

Evidence from juvenile Manila clam culture showed that increasing density reduced shell size and the percentage of sowable clams at harvest, even when survival remained acceptable in some treatments (Bordignon et al., 2021). Sediment management can reinforce this strategy, because juvenile Manila clams performed best in poorly sorted sediment with an average grain size of medium sand, which improved survival, growth, and condition relative to less suitable bottoms (Joo et al., 2021).

Dynamic density adjustment should respond not only to size divergence but also to system feedbacks indicating emerging competition. Carrying-capacity analysis showed that oversaturation leads to poor growth and heavy mortality when food and oxygen become limiting, making periodic density reduction a preventive rather than corrective measure. In polyculture systems, clam density also alters plankton structure and ecosystem metabolism, with high-density razor clam treatments depressing macro-, micro-, and nanoplankton biomass and production more strongly than low-density treatments (Zhang et al., 2025). A practical dynamic strategy is to maintain relatively moderate densities at settlement and early nursery phases, then thin or regrade once growth dispersion widens and resource competition intensifies. This approach is supported by evidence that low-density culture improved juvenile performance in both razor clams and soft-shell clams under protected field conditions. It is also compatible with integrated pond systems, where moderate-to-high densities can increase areal yield but excessive crowding reduces individual growth (Ngô et al., 2025).

7.3 Intelligent monitoring and precision aquaculture management

Intelligent monitoring can make density management more precise by detecting when environmental conditions no longer support the standing biomass. Reviews of aquaculture sensing technologies show that IoT-based monitoring of pH, temperature, dissolved oxygen, and related variables improves growth, reduces mortality, and enables rapid detection of abnormal water conditions (Flores-Iwasaki et al., 2025). These parameters are central because water quality is one of the main constraints linking stocking density to performance and product quality in shellfish systems. Real-time monitoring is especially useful for clam culture because density effects often become severe only when oxygen, temperature, or food conditions deteriorate. In suspended Manila clam pre-fattening, the highest density caused marked mortality only under challenging water conditions near harvest, showing that “safe” density is conditional rather than fixed. Continuous monitoring systems are designed for exactly this problem, since they can issue alerts or trigger interventions when dissolved oxygen falls below critical thresholds (Jais et al., 2024).

Precision aquaculture moves beyond observation to automated control. IoT-ML systems have demonstrated continuous tracking of temperature, dissolved oxygen, pH, and turbidity, with thousands of corrective interventions used to maintain survival above 90% in culture ponds (Baena-Navarro et al., 2025). Fuzzy logic control has likewise maintained dissolved oxygen within an optimal range of 6-8 mg·L⁻¹ by dynamically switching aerators in response to real-time sensor input (Nagothu et al., 2024). For hard-clam farming, the management value of these tools lies in linking biomass decisions to live environmental data. Multi-node sensor networks can collect temperature, pH, and salinity data at short intervals with low error, supporting spatially explicit management across ponds or tidal plots. As a result, density adjustment, grading, bottom management, and harvest timing can be based on measured system capacity rather than fixed schedules, which is the most reliable route to stabilizing both yield and quality.

8 Case Studies

8.1 Pond-based culture

Along the Chinese coast, stocking-density optimization in pond-based Manila clam culture has increasingly shifted from empirical seeding toward stage-specific management that matches density to food supply, nursery function, and transfer size. A representative northern China three-phase system combined indoor early spawning, shallow fertilized nursery ponds, and later mudflat grow-out with optimized stocking size and density, shortening the production cycle to about 10-14 months and markedly increasing marketable output. In parallel, ecological carrying-capacity analysis from Jiaozhou Bay showed that production problems under intensive coastal culture were linked to stock saturation, and recommended reducing Manila clam seeding density to about 700 ind.·m² to improve culture quality and efficiency (Liu et al., 2021).