transcriptomics under salinity 5 versus 30 showed that inorganic ion channels and transporters, mineral absorption, and bile secretion contribute to iono-osmoregulation and cell-volume regulation, while tissue-specific analysis identified the kidney, gill, and spleen as major osmoregulatory organs. Complementary work further showed that low salinity activates PI3K-AKT signaling in osmoregulatory organs and that pathway inhibition suppresses ion-channel gene expression, indicating that signal transduction positively regulates ion transport during osmotic adjustment (Cui et al., 2020).

Hormonal and osmolyte-mediated regulation also plays a central role in salinity adaptation. Under low-salt stress, pituitary PRL expression and PRLR expression in gill and kidney increased and peaked at 12 h, while long-term low-salinity exposure maintained especially high PRLR expression in the gill, suggesting that PRL signaling is important in sustained hypoosmotic regulation (Liu et al., 2020). In parallel, the myo-inositol biosynthesis pathway showed adaptive expression with a 12 h turning point across tissues, and RNAi knockdown weakened gill osmotic regulation and shortened survival under salinity stress, showing that organic osmolyte metabolism is a functional component of turbot osmoregulation.

4.2 Effects of salinity fluctuations on physiological stability

Salinity fluctuations affect physiological stability by changing the energetic cost of ion regulation and altering core blood and enzyme indicators. In juvenile turbot reared for three months across 15, 25, and 33.5‰, gill Na+, K+-ATPase activity, plasma chloride, and osmolality were lowest at 15‰, and estimated optima for minimum osmoregulatory load clustered around intermediate salinities, supporting the view that moderate salinity reduces the energy expenditure required for homeostasis (Liu et al., 2020). This energetic dimension is reinforced at the molecular level by evidence that salinity challenge changes AMPK α1/α2 expression in gill in a time- and salinity-dependent manner and that AMPK expression is positively correlated with Na+, K+-ATPase activity, linking salinity stress directly to cellular energy sensing.

When salinity departs too far from normal seawater, stability is maintained only through broader metabolic and endocrine compensation. Low salinity caused major liver transcriptional changes, with 826 differentially expressed genes enriched in energy metabolism and especially lipid metabolism, and serum triglycerides decreased over time in freshwater exposure, indicating metabolic disturbance rather than neutral acclimation (Liu et al., 2020). Over longer exposure, low salinity at 10 ppt remodeled circadian organization of physiological markers by shifting or replacing normal daily rhythms of T3, T4, and ALT without clear oxidative damage, suggesting that chronic hyposmotic stress can preserve short-term balance but only by reorganizing endocrine and metabolic timing (Liu et al., 2026).

4.3 Interaction between salinity stress and pathogen infection

Salinity stress interacts with infection largely through its effects on host immunity and resistance rather than through direct pathogen measurements alone. In juveniles reared at 8, 20, 32, and 40, fish at salinity 20 had the highest 4-day LD50 after *Vibrio anguillarum* challenge and also showed the highest lysozyme, complement, and phagocytic activity, whereas immunity was poorest at salinity 40, indicating that intermediate salinity supports stronger disease resistance than more extreme salinity conditions. Additional response-surface analysis showed that salinity significantly shapes expression of immune markers such as *hsp70* and IgM in liver and kidney, with a significant temperature-salinity interaction for kidney IgM, supporting the conclusion that salinity modifies immune competence in a tissue-specific way (Cui et al., 2020).

Mechanistic studies suggest that improved osmotic capacity can indirectly strengthen resistance to salinity-associated health decline. Dietary or immersion myo-inositol increased gill myo-inositol content, extended survival under salinity stress, and enhanced osmoregulatory, antioxidant, and immune-related functions, with steroid-associated pathways occupying a central place in this response (Cui et al., 2020). Consistently, dietary myo-inositol also prolonged survival under low salinity by modulating cortisol synthesis, increasing Na+-K+-ATPase activity and ion-channel gene expression, whereas suppression of cortisol eliminated these benefits, indicating that endocrine support for osmoregulation can help buffer the immune and survival costs that accompany salinity stress.