

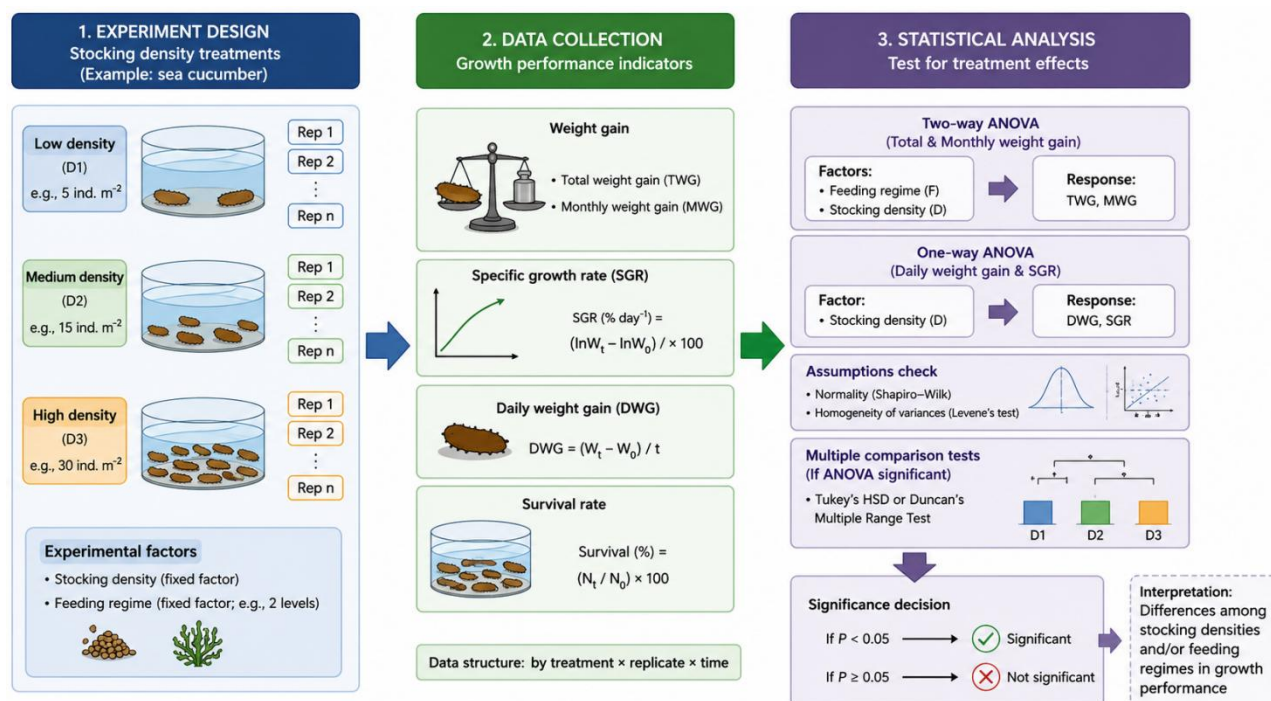


Figure 1 Statistical framework for analyzing stocking density effects on growth performance using ANOVA and multiple comparison tests in aquatic culture systems. Adapted from standard experimental designs in aquaculture growth studies

More advanced approaches combine regression modeling and resampling to capture continuous density-growth relationships. In a floating-cage study on spotted rose snapper, growth was modeled using von Bertalanffy, logistic and Gompertz curves, with model selection via Akaike and Bayesian information criteria, and the logistic model chosen as best (Jurado-Molina et al., 2023). Bootstrap simulations (1,000 runs per density) were then used to estimate the distribution of the instantaneous growth rate parameter (K) for each density, and ANOVA followed by Tukey HSD compared K among densities, revealing an optimal intermediate density not evident from simple length-at-age comparisons (Jurado-Molina et al., 2023).

5 Mechanisms Underlying the Effects of Stocking Density on Sea Cucumber Growth

5.1 Physiological mechanisms underlying the growth-promoting or growth-inhibiting effects of stocking density

Physiological responses to density determine whether stocking promotes or suppresses sea cucumber growth by shaping energy allocation between maintenance and somatic gain. Experiments on *Apostichopus japonicus* show that high densities elevate cortisol and lactate in coelomic fluid, while glucose declines, indicating chronic crowding stress that accelerates energy consumption and reduces resources available for tissue growth. In contrast, moderate densities can enhance metabolic activity and nutrient utilization, as shown by higher metabolizable energy, excretion energy and activities of key respiratory enzymes at intermediate stocking levels, which coincide with superior growth performance (Mei et al., 2022). Behavioral and neuroendocrine adjustments further mediate physiological effects of density on growth. Under high density, *A. japonicus* shows increased crawling in the short term but pronounced long-term inhibition of feeding, directly limiting energy intake and growth potential. Density also alters neurotransmitter profiles: γ -aminobutyric acid (GABA) increases significantly at high density, and transcriptomic changes in lipid and energy metabolism pathways have been observed, suggesting central regulation of behavior and metabolic partitioning that reinforces growth inhibition under crowding (Tian et al., 2024).

5.2 Ecological mechanisms regarding competition for substrate resources and space utilization efficiency

Ecologically, stocking density modifies competition for benthic food and sediment surface, thereby affecting growth and size structure within populations. In integrated mariculture of *Holothuria scabra* with *Eucheuma denticulatum*, low-density treatments showed the highest individual growth rates, whereas high-density treatments had the lowest,