Smallest Algae Thrive As the Arctic Ocean Freshens

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As global climate changes, conditions will favor some organisms more than others; there will be ecological winners and losers. In the Arctic, rising air temperature, increasing precipitation, higher river flows, and declining snow cover have lead to large and rapid change in the upper ocean. Surface waters in the Canada Basin have also freshened in recent years because of increased sea ice meltwater and episodic input of large river runoff (*1*). The reduction of sea ice in summer, which is occurring more rapidly than forecasted (*2*), may affect phytoplankton production. As the ice edge retreats away from the continental shelf break, wind-driven upwelling of deep nutrient-rich waters can be expected to enhance shelf production (*3*). A greater open sunlit area and a longer growing season also combine to increase annual primary production (*4*); however, Arctic phytoplankton production appears to be limited by the supply of nitrogen and not cumulative irradiance (*5*). The constraints and requirements imposed by nutrients differ among phytoplankton types, so the response to change presumably differs.

Here, we show that, in the changing Arctic Ocean, the smallest phytoplankton cells thrive but larger cells languish. Although the time series of basinwide summer averages is short, the trend of a warmer and fresher upper ocean is evident (Fig. 1A) from a repeated survey of 23 stations (figs. S1 and S2). The density of deep water has remained about the same over this period, so the decreasing density of the upper ocean results in stronger stratification (Fig. 1A). Similarly, deep water nutrients have not changed, but upper ocean nutrients have decreased (Fig. 1A). Picoplankton, being very small (<2 μm diameter), have a large surface-area-to-volume ratio that provides effective acquisition of nutrient solutes and photons, as well as hydrodynamic resistance to sinking. Predictably (*6*), these cells increased (Fig. 1B) in a regime of lower nitrate supply and greater hydrodynamic stability. Conversely, larger nanoplankton (2 to 20 μm) decreased (Fig. 1B). Upper ocean bacterioplankton increased at the same relative rate (~10% year^{-1}) as picophytoplankton, but deep ocean bacterioplankton remain unchanged (Fig. 1C), suggesting that heterotrophic and photosynthetic changes are coupled in the picoplankton. A reduction in community average body size because of an increase in the abundance of individuals belonging to small-sized species may be a common response to global warming (*7*).

Total phytoplankton biomass, represented as the universal photosynthetic pigment chlorophyll *a*, remained unchanged (Fig. 1B). This biomass, alternately represented as the sum of diagnostic pigments (*8*), is largely (~85%) a complementary mix of cells containing either chlorophyll *b* (picoplanktonic green flagellates) or fucoxanthin (microplanktonic diatoms) (Fig. 1D). Prasinophytes, especially a genetically unique pan-Arctic cold-adapted ecotype of *Micromonas*, constitute a large proportion of picophytoplankton in these waters (*9*). Accepting a time-for-space substitution, the observed increase in picoplankton may thus be associated with a redistribution of pigment groups within the community observed across stations. A secular trend cannot be discerned without a much longer observational time series because of inherent interannual variability. However, if current changes persist, an altered food web may be expected because community size structure is a strong determinant of ecosystem carbon flux. Picoplankton-based systems tend not to support large exports of biogenic carbon, either for extraction (e.g., harvest) or for sequestration (e.g., burial).

References and Notes

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10. Financial and ship time support were provided by Fisheries and Oceans Canada, International Polar Year Program Canada's Three Oceans project, U.S. NSF Beaufort Gyre Exploration Project, and the Japan Agency for Marine-Earth Science and Technology. We thank S. Zimmermann, J. Eert, K. Scarcella, D. Horn, T. Perry, and the men and women of Canadian Coast Guard Ship *Louis S. St-Laurent*.

Supporting Online Material
www.sciencemag.org/cgi/content/full/326/5952/539/DC1
Materials and Methods
Figs. S1 and S2
References

28 July 2009; accepted 9 September 2009
10.1126/science.1179798

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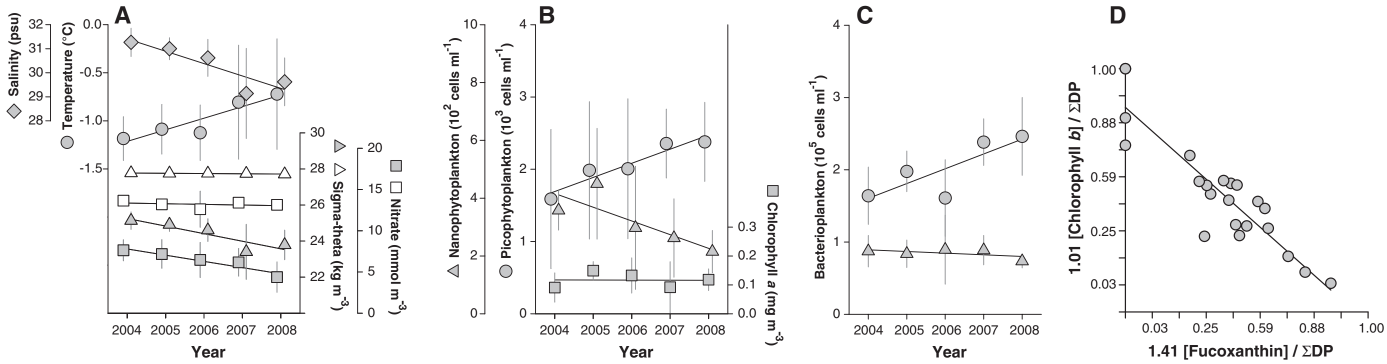

Fig. 1. Summer conditions in the Canada Basin. (**A**) Upper ocean (gray symbols) temperature (P = 0.05), salinity (P = 0.0004), density (P = 0.001), and nitrate (P = 0.06); deep ocean (open symbols) density (P = 0.8) and nitrate (P = 0.9). (**B**) Upper ocean picophytoplankton (P = 0.01), nanophytoplankton (P = 0.09), and chlorophyll *a* (P = 1.0). (**C**) Upper ocean (circles, P = 0.09) and deep ocean (triangles, P = 0.3) bacterioplankton. Error bars are standard deviation of station averages (fig. S1); probability values test for significance of linear regression. (**D**) Proportion (p) of phytoplankton biomass (ΣDP is the sum of diagnostic pigments) represented by green flagellates (1.01Chl*b*) versus diatoms (1.41Fucoxanthin) from 2007 station survey shown on angular transformed scale (arcsin $p^{1/2}$) for normalization of platykurtic distribution, according to pigment scheme of Uitz *et al.* (*8*).