

rapid warming, hypoxia, or deteriorating nitrogen conditions. Integrating these measurements can therefore distinguish random microbial fluctuation from an ecological transition with plausible biological consequences.

Sanggou Bay provides a field-scale example: seasonal bacterial restructuring and potentially pathogenic *Vibrio* patterns were analyzed alongside physicochemical variables rather than interpreted in isolation (Lu et al., 2025). The practical lesson is simple. A health dashboard should not contain “microbiome” as a separate compartment; microbial, environmental, husbandry, and host data should be treated as interacting dimensions of the same production system.

6.4 Microbial health risk classification

A three-level classification offers a practical way to translate continuous microbial variation into management decisions. The categories below are conceptual rather than validated universal thresholds. Numerical cutoffs should only be established after longitudinal calibration for a specific species, farm, production stage, sample type, and analytical method (Table 1).

Level I: Healthy

At this level, microbial measurements remain within an established farm- and stage-specific baseline. Potential pathogens are absent, low, or stable relative to historical observations; community turnover follows expected seasonal or developmental trajectories; environmental parameters remain acceptable; and animals show normal feeding, behavior, and survival. Routine monitoring continues without unnecessary intervention.

Level II: Alert

An alert should be triggered by convergence rather than one isolated result. Examples include repeated increases in an opportunistic pathogen, unexpected community displacement, reduced stability, disappearance of persistent health-associated taxa, or environmental stress occurring at the same time as microbial change. Sampling frequency should increase, the signal should be confirmed by an independent or targeted method, and modifiable husbandry factors should be reviewed before disease becomes clinically evident.

Level III: High Risk

High risk is characterized by multiple lines of evidence suggesting loss of system resilience: substantial pathogen enrichment or virulence-marker detection, persistent dysbiosis, unfavorable environmental change, and early host-health abnormalities. At this point, farm biosecurity and diagnostic procedures should be escalated, affected production units assessed separately, and any therapeutic intervention based on appropriate veterinary and laboratory evidence rather than microbiome data alone.

Table 1 Conceptual microbial indicators and corresponding management responses. These signals are intended for farm-specific calibration; they are not universal diagnostic thresholds

Indicator domain	Routine/healthy pattern	Alert or high-risk signal	Management interpretation and action
Target pathogens	Stable low background or non-detection	Repeated increase; virulence marker confirmed	Re-sample; confirm with qPCR/dPCR or culture; strengthen diagnostics and biosecurity
Community structure	Expected seasonal/developmental variation	Abrupt or persistent deviation from baseline	Increase monitoring; examine recent husbandry and environmental changes
Diversity/stability	Farm-specific normal range	Sudden loss of stability or resilience	Treat as supporting evidence, not diagnosis by itself
Health-associated taxa	Persistent baseline pattern	Repeated decline or disappearance	Examine concurrent stressors; avoid assuming causality without validation
Functional genes	Stable functional profile	Enrichment of virulence, stress, or resistance functions	Confirm target identity/activity; review antimicrobial and biosecurity history
Water quality	Expected operational range	Warming, hypoxia, nitrogen stress, organic loading	Correct manageable environmental stress and assess interaction with microbial signal
Host condition	Normal feeding, behavior and survival	Reduced feeding, lesions, abnormal behavior, increased mortality	Escalate clinical/pathogen diagnostics and targeted intervention