An Alternate Future for the Oceans Biological Carbon Pump

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Covering roughly 60% of the ocean’s surface area, oligotrophic gyres are extremely important components of the global ocean carbon cycle. One such gyre, the Sargasso Sea, is arguably the most well studied region in the open ocean with the longest continuous hydrographic time-series, Hydrostation ‘S’ dating back to the mid-1950’s and one of the longest biogeochemical time-series, the Bermuda Atlantic Time-series Study (BATS) dating back to 1988. Through these programs, scientists at the Bermuda Institute of Ocean Sciences (BIOS) have documented substantial changes not only in ocean hydrography but also biology and geochemistry of the upper ocean.

Over the past several decades, the waters above the permanent thermocline have warmed by near ~0.5°C and have become saltier by ~0.1 units, although there is very high year to year variability, resulting in a general increase in stratification. Over much of this same period, CO\textsubscript{2} concentrations have increased significantly, roughly 40 \textmu m\textsuperscript{atm}, showing clear evidence of ocean acidification. These changes have been tightly linked to climate change, however the response of ocean biology and the biological carbon pump have been as predicted.

Over the past two decades phytoplankton biomass has increased substantially, with a shift in biomass from larger phytoplankton (e.g. diatoms) to increased importance of smaller photosynthetic bacteria – an observation consistent with hypothetical responses to increased stratification (Lomas et al. 2010, see Figure). Unexpected however was the increase in rates of primary production and size-fractionated zooplankton biomass. A paradigm in oceanography is that communities dominated by small cells, as a result of high grazing rates, have stable biomass levels due to tight coupling of trophic levels. These data from BATS counter that idea and show that there can be significant accumulation of biomass at multiple trophic levels.

Perhaps a more important observation for understanding the biological sequestration of carbon in the ocean is the observed increase in particulate carbon export from the Sargasso Sea euphotic zone. There are several mechanisms that can account for this increase. The first, and most obvious, is the increase in zooplankton biomass and associated increase in active and passive carbon fluxes. Second is the recently recognized role of aggregation and export of small photosynthetic plankton previously considered to not contribute to particulate carbon export. Lastly, is the deviation of particulate nutrient ratios, namely carbon, nitrogen and phosphorus, from their canonical ratio, defined as the Redfield ratio, in response to reduced nutrient inputs associated with increased stratification. Direct evidence for the latter two mechanisms has recently been documented at BATS.

Reasonable predictions of the future strength of the oceans biological carbon pump, in response to the impact of climate change on the oceans, will require incorporation of these newly appreciated ‘ecosystem mechanisms’, which may be relevant in other ocean time-series locations, and move beyond simple paradigms of the past.