Response of North Atlantic zooplankton populations to environmental forcing

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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.
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.

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 CO₂ and pH are important; impacts are just beginning to be understood.

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**

- Yearly data
- 5-point running average

Mean Temp 1900-2000 = 15.6°C

**Atlantic Multidecadal Oscillation (AMO)**

- 5-year running average

Data from: http://www.esrl.noaa.gov/psd/data/timeseries/AMO/

**Arctic Oscillation (AO)**

- 5-point running average

Data from: https://climatedataguide.ucar.edu/sites/default/files/climate_index_files/nam_pc_djfm.ascii

**North Atlantic Oscillation (NAO)**

- 5-year running average

Data from: http://www.cgd.ucar.edu/cas/jhurrell/indices.html

- **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

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

Bieszczyska-Möller, and Dye, (Eds.) 2013. ICES 2012 Ocean Climate Report
Upper Ocean Zooplankton Anomalies

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;

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$_2$).

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.

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.

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**

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?

From: SAHFOS Marine Ecological Status Report 2010
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.

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

Proshutinsky, and Johnson, 1997; Mountain, 2012.
Low zooplankton biomass in 1980s; higher biomass in 1990s; variable through 2000s.

Regime shift in zooplankton assemblage in 1989

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.

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
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.
**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.
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..