Responses of *Calanus finmarchicus* to climate-related changes in phytoplankton bloom dynamics in Northwest Atlantic shelf and sub-polar gyre regions

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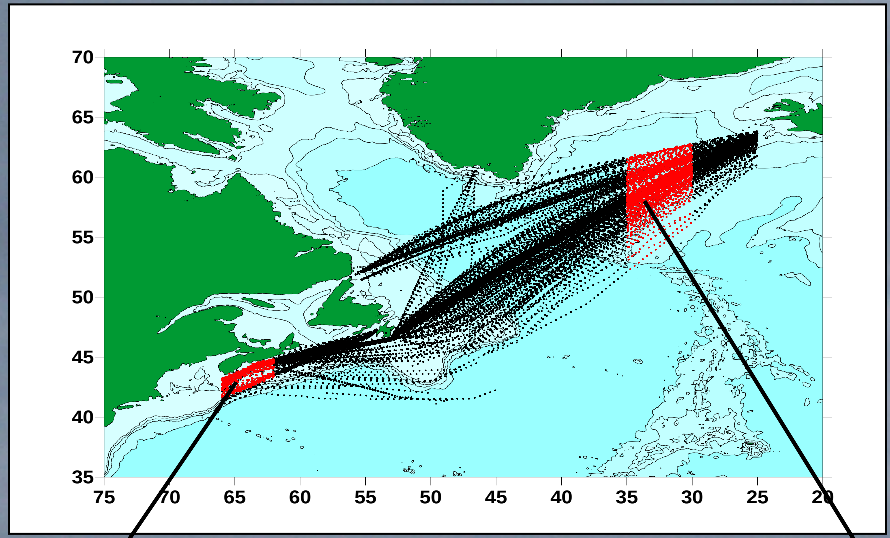
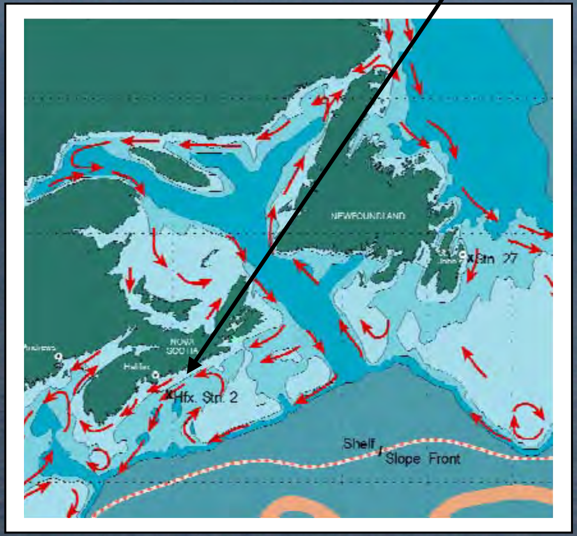
Continuous Plankton Recorder (CPR) sampling positions in the Northwest Atlantic between 66 and 25^{o}W and between 1957 and 2009 and near surface circulation



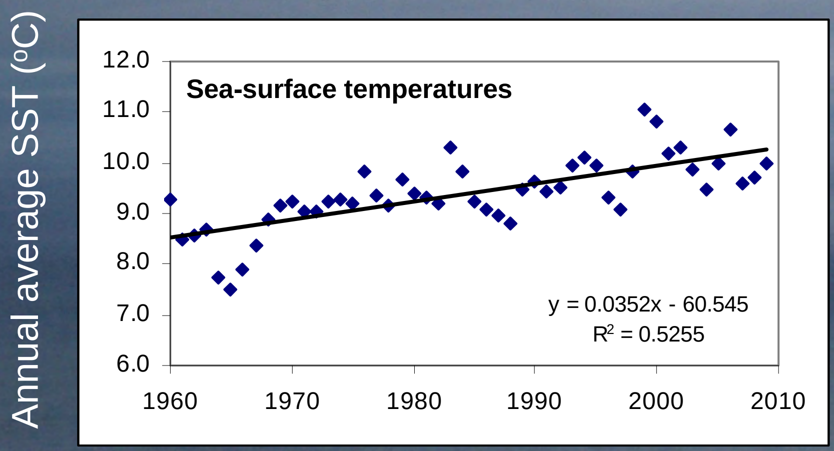
The Western Scotian Shelf (WSS) CPR sampling region is influenced by outflow from the Gulf of St Lawrence and intrusion of slope water from beyond the shelf-break.



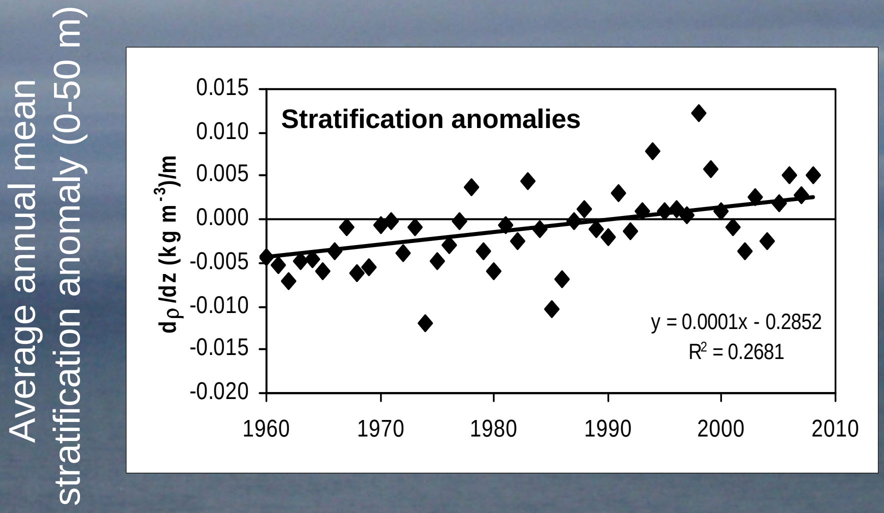
The Central Irminger Sea (CIS) CPR sampling region is located in the northeast lobe of the NW Atlantic sub-polar gyre.

Western Scotian Shelf
Trends in annual average sea-surface temperatures and stratification anomalies

- Sea-surface temperatures (SSTs) and stratification have been increasing on the Western Scotian Shelf since 1960.
- Annual SSTs and surface salinity are both correlated with stratification over this period, with salinity having a greater influence on stratification.



Data courtesy of Todd O'Brien (NOAA, NMFS)

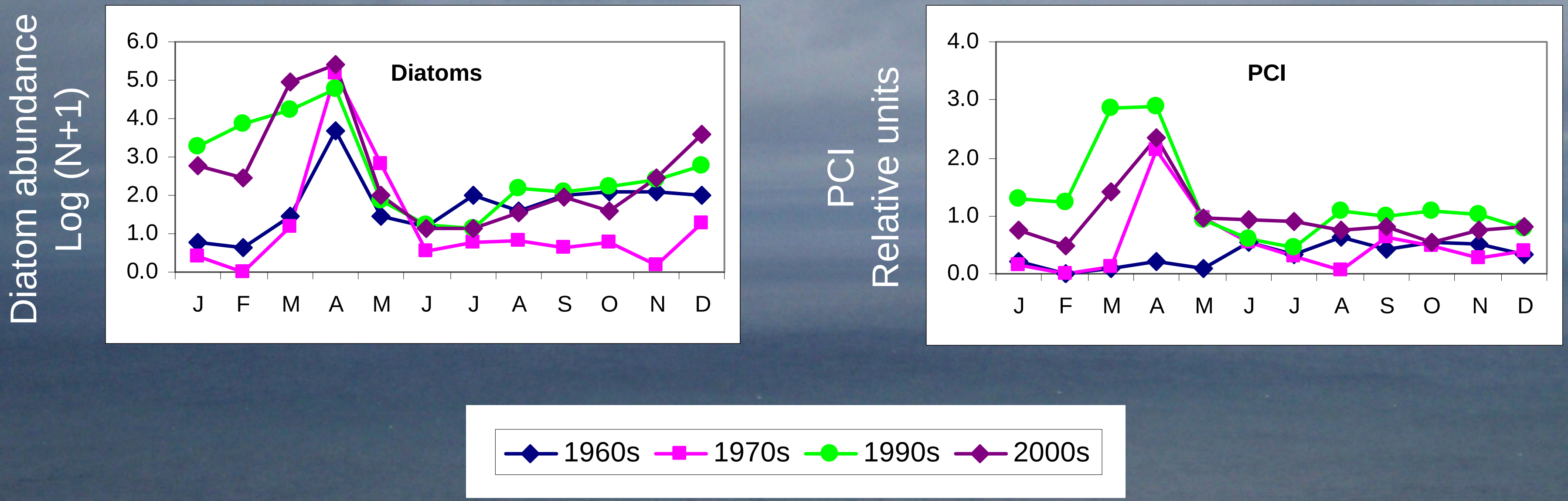


Data courtesy of Brian Petrie (DFO, BIO)

Western Scotian Shelf
Seasonal cycles of phytoplankton abundance/biomass by decade

- CPR samples have been collected on the WSS since 1961, although only a few months per year were sampled in most years before 1979 and there was no sampling in the 1980s.

- Monthly values within each decade were averaged to give decadal monthly means. These were substantially higher for diatoms and the phytoplanktkon colour index (PCI) in Jan-Mar in the 1990s and 2000s than they were in the 1960s and 1970s.



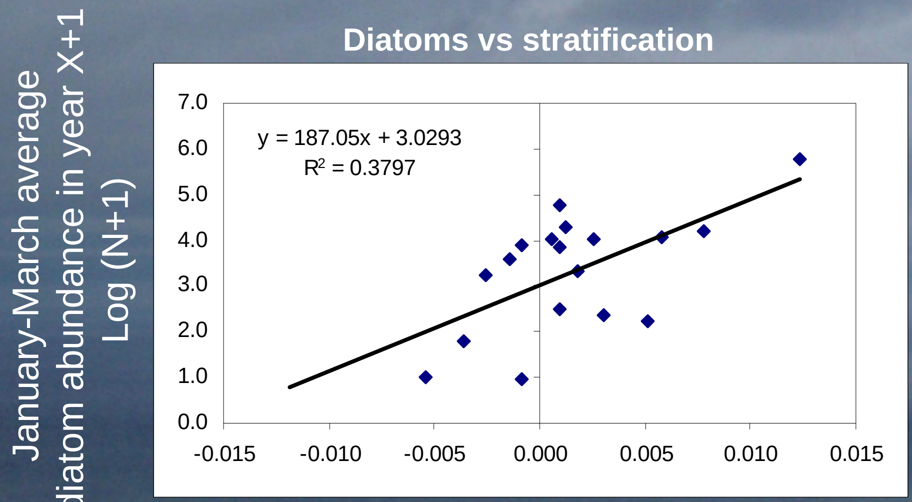
The differences were significant in March for both phytoplankton taxa.

Western Scotian Shelf

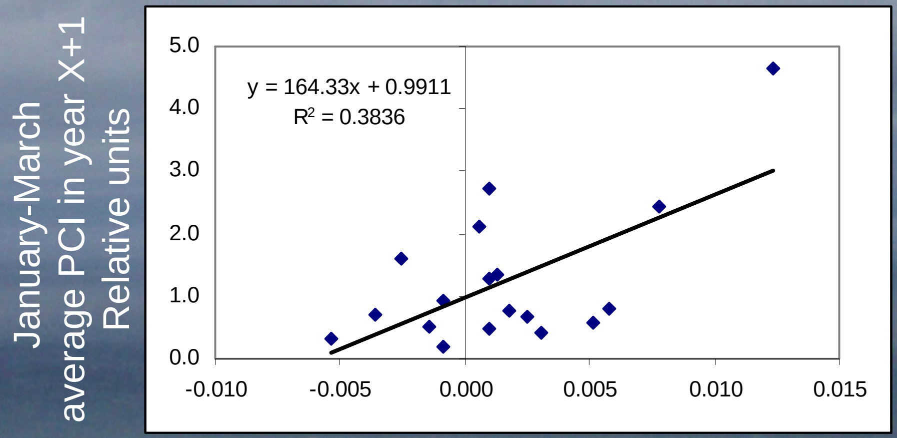
Average January-March abundance of diatoms (left) and the PCI (right) *versus* average annual stratification anomalies lagged by 1 year

- A higher annual stratification anomaly in one year is associated with a higher phytoplankton abundance in Jan-Mar in the next.
- This suggests high stratificatioin in summer/autumn leads to less extensive vertical mixing in winter, leading to less light limitation of phytoplankton growth during the winter months.

Diatoms vs stratification



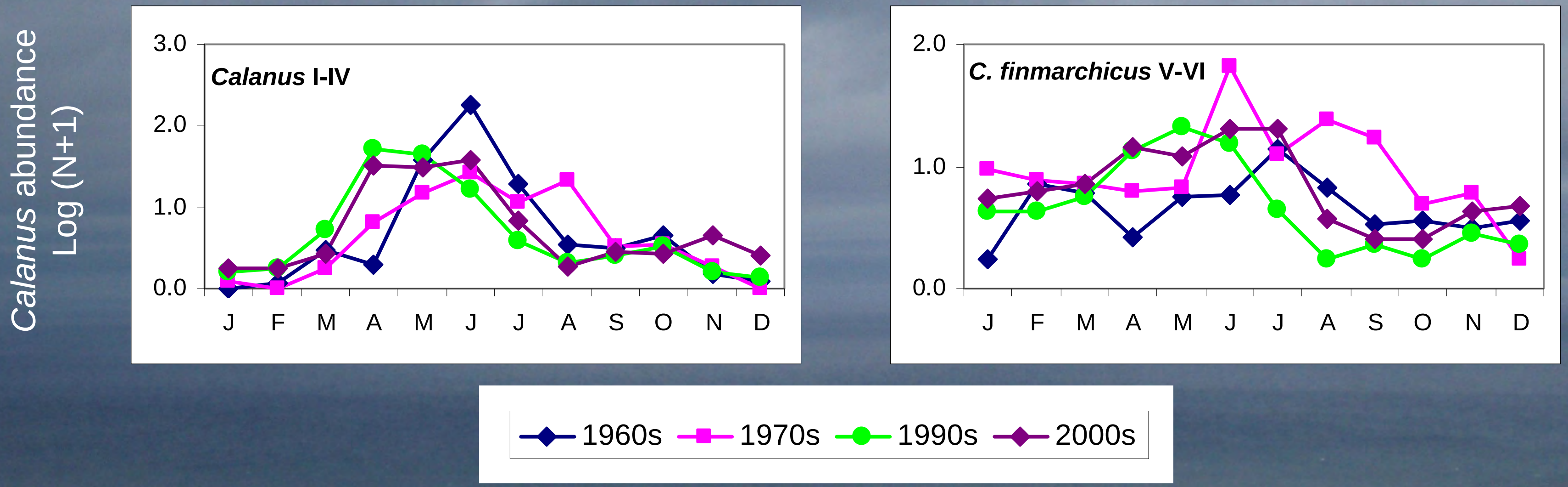
PCI vs stratification



Annual average stratification anomaly in year X (kg m^{-3})/m

Western Scotian Shelf - Seasonal cycles of *Calanus* I-IV (left) and *Calanus finmarchicus* V-VI (right) by decade

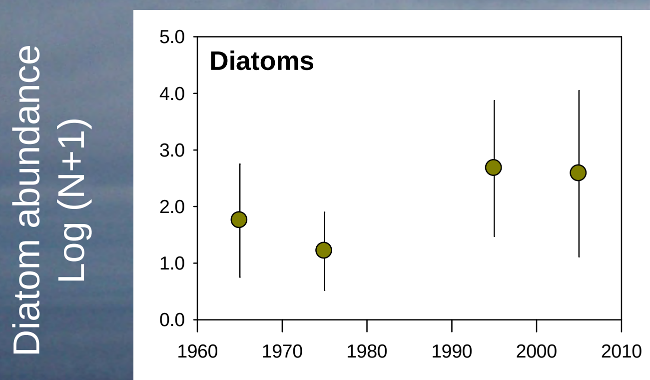
- Sampling in AZMP shows that *C. finmarchicus* accounts for >80% of the *Calanus* I-IV in April.
- *C. finmarchicus* CI-IV abundance has increased from low winter values earlier since the 1990s.
- *C. finmarchicus* CV-CVI showed no consistent patterns or changes over the decades.

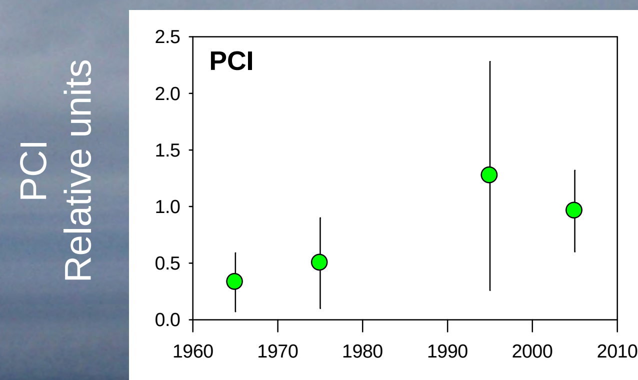


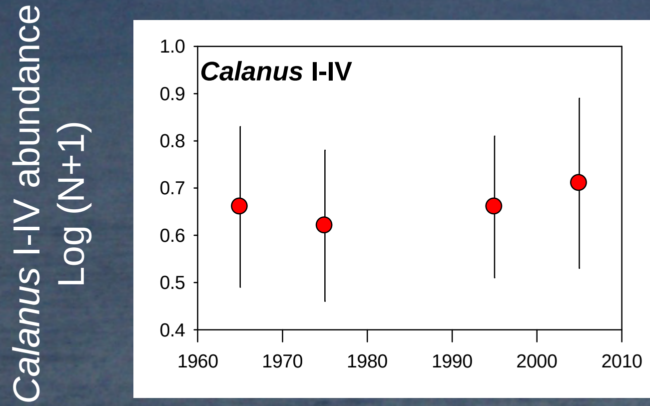
The differences in *Calanus* I-IV abundance in April were real.

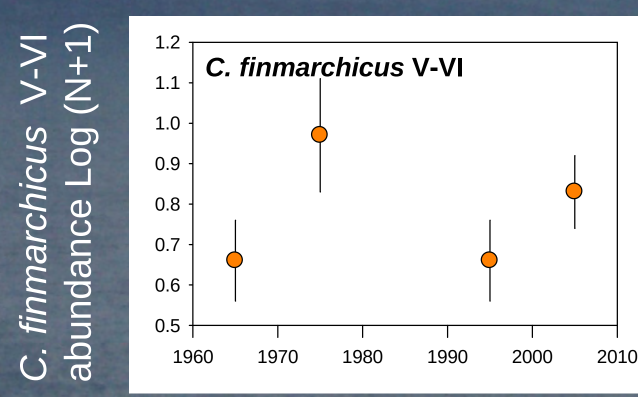
Western Scotian Shelf - Changes in decadal annual averages for phytoplankton abundance/biomass and *Calanus finmarchicus* abundance

- Decadal annual averages were calculated from the decadal monthly means.
- Annual phytoplankton increases in the 1990s were probably not due to increased primary production (no changes in nutrients).
- Instead they are probably due to the development of a temporal “mis-match” between the timing of the phytoplankton bloom and the production cycle of *C. finmarchicus* and other grazers.









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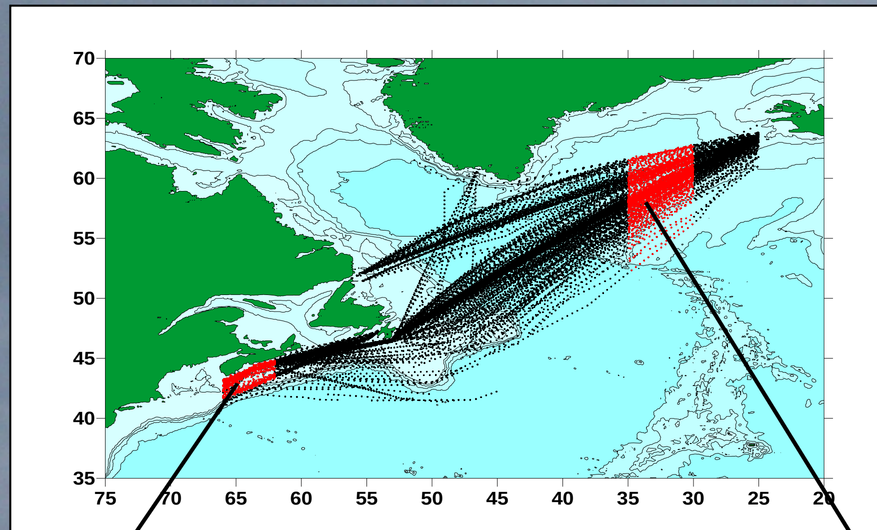

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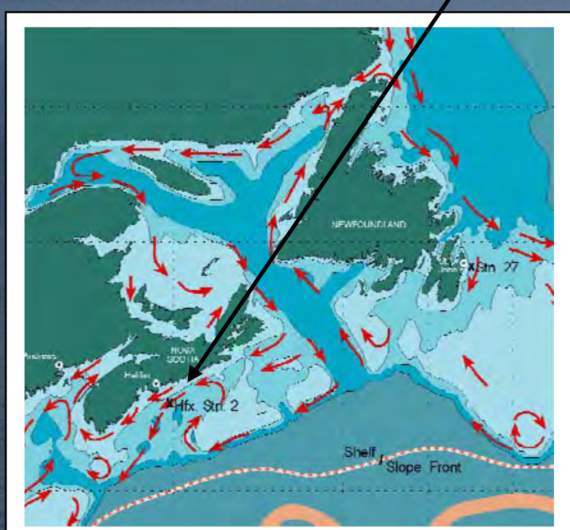
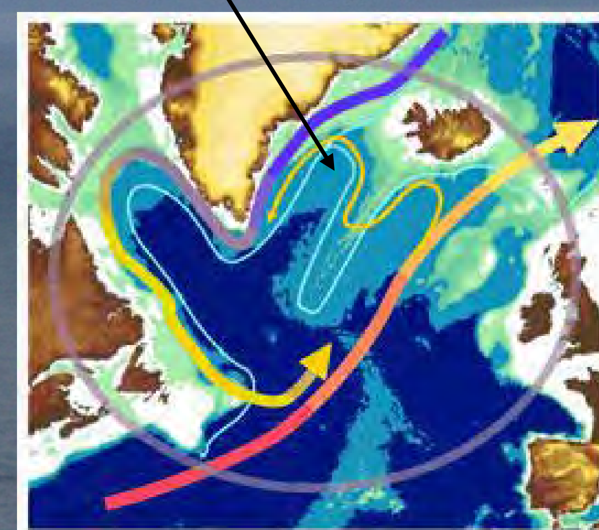




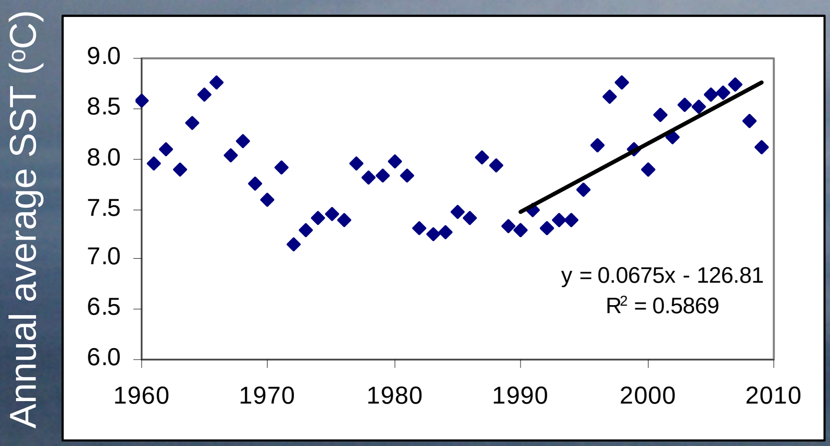
Central Irminger Sea (sub-polar gyre)

Trends in annual average sea-surface temperatures and stratification anomalies

- There were high sea-surface temperatures in the 1960s, due to reduced deep convection in the Labrador Sea (low NAO). Stratification was also low in the 1960s.

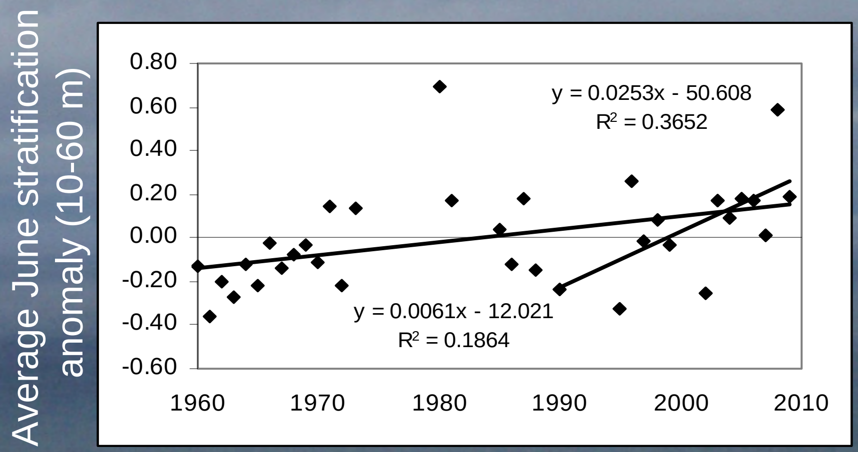
- Sea-surface temperatures and stratification have been increasing rapidly in the Central Irminger Sea (sub-polar gyre) since about 1990.

Sea-surface temperatures



Data courtesy of Todd O'Brien (NOAA, NMFS)

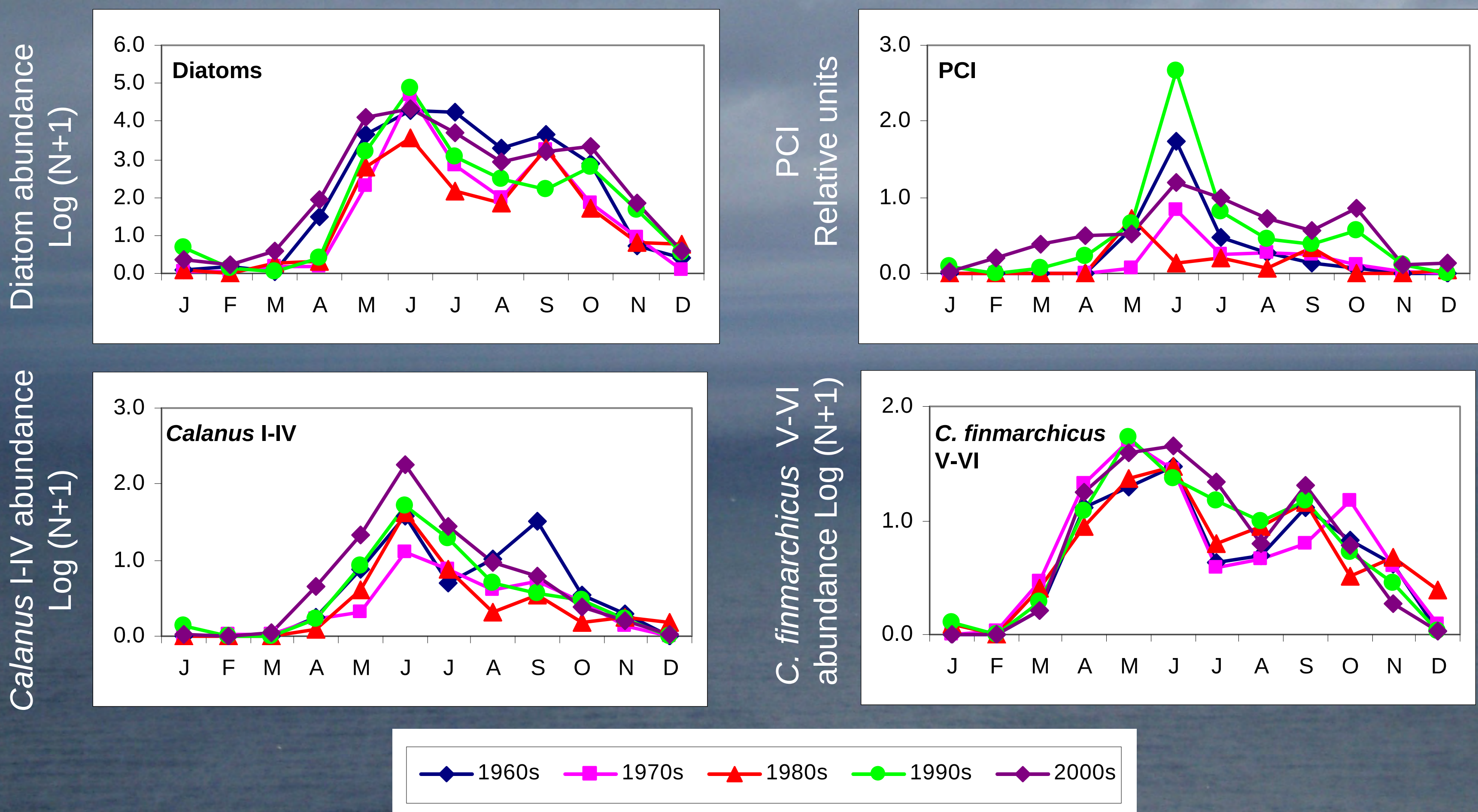
June stratification anomalies



Data courtesy of Igor Yashayaev (DFO, BIO)

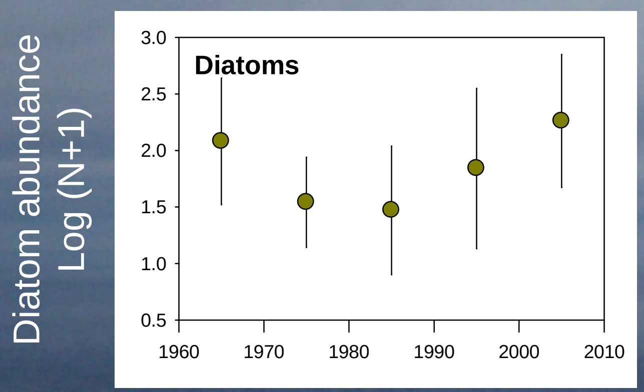
Central Irminger Sea - Seasonal cycles of phytoplankton abundance/biomass and *Calanus finmarchicus* abundance by decade

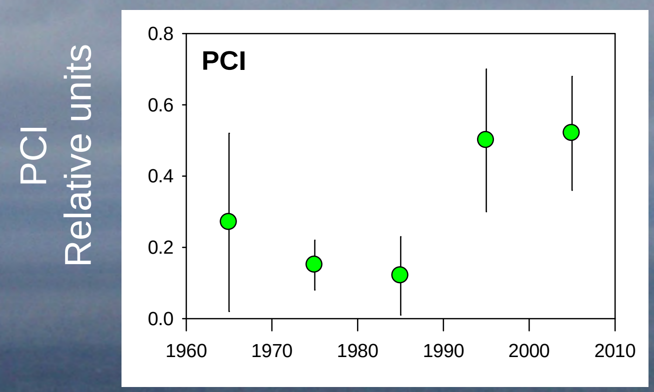
- CPR samples were collected from 1957 onwards and there was some sampling in the 1980s.
- *Calanus finmarchicus* is by far the dominant *Calanus* species in the region.
- No major changes in seasonal cycles. Seasonal cycles for phytoplankton and *Calanus* I-IV are synchronous.

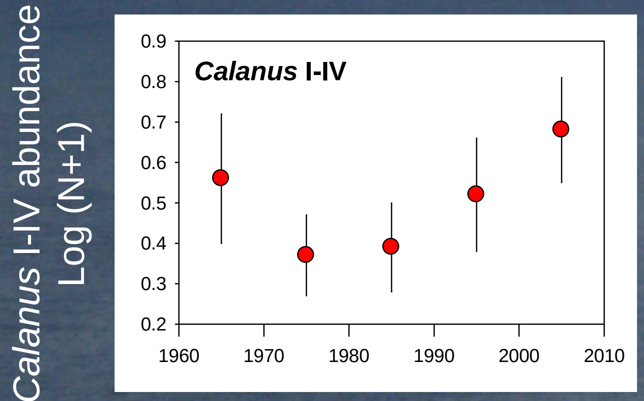


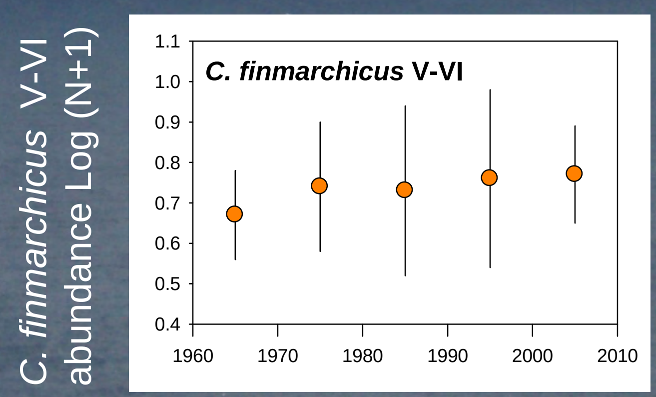
Central Irminger Sea - Changes in the decadal annual averages for phytoplankton abundance/biomass and *Calanus finmarchicus* abundance

- Annual phytoplankton levels increased in the 2000s, perhaps due to increased primary production. Light limitation is more important than nutrient limitation here, and increased stratification reduces light limitation. As well, nitrate levels have been increasing.
- Phytoplankton and *Calanus* I-IV levels have varied in parallel, suggesting “bottom-up” control, possible because phytoplankton increases occurred during the *Calanus* I-IV growth period. Increasing SSTs since the 1990s could also be having a direct affect.
- *C. finmarchicus* late stage abundance is not linked to food.



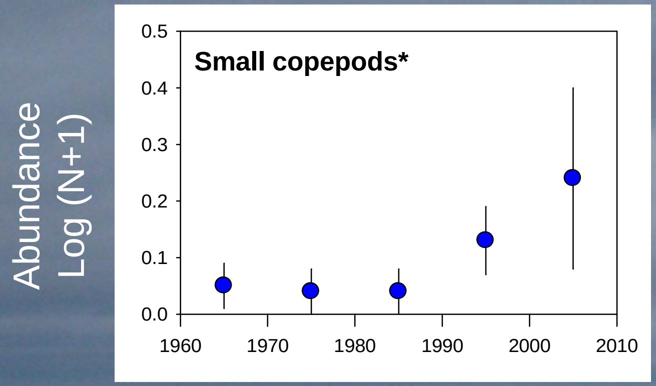


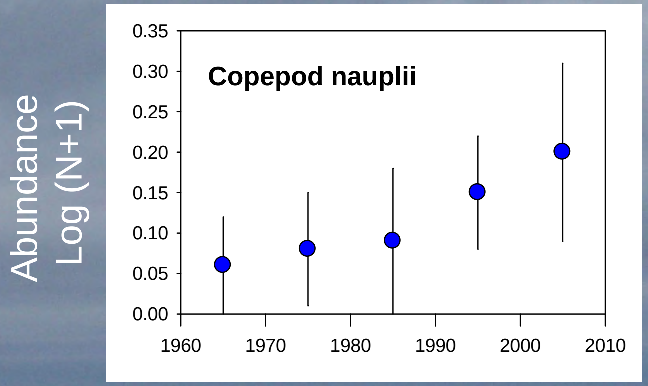


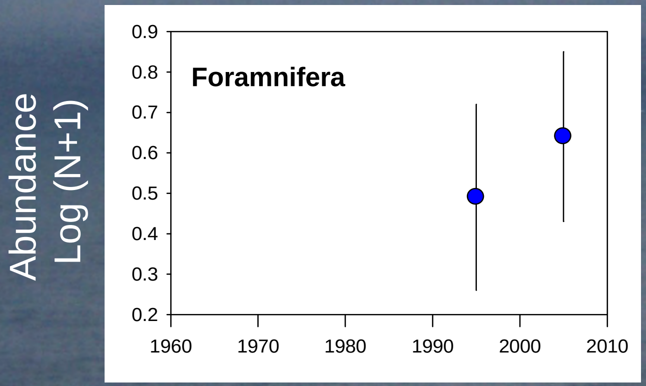


Central Irminger Sea - Changes in the decadal annual averags for the abundance of small copepods*, copepod nauplii, hyperiid amphipods and foramnifera

- Zooplankton taxa other than *C. finmarchicus* have responded to the increases in SST, stratification and/or phytoplankton abundance since the 1980s.
- All have seasonal cycles of abundance similar to those of the phytoplankton.







* The CPR category *Paracalanus/Pseudocalanus*

Summary

On the Western Scotian Shelf

- Sea-surface temperatures and stratification have been increasing since the 1960s.
- Since the 1990s spring blooms have been occurring earlier in the year and young stage *C. finmarchicus* have been appearing earlier.
- Since the 1990s increased annual average phytoplankton abundances have not been accompanied by changes in annual abundances of *C. finmarchicus*.
- The increases in phytoplankton abundance are probably caused by the development of a mis-match in the production cycles of the phytoplankton and a major grazer (*C. finmarchicus*).
- These early blooms may result in increased flow of organic material to the benthos.

In the Central Irminger Sea

- Sea-surface temperatures and stratification have been increasing rapidly since 1990.
- Annual average phytoplankton abundances have increased and so have those of young stage *C. finmarchicus* and some other zooplankton taxa.
- The increases in phytoplankton abundance are probably due to increased primary production, leading to increased transfer of organic material to pelagic zooplankton.