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### **Decreasing phytoplankton size adversely affects ocean food chains**

Commentary on Schmidt et al. *Increasing picocyanobacteria success in shelf waters contributes to long-term food web degradation*

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Skilful projection of the impacts of global changes on marine systems depends on better representation of the mechanisms that link processes across scales from the sub-microscopic to the oceanic. The diversity, complexity and range of scales over which the life histories of bacteria, primary producers and animals play out in the oceans makes this a daunting challenge.

However, a recent paper on the increasing abundance of picocyanobacteria in NE Atlantic shelf waters in summer (Schmidt et al. 2020) provides an example of our ability to observe and interpret across a huge range of scales. The consequences of the increase, particularly in *Synechococcus*, affect the role of the oceans in both carbon sequestration and food production. An increase in the proportion of primary production by nano- and picophytoplankton has qualitative as well as quantitative consequences for future food production from the oceans, since this is where the biosynthesis of important components of our diet takes place.

### **Background from a recent Earth System Model (ESM)**

Change in net primary production of the oceans (NPP) affects climate-carbon pathways as well as production of their grazers and higher predators including fish. Climate-carbon pathways include export of organic carbon to the deep oceans and effects on atmospheric CO<sub>2</sub>. There is satellite

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evidence that NPP has been declining since 1980 (Boyce, Lewis, & Worm, 2010; Gregg, Conkright, Ginoux, O'Reilly, & Casey, 2003, Gregg & Rousseaux, 2019). In spite of uncertainties, ESMs also broadly agree that global NPP is declining and will continue to decline as warming of the upper layers of the oceans enhances stratification and reduces vertical resupply of nutrients (Elsworth, Lovenduski, McKinnon, Krumhardt, & Brady, 2020). The projected decline in NPP is greater at low and mid-latitudes, but is partly offset at higher latitudes because light becomes less limiting as the mixed layer depth rises and sea ice disappears.

A 21<sup>st</sup> century decline in NPP of the North Atlantic of 17% (0.7 PgC/yr) was projected by a recent ESM study (Kwiatkowski et al., 2019) under the extreme IPCC RCP 8.5 scenario, and with even greater decline when Greenland ice melt is included in the model. Nanophytoplankton and diatoms are represented in this ESM, with the latter declining twice as fast as the former due to greater sensitivity to low nutrient levels. Thus, not only is the NPP declining, but the composition of primary producers is changing as well. This provides a global background against which to compare the results of the paper by Schmidt et al. 2020 on the increase in picocyanobacteria in NE Atlantic shelf waters and the effects that this has on the planktonic and higher food web.

Picophytoplankton (0.2-2µm), which are not included in this recent ESM, are less sensitive than nanophytoplankton (2-20µm) to low nutrient levels, but probably contribute less to both carbon sequestration and marine food chains leading to fish.

### **Long-term food web degradation**

Schmidt et al. observed that in the western English Channel picophytoplankton increased to up to 90% of the combined pico- and nanophytoplankton biomass during summer, associated with reduced nutrient availability due to lower river runoff. The cyanobacterium *Synechococcus* in particular has a competitive advantage and flourishes when iron and nitrogen resupply to surface waters is diminished. Summer transects across the Celtic Sea show increases in *Synechococcus* across the shelf, but at the shelf break, where internal tides mix the water column and nutrients are resupplied from depth, the summer abundances of *Synechococcus* remain low. They also analysed satellite (1997- 2018) and Continuous Plankton Recorder (1958-2017) data for the NE Atlantic shelf to show that summer abundances of picophytoplankton increased, while diatoms, dinoflagellates, and copepods declined, with copepods declining by as much as ~50% during the 60 year period.

Global fisheries are mainly located on the continental shelves and are dependent on seasonal production of zooplankton that feed on diatoms and dinoflagellates. The food chain from picophytoplankton to fish passes through more trophic steps and is therefore less efficient.

*Synechococcus* is particularly poor as a base for the food chain to fish because the price paid for being able to utilise very low levels of light and iron is low conversion efficiency. Also, cyanobacteria do not produce essential biomolecules such as omega-3 polyunsaturated fatty acids and sterols.

## Conclusions

The consequences for climate-carbon pathways of a decline in NPP, with a greater fraction coming from nano- and picophytoplankton, are not dealt with by Schmidt et al. but are of obvious concern. In addition to the possible effect of the decreasing phytoplankton size composition on export of carbon to the deep ocean (Mousing, Ellegaard, & Richardson, 2014), it is known that *Synechococcus* is abundant in the coastal upwelling along the Arabian Peninsula during the SW monsoon period (July – September) when the flux of CO<sub>2</sub> to the atmosphere is high (Goyet et al., 1998; Tarran, Burkill, Edwards, & Woodward, 1999).

The results of Schmidt et al. indicate that the changes that have taken place in primary producers and zooplankton on the NE Atlantic shelf over the past 60 years are substantial and have had consequences for fisheries and probably also for climate-carbon pathways. Both the quantitative and qualitative impacts need to be taken into account in making projections for the 21<sup>st</sup> century. The value of continued monitoring of all sizes of plankton is evident as is the need to determine whether similar changes in plankton size structure are happening globally.

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