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CHALLENGES IN AQUATIC SCIENCES

Effect of the invasive bivalve *Mytilopsis sallei* on the macrofaunal fouling community and the environment of Yundang Lagoon, Xiamen, China

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Abstract *Mytilopsis sallei* is a small marine bivalve and is considered as a serious pest. We assume that the invasive bivalve *M. sallei* changed the community structure of fouling macrofauna and reduced the species diversity index in Yundang Lagoon, Xiamen, China. In order to verify the above hypothesis, test panels were submerged seasonally at five stations during four seasons in Yundang Lagoon, and some chemical parameters were determined. The results showed there were significant differences in density and biomass of *M. sallei* and other fouling macrofauna with season and with station. The species diversity of the macrofaunal fouling community at stations B and F was low in summer, because high density of *M. sallei* was found at two stations. There were significantly positive correlations between density and biomass of *M. sallei* and water temperature and COD, and significantly negative correlations with pH. The results confirmed that this invasive species changed the density and biomass compositions of fouling macrofauna, reduced the species diversity index during the summer period, and somewhat worsened the aquatic environmental quality in Yundang Lagoon, because the pH and the DO were the lowest, and the BOD and the COD were the second lowest in summer among four seasons.

Keywords Invasive species · *Mytilopsis sallei* · Macrofaunal fouling community · Aquatic ecosystem · Xiamen Yundang Lagoon

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Introduction

The introduction or immigration of foreign species is a major cause of biodiversity loss (Crooks, 2002). The impact of alien species might affect three major biodiversity aspects: species, their genetic structure, and landscape (Wiegleb et al., 2013). Among bivalves, some dreissenids have become invasive pests when being introduced to or invading new environments (Kennedy, 2011a). As sessile suspension feeders, dreissenid and mytilid bivalve molluscs have become some of the most important invasive organisms in marine, brackish, and freshwater ecosystems (Aldridge et al., 2008). *Mytilopsis sallei* has successfully invaded several major ports in East Asia (Wong et al., 2011). *M. sallei* was reported in an oyster bed at Tapeng Bay, near Tungkang Port, in Taiwan, in 1977 (Chang, 1985) and in Kiyomizu harbour, Japan, in 1979 (Ishibashi & Kasaka, 1980). *M. sallei* was collected alive from Hong Kong waters (Tolo Harbour) attached to a floating wreckage (Morton, 1980). *M. sallei* was introduced to Maluan Bay in Xiamen as feed for cultured fishes and shrimps at the beginning of the 1990s, and soon it became a dominant species within its fouling community (Wang et al., 1999). A high mortality of *Balanus reticulatus* was noted when *M. sallei* occurred at high density in Maluan Bay, Xiamen, China (Cai et al., 2005, 2006). The Caribbean false mussel *M. sallei* (Récluz, 1849) occurs in tropical monsoon drains of Singapore (Tan & Morton, 2006). *M. sallei* colonized Yundang Lagoon in the year 2000 (Cai et al., 2010). The bivalve *M. sallei* was reported as an invasive species in Indian waters (Gaonkar et al., 2010a, b). In the south-western region of Taiwan, *M. sallei* causes not only abundance declines of native hard clam, but also undesirable changes in aquaculture systems and economic losses (Liao et al., 2010).

Other species of the genus *Mytilopsis* were found abundantly in several countries. Conrad's false mussel, *M. leucophaeata*, is a highly euryhaline species, originating from the Atlantic coast of the United States and the Gulf of Mexico (Marelli & Gray, 1983, 1985), and now settles in industrial cooling water systems in Europe (Jenner et al., 1998), with settlement densities as high as 5.5 million m^{-2} (Rajagopal et al., 2003). Rajagopal et al. (1997) reported *M. leucophaeata* to be the dominant macrofouling organism of electricity-generating stations in the Noordzeekanaal of the Netherlands. Laine et al. (2006) reported that *M. leucophaeata* was near a power plant's cooling water discharge in the Baltic Sea. Originating from the Pacific coast of Panama, *M. adamsi* appeared later in a shrimp farm along the Pacific coast of Mexico (Salgado-Barragán & Toledano-Grandos, 2006). Since the discovery of *M. trautwineana* within a shrimp farm at the Caribbean coast of Colombia, the mussel has reached high abundances in the beds of some ponds, where it builds up layers of up to 10 cm (Aldridge et al., 2008).

From mussels to barnacles to algae, studies suggest that such "hull-fouling" organisms could pose an invasion threat that is "equally strong if not stronger" than that from organisms transported by ballast water (Dahms et al., 2004a; Strain, 2012). *M. leucophaeata* usually occurs in very low numbers and has rarely been mentioned in field survey reports; However, occasionally in its native habitat and often in habitats where it has been introduced (as in Europe and Brazil), it may undergo population break-downs for no clear reason (Kennedy, 2011a).

To assess the invasive ability of *M. sallei*, both spatial and temporal variables should be considered. Local biotic effects such as on top-down control by predatory fish and any relationship to the benthic community need to be surveyed and then be extrapolated to the entire ecosystem (Karatayev et al., 2007). This particularly holds for the suspension-feeding ability of *M. sallei* (Borthagaray & Carranza, 2007). The system-wide effects depend not only on the characteristics of the water bodies (invasibility), but also on the invasiveness of *M. sallei*. Its initial impact is expected to be modified over time (Hicks, 2004).

Predicting the ecosystem consequences of simultaneous gains (invasion) and losses (extinction) requires that we first understand which biological traits predispose life forms to higher probabilities of extirpation or establishment (response traits), and detail how response traits covary with traits that drive ecosystem functioning (effect traits) (Cardinale 2012; Wiegleb et al., 2013). We assume that the invasive bivalve *M. sallei* changed the community structure of fouling macrofauna (the proportions among fouling macrofauna groups), reduced the species diversity index, and increased some chemical materials in Yundang Lagoon, Xiamen, China. Following this hypothesis, the present study aims to analyze the temporal and spatial distribution of *M. sallei* and the relationship between density and biomass of *M. sallei* and environmental factors, as well as between *M. sallei* and other fouling macrofauna in Yundang Lagoon, Xiamen, China.

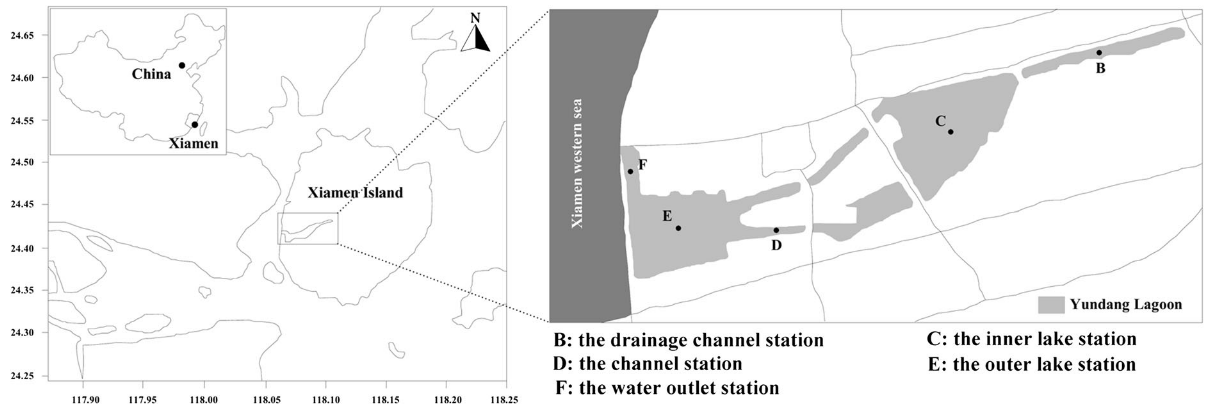

Fig. 1 Panel test stations for fouling macrofauna in Yundang Lagoon, Xiamen, China

Materials and methods

Study site

Yundang Lagoon (24°29′N, 118°04′E), which used to be a natural bay called Yundang Harbour, is located in the western bay of Xiamen, China. Since the early 1970s, a great number of land reclamation projects were carried out by the Xiamen government, and the Yundang Harbour gradually became an almost-closed salt lake, with its area reduced from the original 10 to 2.2 km^2. Floodwater draining channels in the urban district were built along the site of Yundang Lagoon. A sea wall was constructed to keep Yundang Lagoon from the Western Sea of Xiamen. However, in order to circulate the water, the incoming waters of natural tides were utilized by regulating the water gate diurnally. This way of circulating seawater was transported by tidal force. The circumference of Yundang Lagoon is now a main shopping center, residential area, and recreation park of Xiamen.

Field methods

Five stations, identified as B–F, were investigated in terms of fouling macrofauna that settled on pine test panels (Fig. 1). Station B was at the drainage channel; more residential sewage outlets were there. Station C was at an inner lake. Station D was at the channel between the inner and outer lake. Station E was at the outer lake, and Station F was close to the water outlet. Two seasonal test panels were placed submerged in the water for 90 days and replaced by another set of two panels after retrieval at a panel station. Each panel measured 20 cm × 20 cm × 2 cm.

All samples and retrieved panels were immediately fixed in 5% formalin until examination in the laboratory. In the laboratory, the samples were sieved through a 0.5 mm mesh. Fouling macrofauna retained on the sieve was stored in 70% ethanol. Fouling macrofauna was identified to species level or to the lowest taxonomic level possible, e.g., genus, which was then treated as a distinct taxon in the analysis. Fouling macrofauna was counted under a dissection microscope and weighed using an electronic balance (sensitivity as 0.1 mg) (see Dahms et al., 2004b).

Eight environmental factors, i.e., water temperature, salinity, pH, DO (dissolved oxygen), BOD (biochemical oxygen demand), COD (chemical oxygen demand), NH_3-N (nitrate nitrogen), and DIP (dissolved inorganic phosphate = reactive phosphate) were calculated for every sampling (see Dahms & Qian, 2005).

Statistical analysis

The species diversity index of each station was calculated using Shannon–Weaver index (H').

Multi-factorial Analysis of Variance (ANOVA) from SPSS software was used to investigate differences between seasons (summer, winter, spring, and autumn) and stations (B–F) for density and biomass of fouling macrofauna. To identify homogeneous subsets of means, ANOVA was followed by pairwise multiple comparison using Tukey's posthoc test. Cluster analysis and Multidimensional scaling (MDS) ordinations

Table 1 Mean density and biomass of *M. sallei* and fouling macrofauna during four seasons and five stations in Yundang Lagoon

Season or station	Mean density (ind./m^2)		Mean biomass (g/m^2)	
	M. sallei	Fouling macrofauna	*M. sallei*	Fouling macrofauna
Summer	29,005 ± 24,088	59,705 ± 23,583	5,943 ± 2,933	8,826 ± 3,884
Autumn	2,495 ± 1,038	32,570 ± 10,173	128 ± 51	1,439 ± 407
Winter	20 ± 27	26,175 ± 8,916	4 ± 8	141 ± 104
Spring	280 ± 236	11,425 ± 8,986	9 ± 7	960 ± 544
Station B	6,550 ± 11,490	20,906 ± 10,913	485 ± 874	848 ± 966
Station C	4,750 ± 7,745	27,531 ± 18,979	1,850 ± 3,611	2,732 ± 3,677
Station D	5,800 ± 10,581	42,481 ± 21,703	1,899 ± 3,750	3,812 ± 5,305
Station E	4,113 ± 5,571	35,556 ± 18,378	1,081 ± 2,015	2,730 ± 3,479
Station F	18,438 ± 35,258	35,869 ± 38,379	2,290 ± 4,496	3,459 ± 5,541

were used to visually assess spatial and seasonal differences in macrofaunal fouling communities in Yundang Lagoon (Clarke & Warwick, 1994; Clarke & Gorley, 2006). MDS ordination was constructed from Bray–Curtis similarity matrices, after fourth root transformation and row standardization of density data. Non-parametric correlations (Spearman-rank) were performed between density and biomass of dominant fouling organisms and environmental factors. The BIOENV function was used to highlight the key factors, or a combination of factors, that accounted for the macrofaunal fouling community.

Results

Density and biomass of *M. sallei* and fouling macrofauna in Yundang Lagoon

A total of 28 species of sessile macrofauna were identified from the test panels in Yundang Lagoon taken throughout all four seasons. There were 11 polychaetes, 6 bivalves, 6 crustaceans, 1 platyhelminthes, 1 nemertean, 1 bryozoan, and 1 urochordate.

The density and biomass of *M. sallei* were both highest in summer, second highest in autumn, third highest in spring, and lowest in winter. The density of fouling macrofauna was highest in summer, second highest in autumn, third highest in winter, and lowest in spring, while the biomass of fouling macrofauna was highest in summer, second highest in autumn, third highest in spring and lowest in winter (Table 1).

The density of *M. sallei* was highest at station F, second highest at station B, third highest at station D, fourth highest at station C, and lowest at station E, while the biomass of *M. sallei* was highest at station F, second highest at station D, third highest at station C, fourth highest at station E, and lowest at station B (Table 1). The spatial distribution of other fouling macrofauna was the same as that of *M. sallei*.

Univariate tests on the distribution of *M. sallei* and fouling macrofauna revealed that *M. sallei* and fouling macrofaunal density and biomass were significantly influenced by season, station, and season × station (Table 2).

Percentage of each group within the macrofaunal fouling community in Yundang Lagoon

The density percentage of each group within the macrofaunal fouling community was different for each season. Bivalves occupied 49.50% of the area in summer when *M. sallei* was abundant. But bivalves occupied only 0.25% in summer supposed there was no *M. sallei* (Fig. 2). Polychaetes and crustaceans occupied 3.83 and 46.57%, respectively, in summer when there was *M. sallei*. But polychaetes and crustaceans occupied 17.90 and 81.71% in summer, respectively, supposed there was no *M. sallei*. The density percentage of polychaetes and crustaceans in the fouling macrofaunal community changed little seasonally in autumn, winter, and spring, irrespective whether there was *M. sallei* or not.

The biomass percentage of each group in the macrofaunal fouling community was the same as the density percentage of each group (Fig. 3).

Table 2 The *F* and *P* values between seasons and stations for density and biomass of *M. sallei* and fouling macrofauna ($n = 40$)

	Season		Station		Season × Station	
	F	*P*	*F*	*P*	*F*	*P*
Density of *M. sallei*	302.075	<0.001*	43.047	<0.001*	44.702	<0.001*
Biomass of *M. sallei*	511.473	<0.001*	24.819	<0.001*	25.481	<0.001*
Density of fouling macrofauna	81.834	<0.001*	11.367	<0.001*	8.132	<0.001*
Biomass of fouling macrofauna	390.573	<0.001*	29.229	<0.001*	19.555	<0.001*

* Significant at the 0.001 level

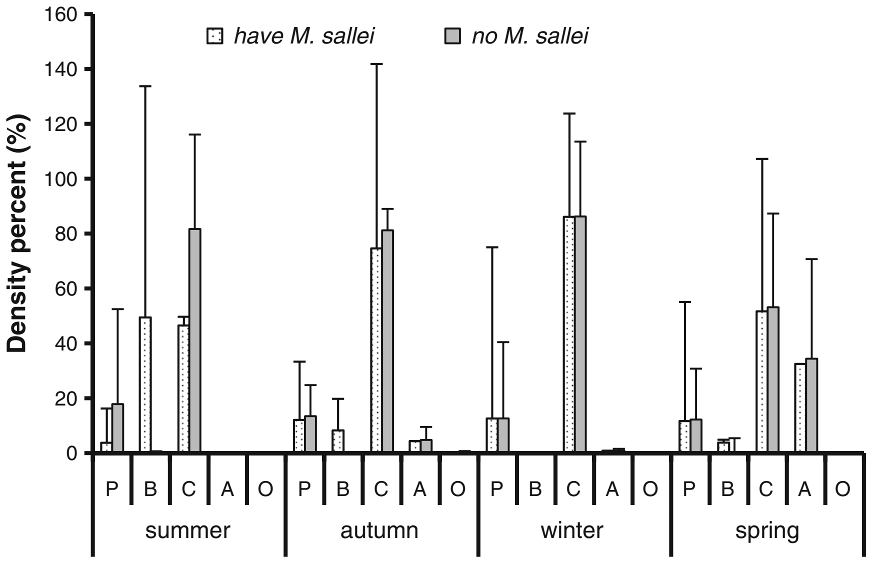

Fig. 2 Density percentage of each macrofouling group that have *M. sallei* and no *M. sallei* in Yundang Lagoon (P: Polychaeta; B: Bivalvia; C: Crustacea; A: Ascidiacea; O: Others)

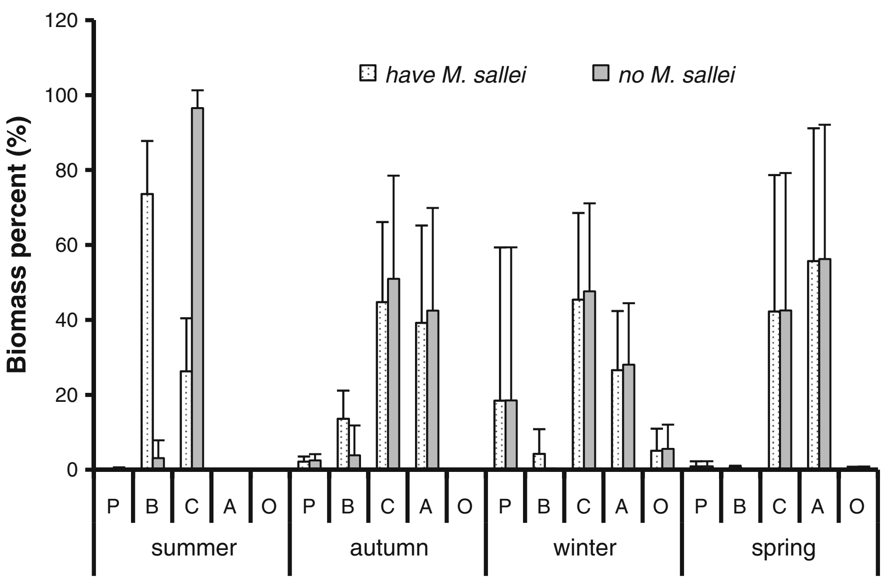

Fig. 3 Biomass percentage of each macrofouling group that have *M. sallei* and no *M. sallei* in Yundang Lagoon (P: Polychaeta; B: Bivalvia; C: Crustacea; A: Ascidiacea; O: Others)

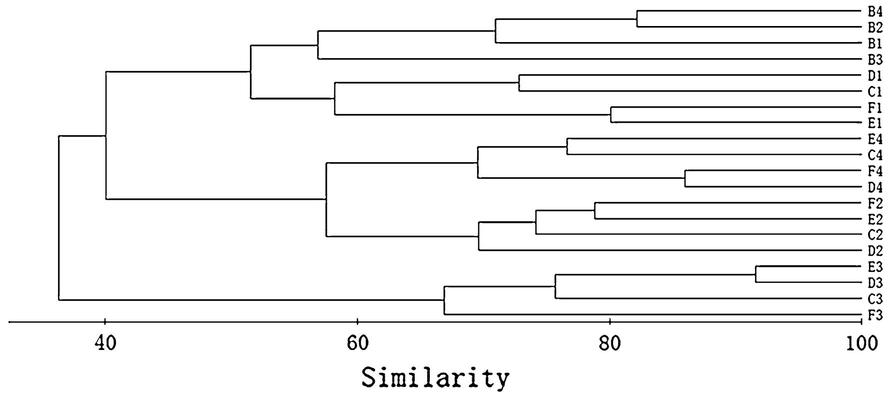

Fig. 4 Cluster analysis showing the similarity of stations of the macrofaunal fouling community in Yundang Lagoon (B1–F1: summer stations; B2–F2: autumn stations; B3–F3: winter stations; B4–F4: spring stations)

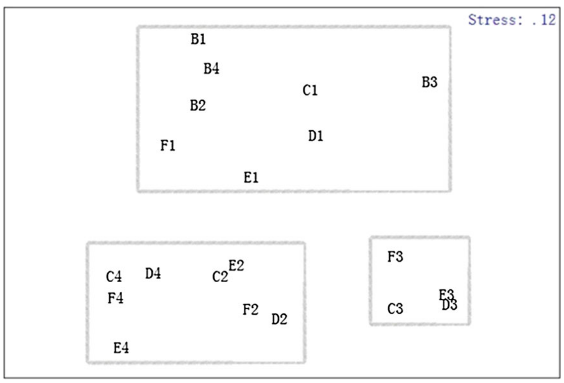

Fig. 5 MDS plot showing the similarity of the macrofaunal fouling community in Yundang Lagoon (B1–F1: summer stations; B2–F2: autumn stations; B3–F3: winter stations; B4–F4: spring stations)

Cluster and MDS analysis

There was significant seasonal variation for the macrofaunal fouling community in Yundang Lagoon (Fig. 4). A MDS plot showed similar results as the cluster analysis (Fig. 5). The polychaetes *Capitella capitata* and *Polydora ciliata*, pollution resistant species, were found during all seasons at station B.

Species diversity of macrofaunal fouling community in Yundang Lagoon

The species diversity of the macrofaunal fouling community at stations B and F was no more than 0.6 in summer. The species diversity indices at stations B, F in summer were all lower than those at stations B, F in autumn and winter, respectively (Fig. 6). The density and biomass of *M. sallei* at stations B and F were all higher than at other stations (Table 1).

Relationship between *M. sallei* and environmental factors in Yundang Lagoon

The mean water temperature was highest in summer, second highest in autumn, third highest in spring, and lowest in winter. The seasonal variation of water temperature was the same as that of density and biomass of *M. sallei*. The seasonal variations of salinity, pH, DO, BOD, COD, and NH_3-N did not show congruence with that of density and biomass of *M. sallei*, and were different from each other. The mean pH and DO values in summer were lower than during the other three seasons (Fig. 7).

There was a significantly positive correlation between density and biomass of *M. sallei* with water temperature and COD. There was a significantly negative correlation with pH but no significant correlation with salinity, DO, BOD, NH_3-N, and DIP (Table 3). BIOENV analysis showed that water temperature, pH, COD, and DIP were related to the macrofaunal fouling community in Yundang Lagoon (Table 4).

Discussion

As an exotic macrofauna species, *M. sallei* invaded the fouling community and became a dominant species in Yundang Lagoon in summer (Cai et al., 2010). Our results showed that *M. sallei* changed the species composition of macrofaunal fouling community. For example, if there was no *M. sallei*, the dominant

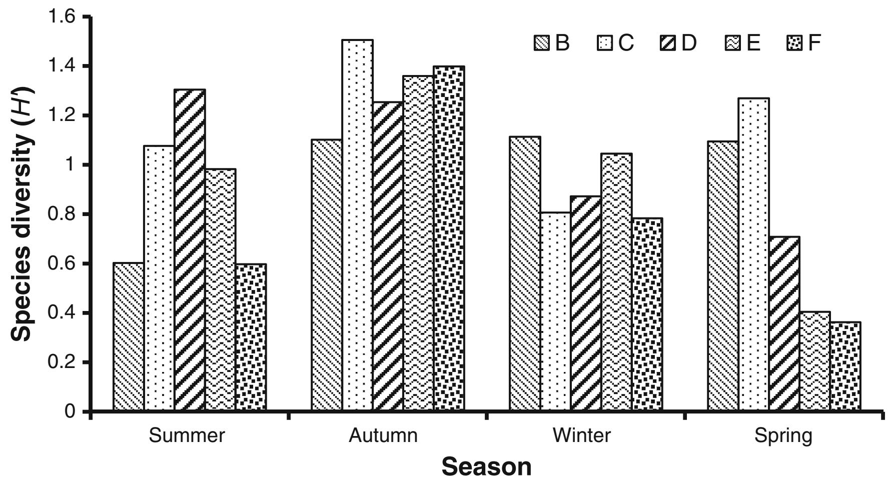

Fig. 6 Species diversity indices of macrofaunal fouling community in Yundang Lagoon

groups in summer would be crustaceans, the sessile *Balanus reticulatus*, and the soft bottom inhabiting amphipod *Corophium uenoi* (both of them are crustaceans) that are known to be the dominant macrofaunal species before the invasion of *M. sallei* (Wang et al., 1996; Cai et al., 2010). This could be shown for another species, *M. adamsi*. By attaching to each other, *M. adamsi* could even colonize several substrata and cause rapid changes in local communities, because the mussel commonly builds up dense layers that excluded other sessile organisms (Wangkulangkul & Lheknim, 2008). However, mussels of the genus *Mytilopsis* subsequently also provide a new habitat for associated fauna, such as amphipods and polychaetes to colonize with the potential of changing the community structure even further as has been described before for dreissenids and mytilids (Crooks & Khim, 1999; People, 2006; Borthagaray & Carranza, 2007). Positive correlations could be demonstrated between *M. sallei* and the polychaetes *Capitella capitata* and *Polydora ciliata* in Xiamen Maluan Bay (Cai et al., 2006). Both *Capitella capitata* and *Polydora ciliata* are opportunists and pollution resistance species; if they were abundant, the ecosystem would be changed (Cai et al., 2006, 2010). Our results confirmed that appropriate density of *M. sallei* is propitious to increase the biodiversity within the macrofaunal fouling community. For example, the higher density of *M. sallei* and the lower diversity index at stations in Yundang Lagoon in summer (Fig. 6). The densities of *M. sallei* at stations B, C, E, and F in autumn were lower than those at stations B, C, E, and F in summer, respectively, but the diversity indices of macrofaunal fouling community at stations B, C, E, and F in autumn were higher than those at stations B, C, E, and F in summer, respectively. Biodiversity in turn commonly improves water quality (Cardinale, 2011).

Temperature is not the main restricting environmental variable for adult *M. leucophaeata* (Verween et al., 2007). This species was recorded in fluctuating water temperatures ranging from 5°C in Finland (Laine et al., 2006) up to 30°C in Miami (Siddall, 1980). A seasonal effect was clearly reflected in dissolved oxygen levels; when temperatures dropped from autumn to winter, DO levels increased (Morton, 1989). However, temperature remained an important factor for the initiation of spawning (de Vooys, 1999). According to our results, there was a significantly positive correlation between density and biomass of *M. sallei* and water temperature because many juveniles of *M. sallei* were found attached to the panels during summer and autumn, but no juveniles were found in winter. A few large individuals of *M. sallei* were found on panels in winter could have moved there from other places. *M. sallei* is capable of detaching itself and reattaching to new surfaces (Morton, 1989). *M. leucophaeata* moves and reattaches to substrata which are protected from predators (Kennedy, 2011b). The seasonal variation of *M. sallei* density in Yundang Lagoon confirmed that water temperature was a limiting factor for its hatching larvae since this species originated from tropical waters.

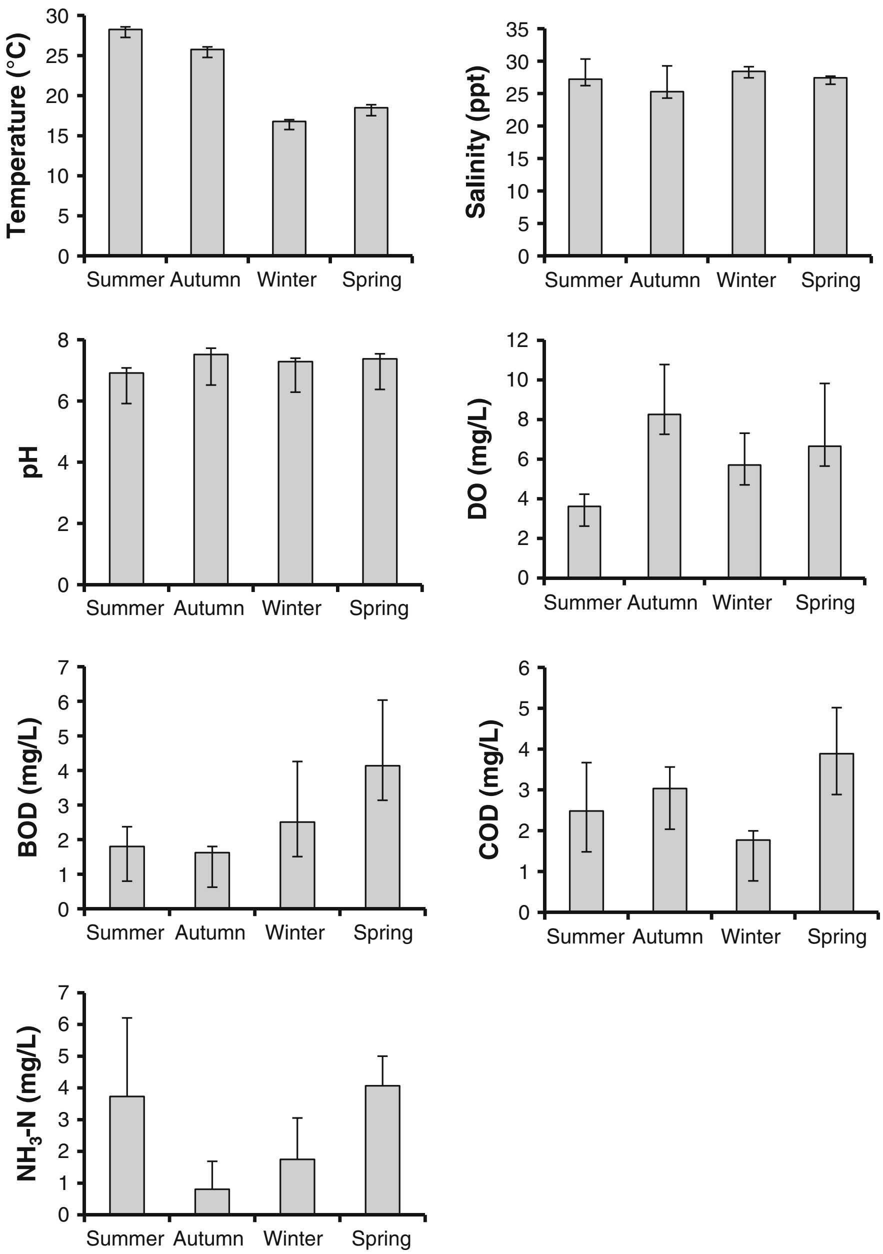

Fig. 7 Seasonal variations of some environmental factors in Yundang Lagoon

Table 3 Correlation coefficient between density and biomass of *M. sallei* and environmental factors ($n = 20$)

Environmental factor	WT	Salinity	pH	DO	BOD	COD	NH_3-N	DIP
Density of *M. sallei*	0.540*	−0.165	−0.575**	−0.128	0.150	0.380*	0.105	0.091
Biomass of *M. sallei*	0.558*	−0.112	−0.539*	−0.182	0.152	0.391*	0.131	0.033

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 4 BIOENV results carried out on the macrofaunal fouling community in Yundang Lagoon

Number of variables	Correlation	Selection
3	0.280	Water temperature, COD, DIP
4	0.279	Water temperature, pH, COD, DIP
3	0.278	Water temperature, pH, COD

Mytilopsis sallei is often found in polluted inner bays and lagoons (Huang & Chen, 2002; Cai et al., 2005, 2006, 2010; Wangkulangkul & Lheknim, 2008; Gaonkar et al., 2010a). *M. sallei* is not reported from Xiamen western waters and other open sea waters (Wang et al., 1996; Cai et al., 2010). The habitat of *M. sallei* is similar to *M. leucophaeata* which was only found on tidal mud flats along river banks and none was found at seven other locations in the Wadden Sea area of the North Sea (Buschbaum et al., 2012).

Zebra mussel populations are capable of removing over 90% of organic matter from the water (MacIsaac, 1996). About 50% of precipitated matter was utilized within zebra mussel populations, while the rest was deposited as feces and pseudofeces, and served as sources for organic pollution in the eastern Gulf of Finland (Orlova et al., 2004). The biodeposition of zebra mussels increased with temperature and water Chl *a* content, but these effects were less effective than those of salinity (Lauringson et al., 2007). Fouling organisms that settled on cages or buoys contributed much to phytoplankton depletion, oxygen consumption and the increase of ammonia and phosphate concentrations in waters during the peak fouling period (Su et al., 2007). The content of DO in summer in Yundang Lagoon was lower than during other seasons. One of the reasons was certainly related to oxygen consumption by *M. sallei* because of its high density.

The effects of the globally invasive species *M. sallei* on macrofaunal fouling communities are attributed to its competitive advantages in colonizing polluted inner bays, its contribution to changes of species composition and diversity of the macrofaunal fouling communities during the summer period (Cai et al., 2006, 2010). *M. sallei* consumed a large amount of nutrient substance from the water in Maluan Bay, Xiamen (Ji, 1998).

As other dreissenids, *Dreissena polymorpha* provides a number of physical, chemical, and biological characteristics that influence the structure of co-occurring macroinvertebrates (Laine et al., 2006; Lauringson et al., 2007). Mollusk shells are abundant, persistent, and ubiquitous physical structures in aquatic habitats (Kennedy, 2011b). Sardiña et al. (2008) carried out an experimental study with the golden mussel *Limnopernea fortunei* in order to examine the influence of this newly created habitat on benthic invertebrate communities. They showed that the lowest abundance and diversity of benthic invertebrates are recorded in substrates lacking golden mussels. Oligochaetes were an exception to this rule, as they were significantly more abundant on substrata with live mussels (Sardiña et al., 2008). Here, oxygen levels are probably low within the interstitial spaces of the mussel shells due to bacterial decomposition of the accumulated organic deposits, the low oxygen levels will favor the presence of oligochaete animals. This indicates that physical attributes of the environment, as much as biological attributes of the golden mussel, influence the structure, diversity, and abundance of the benthic community. Clumped mussels have abundant interstitial spaces that serve as refugia from disturbance and predation for small organisms. It should be mentioned that dense coverage of hard surfaces by mussels may reduce or displace native species as shown by the golden mussel *L. fortunei* (Darrigran & Damborenea, 2011).

High density of mussels consumes a large of phytoplankton from the water which results in the lack of primary producers (Baudinet, et al., 1990). The Zebra mussel, *D. polymorpha*, a major consumer of phytoplankton, exerts a significant top-down control on riverine phytoplankton (Caraco et al., 1997). Before *M. sallei* invaded Xiamen Maluan Bay, the phytoplankton abundance was high, after the establishment of *M. sallei*, the phytoplankton abundance was low and stabilized at a low abundance (Lin & Yang, 2006).

Conclusions

To understand the impact of the invasive bivalve *M. sallei* on a native macrofaunal fouling community, it is essential to determine the spatial and temporal distribution of *M. sallei* and other fouling macrofauna as well as the relationship between *M. sallei* and environmental factors. Our results demonstrated significant positive correlations between density and biomass of *M. sallei* and water temperature and COD, and a significantly negative correlation with pH. BIOENV analysis showed that water temperature, pH, COD, and DIP were key environmental factors affecting the community structure of fouling macrofauna in Yundang Lagoon. These results confirmed that the invasive species changed the density and biomass composition of fouling macrofauna and reduced the species diversity index during the summer period, and somewhat worsened the aquatic environmental quality in Yundang Lagoon because the pH and the DO were the lowest, and the BOD and the COD were the second lowest in summer among four seasons.

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