

Importantly, the baseline is a distribution, not a single reference sample. Longitudinal studies repeatedly demonstrate natural microbial succession in aquaculture systems (Kim et al., 2022; Bui et al., 2026). A farm that samples only during disease events has no reliable ecological reference against which to judge those events. Routine surveillance is therefore the foundation on which all later warning thresholds depend.

7.2 Microbial early-warning management model

Early-warning management focuses on deviation rather than diagnosis. A rapid monitoring tool might first identify an unusual cell-density pattern, pathogen increase, or community fingerprint. The result should then trigger confirmation using a more specific method and a simultaneous review of environmental and host data. This layered strategy balances speed with diagnostic reliability.

The approach is particularly attractive in hatcheries because microbial conditions can change quickly and early life stages are often vulnerable. Findings from oyster and barramundi larviculture suggest that community trajectories contain information related to later performance, although the predictive signals are not yet universal (Cram et al., 2024; Bui et al., 2026). Early warning should consequently be framed as increased probability requiring attention, not as certainty that disease will occur.

7.3 Risk-based intervention model

A risk-based model links intervention intensity to the weight of evidence. Low-risk conditions require routine husbandry; alert conditions justify increased sampling and correction of obvious environmental stress; high-risk conditions require focused diagnostic and biosecurity responses. Where intervention is necessary, management may include adjustment of feeding, aeration, water exchange, system hygiene, movement of animals, or other measures appropriate to the culture system.

This model also discourages prophylactic antimicrobial use based solely on a nonspecific microbial shift. Antimicrobials can themselves disrupt microbiomes, while responsible use is important for limiting resistance selection (Rosado et al., 2023). A microbiome-informed system should therefore reduce diagnostic uncertainty rather than create a new reason for indiscriminate treatment.

7.4 Microbiome regulation-based health management

Once a reproducible adverse microbial state has been identified, management can move beyond observation toward ecological regulation. Probiotics, prebiotics, synbiotics, biofloc management, and carefully selected microbial consortia are plausible tools for maintaining competitive microbial communities and improving host resilience. Evidence for *Phaeobacter* and other probiotic candidates shows that antagonism against pathogens can be harnessed, although effects remain strain- and system-dependent (Sonnenschein et al., 2021).

A more sophisticated goal is restoration of microbial function rather than introduction of one “beneficial” species. That idea remains ahead of current commercial evidence. Synthetic consortia, microbiota transplantation, and targeted microbiome engineering will require ecological and biosafety validation, especially in open marine systems where introduced microorganisms can interact with natural communities.

7.5 Adaptive and feedback-based health management

Health management becomes adaptive when monitoring does not end after intervention. Post-intervention samples should determine whether pathogen abundance decreased, microbial structure returned toward its normal range, environmental stress was corrected, and host condition improved.

7.6 Toward precision health management in marine aquaculture

Precision management requires thresholds that are specific enough to the farm to be meaningful but standardized enough to be transferable and audited. A practical future architecture may combine continuous environmental sensors with frequent low-cost microbial screening, less frequent sequencing for baseline renewal, and targeted molecular assays when warning signals appear.