Effects of *Spartina alterniflora* invasion on distribution of *Moerella iridescens* in a tidal flat of Western Pacific Ocean

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Abstract

The invasion of *Spartina alterniflora* significantly affected the local ecosystem of Western Pacific Ocean where *Moerella iridescens* lives. Five patches with different invasion stages of *S. alterniflora* were selected and the influence on distribution of *M. iridescens* was studied on the coast of Wenzhou Bay, China in 2007. The aggregated distribution pattern was proved by using Taylor's power regression and Iwao's plot regression methods (p<0.001). The densities were significantly affected by the factors of *S. alterniflora* invasion stage and season (p<0.001), but no significant effect of interaction (p=0.805) occurred. *M. iridescens* mainly clumped in the habitats of no invasion and initial invasion of *S. alterniflora* was in the high tidal zone, and the lowest density was recorded where complete invasion occurred. The densities were larger in warmer than in cooler seasons. There were significant positive correlations among the average densities in seasons. Density variation must be the response of *M. iridescens* to the environment, including *S. alterniflora* invasion stage, temperate stress and interspecific associations.

Keywords: Coastal wetland, Distribution pattern, Habitats, Lingkun Island

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Introduction

Bivalves, especially large forms found in dense aggregations, similar to those grown in aquaculture, may have a considerable influence on the ecosystem (Crooks, 2002). Some bivalves are relatively large, dominant in terms of biomass or abundance, and have a positive effect on community inhabitants as a consequence of their physical presence and not their actions. Their effect may extend beyond the communities of exotic bivalves themselves and into adjacent habitats (Dame, 1996). As such, they facilitate or otherwise influence benthic communities by creating general habitats, providing refuge from predation, reducing physical and physiological stress, enhancing settlement and recruitment, and increasing food supply (Bruno *et al*., 2001). Some bivalves have also been found to have a number of other important ecosystem effects, including, inter alia, increasing diversity of the community, altering nutrient fluxes, etc. (McKindsey *et al*., 2007).

Moerella iridescens is a high-valued marine mollusk species which can be used as food for people. It is a kind of bivalve which is widely distributed in the coast of Western Pacific Ocean, including the coast of Chian, Korea, Japan (Li *et al*., 2013). Due to unsustainable exploitation and ecological deterioration of the coastal environment, *M. iridescens* resources have been declining in Jiangsu, Shanghai, Zhejiang and Fujian of China, where *Spartina alterniflora* had spectacularly invaded (An *et al*., 2007). The invasion of *S. alterniflora* has been considered as an important environmental factor which significantly affects local ecosystems where *M. iridescens* lives on the coast of eastern China (Yang *et al*., 2013).

The salt-adapted grasses of the genus *Spartina* (cordgrass) have invaded Western Pacific coasts during the past decades, including those of Japan and China (Greenberg *et al*., 2006). Many species of cordgrass are known to be highly invasive (Daehler and Strong, 1996), and the genus *Spartina* was readily identified as a group of key ecosystem engineers in the salt marsh ecosystem (Pennings and Bertness, 2001; Brusati and Grosholz, 2006) which could change the benthos community significantly (Hedge and Kriwoken, 2000; Neira *et al*., 2006). It has been reported that *S. alterniflora* may out-compete native plants, threaten the native ecosystems and coastal aquaculture, and cause declines in native species richness (Neira *et al*., 2005; Levin *et al*., 2006). But, whether the invasion of *S. alterniflora* declines or increases the biodiversity of the wetland ecosystem has not been answered clearly, and is still a highly controversial topic (Alphin and Posey, 2000; Wang *et al*., 2010). To date, research on the question of how the bivalves distribute in patches from the tidal flat with different *S. alterniflora* invasion stages has been seldom reported (Neira *et al*., 2007).

The present study addresses the question of how the *S. alterniflora* invasion stages influenced the distribution of *M. iridescens*. During 2007, the distribution of *M. iridescens* in patches with different *S. alterniflora* invasion stages on the east tidal flat of Lingkun Island, Wenzhou Bay, China was investigated.

Materials and methods

Investigation area and sampling protocol

The study area is located on the east tidal flat of Lingkun Island (N 27.96°, E 120.91°), Wenzhou Bay, China, where the estuary of Oujiang River, and the soft sediment is mainly silt composed. The study area has a sub-tropical climate, an informal semidiurnal tide type with an average of 4.5 m tidal range, and the average salinity of the seawater at the tidal flat is 16 psu (Lu *et al*., 2005; Ge *et al*., 2011). *S. alterniflora* was introduced in 1989, and then it had become the dominant plant of the upper and high tidal zones by 2007 (Li *et al*., 2009).

Five habitats were selected in the tidal zone of the eastern Lingkun Island (Fig. 1) such that, their environmental characteristics (e.g. climate, salinity) were similar (Ge *et al*., 2012). In the high tidal zone, four kinds of patches of different *S. alterniflora* invasion stages were selected, namely no invasion, initial invasion, invasion underway and invasion completed. Then a parallel habitat was selected in the middle tidal zone, which was namedthe naked mud flat. The area of the patches and canopy of *S. alterniflora* were graded to indicate the sequence of invasion stages (years) on the high tidal flat (Table 1).

The investigation was conducted in February (winter), May (spring), August (summer) and November (autumn) of 2007. At each type of habitats, 5 repeated plots (1 m×1 m) were collected randomly. All the *M. iridescens* (normally the length of body>0.5 cm) were stored by hand in the plots. Totally 25 plots of samples were collected for analyses in each season.

Data multivariate analyses

For point pattern processes, indices are mainly based on counts of individuals per unit of a grid, called quadrant. The simplest indices are based on the variance (S^2), mean crowding (m) and the mean (x) population density per quadrant. Taylor's power regression $\ln S^2=a+b\ln x$ (Taylor, 1961) and Iwao's plot regression $m=\alpha+\beta x$ (Iwao, 1968) make it possible to assess the level of aggregation by means of slope b and β that indicate a uniform ($b/\beta<1$), random ($b/\beta=1$), or aggregated ($b/\beta>1$) distribution of population (Arnaldo and Torres, 2005; Vinatier *et al*., 2011).

The two-way ANOVA analysis (general linear model, GLM) was used to check the factor of invasion stage, season and the interaction between them on density (Ge *et al*., 2011). The one-way ANOVA was used for detecting the difference of the density by the factor of habitat and season.

Table 1: The sample habitats with different *Spartina alterniflora* invasion stages.

Habitat discribe	Tidal zone	Coverage and area	Year(s)
No invasion	High	Bare	0
Initial invasion	High	≈ 10% (in winter) - 30 % (in summer), ≈ 15 m^2	1 - 2
Invasion underway	High	≈ 40% (in winter) - 70 % (in summer), ≈ 50 m^2	3 - 4
Invasion completed	High	≈ 70% (in winter) - 100 % (in summer), > 100 m^2	5 - 6
Naked mud flat	Middle	Bare	0

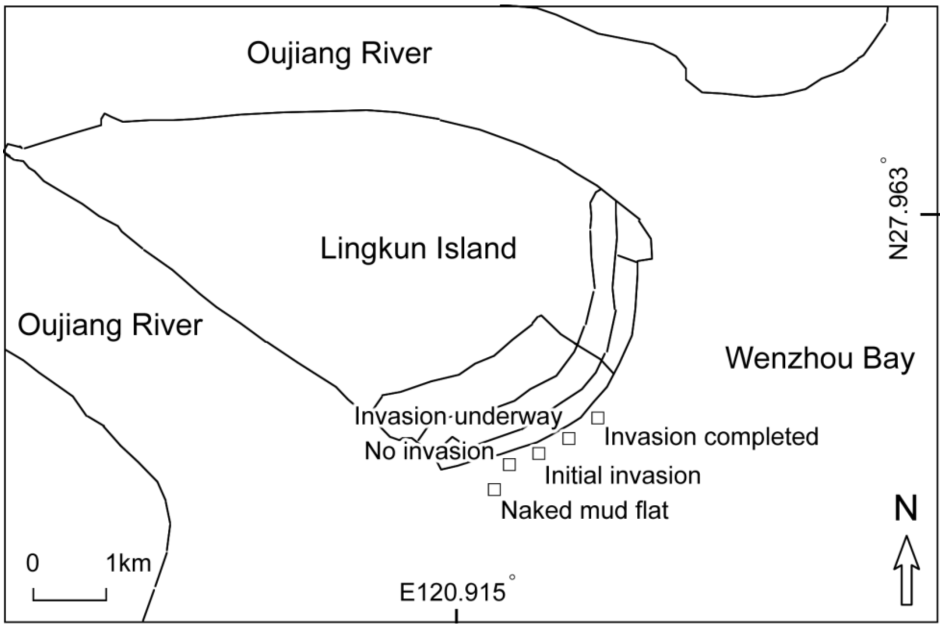

Figure 1: The location of the study area and the sampling sites.

If significant differences occurred, Duncan's test was used. Then the data sets of mean densities with the invasion stages were checked by 2-tailed Pearson correlation coefficients among seasons.

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

Results

When *M. iridescens* was aggregated in a season or habitat, the *b*/β value was slightly>1 (p<0.001) (Table 2). The two-way ANOVA analysis revealed a significant effect of the invasion stage ($F_{(4,19)}$=30.861, p<0.001) and season ($F_{(3,19)}$=7.415, p<0.001) on the abundance of *M. iridescens*, but no significant effect interaction of season × invasion stage ($F_{(12,19)}$=0.637, p=0.805) occurred.

The densities of *M. iridescens* were larger in warmer seasons than in cooler seasons, while the average density was 10.65±0.40 ind./m^2. Significant differences on abundance distribution in each season were detected (p<0.050, Fig. 2).

Table 2: The analysis of distribution pattern.

Season	N	Taylor's power regression				Iwao's plot regression			
		a	*B*	R^2	P	A	β	R^2	P
Winter	25	-1.126	1.159	0.826	0.016	-0.600	1.007	0.999	<0.001
Spring	25	-0.942	1.072	0.982	<0.001	-0.563	1.002	0.999	<0.001
Summer	25	-1.485	1.552	0.918	0.005	-0.644	1.045	0.997	<0.001
Autumn	25	-1.860	1.705	0.974	0.001	-0.852	1.065	0.999	<0.001
Total	100	-0.934	1.180	0.643	<0.001	-0.483	1.010	0.996	<0.001

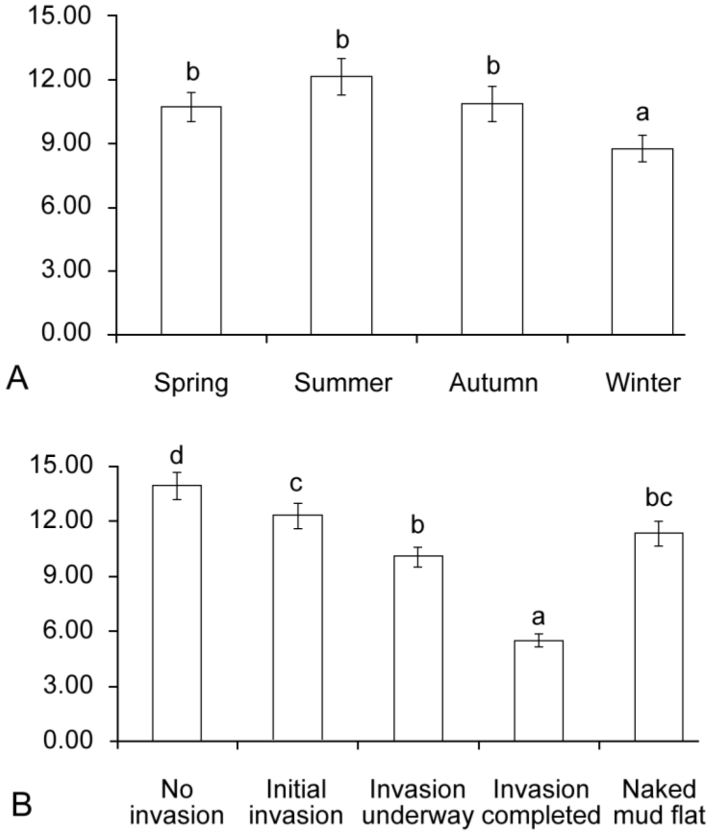

Figure 2: The density of *Moerella iridescens* (ind./m^2, Mean±SE) in different seasons (A) and *Spartina alterniflora* invasion stages (B). (The means with different scripts are significantly different by Duncan's test, α=0.05).

M. iridescens mainly clumped in the habitats of no invasion and initial invasion of *S. alterniflora* in high tidal zones. The highest density (12.16±0.88 ind./m^2) occurred in summer, while in winter the lowest density (8.76±0.63 ind./m^2) was observed. The average density in the naked mud flat in the middle tidal zone showed a medium value (11.35±0.69 ind./m^2) compared with the densities in other habitats (5.50±0.34 to 13.95±0.76 ind./m^2) (Table 3, Fig. 2).

Significant positive correlations on abundance distribution occurred in each comparison among average densities of seasons (p<0.050), and then the distribution of densities showed a similar trend among habitats in each season (Table 4).

Table 3: The densities in different habitats and seasons (ind./m^2, Mean ± SE).

Habitat/season	Winter	Spring	Summer	Autumn	Average
No invasion	11.00 ± 1.45	14.00 ± 1.14	16.40 ± 1.21	14.40 ± 1.54	13.95 ± 0.76
Initial invasion	10.60 ± 1.29	11.80 ± 1.58	14.00 ± 1.14	12.80 ± 1.66	12.30 ± 0.67
Invasion underway	8.80 ± 1.07	10.40 ± 1.08	11.20 ± 1.07	9.80 ± 1.16	10.05 ± 0.54
Invasion completed	5.00 ± 0.71	6.00 ± 0.71	5.40 ± 0.68	5.60 ± 0.81	5.50 ± 0.34
Naked mud flat	8.40 ± 0.81	11.40 ± 0.93	13.80 ± 1.16	11.80 ± 1.59	11.35 ± 0.69
Average	8.76 ± 0.63	10.72 ± 0.68	12.16 ± 0.88	10.88 ± 0.84	10.65 ± 0.40

Table 4: The coefficient of Pearson correlation test on average densities among seasons.

Season	Summer	Autumn	Winter
Spring	0.993, p<0.001	0.988, p=0.002	0.955, p=0.011
Summer		0.994, p<0.001	0.941, p=0.017
Autumn			0.957, p=0.011

Discussion

Bivalves live exclusively on filtration in the water environment which is contrary to all other molluscs, thus leading to differences in life history characteristics (Perez *et al*., 2013). In this study, we found that *M. iridescens* presented an aggregated spatial distribution pattern, which was similar to what some populations of gastropods presented (Ye and Lu, 2001; Ge *et al*., 2013). Significant difference in *M. iridescens* densities among different seasons occurred, in spite of the fact that previous research indicated that the density variation of species would affect the distribution pattern (Hanberry *et al*., 2011) for spatial disposition was density dependent (Taylor *et al*., 1978). Here, we found that the variation of densities did not change the distribution pattern of *M. iridescens*. This spatial distribution pattern indicated that the environmental resources are unevenly distributed in the tidal flat with the sampling scale.

In this study, *M. iridescens* tended to distribute in patches of no invasion and initial invasion at higher densities, and in patches of invasion completed, lower densities occurred (Fig. 2). This performance may have been caused by the environmental changes due to different *S. alterniflora* invasion stages among habitats (Wang *et al*., 2006). *M. iridescens* lives on filtration in the mud flat, and then the root development of *S. alterniflora* directly affected the forage of *M. iridescens* in the study area. In the state of initial invasion, the environment can offer a greater variety of micro-habitats for benthos as a result of the low density of *S. alterniflora*, where the environmental characters were suitable for the survival of bivalves because roots of *S. alterniflora* were seldom in the sediment (Wang *et al*., 2006). However, when the root of *S. alterniflora* harden, and the sediment and then stems and leaves develop above ground after the initial invasion stage, the habitat changes and is no longer fit for the species of bivalves and the density must have significantly decreased (Neira *et al*., 2007; Wang *et al*., 2010). It has been proved that the hydrodynamic condition generated by sea water waves is the major factor controlling growth performance of some bivalves (Perez *et al*., 2013), but different statuses of *S. alterniflora* invasion can lead to alterations in ecosystem processes, including litter production, below-ground biomass, sediment organic content and nutrient cycling (Talley *et al*., 2001), associated with food availability and environmental characters of habitat for benthos (Neira *et al*., 2005). Then the distribution of benthos must have been affected by the invasion stages in the tidal flat (Levin *et al*., 2006).

In winter, the density of *M. iridescens* decreased to a lowest value, which reflected that winter was a severe season for the species survival (Table 3, Fig. 2). Though temperate stress has been suggested to be the driving power for the seasonal variation of distribution in wild for some species, the impact of migratory birds in winter should be considered additionally (Ge *et al*., 2011). In the tidal flat of Wenzhou Bay, it has been found that the coast was used as a migration stopover or wintering habitat for some kind of birds, such as *Larus saundersi*, *Pelecanus crispus* etc. (Butler *et al*., 2001; Shi *et al*., 2008). The coast of Western Pacific Ocean (especially in southeastern Asia) is an important wintering and migration stopover wetland for some species of birds (Butler *et al*., 2001), resulting in the benthos and birds both to be involved in a complex food web (Valiela *et al*., 2004). Our findings indicated that the influence of temporal and spatial organization on interspecific associations should be considered in the application of coastal living resource conservation and management.

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