whereas a standard commercial diet resulted in 35%-50% mortality, demonstrating that targeted dietary interventions can substantially reduce economic losses during hot periods. Where active temperature control is feasible, engineering and economic analyses indicate that it can be cost-effective when carefully designed. Energy-modelling of a New Zealand land-based abalone farm found that temperature control using a semi-closed conditioning system with heat pumps can enhance growth and reduce summer mortality, but poor design may create very high energy demand; the study shows that plant design strongly influences operating costs (Jayatissa et al., 2002). For broodstock in cold regions, switching from flow-through heated systems to a simple closed recirculating system reduced electric power consumption for heating to about one-seventh while maintaining or even improving gonad development, showing that recirculation with heat retention can greatly cut energy costs without sacrificing biological performance (Matsumoto and Maeda, 2021).

8 Management Strategies for Temperature Regulation in Abalone Aquaculture

Technological solutions that actively regulate water temperature are central to stabilizing production in intensive abalone systems. In cold regions, Japanese hatcheries that induce gonadal maturation of *Haliotis discus hannai* by heating seawater can substantially cut energy costs by shifting from flow-through to simple closed recirculating systems that reuse warmed water, reducing power consumption for heating to about one-seventh while maintaining water quality and normal gonad development. More advanced engineering approaches in recirculating aquaculture workshops use computational fluid dynamics to simulate heat exchange between indoor air and water, allowing accurate estimation of cooling loads and optimization of ground-source heat pump units, which reduces over-design and investment in temperature-control equipment. Thermal models and low-cost control hardware further refine facility operation. Heat-balance modelling for recirculating aquaculture systems has produced user-friendly tools capable of predicting hourly to annual heating and cooling requirements, solar radiation and water temperature, with realistic accuracy relative to measured tank temperatures; these tools support design choices that minimize heating costs while maintaining optimal thermal regimes. Experimental work on small recirculating tank systems shows that inexpensive in-situ coil heat exchangers, coupled to computer-controlled chillers and heaters, can impose desired temperature regimes efficiently, illustrating a practical route for fine-scale temperature management in multi-tank abalone facilities.

Stocking density interacts strongly with temperature and water quality, so coordinated management is necessary to sustain growth and survival. In land-based recirculating systems, *Haliotis discus hannai* stocked at 600-1000 ind m^{-2} showed significantly higher survival, specific growth rate and food intake than abalone held at 1500 ind m^{-2}, with the high-density group exhibiting elevated moisture, lactic acid and antioxidant enzyme expression, indicating heightened metabolic and oxidative stress despite identical environmental conditions. complementary studies under flow-through conditions show that at 1200-1500 ind/m^2, glycolytic and anaerobic enzymes (hexokinase, pyruvate kinase, lactate dehydrogenase) are upregulated and more energy is diverted to resisting oxidative damage, leaving little energy for growth, whereas 900 ind/m^2 yields the highest survival and energy accumulation for growth and is recommended as an upper practical density. Optimizing density also depends on culture system and exposure to open-water temperature fluctuations. On an offshore mechanized platform, increasing coverage from 20 to 50% of cage surface area reduced survival and growth of abalone over 240 days, even though food was adequate, while well-chosen densities and diets on this offshore system improved growth relative to a traditional nearshore model and reduced pressure on warmer, more variable coastal environments. Long-term cage trials with *Haliotis* asinina similarly found an inverse relationship between growth and density but little effect on survival, highlighting that economic choices must balance individual growth rates against total biomass gain, with moderate densities often providing the most favourable trade-off under given environmental conditions.

Building climate-resilient abalone farming systems requires integrating genetic, technological and ecosystem-based strategies to buffer increasing temperature variability and extremes. Reviews of aquaculture adaptation emphasize selective breeding, species diversification, and advanced systems such as recirculating aquaculture, aquaponics and integrated multi-trophic aquaculture (IMTA) as core climate-resilient approaches that enhance adaptive capacity to warming, acidification and extreme weather while supporting sustained production. In an abalone-specific context,