Marine viruses: Submerged players of climate change

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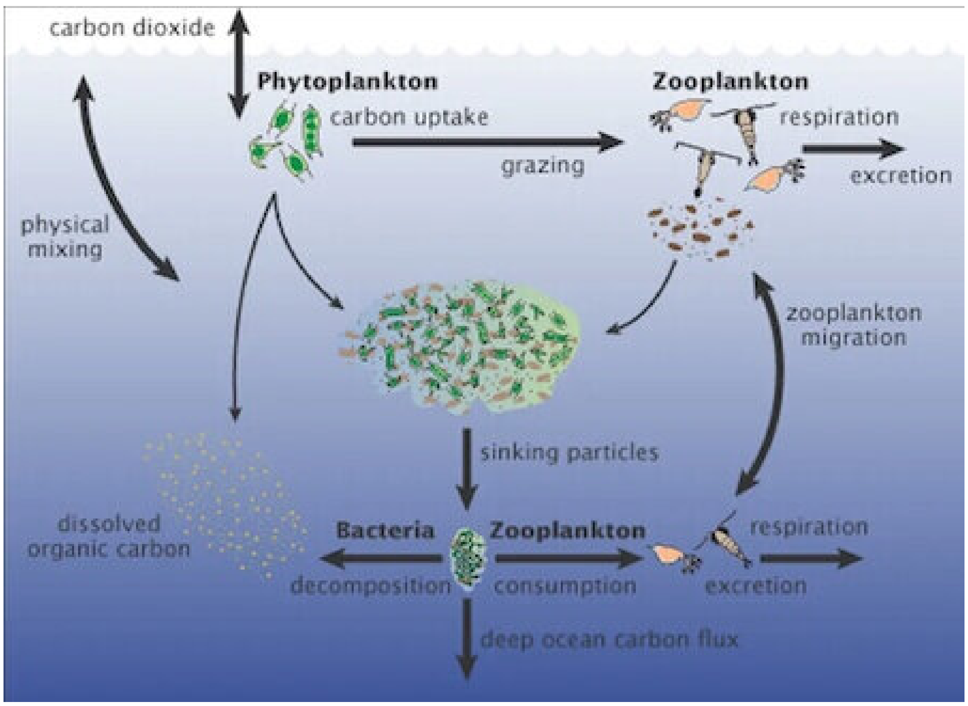


Marine carbon cycle. Credit: Wikipedia

While the world has been heavily focused on the usual players of global climate change, like fossil fuels and deforestation, a group of unlikely contenders has emerged from the depths of the ocean—marine viruses. These minuscule but mighty entities are now stealing the limelight as scientists unravel their profound influence on our planet's climate.

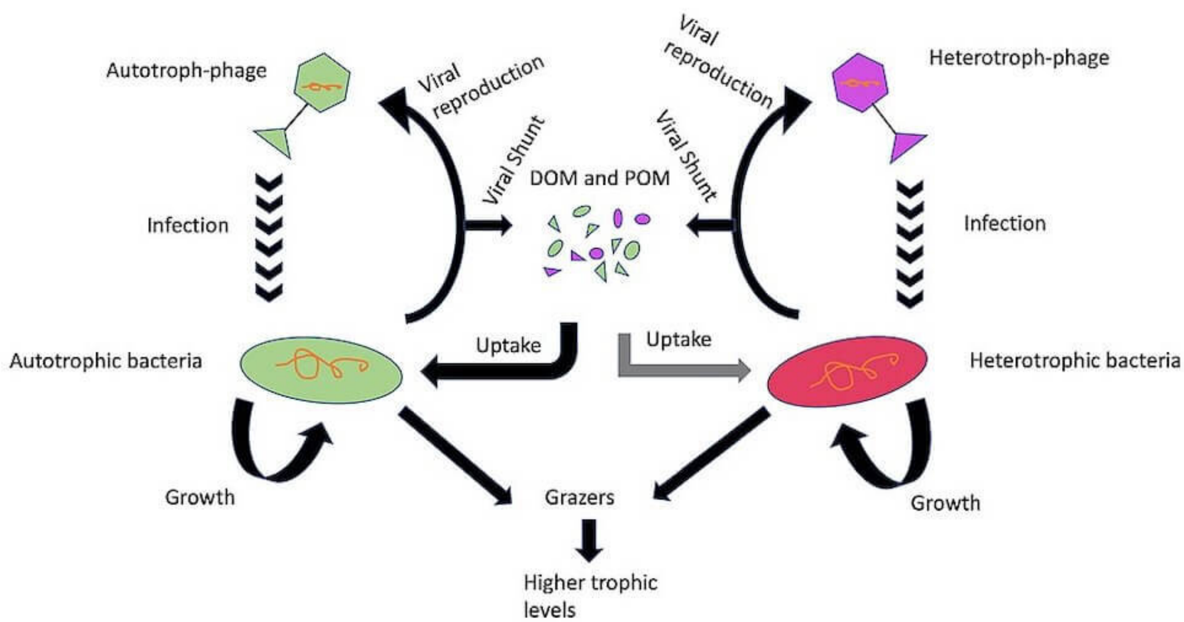
With an army of an estimated 10^{30} virus particles, marine viruses rule the vast expanse of the ocean with their astonishing diversity. All aquatic organisms are impacted by their presence in one way or another—be it bacteria, algae, protists or fish. The jury is still out on whether the net impact of marine viruses on climate change is positive or negative. However, the mounting evidence is difficult to ignore—marine viruses possess a transformative power capable of reshaping the very fabric of the marine ecosystem—and their impact on biogeochemical cycles is anything but subtle.

Viral shunting: Unraveling the ocean's carbon cycle

Bacteriophages (or simply phages)—viruses that infect bacteria—are the dominant viruses in the ocean. Upon infection, phages cause their hapless bacterial hosts to burst open through a process known as viral lysis, thereby releasing nutrients and organic matter into the surrounding seawater. This phenomenon, known as viral shunting, diverts microbial biomass from secondary consumers in the food web, such as plankton and fish, and into the pool of dissolved organic matter that is primarily consumed by heterotrophic bacteria.

When bacteria die and undergo decomposition, their organic matter has the potential to contribute to either the pool of particulate organic matter (POM) or dissolved organic matter (DOM). POM consists of complex structures and is not easily broken down by marine microbes. Consequently, it is often transported to the deeper parts of the ocean. However, DOM is more readily digestible for microbes, thus becoming incorporated into their biomass. As the microbial biomass in the ocean expands, it becomes a food source for organisms at higher trophic levels, including plankton, which in turn serve as prey for fish.

But phages can also prey upon these microbes. It is estimated that phages kill about 10 to 20% of heterotrophic bacteria and 5 to 10% of autotrophic bacteria in the ocean daily, resulting in a significant release of carbon, nutrients and other trace elements into the microbial food web. The dissolved organic matter, in turn, triggers a bacterial feast as the microbes eagerly consume the newly available nutrients and carbon, limiting their flow through higher trophic levels. Hence, viral lysis promotes bacterial respiration that retains carbon in the oceans instead of releasing them into the atmosphere. In this way, phages indirectly help [sequester approximately 3 gigatons of carbon per year](#).



Flow of particulate and dissolved organic matter (POM/DOM) in the viral shunt pathway. Credit: Wikimedia Commons

Viral lysis: Driving nutrient cycling in marine microbes

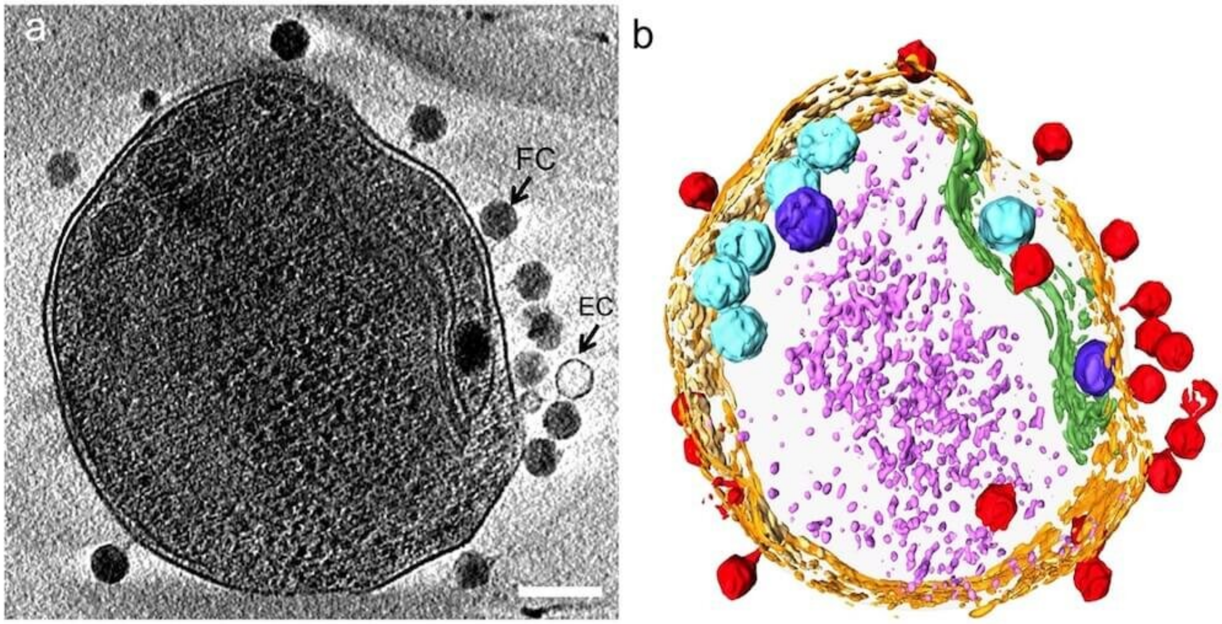
Viral lysis also plays a crucial role in the release of other vital nutrients into the ocean's microbial food web, such as nitrogen and phosphorous, which are encapsulated within bacterial cells in the form of nucleic acids and amino acids. These nutrient-rich compounds fuel growth and metabolic activities and serve as a valuable resource for both heterotrophic and autotrophic microbes.

Phages can also alter the carbon cycle by reshaping metabolism in cyanobacteria, one of the major players in global CO_2 fixation. For instance, researchers found that cyanophages infecting Synechococcus sp. alter host photosynthesis by maximizing energy production but inhibiting CO_2 fixation. However, the broader implications of this phenomenon at the ecosystem level remain enigmatic, presenting a crucial area ripe for future research.

Blooming nightmares: Viral vigilantes at work

Marine algae play a vital role in regulating atmospheric carbon dioxide levels through their photosynthetic prowess. However, trouble lurks in the depths when an abundance of marine algae emerges. Enter the dreaded algal blooms, those uncontrollable bursts of algae growth in aquatic ecosystems. These blooms unleash a cascade of detrimental effects on marine ecosystems, ranging from oxygen depletion and food web disruptions to the production of harmful toxins.

Once again, viruses take center stage. Lytic viruses that can infect marine algae play a critical role in the demise of algal blooms and trigger a surge of dissolved organic matter that, once again, fuels the growth of surrounding heterotrophic bacteria and restricts energy flow to higher trophic levels.



Cryo-electron microscopy image of cyanophages infecting the marine cyanobacterium Prochlorococcus. Credit: Murata K. et al./ *Scientific Reports*, 2017, available under CC-BY-4 license

As a result, scientists are exploring the idea of using viruses to naturally control and remove algal blooms. This exciting area of study is still in its early phases, and scientists are currently conducting small-scale pilot studies to gather more information and explore the potential of the approach. One such example is the investigation of Heterosigma akashiwo virus (HaV), which has shown promise in preventing the reoccurrence of toxic red tides caused by the damaging algal species Heterosigma akashiwo, ultimately safeguarding fisheries. Another study suggests that a cocktail of viruses isolated from a natural lake decreased the abundance of the toxic cyanobacterium Microcystis aeruginosa in lab cultures by 95% in six days.

However, several challenges limit large-scale applications of viruses (and cyanophages) for the control of algal blooms. The dynamics of algal blooms in natural ecosystems are complex, and implementing viral interventions on a larger scale presents both logistical and environmental challenges. Another significant concern is the potential development of microbial resistance to viruses, similar to how microbes evolve resistance to antibiotics. Some potential workarounds to overcome resistance are using a virus cocktail, instead of a single lytic virus, and engineering viruses that are specific to the algae of concern. Despite these limitations, the utilization of viruses for algal bloom remediation holds promise and continues to be an active area of research.

Beyond the horizon

The role of marine viruses and phages in global climate change is still unfolding, and there is much more to discover. As scientists continue to delve deeper into this fascinating field, there are several future steps that hold immense promise.

First and foremost, further research is needed to uncover the full extent of viral diversity in the oceans, as well as the interactions between viruses and different microbial communities under various environmental conditions. Recently, scientists have made a remarkable discovery regarding the existence of "giant viruses," which possess extraordinarily large genomes (ranging in size from 300-1000 kilobase pairs (kbp)) and infect ocean hosts. What makes these viruses even more intriguing is the discovery that they are highly prevalent and possess the ability to infect a wide range of eukaryotic hosts. However, the extent to which giant viruses influence marine ecosystems and biogeochemical processes remains largely unexplored, warranting further investigation.

Additionally, understanding the mechanisms behind viral-mediated nutrient recycling and carbon sequestration can pave the way for innovative approaches to mitigate algal blooms and enhance carbon sequestration efficiency in the oceans. Moreover, integrating viral dynamics into oceanographic models will help refine predictions of ecosystem responses to climate change.

With the growing recognition of viruses as influential agents in the oceans, further research into the roles and interactions of marine microorganisms will undoubtedly contribute to our ability to mitigate environmental challenges and promote the health and resilience of marine ecosystems in the face of a changing world.

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