

## SHORT COMMUNICATION

# Density-dependent mortality of the scallop *Chlamys farreri* (Jones & Preston) in grow-out culture

Xuelei Zhang<sup>1,2</sup>, Mingyuan Zhu<sup>2</sup>, Ruixiang Li<sup>2</sup>, Zongling Wang<sup>2</sup>, Bin Xia<sup>2</sup>, Lihong Zhang<sup>3</sup>

<sup>1</sup>College of Marine Life Science, Ocean University of China, Qingdao, China

<sup>2</sup>Key Lab for Science & Engineering of Marine Ecological Environment, First Institute of Oceanography, State Oceanic Administration, Qingdao, China

<sup>3</sup>College of Chemistry and Chemical Engineering, Ocean University of China, Qingdao, China

**Correspondence:** Dr X L Zhang, Key Lab for Science & Engineering of Marine Ecological Environment, First Institute of Oceanography, State Oceanic Administration, Xianxialing Road 6, Hi-technology Industrial Zone, Qingdao 266061, China. E-mail: zhangxl@fio.org.cn

Shellfish aquaculture has grown rapidly and has been a significant component of the worldwide increase in global aquaculture production (FAO 2002). A key issue for shellfish culture development is to assess whether the bivalve growth and survival is density-dependent. Many studies have documented the negative relationship of individual growth and stocking density of cultured bivalves, but mortality was often found to be unrelated to density (Fréchette & Daigle 2002; Honkoop & Bayne 2002), although several cases of density-dependent mortality have been reported in cultured scallop *Patinopecten yessoensis* (Jay) (Aoyama 1989), the Japanese oyster *Crassostrea gigas* (Thunberg) (Héral 1991) and the mussel *Mytilus edulis* L. (Mallet & Carver 1991; Fréchette, Bergeron & Gagnon 1996).

In northern China seas, the scallop *Chlamys farreri* (Jones & Preston) is a major cultured species (Zhu, Zhang, Li & Chen 2000). As the scallop culture expanded, however, mass mortality (nearly 100% in the most severe cases) of *C. farreri* in the warm season has re-occurred in major production regions since 1997, threatening the sustainability of this industry (Zhang & Yang 1999). Although the high stocking densities of *C. farreri* has often been postulated as a major cause, no evidence is available to substantiate this. We therefore assessed the relationship between mortality and stocking density of *C. farreri*.

Scallops *C. farreri*, shell height  $45.9 \pm 3.9$  (mean  $\pm$  sd) mm, were obtained from grow-out culture in Sanggou Bay ( $37^{\circ}8.4'N$ ,  $122^{\circ}33.6'E$ ), Yellow Sea, China, where scallop culture has shrunk to a small

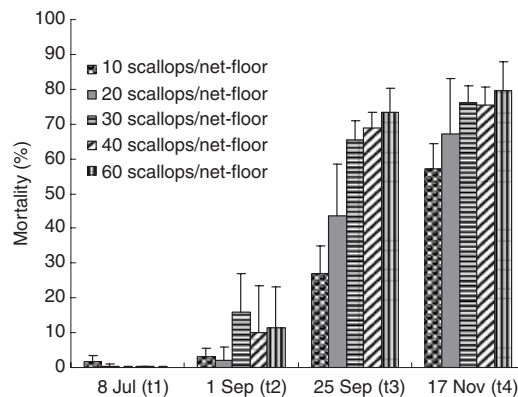
area of the bay due to the mortality problem. The scallops were re-stocked in lantern nets (each with eight 30-cm diameter floors and wrapped with 2-cm rhomboidal mesh) at five stocking densities, 10 ( $\times$  8 nets), 20 ( $\times$  8 nets), 30 ( $\times$  4 nets), 40 ( $\times$  6 nets) and 60 ( $\times$  7 nets) scallops/net-floor ( $\sim$ 25–150% floor area coverage and 13–80 scallops/m<sup>2</sup> water area), so that there was one density lower than and one equal to the stocking density in traditional practice, and three densities representing the so-called 'over-stocking' practice. The nets were arranged at the same site following the same culture practice as local farmers. Briefly, the nets were spaced 1.5-m apart and suspended in 2.5 m water depth along the long line, and the nearest long line was 4 m away.

The experimental manipulation started on 19 June 2003. Scallops in each net were examined for survival on 8 July 2003 (t1), 1 September 2003 (t2), 25 September 2003 (t3) and 17 November 2003 (t4), encompassing summer and autumn when mass mortality of *C. farreri* happened. Dead scallops were removed and not replaced.

Mortality of *C. farreri* was not significant ( $< 3\%$ ) in any nets until at t2 when significant mortality ( $> 10\%$ , many dead scallops' tissue still fresh indicating their recent death) occurred at the three 'over-stocking' densities. From t2 to t3 higher mortality (20–60%) was noted at all densities, and from t3 to t4 significant but lower mortality (6–30%) continued to appear at all densities, making final accumulated mortality at t4 range between 44% and 86% in all experimental nets and average from 57% at the den-

**Table 1** *Chlamys farreri*. Mean ± standard deviation of the accumulated mortality and the replicate number (in the brackets) at different stocking densities and observation times in Sanggou Bay, 2003

Density (scallops/net-floor)	Mortality (%)			
	t1	t2	t3	t4
10	1.9 ± 1.6 (n = 8)	3.0 ± 2.5 (n = 8)	27.0 ± 7.9 (n = 7)	57.0 ± 7.4 (n = 7)
20	0.4 ± 0.7 (n = 8)	2.2 ± 3.6 (n = 8)	43.8 ± 14.6 (n = 8)	67.2 ± 15.9 (n = 8)
30	0.1 ± 0.2 (n = 4)	15.9 ± 10.9 (n = 4)	65.5 ± 5.3 (n = 4)	76.2 ± 4.8 (n = 4)
40	0.2 ± 0.3 (n = 6)	10.0 ± 13.6 (n = 6)	68.8 ± 4.5 (n = 6)	75.3 ± 5.1 (n = 6)
60	0.1 ± 0.2 (n = 7)	11.6 ± 11.6 (n = 7)	73.4 ± 7.0 (n = 7)	79.4 ± 8.4 (n = 7)



**Figure 1** *Chlamys farreri*. Accumulated mortalities at different stocking densities and observing times in Sanggou Bay, 2003.

sity of 10 scallops/net-floor to 79% at 60 scallops/net-floor (Table 1; Fig. 1).

Two-way ANOVA (Zar 1984) with arcsine transformed data from t2 to t4 revealed significant effects of stocking density ( $P < 0.01$ ), observing time ( $P < 0.01$ ) and their interaction ( $P < 0.05$ ) on the accumulated scallop mortalities. Results of Scheffé’s test (Zar 1984) showed that mortalities at high densities were higher than those at the two lowest densities (Table 2). There were no significant differences between the three ‘over-stocking’ densities 30, 40 and 60 scallops/net-floor. At t3 when monthly mortality peaked, accumulated mortality at the lowest density was significantly lower than that in the second lowest density representing the traditional practice, while at other times differences were not significant between these low densities.

The density dependence of *C. farreri* mortality was proved by the results that significant mortalities of *C. farreri* occurred earlier at the ‘over-stocking’ densities and overall mortalities were significantly higher at these high densities throughout the mass mortality

**Table 2** Scheffé’s test for differences ( $P < 0.05$ ) of accumulated mortalities between densities and density groups at each time

Observing times	Mortality at different densities	Mortality at different density groups
t2	30 = 60 = 40 > 10 = 20	$\frac{30 + 40 + 60}{3} > \frac{10 + 20}{2}$
t3	60 = 40 = 30 > 20 > 10	$\frac{30 + 40 + 60}{3} > \frac{10 + 20}{2}$
t4	60 = 30 = 40 > 20 = 10	$\frac{30 + 40 + 60}{3} > \frac{10 + 20}{2}$

The numbers 10, 20, 30, 40 and 60 denote the five stocking densities (scallops/net-floor) respectively.

seasons. Two factors, increased chance for disease(s) infection, and nutrition/immunocompetence limitations at high stocking densities, could have contributed to these differences. Mass mortality of *C. farreri* due to infection of a herpes virus has been proposed (Wang, Wang, Li, Wang, Zheng, Hu, Gong & Song 2002). Increasing stocking density could increase the possibility of horizontal transmission of pathogens and raise the overall chance of disease outbreaks among the scallops. On the other hand, consequence from infection by herpes viruses to animals depends on conditions of the host (Elston 1997). It is well known that the nutritional status of an animal affects its immunocompetence and Askew (2001) reported that the ability of oysters to resist diseases was higher at low stocking density. In our experiment, the scallops were presumably stressed due to reduced food availability at high stocking densities. This was evidenced by their decreased growth and poor condition index (unpublished data) and by modeling results showing the high scallop densities approaching the maximum that can be supported by Sanggou Bay (Nunes, Ferreira, Gazeau, Lencart de Silva, Zhang, Zhu & Fang 2003). Food limitation could then affect the nutritional and physiological condi-

tion of the scallops, thus raising their susceptibility to diseases at high stocking densities.

Our study results also indicated that region-wide effects can override within-net effects. This was inferred from that final mortality was over 50% at every density (Table 1), although mortality at the lowest densities was still significantly lower than at the 'over-stocking' densities (Table 2). This means mere manipulations within several nets will fail to provide a satisfying refuge from mortality in an over-stocked region given sufficient time. Therefore, scallops should be harvested earlier (e.g. at t2 or t3) when within-net manipulation is more effective, or/and management effort should be made to reduce region-wide stocking levels.

Over-stocking scallops resulted not only in decreased growth but increased mortality. This kind of culture practice should be avoided because it increases the costs for spat collection and maintenance, prolongs the time for farmers to get economic rewards, and more importantly, wastes resources that may be otherwise directed to other aquatic products or usage.

### Acknowledgments

This study was funded by the Ministry of Science and Technology of China (contract no 2002CB714008). We are grateful to Xunshan Fisheries Co. for providing the test scallops and collaboration in the field work. We also thank two anonymous reviewers for their critical and helpful comments on the manuscript.

### References

- Aoyama S. (1989) The Mutsu Bay scallop fisheries: scallop culture, stock enhancement, and resource management. In: *Marine Invertebrate Fisheries: Their Assessment and Management* (ed. by J.F. Caddy), pp. 525–539. John Wiley, New York, USA.
- Askew C. (2001) Oyster pioneer dies. *Shellfish News* **12**, 5–6.

- Elston R. (1997) Special topic review: bivalve mollusc viruses. *World Journal of Microbiology and Biotechnology* **13**, 393–403.
- FAO (2002) *The State of World Fisheries and Aquaculture (SO-FIA)*. Food and Agriculture Organization of the United Nations, Rome, Italy, 150pp.
- Fréchette M. & Daigle G. (2002) Growth, survival and fluctuating asymmetry of Iceland scallops in a test of density-dependent growth in a natural bed. *Journal of Experimental Marine Biology and Ecology* **270**, 73–91.
- Fréchette M., Bergeron P. & Gagnon P. (1996) On the use of self-thinning relationships in stocking experiments. *Aquaculture* **145**, 91–112.
- Héral M. (1991) Approches de la capacité trophique des écosystèmes conchylicoles: synthèse bibliographique. In: *The Ecology and Management Aspects of Extensive Mariculture. ICES Marine Science Symposium 19*, ICES, Copenhagen, Denmark (ed. by S.J. Lockwood), pp. 48–62.
- Honkoop P.J.C. & Bayne B.L. (2002) Stocking density and growth of the Pacific oyster (*Crassostrea gigas*) and the Sydney rock oyster (*Saccostrea glomerata*) in Port Stephens, Australia. *Aquaculture* **213**, 171–186.
- Mallet A.L. & Carver C.E. (1991) An assessment of strategies for growing mussels in suspended culture. *Journal of Shellfish Research* **10**, 471–477.
- Nunes J.P., Ferreira J.G., Gazeau F., Lencart de Silva J., Zhang X.L., Zhu M.Y. & Fang J.G. (2003) A model for sustainable management of shellfish polyculture in coastal bays. *Aquaculture* **219**, 257–277.
- Wang X.H., Wang C.M., Li Y., Wang X.H., Zheng G.L., Hu X.Z., Gong J. & Song W.B. (2002) Epidemiological study on massive death of the cultured scallop *Chlamys farreri* in the Jiaozhou Bay. *Journal of Fisheries of China (China)* **26(2)**, 149–156.
- Zar J.H. (1984) *Biostatistical Analysis*, 2nd ed. Prentice-Hall International, New Jersey, USA, 718pp.
- Zhang F.S. & Yang H.S. (1999) Analysis of the causes of mass mortality of farming *Chlamys farreri* in summer in coastal areas of Shandong. *China Marine Sciences (China)*, **1999(1)**, 44–47.
- Zhu M.Y., Zhang X.L., Li R.X. & Chen S. (2000) Impacts of shellfish culture on the coastal ecosystem. *Journal of Ocean University of Qingdao (China)* **30(2II)**, 53–57.

**Keywords:** stocking density, mortality, scallop, *Chlamys farreri*