Temporal and spatial distribution pattern of *Bullacta exarata* in a tidal flat at south shore of Hangzhou Bay, China

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Received: January 2012 Accepted: April 2012

Abstract

The distribution pattern of *Bullacta exarata* was studied in different seasons of 2004 at south shore of Hangzhou Bay, China. We found that the distribution pattern of *B. exarata* was aggregated in each season by Taylor's power regression and Iwao's plot regresses methods ($P < 0.001$). Based on two-way ANOVA analysis, the results indicated that the densities were significantly affected by the factors of season ($P < 0.001$), distance to the dyked dam ($P < 0.001$) and the interaction between them ($P < 0.001$). The densities distribution followed with the distance gradient was significantly different in each season with one-way ANOVA analysis. The results of Pearson correlation coefficients analysis on data of density indicated that in the warmer seasons (spring and summer) the highest densities occurred at 150 m to the dyked dam, while in the cooler seasons peak in densities were at 250 m to the dyked dam (autumn and winter). In the study area, seasonal variation of *B. exarata* densities should be the response of the species to the environmental change, especially the food resource.

Key words: *Bullacta exarata*, Density, Benthic community, Zhejiang Province

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Introduction

The gastropods often have large effects on benthic community structure, through their foraging activities (Castilla and Duran, 1985; Anderson and Underwood, 1997). For example, predatory snails that consume competitively dominant species increase local diversity by creating space for competitively inferior organisms (Menge et al., 1994). Furthermore, grazing by herbivorous snails can strongly influence the distribution, composition and biomass of micro- and macro-algal assemblages in soft-sediment habitats (Kelaher et al., 2003). Therefore, the gastropods play an important role in the habitat and ecosystem of the tidal flat.

Bullacta exarata (Philippi, 1849) is a marine gastropod mollusc species commonly named as mud snail, which widely distributes in the coastal waters of West Pacific Ocean in China, Japan and Korea (Ye and Lu, 2001; Malaquias, 2010). *B. exarata* is an important species in the macrobethic communities at the natural tidal flat of Jiangsu, Shanghai and Zhejiang (Ye and Lu, 2001; Zhou et al., 2009; Ge et al., 2011) which was considered as an economically important shellfish species in eastern China. Recently, some problems presented in aquaculture of *B. exarata*, such as over fishing, lack of effective management, the deceasing output (Wang et al., 2010), then the tough challenges for protection of *B. exarata* resource is the most important potential problem. Aspects of the histology, gonadal maturation, and population dynamics of *B. exarata* have received considerable attention (Malaquias, 2010). However, little is known about the seasonal variation of distribution pattern of this species (Ye and Lu, 2001).

Some studies have suggested that physical stress, predation, and competition may be important in structuring intertidal communities and species distribution pattern (McClanahan, 1992; Guerry et al., 2009; Zhou et al., 2009; Gingold et al., 2010; Aguilera and Navarrete, 2011). Here we addressed this question for evaluating the *B. exarata* population spatial distribution pattern and the seasonal variation in a tidal flat of eastern China, which could be used for presenting the biological characters in the life history of this kind of shellfish in wild. Therefore, this research could contribute to do better conservation and management strategies on *B. exarata* populations.

Materials and methods

Investigation area and sampling protocol

The field work was conducted at south shore of Hangzhou Bay (30.35°N, 121.29°E), Zhejiang Province, China (Fig. 1), which characterized by a subtropical climate. Average salinity of the seawater at the tidal flat is 11-15 psu (Hou et al., 2011). The sediment in the study area is soft, mainly composed by silt (Xie et al., 2009).

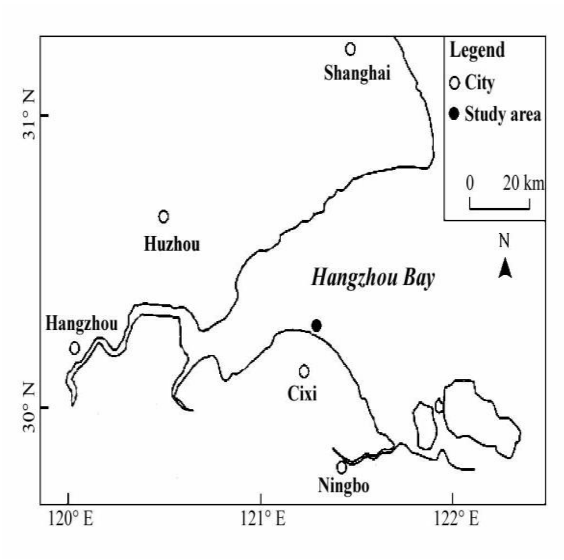

Figure 1: The location of the study area

The investigation was conducted at February (winter), May (spring), August (summer) and November (autumn) of 2004 in the tidal flat outside of the dyked dam, the dam located at the high tidal zone in the tidal flat and constructed in 2000. Six sample lines were selected followed the vertical distance gradient to the dam at the distance of 50 m (lowest of the high tidal zone), 150 , 250 , 350 m (middle tidal zone), 450 and 550 m (low tidal zone), at each sample line 10 repeated plots (1 m × 1 m) were collected every 5 m. All the *B. exarata* (normally length of body > 0.5 cm) were stored by hand in the plots. Totally 60 plots of samples were collected for analyzing in each season.

Data multivariate analyses

For point pattern processes, indices are mainly based on counts of individuals per unit of a grid, called quadrat. The simplest indices are based on the variance (S^2) and the mean (x) of population density per quadrat. Taylor's power regression $\ln S^2 = a + b\ln x$ (Taylor, 1961) makes it possible to assess the level of aggregation by means of slope b that indicates a uniform ($b < 1$), random ($b = 1$), or aggregated ($b > 1$) distribution of population (Arnaldo and Torres, 2005). Iwao's plot regresses $m = \alpha + \beta x$ (Iwao, 1968) between mean crowding (m) and mean density (x) indicates the contagiousness inherent to the species (intercept of the regression) and the manner in which individuals distribute themselves in their habitat with change in the mean density (slope of the regression).The means of slope β can indicate a uniform ($\beta < 1$), random ($\beta = 1$), or aggregated ($\beta > 1$) distribution of population (Vinatier et al., 2011).

The two-way ANOVA analysis (General Linear Model, GLM) was used to determine mean differences in density by distance, season and the interaction between them, Levene's test was used to determine equality of variance prior to using the GLM, and all the data sets passed the Levene's test in the study (Ge et al., 2011).

The one-way ANOVA was used for detecting the difference of the density of sample plots in each season, the Student-Newman-Keuls (SNK) method was used if significant difference occurred. Levene's test was used to determine equality of variance prior multiple comparisons, When a dataset did not pass Levene's test the data was ln(x+1) transformed (Kendrick and Walker, 1995). Then the data sets of mean densities with the distance gradient to the dyked dam were checked by Pearson correlation coefficients among seasons.

SPSS 16.0 (SPSS Inc.) and Microsoft Office Excel 2003 (Microsoft Inc.) were employed for statistical analysis.

Results

The *B. exarata* was aggregated in each season, and then the b(β) is slightly >1 ($P < 0.001$) (Table 1).

Table 1: The analysis of distribution pattern

Season	**Taylor's power regression**				**Iwao's plot regresses**			
	a	***b***	**R^2**	***P***	**A**	**β**	**R^2**	***P***
Winter	0.142	1.214	0.943	<0.001	0.163	1.238	0.934	<0.001
Spring	0.132	1.382	0.959	<0.001	0.133	1.392	0.957	<0.001
Summer	0.136	1.342	0.961	<0.001	0.103	1.381	0.936	<0.001
Autumn	0.123	1.411	0.935	<0.001	0.009	1.437	0.942	<0.001
Average	0.042	1.337	0.950	<0.001	0.106	1.362	0.942	<0.001

The two-way ANOVA analysis revealed significant effect of season [$F_{(3,23)} = 23.946$, $P < 0.001$], distance to the dam[$F_{(5,23)} = 108.660$, $P < 0.001$] and interaction of season × distance to the dam [$F_{(15,23)} = 6.520$, $P < 0.001$] on the abundance of *B. exarata*.

Table 2: The correlations test of densities among seasons (2-tailed and n = 6 for each season)

Season	Parameter	Spring	Summer	Autumn
Winter	Pearson correlation	0.754	0.675	0.951
	P	0.083	0.142	0.004
Spring	Pearson correlation		0.950	0.823
	P		0.004	0.044
Summer	Pearson correlation			0.826
	P			0.043

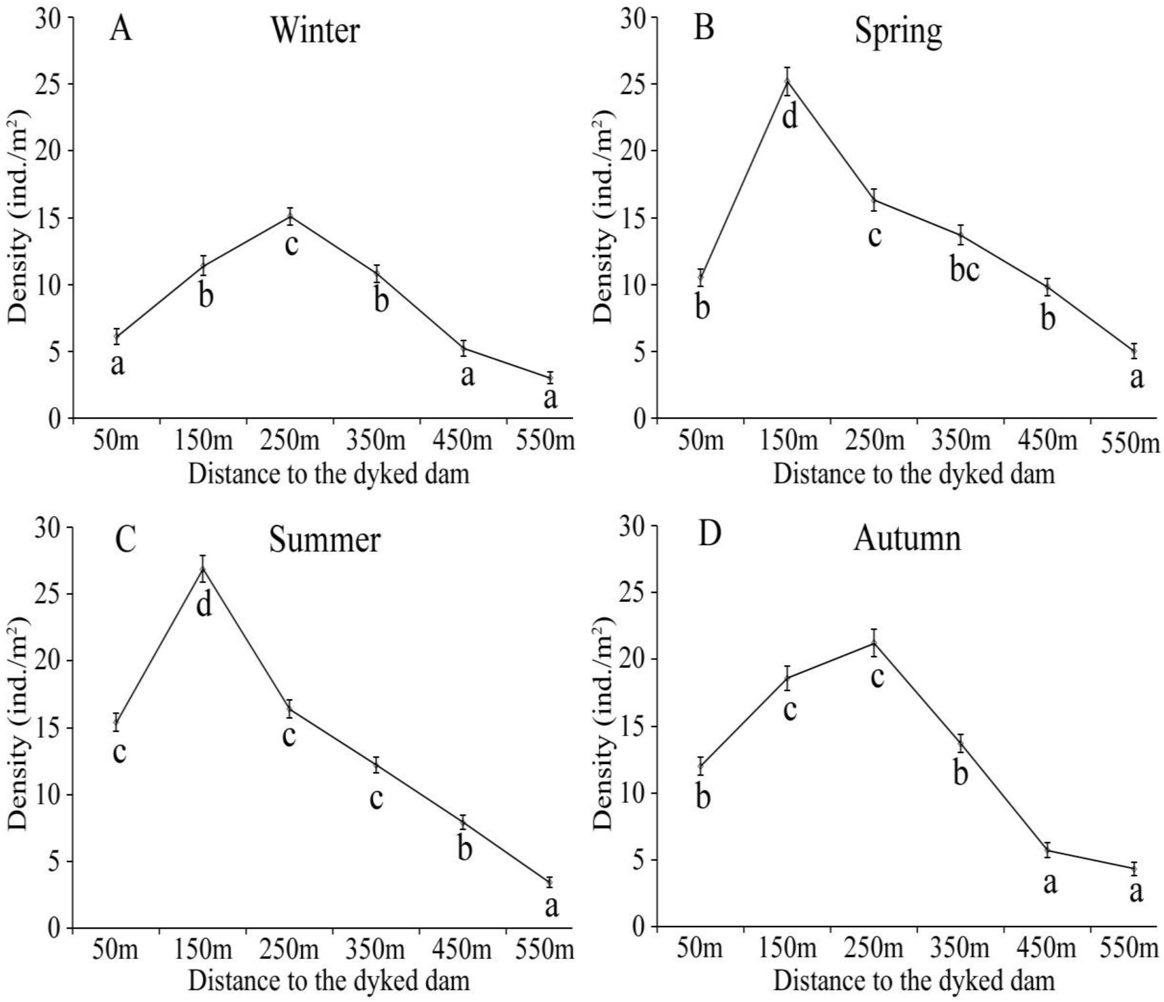

Figure 2: The densities (Mean±SE) distribution of *B. exarata* in each season. The means with different scripts are significantly different by SNK test, α = 0.05.).

Significant differences on abundance distribution in each season were detected (SNK test, Fig. 2). The *B. exarata* mainly clumped at middle tidal zone in the south shore of Hangzhou Bay. And then the highest density occurred at 150 m to the dam in spring (Fig. 2 B) and summer (Fig. 2 C), at 250 m to the dam in autumn (Fig. 2 D) and winter (Fig. 2 A), while in low tidal zone lowest density occurred. Significant positive correlations on abundance distribution occurred in autumn vs. winter (P = 0.004), spring vs. summer (P = 0.004), autumn vs. spring (P = 0.044), autumn vs. summer (P = 0.044) by Pearson correlations test for densities distribution among seasons.

Discussion

It has been reported that the population of *B. exarata* presented an aggregated spatial distribution pattern at Yangtze River Estuary in summer (Ye and Lu, 2001), here same result was presented in south shore of Hangzhou Bay. In this research, the densities in different season did not change the distribution pattern of *B. exarata*, while some research indicated that the densities variation of species should affect the distribution pattern (Hanberry et al., 2011) for spatial disposition was density-dependence (Taylor et al., 1978).

The comparisons of spatial distribution among seasons showed that the *B. exarata* tended to aggregate at higher tidal zone in spring and summer, while at lower tidal zone in autumn and winter. This performance would be caused by the vertical movement of *B. exarata* population which was described in previous research without statistical analysis provided (You et al., 1994; Ye and Lu, 2001), here the seasonal variation of distribution was proved by statistical method.

The density of *B. exarata* reflected that winter was the severe season for the population, the density decreased to the lowest value in wild (You et al., 1994). Temperate stress has been suggested to be the driving power for the seasonal variation of distribution of *B. exarata* among tidal zones (You et al., 2003). The seasonal variation of densities was consistent with the life history cycle (You et al., 2003; Malaquias, 2010). The diatoms (the *Pennales* mostly) were the dominant food items which were sensitive to seasonal change of environmental temperate (Malaquias, 2010). The results of this research indicated that the influence of temporal and spatial organization on interspecific associations should be considered in the application of resource conservation and management (Aguilera and Navarrete, 2011).

Acknowledgements

We would like to thank Xiang Zheng for participate in the field work. This research was supported by Zhejiang Provincial Natural Science Foundation of China (No. ZE0204), Natural Science Foundation of Jiangsu Province (BK2011421), Natural Science Foundation of the Jiangsu Higher Education Institutions of China (No. 12KJB180016), and Natural Science Foundation of Yancheng (YKN2011006).

References

Aguilera, M. A. and Navarrete, S. A., 2011. Distribution and activity patterns in an intertidal grazer assemblage: influence of temporal and spatial organization on interspecific associations. *Marine Ecology Progress Series*, 431, 119-136.

Anderson, M. J. and Underwood, A. J., 1997. Effects of gastropod grazers on recruitment and succession of an estuarine assemblage: a multivariate and univariate approach. *Oecologia*, 109, 442-453.

Arnaldo, P. S. and Torres, L. M., 2005. Spatial distribution and sampling of *Thaumetopoea pityocampa* (Den & Schiff) (Lep. Thaumetopoeidea) populations on Pinus pinaster Ait. in Montesinho, N. Portugal. *Forest Ecology and Management*, 210, 1-7.

Castilla, J. C. and Duran, L. R., 1985. Human exclusion from the rocky intertidal zone of Central Chile - the effects on *Concholepas concholepas* (Gastropoda). *Oikos*, 45, 391-399.

Gappa, J. L., Calcagno, J. A. and Tablado, A., 1997. Spatial pattern in a low-density population of the barnacle *Balanus amphitrite* Darwin. *Hydrobiologia*, 357, 129-137.

Ge, B. M., Bao, Y. X. and Cheng, H. Y., 2011. Tempo-spatial variation of macrobenthic communities on a tidal flat of Wenzhou Bay, China. *Revista de Biología Marina y Oceanografía*, 46, 281-286.

Gingold, R., Mundo-Ocampo, M., Holovachov, O. and Rocha-Olivares, A., 2010. The role of habitat heterogeneity in structuring the community of intertidal free-living marine nematodes. *Marine Biology*, 157, 1741-1753.

Guerry, A. D., Menge, B. A. and Dunmore, R. A., 2009. Effects of consumers and enrichment on abundance and diversity of benthic algae in a rocky intertidal community. *Journal of Experimental Marine Biology and Ecology*, 369, 155-164.

Hanberry, B. B., Fraver, S., He, H. S., Yang, J., Dey, D. C. and Palik, B. J.,

2011. Spatial pattern corrections and sample sizes for forest density estimates of historical surveys. *Landscape Ecology,* 26, 59-68.

Huo, Y. Z., Xu, S. N., Wang, Y. Y., Zhang, J. H., Zhang, Y. J., Wu, W. N., Chen, Y. Q. and He, P. M., 2011. Bioremediation efficiencies of *Gracilaria verrucosa* cultivated in an enclosed sea area of Hangzhou Bay, China. *Journal of Applied Phycology*, 23, 173-182.

Iwao, S., 1968. A new regression method for analyzing the aggregation pattern of animal populations. *Research on Population Ecology,* 10, 1-20.

Kelaher, B. P., Levinton, J. S. and Hoch, J. M., 2003. Foraging by the mud snail, *Ilyanassa obsoleta* (Say), modulates spatial variation in benthic community structure. *Journal of Experimental Marine Biology and Ecology,* 292, 139-157.

Kendrick, G. A. and Walker, D., 1995. Dispersal of propagules of *Sargassum* spp. (Sargassaceae: Phaeophyta): Observations of local patterns of dispersal and consequences for recruitment and population structure. *Journal of Experimental Marine Biology and Ecology,* 192, 273-288.

Malaquias, M. A., 2010. Systematics, phylogeny, and natural history of *Bullacta exarata* (Philippi, 1849): an endemic cephalaspidean gastropod from the China Sea. *Journal of Natural History,* 44, 2015-2029.

McClanahan, T. R., 1992. Epibenthic gastropods of the middle Florida keys: the role of habitat and environmental stress on assemblage composition. *Journal of Experimental Marine Biology and Ecology,* 160, 169-190.

Menge, B. A., Berlow, E. L., Blanchette, C. A., Navarrete, S. A. and Yamada, S. B., 1994. The keystone species concept-variation in interaction strength in a rocky intertidal habitat. *Ecological Monographs,* 64, 249-286.

Taylor, L. R., 1961. Aggregation, variance and the mean. *Nature*, 189, 732-735.

Taylor, L. R., Woiwod I. P. and Perry, J. N., 1978. The density-dependence of spatial behavior and the rarity of randomness. *Journal of Animal Ecology,* 47, 383-406.

Vinatier, F., Ticier, P., Duyck, P. F. and Lescourret, F., 2011. Factors and mechanisms explaining spatial heterogeneity: a review of methods for insect populations. *Methods in Ecology and Evolution,* 2, 11–22.

Wang, S. L., Niu, D. H., Jia, M. J. and Li, J. L., 2010. Polymorphic microsatellite loci for population studies of *Bullacta exarata*. *Conservation Genetics* 11, 1231-1233.

Xie, D., Wang, Z., Gao, S. and De Veriend, H. J., 2011. Modeling the tidal channel morphodynamics in a macro-tidal embayment, Hangzhou Bay, China. *Continental Shelf Research,* 29, 1757-1767.

Ye, S. F. and Lu, J. J., 2001. Analysis on the spatial distribution of *Bullacta exarata* (Mollusca: Gastropoda: Atyidae) population in Yangtze River Estuary, China. *Zoological Research*, 22, 131-136. (In Chinese).

You, Z. J., Lu, T. X. and Wang, Y. N., 2003. Studies on reproductive biology of *Bullacta exarata*. *Journal of Tropical Oceanography*, 22,30-35. (In Chinese).

You, Z. J., Wang, Y. N., Ding, W. and Xu, H. J., 1994. Some environmental factors on the different development stages of the mud snail *Bullacta exarata*. *Journal of Zhejiang College of Fisheries*, 13, 79-85. (In Chinese).

Zhou, H. X., Liu, J. E. and Qin, P., 2009. Impacts of an alien species (*Spartina alterniflora*) on the macrobenthos community of Jiangsu coastal inter-tidal ecosystem. *Ecological Engineering*, 35, 521-528.