

severe clinical signs and high mortality, indicating that poor water quality mainly increases stress and susceptibility rather than acting as the sole cause of infection. A broader systematic review of marine cage culture in East and Southeast Asia notes that environmental triggers, including water quality deterioration, are important in initiating outbreaks of *Vibrio* spp., parasitic infections, and viral diseases such as iridoviruses and nervous necrosis virus (Jahangiri et al., 2022).

Quantitative farm-level data link specific water quality variables to pathogen presence in cage-cultured grouper. A survey of marine cages found multiple co-occurring pathogens, including *Vibrio alginolyticus*, *V. vulnificus*, *Photobacterium damsela*, nervous necrosis virus, and iridovirus, and identified water temperature, dissolved oxygen, ammonia, iron, and nitrite as the most significant physicochemical factors associated with their occurrence. A review of fish health aspects in grouper culture further emphasizes that environmental deterioration and intensive practices contribute to frequent viral, bacterial, and parasitic disease problems, complicating large-scale production (Figure 3).

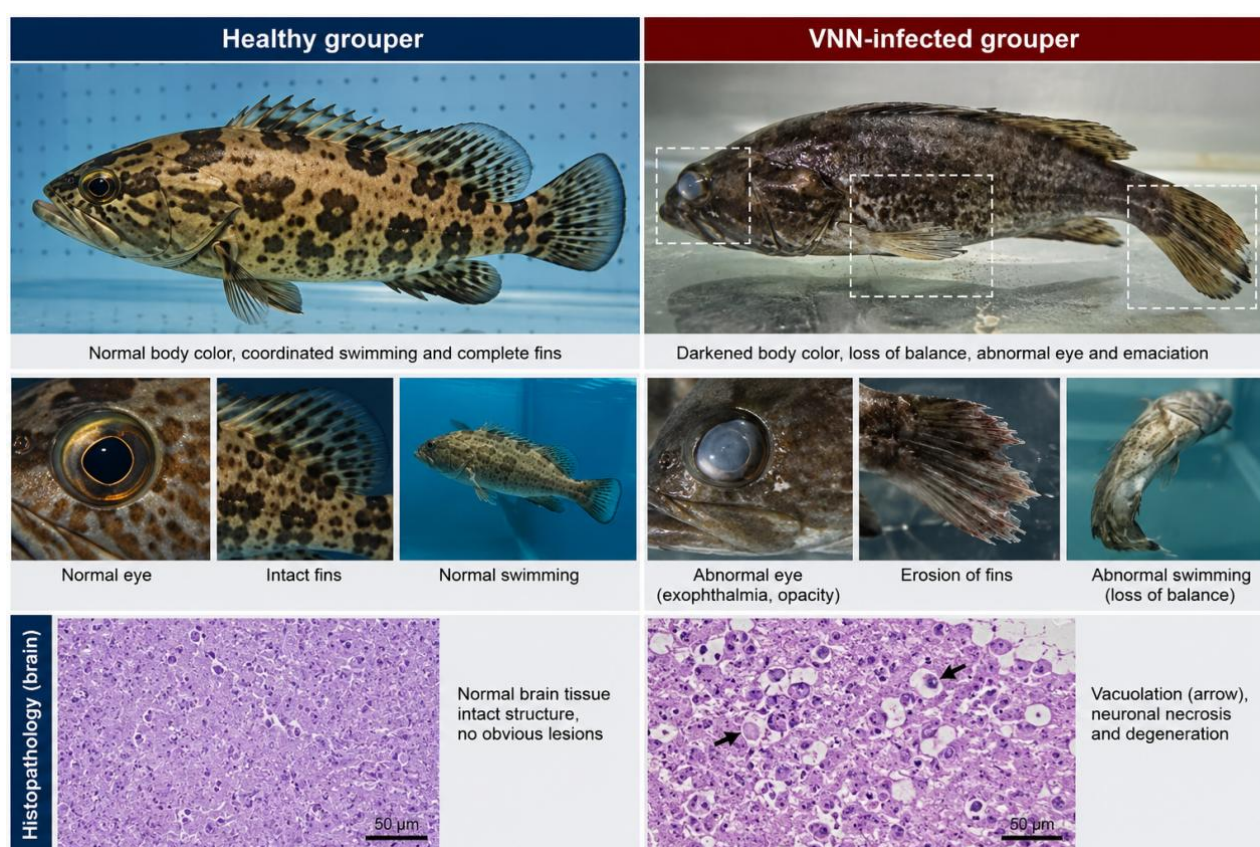


Figure 3 Representative clinical signs observed in healthy and diseased cage-cultured grouper

8.3 Growth performance and survival rate variations

Water quality management regimes strongly influence grouper growth and survival outcomes. In a 40-day nursery trial comparing flow-through, recirculation, and recirculation with bioremediation, the bioremediation treatment achieved the most stable salinity and ammonia ranges and inhibited *Vibrio* spp., yielding the highest survival (94.8 %), fastest length and weight growth, and lowest feed conversion ratio (Ismi et al., 2023). Similarly, combining water exchange with siphoning in hybrid grouper culture improved water quality by reducing ammonia, phosphate, and total organic matter, and achieved 100 % survival and better feed utilization than treatments with poorer waste removal (Putra et al., 2025).

Specific water quality parameters also determine growth efficiency and mortality risk. Cage experiments with tiger grouper under different salinities showed that 32 psu produced the highest absolute and specific growth rates and survival, along with the most favorable feed conversion ratio, whereas lower salinities reduced survival. In