Ecology of Marine Viruses

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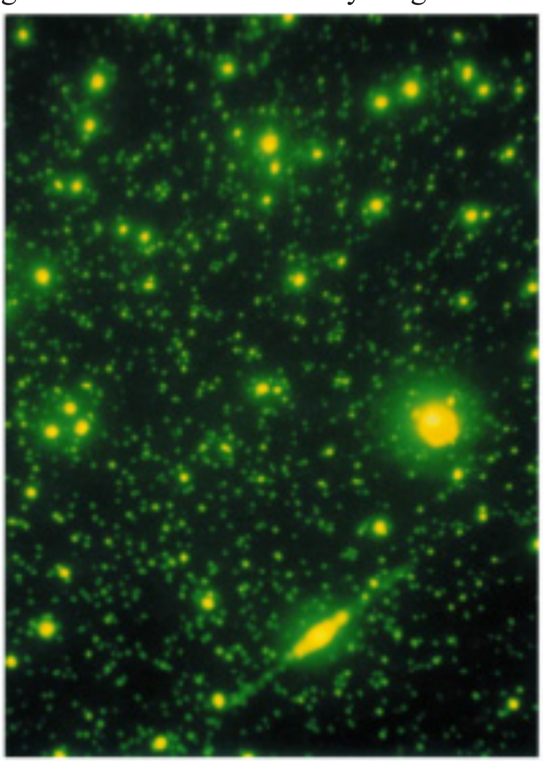
Abstract

Marine viruses have played a critical role in the development of life on our planet. They are often seen negatively as disease pathogens, but their ecological roles and behaviors have played a major role in the evolution of all species, they have shaped populations and ecosystems, and have many important uses and relationships with their hosts. Their vast abundance and diversity have shaped whole ecosystems and drive population rates in organisms such as marine microbes to corals and pilot whales. They have been seen to have a mutualistic symbiotic relationship with corals, sea slugs, and many other marine organisms. Marine viruses reduce the harmful plankton populations in algal blooms. They play a very important role in the stabilization of ocean ecosystems through biogeochemical and nutrient cycling.



(Fuhrman 542)

Introduction

The word virus tends to hold a negative connotation. But like Joan Jett in 1981, viruses probably don't give a damn about their bad reputation (Jett). We may not know much about marine viruses today, but we do know they play a very important role in the health of our oceans. The ecological roles and behaviors of marine viruses drive evolution, shape populations and ecosystems, and with advances in technology, can potentially be used in the near future to increase the health of our oceans and prevent marine life and habitat loss caused by climate change.

About Marine Viruses

Viruses are found virtually everywhere on the planet and are abundant around any forms of life. Life is defined as having internal stability, a form of energy consumption, being capable of growth, adapting to surroundings, responding to external forces, reproducing, and most importantly, being composed of at least a single cell (Lloyd 11). Following these rules, these loose strands of genetic code are not technically qualified as living, but they are the most abundant and diverse biological entities in the ocean (Suttle 2007). In the 1980s, scientists estimated the amount of marine viral bodies in one milliliter of seawater to be well over a million using electron microscopy (Suttle 2005). And being biological entities, viruses have taxonomic classifications and fall under Phylum Vira.

Structure and Reproduction

Viruses are very small particles ranging from 20 nanometers to no longer than 200 nanometers. Some of the smallest known viruses contain only three to four genes in their DNA or RNA (Bidle 1). Their true origin is unknown, but it is clear that viruses did not evolve from cells (Suttle 2013). Viruses have a fairly simple structure, being composed of a core containing RNA (single-stranded) or DNA (double-stranded) nucleic acids surrounded by a coat of proteins and sometimes lipids called a capsid (Fuhrman 1). Some viruses may have a membrane layer called an envelope surrounding the capsid. Capsids can occur in an icosahedral, filamentous, or head-tail shapes. Icosahedral capsids have 20 triangular faces. Filamentous are long, rod- or helical-shaped. Head-tail forms contain both an icosahedral head and a filamentous tail. Their structures have evolved for best survival, dependent on their ability to infect a select host. Viruses have "no intrinsic metabolism, [and function] only as parasites through cellular machinery of a host organism" (Fuhrman 541). Viruses are typically classified by their configuration and host organism: bacteria (bacteriophage), plants, or animals. Microbes are the most common host to a marine virus because of their abundance, especially in the oceans. Viruses are able to reproduce through a process known as lytic infection where they enter a host cell, create a copy of their DNA/RNA and the host cell potentially bursts or lyses.

History of Virology

"In the human world, viruses will continue to have a lousy reputation thanks to the traumatic impact of a few devastating infections that have plagued humans throughout recorded history," Christopher Lloyd says in *The Story of the World in 100 Species* (Lloyd 15). We have barely started to scratch the surface of understanding marine viruses. The study of viruses, known as virology, has shed much light on the behavior and ecological roles of marine viruses over the past few decades. Virology exponentially advanced with the invention of the transmission electron microscopy (TEM). This gave scientists the ability to distinguish viruses from other microbial forms and to see their vast abundance. Before TEMs, "viruses were not regarded as quantitatively important components of marine food webs until they were shown by direct counts to be highly abundant" (Fuhrman 541). Up until the 1990s, marine viral infections were not seen to play such a major role with oceanic ecosystems and processes. Mathias Middelboe argues that "the large number of unknown viral populations in the marine metagenome emphasizes the need for further isolation, characterization and sequencing of specific marine viruses" (Middelboe 1).

Diversity and Abundance

Viruses are incredibly widespread and diverse. Every cellular organism on the planet is susceptible to viral infection by at least one type of virus. This implies that viruses are the most diverse of all biological entities on the planet (Fuhrman 541). Viruses are especially diverse and abundant in the oceans. Curtis Suttle calculated that "if we compare the number of viruses in the oceans to the numbers of stars in the universe, there are about 10^{23} stars in the universe. In contrast, there are about 10 million-fold more viruses in the ocean than there are stars in the universe… [approximately] 10^{30} viruses in the ocean" (Suttle 2013). Although marine viruses are so abundant, diversity is "hard to measure because viruses do not have a universally conserved gene like the ribosomal DNA genes in cellular organisms, and because most viral hosts are difficult to culture" (Rohwer 207). The abundance and diversity of marine viruses have created important roles in ocean productivity and biogeochemical cycles.

Viral abundance is possible partially because of their evolutionary ability to adapt to harsh, oxygen and nutrient poor environments. While most viruses will be found closer to the water's surface, some impressive marine viruses have adapted to live and even thrive in harsh areas such as deep-sea hydrothermal vents. These deep-sea hydrothermal vents, typically found along tectonically active mid-ocean ridges, can reach extreme temperatures up to 400°C, or 752°F (Ortman 1516). Surprisingly, there are other forms of life in these vents. The marine viruses are supported by an abundance of chemosynthetic and heterotrophic prokaryotes that become their hosts.

Driving Evolution and Shaping Whole Ecosystems

Viruses are able to drive evolution in terms of their host cells, developing defense strategies against viral lytic infections over millions and millions of years. This cycle of host cells and viruses, both adapting to attack or defend, has led to incredible evolution in host cells (Middelboe 4). The evolution of both host cells and viruses has made viruses capable of infecting life of all sizes. Different classes and species of marine viruses can infect single-celled bacteria all the way up to the largest marine mammals.

Pilot Whales

A study in 2014 of an influenza virus from a pilot whale showed the success of the virus and its capability of infecting multiple advanced species. The research team was only able to collect a virus with a partial genome sequence from the diseased pilot whale, but they were able to distinguish it as an influenza A virus of the family *Orthomyxoviridae* and genus *Influenzavirus.* This genus of virus is capable of infecting seagulls, terns, waders, and other marine mammals, like pinnipeds and other cetaceans. The study found that the influenza virus in the pilot whale was likely spread by contact with a seabird while the whale was at the surface (Groth 183).

Anthozoans

It is well known that "the health of coral reefs is declining on a global scale" (Weynberg 2015). Different diseases, including white plague coral disease, are a rampant cause of death and bleaching for reefs worldwide. Cnidarian viruses are "the least-studied constituents in the coral holobiont" (Marhaver 2277), meaning there is much to be researched and learned. Only recently have scientists discovered that a herpes-like virus plays a key role in plagued reefs in the Caribbean (Soffer 271), although bacteria are also suspected to play a role. Metagenomic analyses of the coral and its symbiotic algae, zooxanthellae, showed that a sequence for the herpes-like virus counted for 4-8% of the total microbial sequencing (Marhaver 2277). As detrimental as viruses can be to corals and reef ecosystems, they have been found to play a necessary role in healthy corals' lives.

Bacteriophages and Eukaryotic Microbe Viruses

Microbes such as bacteria, archaea, and eukaryotic organisms are a huge source of food in the oceans and the most popular host for a virus. Bacteriophages, or phages, are viruses that have adapted to infecting bacterial and archaeal cells for replication. Phages are known to actually carry and transfer host genes. While these phenomena typically have negative effects on the host cell, including destruction, of the metabolism, immunity, and distribution, mutualistic symbiotic relationships may occur as well (Rohwer 207). Studies have shown that marine viruses kill "about 20% of the living material in the ocean every day" and are important in maintaining stable global cycles (Suttle 2013). Nearly all of the 20% biomass is of single celled organisms, which also make up a large portion of oceanic food webs. This number seems fairly significant, but "fortunately, phytoplankton [and other microbes] are avid propagators and replenish themselves quickly" (Ehrenberg). Marine viruses play a key role in both pelagic and benthic food webs, largely by managing the prokaryotic and eukaryotic diversity and abundance (Danovaro 1020). Phages are responsible for "controlling prokaryotic diversity and impacting biogeochemical cycles" (Danovaro 1020).

Giving Marine Viruses a Good Reputation

Marine viruses deserve credit where credit is due. Viruses should be seen as crucial players in worldwide ecosystems "other than as purveyors of disease, and if it were not for viruses, life on the planet would probably not exist" (Suttle 2013). Viruses are used in many unseen ways in our lives, like cheeses and other dairy products being treated with certain viruses to prevent bacterial growth and mold. Some viruses have attained important mutualistic symbiotic relationships with their host organism, including bacteria, insects, plants, fungi, and animals (Roossinck 99).

Symbiotic Relationships

Marine viruses play a notably important and beneficial symbiotic role in healthy coral reef holobionts. Kristin Marhaver explains this unlikely mutualistic symbiosis:

> Viruses can serve as a stabilizing force for symbioses by establishing addiction systems within a host. For example, zooxanthellae infected with a latent virus are resistant to lysis by VLP [virus-like particles]. Phages may also stabilize symbioses. For example, a phage specific to *Hamiltonella defensa*, a bacterial symbiont of the pea aphid, produces a toxin that appears to protect host aphids from eukaryotic parasites. The diversity of constituents in the coral holobiont elevates the potential for these types of viral functions to exist therein. In fact, the stability of the holobiont itself may ultimately depend on the action of viruses. The study of viruses within the coral holobiont will shed new light on the basic biology of symbiosis, but it will also be particularly important as corals face ever-increasing threats to their health and habitats. (2283)

The symbiotic virus found within corals is a herpes-like virus found both within healthy and bleaching corals (Marhaver 2283) and different virus species target specific hosts within the coral, being the coral itself, its symbiotic zooxanthellae, and other microbes in the polyp (Thurber 102). The "solar-powered" emerald-green sea slug, *Elysia chlorotica,* is another marine organism that benefits from its viral inhabitants. This sea-slug gets its color and all its nutrients from photosynthetic algae, *Vaucheria litorea*, in its tissues. Research has shown that the chloroplast genome in the algae "doesn't contain all the necessary genes" to give the sea slug all its required nutrients alone and it has been found that the algae likely "acquired these photosynthetic genes via a virus" (Ehrenberg).

Algal Blooms

"Viral abundances are dynamic, being particularly responsive to changes in ecological conditions such as algal blooms--this provides strong evidence that viruses are active members of the community rather than inert particles" (Fuhrman 542). Harmful algal blooms, which are swarms of phytoplankton, produce toxins that increase the mortality of marine organisms and also have an effect on public health (Gokul 2). Algal blooms are a natural phenomenon, but are greatly affected by water temperatures, pH levels, nutrient levels, local ecology, and urban and industrial pollution. Marine viruses are responsible for reducing algal bloom, causing phytoplankton populations by 10-40% (Brum 147). Mortality rates are in the higher 40% range during large algal bloom events. With the changing climate, algal blooms are becoming more frequent and intense. Research looking at potentially utilizing viruses as a natural and effective defense against blooms is important right now as blooms become more detrimental.

Biogeochemical and Nutrient Cycling

Our planet has seen a 40% increase in carbon dioxide (CO_2) levels in the past 250 years. Preindustrial CO_2 levels measured around 280 parts per million compared to 384 parts per million in 2007 (Danovaro 993). Because the oceans function as a "major sink of anthropogenic carbon from fossil fuel use" (Danovaro 1016), accounting for as much as 25% of retained CO_2 emissions, ocean acidification is becoming a growing threat to many marine organisms. Functionality, productivity, growth, and survival of marine calcifying organisms, such as coccoliths, foraminifera, coral reefs, and bivalves, is heavily affected by decreasing pH levels in the ocean (Danovaro 1017). Concern is growing as we see reduced growth and even disappearance in many species in different areas. Acidification affects marine viruses differently and effects are fairly unpredictable. Some viruses are seen to be fully unaffected in water pH levels less than 3, where others see significant changes at pH levels less than 7 (Danovaro 1017). Today, average oceanic pH levels are at 8.1, but slowly it is becoming more acidic.

Marine viruses exhibit a behavior called viral shunt where "viral-induced alterations of organic matter flows, within microbial food webs" (Danovaro 997). Viral "contribution to the microbial loop in which viruses not only cause host mortality, but also facilitate recycling of organic matter and nutrients vial the viral shunt" (Brum 147). Viral lysis "converts cellular components into dissolved organic matter" (Ortman 1516). Roberto Danovaro suggests that:

> The integration of viruses into microbial food web models has shown, moreover, that viral lysis of microbial cells enhances the transfer of microbial biomass into the pool of dissolved organic matter… This in turn can influence nutrient cycling, alter pathways of OC use by prokaryotes, and divert microbial biomass away from higher trophic levels… The viral shunt has also a profound impact on microbial population sizes and biodiversity and horizontal transfer of genetic material. Because prokaryotes and autotrophic protists play pivotal roles in biogeochemical cycles and global ocean functioning, viral infections of these groups of organisms have important ecological consequences" (p 997).

Danovaro also proposes that "viral lysis can be an important mechanism involved in the recycling of essential organically bound trace elements such as iron, whose availability influences primary and secondary production in a large sector of the oceans" (Danovaro 998).

The White Cliffs of Dover in England are a well-known example of land being altered by biogeochemical processes. The large, chalky, 350 foot cliffs are an accumulation of coccolithophores over an expansive period of time. Coccolithophores are single celled eukaryotes with skeletons that are primarily calcium carbonate and occasionally swarm together in the ocean in blooms. Death of coccolithophores during blooms are directly linked to marine viruses and after the dead cells all sink to the sea floor, they are moved by ocean currents to form the White Cliffs of Dover.

Conclusion

Life on this planet essentially began as a virus, and after three and a half billion years, viruses have played a major role in the evolution of all species. Found in any environment that any form of life is found, viruses are incredibly abundant, diverse, and successful. Their bad reputation is being questioned by new discoveries and advancing technologies.

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