

thresholds (Tian et al., 2024). On farms, optimization measures combine density control with husbandry adaptations. In intensive *H. scabra* culture, providing highly nutritious diets and appropriate feeding regimes can partially compensate for food competition at higher densities, improving feed conversion and protein efficiency, though excess crowding still reduces growth. In land-based IMTA tanks, adjusting sea cucumber density and tank-cleaning frequency can optimize bioremediation and co-cultured species performance: higher *Neostichopus grammatus* density lowered nitrite and, at an intermediate cleaning frequency, improved abalone mean weight without affecting sea cucumber growth, illustrating that careful density-management combinations can alleviate some high-density issues (Onomu et al., 2024).

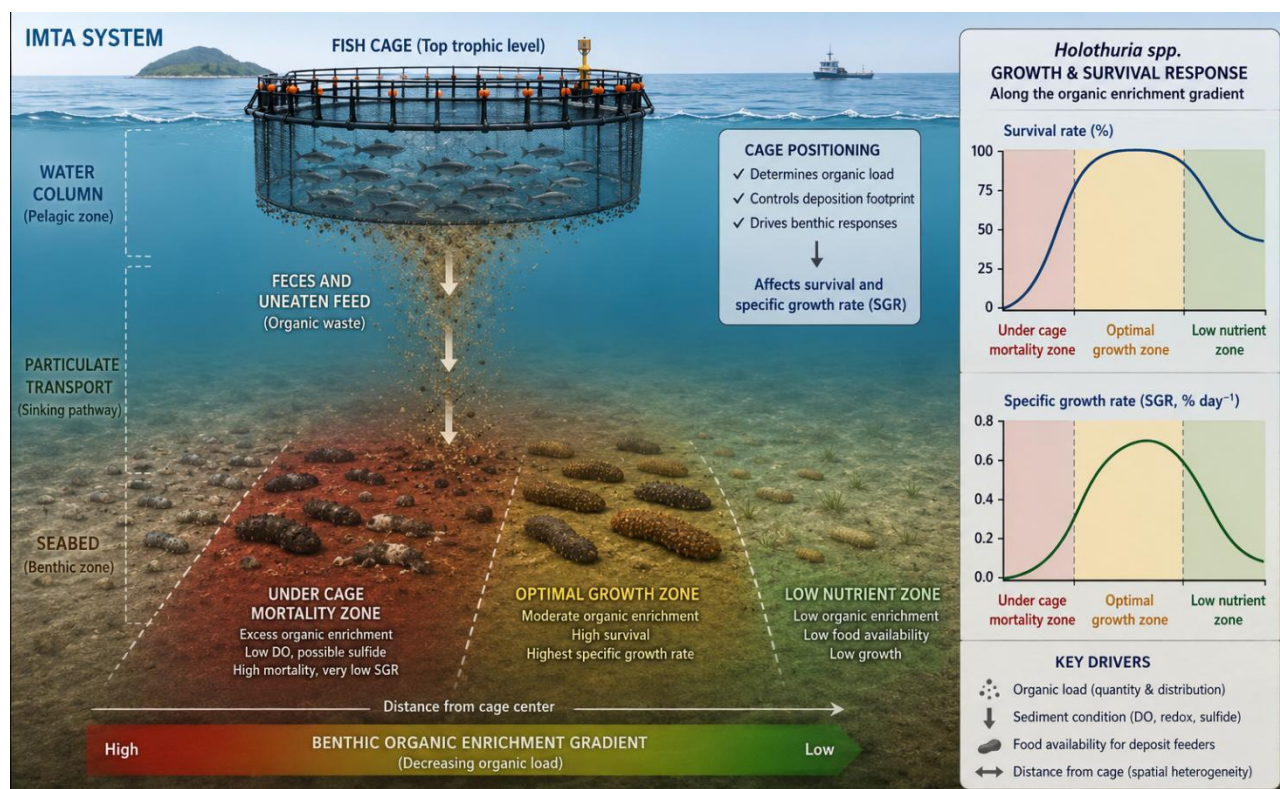


Figure 2 Schematic representation of integrated multi-trophic aquaculture (IMTA) systems showing organic matter deposition gradients and spatial variation in *Holothuria* spp. growth and survival

7.3 Comprehensive assessment of economic and ecological benefits based on field data

Field studies at community sea-pen farms and ranching sites demonstrate that stocking density management directly influences both economic returns and ecological co-benefits. In tropical *H. scabra* mariculture, cost-benefit analyses show that labour and utility costs can preclude profitability of monoculture pond farming, pushing farmers toward co-culture or lower-cost sea ranching, with profitability shaped by growth to larger body sizes that fetch exponentially higher prices (Azari et al., 2021). At a village-scale farm in Madagascar, pens stocked with *H. scabra* at relatively high densities (~300 g/m²) significantly increased leaf extension rates of the dominant seagrass *Thalassia hemprichii* by about 30%, indicating that income-generating sea cucumber farming can simultaneously enhance key coastal habitats (Arnall et al., 2021). At the fish-farm scale, modeling and IMTA assessments reveal trade-offs between stocking density, bioremediation performance and broader environmental impacts. An integrated red drum-*H. scabra* system showed that co-culture reduced eutrophication impacts and net primary production use relative to finfish monoculture, but only slightly lowered net particulate waste because current limits to sea cucumber stocking density constrain bioremediation potential (Chary et al., 2020). More generally, reviews emphasize that exceeding optimal stocking densities may improve local organic matter bioremediation but compromise sea cucumber growth yield, and call for more comprehensive economic evaluations of large-scale IMTA systems including high-value holothurians (Ciriminna et al., 2024).