

These case studies indicate that pond performance depends not only on absolute density, but also on whether density is synchronized with nursery productivity and subsequent grow-out conditions. Juveniles reared in shallow fertilized nursery ponds grew faster than in the natural environment because of warmer water and richer natural food, showing why relatively intensive early pond phases can support later yield gains when transfer timing is managed well. Yet the Jiaozhou Bay assessment also showed that many existing culture areas had already exceeded carrying capacity and were experiencing high mortality, which means pond intensification without density control can undermine both survival and final harvest stability (Liu et al., 2021).

8.2 Tidal flat systems

In tidal-flat enhancement and bottom-culture systems, density optimization is usually framed as a balance between individual growth, biomass yield, and environmental variability. A demographic model developed from lagoon culture data showed that Manila clam growth and survival are shaped by temperature-driven variation and density-dependent survival, and projected that maximum biomass yield could reach about $6 \text{ kg} \cdot \text{m}^{-2}$ when seeding occurred in spring and harvest in late autumn of the following year (Melià et al., 2004). That same modeling work emphasized a tradeoff between maximizing average yield and minimizing yield variance, which is directly relevant to stocking decisions in enhancement-oriented tidal flats.

Field evidence also shows that the biologically optimal density depends on the production objective. In intensive marine-pond on-growing, lower density near $100 \text{ ind.} \cdot \text{m}^{-2}$ produced the best final size, but $300 \text{ ind.} \cdot \text{m}^{-2}$ gave the most favorable overall intensive-rearing outcome by combining 84% survival with final biomass of $4 \text{ kg} \cdot \text{m}^{-2}$. Likewise, suspended pre-fattening trials found that increasing density reduced shell size and the proportion of sowable juveniles, while $30,000 \text{ clams/m}^2$ provided a practical compromise between output and robustness under variable water conditions (Bordignon et al., 2021).

8.3 Ecological models

High-efficiency ecological aquaculture models regulate clam density not only to raise harvest output, but also to improve whole-system carbon use, water conditions, and economic performance. In tri-trophic pond polyculture with crab, shrimp, and short-necked clam, the best combined ecological efficiency and economic benefit occurred at $30\text{-}60 \text{ clams/m}^2$, with the intermediate 30 clams/m^2 treatment showing the highest organic-carbon utilization efficiency and the highest shrimp survival and yield. A more recent pond-ecosystem study similarly found that low clam density strengthened the CO_2 sink function through bottom-up stimulation of nutrient cycling and primary production, whereas high density weakened that function through stronger top-down filtering pressure (Li et al., 2024).

Economic and environmental case studies together suggest that moderate density usually outperforms both understocking and overstocking in integrated systems. In Taiwanese hard-clam farms, stocking density had a negative effect on cost efficiency overall, but farms using about $1.1\text{-}1.2 \text{ million clams/ha}$ achieved higher cost efficiency than farms stocked at either lower or higher levels, especially when combined with shrimp or fish polyculture. Evidence from integrated shrimp-bivalve ponds also suggests that a reasonable density increase does not necessarily degrade water quality or phytoplankton structure, indicating that ecological models can sustain higher productivity when density remains within system tolerance rather than exceeding it (He et al., 2025). Across these case studies, stocking density optimization in Manila clam aquaculture is not a single fixed number but a system-specific balance among food supply, survival risk, size targets, and ecological carrying capacity. The strongest recurring pattern is that moderate, stage-matched densities deliver the most reliable gains in yield and quality across pond, tidal-flat, and integrated ecological production systems.

9 Future Research Directions and Development Prospects

Future research on stocking density in hard clam culture should move beyond single-factor experiments and focus on interactive environmental regulation. Recent work on Manila clam pre-fattening shows that growth declines not only as density increases, but also as water flow decreases, indicating that the effect of density depends strongly on hydrodynamic exchange. Similar interaction patterns have been observed in larval clams, where growth, survival,