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Filter feeder's role in disease management: A review

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Abstract
Filter-feeding invertebrates, particularly bivalves, play a crucial role in regulating pathogen dynamics in aquatic ecosystems. By filtering large volumes of water, mussels, oysters, and clams can capture and remove bacteria, viruses, protozoans, and parasite larvae, thereby reducing infection risks for both aquatic organisms and humans. Evidence such as the inactivation of avian influenza virus by *Corbicula fluminea* highlights their potential as natural disease buffers at the wildlife-environment interface. In aquaculture—especially Integrated Multi-Trophic Aquaculture (IMTA) systems—filter feeders contribute to disease control by lowering microbial loads, suppressing opportunistic pathogens like *Vibrio* spp., and reducing reliance on antibiotics. However, their role is dual: while some pathogens are degraded or inactivated during filtration, others, such as noroviruses and *Vibrio* spp., can persist in tissues, making bivalves both pathogen sinks and reservoirs. Other filter-feeding invertebrates, including sponges and ascidians, also exhibit high clearance rates and show potential applications in bioremediation. Climate change drivers—warming, acidification, and eutrophication—are expected to further shape filter-feeder-pathogen interactions. Overall, filter feeders provide valuable ecosystem and aquaculture services by enhancing water quality and contributing to natural disease management.

Keywords: Filter feeders, pathogen management, bivalves, IMTA, disease ecology, climate change, aquaculture sustainability

1. Introduction

Aquatic ecosystems are shaped by complex host-pathogen interactions influenced by biological and environmental factors. Filter-feeding organisms, especially bivalves like mussels, oysters, and clams, play a dual role in these dynamics [16]. By filtering large volumes of water, they reduce pathogen loads and disrupt transmission pathways, acting as natural "biological filters" [30, 9]. However, they can also serve as reservoirs for pathogens such as *Vibrio* spp. and noroviruses, posing risks to consumers [37].

In aquaculture, filter feeders are central to Integrated Multi-Trophic Aquaculture (IMTA), where they improve water quality, regulate microbial assemblages, and mitigate disease [32, 15]. Wild populations of bivalves, sponges, and ascidians likewise influence pathogen transmission at the wildlife environment interface [4]. Yet, climate change stressors, warming, acidification, and hypoxia alter both filter-feeder physiology and pathogen dynamics, complicating predictions of their net effect [5]. Thus, evaluating filter feeders' role in disease regulation is vital for sustainable aquaculture, ecosystem-based management, and marine disease ecology.

This review examines the ecosystem services of filter-feeding organisms in the context of pathogen management, highlighting their dual role as pathogen reducers and reservoirs. It further explores their applications in aquaculture, the comparative roles of different filter-feeding taxa, resilience mechanisms of pathogens against filtration, and the potential impacts of climate change on these interactions. By integrating ecological, epidemiological, and applied perspectives, this review aims to provide a holistic understanding of how filter feeders contribute to disease regulation in aquatic environments.

2. Ecosystem Services of Filter Feeders: Implications for Pathogen Management

Filter-feeding bivalves provide essential ecosystem services in aquatic environments, not only through nutrient cycling and water clarification but also by regulating disease dynamics.

Their ability to filter large volumes of water enables them to capture and remove pathogenic microorganisms, including bacteria, viruses, and protozoans, from the water column. Several studies have demonstrated that bivalves such as clams and mussels can reduce concentrations of waterborne pathogens. For example, [9] showed that the Asiatic clam *Corbicula fluminea* efficiently removed avian influenza virus from water, preventing transmission to susceptible hosts like waterfowl. Viral titres were reduced to undetectable levels within 48 hours, highlighting their role in limiting pathogen persistence in aquatic ecosystems.

Importantly, filter feeders act as biological buffers at the wildlife environment interface by disrupting the faecal oral cycle that facilitates disease spread among aquatic organisms. By reducing pathogen loads in water, they lower infection risk for fish, shellfish, birds, and even humans in aquaculture and wild systems. In some cases, this bioremediation potential positions bivalves as natural disease control agents, contributing to the management of viral, bacterial, and parasitic infections in aquatic environments. However, their role is complex and context-dependent. While filter feeders can inactivate or sequester certain pathogens (e.g., avian influenza viruses), other microbes, such as *Vibrio* spp., hepatitis A virus, and norovirus, can persist within their tissues and pose a risk of transmission when consumed by higher trophic organisms, including humans. This dual role underscores the need to recognize filter feeders as both pathogen sinks and potential pathogen reservoirs, depending on host-pathogen interactions.

Overall, dense populations of filter-feeding bivalves contribute to natural disease mitigation by removing pathogens from the environment, limiting their circulation, and reducing opportunities for epizootics. This function emphasizes their ecological and epidemiological importance and suggests that maintaining healthy bivalve populations can enhance aquatic ecosystem resilience against disease outbreaks [9].

3. Filter feeders in IMTA and disease management

Filter feeders, particularly bivalves such as mussels (*Mytilus edulis*), oysters (*Crassostrea gigas*), and clams (*Ruditapes philippinarum*), play a crucial role in Integrated Multi-Trophic Aquaculture (IMTA) systems by contributing to disease management through their natural filtration capacity. These organisms can filter large volumes of water, effectively removing suspended particles, including phytoplankton, organic detritus, and importantly, pathogenic microorganisms such as *Vibrio* spp., *Escherichia coli*, and fish viruses. By reducing the abundance of potential pathogens in the water column, filter feeders help mitigate disease transmission risks in co-cultured species, thereby enhancing the biosecurity of aquaculture systems. Studies have demonstrated that mussels and oysters can significantly lower microbial loads, acting as "biological filters" that limit pathogen accumulation in the environment [32]. Moreover, their presence in IMTA not only improves water quality but also reduces the need for chemical treatments and antibiotics, aligning with sustainable aquaculture practices. Thus, incorporating filter feeders into IMTA provides a dual benefit: supporting ecological balance and contributing to natural disease control mechanisms within aquaculture ecosystems. Beyond their filtration capacity, filter feeders in IMTA also influence disease dynamics through indirect ecological interactions. By reducing phytoplankton biomass and organic matter, bivalves and other filter-feeding organisms minimize eutrophication, which otherwise fosters the proliferation of opportunistic pathogens such as *Vibrio* spp. and *Aeromonas* spp. Furthermore, the mucus and biodeposits produced by bivalves can promote beneficial microbial communities that compete with or inhibit pathogenic bacteria, thereby enhancing microbial balance in the system. Certain species, such as *C. gigas* oysters and *M. edulis* mussels, are reported to trap and inactivate viral particles, including fish rhabdoviruses, highlighting their potential role in controlling viral outbreaks. Incorporating filter feeders into IMTA not only improves the health of co-cultured finfish but also reduces the overall risk of pathogen persistence in sediments and the water column. This natural bioremediation function positions filter feeders as an eco-friendly and economically viable strategy for sustainable disease management in aquaculture.

4. Comparative Role of Different Filter Feeders in IMTA Disease Management

Different filter-feeding species contribute uniquely to disease management in IMTA systems due to variations in their feeding strategies, clearance rates, and interactions with microbial communities. Mussels (*Mytilus edulis*) are among the most effective biofilters, capable of removing high loads of suspended bacteria, including *Vibrio* spp., thereby reducing the risk of fish infections in salmon farms [7]. Oysters (*Crassostrea gigas*), besides filtering bacteria, are also reported to entrap and neutralize viral particles, such as fish rhabdoviruses, making them particularly valuable in controlling viral diseases [22]. Clams (*R. philippinarum*) play a dual role by improving benthic water quality through their sediment-burrowing activities, which limit the accumulation of organic matter that could otherwise harbor pathogenic bacteria (Gutierrez *et al.*, 2003). In addition, ascidians (sea squirts) and tunicates are emerging as promising filter feeders in IMTA; they demonstrate high clearance rates of bacteria and microalgae, while some ascidian species harbor symbiotic microbes with antimicrobial properties that may further suppress pathogens. The integration of multiple filter feeder species in IMTA can therefore create a complementary disease-control system, strengthen ecosystem resilience, and reduce dependence on chemotherapeutic measures [26].

5. What are the known impacts of bivalve filtration on marine disease?

Bivalves often form dense beds that provide habitat for various species and improve water quality by filtering pathogens and suspended matter from the water column [6]. Here, we focus on the epidemiological outcomes of pathogen filtration. Pathogens may be amplified through aggregation and replication within reservoir hosts or reduced through direct ingestion. Live pathogens can also be released into the environment via faeces or pseudofaeces. The following section addresses both transmission amplification and reduction.

5.1 Transmission augmentation

Bivalves play a well-documented role in transmitting human pathogens and are increasingly recognized in wildlife disease transmission. They can filter and concentrate pathogens, acting as passive reservoirs for viruses, e.g., Hepatitis A, Norovirus [39], bacteria (e.g., *Vibrio* spp., *E. coli*), diatoms and dinoflagellates (e.g., *Pseudo-nitzschia*, *Alexandrium*, *Gymnodinium* spp, [1], and protists (e.g., *Cryptosporidium*). Mussels (*Mytilus galloprovincialis*) are intermediate hosts for *Toxoplasma gondii*, affecting sea otters [2], while oysters (*Crassostrea gigas*, *C. virginica*) serve as passive reservoirs for fish reoviruses [27]. Additionally, bivalves may act as active reservoirs, supporting pathogen replication and transmission within or between species [4].

5.2 Transmission reduction

Consumption and degradation of parasites (termed "degradation" here) effectively reduce pathogen loads in aquatic environments. Filter-feeders like mussels and oysters can selectively remove particles by size, actively targeting larger or specific organisms. For instance, the non-host Pacific oyster reduced *Himasthla elongata metacercaria* in cockles (*Cerastoder maedule*) by up to 91% [44]. Although bivalves typically filter particles sized 4-250 µm, some, along with other filter-feeders (e.g., sponges, sabellid worms), can remove microbial pathogens, including viruses [11]. The Asiatic clam (*Corbicula fluminea*), for example, removes avian influenza virus from water, reducing infection in wood ducks (*Aix sponsa*) [9]. Pathogen removal also occurs through non-selective means; Pacific oyster shells alone reduced *H. elongate* by 44%, suggesting adhesion plays a role [44]. Viruses and bacteria can attach to clay particles in sediment and pseudofaeces [43], which often settle out of the water column, reducing transmission potential [12].

6. Which other high-filtration capacity invertebrates may function as pathogen biofilters?

While their role in changing water quality may be less well-studied, organisms such as sponges and ascidians are important filter-feeding invertebrates and can also act as bio-filters. Here, we view the known effects of these taxa on pathogen transmission.

6.1 Sponges

Sponges (Phylum: Porifera) have high microbial filtering and clearance rates and are used as biofilters in aquaculture worldwide (18). They can filter up to 14 L/h/m² of tissue [28]. As non-selective suspension feeders, sponges effectively remove up to 25% of dissolved and particulate total organic carbon (TOC), supporting microbial symbionts that make up over two-thirds of their biomass [45]. Although pathogen removal is considered a byproduct of filtering pico-and nanoplankton, lab studies show sponges can selectively consume specific pathogens [25]. Pathogens like *Aspergillus sydowii*, linked to sea fan aspergillosis, have been detected in healthy sponges [29]. Consequently, sponges are proposed as bioremediation tools for clearing pathogens from the water column [21].

6.2 Ascidians

Ascidians (Phylum: Chordata), solitary or colonial filter-feeding invertebrates, may help reduce pathogen abundance in marine environments. They pump seawater through a branchial basket, trapping particles on a mucus filter lining the pharynx [38]. While particles from 0.5 to 100 µm are ingested, those >600 nm, such as phytoplankton and larger bacteria, are retained most efficiently [34]. Filtration rates vary with size, temperature, and particle concentration, ranging from 10-200 ml/min. *Ciona intestinalis*, a solitary ascidian, filters 5-34 ml/min and can clear an entire cove daily [33]. The colonial *Polyandro carpazorritensis* ingests and reduces concentrations of allochthonous bacteria, including pathogens, but may also act as a reservoir due to selective digestion [40]. Like bivalves and sponges, ascidians show promise as pathogen biofilters, though further research is needed on their ability to filter, retain, and digest specific pathogens [40].

7. What makes a pathogen more resilient to filtration or degradation?

Some pathogens have evolved mechanisms to resist degradation within filter-feeders. Human disease outbreaks linked to bivalve consumption show that certain bacteria and viruses persist in bivalve tissues. Bacteria such as *Salmonella* and *Vibrio* spp. are commonly isolated from bivalves and are major causes of foodborne illness [37]. Non-enveloped viruses, like noroviruses, also resist degradation, likely due to their greater environmental stability [36]. Particle size affects susceptibility to filtration and degradation; larger particles are more efficiently filtered [19]. For example, *C. gigas* and *M. edulis* filter large diatoms efficiently, but filtration declines with smaller particles like viruses (<200 nm) [35]. However, microbes attached to organic aggregates (marine snow) are more easily filtered, and *Vibrio* spp. are known to associate with these particles [10]. The bivalve immune system also influences degradation resistance; some bacteria, such as *Vibrio* spp., better survive hemocyte activity than *E. coli* [37]. Additionally, molecular binding to bivalve tissues contributes to viral persistence, with oysters differentially concentrating Norovirus strains via tissue-specific ligands [23]. These findings highlight the need for further research on pathogen-filter-feeder interactions to guide effective bioremediation strategies.

8. What are the potential impacts of ocean or climate change on interactions between filter-feeders and pathogens?

Climate change is impacting marine species, including disease-causing microbes [5] and filter-feeding bivalves [14], with future effects expected to intensify (Howard *et al.*, 2013). Ocean changes such as warming, acidification, salinity shifts, hypoxia, and increased storm events affect marine organisms through physiological and population-level changes, ultimately altering ecosystems [8]. These shifts may influence whether filter-feeders reduce or enhance disease transmission. For example, outbreaks of *Vibrio* diseases in humans rise with warmer temperatures and extreme weather [5], as heat boosts bacterial growth and virulence [24].

Rising temperatures can increase bivalve filtration rates within physiological limits, potentially reducing pathogen loads in the water. However, this relationship is non-linear, as filtration rates drop beyond thermal thresholds [42]. Both bivalves and the particles they filter exhibit temperature-dependent metabolic rates, and warming can alter ocean plankton and microbiome dynamics. Yet, the structure of the ocean microbiome under warming remains poorly understood [41].

Ocean acidification, driven by rising CO_2, affects filter-feeders by altering metabolism [17], reducing body condition, impairing larval development [3], and damaging shells [3]. It may also change pathogen abundance and dynamics. Effects on filter-feeder physiology are species-dependent [20], and extreme weather may exceed adaptive capacities [13]. Most climate-related conclusions are drawn from short-term studies, leaving long-term responses and filter-feeder-pathogen interactions unclear. However, positive transgenerational effects have been observed, such as improved resilience in Sydney rock oyster offspring after acidification exposure [31]. Due to limited data, predicting how climate change will affect disease mitigation or augmentation by filter-feeders remains uncertain.

9. Pathogen reduction in aquaculture

Aquaculture is growing globally as a key source of food and income, but rising infectious disease losses have made disease control a priority. Intensive farming of genetically similar or densely packed stock can promote disease outbreaks, while natural disease controls such as predation, host resistance, or pathogen dilution may be absent. Bivalve filtration has been proposed to reduce disease risks for farmed and nearby wild species. Its success depends on the specific pathogen, filter-feeder species, and interactions with other pathogens in the system.

For instance, lab studies show blue mussels (*Mytilus edulis*) and Atlantic Sea scallops (*Placopecten magellanicus*) can ingest sea lice (*Lepeophtheirus salmonis*), a major salmon pest. However, these bivalves may also concentrate and excrete infectious pancreatic necrosis virus (IPNv) for up to seven days post-exposure, making local disease risks critical to assess. Environmental conditions also influence filtration effectiveness. For example, winter runoff increased F+ coliphage accumulation by up to 99-fold. Environmental manipulation, like using light to attract sea lice toward filter-feeders, may enhance filtration.

This strategy holds promise for integrated multi-trophic aquaculture, especially since many filter-feeders also have commercial value. Bivalves may also help reduce pathogen exposure in other mollusks; oysters near mussel farms showed lower risk of *OsHV-1* infection. On land, bivalves are being tested to reduce microbial loads in farm effluent, including efforts to prevent bacterial release from abalone farms.

Other filter-feeders are also under consideration. Mediterranean sabellid worms (*Branchiom maluctuosum* and *Sabella spallanzanii*) have shown high bacterioplankton filtration and reduced *V. alginolyticus* levels. As aquaculture expands, innovative filter-feeder applications for disease control are likely to increase.

10. Role of Filter Feeders in Controlling Waterborne Pathogens

Filter-feeding bivalves play a crucial role in aquatic ecosystems by influencing pathogen dynamics, thereby contributing to natural disease management. The study [9] demonstrated that the Asiatic clam *C. fluminea* can significantly reduce the concentration and infectivity of avian influenza (AI) viruses in water. Viral titres in water containing clams dropped below detectable limits within 48 hours, while water without clams maintained infectious virus levels. This reduction was attributed primarily to the active filtration behaviour of the clams rather than abiotic factors such as pH changes or shell surface adsorption.

Importantly, *A. sponsa* exposed to highly pathogenic H5N1 AI virus through water filtered by clams, or through ingestion of clam tissue, showed no morbidity, mortality, or evidence of infection, in contrast to 100% mortality in ducks exposed to unfiltered virus-containing water. These findings indicate that while some viruses (e.g., hepatitis A, norovirus) remain infective within bivalve tissues and can be transmitted via consumption, AI viruses were inactivated or sequestered in clam tissues, preventing transmission.

This suggests that dense populations of filter-feeding bivalves provide an ecosystem service of disease control by lowering pathogen loads in aquatic habitats. By filtering viral particles (80-120 nm in diameter) along with organic material, clams reduce the risk of faecal-oral transmission routes that sustain disease circulation in wild bird populations. Such natural "biological filtration" highlights the potential of bivalves as bioremediators that mitigate pathogen persistence in aquatic ecosystems, ultimately contributing to disease regulation at the wildlife environment interface. Thus, filter feeders not only maintain water clarity and nutrient cycling but also act as biological buffers against infectious disease transmission, underscoring their ecological and epidemiological importance in aquatic disease management strategies [9].

11. Future Prospects and Applications

The role of filter-feeding invertebrates in pathogen management holds significant promise for future applications in both natural ecosystems and aquaculture. First, their integration into IMTA systems offers a sustainable, eco-friendly approach to disease mitigation, reducing reliance on antibiotics and chemotherapeutics. Strategic co-cultivation of bivalves with finfish, crustaceans, and seaweeds could enhance overall system biosecurity while simultaneously generating economic value from harvested shellfish. Beyond aquaculture, filter-feeders can be applied as bioremediation tools in coastal and estuarine environments affected by anthropogenic pollution. Deployment of bivalve beds, sponges, or ascidians near wastewater discharge zones could reduce microbial contamination, thereby lowering the risk of zoonotic disease outbreaks. Such approaches may complement existing wastewater treatment technologies and enhance water quality in recreational and shellfish-harvesting areas. Emerging research also points to the potential of engineered or selectively bred bivalves with enhanced pathogen filtration and resistance traits. Genomic and microbiome-based approaches could facilitate the development of lines optimized for both aquaculture productivity and ecosystem services. Moreover, the symbiotic microbial communities within sponges and ascidians present an underexplored resource for discovering natural antimicrobial compounds that may suppress pathogenic bacteria in aquaculture settings.

Future studies should also investigate the effects of climate change-such as warming, acidification, and hypoxia-on the filtration efficiency and pathogen-interaction dynamics of filter feeders. Understanding these responses will be essential for predicting the resilience of filter-feeding populations and for designing adaptive disease management strategies under shifting oceanic conditions. Ultimately, harnessing the natural filtration and disease-regulating capacity of filter feeders could transform them into living biofilters for ecosystem health, sustainable aquaculture, and even public health protection. With further research and targeted application, these organisms may serve as key allies in mitigating waterborne disease risks in an era of intensifying aquaculture expansion and environmental change.

12. Conclusion
Filter-feeding invertebrates, particularly bivalves, are central to aquatic disease dynamics, functioning as both pathogen sinks and reservoirs. By removing bacteria, viruses, protozoans, and parasites from the water column, they contribute to ecosystem health, aquaculture sustainability, and natural disease regulation. Yet, their role is context-dependent: while some pathogens are degraded, others persist in their tissues, posing risks of transmission to humans and wildlife. Climate change further complicates these interactions by altering both filter-feeder physiology and pathogen dynamics. In aquaculture, especially through Integrated Multi-Trophic Aquaculture (IMTA), filter feeders offer an eco-friendly and sustainable strategy for reducing pathogen loads and reliance on antibiotics. Future research should prioritize species-specific pathogen removal efficiencies, microbiome-mediated interactions, and the resilience of filter-feeder-pathogen systems under changing environmental conditions. Overall, filter feeders are not only ecosystem engineers but also key allies in global aquatic disease management. Harnessing their bioremediation potential through interdisciplinary approaches can enhance ecosystem resilience, reduce aquaculture disease risks, and safeguard human and environmental health.

13. Conflict of Interest
The authors declare that there is no conflict of interest regarding the publication of this review paper.

14. Consent to Publish
All authors have read and approved the final manuscript and consent to its publication.

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