Zooplankton responses to shifting oceanographic conditions in the Gulf of Maine and implications for the Nantucket Shoals prey field

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With acknowledgement of the participation and contributions of multiple researchers, technical staff and students at multiple institutions for the collection and analysis of NERACOOS ISMN time series samples and data, and of funding support from the following:

UNH Center for Coastal Ocean Observation and Analysis (*COOA*)

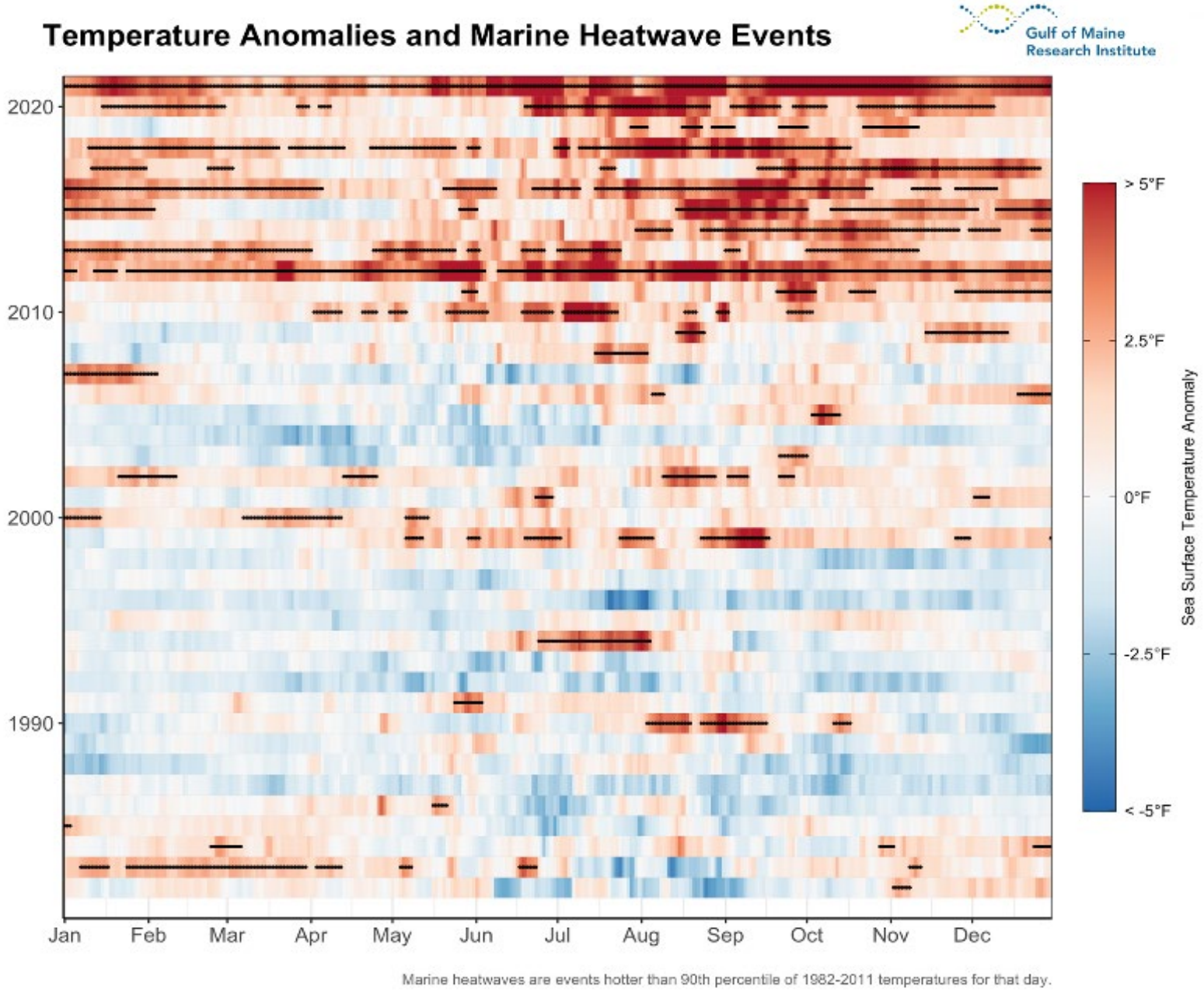
General circulation in the coastal NW Atlantic

Sorochan et al. 2021. Availability, supply and aggregation of prey (Calanus spp.) in foraging areas of the North Atlantic right whale. ICES JMS 78(10):3498-3520

- The Gulf of St. Lawrence and the Gulf of Maine can be considered as a large scale coupled advective estuarine system driven by the St. Lawrence River
- Supply of water into the eastern GoM from the Scotian Shelf/Nova Scotia Current (cold and fresh) and Warm Slope Water or Labrador Slope Water through NE Channel
- Since 2010, evidence for a northward shift in Gulf Stream and greater transport of WSW and modified Gulf Stream Water into the GoM
- See Townsend et al. 2023 Prog. Oceanogr.

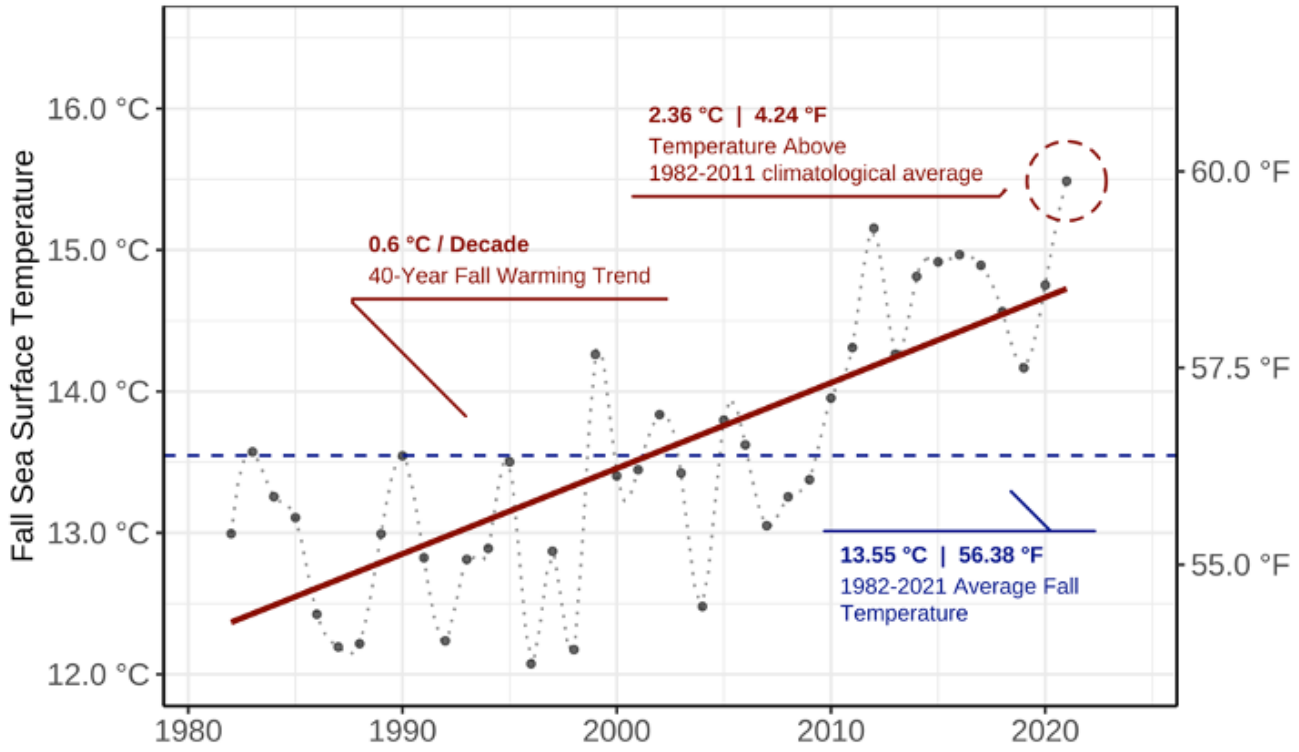
Warming trend in the Gulf of Maine: Sea Surface Temperature

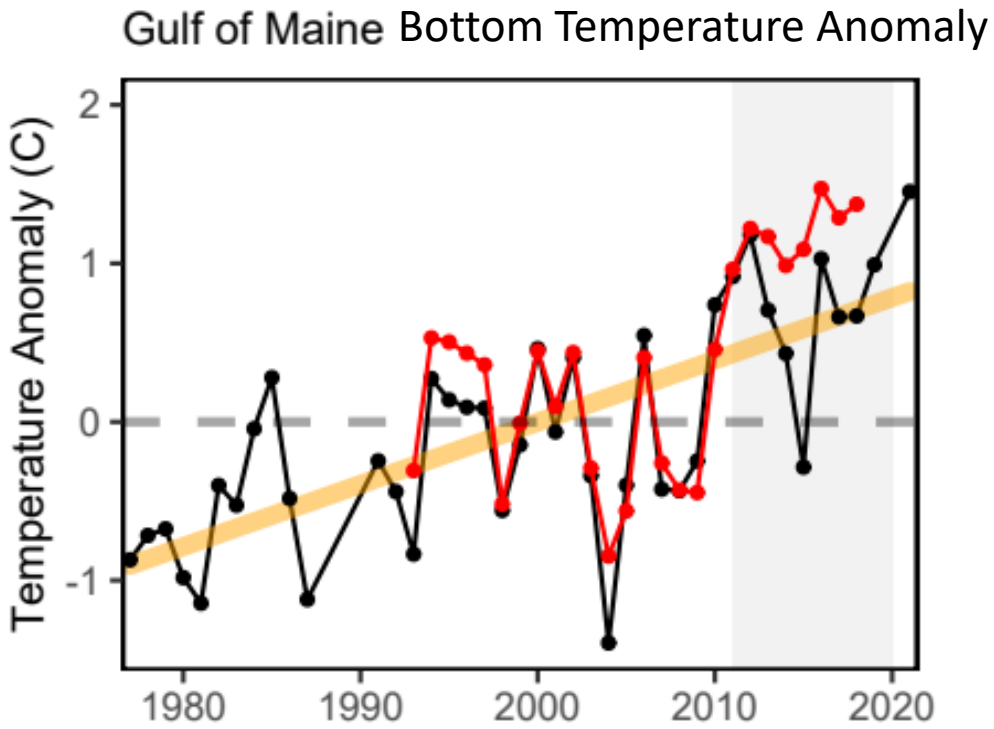
2010 →



Gulf of Maine Research Institute website: https://www.gmri.org/stories/fall-2021-warming-update/

Warming in the Gulf of Maine is occurring at both the surface and the bottom





Gulf of Maine Research Institute website:
https://www.gmri.org/stories/fall-2021-warming-update

NOAA Fisheries State of the Ecosystem Report:
New England 2022

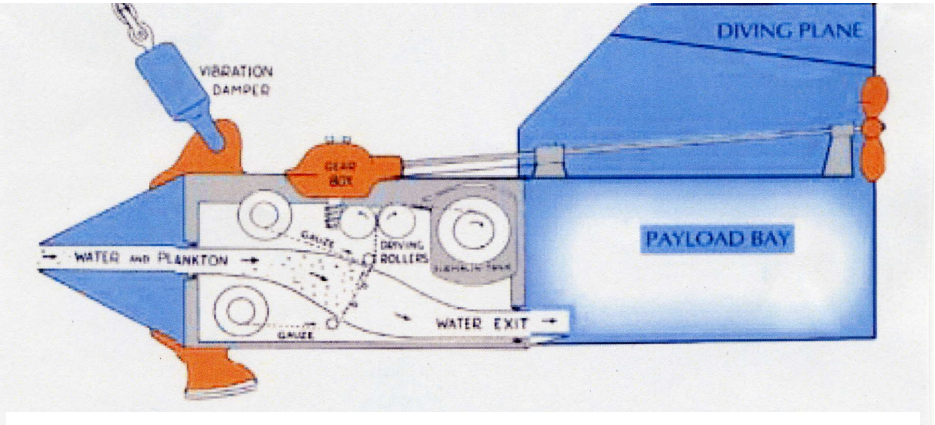
See also Townsend et al. 2023. Prog. Oceanogr.

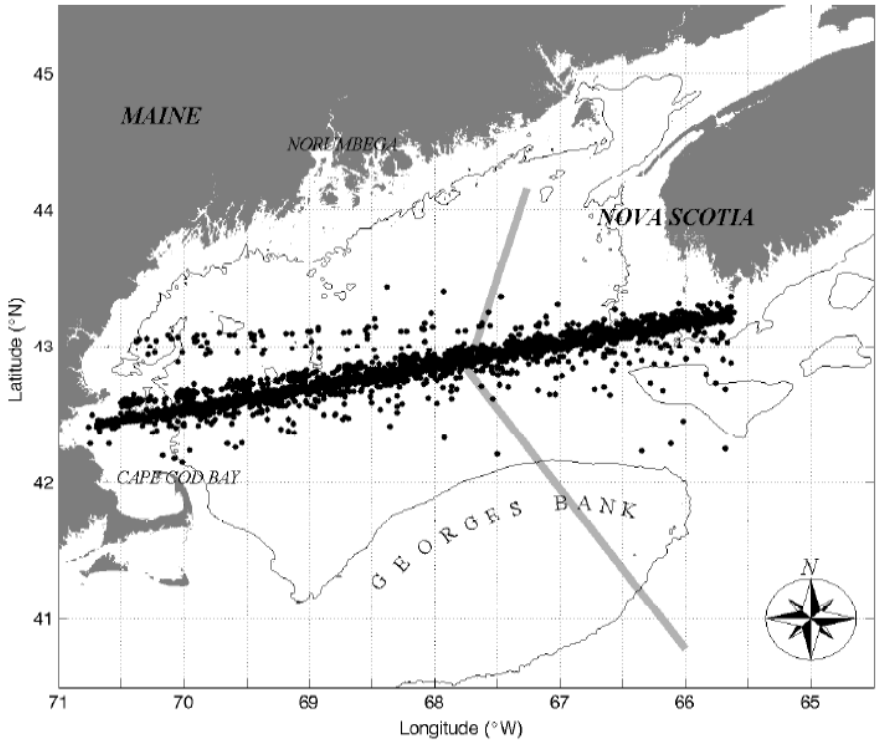
Zooplankton Responses to Oceanographic Conditions and Implications for Nantucket Shoals prey field

- Zooplankton Observing Programs in the Gulf of Maine (GoM)
- Recent (decadal) trends in oceanographic conditions and zooplankton abundance in the GoM, with a focus on *Calanus finmarchicus*
- Implications for Nantucket Shoals zooplankton and wind turbine impacts

Continuous Plankton Recorder

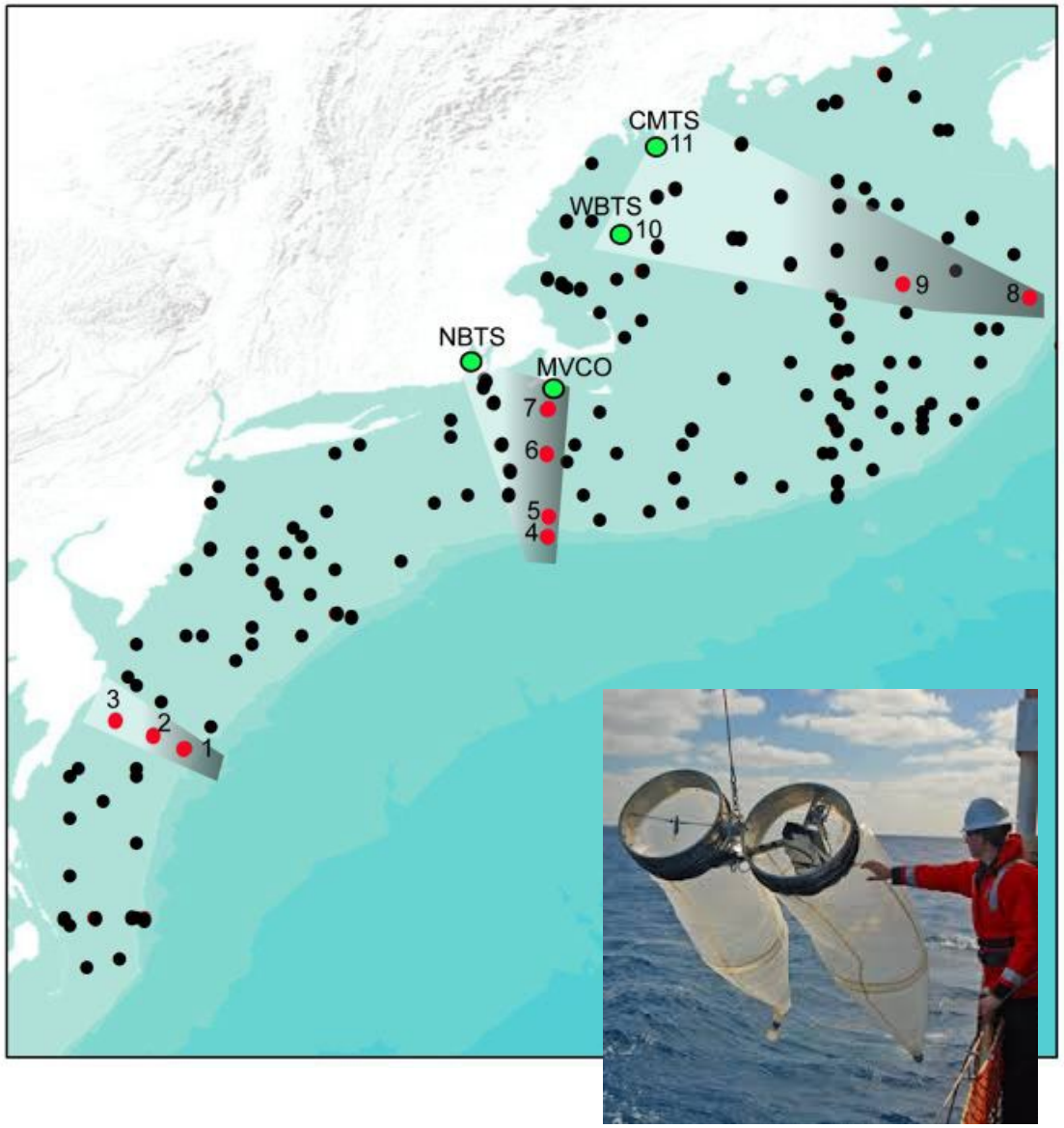
Sir Alister Hardy Foundation for Ocean Sciences (SAHFOS)





- Conceived by Sir Alister Hardy: First survey in 1931; routes concentrated in North Sea and N. Atlantic but now global
- Towed at depth of 5-10 m behind merchant marine ships on scheduled routes.
- Weight: 85 kg. Aperture size: 1.3cm^2. Mesh size of plankton silk: 270 µm
- CPR line in Gulf of Maine co-managed between NOAA and SAHFOS, since 1961

NOAA Ecomon/MARMAP surveys



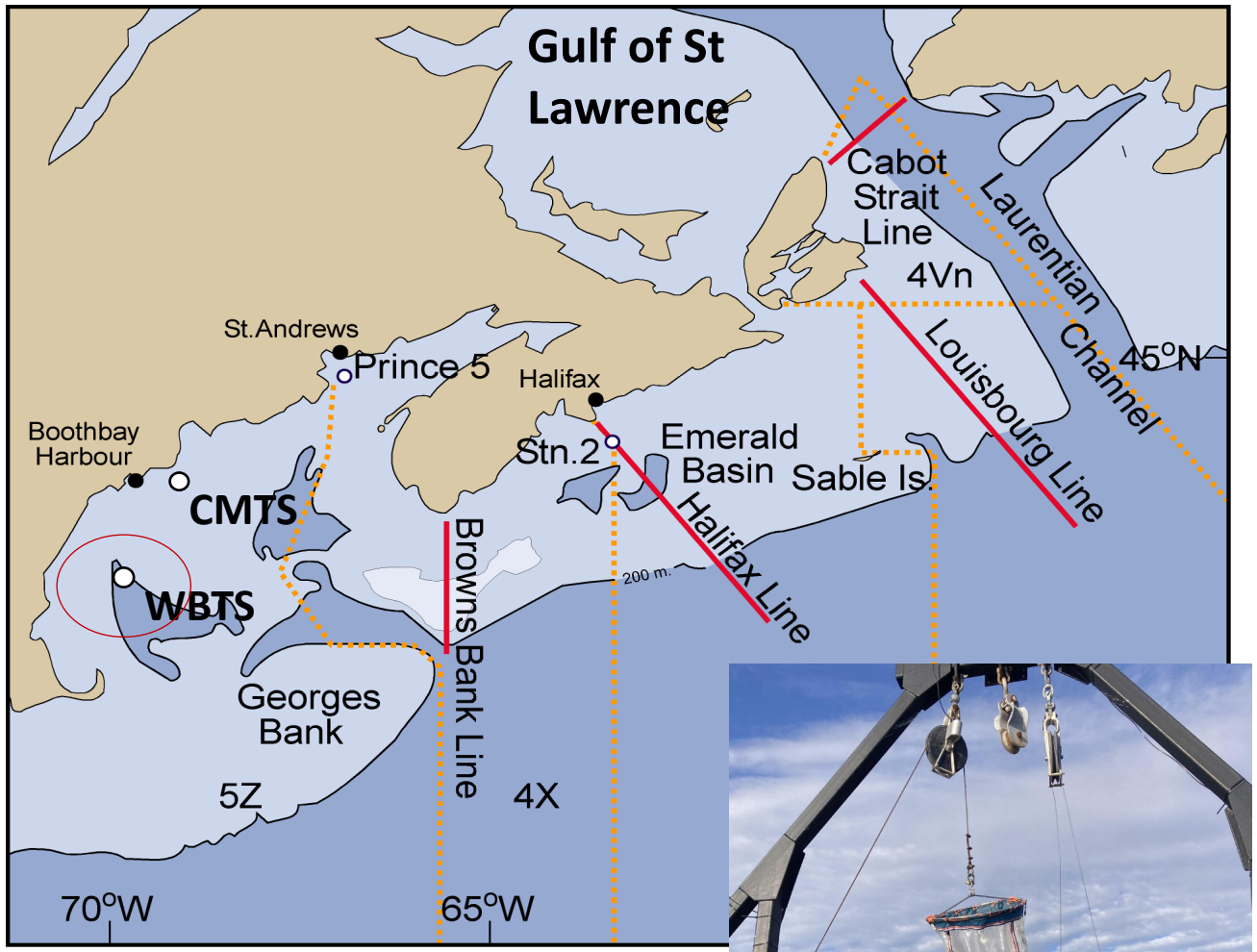
Example annual survey station locations: Time series stations (not part of EcoMon) also shown

- Surveys since 1977
- Stratified random design: each year different
- Bongo net tows with 333µm mesh
- 2-6 surveys per year

https://www.fisheries.noaa.gov/new-england-mid-atlantic/ecosystems/monitoring-ecosystem-northeast

NERACOOS operates the Integrated Sentinel Monitoring Network (ISMN) for U.S. Northeastern waters, including the Gulf of Maine

Monthly collection of environmental and plankton data at the Coastal Maine Time Series (CMTS) and the Wilkinson Basin Time Series (WBTS) Stations. Protocols similar to the Atlantic Zone Monitoring Program (AZMP) established in 1999



WBTS sampled: 2004-present. Hiatus 2009, 2011

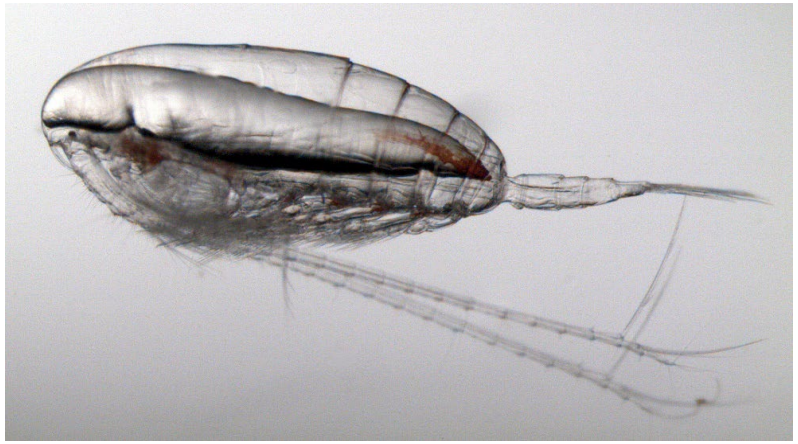
CMTS: 2008-2017; 2020-2022. Hiatus 2018-2019

https://espis.boem.gov/final%20reports/BOEM_2023-015.pdf

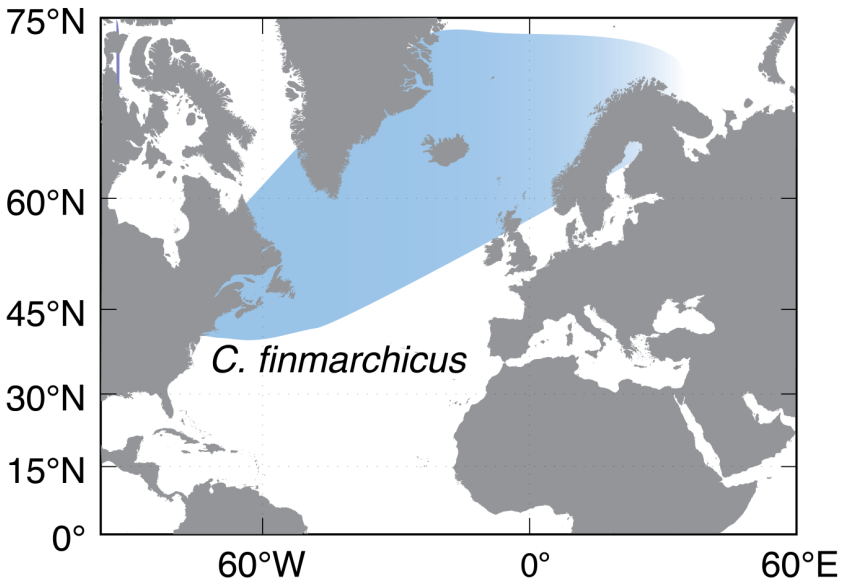
AZMP: https://publications.gc.ca/site/eng/9.909043/publication.html

Cruise Cruise baby: https://www.youtube.com/watch?v=Gjzkf1xiQ-8

The subarctic planktonic copepod, *Calanus finmarchicus*

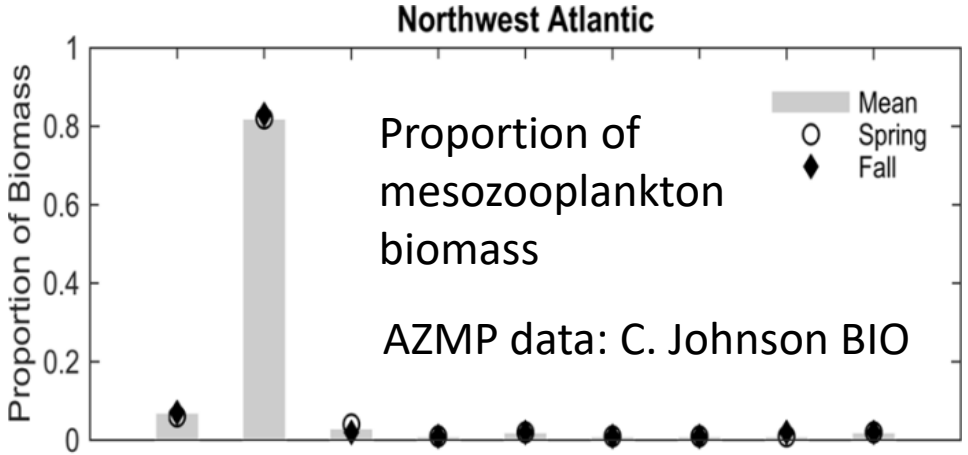


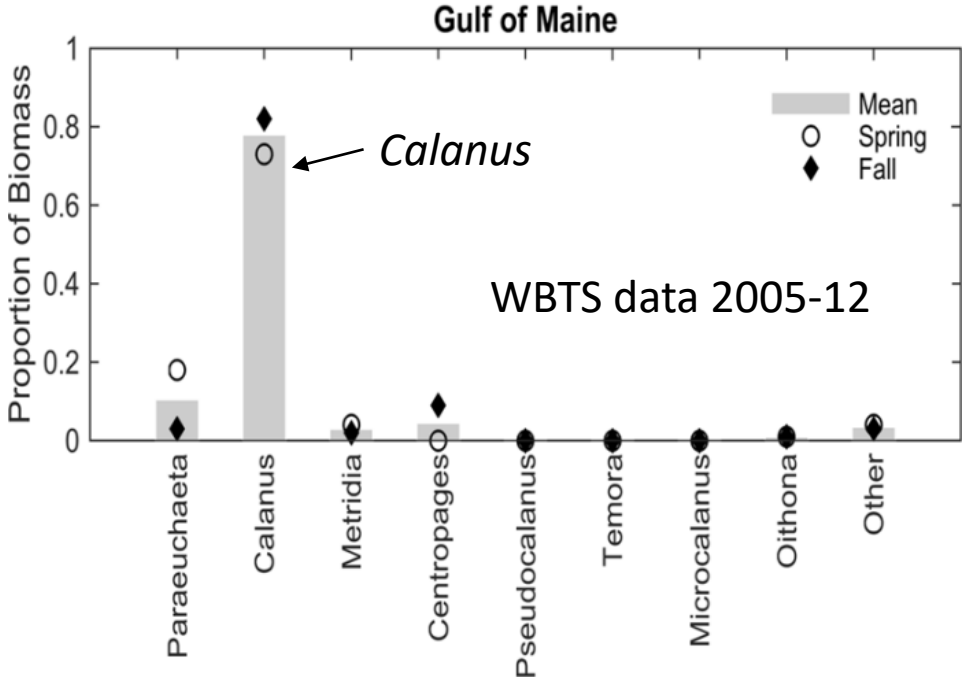
Overwintering preadult stage



The subarctic distribution of *C. finmarchicus*

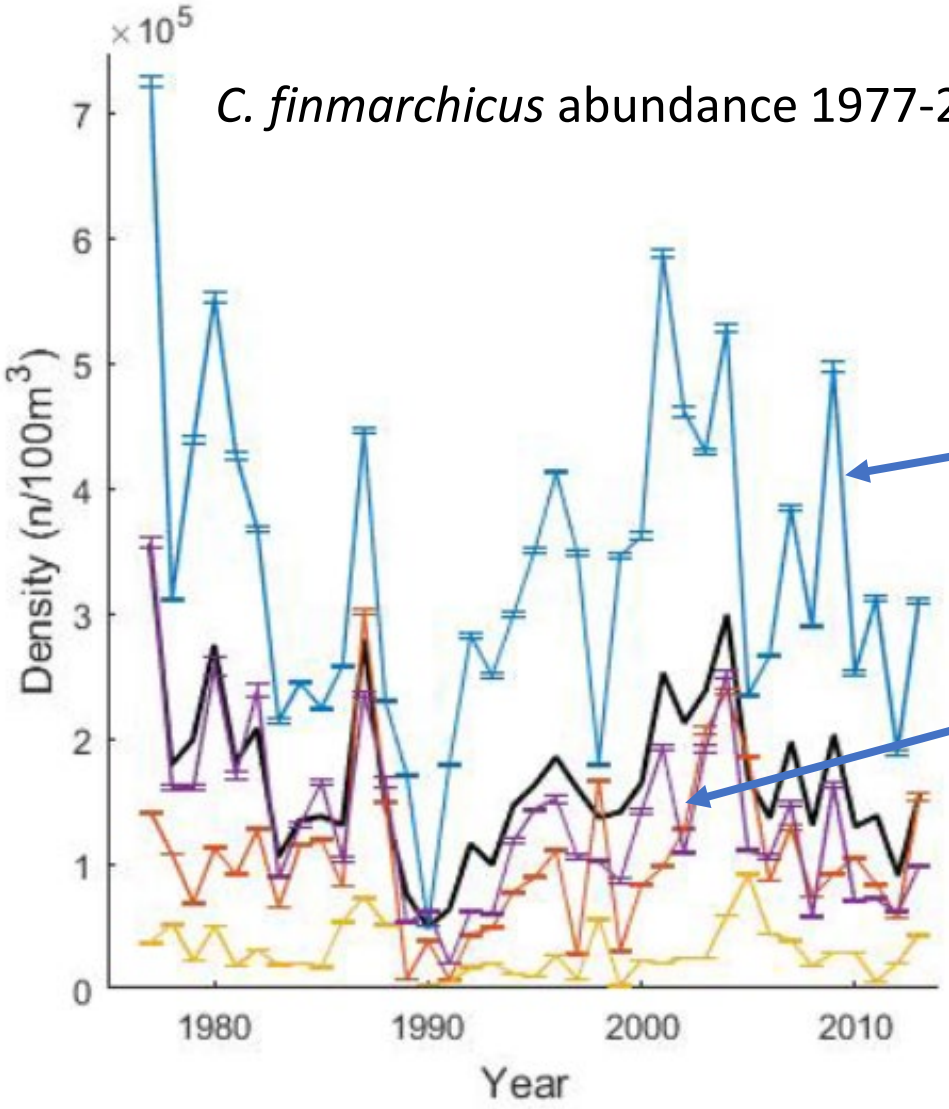
This species is remarkably abundant across the northern North Atlantic Ocean and especially in the Gulf of Maine



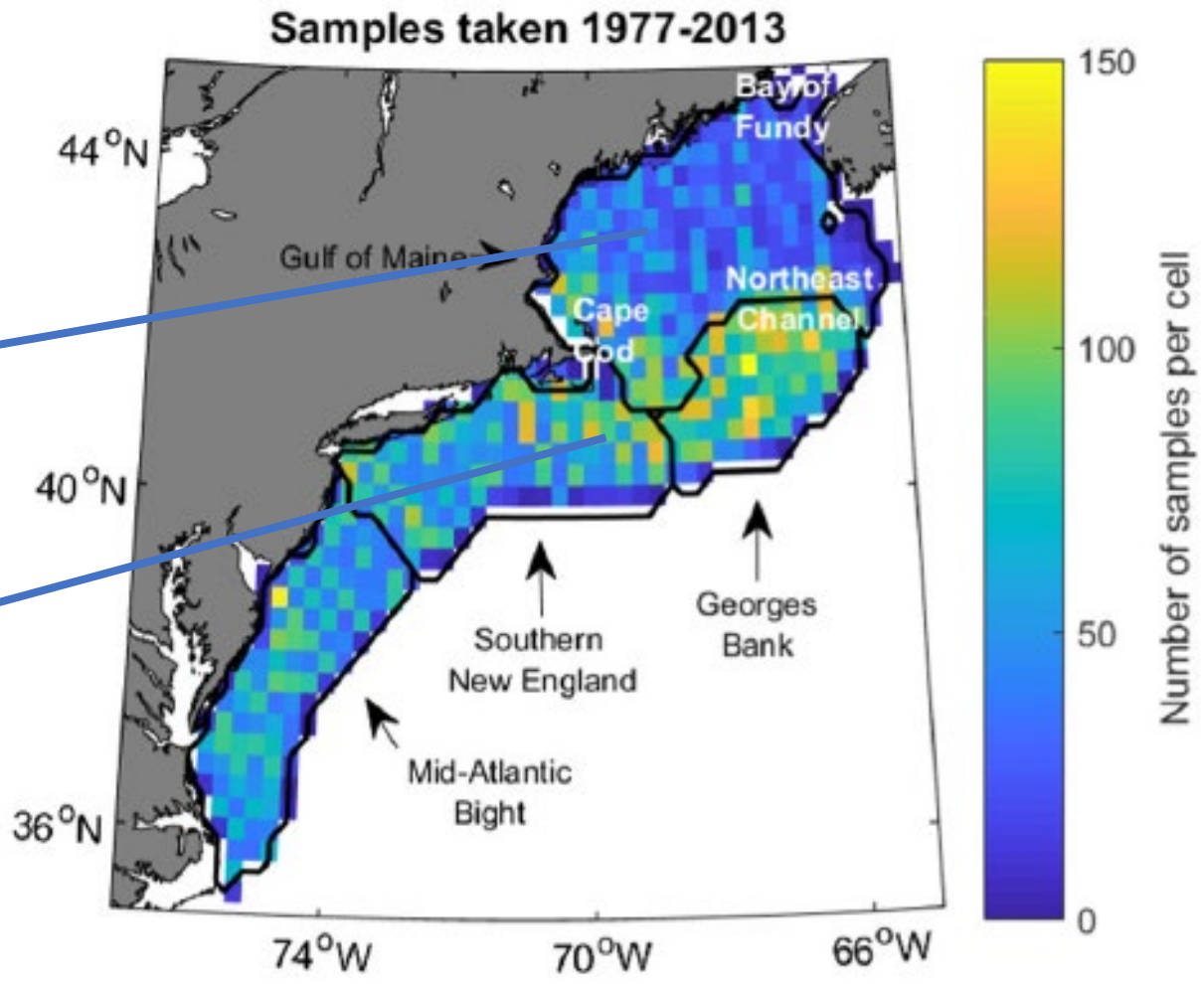


Copepod taxa from largest to smallest

NOAA EcoMon surveys (2-6 times a year since 1977)



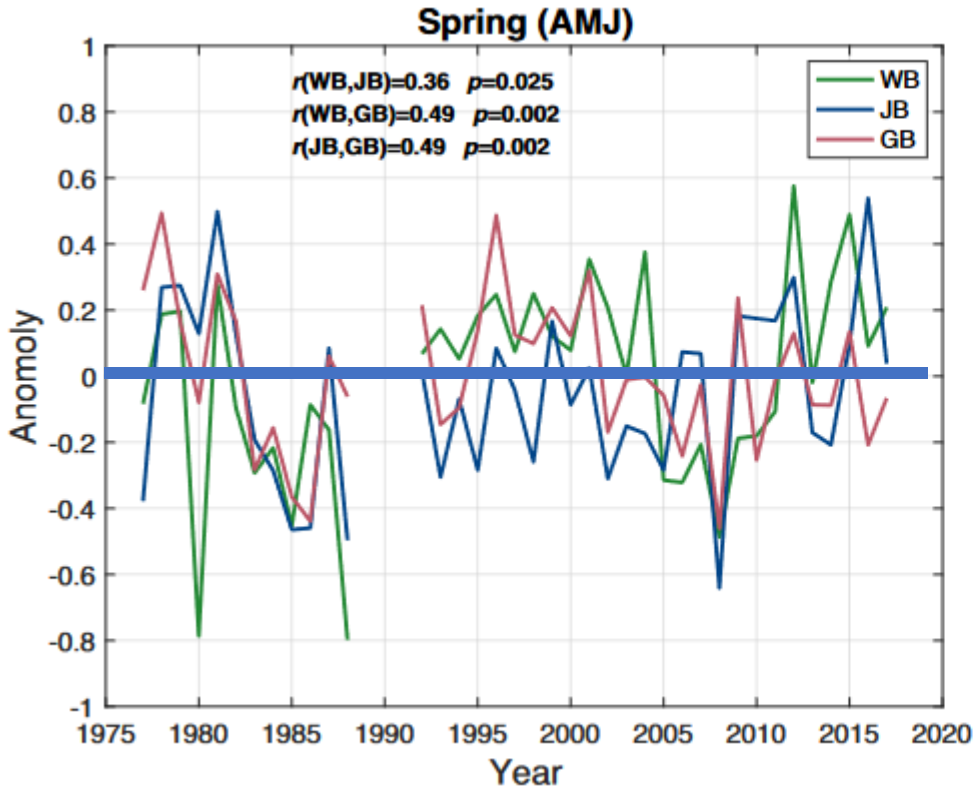
C. finmarchicus abundance 1977-2013

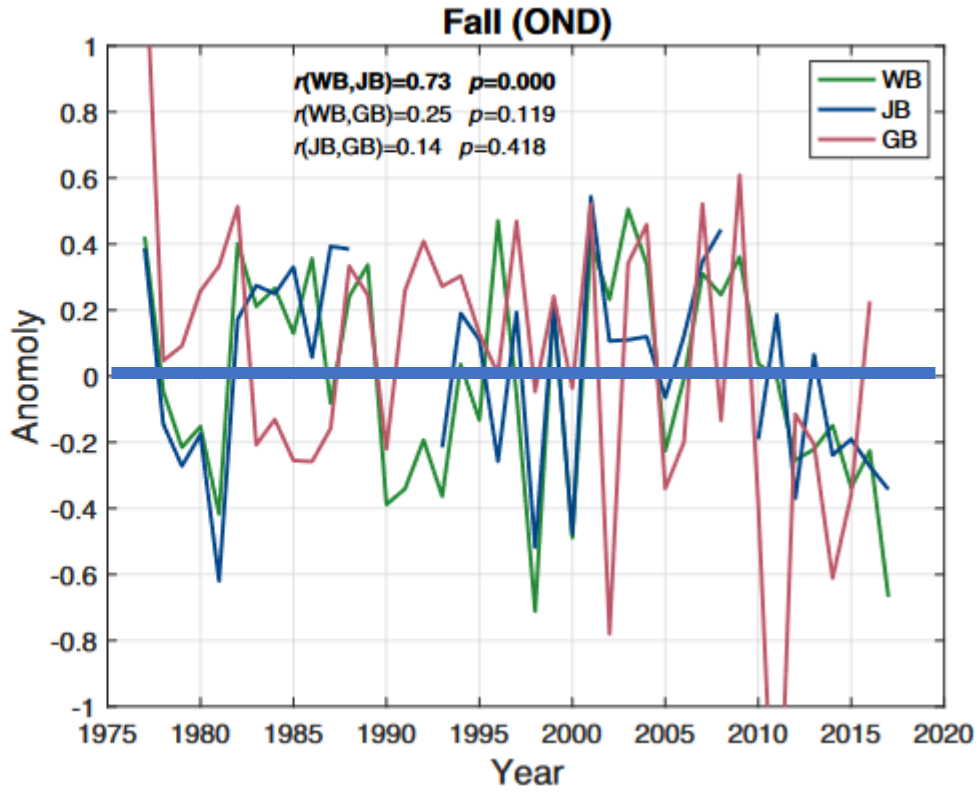


Grieve et al. 2017.

NOAA MARMAP/EcoMon *C. finmarchicus* abundance anomalies (log scale): 1977-2017

WB: Wilkinson Basin; JB: Jordan Basin; GB: Georges Basin



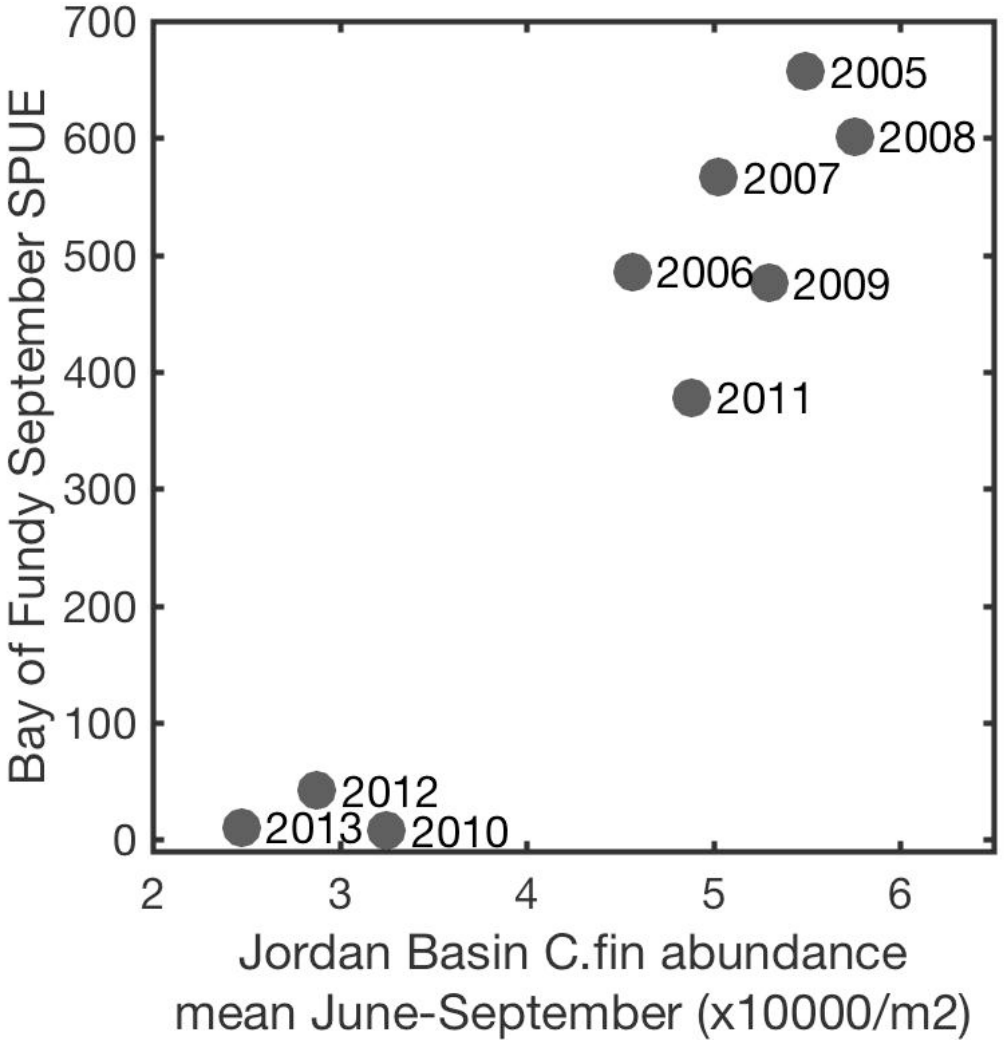


Spring: no long-term trend

Fall: strong decline since 2010 in WB and JB

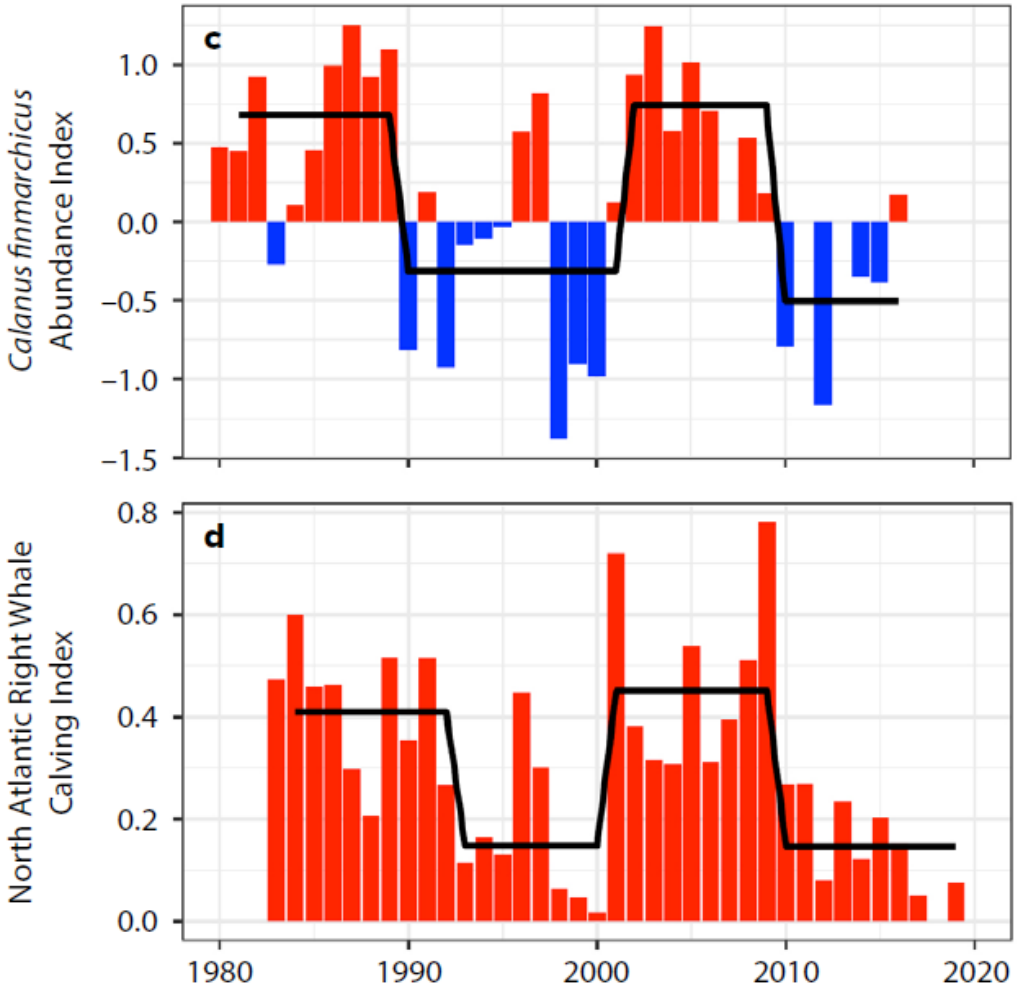
Ji, R., J. A. Runge, C.S. Davis and P. Wiebe. 2022. Drivers of variability of *Calanus finmarchicus* in the Gulf of Maine: roles of internal production and external exchange. ICES Journal of Marine Science. 79 (3): 775–784. https://doi.org/10.1093/icesjms/fsab147.

Record et al. 2019. Oceanography



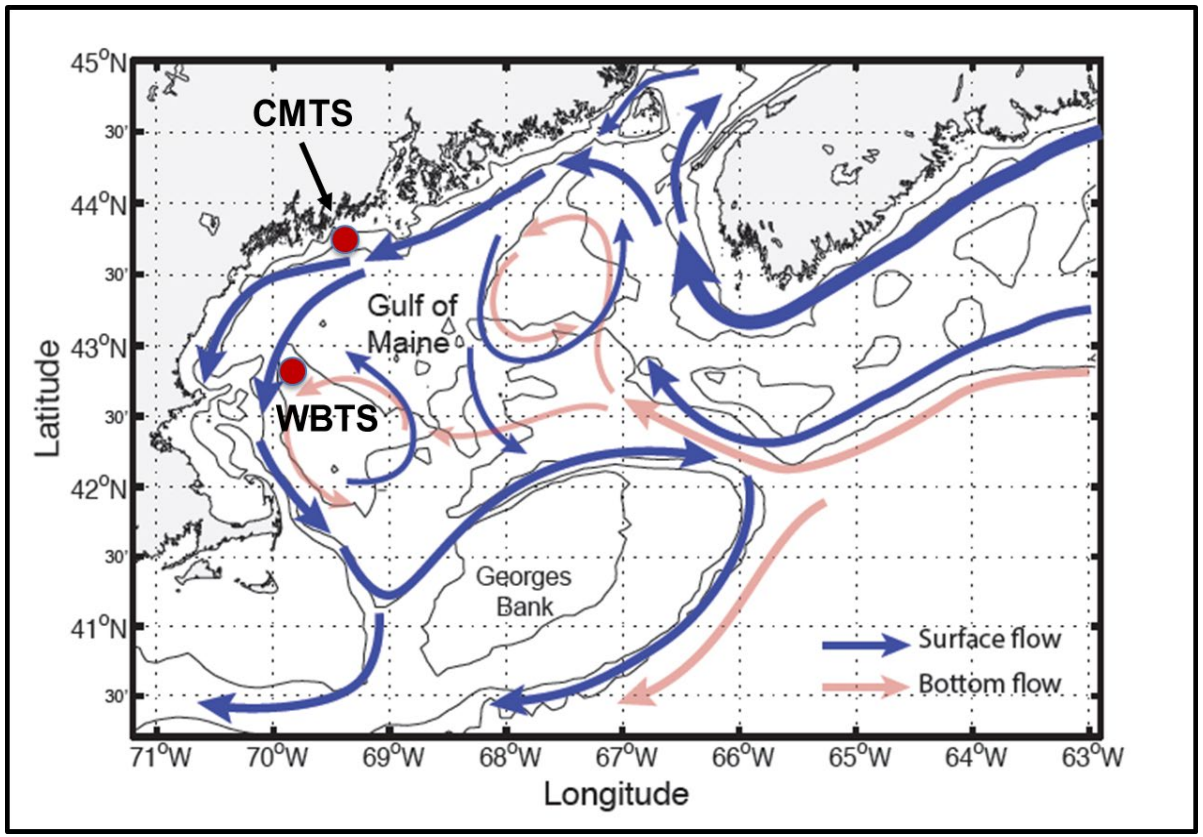
Sightings per Unit Effort (SPUE) of right whales in the Bay of Fundy down since 2010, correlated with eGoM *C. finmarchicus* abundance (EcoMon data)

Meyer-Gutbrod et al. 2021 Oceanography



"In 2010, the Gulf of Maine and Scotian Shelf regions of the Northwest Atlantic underwent an unprecedented regime shift." *Calanus* abundance index for eGoM (Continuous Plankton Recorder) and Calving Index (observed births/female)

What sustains the remarkable abundance of *C. finmarchicus* in the western GoM: Coastal Amplification of Supply and Transport (CAST)



R.Ji and C. Chen, redrawn from Beardsley (1997)

Ji R, et al. 2017. Coastal amplification of supply and transport (CAST): a new hypothesis about the persistence of *Calanus finmarchicus* in the GoM. ICES. J. Mar. Sci. 74(7): 1865–1874.

- *Calanus* individuals are transported into the eastern Gulf of Maine in spring through fall, historically from the Nova Scotia current
- These individuals multiply in spring and many are entrained in the Maine Coastal Current (MCC), which is cold and food-rich throughout summer
- Through reproduction and growth, the population amplifies in the MCC, supplying Wilkinson Basin, the principal overwintering habitat in the western GoM, as well Stellwagen Bank
- The overwintering stock in WB comes out of diapause in Dec-Mar and local egg production and growth there supplies the spring stock for the wGoM

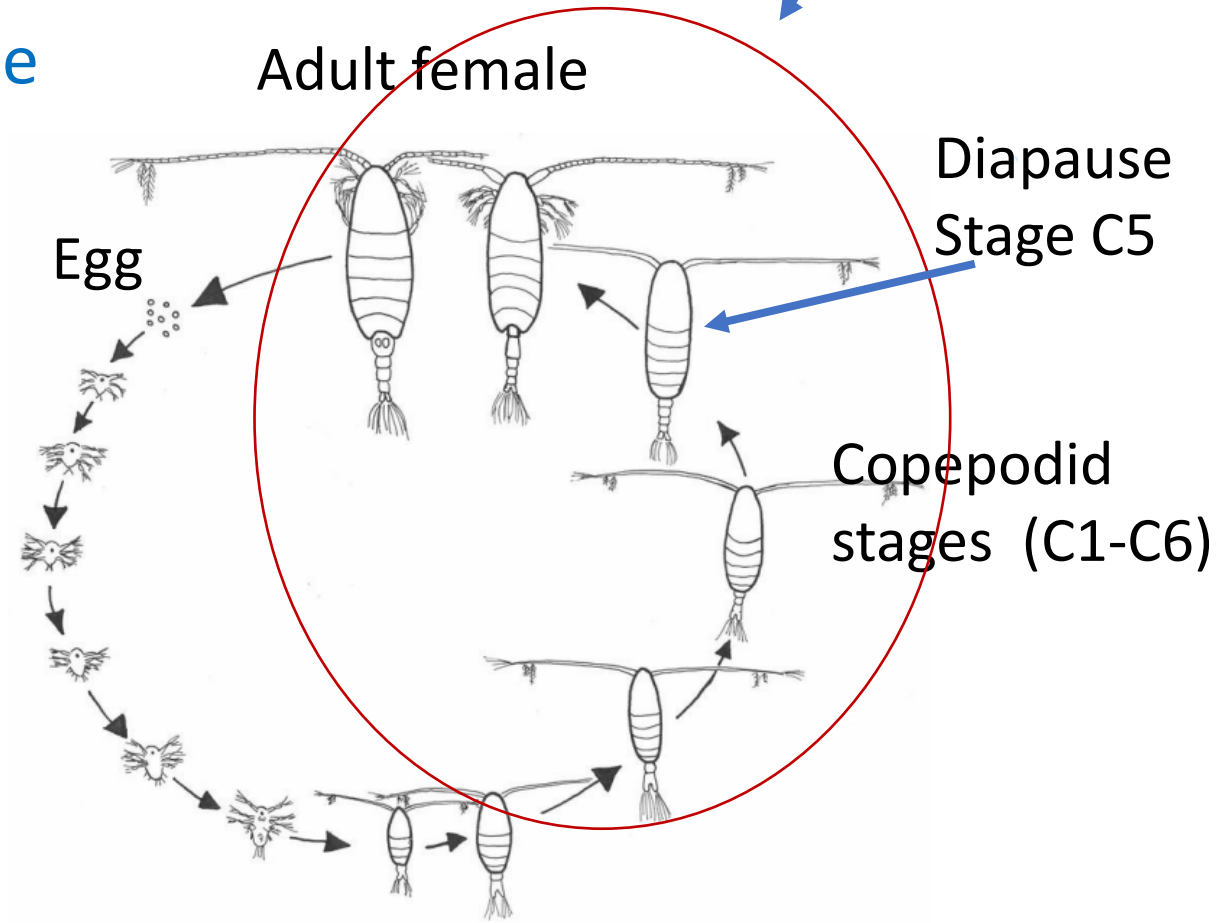
The seasonality of primary drivers controlling the abundance of *Calanus finmarchicus* in the western GoM

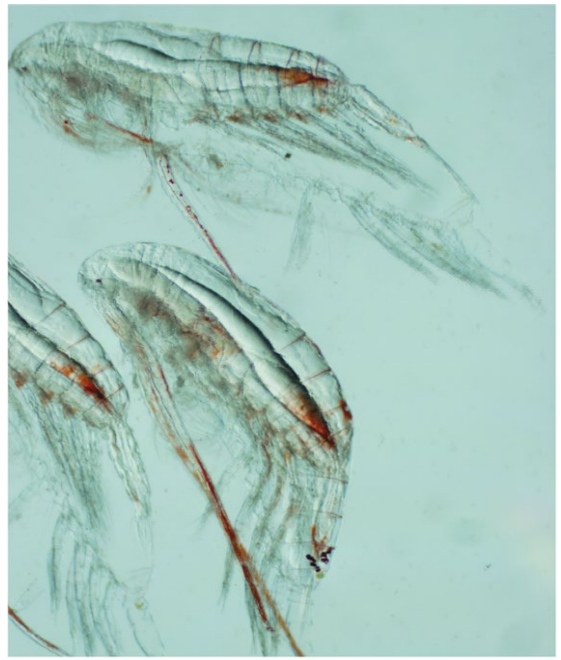
- **Advective supply**: Evidence for a regime shift in about 2010 affecting external supply to the eastern Gulf of Maine. This affects supply to Wilkinson Basin in **late summer** primarily via Maine Coastal Current.
- **Local production**: phytoplankton regime and temperature affecting lipid accumulation, timing of diapause and reproduction. Amplification of supply in Maine Coastal Current **in summer**; Egg production and cohort growth in Wilkinson Basin in **spring/early summer**
- **Predation**: shifting predator diversity; higher mortality at higher temperature; match-mismatch: early winter spring reproduction escapes predator field. Predator fields highest at the end of active season in **late summer-fall**

  - See Ji et al. 2021. Drivers of variability of *Calanus finmarchicus* in the Gulf of Maine: roles of internal production and external exchange. ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsab147

The Calanus Index: Abundance of Stages C3-C6 (includes the lipid rich stages C4-C6

The Calanus Life Cycle



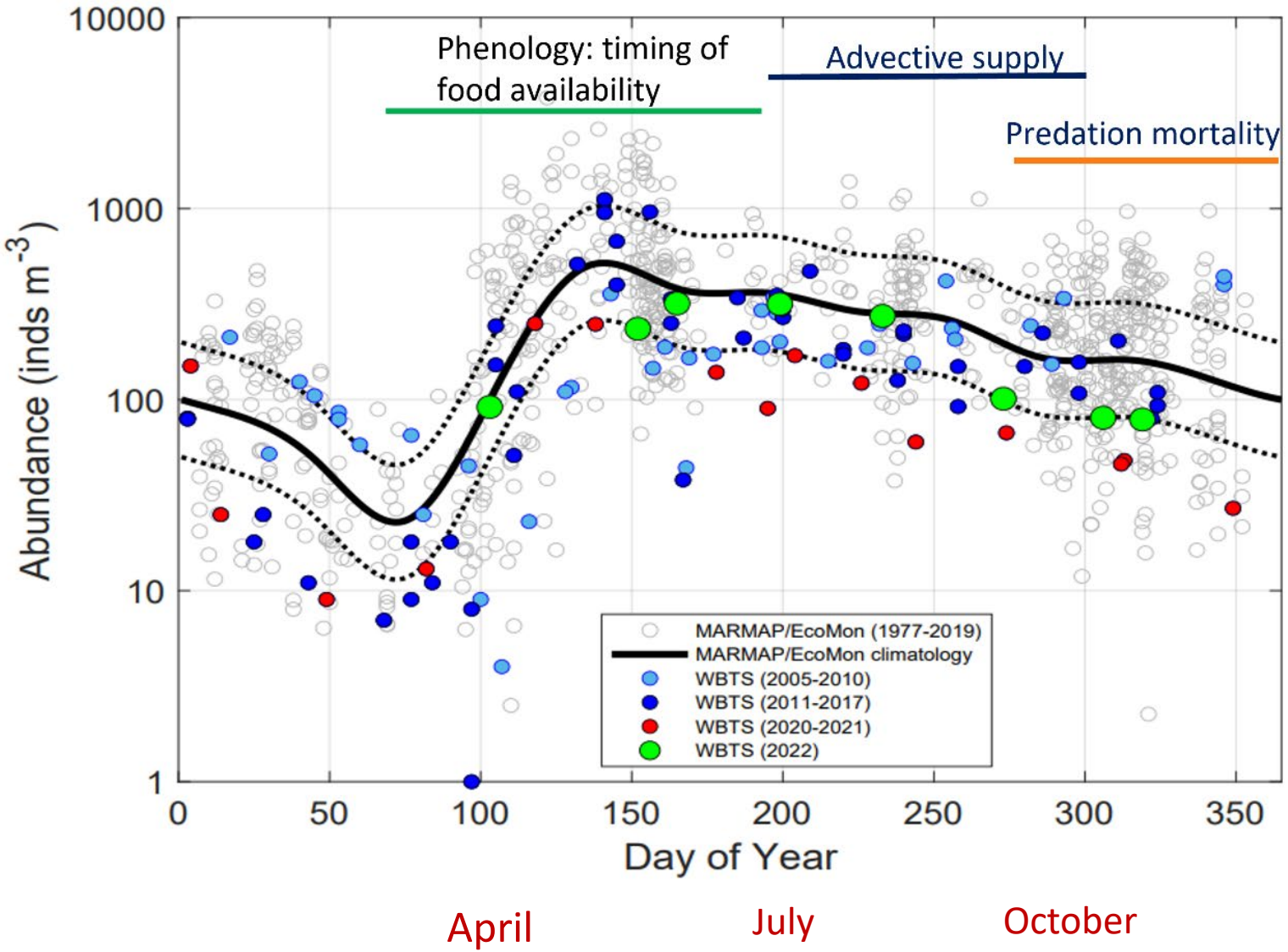


Molting new *Calanus* C5 casting off their old exoskeleton

<u>Egg to CV</u>:
80 d at 4C
25 d at 12C
Diapause 3-6 mo

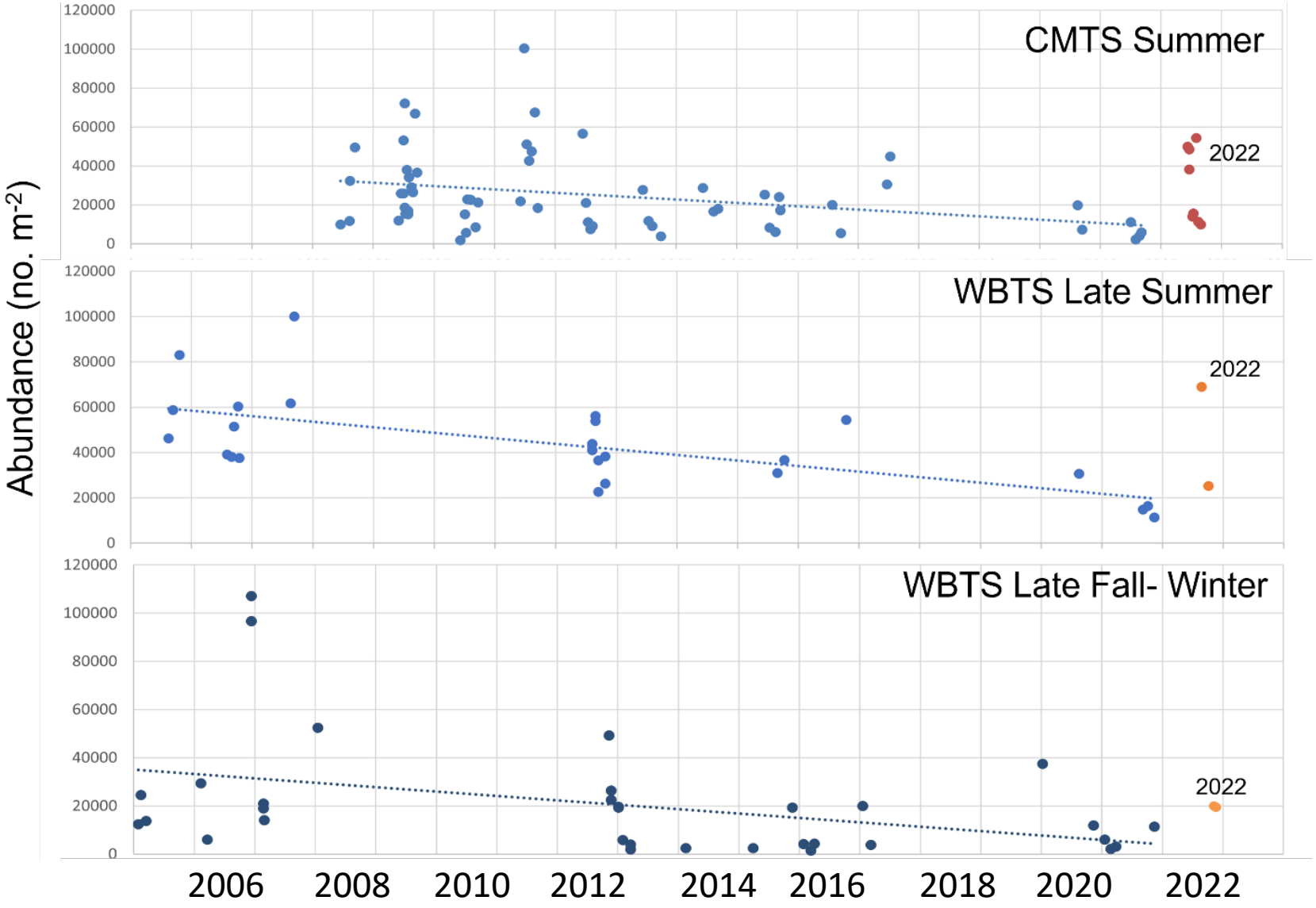
Calanus Index: WBTS phenology

Note log scale



Runge J, Karp Boss L, Dullaert E, Ji, R, Motyka J, Young-Morse R, Pugh, D, Shellito S, Vandemark D. 2023. Sustained monitoring of zooplankton populations at the Coastal Maine Time Series (CMTS) and Wilkinson Basin Time Series (WBTS) stations in the western Gulf of Maine: Results from 2005-2022. OCS Study BOEM 2023-015.

Calanus Index Time Series, Summer through Winter, show significant declines

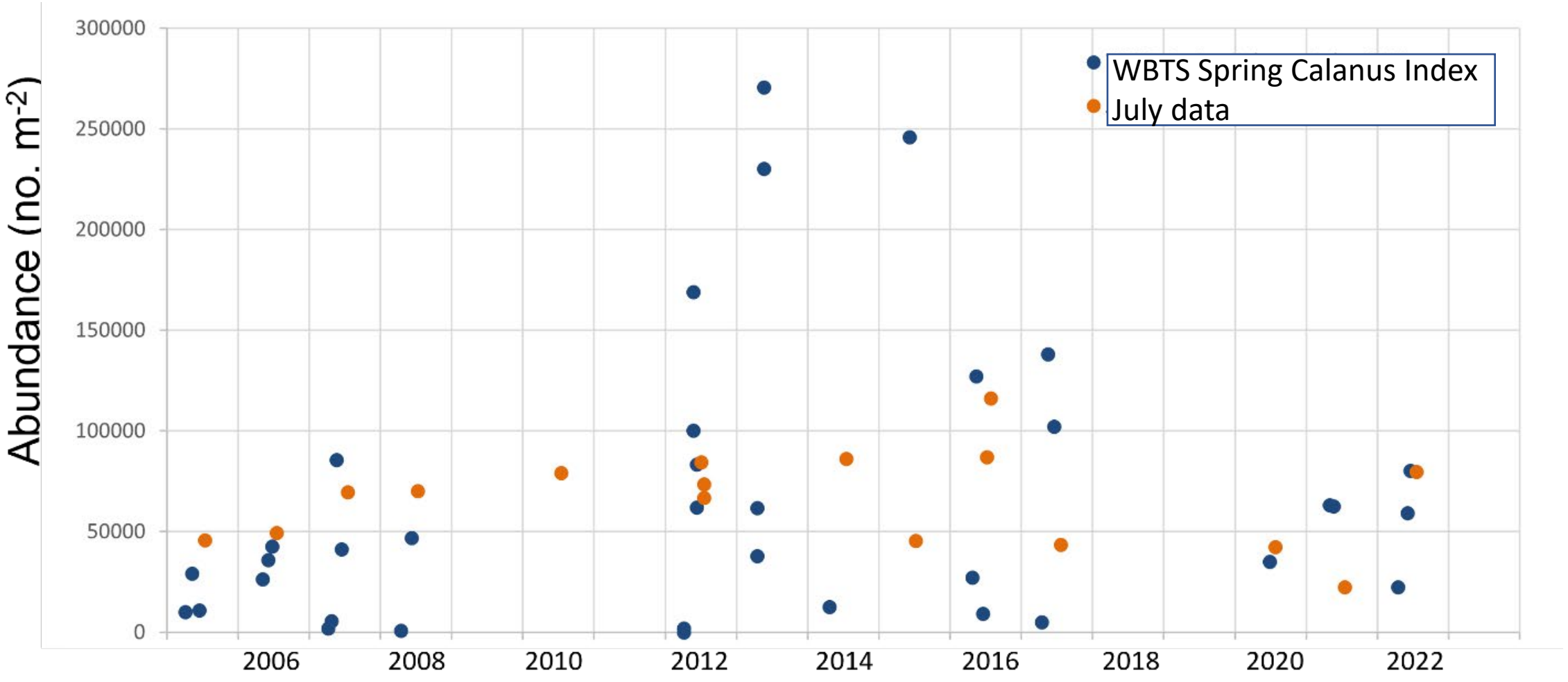


Abundance levels (no m^{-2})

2008	2021	(%)
37,588	11,423	30
51,598	19,806	38
27,810	4,085	15

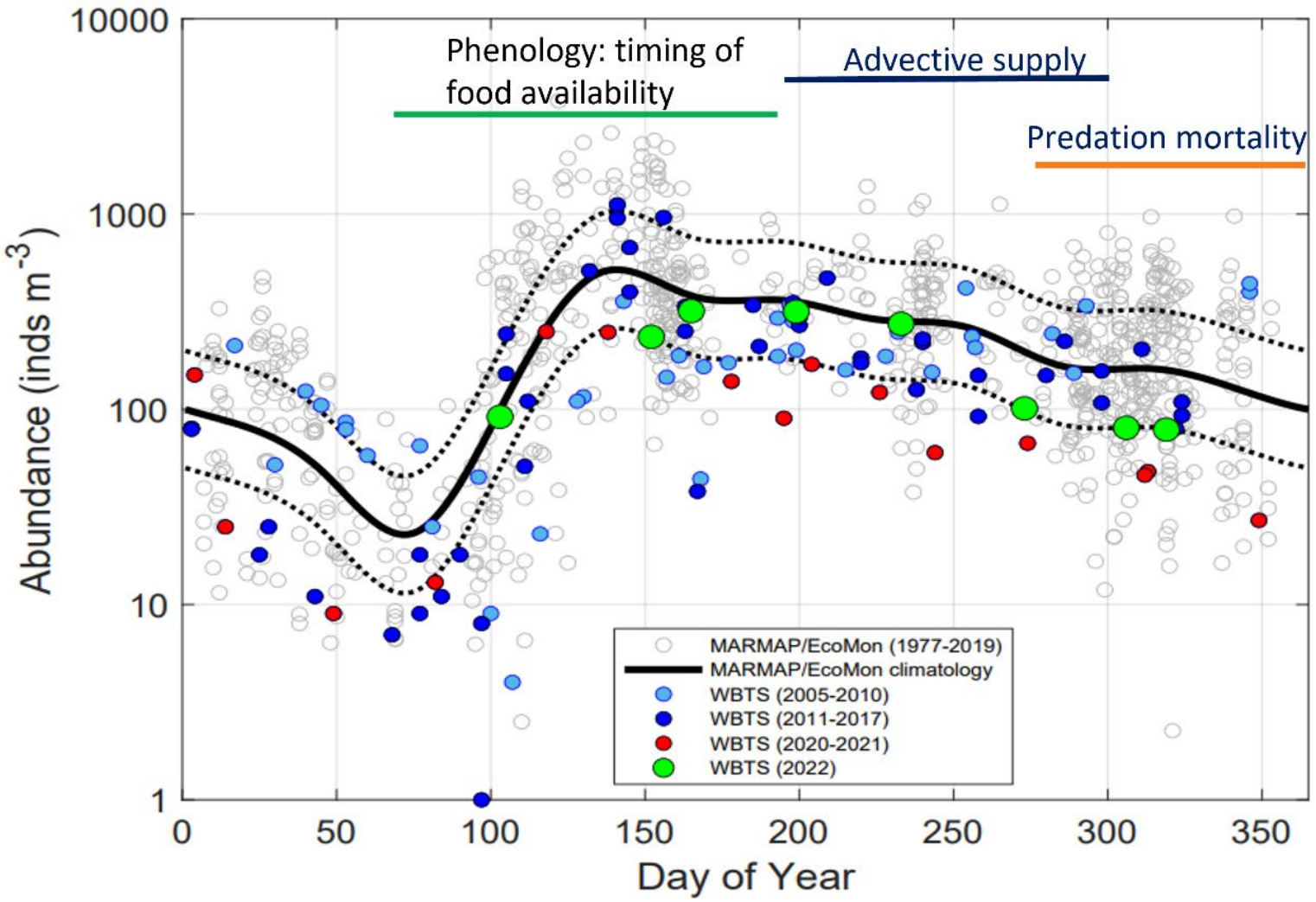
Runge et al. 2023 BOEM 2023-015

Calanus Index: WBTS Spring-Early Summer

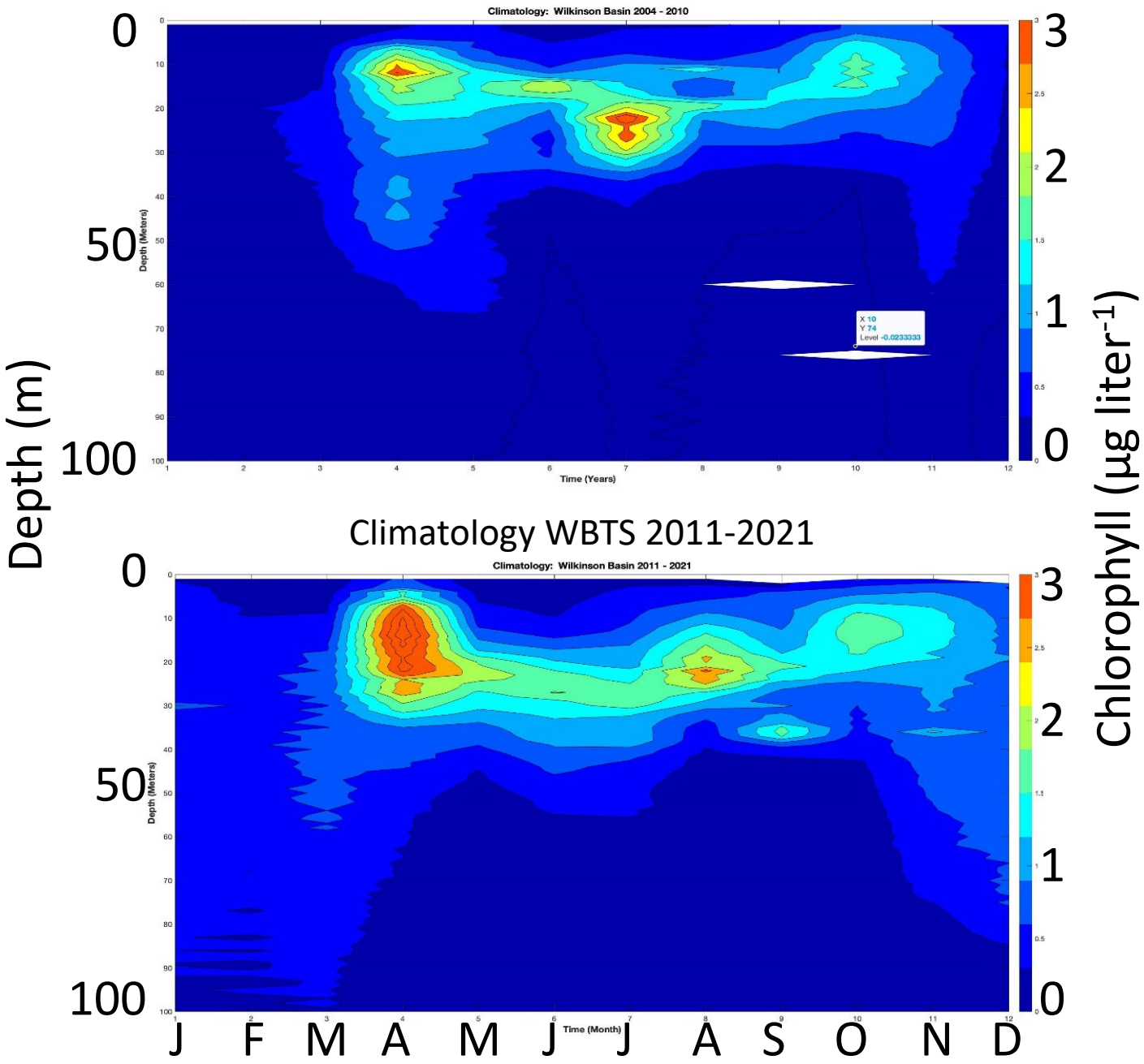


Runge et al. 2023 BOEM 2023-015

Calanus Index: WBTS phenology



Climatology WBTS 2004-2010

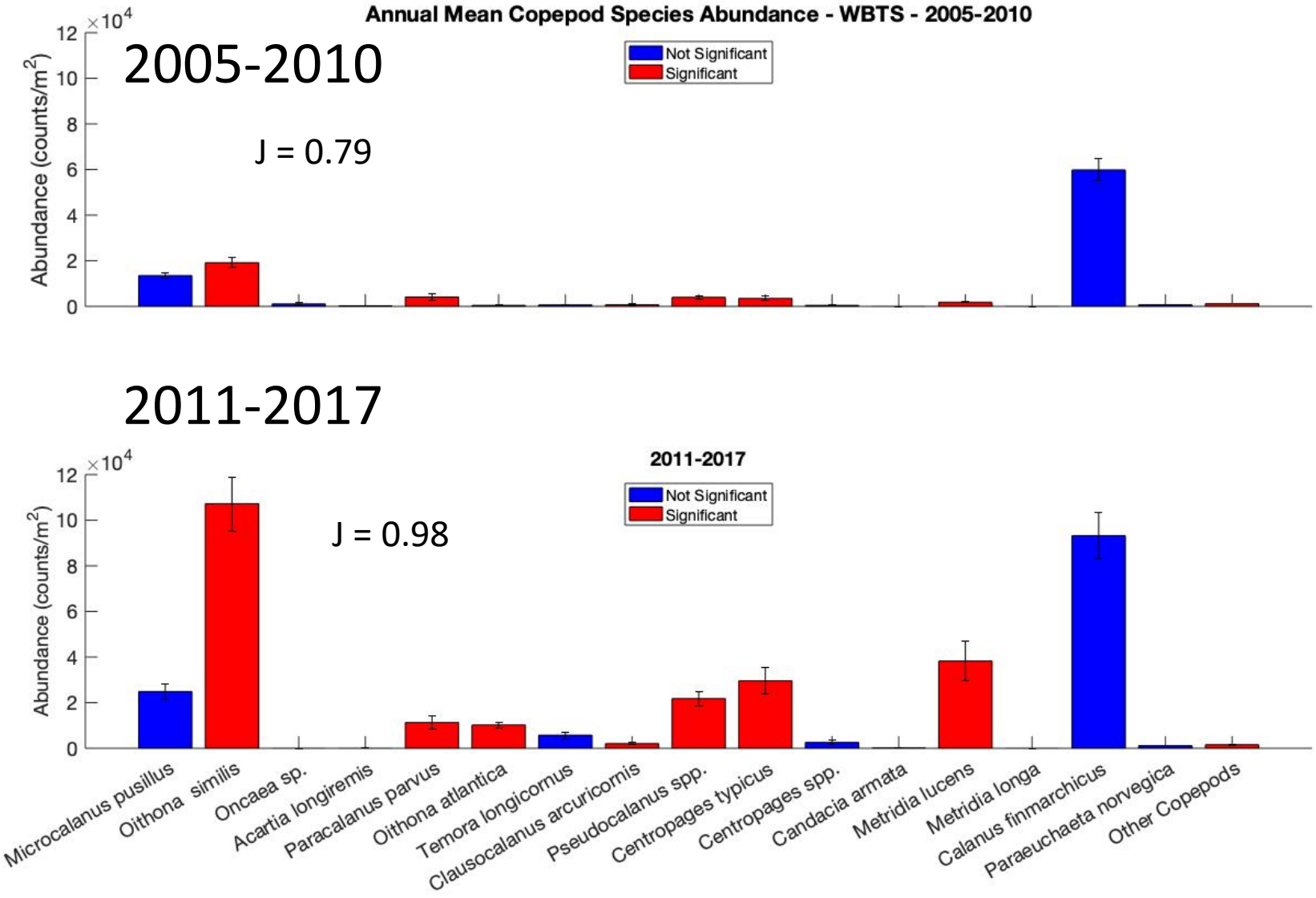


Climatology WBTS 2011-2021

Phenological shift in food availability (increased phytoplankton biomass in Jan-Mar consistent with no change in Spring Calanus Index

Runge et al. 2023 BOEM 2023-015

Changes in Community Composition

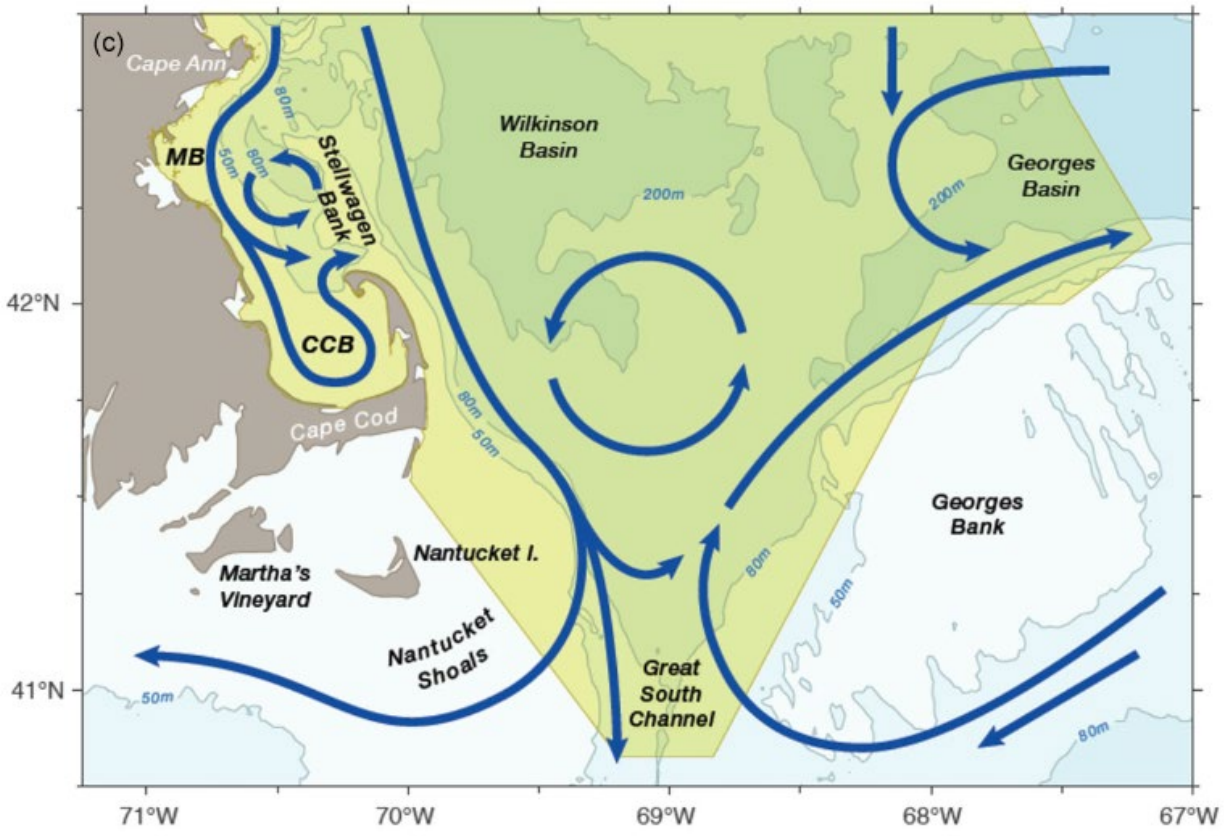


Comparing decades before and after 2010:

- Increase in diversity
- Increase in abundance of smaller copepod species, especially *Oithona, Pseudocalanus,* and *Centropages*
- Obscures seasonal changes in *Calanus finmarchicus* abundance

Emma Dullaert, UMaine Master's Thesis (2023)

Implications for the Nantucket Shoals (NS) Zooplankton Prey Field

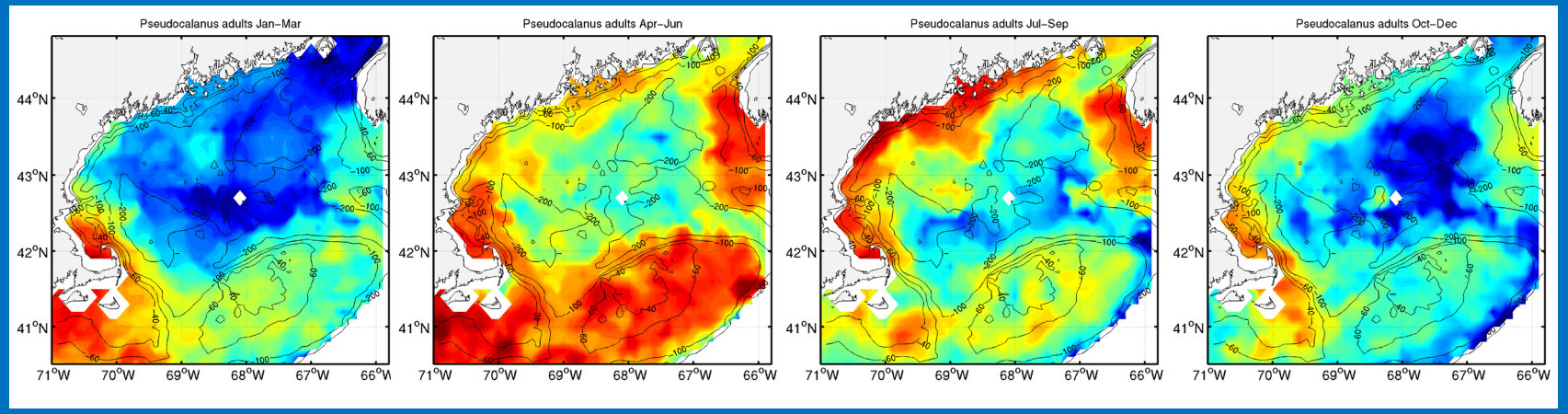


Sorochan et al. 2021. ICES JMS 78(10):3498-3520

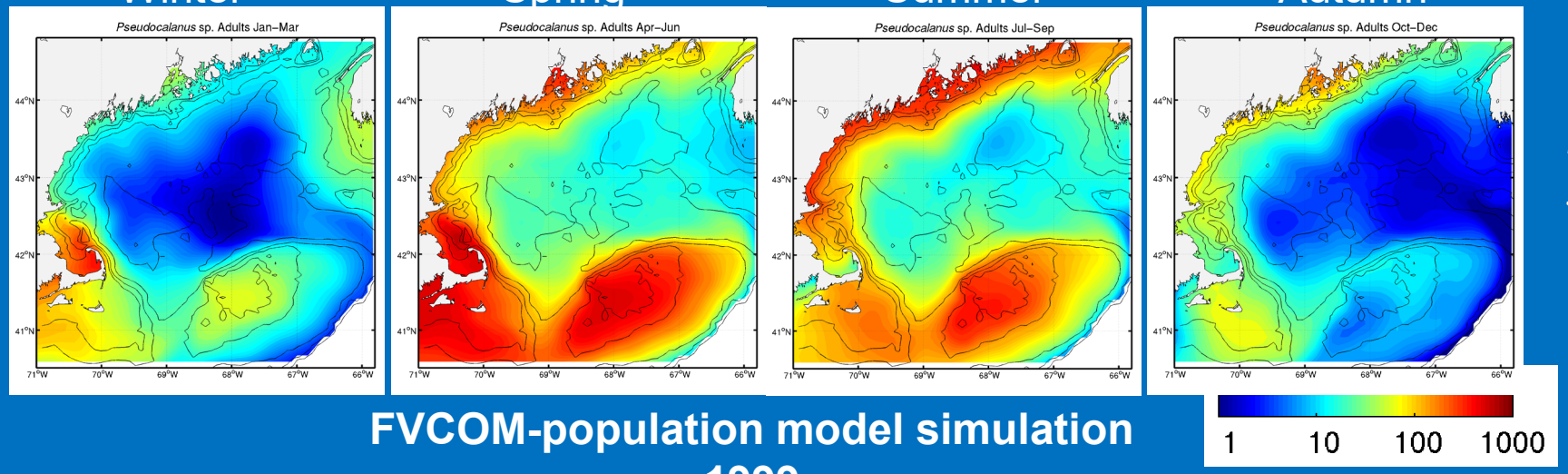
1. The Gulf of Maine (Maine Coastal Current, WB) is the primary source of supply of zooplankton to NS
2. NS harbors the highest abundances of *Pseudocalanus* and *Centropages* in the Gulf of Maine in fall and winter
3. Since 2010, abundances of *Pcal* and *Ctyp* have increased in the western GoM, likely due to increased temperature and higher chlorophyll a concentrations in fall and winter
4. Late, lipid-rich stages of *C. finmarchicus* may not be found in abundance at depths shallower than 75 m (due to high predation)

Seasonal adult abundance: *Pseudocalanus* spp.

MARMAP climatology 1977-2006



Winter | Spring | Summer | Autumn



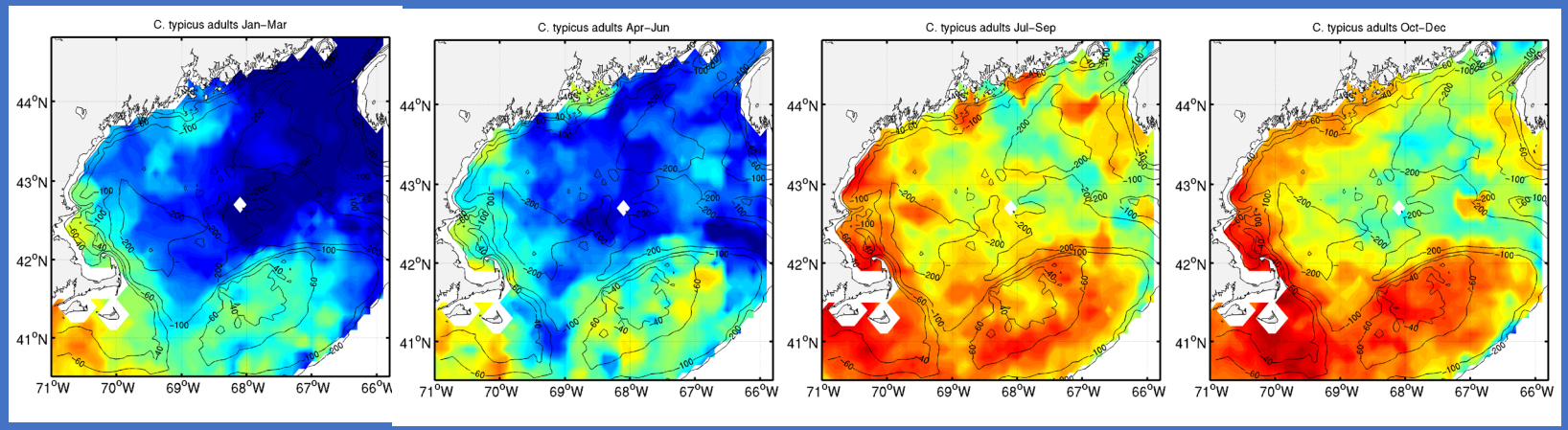
FVCOM-population model simulation 1999

Courtesy of R. Ji

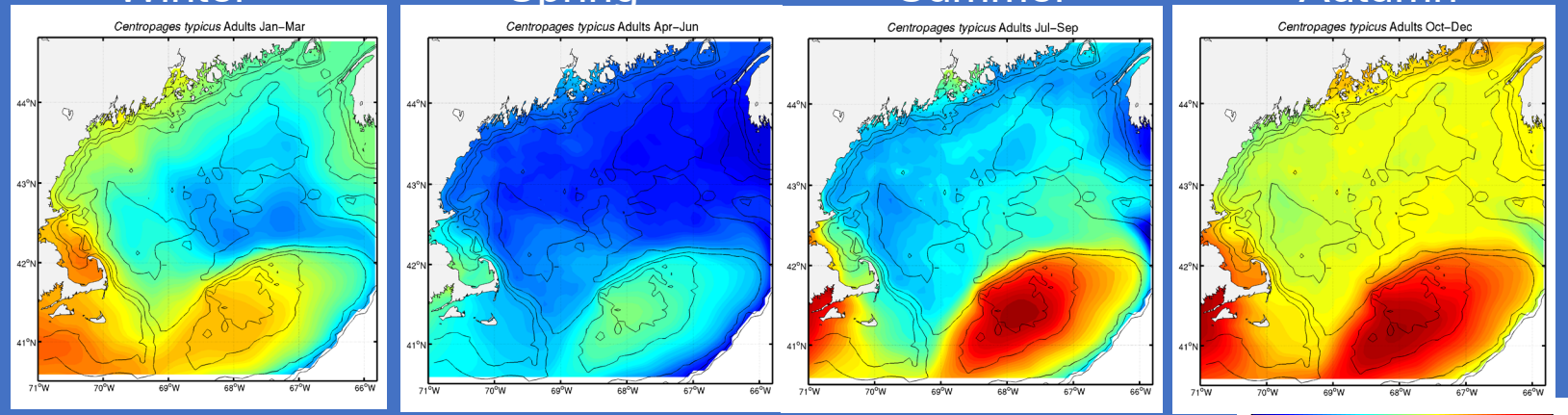
Ji, R., Davis, C.S., Chen, C. and Beardsley, R.C. 2009. Life history traits and spatiotemporal distributional patterns of copepod populations in the Gulf of Maine-Georges Bank region. *Marine Ecology Progress Series*, *384:* 87-205.

Seasonal adult abundance: *Centropages typicus*

MARMAP climatology 1977-2006



Winter | Spring | Summer | Autumn



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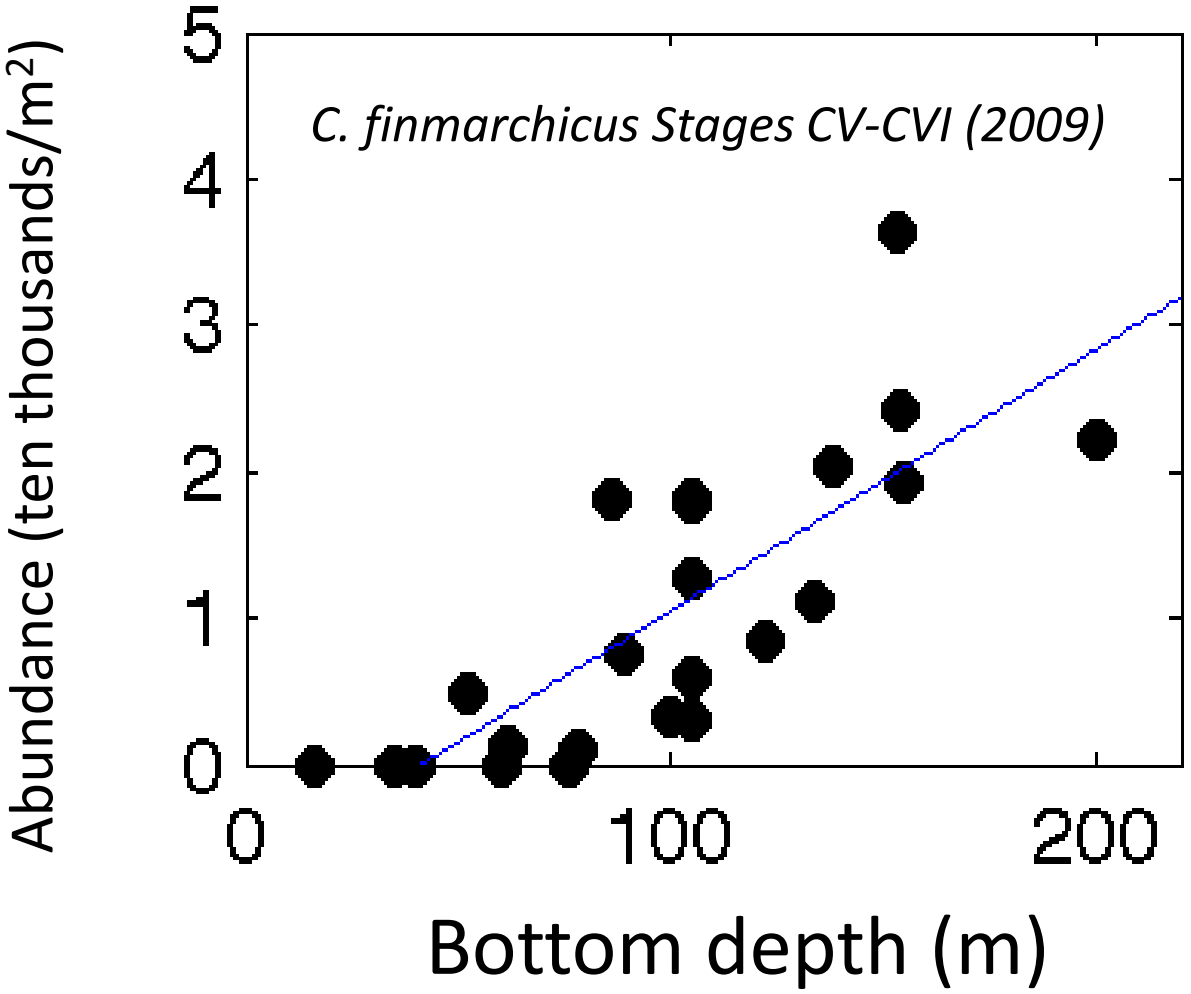
Lipid-rich stages of *C. finmarchicus* are typically not abundant in waters shallower than 75-100 m



Data from transects along the Maine coast in July 2009

Despite the shallow depth of NS, does advection supply seasonally high abundance of lipid rich Calanus (stages C3-C6) and do they aggregate there?

Runge, J.A., Jones, R.J., Record, N.R. and Pershing, A.J., 2012. Summer distribution of the planktonic copepod, Calanus finmarchicus, along the coast of the Gulf of Maine. *Report for the State of Maine's Department of Marine Resources*. Available on request

Questions about impact of offshore wind development on zooplankton prey fields

1. Are there fine scale patches/aggregations of *Pseudocalanus*, *Centropages* and *Calanus* on Nantucket Shoals, or does mixing on the shoals prevent aggregations from occurring?
2. Would a field of offshore wind turbines significantly disrupt zooplankton aggregations if they occur?
3. Are North Atlantic right whales feeding on other prey besides *Calanus*, *Pseudocalanus* and *Centropages* on NS?
4. Would a field of offshore wind turbines, by altering turbulence and vertical distribution of phytoplankton and microzooplankton, affect feeding rates of suspension feeding zooplankton? Note: I would expect any impact on feeding rates to possibly affect population abundance downstream, not local abundance on NS, which I expect to be controlled by advective supply.