The North Atlantic Bloom: Species composition and vertical fluxes

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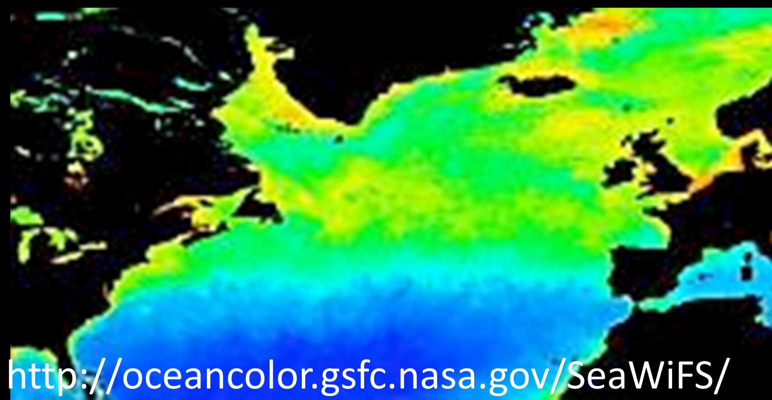
- North Atlantic-Arctic ecocsystems
  - Develop a process-based understanding of the impact of climate change on biogeochemistry and resultant feedbacks to climate.
  - Utilization of process knowledge for development and application of coupled atmosphere-ocean-ecosystem models capable of (acclimation), evolution and adaptation, thereby providing predictive ability.

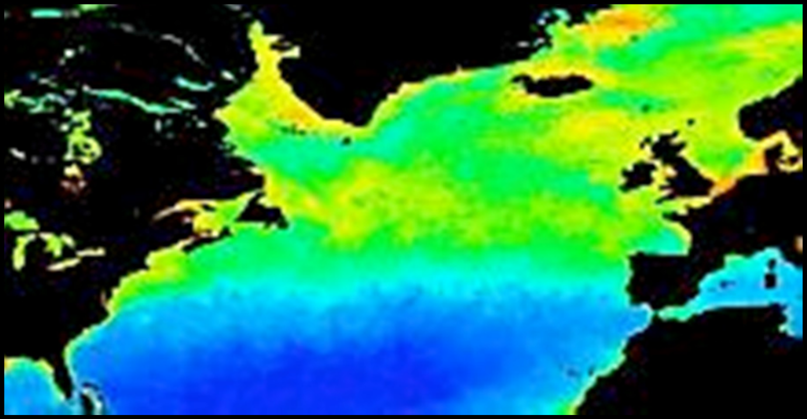
North Atlantic Spring Bloom



http://oceancolor.gsfc.nasa.gov/SeaWiFS/

- The North Atlantic accounts for ~23% of global marine sequestration of anthropogenic CO_2 (Sabine et al., 2004)
- Biological pump in the North Atlantic:
  - CO_2 uptake and potential C sequestration by large phytoplankton during the spring bloom
  - Combination of physical and biological processes

What is the biggest challenge in understanding biological processes?

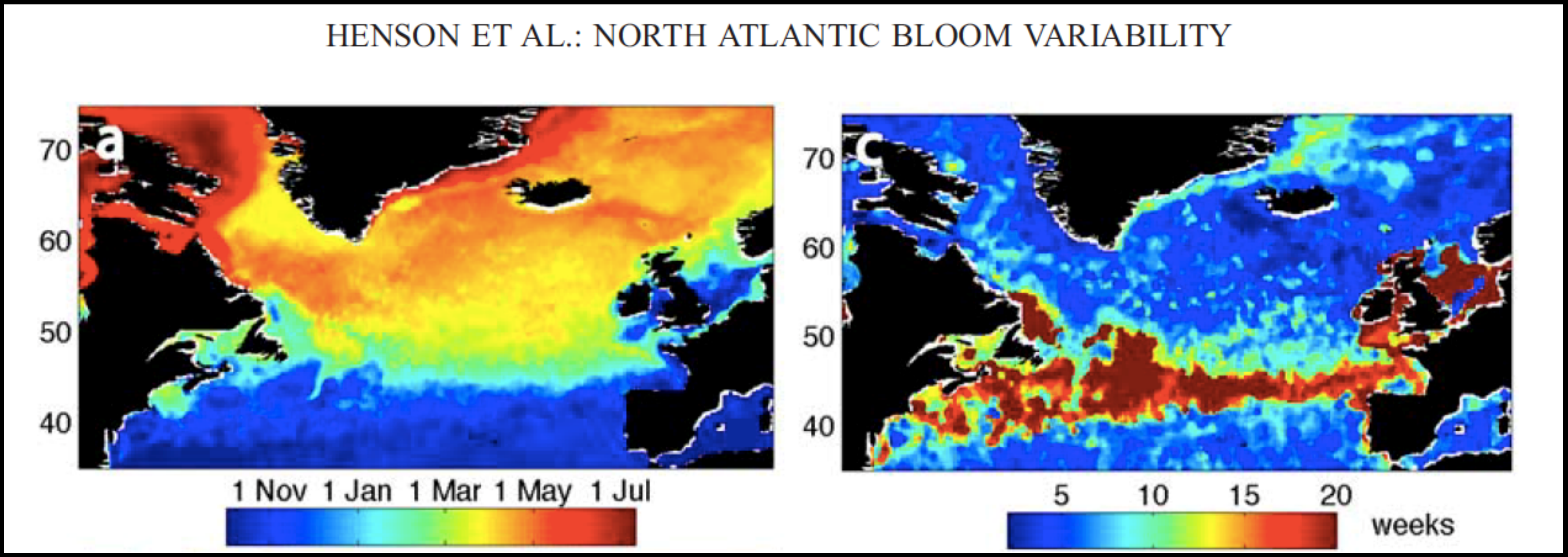


The impact of plankton ecology on vertical fluxes.
(Ragueneau et al. 2006)

What roles do ecological processes play in modulating C flux to the ocean’s interior?

- The influence of plankton ecology on vertical fluxes in 2 parts
  - What you see is not what you get: species composition at surface and depth
  - Sex in the open ocean: low frequency, high impact?

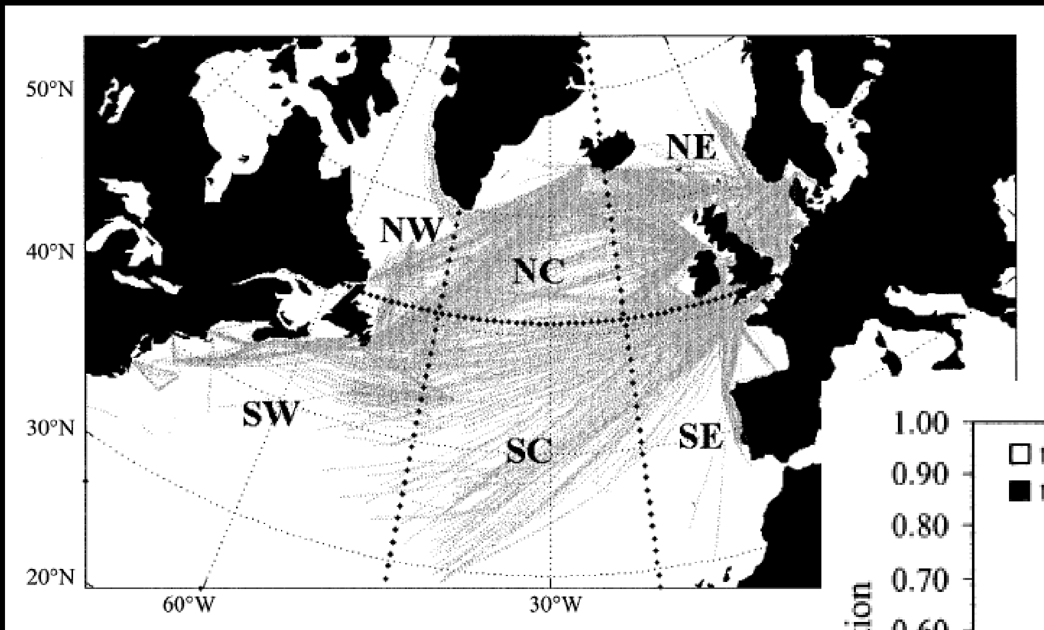
Ecological processes in the North Atlantic: Start date of the spring bloom

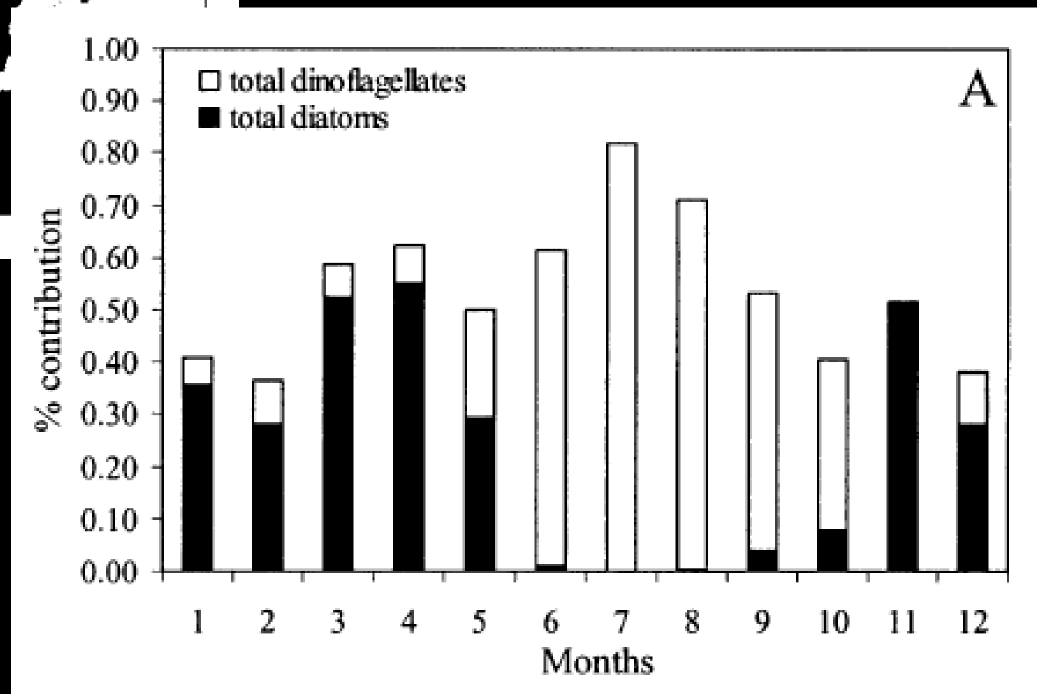


Henson et al. 2009

- Mean (1998-2004) start date from SeaWiFS
- Range in start date from SeaWiFS

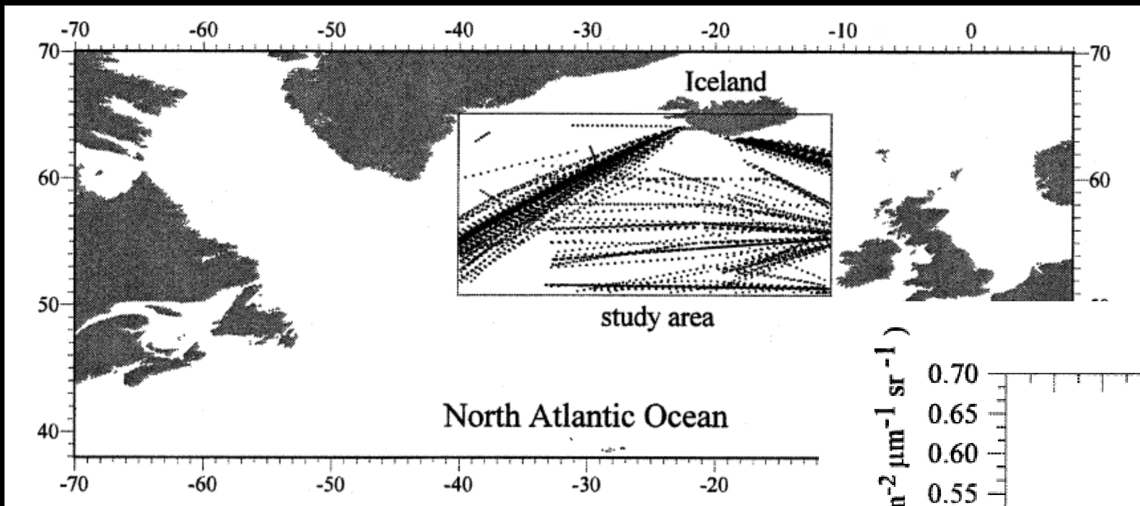
Species composition - CPR

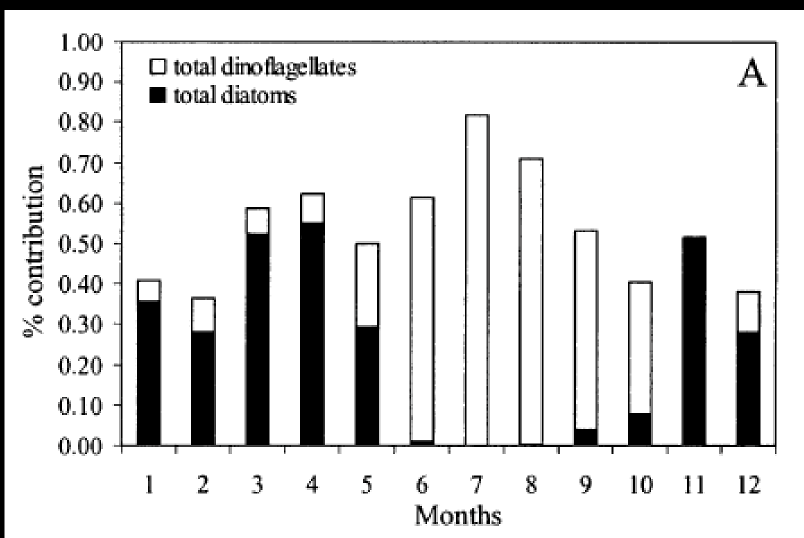




Leterme et al. 2005

Coccolithophore abundance- CPR





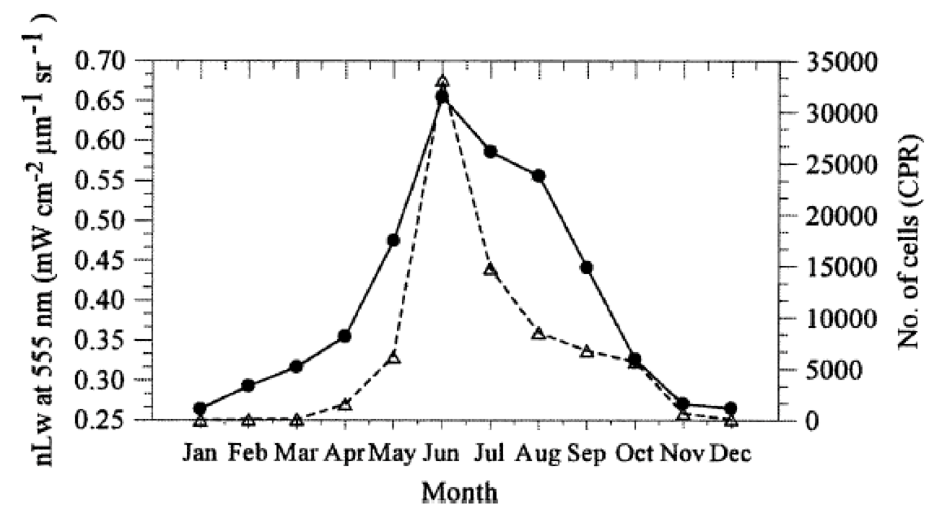
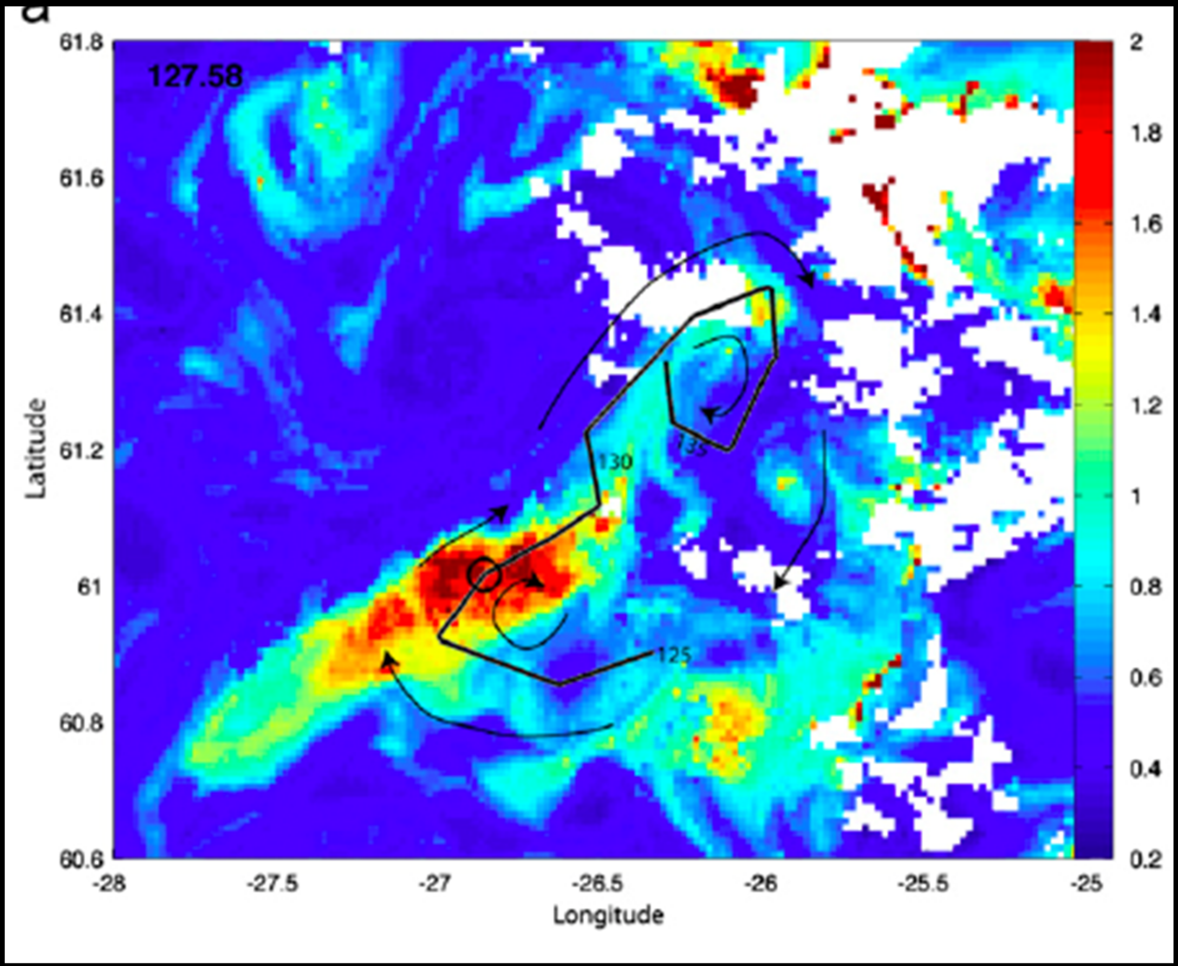


Fig. 3. Monthly mean of SeaWiFS nLw_555 (solid line) and CPR coccolithophore numbers (dashed line) from January 1998 to December 2002 (3,977 samples) in the study area. The spatial distribution of the samples can be seen in Figure 1.

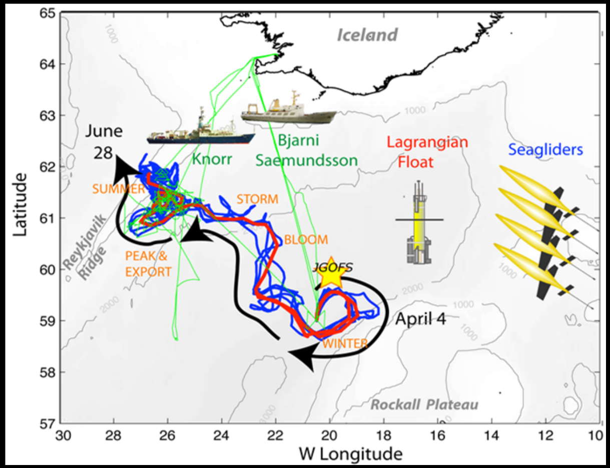
Raitsos et al. 2006

What you see is not what you get: species composition at surface and depth

North Atlantic Spring Bloom Experiment 2008



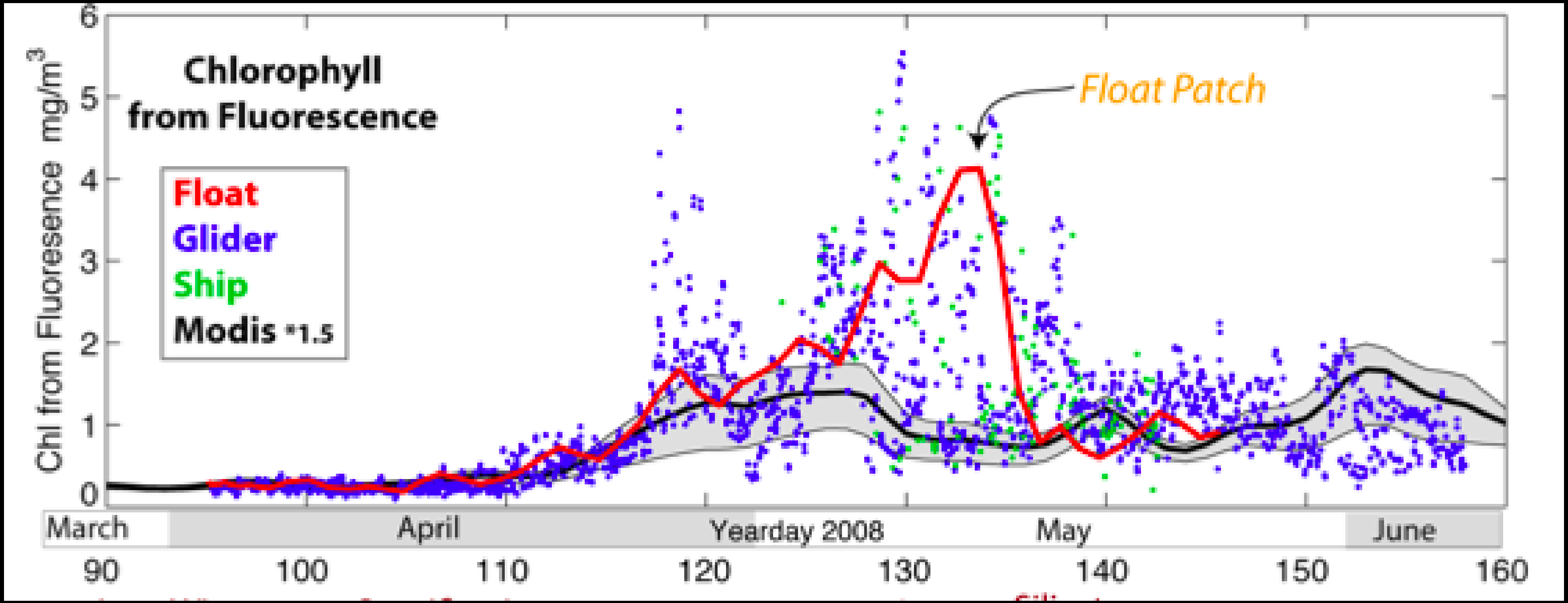
Martin et al, 2010



There is a spring bloom.

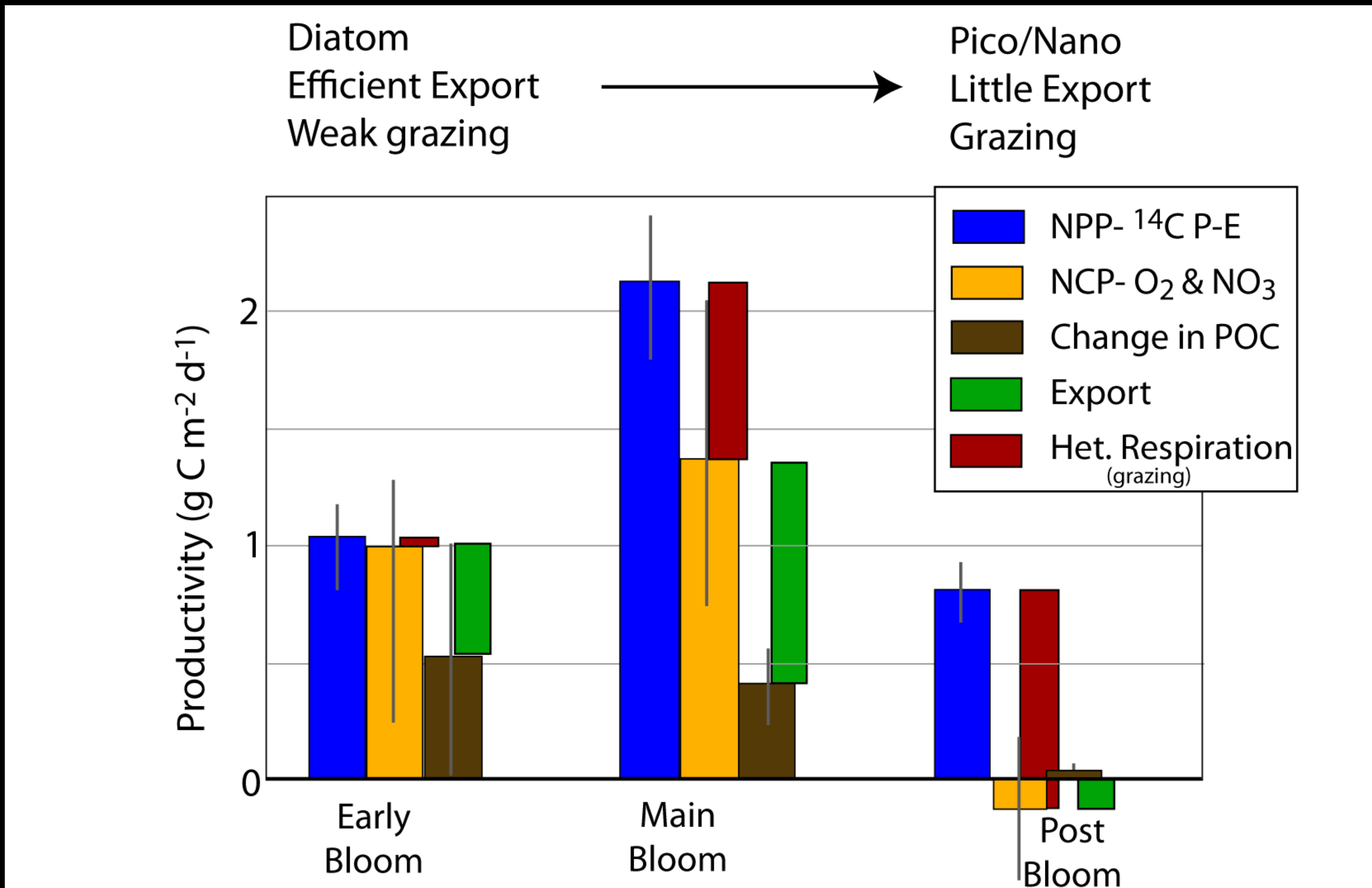
It's a diatom bloom.

It's a patchy bloom.



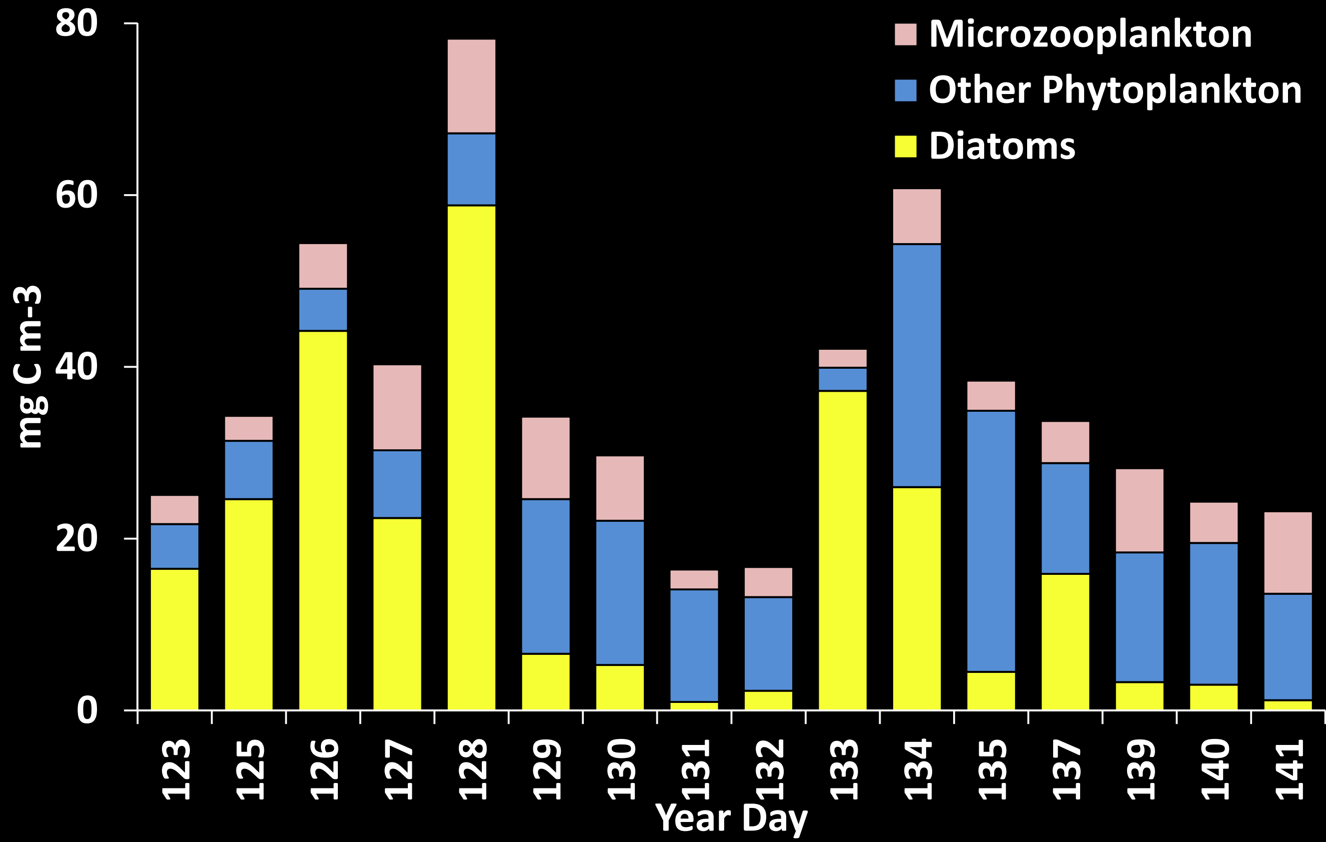
Mahadevan et al., 2012

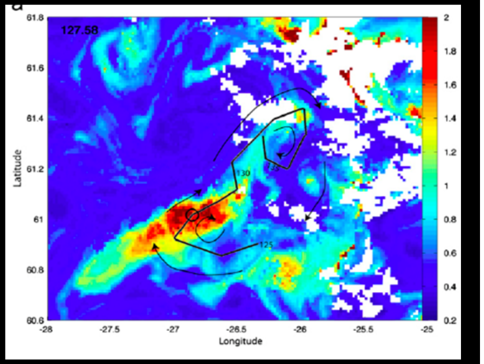
Characterize the state of the carbon cycle autonomously



D’Asaro et al., in prep.

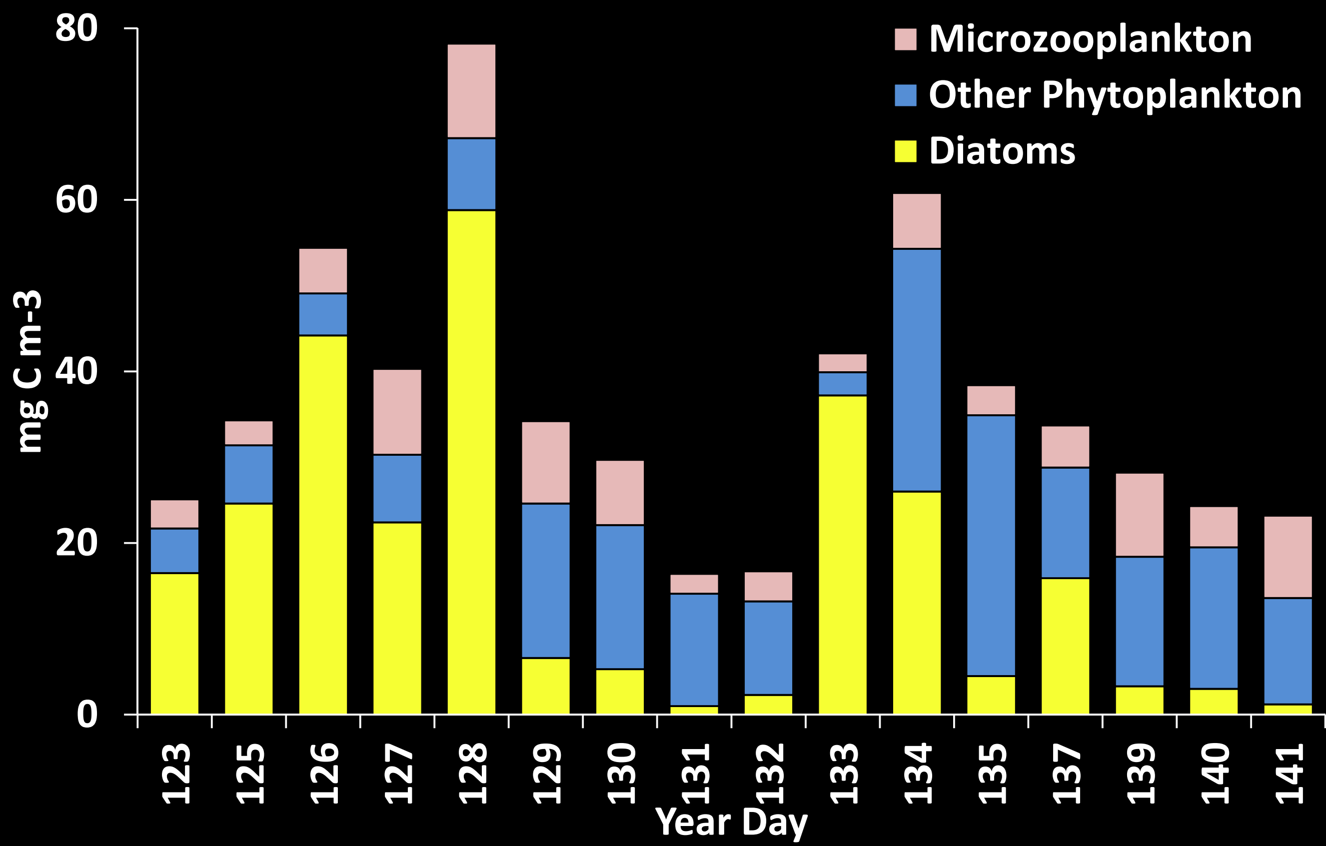
Surface community composition, > 2μm

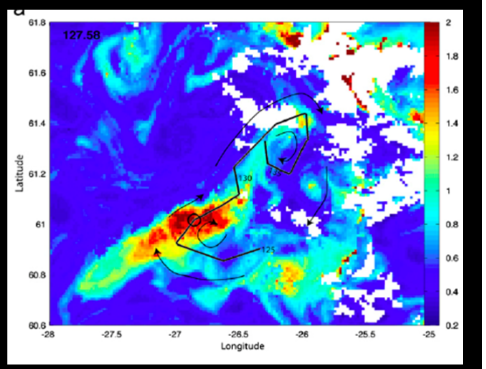




Rynearson et al., 2013

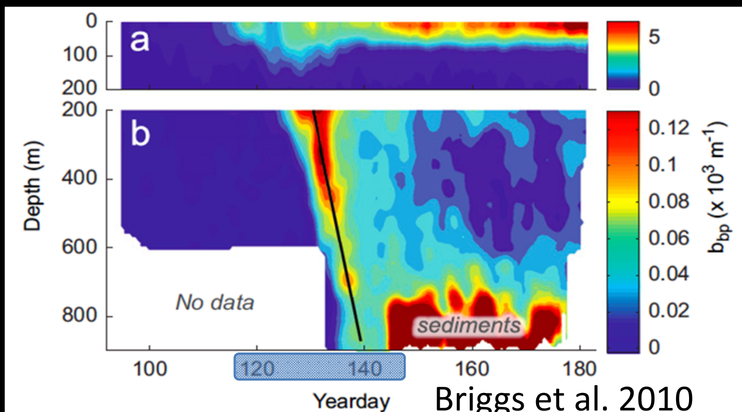
How does surface community composition connect to C fluxes?



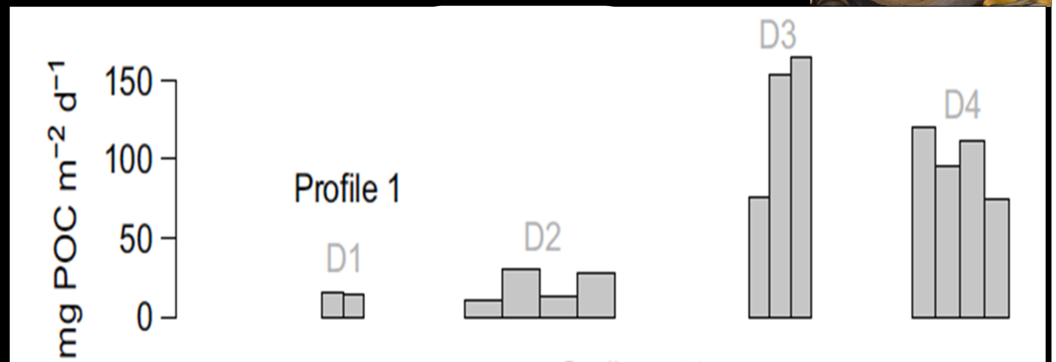


Rynearson et al., 2013

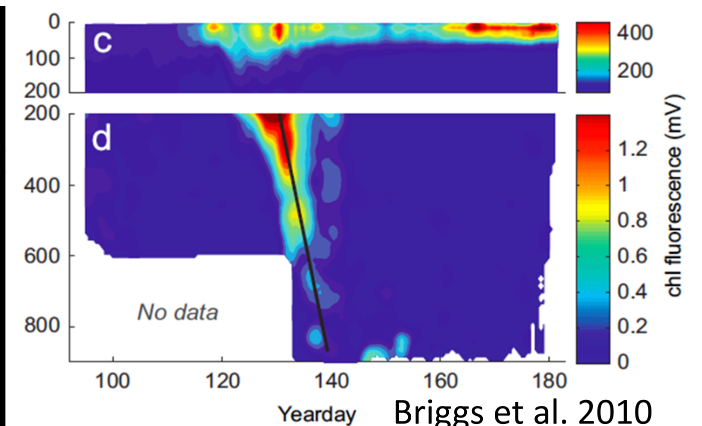
Seagliders & PELAGRA floating sediment traps capture flux event



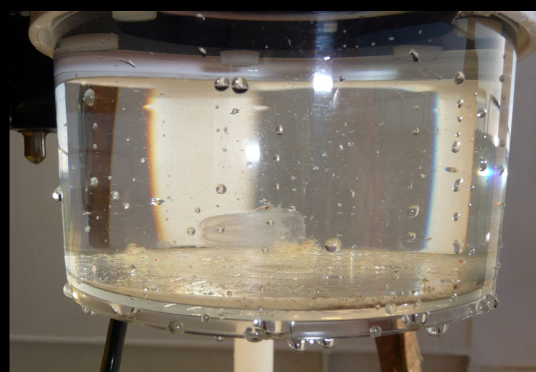
Briggs et al. 2010

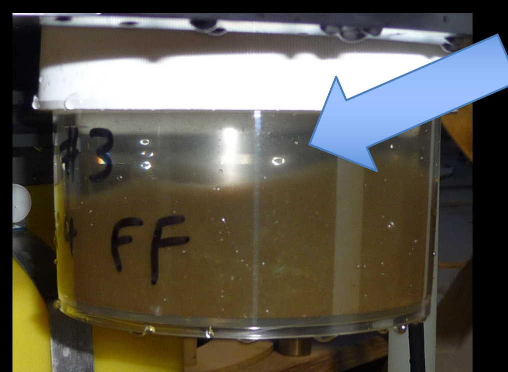


Martin et al, 2010

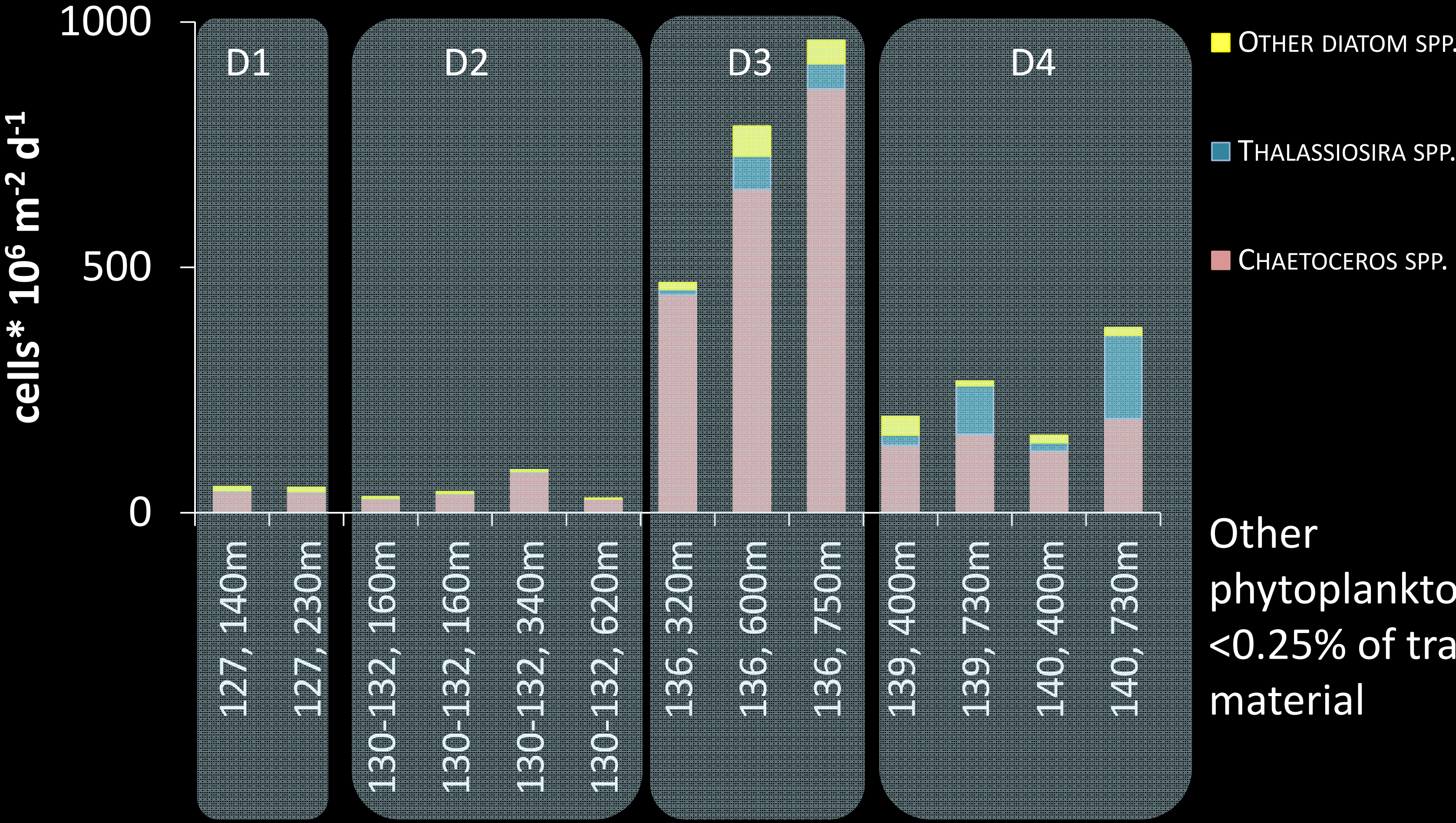


Briggs et al. 2010





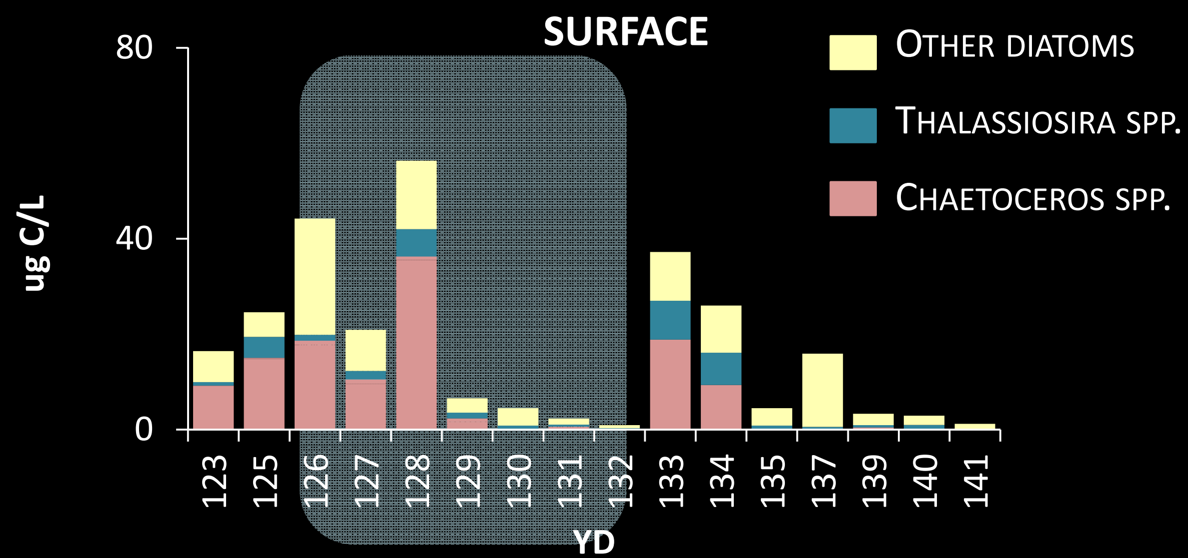
Sediment traps dominated by diatoms



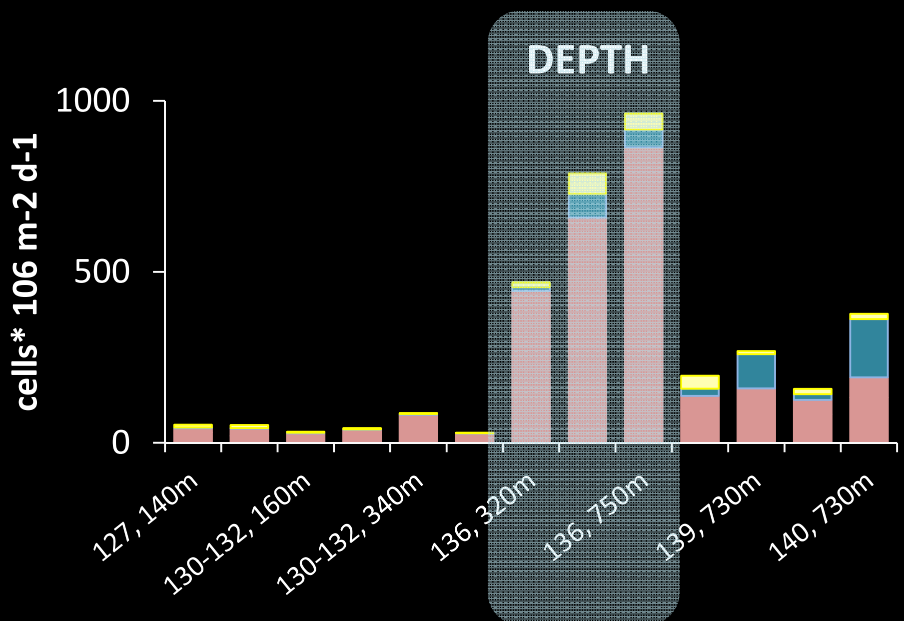
Other phytoplankton = <0.25% of trap material

Rynearson, T. A., K Richardson, R. S. Lampitt, M. E. Sieracki, A. J. Poulton, M. M. Lyngsgaard, and M. J. Perry (2013) Deep Sea Res. I

How comparable is species diversity at surface and depth?

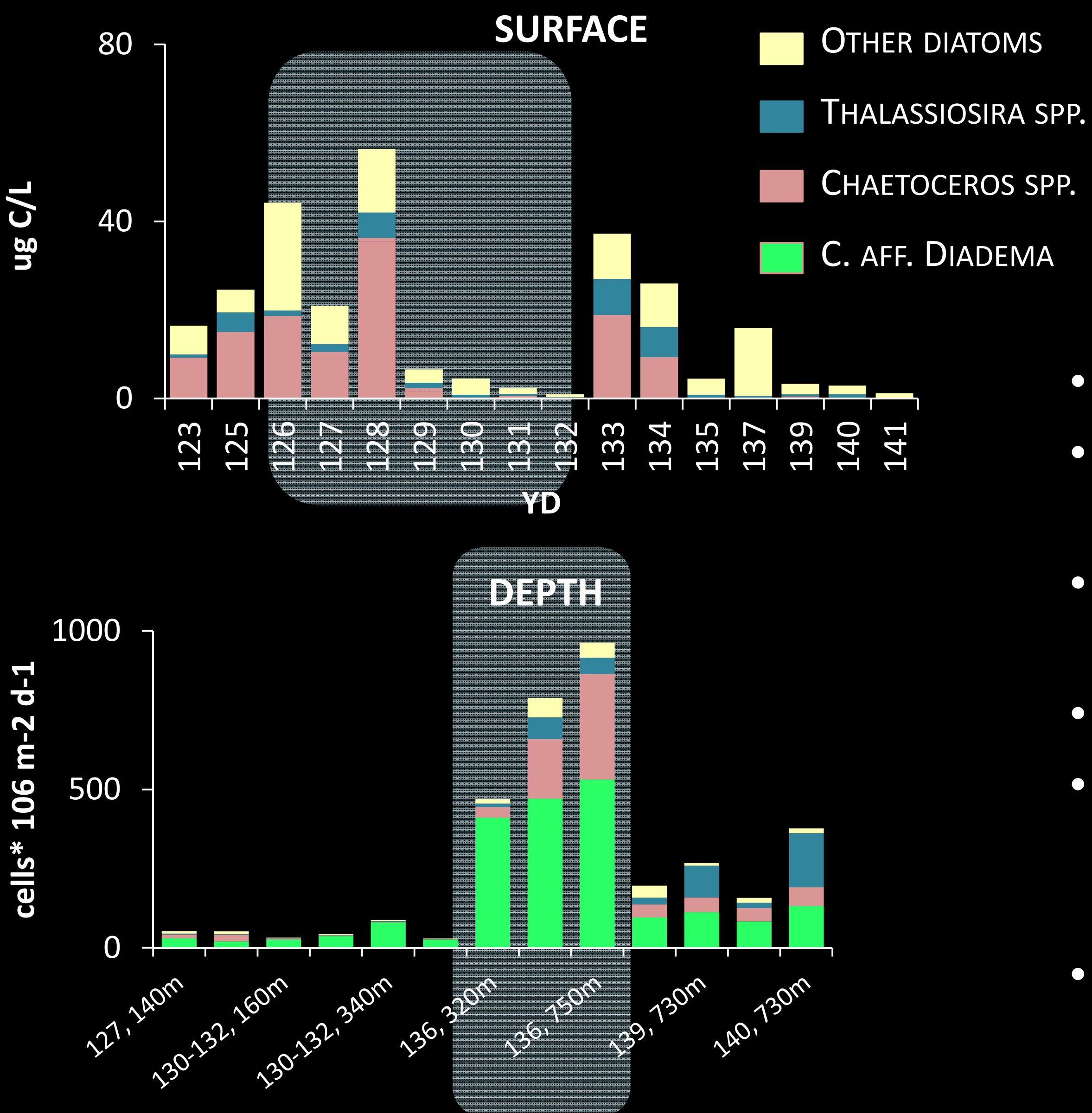


- Sinking rates of ~75m day^{-1} (Briggs et al. 2010)
- Flux from surface YD 126- 132



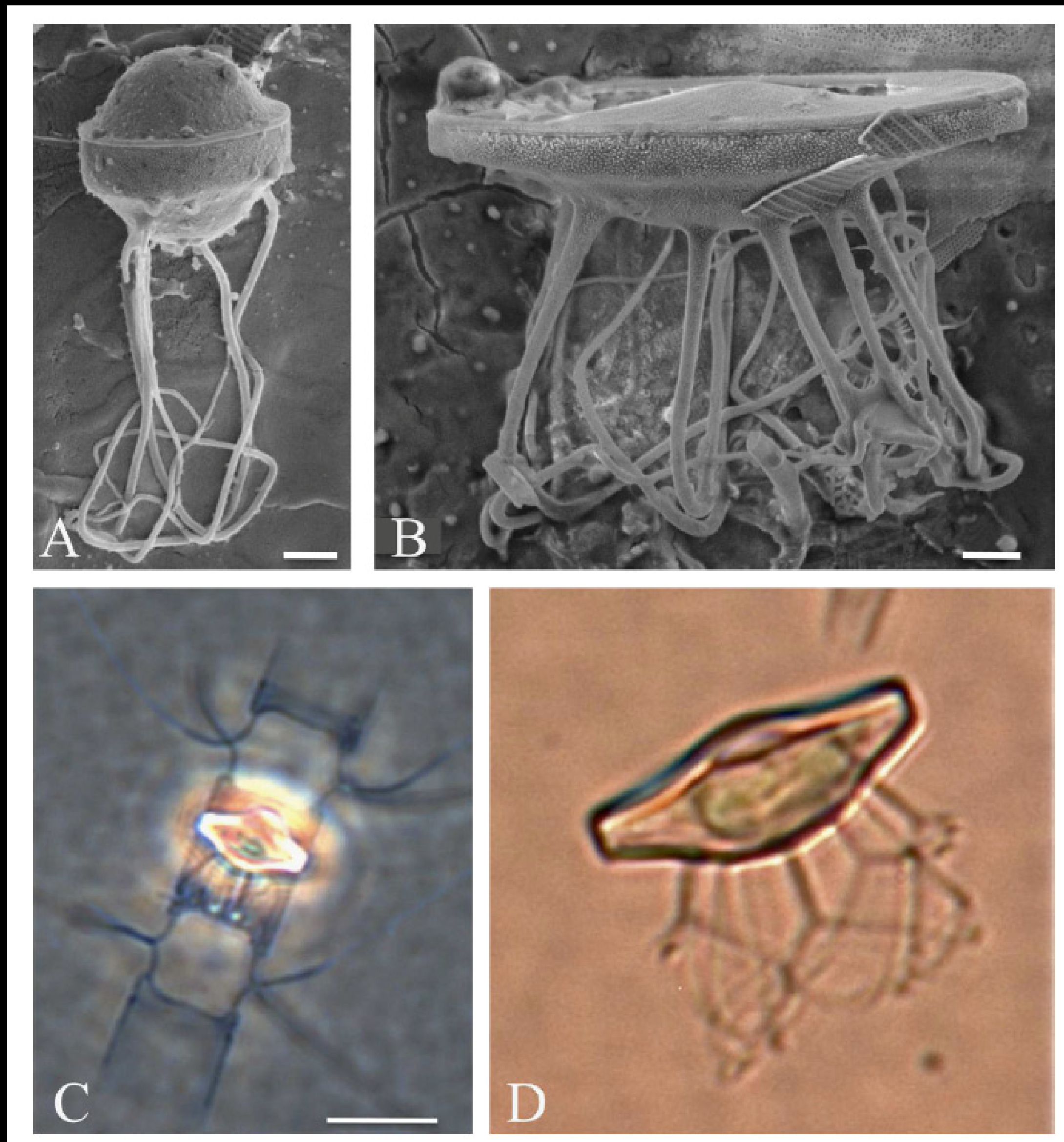
- Significant differences in composition
  - Shift in classes & species
- *Chaetoceros spp.*
  - >80% cell flux to Pelagra traps
  - 30% of biomass at the surface
  - What is w/in the *Chaetoceros*?

How comparable is species diversity at surface and depth?



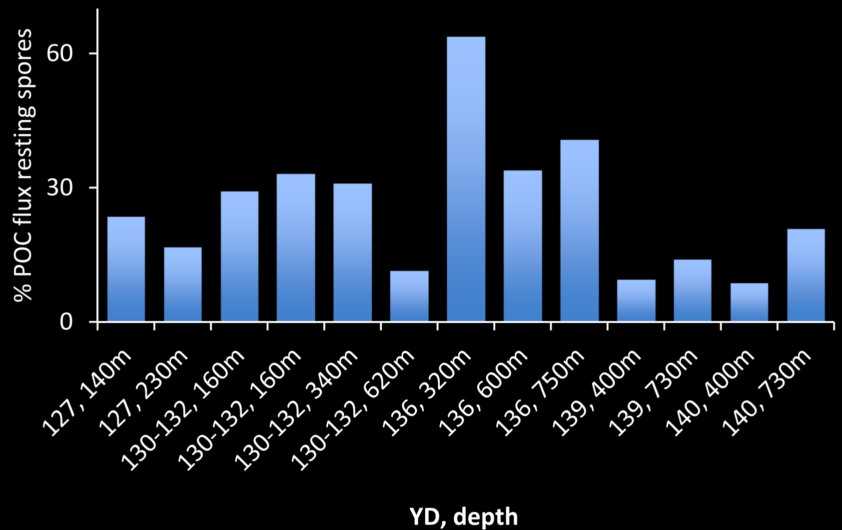
- *Chaetoceros* aff. *diadema*
- 1-5 % of biomass at the surface
- 35-92% of the cell flux to depth
- Form of resting spores
- What are the biogeochemical implications?
- How is this possible?

“Little UFOs ???”

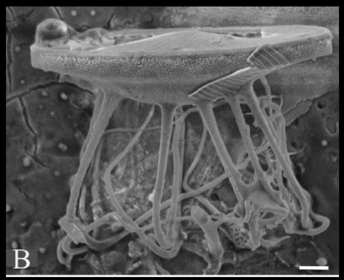


Resting spores – Biogeochemical implications

- Resting Spore Carbon
  - Up to 64% of peak POC flux
  - C estimates were conservative
    - Menden-Deuer and Lessard (2000)
    - Resting spores 4-10X more C per cell (French and Hargraves 1980)



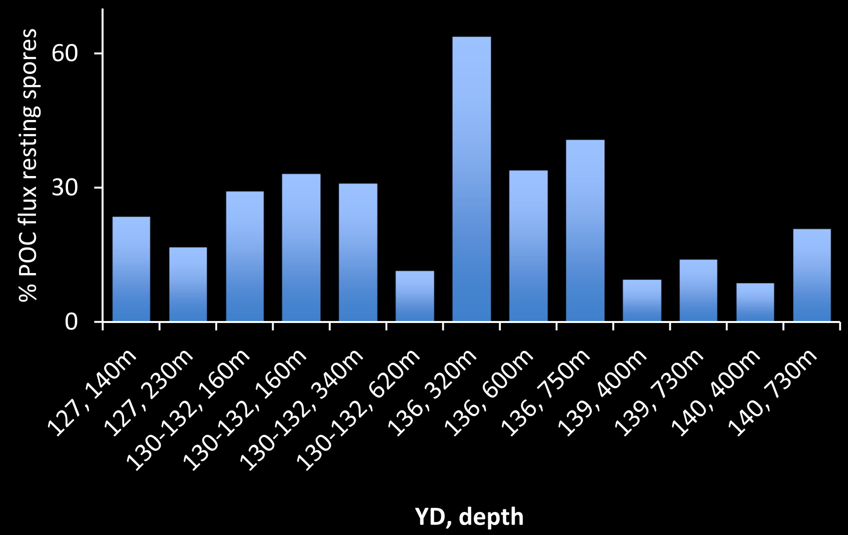
- Sinking
  - Spores heavily silicified (Stockwell and Hargraves 1988)
  - Spores sink rapidly (2-16 m/day) (French and Hargraves 1980)
  - Resistant to grazers (Durbin, 1978)
  - TEP & aggregates were observed (Briggs et al. 2010, Martin et al. 2011)

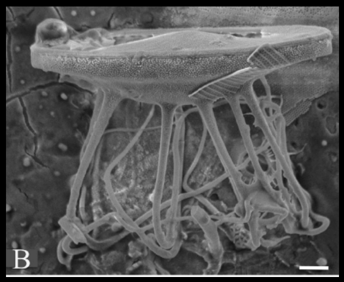


Rynearson et al., 2013

Resting spores – Biogeochemical implications

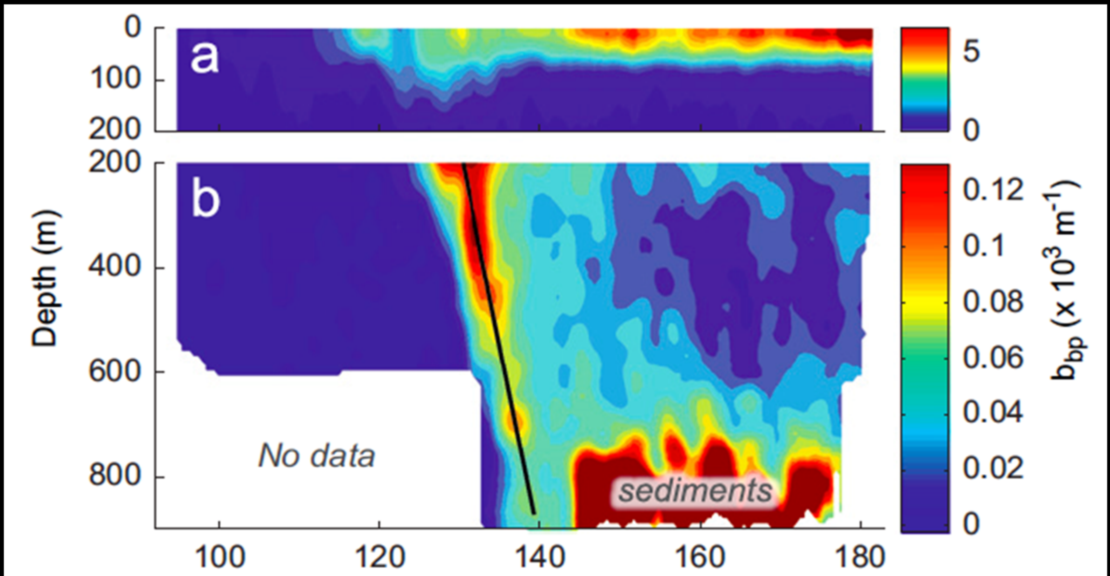
- High transfer efficiencies
  - Transfer efficiencies in this region of the N Atl. amongst the highest measured in the global ocean (Buessler & Boyd, 2009)
  - Up to 43% of the POC at 100 m transferred to depths of 750 m or greater (Martin et al. 2011)
  - Direct algal sinking & little flux attenuation with depth during N. Atlantic bloom
  - Suggests flux of resting spores may not represent an isolated event





Resting Spores: Ecological implications

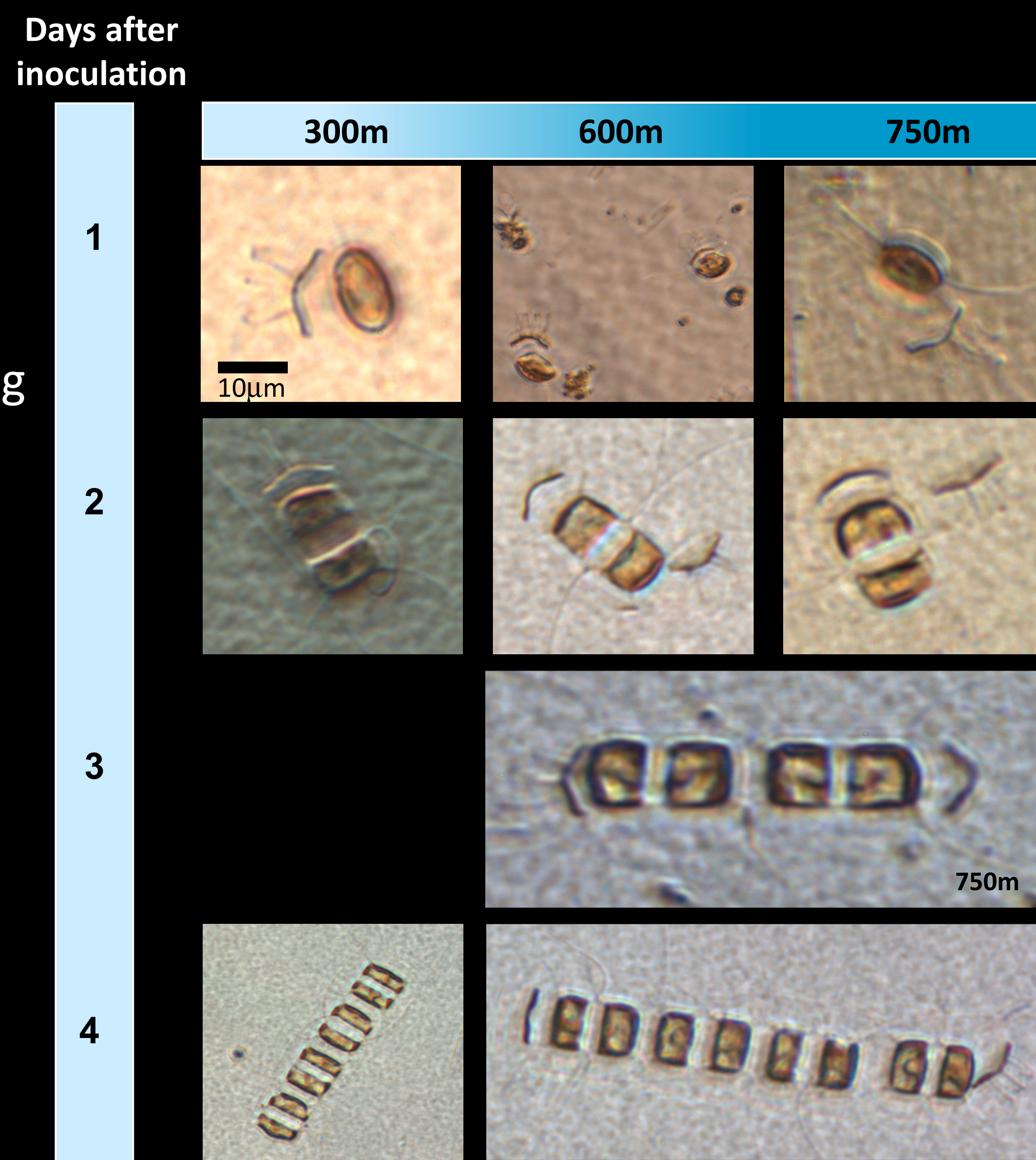
- C source for benthic organisms
- Spores may seed future blooms
  - Survival > 1 yr (Hollibaugh et al, 1981)
  - Deep winter mixing in North Atlantic may resuspend cells



Briggs et al. 2010

Resting Spores: Ecological implications

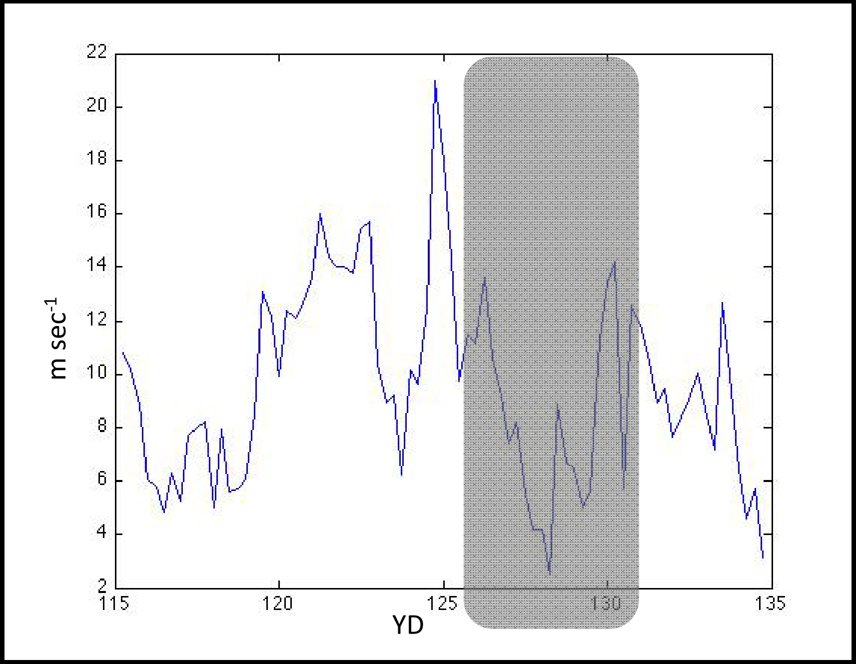
- Future blooms
  - Return to light?
  - Rapid germination & subsequent growth (1 doubling day^{-1})



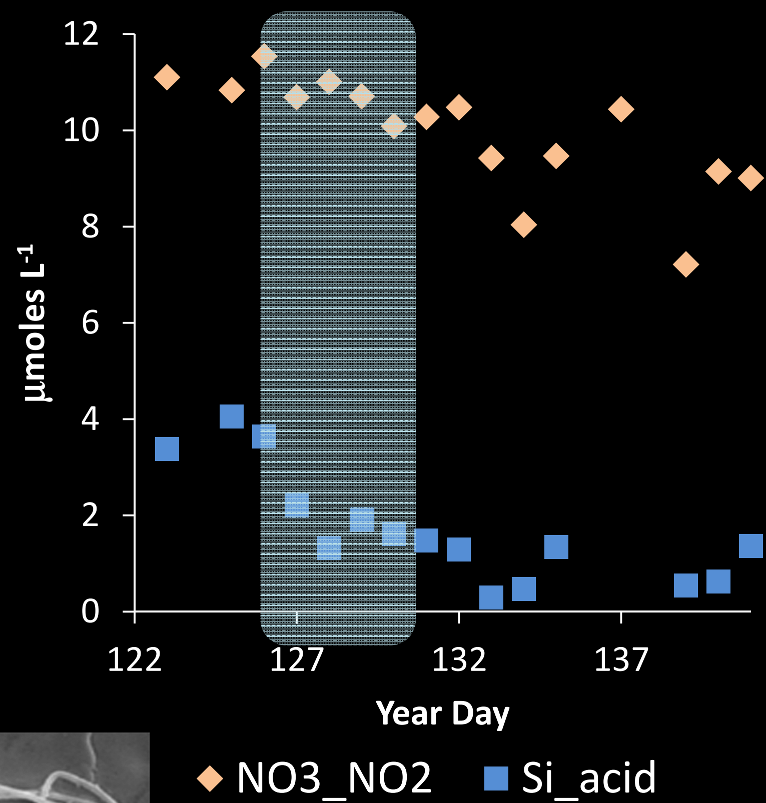
Rynearson et al., 2013

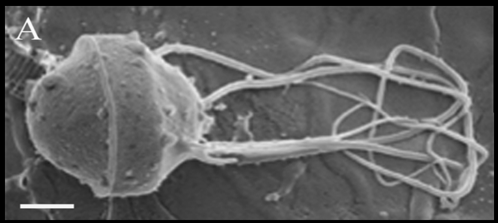
What led to the resting spore flux event?

- Wind?



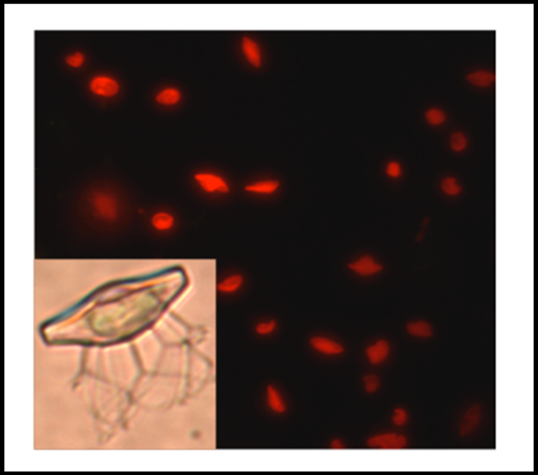
- Nutrient limitation?

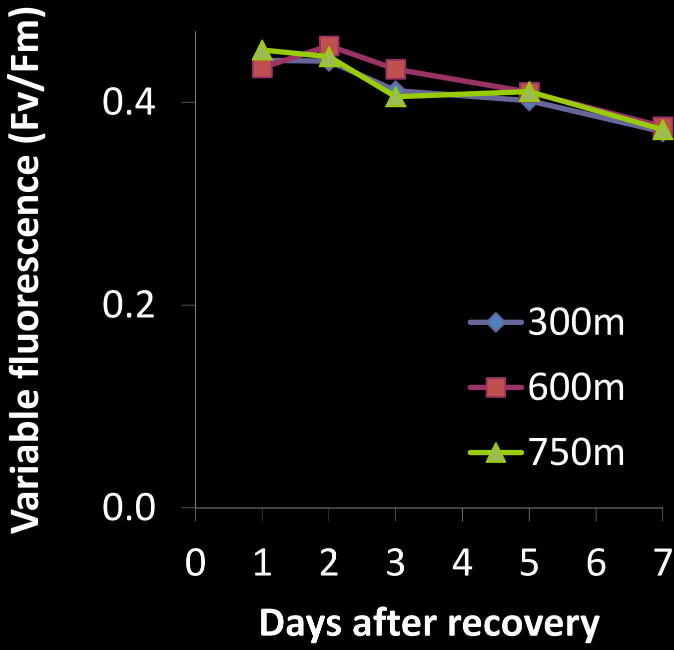




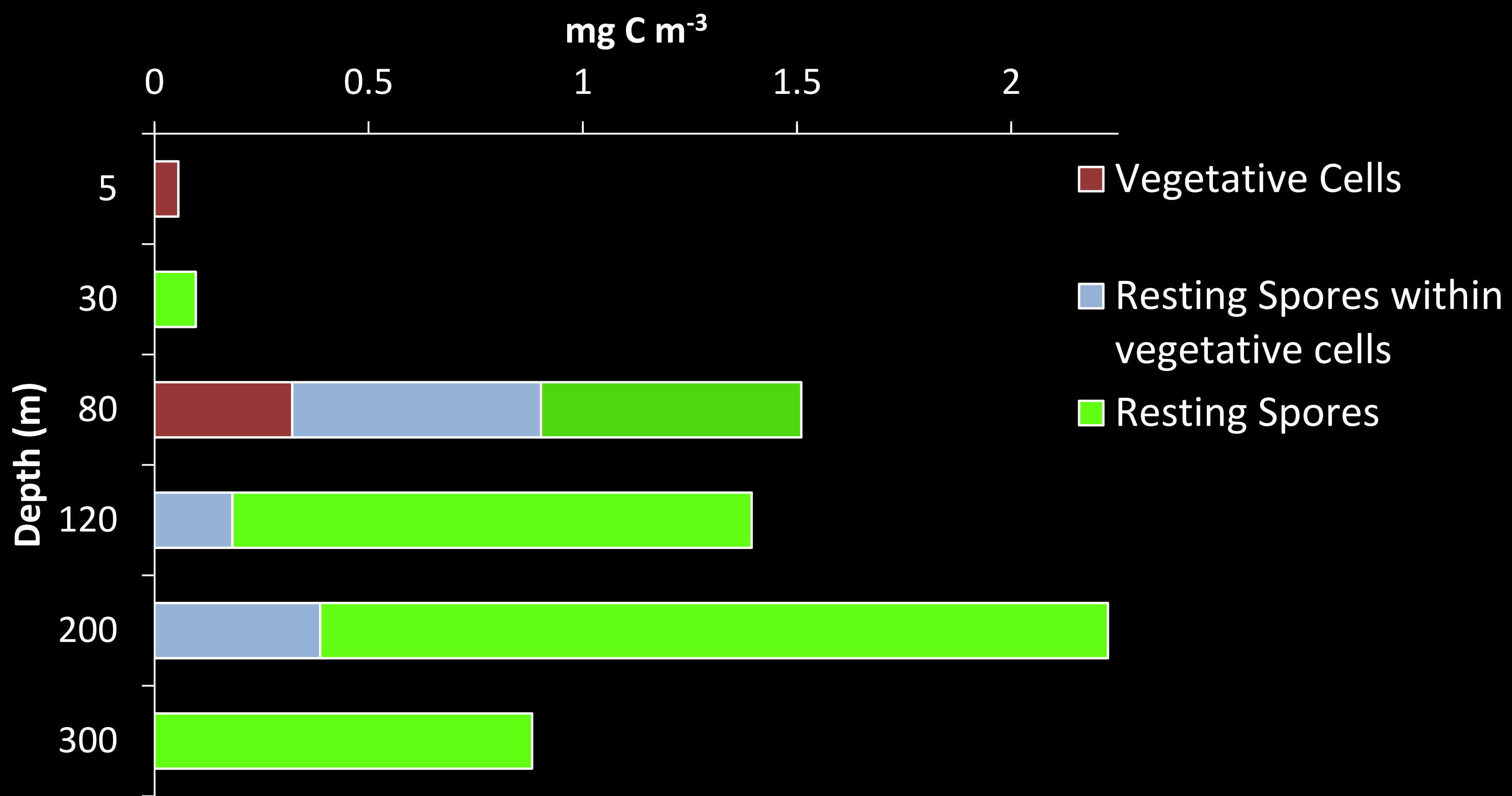
Physiological status of resting spores?

- Autofluorescence
  - High levels of chlorophyll
- High variable fluorescence (F_v/F_m)
  - Functioning photosynthetic machinery
- Physiologically intact cells
  - NOT stressed, senescing cells
- High quality, labile carbon transported to depth rapidly.



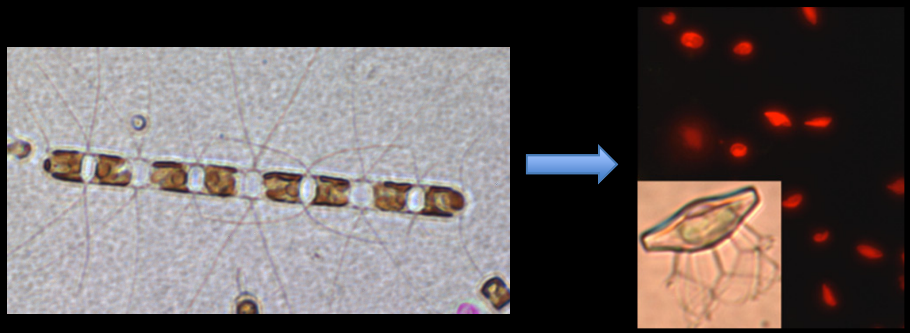


Spore formation at depth?



Influence on nutrient ratios?

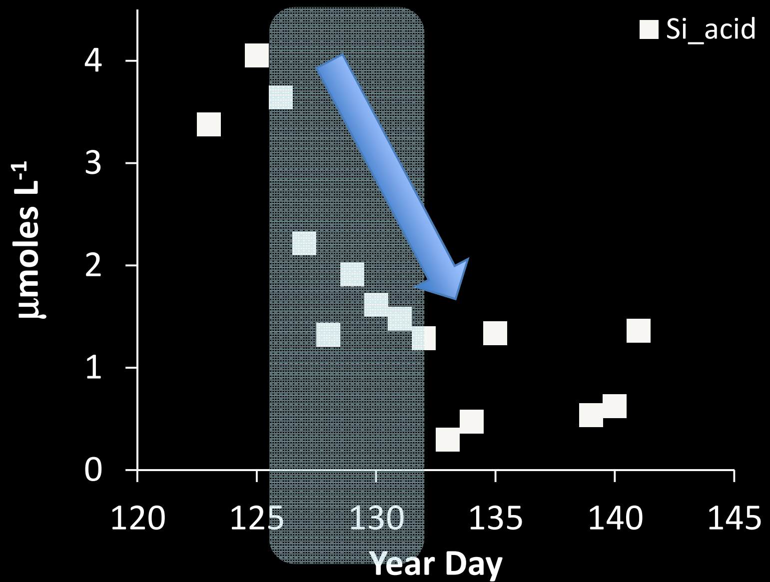
Resting spore formation is a wholesale metabolic and morphological transformation



- Resting spore formation requires:
  - Silicic acid in excess of vegetative cells by 3-4x
  - Increased C content (Lipids?)
  - Cessation of cell division (6-48 hrs?)

- Potential changes in nutrient ratios dependent on depth where transformation occurs

Nutrient "limitation"?

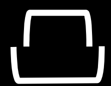


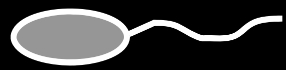
What roles do biodiversity and ecology play in modulating C flux to the ocean's interior?

- The influence of plankton ecology on biogeochemistry in 2 parts
  - What you see is not what you get: species composition at surface and depth
  - Sex in the open ocean: low frequency, high impact?

Sex in the open ocean: low frequency, high impact?

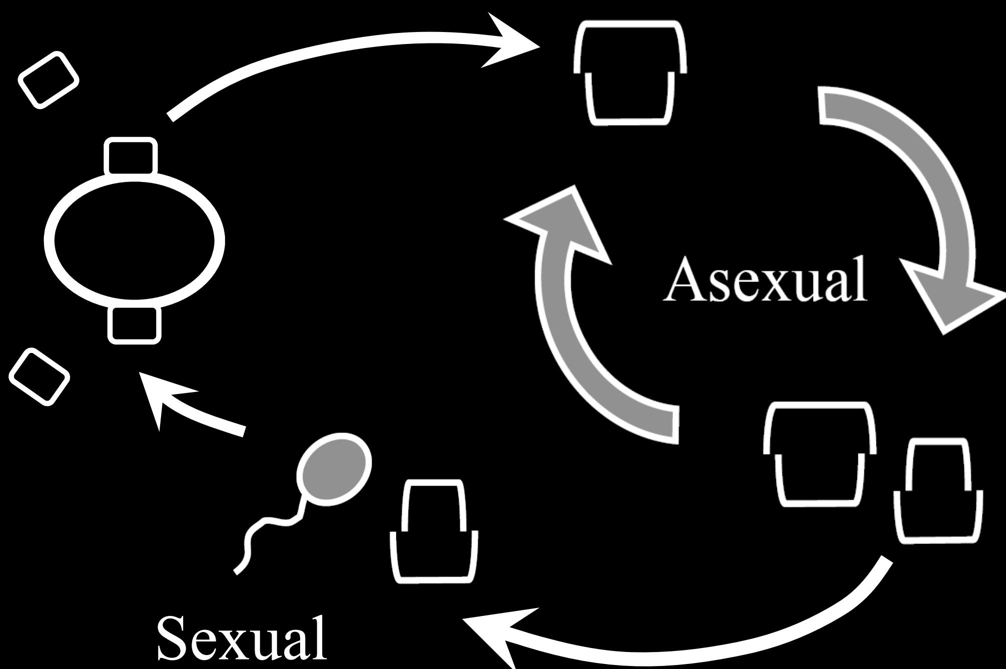
- Frequency in natural phytoplankton populations is virtually unknown
- Eg Diatoms
  - 1 /yr to 1/40 yrs





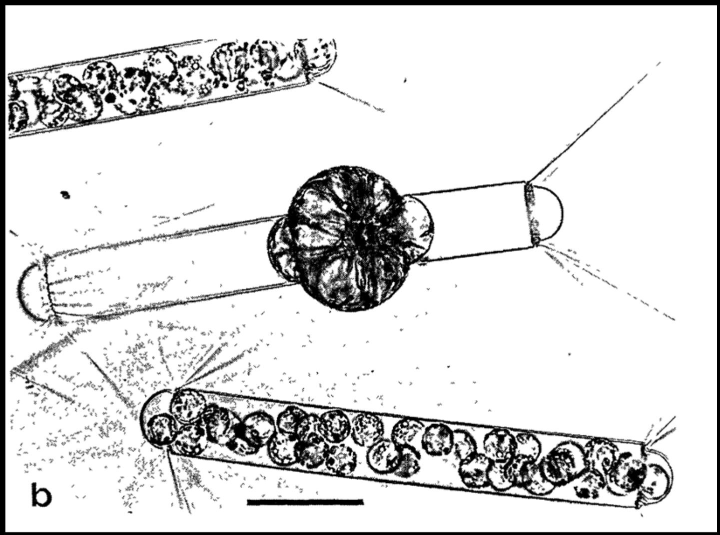
- Does sex influence vertical fluxes? An example from the diatoms.

Could sex influence fluxes?



- Empty frustules sink much faster than live cells (Smayda 1970)
- Sex: a causative factor in mass sedimentation of silica frustules? (Crawford 1995)

Could sex influence fluxes?



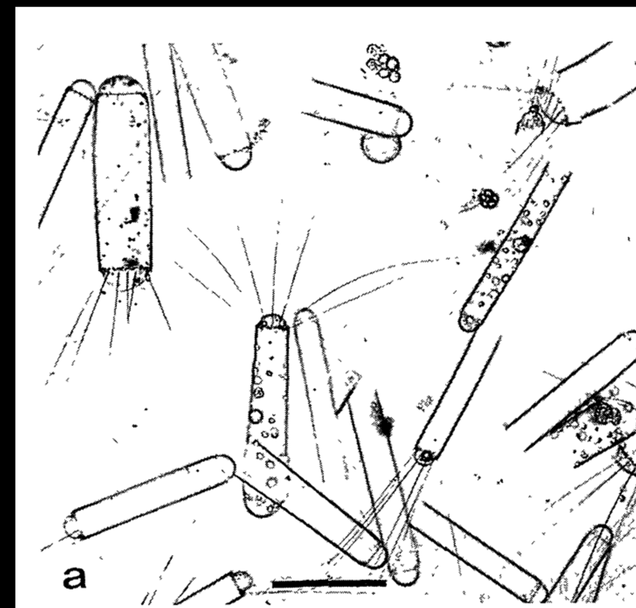
M. Vernet; http://icestories.exploratorium.edu/dispatches/reproduction-in-antarctic-diatoms/
Crawford, 1995

Sex in the Southern Ocean

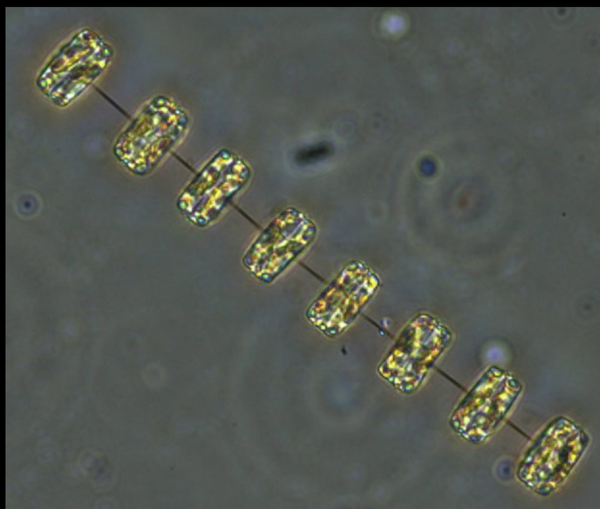
- Surface waters:
  - Large diatom bloom dominated by *Corethron criophilum* (JGOFS Atlantic, Crawford, 1995)
  - “Empty” half cells dominated samples from >100 m
  - Observed before
    - >60% “sexual” cells in Prydz Bay (Stockwell et al 1992)

- Sediments:
  - Monospecific layers of *Corethron*, 3 - 8 cm thick (Jordan et al. 1991, Leventer et al 1993).
  - Comprised of small diameter cells
  - Likely due to a mass sedimentation event following sex (Crawford. 1995)

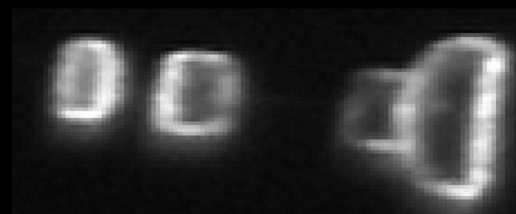
- Fluxes?
  - Si flux uncoupled from C flux, following a bloom



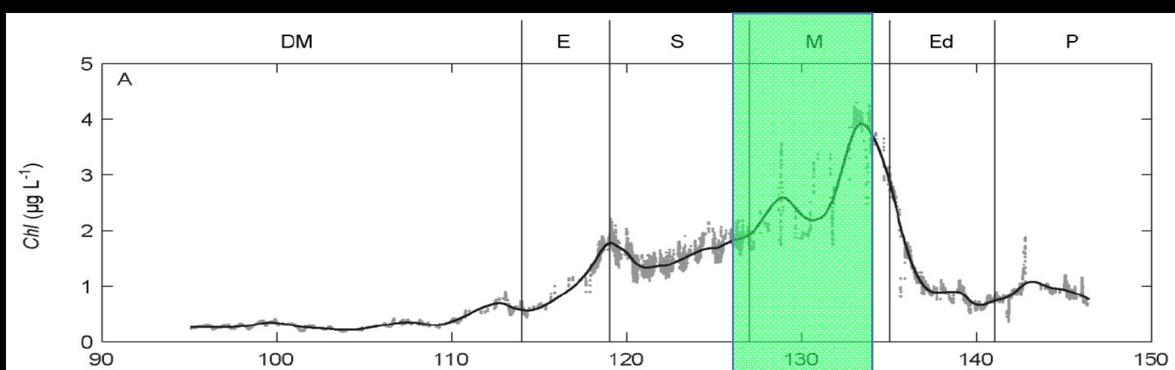
Sex in the North Atlantic



Thalassiosira gravida

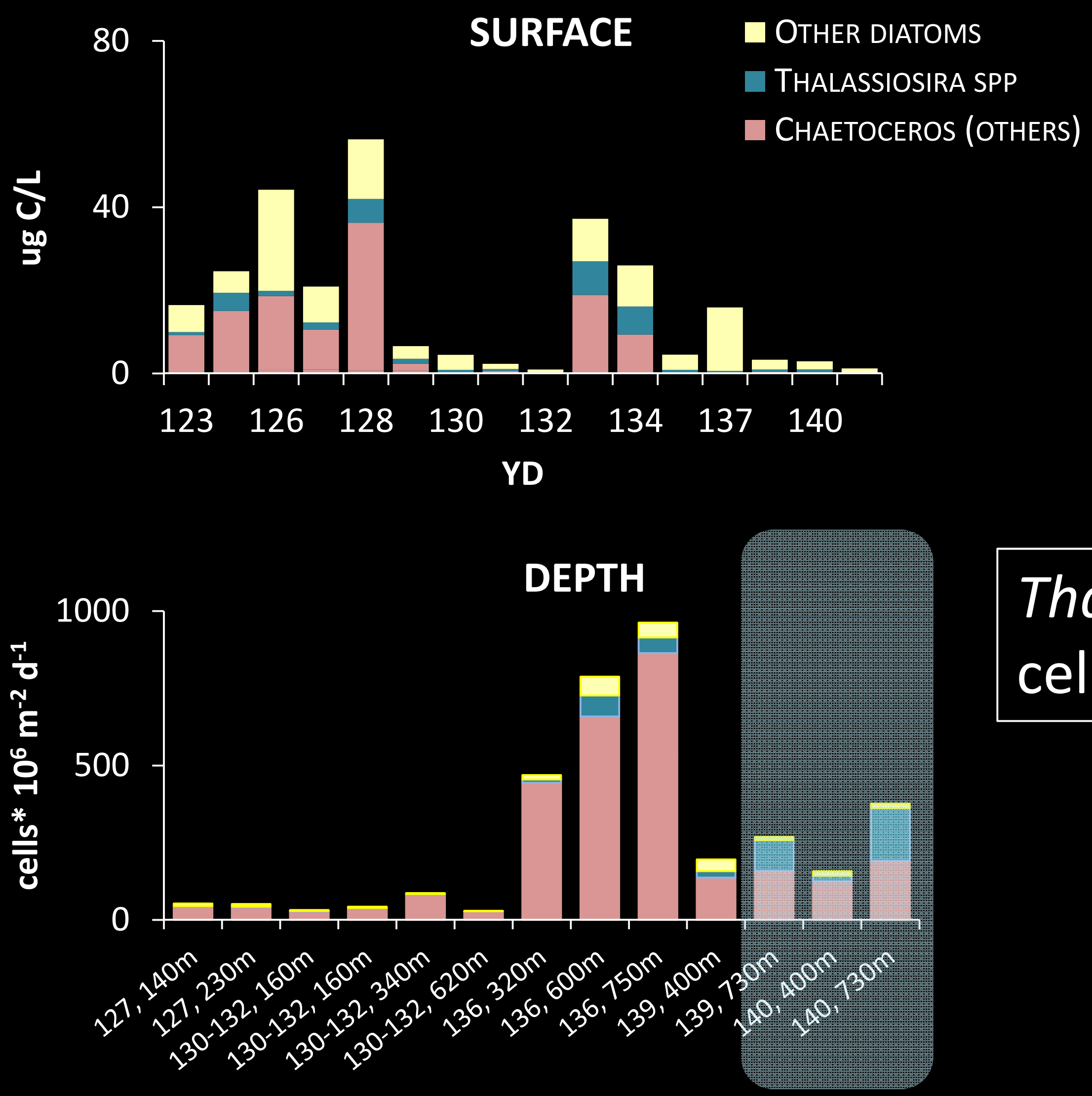


(Horner 2002)



Cetinic et al., in review

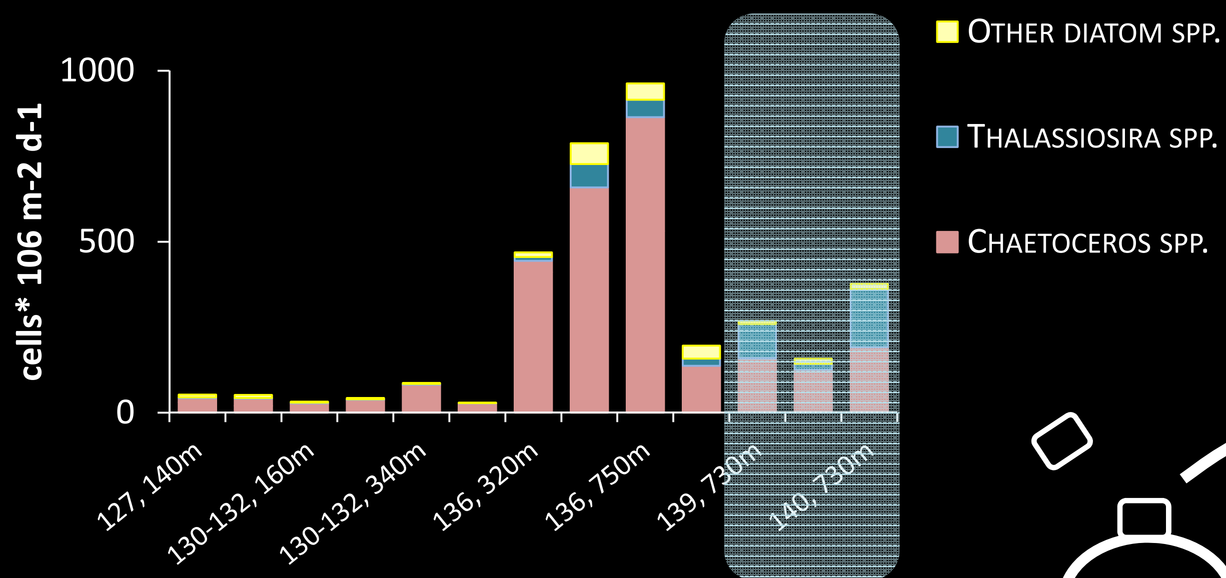
Signal of sex in North Atlantic fluxes?

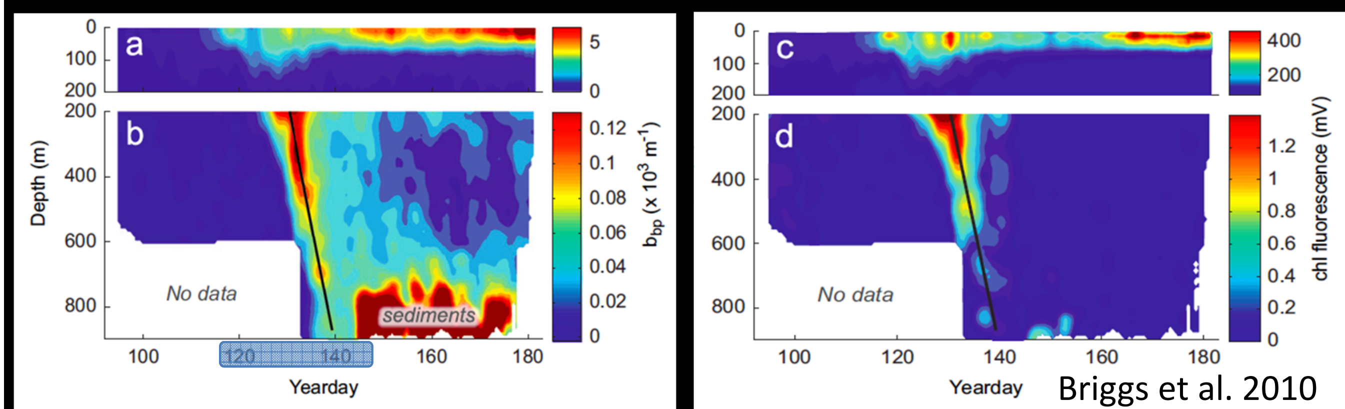


Thalassiosira spp.: 45% of cell flux on YD 140

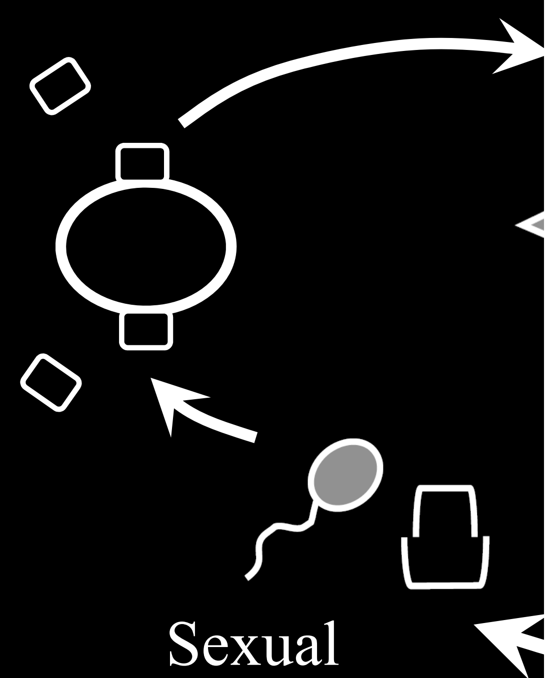
Gang and Rynearson, in prep

Signal of sex in North Atlantic fluxes?

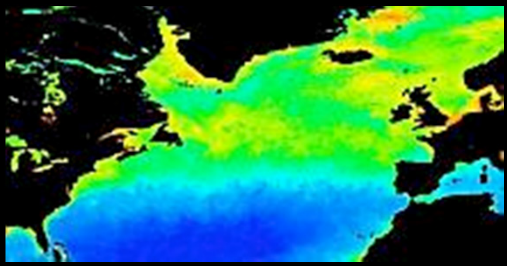




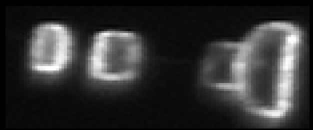
Briggs et al. 2010

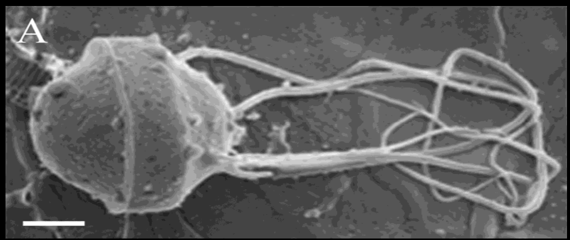


Biogeochemical and Ecological Implications

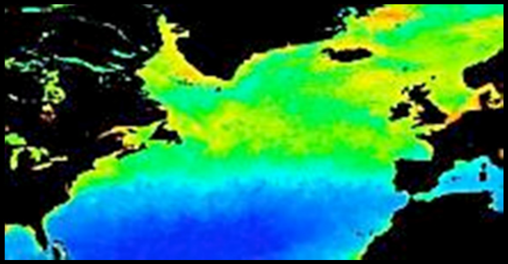


- Ragueneau's "biggest challenge." How does plankton ecology impact vertical flux?
- Individual species matter.
  - Non-dominant species can contribute disproportionately to carbon flux.
- Life history stage matters.
  - Resting spores may play a larger role than suspected in the efficient and rapid transport of POC to depth in the open ocean
  - Spore formation = strong and efficient biological pump in N. Atlantic
- Sexual reproduction
  - Leads to mass sedimentation of empty frustules. Role in fluxes still open question.





Conclusions



- Processes at the species level can influence fluxes
- Currently, we lack a mechanistic understanding of many of these processes
- Implications for our ability to forecast changes in response to climate change
- N. Atlantic-Arctic program:
  - To understand the mechanisms contributing to fluxes, need to include a focus on individual taxa and the array of species-specific processes that lead to episodic, but significant, fluxes to depth.

Thank you!