

Spatial comparisons across multiple mariculture systems reveal that system type and layout also influence water quality patterns. In a Chinese coastal region containing seaweed, shellfish, and cage-fish areas, DO and transparency were relatively higher in seaweed zones, while nutrient concentrations were elevated in cage fish and shellfish areas compared with a blank control, indicating distinct local water quality signatures for each system (Zhu et al., 2023). Principal component and redundancy analyses further linked spatial differences in phytoplankton composition to gradients in total nitrogen, salinity, and transparency, illustrating how physical and chemical heterogeneity structures biological communities within and among farming areas.

5 Mechanisms of Aquaculture Activities Affecting Water Quality

5.1 Feed input and residual feed decomposition processes

In cage-culture systems, feed is the primary input of nutrients and organic matter, and a considerable fraction is not converted into fish biomass but lost as uneaten pellets and associated particulates. Mass-balance analyses show that only about 39%-43% of feed nitrogen and phosphorus are retained in salmon tissues, with the remainder released as organic particulates and dissolved wastes (Wang and Olsen, 2023). Conceptual nutrient budgets for cage aquaculture similarly indicate that on the order of 130 kg •N and 25 kg •P can be discharged per ton of fish produced, emphasizing the central role of feed inefficiency in nutrient emissions.

Uneaten feed that sinks below cages undergoes mineralization, releasing dissolved inorganic nitrogen and phosphorus and contributing to eutrophication, oxygen depletion, and increased biological oxygen demand. Studies in floating net cages report that 20%-30% of feed is uneaten and partially decomposes in the water, becoming a major source of nitrogen, phosphorus, and organic matter pollution (Astuti et al., 2023). Reviews of aqua-feed wastes further note that the dietary composition of feeds governs the proportion and form of nitrogenous and phosphorus compounds entering the environment, which in turn drive changes in pH, algal turbidity, and eutrophication risk.

5.2 Waste excretion and organic load accumulation

Beyond uneaten feed, fish metabolism generates substantial dissolved and particulate wastes that accumulate in and around cages. Mass-balance models for Atlantic salmon indicate that approximately 18% of consumed carbon, nitrogen, and phosphorus is lost as defecation, while 39%-43% is released through excretion or respiration, underscoring the importance of metabolic pathways in waste generation. Similar modeling approaches for cage farms estimate that over 60% of phosphorus waste is solid, whereas more than 65% of nitrogen waste is excreted as dissolved ammonia, illustrating how excretion loads the water column with reactive nitrogen.

These waste fluxes can alter water and sediment chemistry when they exceed local assimilative capacity. In a eutrophic lake with Nile tilapia cages, increased concentrations of nitrogen and phosphorus near cages stimulated algal growth, while organic material accumulated beneath cages elevated benthic biochemical oxygen demand and promoted anoxic conditions and reduced redox potential (Musa et al., 2022). A broader review of aquaculture wastewater confirms that aquafeed, drugs, and metabolic wastes collectively contribute conventional pollutants and organic compounds to receiving waters, requiring improved treatment and management to avoid long-term environmental and health risks (Liu et al., 2024).

5.3 Biological disturbance and ecological feedback effects

Organic enrichment from feed and wastes modifies benthic habitats, driving biological disturbance and feedbacks on water quality. Case studies around Mediterranean fish farms show that sediments beneath cages experience biodiversity loss and are dominated by opportunistic species such as *Capitella* sp. I, with the impact generally confined to tens of meters but closely linked to cultured biomass and hydrodynamic conditions. Similar patterns appear in tropical environments, where elevated organic waste deposition directly beneath and adjacent to cages leads to highly perturbed macrobenthic communities with extremely low diversity and dominance of second-order opportunists (Grouazel et al., 2025).