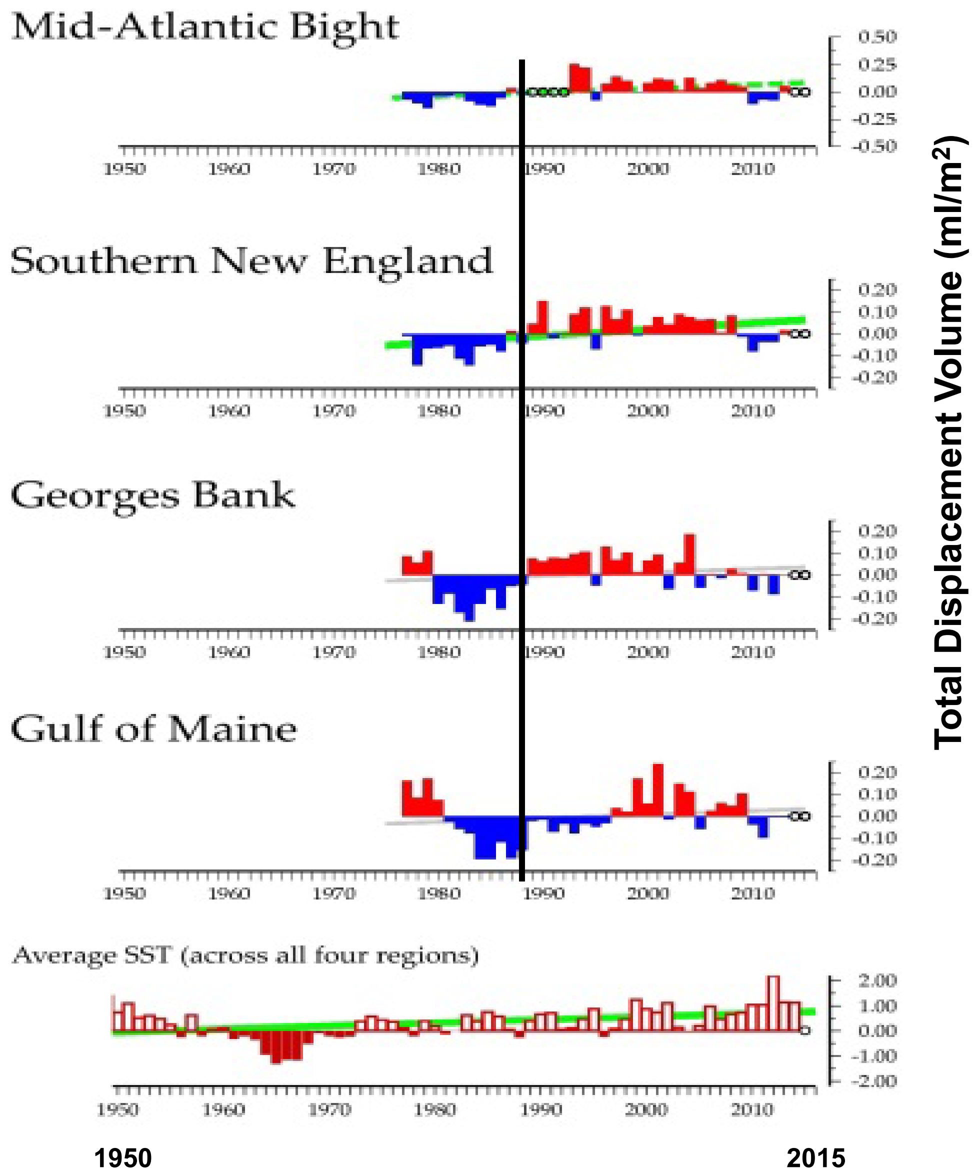
Freshwater input to Gulf of Maine and Georges Bank has multiple sources and pathways.

Biological Consequence:
Inputs impact seasonal stratification and production cycles.

Proshutinsky, and Johnson, 1997; .Mountain, 2012.

NW Atlantic MarMap and EcoMon Time Series





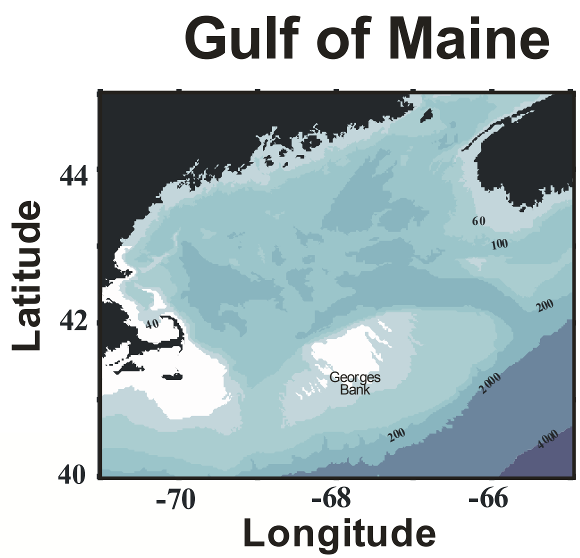
Low zooplankton biomass in 1980s; higher biomass in 1990s; variable through 2000s.

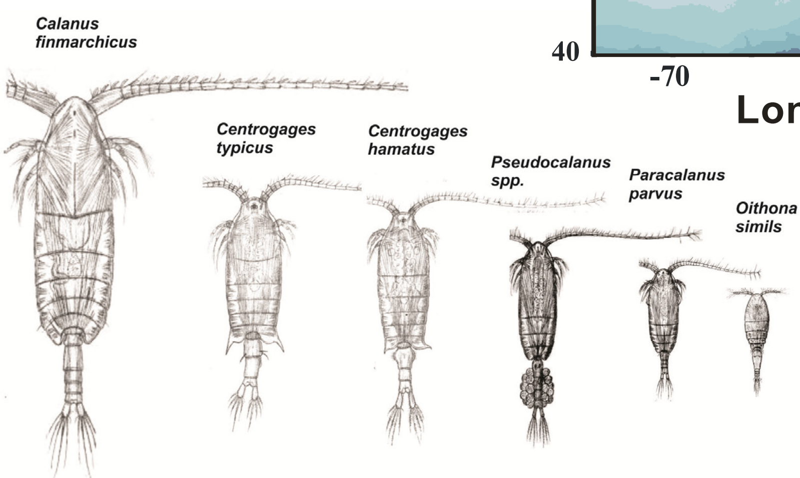
Regime shift in zooplankton assemblage in 1989

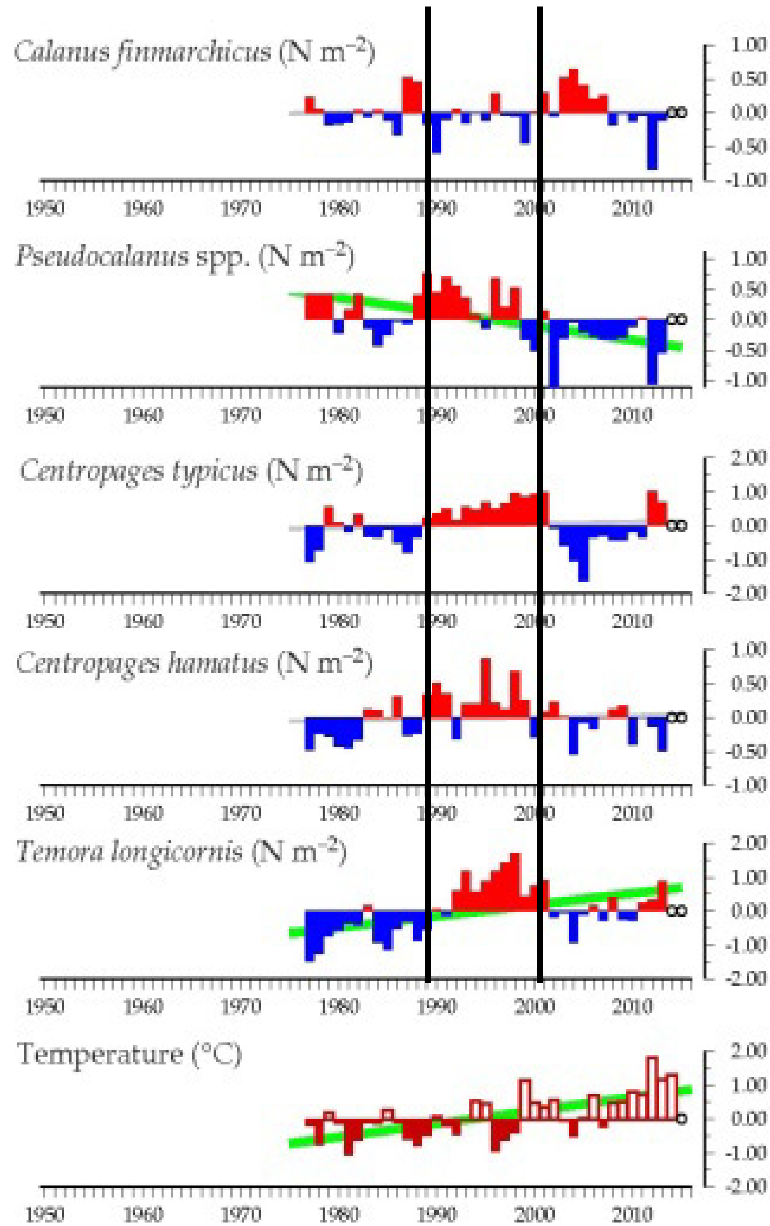
O'Brien, Wiebe, and Falkenhaug, 2013.

Copepod Species Abundances in the NW Atlantic

Dominant copepod species on Georges Bank showed decadal variability.







Calanus finmarchicus **abundance was low in the 1990's and higher in the 2000's.**

Other smaller species had higher abundance in the 1990s and lower recently.

O'Brien, Wiebe, and Falkenhaug, 2013.

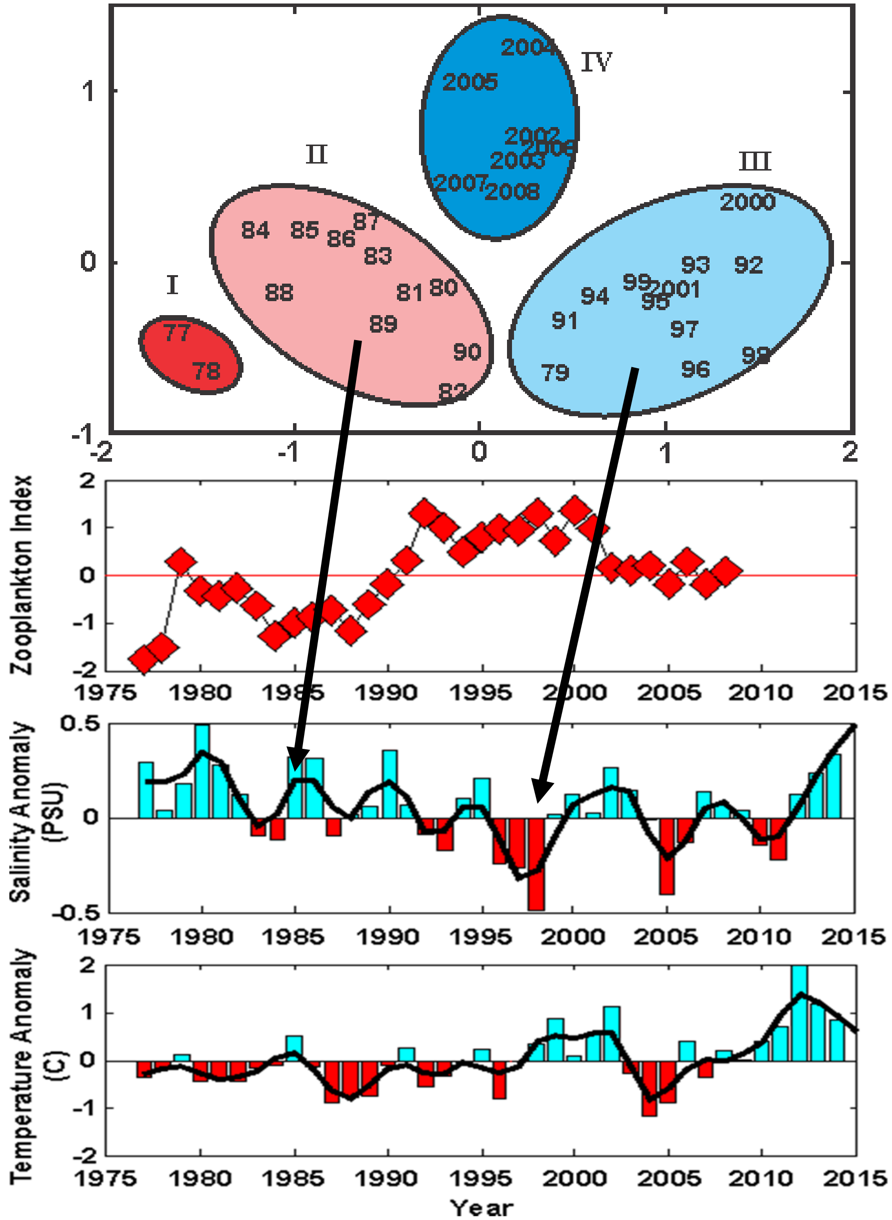
Zooplankton Species Abundances in the NW Atlantic

- **Multi-dimensional scaling (MDS) analysis of interannual variation in abundances of 23 zooplankton species collected during MARMAP / EcoMon surveys on Georges Bank 1977 - 2008.**

- **Groups I (1977-1978) and II (1980-1990) had low abundance, negative Zoo Index, and high salinities.**

- **Group III (1979, 1991- 2001) showed high abundances with ~10-fold increases of smaller copepod species, positive Zoo Index, and inflow of low salinity water from the Scotian Shelf.**

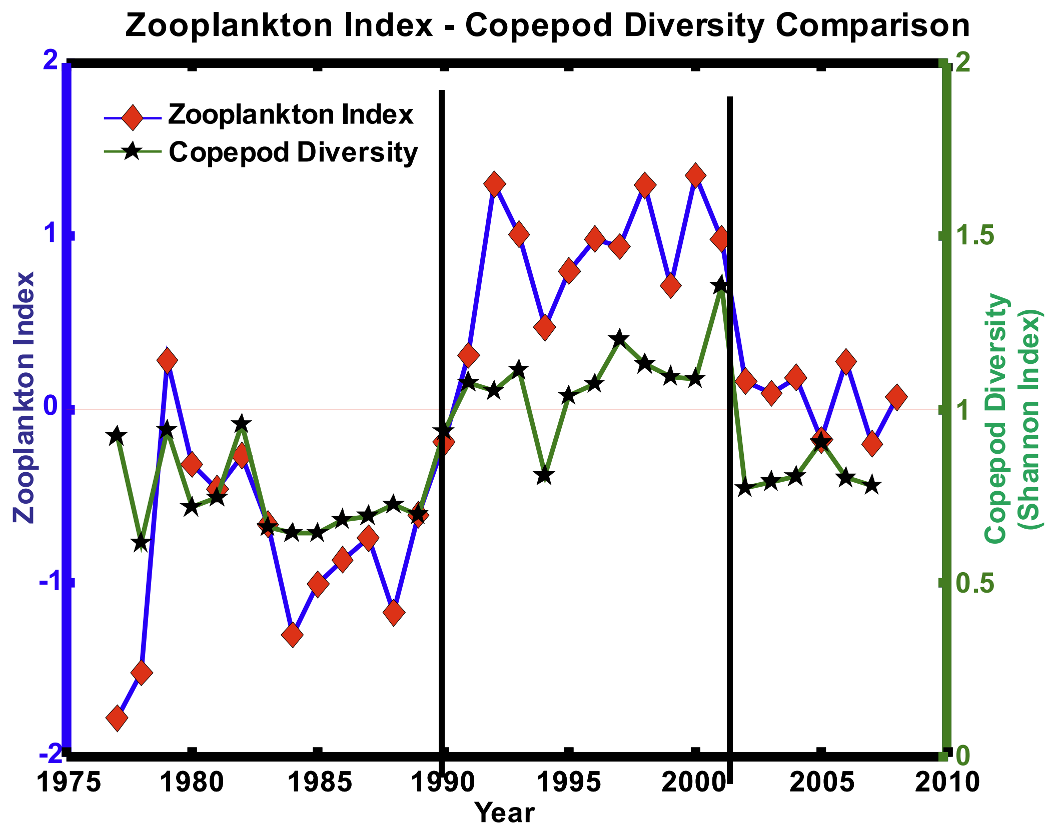
- **Group IV (2002-2008) patterns of species abundances were stable, despite interannual variation in temperature and salinity.**



Zooplankton From: Hare, and Kane. 2012.; Anomalies from Fratantoni, NOAA/NFSC

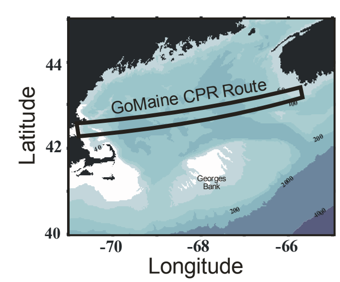
Comparative Analysis of Zooplankton in NW Atlantic

Strong agreement between copepod species diversity based on CPR samples taken along a transect in the Gulf of Maine and the MDS Zooplankton Index based on Georges Bank samples.



- **Both analyses show a large-scale changes in zooplankton abundances during the 1980's and 1990's.**

- **"The increased abundance of small copepod species is hypothesized to be driven either by increased fall stratification, leading to more intense and longer duration fall phytoplankton productivity, or to increased influx of zooplankton from the Scotian Shelf."**



From: Johnson et al., 2011; Hare and Kane,. 2012.

Summary

NE Atlantic

- Zooplankton species biogeographical boundaries shifted North with warming and water column stratification.
- Warm water species are replacing temperate / boreal species, thus altering food chain structure.
- The shift to the smaller warm-water phytoplankton and zooplankton results in longer residence times for organic particles in surface waters and a diminished flux into mid-water depths.

NW Atlantic Shelf

- Regime shifts in the zooplankton assemblage may be driven by bottom-up forcing, resulting from salinity variation (with advection of freshwater from multiple sources) coupled to warming.
- Relationships between zooplankton assemblage, NAO index, and environmental parameters show *non-stationary relationships over time series.*
- Understanding causes of complex patterns of zooplankton distribution, abundance and diversity in relation to physical parameters and large-scale forcing should be a priority for basin-scale climate and ecosystem research.

Closing Thoughts

- **Patterns of change in the N Atlantic zooplankton assemblage differ among regions due to differing magnitudes and mixtures of natural and anthropogenic forces.**
- **Comparisons BETWEEN REGIONS are difficult since measurement methods differ for zooplankton bulk properties and species identification is uncertain.**
- **Zooplankton species and species composition are more sensitive indicators of ecosystem response to interannual climate variation than zooplankton abundance or biomass.**
- **Coordinated basin-scale approach is needed to understand the dynamics of N Atlantic zooplankton assemblages and ocean ecosystems.**
- **Time-series of environmental properties and composition of lower trophic levels are essential for future understanding of climate impacts in the Anthropocene.**

This is a IGMET contribution. Photos by R. Hopcroft, L. Madin, C. Clarke, and Z Solvin..