Unexpected Importance of the Smallest Phytoplankton in the Northern Gulf of Alaska Ecosystem

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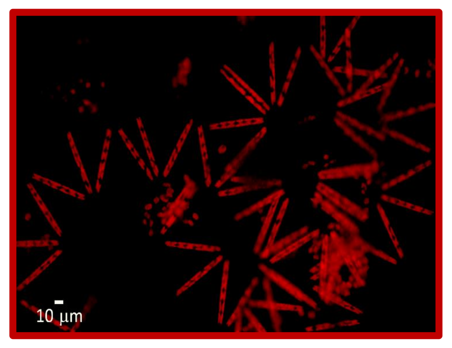
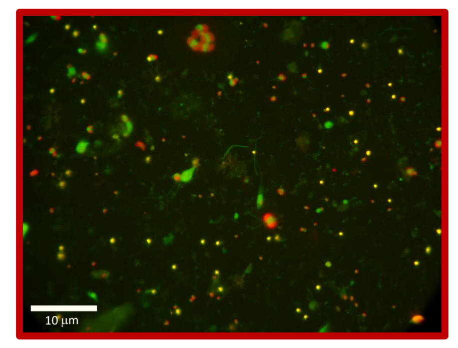
Background

While the importance of diatom blooms to northern coastal ecosystems is well known, our recent work in the northern Gulf of Alaska (NGA) has highlighted the high abundance and multiple roles of the smallest phytoplankton (the cyanobacteria *Synechococcus* and <20 µm flagellates) in the planktonic ecosystem.



Epifluorescent microscope photo of a spring diatom bloom in the NGA. Diatom blooms occur in the spring, and in a few "hot spots" like fronts and eddies.



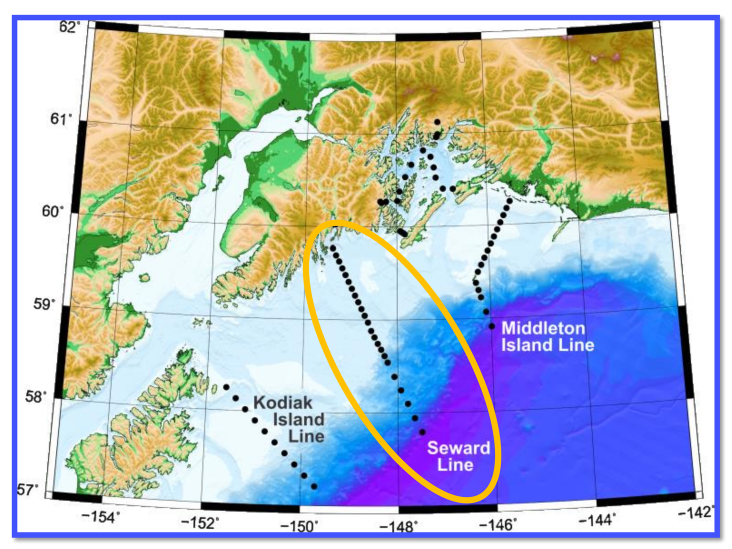
Most often the NGA planktonic community is comprised of small cells – autotrophs, heterotrophs, mixotrophs and picocyanobacteria.

Study site and sampling parameters

As part of the Northern Gulf of Alaska Long Term Ecological Research Program (NGA LTER), spring, summer and fall cruises occur every year.

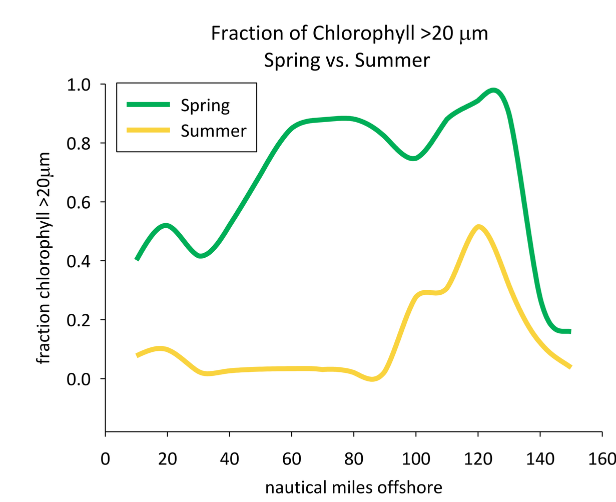
Lower trophic level variables measured (2018 data shown here):
* Biomass (chlorophyll and carbon)
* Primary production (^{13}C)
* Community composition

In summer 2019, experimental studies measured:
* Phytoplankton growth and microzooplankton grazing rates
* Photosynthetic efficiencies (Fv/Fm)
* Mixotroph grazing on picocyanobacteria

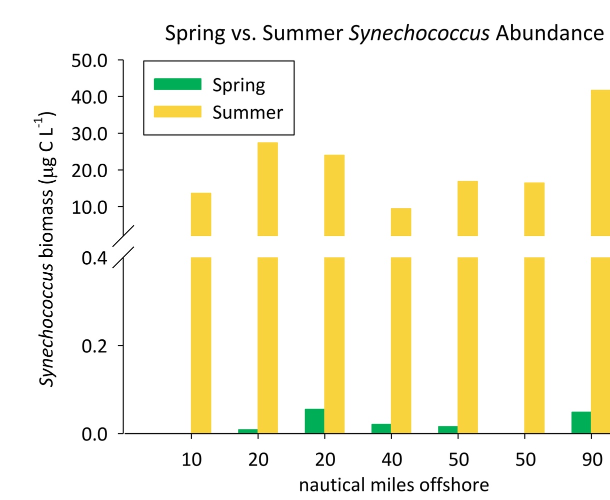


NGA LTER study area. Most of the data shown were collected along the Seward line (center).

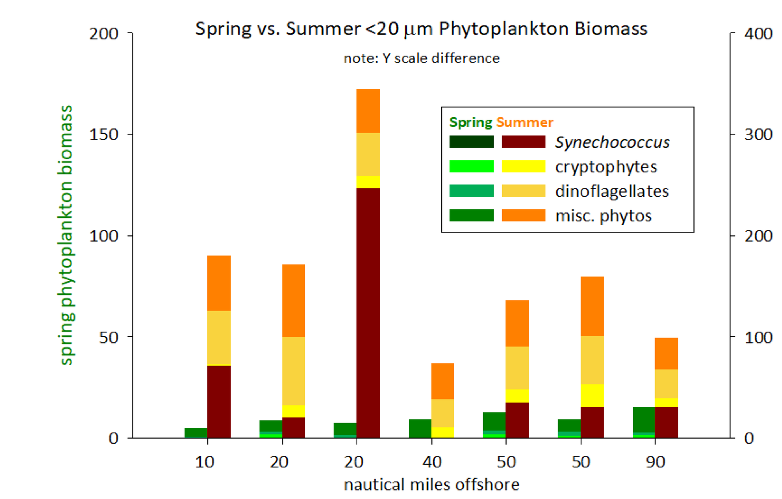
Pre- and post-bloom, small phytoplankton cells dominate



Across the shelf, the fraction of the total chlorophyll in large (>20 µm) cells in spring (green) vs. summer (yellow) at 10 meters. **Most of the phytoplankton is large cells in the spring and small in the summer.**

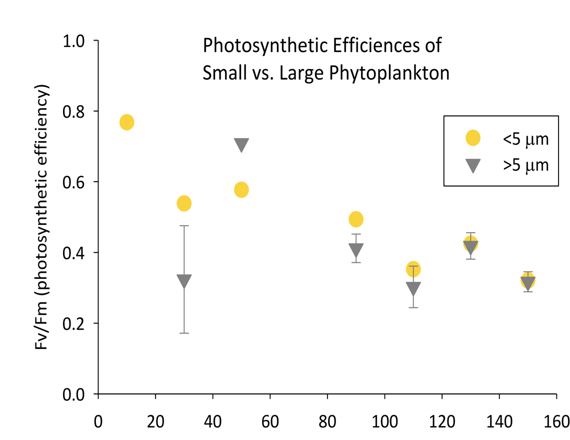


Biomass of picocyanobacteria *Synechococcus* in spring (green) and summer (yellow) at 10 meters. ***Synechococcus* abundance (cells/ml) was 1000x higher in summer vs. spring**.

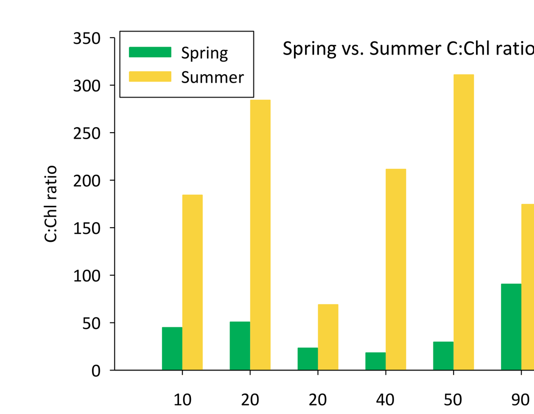


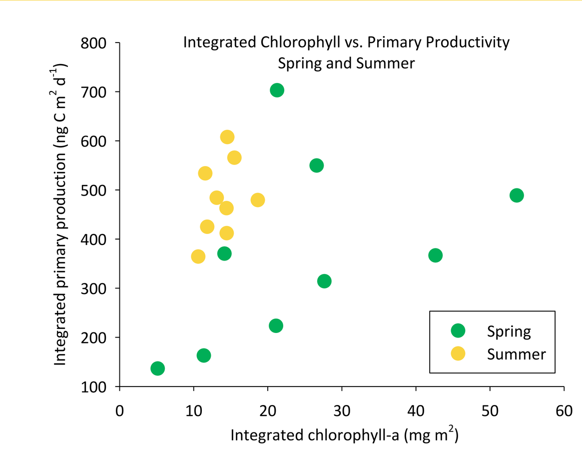
The spring (greens) and summer (oranges) biomass of the small phytoplankton, broken down into 4 taxonomic categories at 10 meters. **Small phytoplankton biomass was 14x higher in summer vs. spring.**

Small cell-dominated communities are doing well



Left: Fv/Fm is a measure of photosynthetic efficiency – 10 meter summer plankton were size-fractionated into very small cells (<5 µm), and larger cells (>5 µm). **The smallest cells often have the highest photosynthetic efficiencies**, the exception being stations farthest offshore, where efficiencies are the same.

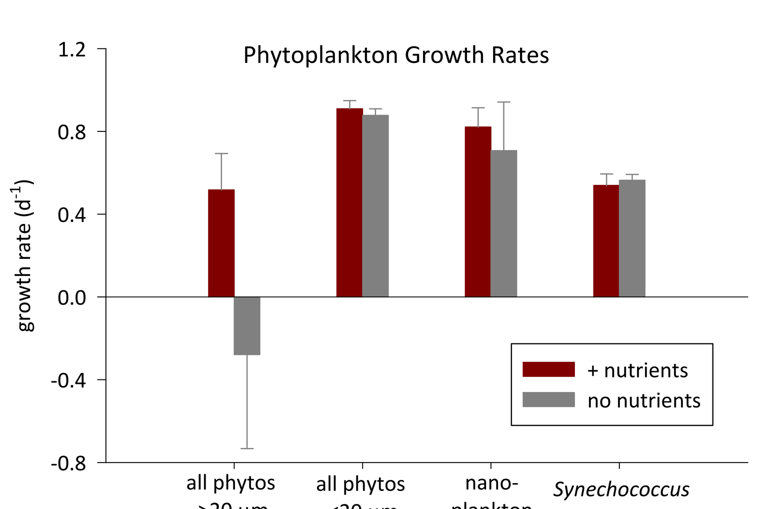




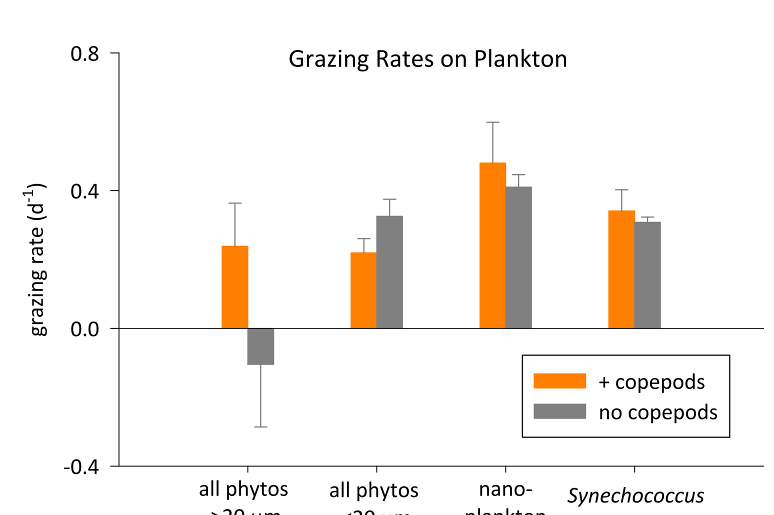
Left: spring (green) and summer (yellow) carbon to chlorophyll (C:Chl) ratios for the <20 µm phytoplankton at 10 meters. Right: integrated primary production rates as a function of chlorophyll biomass, samples taken in 2018 throughout the euphotic zone. **Summer communities had 5x higher C:Chl ratios, and 3x more carbon fixation per unit chlorophyll.**

Small cells are significant contributors to the NGA food web

Small phytoplankton are growing and being eaten rapidly

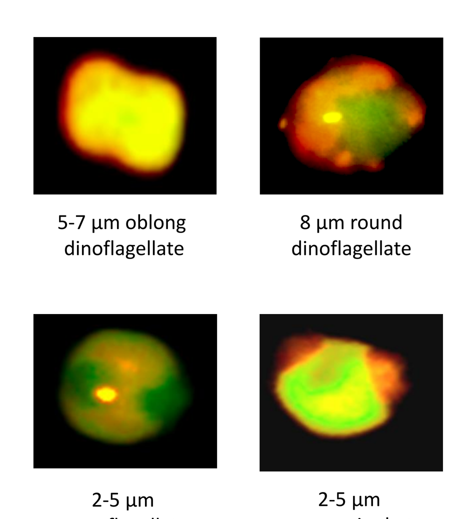


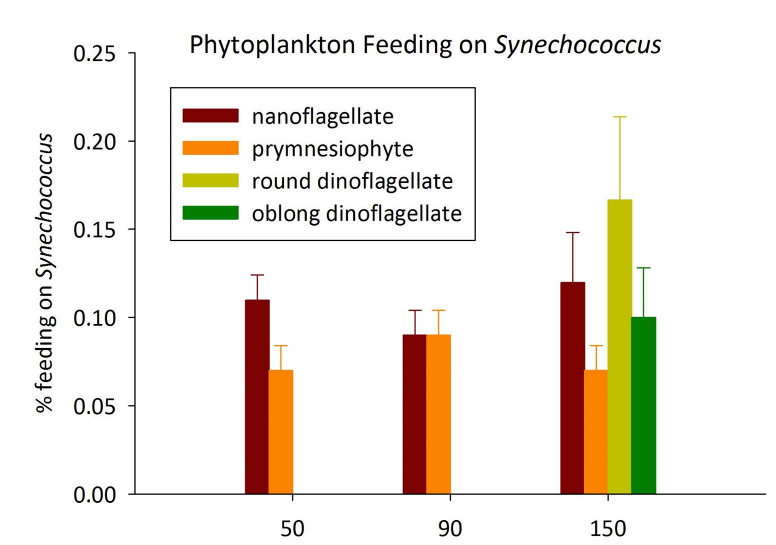
Phytoplankton intrinsic growth rates in summer for large (>20 µm) vs. small (<20 µm) cells, determined from chl-a dynamics in dilution experiments from 4 meters depth, 50 nm offshore along the Seward line. Nanoplankton and *Synechococcus* within the <20 µm size fraction were quantified with flow cytometry. **Small phytoplankton had the highest growth rates and, unlike the larger cells, were not nutrient limited.**



Microzooplankton grazing rates in summer from the same dilution experiments, with and without the addition of copepods *(Pseudocalanus* spp.). **Microzooplankton grazing was substantial on all small phytoplankton cells.** The addition of copepods only strongly affected the largest cells.

Mixotrophy: small phytoplankton are feeding on *Synechococcus*





Mixotrophy, by definition, is when a single organism has multiple modes of nutrition (e.g. photosynthesis and phagotrophy). Left: four types of phytoflagellates that were ingesting *Synechococcus* (yellow-fluorescing inclusions) in the NGA in summer 2019. Experiments were performed at the 50% light level (4 or 5 meters) along the Seward line. Right: the percent of each phytoflagellate population with ingested *Synechococcus* at three different locations across the shelf. Mixotrophic dinoflagellates were only observed in high abundances at the farthest offshore station, but **feeding on *Synechococcus* by photosynthetic flagellates was occurring at all stations.** Feeding by obligately photosynthetic flagellates likely provides a nutrient supplement in stratified summer surface waters, promoting high Fv/Fm and growth rates in these small cells.

Conclusions

Synechococcus and small photosynthetic flagellates comprise most of the photosynthetic biomass in the NGA most of the year.

These organisms are doing well!
- Small phytoplankton have high photosynthetic efficiencies and high, non-nutrient-limited growth rates
- Very high *Synechococcus* abundances - is it because they produce iron-binding siderophores?

Small phytoplankton are active participants in the food web:
- Grazed on at high rates by 'microzooplankton'
- Many phytoflagellate groups are mixotrophic (i.e. phytoplankton are part of the 'microzooplankton')
- Grazing by small phytoplankton could contribute to high growth rates

Importance of the C:Chl ratio:
Very high C:Chl ratios make it easy to underestimate the importance of small cells - the use of chlorophyll to predict biomass and production in the NGA will result in significant underestimates, unless seasonally and spatially adjusted C:Chl ratios are used.

In Summary:
Biochemical (high C:Chl) and nutritional (mixotrophy) adaptations allow the smallest phytoplankton to thrive and likely dominate carbon fixation and lower trophic level carbon fluxes during large portions of the year in the NGA.

Acknowledgements

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