

clams and lower susceptibility to deteriorating water conditions than 50,000 clams·m⁻² (Bordignon et al., 2021). In open-area culture, carrying-capacity analysis recommended reducing average seeding density to about 700 ind·m⁻² in Jiaozhou Bay (Liu et al., 2021); in Korean cage culture, survival and shell growth both declined as density increased from 100 to 2,000 clams·m⁻², illustrating the sharp penalty of exceeding local tolerance limits. Overall, stocking density influences Manila clam yield not by a simple linear rule, but through a balance between individual growth, survival, and areal biomass. The most defensible conclusion from the available evidence is that moderate, system-specific densities produce the best compromise between marketable size, stable survival, and efficient yield formation.

5 Effects of Stocking Density on Quality Characteristics of Manila Clam

5.1 Condition index and soft tissue development

Stocking density consistently alters soft-tissue development by changing individual growth trajectories and the balance between biomass accumulation and competition for food and space. In suspended pre-fattening systems, increasing density reduced shell length and body weight, with B3 clams at the northern site showing mean weight after 4 weeks of 0.239 g at low density, 0.211 g at medium density, and 0.187 g at high density (Bordignon et al., 2021). A similar density-dependent decline in growth was observed in early pre-fattening upwelling systems, where specific growth rate fell as stocking density increased (Zanella et al., 2025). At the larval stage, growth also decreased significantly with increasing density, and 5-10 larvae·mL⁻¹ supported normal development better than denser treatments. These patterns indicate that excessive crowding suppresses tissue accretion well before market size is reached, thereby lowering the probability of achieving a high condition index at later stages.

Condition index responses appear to depend on both density level and food environment rather than on density alone. On the Korean west coast, the condition index of individual Manila clams decreased as adult population density increased, but increased with higher spat density, suggesting stage-specific density effects. The same study showed that condition index and clam density were affected by chlorophyll *a* in both the water column and sediment, linking tissue condition to food supply under crowded conditions (Kim et al., 2017). Evidence from Arcachon Bay further supports the use of condition index as a sensitive indicator of reproductive and somatic status, while showing that poor population performance can coincide with low gametogenic condition. More broadly, bivalve studies report that condition index and edibility metrics are useful indicators of productive tissue development, even when proximate composition differences between species are limited (Parvathy et al., 2023). Taken together, moderate stocking densities appear more favorable for maintaining soft-tissue fullness and commercial flesh development than either overcrowded or otherwise biologically imbalanced conditions.

5.2 Nutritional composition

Direct evidence on stocking density effects on the proximate composition of Manila clam soft tissue remains limited, but the available literature strongly suggests that density can modify nutritional quality indirectly through growth, energetic status, and food competition. Biochemical assessment methods developed for *Ruditapes* tissues show that protein, lipid, carbohydrate, and nonprotein nitrogen fractions are sensitive indicators of energetic status, and that tissue composition can shift with biological condition, diet, and sex. In Manila clam populations, higher tissue carbohydrate in some organs has been associated with lower relative lipid and protein proportions across physiological states, indicating that nutritional composition is dynamic rather than fixed. Because high density reduces growth in both larval and juvenile Manila clams, it likely changes the partitioning of assimilated energy among maintenance, structural growth, and reserves rather than only reducing size (Yan et al., 2006).

Comparative aquaculture studies reinforce this interpretation by showing that density-related stress can reshape proximate and flavor-relevant composition. In large yellow croaker, medium density improved several muscle-quality traits, while low-, medium-, and high-density groups differed in crude fat, essential amino acids, fatty acids, and aroma-related compounds (Jia et al., 2025). In a multitrophic biofloc system, the highest oyster density reduced the nutritional quality of associated microbial flocs to 14.96% protein and 3.71% lipid, showing that excessive bivalve loading can degrade the nutritional environment of the culture system itself. Baseline bivalve studies also