Massive Phytoplankton Blooms Under Arctic Sea Ice

Kevin R. Arrigo,*† Donald K. Perovich, Robert S. Pickart, Zachary W. Brown, Gert L. van Dijken, Kate E. Lowry, Matthew M. Mills, Molly A. Palmer, William M. Balch, Frank Bahr, Nicholas R. Bates, Claudia Benitez-Nelson, Bruce Bowler, Emily Brownlee, Jens K. Ehn, Karen E. Frey, Rebecca Garley, Samuel R. Laney, Laura Lubelczyk, Jeremy Mathis, Atsushi Matsuoka, B. Greg Mitchell, G. W. K. Moore, Eva Ortega-Retuerta, Sharmila Pal, Chris M. Polashenski, Rick A. Reynolds, Brian Schieber, Heidi M. Sosik, Michael Stephens, James H. Swift

The seasonal sea ice and snow cover in the Arctic Ocean strongly reflect and attenuate incoming solar radiation. Consequently, current estimates of pan-Arctic primary productivity assume that the growth and biomass of phytoplankton, free-floating single-celled photosynthetic organisms at the base of the marine food web, are negligible in waters beneath ice because of insufficient light (*1*). However, during the 2011 ICESCAPE (Impacts of Climate on EcoSystems and Chemistry of the Arctic Pacific Environment) cruise, we observed a massive phytoplankton bloom that had developed beneath the 0.8- to 1.3-m-thick first-year sea ice on the Chukchi Sea continental shelf.

From 4 to 8 July, we sampled (*2*) along two 250-km transects extending from open water far into the ice pack (fig. S1). Depth-integrated phytoplankton biomass beneath the ice was extremely high (Figs. 1, A and B), about fourfold greater than in open water. This massive under-ice bloom extended for >100 km into the ice pack. Peak particulate organic carbon biomass (28.7 to 32.5 g C m^{-2}) was located far within the pack in the vicinity of the shelf break where ice was thickest and nutrient upwelling had been driven by easterly winds. Biomass was greatest (>1000 mg C m^{-3}) near the ice/seawater interface and was associated with nutrient depletion to depths of 20 to 30 m (Fig. 1, C and D), indicative of phytoplankton, rather than ice algal, growth. Species composition of the bloom was distinct from that in the overlying ice and was overwhelmingly (>80% by cell cross-sectional area) dominated by healthy pelagic diatoms of the genera *Chaetoceros*, *Thalassiosira*, and *Fragilariopsis*. Furthermore, rates of phytoplankton growth (0.83 to 1.44 day^{-1}) and carbon fixation (1.2 to 2.0 mg C mg^{-1} chlorophyll *a* $hour^{-1}$), and the maximum efficiency of photosystem II (>0.5), were high to depths of >50 m within the under-ice bloom.

In contrast, phytoplankton biomass in open waters was markedly lower than that beneath the ice and was greatest at depths of 20 to 50 m (Fig. 1, A and B) because of nutrient depletion near the surface (Fig. 1, C and D). The high oxygen (480 μmol l^{-1}) and low dissolved inorganic carbon (2020 μmol l^{-1}) relative to the low phytoplankton concentrations (~150 mg C m^{-3}) in these nutrient-depleted waters suggest that they had recently supported high rates of phytoplankton growth. Thus, the ice-free portions of both transects likely harbored remnant under-ice blooms that had developed near the surface weeks earlier, when the region was ice-covered.

The light required by the under-ice bloom had to penetrate the fully consolidated ice pack to reach the upper ocean. Light transmission through ice was enhanced by a recent increase in the fraction of first-year ice, which is much thinner (0.5 to 1.8 m) than the historically dominant multiyear ice pack (2 to 4 m), and especially by a high surface melt pond fraction (25 to 50%). Optical measurements showed that the ice beneath these melt ponds transmitted fourfold more incident light (47 to 59%) than adjacent snow-free ice (13 to 18%). Although the under-ice light field was less intense than in ice-free waters, it was sufficient to support the blooms of under-ice phytoplankton, which grew twice as fast at low light as their open ocean counterparts.

The Arctic Ocean has an enormous, mostly ice-covered continental shelf, ~50% of which has surface nitrate concentrations >10 μmol l^{-1} in early spring (*3*), making these potential sites for under-ice phytoplankton blooms. Previous reports hinted at similar blooms in the Barents Sea, Beaufort Sea, and Canadian Arctic Archipelago (*4*–*6*), suggesting that under-ice blooms are widespread. If so, current rates of annual net primary production on Arctic continental shelves, based only on open water measurements, may be drastic underestimates, being 10-fold too low in our study area. Work is still required to determine the timing and spatial distribution of under-ice phytoplankton blooms across the Arctic Ocean, the extent to which they are controlled by thinning sea ice and proliferating melt pond fractions, and how they affect marine ecosystems. This is particularly important if we are to understand and predict the biological and biogeochemical impacts of ongoing and future changes in the Arctic Ocean physical environment.

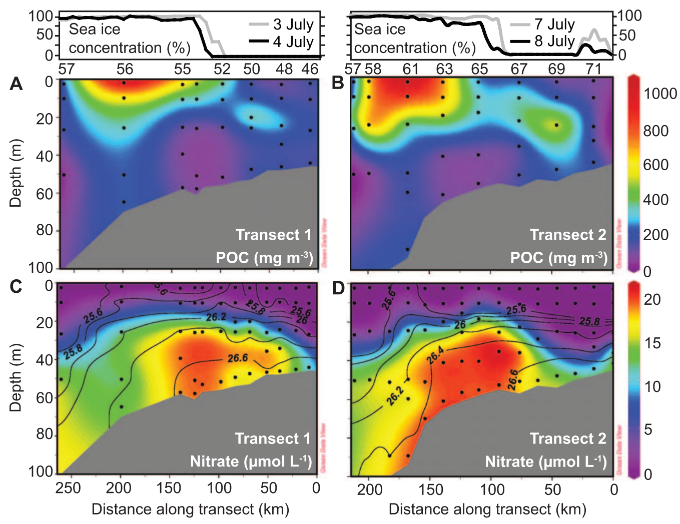

Fig. 1. Under-ice phytoplankton bloom observed during ICESCAPE 2011. (**A**) Particulate organic carbon (POC) and (**C**) nitrate from transect 1. (**B**) POC and (**D**) nitrate from transect 2. Sea ice concentrations and station numbers are shown above (A) and (B); black dots represent sampling depths; black lines denote potential density.

References and Notes

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Supplementary Materials

www.sciencemag.org/cgi/content/full/336/6087/1408/DC1
Materials and Methods
Fig. S1
References (*7*–*15*)

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*The full list of author affiliations can be found in the supplementary materials.

†To whom correspondence should be addressed. E-mail: arrigo@stanford.edu