**Will Phytoplankton Continue to Help with Removing Carbon Dioxide From the Atmosphere?**

By Tara Illgner

The oceans cover over 70% of our planet and contain 99% of the living space on Earth.[[1]](#endnote-1) Phytoplankton are microscopic free-floating plants throughout the world’s oceans[[2]](#endnote-2) that act as the oceans’ lung by moving carbon dioxide from the atmosphere into the ocean and moving oxygen out into the atmosphere, making them profound controllers of the atmosphere. While the US congress discusses the enormous cost of trying to save our planet by investing in facilities that could actively remove carbon dioxide (CO2) from the atmosphere, called Carbon Capture and Storage (CCS), mighty microscopic phytoplankton have been quietly performing this tremendous service to our planet for free! Annually, this global biological carbon pump moves 10 gigatons of carbon from the atmosphere to the deep ocean[[3]](#endnote-3), and produces half of the Earth’s oxygen[[4]](#endnote-4).

Ranging in size between 0.2µm and 200µm, phytoplankton are tiny, ubiquitous, and able to feed themselves with just sunlight, CO2 and nutrients, making them the *primary producers* of food at the foundation for the ocean’s food webs. So, in addition to making the atmosphere more habitable for oxygen-dependent land-animals like ourselves, these tiny plants also serve the ocean’s food web by transforming inorganic resources (sunlight and CO2) into usable energy and nutrients, that the rest of the marine food chain depends on to build their bodies and perform their own critical functional roles. Therefore, any changes among these tiny primary producers can mean profound changes for the world’s oceans and atmosphere that serve and protects us in innumerable ways.

There are different types of microscopic primary producers, also called algae, in the world’s oceans. While the most common algae are the free-floating phytoplankton mentioned above, arctic regions are also home to other types of algae, including those that grow on ice, under ice, and on the edges of ice. As primary producers, these organisms need access to nutrients, such as nitrogen and phosphorous, in addition to sunlight and CO2, in order to do the important work of bringing digestible energy into the ocean to feed the rest of the ocean’s living community. In this way, the foundation of this interconnected ecosystem relies on a comfortable combination of these key ingredients (sunlight, CO2, and nutrients). However, the availability of these ingredients is rapidly changing:

* + 1. *Too much of one key ingredient*: Due to human fossil fuel emissions there is an ever-increasing concentration of CO2 in the atmosphere. While CO2 is necessary for primary producers, on land and in the ocean, to use during photosynthesis, what happens when there is too much CO2?
    2. *Ice melts in a hot car*: A significant property of CO2 is that in the atmosphere these molecules act as a windshield on a car, trapping in more heat within our atmospheric bubble than Earth’s ecosystems have adapted to function in. Furthermore, as the planet heats up under this chemical “windshield”, more sea ice melts, uncovering more open ocean and further increasing the amount of sunlight that is able to reach and warm the ocean.
    3. *Watered-down ocean*: Melting ice also adds more fresh water to the salty ocean; diluting the ocean’s salinity the same way melted ice-cubes dilute the flavor of soda on a hot day. But it turns out that the ocean’s saltiness, or salinity, also changes the way important things work; affecting the ocean’s chemistry, physical properties, and movement (horizontal currents and vertical mixing of nutrients).
    4. *Soda dissolves teeth*: Just as soda is CO2 dissolved in water to create a more acidic (lower pH) liquid that, while tasty, dissolves our calcium-rich teeth, similarly the ocean’s exposure to higher concentrations of CO2 due to fossil fuel emissions also means that the ocean is also becoming more acidic, dissolving the calcium-rich body components of marine organisms.[[5]](#endnote-5) Whereas warm sodas become “flat” quickly, cold sodas remain carbonated longer because cold water can hold more CO2 than warm water can. This means that less ice cover in the arctic exposes more of the cold ocean water to the high atmospheric CO2 concentrations, making arctic waters acidify faster than warmer waters. While loss of calcium from our teeth and bones generally occurs momentarily and sporadically as we sip an occasional soda, marine organisms’ calcium-rich bodies are continually immersed in the increasingly acidic ocean water, making these organisms and the ecosystems that rely on them much more vulnerable to loss under these acidic conditions.
    5. Dark T-shirt versus light t-shirts: As more ice melts, it exposes the dark cold water underneath. This dark ocean water absorbs more heat (long-wave radiation) just as wearing a black t-shirt on a hot day absorbs more heat than a white t-shirt. The ice acts as a white t-shirt, reflecting radiation back into space (called albedo). However, with less ice coverage and more exposed dark arctic water, the Arctic Ocean is warming faster than other part of the globe, amplifying the stress of higher temperatures on the ecosystem (positive feedback).

As phytoplankton are such critical players for our oceans and atmosphere, here we will take a look at the latest research into how phytoplankton may be responding to these changing conditions and to get a glimpse of what the future may hold:

1. How are phytoplankton specifically responding to the oceans’ changing temperature, CO2 concentration, salinity, and pH?
2. Under these new climate conditions, will phytoplankton be more or less able to remove CO2 from the atmosphere?

Sugie, Fushiwara, Nishino et al.[[6]](#endnote-6) directly address these questions in their study by monitoring and comparing phytoplankton responses, specifically to higher temperature, higher CO2, and lower salinity in the arctic ocean. Their study involved incubating separate samples of Western Arctic phytoplankton under different combinations of these conditions. Overall, the authors found that these conditions of higher temperatures, higher CO2, and lower salinity, combined to result in dramatically skewing the sample populations of phytoplankton toward the smaller varieties phytoplankton (<10 µm). In other words, the larger varieties of phytoplankton languished under these conditions, while the smaller varieties thrived. Interestingly, while the overall number of phytoplankton increased, there was a significant decrease in the size of their bodies (biomass) and the diversity of varieties. While larger numbers of phytoplankton might seem to suggest that there is more demand for CO2 and therefore more CO2 uptake, the authors point out that having more *small* phytoplankton means that their bodies consume less CO2, resulting in less CO2 uptake through trophic levels (food chain). Furthermore, the study’s finding of decreased diversity can negatively affect the resilience of the ecosystem, because the fewer varieties of phytoplankton types that there are, the fewer variety of stresses they may be able to weather.

To see what effect these smaller-sized phytoplankton may have on CO2 uptake, Zhu, Suggett, Liu et al.[[7]](#endnote-7) attempted to more precisely measure CO2 uptake (using the electron requirement for carbon fixation) for communities of different phytoplankton sizes. By monitoring over 50 different sites of phytoplankton growth across different regions the arctic during the summer, they looked at the broad spatial trends of phytoplankton size, ice-cover, and the resulting CO2 uptake. Their results shared similar findings as the Sugie, Fujiwara, Nishino, et al. study; that while more sunlight reaching the ice-free ocean surface was good for photosynthesis, the CO2 uptake was actually lower among smaller-sized phytoplankton which tended to dominate in areas of less ice-cover. In other words, they found that less ice-cover tended to favor smaller phytoplankton, and smaller phytoplankton tended to take in less CO2 from the atmosphere.

If these booming populations of smaller phytoplankton are reducing the CO2 uptake in those arctic study sites, how might other types of more widely distributed phytoplankton respond? Kondrik, Kazakov, Pozdnyakov, et al.[[8]](#endnote-8) explored this question in studying the widespread Emiliania Huxleyi (EH), which is a type of phytoplankton called a coccolithophore, that depends on Calcium Carbonate (CaCO3) for their bodies, making them particularly susceptible to the ocean’s changing pH. EH is an especially important variety of phytoplankton to study because they are the most widespread coccolithophore in the world’s oceans. In their long-term study, Kondrik, Kazakov, Pozdnyakov, et al. monitored EH for 19 years (1998-2010), finding that EH’s CO2 uptake actually declined over the nearly two-decade study. The authors conclude that the increasingly acidic water, that dissolves CaCO3, destroys the EH bodily construction and function, and reducing their ability to remove CO2 from the atmosphere as well as they used to.

Similarly, the 2019 study by Vaque, Arrieta, Holding et al.[[9]](#endnote-9) examined the microbial ecosystems of the Svalbard fjords during summer, also noting a decrease in phytoplankton size and biomass leading to a decline in CO2 uptake. Their work, however, also looked at the role of increasing bacterial production due to the warmer conditions, suggesting that bacterial production may be taking up the biomass that the phytoplankton are losing. However, since the bacteria monitored in the study do not contribute to CO2 uptake, the authors surmise that the overall CO2 uptake declined in these areas.

So far, the four studies above are showing a concurring trend of reduced CO2 uptake in their findings, but is there any contrary evidence of phytoplankton responding differently? Interestingly, in the 2019 study by Juranek, Takahashi, Mathis, et al.[[10]](#endnote-10) that looked at CO2 uptake in the Pacific Arctic, found increased CO2 uptake during the late fall. Looking at overall plankton CO2 uptake over a 2 year period in the northern Pacific (Bering, Chukchi, Beaufort), these authors found that the increasingly ice-free open-water conditions were actually contributing to wind-driven mixing that increased the amount of CO2 available in the water for plankton. Their results showed short-term bursts in plankton productivity and a quick localized uptake of CO2.

Similarly, a 2019 study by Ji, Sandwith, Williams, et al.[[11]](#endnote-11) took a close-up look at the gases coming in and out of the ocean surface (top 200 meters) at 30 sites over 6 years in the Beaufort Gyre. They used of oxygen isotopes, which are unusual types of oxygen atoms, to track which way gases were flowing and how much of them. It’s already known that even though the Arctic Ocean is small, it is capable of taking in more than its fair share (per square meter) of CO2 than other parts of the world’s oceans, making the Arctic Ocean a disproportionately large “carbon sink”. By following these unusual atoms (isotopes), the researchers could measure if this part of the arctic ocean is taking in more CO2 from the atmosphere than before, or loosing more CO2 to the atmosphere than before. Their findings corroborate those of Juranek, Takahashi, Mathis et al., showing that diminished ice covering the arctic ocean surface waters, the arctic phytoplankton’s rates of photosynthesis increased and the nutrients recycling efficiency was not compromised.

Among the six studies discussed above, all published within the last year, four of them show clear evidence that arctic phytoplankton are taking up less CO2, while the other two presented evidence of arctic phytoplankton are taking up more CO2. So is arctic phytoplanktons’ CO2 uptake increasing or decreasing under these changing conditions?:

Interestingly, the 2019 study by Benner, Irwin, Finkel, at al.[[12]](#endnote-12) presented some encouraging data about phytoplankton’s potential adaptability to their dramatically changing habitat. Their study focused on Micromonas Polaris (that we will call M&M’s). By exposing this phytoplankton to different temperature treatments, sunlight exposures, and nutrient (Nitrate) levels, the authors found that M&M’s growth rates increased with higher temperatures across all treatments. Specifically, their results suggested that M&M’s actually evolved during the course of the experiment such that their optimum growth conditions actually shifted from 6oC to 13oC!

So what do these changes among the phytoplankton at the base of the food chain mean for the rest of the Arctic food web? One way to track the effect across the food-chain is by using the stable isotope, 13C to trace the carbon from phytoplankton at the base of the food-chain all the way to large mammals. One such study by Vega, Jeffreys, Tuerena, et al.[[13]](#endnote-13) addressed this question in their 2019 study that reported 30 years of marine carbon measurements across 18 ecologically diverse regions across the Arctic Ocean to trace trends in the food web. Most of the world’s carbon (~99%) is in the form of 12C, but 13C is a rare stable version (isotope) of carbon that only makes up about 1% of the world’s carbon. This unique and rare form of carbon allows researchers, such as those in this study, to measure the amount of 13C at the bottom of the food-chain, and then measure 13C at the top of the food-chain, to see how much carbon is passing through the chain. An interesting glitch in studying 13C is that fossil fuels emissions of 12C entering the atmosphere and food webs are diluting normal ratios of 13C, known as the Seuss effect. But even when accounting for the Seuss effect, Vega, Jeffreys, Tuerenta, et al. found that the ratio of 13C (δ13C) has declined among marine organisms at faster rates than had been predicted. The authors explain that while the proportion of carbon that is in the form of 13C varies greatly across the arctic, they concluded overall that as sea-ice melts, less of the 13C-rich ice-algae is entering the food web.

What do these results mean for the larger question of primary producers’ CO2 uptake? Vega, Jeffreys, Tuerenta, et al., are cautious about making larger conclusions based on this study, but their study offers a helpful lead into future work to figure out how much this phytoplankton-driven biological carbon pump is changing due to the new ocean conditions of: higher temperature, higher CO2 concentration, lower sea ice, lower salinity, and lower pH. An important point that all of the researchers here continue to press is how dynamic and variable the effects can be, both spatially and across time. The physical changes in the ocean are changing the way currents move and where nutrients and plankton end up, meaning that seasonal, annual and decadal changes in these currents make it difficult to single out which factors are dominating phytoplankton’s CO2 uptake at any given time. However, more research appears to identify phytoplankton’s decreasing biomass and CO2 uptake in response to the changing marine conditions, more closely matching the phytoplankton of lower latitudes. This poleward shift of lower-latitude marine conditions and phytoplankton demographics, described as “Atlantification”, is noted by Hop, Assmy, Wold, et al.[[14]](#endnote-14) in their 2019 study as part of the Carbon Bridge Project. Their work discusses the changing currents, biomass transport, and the variable physical, chemical, and biological consequences to the ecosystem that these changing currents may be inducing. Studies such as Hop, Assmy, Wold, et al. and Engel, Bracher, Dinter et al.,[[15]](#endnote-15) help clarify and emphasize the role of the ocean’s redistribution processes and timings. Overall, their work, concluding that the arctic marine environment will continue to exhibit more boreal characteristics of lower latitudes, helps clarify what the other studies had also noted: That while the changes are not uniform, the broad-scale changes seem to show a consistent trend of reduced CO2 uptake.

Phytoplankton have been performing this vital function of sequestering carbon deep into ocean sediments, and the majority of the studies reviewed, including those discussed here, suggest that their ability to continue their climate-mitigation work at the same rate may be in danger. Furthermore, aside from the phytoplankton’s active biological role of regulating atmospheric CO2, the physical and chemical processes that allow more CO2 to remain dissolved in colder water, will also likely change as the arctic ocean warms resulting in more CO2 being re-released to the atmosphere. The studies discussed here used a wide variety of methods, timing, and locations to assess the changing CO2 budget in the arctic ocean with profound consequences for the whole planet. While the findings by Benner, Irwin, Finkel, et al., suggest some promising alternative future outcomes for arctic phytoplankton and their CO2 sequestration, future studies may help fill in the gaps by continually repeating these experiments discussed here over new areas in the arctic, to give us a clearer picture of the direction and the rate of these “atlantification” trends.

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