

Such a system does not require sequencing every sample. Indeed, an economically realistic workflow may use high-information technologies during discovery, then translate validated biomarkers into qPCR, dPCR, flow-cytometric, or biosensor assays. The recent development of field-oriented LAMP and rapid microbial fingerprinting supports this two-stage model of discovery followed by operational simplification (Pu et al., 2026; Bui et al., 2026).

8 Applications Across Major Marine Aquaculture Systems

8.1 Marine finfish aquaculture

Finfish provide multiple microbiome compartments for health monitoring, including water, gut, gills, skin, and mucus. External mucosae are particularly informative because they directly experience environmental change while functioning as barriers to infection. In marine-stage Atlantic salmon, specific gill-associated taxa correlated with gill-health status over a year-long production cycle, although general diversity metrics were not sufficient to define health (Clinton et al., 2024).

Gilthead seabream research also demonstrates that infection and antimicrobial treatment can affect different mucosal microbiomes in distinct ways (Rosado et al., 2023). Marine finfish monitoring should therefore avoid assuming that gut samples alone represent whole-animal microbial health. A tissue-specific sampling strategy is more defensible when the disease of interest has a defined portal of entry or mucosal target.

8.2 Shrimp aquaculture

Shrimp farming is particularly suited to microbial surveillance because animals and environmental microorganisms are closely connected through water, sediment, feed, fecal material, and the intestinal tract. Studies in *L. vannamei* have documented developmental changes in intestinal microbiota, salinity-associated restructuring, disease-related dysbiosis, and microbial differences among clear-water, probiotic, and biofloc production approaches (Deris et al., 2022; Vinay et al., 2022; Waiho et al., 2023).

Vibrio monitoring remains important, but its interpretation should extend beyond total relative abundance. Species, virulence potential, absolute load, environmental stress, and broader community structure provide a more defensible assessment. Shrimp studies of dysbiosis also show why community-level signals may complement rather than replace specific pathogen testing (Huang et al., 2020).

8.3 Shellfish aquaculture

Shellfish hatcheries illustrate both the promise and difficulty of microbial prediction. Larval cultures can undergo rapid production failure, yet potential pathogens may not always be the primary trigger. Cram et al. (2024) found that early microbial-community patterns in oyster larvae were related to later batch outcomes, while several organisms enriched during crashes likely took advantage of already deteriorating conditions.

Pacific oyster mortality syndrome provides a further example of complex disease ecology in which viral infection, bacterial communities, host susceptibility, and environment interact. Experimental work has associated microbiota composition with different disease outcomes, supporting the idea that shellfish health may need to be understood as a pathobiome rather than a one-pathogen system (Delisle et al., 2022).

8.4 Recirculating and high-density marine aquaculture systems

Engineered systems provide unusually strong opportunities for microbial health management because water flows, biofilters, aeration, disinfection, and feeding are more controllable than in open-water culture. They also create complex microbial connectivity among water, biofilms, filters, and animal mucosae. Temporal Atlantic salmon RAS research demonstrates that substantial microbial restructuring can occur even in highly controlled production environments (Lorgen-Ritchie et al., 2022).

This controllability makes RAS suitable for testing causal management interventions. When a microbial warning appears, managers can modify operational variables and observe subsequent microbial responses. Over time, such feedback-rich systems could become test beds for validating health indicators before similar concepts are transferred to less controllable cage or coastal farms.