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Mini-Review: Potential Interactions and Immunomodulatory Effects of Marine Virus Exposure on *SARS-CoV-2* Infection Outcomes in Coastal Populations

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Abstract

The *COVID-19* pandemic has underscored the complexity of viral co-infections and their impact on human health. While much attention has been given to terrestrial pathogens, marine viruses particularly those infecting marine mammals and plankton remain underexplored in the context of co-infections with *SARS-CoV-2*. This mini-review examines the potential interactions between marine viruses and *SARS-CoV-2*, focusing on immunomodulatory effects, ecological considerations, and public health implications for coastal populations. We discuss the role of marine viruses in shaping immune responses, their potential to exacerbate or mitigate *COVID-19* severity, and the challenges in diagnosing and managing such co-infections. The review highlights the need for interdisciplinary research to understand the broader ecological and health impacts of marine virus exposure in the era of *COVID-19*.

Key words: *SARS-CoV-2* , Human health , Infection , Immunomodulatory , Marine viruses

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Introduction

The *COVID-19* pandemic, caused by the severe acute respiratory syndrome *coronavirus* 2 (*SARS-CoV-2*), has highlighted the complexity of viral infections and the profound influence of co-infections on disease severity and progression (Maltezou et al., 2023; Shadbash & Bahari Babadi, 2025). While the majority of research has focused on co-infections involving terrestrial viruses such as *influenza*, respiratory syncytial virus, or other *coronaviruses,* little attention has been given to the potential role of marine viruses in modulating *SARS-CoV-2* infections. Marine viruses are the most abundant biological entities in aquatic environments, with estimates suggesting that they outnumber all cellular organisms in the ocean by at least an order of magnitude (Suttle, 2007). These viruses play pivotal ecological roles, influencing microbial community composition, biogeochemical cycles, and the health of marine animals, including mammals that share physiological and immunological similarities with humans. Coastal populations are uniquely positioned at the interface of human and marine ecosystems, where frequent interactions with marine environments can result in exposure to diverse viral communities (Stewart et al., 2008). Marine viruses, including those infecting plankton, fish, and marine mammals, may interact with human hosts either directly through contact with seawater, seafood consumption, or aerosols, or indirectly by modulating environmental microbial communities that influence pathogen dynamics (Malham et al., 2014). Given the immunological crosstalk between environmental viral exposures and human immune responses, there is a plausible hypothesis that marine viruses could impact *SARS-CoV-2* infection outcomes, either by priming the immune system for enhanced antiviral responses or by exacerbating inflammatory pathways that contribute to severe *COVID-19* manifestations. Furthermore, emerging evidence indicates that *SARS-CoV-2* can infect non-human mammals, including domesticated animals and wildlife, raising concerns about potential cross-species viral interactions in marine mammals. Co-infections in these animal reservoirs may not only affect animal health but also influence viral evolution and the risk of zoonotic spillover (Sharun et al., 2021). Understanding these complex interactions requires an interdisciplinary approach, integrating marine biology, virology, immunology, and public health perspectives. This review aims to explore the potential intersections between marine virus exposure and *COVID-19*, highlighting immunomodulatory effects, ecological considerations, and public health implications for coastal populations.

Marine Viruses and Their Ecological Roles

Marine viruses are highly diverse, including DNA and RNA viruses that infect bacteria (bacteriophages), algae, invertebrates, fish, and marine mammals. These viruses are critical drivers of ecological balance in oceans, regulating microbial populations, controlling algal blooms, and influencing nutrient cycling through cell lysis (Middelboe & Brussaard, 2017). For instance, viral lysis of plankton releases organic matter that fuels microbial food webs, a process known as the viral shunt. Marine viruses also play a role in horizontal gene transfer among microorganisms, contributing to the evolution of microbial communities and the emergence of novel traits. In terms of human health relevance, marine viruses may indirectly impact humans through environmental exposure in coastal regions, seafood consumption, or interactions with marine mammals, which can act as reservoirs for viruses with zoonotic potential. Marine mammal viruses, such as cetacean morbilliviruses and influenza-like viruses, share structural and functional characteristics with human pathogens, raising the possibility that co-exposure with *SARS-CoV-2* could influence viral replication dynamics and immune responses. Understanding the ecological roles of these viruses helps contextualize potential human health risks and underscores the importance of monitoring viral populations in marine environments**(Figure1).**

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Table 1. Selected Marine Viruses and Potential Implications for SARS-CoV-2 Co-Infection

Marine Virus Type	Host Range	Transmission to Humans	Potential Interaction with SARS-CoV-2
Cetacean morbillivirus	Dolphins, whales	Direct contact, aerosols (rare)	Potential co-infection in marine mammals; immune modulation in hosts
Influenza A viruses (marine-associated strains)	Seals, seabirds	Zoonotic (contact, aerosols)	Co-exposure may modulate antiviral responses; surveillance relevance
Bacteriophages (marine)	Marine bacteria	Indirect via food chain/microbiome	Microbiome-mediated immune effects that could influence COVID-19 severity
Algal (phytoplankton) viruses	Plankton	Indirect/environmental	Ecosystem-level effects on microbial communities; indirect human impacts
Marine aerosolized microbes/viruses (sea-spray)	Mixed environmental	Inhalation during coastal aerosol exposure	Potential mucosal immune priming or irritation affecting susceptibility

Potential Interactions with *SARS-CoV-2*

Environmental Co-Exposure

Coastal populations are often exposed to seawater aerosols, seafood, and marine wildlife. If marine viruses or viral particles interact with human mucosal surfaces, they could influence susceptibility to *SARS-CoV-2* infection by modulating local innate immunity (Norese et al., 2024).

Cross-Species Transmission

Some marine mammals express receptors compatible with *SARS-CoV-2* entry, such as ACE2 analogs, suggesting that these animals could be co-infected. Such co-infections might affect viral shedding patterns, viral evolution, or even the emergence of recombinant variants, although this remains speculative (Li et al., 2022).

Immune Priming or Dysregulation

Chronic or repeated exposure to marine viruses could prime antiviral innate immunity through mechanisms such as interferon signaling or toll-like receptor activation. Conversely, simultaneous viral exposures might exacerbate inflammatory responses, potentially worsening *COVID-19* outcomes in co-exposed individuals (Filippatos et al., 2025).

Indirect Effects via Microbiome Modulation

Marine viruses can influence bacterial and planktonic communities that enter human food chains or coastal waters. Alterations in microbiomes could indirectly affect human susceptibility to *SARS-CoV-2* or modulate systemic immune responses (Campbell et al., 2023).

Immunomodulatory Effects and Co-Infection Dynamics

Innate Immunity - PRRs (Toll-like receptors and RIG-I-like receptors) detect or identify viruses in the environment and trigger the antiviral response through the production of type I interferons. Early type I interferon responses may decrease the ability of *SARS-CoV-2* to replicate, thus limiting the extent and duration of *SARS-CoV-2* infections (Saha et al. 2025).

Repeated exposure to marine viruses may reshape B-cell and T-cell memory pools, potentially altering adaptive immune responses during *SARS-CoV-2* infection (Sette & Crotty, 2021)., even though true cross-reactive epitopes are unlikely. Such prior viral exposures can also modulate cytokine signaling, where pre-activated immune pathways may intensify inflammatory reactions and heighten the risk of severe *COVID-19* (Lowery et al., 2021). Additionally, marine viruses influence coastal microbial communities, and environmental or dietary shifts in human microbiota may indirectly affect systemic immunity and inflammatory responses to *SARS-CoV-2*. Together, these interactions suggest that marine viral exposure could alter adaptive immunity, cytokine dynamics, and microbiome-immune pathways, ultimately shaping *COVID-19* disease outcomes (Harper et al., 2021).

Challenges in Diagnosis and Management

Innate Immunity: Exposure to marine viruses can activate pattern recognition receptors (PRRs) such as Toll-like receptors (TLRs) and RIG-I-like receptors, which may enhance interferon-mediated antiviral responses. This mechanism could potentially limit the replication of *SARS-CoV-2* during the early stages of infection (Saha et al., 2025).

Adaptive Immunity: Persistent or repeated exposure to marine viruses might influence the memory pools of B-cells and T-cells, thereby modulating adaptive immune responses during *SARS-CoV-2* infection. While cross-reactive epitopes are unlikely, they could theoretically impact immune recognition (Sette & Crotty, 2021).

Cytokine Regulation: Infections caused by marine viruses may trigger cytokine responses that either bolster antiviral defenses or contribute to inflammatory pathology. In individuals infected with *SARS-CoV-2*, pre-existing immune activation from marine viral exposure could intensify cytokine storms, raising the risk of severe disease outcomes (Lowery et al., 2021).

Microbiome-Immune Interactions: Marine viruses can influence bacterial communities in coastal ecosystems. Changes in human microbiota due to dietary or environmental exposure may affect systemic immunity and inflammatory responses during *COVID-19* (Harper et al., 2021).

Potential Interactions with *SARS-CoV-2*

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Microbiome-Immune Interactions

Marine viruses modulate bacterial communities in coastal environments. Altered microbiota in humans due to dietary or environmental exposure may affect systemic immunity and inflammatory responses during *COVID-19* (Harper et al., 2021).

Challenges in Diagnosis and Management

Limited Diagnostic Tools

Most marine viruses are not routinely screened in human clinical settings. Molecular assays and serological tests for marine viral infections are scarce, making it difficult to identify co-infections.

Symptom Overlap

Many viral infections, including potential zoonoses from marine environments, produce non-specific symptoms that overlap with *COVID-19* manifestations, complicating clinical interpretation and management.

Environmental Transmission

Marine viruses may reach humans indirectly through seafood consumption, recreational water activities, or aerosols from seawater. Identifying environmental sources of viral exposure requires interdisciplinary approaches combining virology, marine ecology, and environmental monitoring.

Future Perspectives

Epidemiological Studies

Longitudinal monitoring of coastal populations for marine virus exposure and *COVID-19* outcomes to assess potential correlations.

Immunological Research

Characterization of immune responses induced by marine viruses and their impact on *SARS-CoV-2* infection severity.

Zoonotic Surveillance

Screening marine mammals and other aquatic animals for *SARS-CoV-2* and co-infecting viruses to evaluate cross-species transmission risks.

Environmental Virology

Mapping the distribution of marine viruses in coastal waters and seafood to identify potential sources of human exposure.

Integrated Public Health Strategies

Developing guidelines for safe seafood consumption, recreational water activities, and wastewater management to mitigate co-infection risks.

Conclusion

Marine viruses represent a largely unexplored factor in the landscape of *COVID-19* co-infections. Coastal populations may face unique risks due to frequent interactions with marine environments and potential exposure to marine viral communities. While direct evidence of co-infection with *SARS-CoV-2* remains limited, the ecological, immunological, and zoonotic implications underscore the need for interdisciplinary research. Enhanced surveillance, improved diagnostics, and public health interventions are essential to understand and mitigate potential risks associated with marine virus exposure in the context of *COVID-19*.

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