These concerns are especially relevant because environmental stress in turbot often operates through interacting physiological mechanisms rather than through simple single-factor effects. Elevated temperature in farmed turbot has been linked to increased disease-associated mortality above 20°C and to molecular signatures of oxidative stress and metabolic disturbance under pathogen challenge, while low salinity stress disrupts liver lipid metabolism and depresses key metabolic pathways (Liu et al., 2020). Against this background, the objective of this review is to synthesize current knowledge on how major environmental factors influence the health status of turbot, with emphasis on stress physiology, immune competence, and metabolic regulation. Such a synthesis is significant for improving environmental control in intensive culture systems, guiding health-oriented farm management, and identifying priorities for future research as climate change and production intensification continue to reshape the conditions under which turbot are farmed (Mariu et al., 2023).

2 Biological and Physiological Characteristics of Turbot (*Scophthalmus maximus*)

2.1 Growth traits and ecological adaptation

Turbot is a demersal flatfish distributed from the Northeast Atlantic to the Mediterranean, Baltic, and Black seas, and its life history reflects strong adaptation to benthic habitats. Larvae retain high dispersal potential through a pelagic phase, whereas postlarvae, juveniles, and adults are relatively sedentary, a combination that links local habitat specialization with broader population connectivity. Genomic evidence further indicates that ecological adaptation in this species has been shaped by environmental selection, with temperature and salinity emerging as major drivers and with candidate genes associated with osmoregulation, growth, and disease resistance identified in selected genomic regions.

The species also shows marked physiological and production-related variation in growth. Whole-genome analysis links turbot's adaptation to demersal and relatively cold environments to selection on genes involved in vision and membrane lipid metabolism, and reports sustained growth across approximately 13°C-20°C, indicating capacity to perform under cool and fluctuating thermal conditions. At the individual level, growth is strongly structured by sex and metabolic phenotype: females ultimately outgrow males under most thermal regimes, while fast-growing fish show up-regulation of anaerobic glycolytic pathways in white muscle, consistent with a higher metabolic rate supporting rapid somatic growth.

2.2 Immune system and stress response mechanisms

In turbot, stress responses involve endocrine activation together with tissue-specific immune modulation. Acute handling stress elevates cortisol and plasma K+ after both aerial exposure and net confinement, but unlike the canonical response described for many other teleosts, turbot shows little or no parallel rise in plasma glucose, suggesting a distinctive stress physiology. Chronic crowding likewise acts as a potent stressor: high stocking density suppresses growth, increases plasma cortisol and glucose, and reduces mucus immune activities such as lysozyme, alkaline phosphatase, and esterase, indicating weakened barrier defense at the skin surface (Yang et al., 2020).

Environmental insults also connect the hypothalamic-pituitary-interrenal axis with oxidative stress and immune suppression. Under elevated ammonia exposure, juvenile turbot show increased CRH, ACTH, and cortisol together with reduced lysozyme, complement factors, and IgM, while liver antioxidant responses and heat-shock protein expression rise alongside lipid peroxidation, consistent with stress-induced immune inhibition and oxidative damage. Thermal stress appears to alter disease resistance through a related mechanism: at 21°C, challenged fish exhibit enhanced neutrophil-associated responses, sustained myeloperoxidase-linked oxidative stress, and disturbed NADPH and glucose metabolism, changes proposed to underlie thermo-linked epizootic risk in turbot culture.

2.3 Temperature and salinity tolerance ranges

Temperature and salinity jointly determine performance in juvenile turbot, and their interaction is more informative than either factor alone. In a three-month rearing study, growth, feed intake, and feed conversion efficiency were highest at 15‰ and lowest at full-strength seawater, with the overall optimal growth combination estimated at about 21.8°C and 18.5‰ (Jia et al., 2020). Osmoregulatory measurements support the same pattern: gill Na+, K+-ATPase activity, plasma chloride, and osmolality were lowest at intermediate salinity, implying reduced energetic costs of ion regulation under brackish to moderately saline conditions.