

Density mainly changes the timing and intensity of mortality onset. In the Chinese summer-mortality study, medium- and high-density groups had higher initial death rates than low-density groups, even though all density groups ultimately experienced severe losses. In Korea, survival ranged from 82% to 100% and declined as stocking density increased, with the highest survival at 20 individuals per compartment. Similar cross-species evidence shows that density is often a weak predictor of mortality at low or moderate crowding but becomes important at very high densities, especially when net coverage exceeds practical limits.

6.2 Disease risk and immune stress responses

High stocking density appears to increase disease risk by weakening immune defense and raising microbial pressure. In noble scallops, high-density culture caused significantly higher mortality together with higher bacterial load, higher reactive oxygen species, and lower antibacterial capacity against *Vibrio parahaemolyticus*, indicating that overcrowding shifts scallops toward an oxidative and infection-prone state. A later study on the same species found that high-density groups had much lower survival than normal-density groups and significantly lower expression of CnMyD88, with weaker post-challenge immune expression after *Vibrio* exposure, supporting density-induced immunosuppression at the molecular level (Feng et al., 2023).

The likely mechanism in *C. farreri* is similarly multifactorial rather than attributable to a single pathogen. During mass mortality events, histological observations detected ciliates, larvae of other organisms, and abnormal secretions in the gill cavity, but prokaryotic inclusion bodies showed low prevalence and no clear correlation with deaths, arguing against one dominant infectious cause. More broadly in bivalves, reproduction and post-spawning stress depress haemocyte function, and in scallops granulocyte proportion drops in summer and early autumn around reproduction completion, which provides a physiological basis for the coincidence of density stress, weakened immunity, and seasonal mortality (De La Ballina et al., 2022).

6.3 Determination of optimal survival density threshold

The evidence does not support a single universal survival density for *C. farreri*; instead, the threshold depends on season, unit design, and local carrying capacity. In Jiaozhou Bay, ecological assessment concluded that current scallop culture was saturated and mortality was high, leading to a recommended density reduction to 280 individuals per cage. The same analysis cited earlier field observations that mortality stayed around 5% at ≤ 50 individuals per layer but increased significantly above that threshold, with some years reaching 90% mortality under heavier stocking (Liu et al., 2021).

Field comparisons suggest that a low-to-moderate density window is most defensible for survival-oriented culture. Offshore *C. farreri* culture in Sungo Bay showed that survival was inversely proportional to initial density, while offshore conditions improved outcomes relative to inshore sites because stronger currents likely improved food supply and local flushing. Modeling studies reinforce that density thresholds should be tied to carrying capacity rather than fixed numerically across all farms: scallop carrying capacity is lowest in spring and summer in culture bays, and mean-size scallop density in Sanggou Bay was estimated not to exceed 59 ind m^{-2} (Liu et al., 2025). Overall, for *Chlamys farreri*, optimal survival density is best defined as the highest density that remains below seasonal crowding, warming, and water-exchange limits, rather than as a single constant stocking number.

7 Coupling Relationship Between Water Environment Regulation and Density Effects

7.1 Dissolved oxygen consumption and supply limitations

Stocking density affects dissolved oxygen by changing both biological demand and the rate at which oxygenated water is renewed around cultured scallops. In intensive aquaculture systems, the reduction in dissolved oxygen increases with stocking density and is alleviated by stronger current speed, indicating that oxygen stress is fundamentally a coupled effect of biomass load and water exchange (Wen et al., 2025). This interaction is consistent with ecological carrying-capacity analyses in Chinese bivalve farming areas, where carrying capacity was regulated mainly by filtration rate and temperature, and summer-autumn conditions were identified as the period of lowest scallop carrying capacity.