

worsened outcomes (Jia et al., 2020). These results indicate that relatively small increases above the lower culture range can decisively transform infection from controlled to lethal, making temperature management a central component of viral disease prevention.

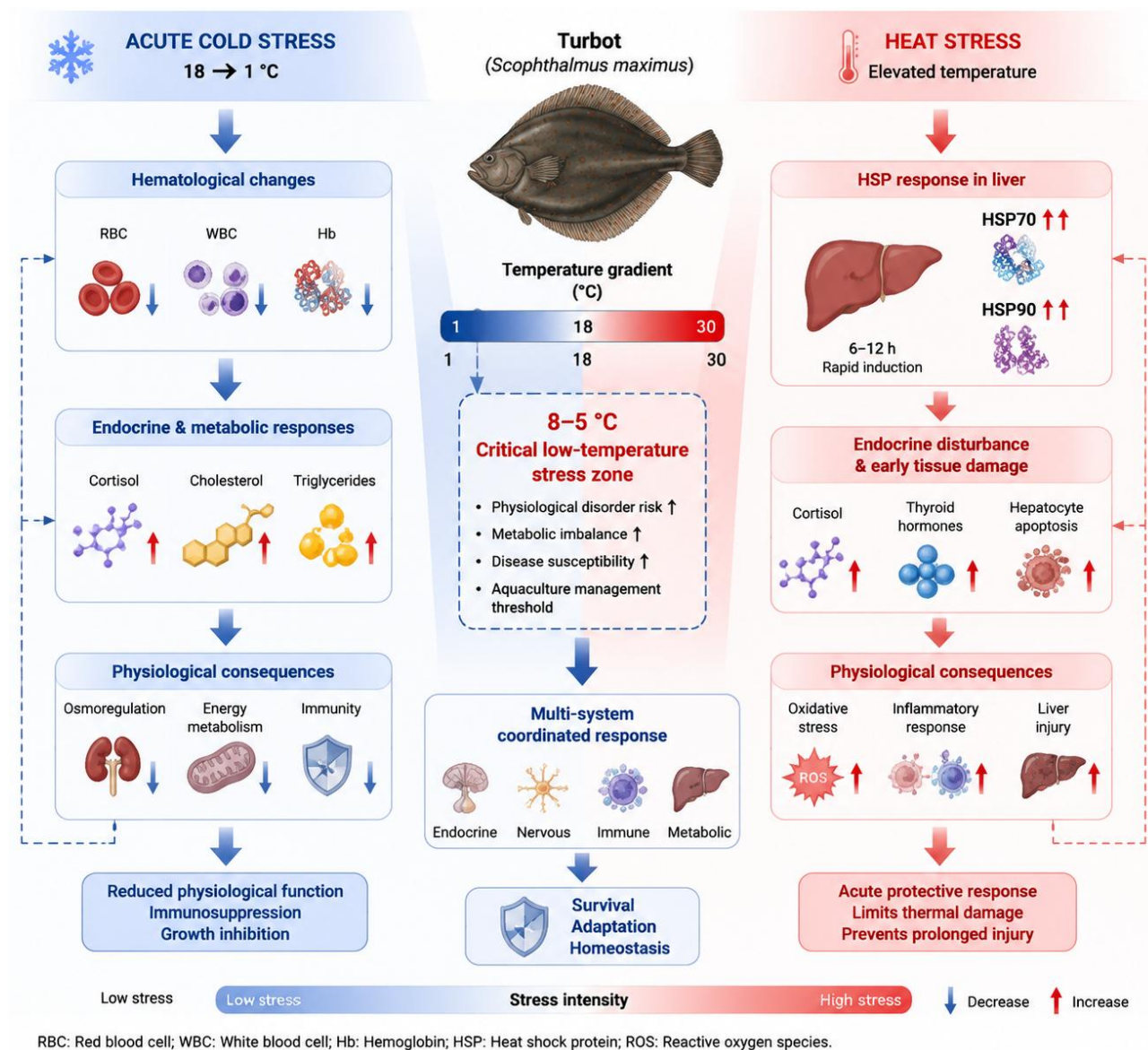


Figure 1 Integrated physiological and molecular stress responses of turbot under acute cold and heat exposure, highlighting hematological changes, endocrine disruption, and HSP70/HSP90 regulation

Evidence from pathogen-mimic challenge further suggests that high temperature can increase disease risk even when immune activity is stimulated rather than suppressed. Integrated transcriptomic and proteomic analyses showed that elevated temperature enhanced neutrophil-mediated responses but also intensified MPO-associated oxidative stress and disturbed NADPH and glucose metabolism, a combination proposed to contribute to thermo-linked epizootics in turbot (Liu et al., 2020). Related work on high water temperature and skin mucus immunity found significant temperature-dependent changes in immune-related factors at the mucosal surface, supporting the view that warming reshapes frontline defense systems as well as systemic stress pathways.

4 Salinity and Osmoregulatory Stress

4.1 Osmoregulation mechanisms in turbot

Turbot osmoregulation depends on coordinated responses across the gill, kidney, and other regulatory tissues, with ion transport and signaling pathways forming the core of adaptation to hypoosmotic challenge. Kidney