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Viromes in Aquatic Ecosystems: Ecological Balance and Viral Predation

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Introduction

Aquatic ecosystems-encompassing oceans, freshwater lakes, rivers, and wetlands-are dynamic biomes teeming with life forms ranging from microscopic phytoplankton to complex vertebrates. While much attention has been historically devoted to macroorganisms and microbial communities, a growing body of research has uncovered the vast and diverse viral populations-collectively termed the virome-inhabiting these environments. Viruses are the most abundant biological entities on Earth, and nowhere is their dominance more pronounced than in aquatic ecosystems. It is estimated that a single milliliter of seawater can contain up to 10 million viral particles, outnumbering microbial cells by at least an order of magnitude. Once thought of merely as pathogens, aquatic viruses are now recognized as key players in ecosystem functioning, influencing microbial diversity, nutrient cycling, carbon sequestration, food web dynamics, and evolutionary processes [1,2].

Description

Metagenomic studies have vastly expanded our understanding of aquatic viral diversity, revealing numerous novel lineages with no known cellular hosts. Viruses in the Mimiviridae, Phycodnaviridae, and Pandoraviridae families have been found to infect large algae and protists, affecting primary production and population dynamics. Additionally, RNA viruses such as those in Picornavirales and Nodaviridae families are widespread in marine plankton and fish species. Taxonomically, aquatic viruses are difficult to classify due to the lack of conserved genetic markers and the high prevalence of "viral dark matter"-uncharacterized sequences with no known homologs. Tools such as viral metagenomics, viromics, single-virus genomics, and cryo-electron microscopy have helped uncover this hidden diversity. The emergence of databases like IMG/VR, ViPR, and ViromeDB has also facilitated viral identification and classification [3].

Phytoplankton form the base of aquatic food webs and are responsible for nearly half of the global primary production. Algal viruses, particularly those infecting Emiliania huxleyi and other bloom-forming species, play critical roles in regulating algal populations and bloom dynamics. For instance, the Emiliania huxleyi virus can terminate massive phytoplankton blooms by inducing programmed cell death. These bloom terminations have cascading effects on food webs, oxygen levels, and carbon flux. Viral-mediated collapse of blooms also releases dimethylsulfoniopropionate, which contributes to cloud formation and affects climate via the sulfur cycle. Moreover, viral infections influence the toxicity of harmful algal blooms (HABs), affecting aquatic animal health and water quality. Understanding the viral triggers and responses during bloom cycles is therefore vital for predicting and mitigating HABs in coastal ecosystems [4].

Climate change, pollution, eutrophication, and habitat degradation are altering aquatic viromes. Warming temperatures can accelerate viral replication rates, modify host susceptibility, and extend viral ranges, potentially leading to more frequent outbreaks and biodiversity loss. Ocean acidification affects viral stability and infectivity, particularly for calcifying plankton hosts. Plastic pollution introduces novel surfaces (plastispheres) for microbial and viral colonization, altering native virome structures. Additionally, antibiotic runoff can select for antibiotic resistance genes within viral genomes, exacerbating the global antimicrobial resistance crisis [5].

Conclusion

Aquatic viromes are far more than a collection of microscopic parasites-they are central to the functioning, resilience, and evolution of aquatic ecosystems. Through viral predation, gene transfer, and the viral shunt, viruses regulate microbial diversity, influence nutrient and carbon cycling, and shape food web dynamics. Their ability to control algal blooms, impact host metabolism, and mediate evolutionary innovation underscores their ecological significance. Yet, aquatic viromes are under increasing pressure from environmental change. As the climate warms and human activities intensify, understanding how viromes respond to perturbations becomes essential for predicting ecosystem shifts, managing fisheries and aquaculture, and preserving biodiversity. Harnessing the ecological potential of aquatic viruses-whether to control harmful algal blooms, monitor ecosystem health, or develop antiviral strategies-requires a multidisciplinary approach integrating virology, ecology, genomics, and oceanography.

Acknowledgement

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Conflict of Interest

None.

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