4.2 Feed conversion efficiency and nutrient utilization

Feed conversion efficiency is a central indicator of farming performance, but it should be interpreted together with broader nutrient-use metrics. In aquaculture, FCR is defined as feed administered divided by weight gained, and it remains the most widely used measure of production efficiency. However, FCR alone does not capture feed composition, edible yield, or nutrient quality of harvested fish, so nutrient retention offers an important complementary perspective when comparing farming systems or feeds. For Chinese sea bass, diet-quality studies show that feed utilization is highly responsive to nutritional balance. A dietary n-3/n-6 PUFA ratio of 0.66 produced the highest final body weight, weight gain, specific growth rate, and protein efficiency ratio, together with the lowest FCR, indicating that system performance depends partly on whether the culture environment allows efficient use of a biologically appropriate diet (Dong et al., 2023). Thus, comparisons among farming systems should consider not only how much feed is consumed, but how effectively environmental conditions translate that feed into growth and retained nutrients.

System conditions can improve or impair feed utilization by altering oxygen availability, crowding, digestion, and activity level. A broad endocrine review shows that low dissolved oxygen reduces growth, feed intake, and overall fish performance, and that FCR is inversely related to dissolved oxygen, making water-quality control a direct determinant of feed efficiency (Canosa and Bertucci, 2023). Density has similar effects. In *Amur sturgeon*, increasing stocking density reduced feeding rate and increased FCR, and the growth suppression was linked to lower food intake and poorer food conversion efficiency under crowding stress. In *Asian seabass* reared in RAS, higher stocking density significantly decreased both growth performance and feed utilization efficiency, while lower-density fish also maintained higher digestive enzyme activities and protein deposition (Ezhilmathi et al., 2022). By contrast, moderate hydrodynamic stimulation can support nutrient use: in Chinese sea bass, moderate flow increased digestive enzyme activity and improved growth, while in simplified indoor recirculating systems, continuous water flow appears to enhance exercise-related protein deposition in muscle. These results suggest that farming systems improve FCR and nutrient utilization when they minimize physiological stress while maintaining water movement, oxygenation, and feeding conditions within the species' optimum range.

4.3 System-related growth regulation mechanisms

The effects of farming systems on growth are mediated by physiological regulation rather than by environment alone. Fish growth is controlled primarily through the GH/IGF axis, and this axis is strongly influenced by external factors such as temperature, salinity, photoperiod, pollutants, and stocking density. More generally, fish performance reflects an interaction between genetic potential and immediate environmental conditions, and adverse conditions such as poor water quality, disturbance, or social stress reduce growth through endocrine pathways rather than through simple feed limitation alone. In Chinese sea bass specifically, temperature and salinity changes regulate growth through a stress-feeding-growth neuroendocrine cascade. Growth after 30 days was markedly better at 21 °C than at 14 °C or 28 °C, and transcriptomic analysis identified responsive modules linking stress signaling to feeding and growth control. This means that farming systems differ in growth outcome partly because they differ in how strongly they activate or suppress these endocrine networks.

Several mechanisms identified across the evidence base are directly relevant to system design. In L. *maculatus*, stress-induced heat shock proteins appear to activate the hypothalamic-pituitary-interrenal axis, then stimulate anorexigenic genes and growth-inhibiting somatostatin, providing a plausible pathway by which unfavorable thermal or salinity conditions suppress feeding and growth. Hydrodynamic conditions also regulate metabolism at the molecular level: higher flow enhanced growth but increased oxidative stress, and transcriptomic analysis identified *foxo3* and the FoxO signaling pathway as key hubs coordinating oxidative stress mitigation and energy mobilization. Density-related regulation follows a similar pattern. In juvenile Chinese sturgeon reared in RAS, high density elevated ACTH, cortisol, glucose, lactate, and HSP70 while down-regulating GH and IGF-I, whereas in *Asian seabass* increasing density down-regulated the GH/IGF axis and up-regulated myostatin. At the tissue-growth level, muscle development depends on GH, IGFs, TOR-related signaling, and myogenic regulators, so any farming system that chronically disrupts endocrine balance, oxygen supply, or activity pattern is likely to limit growth even when feed is abundant.