Introduction

On the eastern coast of Ariake Bay, large sandy tidal flats over 6,000 ha in total area still remain. In the 1970s, the benthic communities on these sandy tidal flats were characterized by dense patches of suspension-feeding bivalves including *Ruditapes philippinarum*, *Mactra veneriformis*, *Meretrix lusoria*, *Solen strictus* etc. (Sugano 1981), which are popular as edible clam. Although very few studies have described the benthic communities on the tidal flats quantitatively in Ariake Bay, it is apparent that the benthic communities have declined drastically in the past three decades judging from the fishery harvest statistics on these edible clams (Kikuchi 2000). For example, in the early 1980s, over 80,000 tons of *R. philippinarum* was harvested annually from the sandy tidal flats in Ariake Bay. However, the harvest of the clam decreased to less than 5,000 tons by the late 1990s (Kikuchi 2000, Tsutsumi 2005).

The causes of the drastic decrease of the clam harvest on the sandy tidal flats in Ariake Bay was not overfishing, because the clam harvest never recovered even after the number of fishermen harvesting the clam on the tidal flats decreased markedly in the 1990s (Tsutsumi et al. 2000). Early studies to find the causes focussed on the increase of mud sedimentation following heavy rain (Kajiyama et al. 1983, Fujimori et al. 1983). However, the mud deposited temporarily on the sandy tidal flats during the rainy season or typhoon season is resuspended into the water soon due to the fast tidal current (Tsutsumi et al. 2002, Tsutsumi 2006). The particulate size composition of the sediment on the sandy tidal flats, therefore, does not change unless the tidal current becomes significantly slower (Tsutsumi et al. 2002, Tsutsumi 2006).

Recent population studies on the *R. philippinarum* on the tidal flats have focussed on the negative impact of biological factors such as predation by shore bird, crab, eagle ray (*Aetobatus flagellum*) and snail (*Glossaulax didyma*)...
Reduction of manganese dioxide in the sediment and its impact on the physiology of the clam

(Nakahara & Nasu 2002, Ishii et al. 2001), lethal effect for respiration through the bioturbation of the sediment caused by a ghost shrimp, Callianassa japonica (Tamaki 2004) (according to Fujiie et al. 2004, this species is identified as Nihonotrypaea harmandii) and a marked decrease in the number of recruits on the tidal flats due to high mortality in the pelagic larval stage (Ishii et al. 2001, Ishii & Sekiguchi 2002). However, ecological studies on the benthic communities on two major sandy tidal flats, Midori River Tidal Flat and Arao Tidal Flat in Ariake Bay, by my research collaborators and myself have found that the clam, R. philippinarum, and mussel, Musculista senhousia, suffered from extremely high mortality just after settlement (Tsutsumi et al. 2000, 2002, Tsutsumi 2005). The recovery project of the fishery sites of the clam on Midori River Tidal Flat by a fishermen’s cooperative association has succeeded in re-establishing dense patches of the clam with several other common species of the macrobenthic animals including bi-valves, M. senhousia, and S. strictus and a polychaete, Neanthes japonica (cf. Hediste sp., Sato & Nakashima 2003) on the newly created sand covers, using natural sand collected from the sea floor of the offshore areas of the bay (Tsutsumi et al. 2000, 2002, Tsutsumi 2005). The total area of the sand covers created on Midori River Tidal Flat reached approximately 105,000 m² by 2003 (Tsutsumi 2005), while the annual clam harvest recovered to 5,038 ton on the tidal flat in 2003 (Kumamoto Prefectural Fisheries Research Center 2004). The recovery of the clam population on the newly created sand covers was also confirmed on Arao Tidal Flat (Tsutsumi 2005). It is, therefore, very likely that various members of macrobenthic animals received negative impact on the establishment of their populations at least on these two major tidal flats. We need to find the environmental factors that can exert a negative impact on the survival of juveniles of the macrobenthic animals just after settlement on the tidal flats.

One possibility is negative impact from the contaminants in the sediment on the survival of juvenile clams just after settlement on the two tidal flats, Midori River Tidal Flat and Arao Tidal Flat. Tsutsumi et al. (2003) examined various heavy metal contents of the sediment on these two tidal flats, comparing the sediment of several other sandy tidal flats located in geographically different locations, but which have been commonly used for the fishery grounds of harvesting R. philippinarum. This study found high manganese concentrations (approximately 1,400 to 2,900 mg kg⁻¹ dry sediment) from the surface sediment only on these two tidal flats, and a significant negative relationship approximated by a geometric function between the biomass of the clam and the manganese concentration of the surface sediment.

Manganese is one of the most common elements and universally distributed in the earth’s crust and waters (The International Manganese Institute 2005), and an essential metal involved in many metabolic functions of both plants and animals (Johnson & Nielsen 1990, Fraust da Silva & Williams 2001). However, when found in excess it becomes toxic and impairs many physiological functions (Baden & Niel 1998). The physiologically toxic effect on the aquatic organisms has been studied mainly in crustaceans, and the results of these studies indicate that 5–20 mg L⁻¹ of dissolved manganese in the water disturbs the functions of the haemolymph, midgut gland, central nervous system, etc. (Baden & Eriksen 2006).

In the coastal area, manganese is continuously discharged from the land, and deposits on the sea floor as manganese dioxide (Hunt & Kelly 1988). In the case of Midori River Tidal Flat and Arao Tidal Flat in Ariake Bay, there is a large source of manganese through the activity of Midori River and Chikugo River, respectively, since the sources of these rivers are at the bases of active volcanoes, Mt. Aso and Mt. Kuju, where high concentrations of manganese, approximately 3,000 to 4,600 mg kg⁻¹, are contained in rock and soil (National Institute of Advanced Industrial Science and Technology 2005), and hot water containing manganese springs out continuously. Therefore, large amounts of manganese are constantly supplied from the bases of these volcanoes through the rivers, and deposit as manganese dioxide on the tidal flats. The organic particulates deposited in the sediment tend to be decomposed anaerobically by bacteria due to restricted availability of dissolved oxygen in the interstitial water on the tidal flats. The bacterial anaerobic decomposition process of the organic matter is partly coupled with reduction of manganese dioxide to manganese ion (Hunt & Kelly 1988, Canfield et al. 1993). Consequently, larger amounts of manganese tend to be liquefied as manganese ion into the interstitial water in the sediment with higher contents of manganese dioxide and organic matter in more reduced conditions.

Although, in the previous studies, little attention has been paid on the negative impact of manganese on the physiology of the macrobenthic animals occurring on the tidal flats, it is likely that manganese ion liquefied into the interstitial water from the manganese dioxide deposited on the sediment has a physiologically critical effect on the survival of juveniles of various macrobenthic animals on Midori River Tidal Flat and Arao Tidal Flat. Tsukuda et al. (2008) detected relatively high concentration of manganese ion from the interstitial water of the sediment on Arao Tidal Flat (2.10 and 2.78 mg L⁻¹) and Midori River Tidal Flat (1.56 and 1.40 mg L⁻¹) in the warm seasons (June 2002) when oxygen consumption tended to be accelerated in the interstitial water of the sediment, and demonstrated a significant decrease in survival rate (approximately 20% decrease relative to the control experiment) of R. philippinarum juveniles with shell sizes of less than 1 mm in length in laboratory experiments with sand and sea water containing 5.4 mg L⁻¹ of manganese ion. These results suggest that manganese reduction in the sediment may have a negative impact on the survival of the clam juveniles.

The manganese ion concentration of the interstitial water of the sediment, however, has tended to be underestimated, due to the technical difficulty of collecting the interstitial...
water (e.g. contamination of sea water from the sediment surface, re-oxidation of manganese ion in the interstitial water sample, etc.). To determine the concentration of manganese ion in the interstitial water and evaluate its potential negative impact on the clams occurring on the tidal flats, we need to improve the detailed sampling techniques of the interstitial water and the methods to determine the concentration of manganese in both the interstitial water and the sediment.

In the present study, on Midori River Tidal Flat and Arao Tidal Flat, I examined various heavy metal contents of the sediment to reconfirm that among heavy metals excluding iron among only manganese deposited on the surface layer of the sediment at extremely high levels. I determined the manganese ion concentration of the interstitial water of the sediment using a portable spectrometer, modifying sampling techniques of the interstitial water of the sediment, and the content of manganese restored as an exchangeable form in the sediment, which manganese ion was weakly bound electronically with organic or inorganic matter. The exchangeable form of manganese tends to be released as manganese ion again into the interstitial water by the action of cations such as \( \text{K}^+ \), \( \text{Ca}^{2+} \), \( \text{Mg}^{2+} \), or \( (\text{NH}_4)^+ \) displacing manganese in relatively low pH conditions (cf. Ure & Davidson 2002). In this paper, I describe these methods, and show the results of the chemical analysis of the sediment and interstitial water on Midori River Tidal Flat and Arao Tidal Flat, in Ariake Bay. I discuss the possibility that manganese ions in the interstitial water is one of the major limiting factors on the occurrence of bivalves on these two tidal flats.

**Materials and Methods**

**Study areas**

Arao Tidal Flat (approximately 1,600 ha) and Midori River Tidal Flat (approximately 2,200 ha) are major sandy tidal flats in the eastern coast of Ariake Bay, Kyushu, Japan (Fig. 1). On Arao Tidal Flat, I established five sampling stations on a transect line with approximately 400 m interval from the near shore area to the offshore area (Stn A1 (32°58′27″N, 130°25′34″E) to Stn A5). On Midori River Tidal Flat, I established one station (Stn M0, 32°43′55″N, 130°34′40″E) on the lower part of the tidal flat to determine the heavy metal contents of the sediment and six sampling stations arranged on two transect lines with approximately 100 m interval on the middle part of the tidal flat (Stn M1 (32°43′50″N, 130°35′45″E) to Stn M3, Stn M4 (32°43′30″N, 130°35′55″E) to Stn M6).

The particle size composition of the sediment on these two tidal flats was described in Tsutsumi et al. (2003). The sediment on Arao tidal flat was poorly sorted. It contained 10 to 17% of mud (silt-clay less than 63 \( \mu \)m in diameter), while the fractions of coarse sand and further coarser ones reached 5 to 17%. On the middle and lower parts of Midori River Tidal Flat, the sediment was moderately sorted, and fine sand (125 to 250 \( \mu \)m) and medium sand (250 to 500 \( \mu \)m) occupied 63 to 90% in their weights.

**Sampling**

I collected the surface sediment up to 1 cm in depth with a plastic core sampler (28 mm in diameter) and at least five small holes of approximately 3 cm in depth in the sediment using a plastic core sampler (28 mm in diameter), and collected the interstitial water that exuded from the sediment into these holes for determination of manganese ion concentration using a syringe (Fig. 2(a)). I also collected the surface sediment up to 5 cm in depth with a core sampler (5 cm \( \times \) 5 cm \( \times \) 5 cm) for particle size composition analysis by wet sieving method and the surface sediment up to 1 cm in depth with a plastic core sampler (28 mm in diameter) at at least five different sites for determination of the contents of exchangeable form of manganese and total manganese (mainly manganese dioxide). At Stn M1 to Stn M6 on Midori River Tidal Flat on August 24, 2006, I made at least five small holes of approximately 3 cm in depth in the sediment using a plastic core sampler (28 mm in diameter), and collected the interstitial water that exuded from the sediment into these holes for determination of manganese ion concentration using a syringe (Fig. 2(a)). I also collected the surface sediment up to 5 cm in depth with a core sampler (5 cm \( \times \) 5 cm \( \times \) 5 cm) for particle size composition analysis by wet sieving method and the surface sediment up to 1 cm in depth with a plastic core sampler (28 mm in diameter) at at least five different sites for determination of the contents of exchangeable form of manganese and total manganese (mainly manganese dioxide). At Stn M1 to Stn M6 on Midori River Tidal Flat on September 7, 2006, the interstitial water of the sediment and the surface sediment were collected for determination of manganese ion concentration of the interstitial water, the particle size composition of the sediment, and the contents of exchangeable form of manganese and total manganese of the sediment as the same manner with Stn A1 to Stn A5 on Arao Tidal Flat.

**Measurement of heavy metal contents of the sediment**

For the determination of the heavy metal contents of the sediment, the sediment samples were heated with nitric acid and hydrochloric acid, and the heavy metals were decomposed and extracted from the sediments. In line with the recommendations of the Environment Agency, Japan (1988), the concentrations of cadmium, lead, arsenic, selenium, boron, and zinc in the extracts were determined with inductively coupled plasma-atomic emission spectrometry. Those of mercury, copper, and manganese were determined by atomic emission spectrometry. The concentration of chromium was determined by diphenylcarbazide absorption spectrophotometry. The concentration of fluorine was determined by ion chromatography.

**Measurement of manganese ion concentration of the interstitial water of the sediment**

At each sampling station, the interstitial water sample was immediately filtered with a disposable syringe filter.
(0.45 μm) (Fig. 2(b)), 10 mL of the filtered interstitial water was kept in a vial, and the manganese ion concentration of the water was determined by periodate oxidation method, using a portable spectrometer (DR 2400, Hach). According to the operation guide book for the portable spectrometer (Central Kagaku, Corp. 2002), a citric acid agent (No. 21076-69, Hach) to prevent oxidization of manganese ion and adhesion on the vial until it was analyzed. In the laboratory, an indicator, sodium periodate (No. 21077-69, Hach) was added in the vial (Fig. 2(c)), and the manganese ion concentration of the water was determined with the portable spectrometer (Fig. 2(d)).
Determination of exchangeable form of manganese and total manganese of the sediment

For determination of the exchangeable form of manganese contained in the sediment, the sediment sample was treated with magnesium dichloride solution at pH 7.0 conditions for 20 min (cf. Tessier et al. 1979), the amount of manganese ion liquated from the sediment was determined by the flame atomic absorption method (Environment Agency, Japan, 1988), using atomic absorption spectrophotometry (Hitachi, Z-5310). For determination of total manganese content of the sediment, the sediment sample was heated with nitric acid and hydrochloric acid to extract manganese from the sediment. The concentrations of manganese in the extract were determined by the flame atomic absorption method in the same manner as the exchangeable form of manganese.

Results

Heavy metal contents of the surface sediment

Table 1 shows the content of heavy metals in the surface sediment at Stn A3 on Arao Tidal Flat and Stn M0 on Midori River Tidal Flat. Among these heavy metals on the two tidal flats, the contents of cadmium, lead, chromium, arsenic, mercury, copper, selenium, boron, fluorine and zinc were were below detectable levels of the devices for chemical analysis or near the lowest levels that the devices could detect (lead: 4 mg kg$^{-1}$ dry sediment at Stn A3 and Stn M0, zinc: 25 mg kg$^{-1}$ dry sediment at Stn A3 and 14 mg kg$^{-1}$ dry sediment at Stn M0). Only the manganese content of the sediment was at exceptionally high levels (1,560 mg kg$^{-1}$ dry sediment at Stn A 3,770 mg kg$^{-1}$ dry sediment at Stn M0).

To confirm the extremely high content of manganese (=total manganese) on these two tidal flats, the manganese content of the surface sediment was determined at five sampling stations (Stn A1 to Stn A5) on Arao Tidal Flat (August 24, 2006) and at six sampling stations (Stn M1 to Stn M6) on Midori River Tidal Flat (September 6, 2006) (Table 2). The manganese content of the surface sediment was extremely high at the five stations on Arao Tidal Flat (790 to 2,230 mg kg$^{-1}$ dry sediment) and at the six stations on Midori River Tidal Flat (790 to 1,280 mg kg$^{-1}$ dry sediment).

Manganese ion concentration of the interstitial water and exchangeable form of manganese in the surface sediment

Detection of manganese ion from the interstitial water of the sediment and exchangeable form of manganese from the sediment indicate that manganese reduction occurs in the sediment. As shown in Fig. 2, at five sampling stations...
on Arao Tidal Flat, the concentration of manganese ion of the interstitial water ranged between 1.4 and 2.8 mg L$^{-1}$, and the content of exchangeable form of manganese of the surface sediment reached 28.8 mg kg$^{-1}$ dry sediment at Stn A4 and 28.1 mg kg$^{-1}$ dry sediment at Stn A5. In contrast, at six sampling stations on Midori River Tidal Flat, the content of exchangeable form of manganese of the sediment ranged between 2.0 and 8.5 mg kg$^{-1}$ dry sediment), but high concentration of manganese ion of the interstitial water were detected from Stn M3 (9.9 mg L$^{-1}$), Stn M5 (8.1 mg L$^{-1}$) and Stn M6 (5.8 mg L$^{-1}$).

Figure 3 shows the relationship between the mud content and the content of exchangeable form of manganese of the surface sediment. Higher content of exchangeable form of manganese of the sediment tends to be recorded from the sediment with higher mud content ($r^2=0.411$, $p<0.05$, Pearson’s correlation coefficient). This fact indicates that manganese ion produced by reduction of manganese dioxide in the sediment tends to be bound with fine particles, and restored as exchangeable form in the sediment, as shown in the sediment on Arao Tidal Flat. In the low mud content of the sediment (1.6% to 7.0%, mean 3.5%) on Midori River Tidal Flat, it seems that manganese ion tends to remain in the interstitial water due to limitation of fine particles in the sediment, if manganese reduction occurred in the sediment.

Table 1. Heavy metal contents of the sediment at Stn AR on Arao Tidal Flat (December 4, 2005) and at Stn M0 on Midori River Tidal Flat (May 24, 2005).

|                | Cd | Pb | Cr | As | Hg | Cu | Se | B  | F  | Zn | Mn |
|----------------|----|----|----|----|----|----|----|----|----|----|----|
| Stn A3 on Arao Tidal Flat | <1 | 4  | <2 | <1 | <0.2 | 10 | <1 | <40| <40| 25 | 1,560 |
| Stn M0 Midori River Tidal Flat | <1 | 4  | <2 | <1 | <0.2 | 10 | <1 | <40| <40| 14 | 770  |

Table 2. Total manganese and exchangeable form of manganese contained in the surface sediment and manganese ion concentration in the interstitial water at five stations on Arao Tidal Flat (August 24, 2006) and at three stations on Midori River Tidal Flat (September 6, 2006).

| Form of manganese | Arao Tidal Flat | Midori River Tidal Flat |
|-------------------|----------------|------------------------|
|                    | A1  | A2  | A3  | A4  | A5  | M1  | M2  | M3  | M4  | M5  | M6  |
| Total manganese (mg kg$^{-1}$ dry sediment) | 790 | 2,230 | 1,250 | 1,180 | 2,120 | 890 | 1,280 | 790 | 1,190 | 1,070 | 970 |
| Manganese ion (mg L$^{-1}$) | 2.8 | 2.3  | 1.5  | 1.4  | 1.4  | 1.6  | 0.4 | 9.9 | 0.1 | 8.1 | 5.8 |
| Exchangable form (mg kg$^{-1}$ dry sediment) | 3.4 | 9.7  | 6.7  | 28.8 | 28.1 | 6.4  | 2.4 | 7.2 | 2.0 | 3.6 | 8.5 |

Mud content of the sediment (%) | 1.2 | 12.7 | 5.2  | 8.2  | 11.2 | 2.1  | 1.6 | 4.0 | 2.2 | 7.4 | 3.5 |

Discussion

As shown in Table 1 and 2, the manganese content of the sediment ranged between 790 and 2,230 mg kg$^{-1}$ dry sediment on Arao Tidal Flat and between 770 and 1,280 mg kg$^{-1}$ dry sediment on Midori River Tidal Flat. We have compared the manganese content of the sediment among various sandy tidal flats, where the clam including *Ruditapes philippinarum* dominates in the macrobenthic communities, in Japan and Korea (Tsutsumi et al. 2003, 440 mg kg$^{-1}$ dry sediment on Kikuchi River Tidal Flat facing Ariake Bay in Kumamoto, 300 mg kg$^{-1}$ dry sediment on Sonjedo Tidal Flat in the western coast of Korea, unpublished; 150 mg kg$^{-1}$ dry sediment on Hichiripu in the eastern Hokkaido, 270 to 350 mg kg$^{-1}$ dry sediment on Obitsu River Tidal Flat in Chiba facing Tokyo Bay, and 500 to 620 mg kg$^{-1}$ dry sediment on Sone Tidal Flat in Kitakyushu facing Seto Inland Sea, 84 to 530 mg kg$^{-1}$ dry sediment on Hondo Sea Tidal Flat in Amakusa, 320 to 510 mg kg$^{-1}$ dry sediment on Kongo Tidal Flat facing Yatsushiro Bay in Kumamoto, 530 to 580 mg kg$^{-1}$ dry sediment on a tidal flat facing Gomso Bay in the western coast of Korea). These detailed data will be reported elsewhere. Thus, the man-
ganese contents of the sediments on all these sandy tidal flats are commonly lower than the ranges of manganese of the sediment on Arao Tidal Flat and Midori River Tidal Flat, because there are no special sources of manganese discharge related to geothermal activities such as volcanos or hydrothermal vents.

The deposition of extremely high concentrations of manganese in the sediment on Arao Tidal Flat and Midori River Tidal Flat seems to be an unique phenomenon occurring on tidal flats, where major rivers transport continuously large amounts of various forms of manganese such as particulates of manganese dioxide, exchangeable forms of manganese attached on the sand particles, and soluble forms of manganese in the water, from the upper reaches of the rivers around the active volcanos. There, these manganese forms are produced by weathering the rocks and earth containing high concentrations of manganese (National Institute of Advanced Industrial Science and Technology 2005), and the hot water with manganese springs out from the underground and enters the river. The sand is, however, produced by weathering the rocks in the whole areas along the rivers not only in the upper reaches of them around the active volcanos but also the areas outside them where have limited supply of manganese to the rivers. The sand with low concentrations of manganese that was produced from the areas except the upper reaches of the rivers around the active volcanos seems to have an effect that dilutes the manganese concentration of the sediment on the tidal flats. However, on the tidal flats, the sand supply from the rivers had decreased markedly since the 1970s, due to collection of large amounts of sand in the rivers for use in making concrete (Yokoyama 2005), while the manganese has been transported constantly from the upper reaches of the rivers around the active volcanos, and deposited on the tidal flats. It is very likely that the marked decrease of sand supply from the rivers leaded a large increase in manganese concentration of the surface sediment over the past three decades.

My research collaborators and I determined the sedimentation rates on several tidal flats in the innermost areas of Ariake Bay, including Arao Tidal Flat, using GeoSlicer (Fukken, Ltd.), and found that the sedimentation has almost stopped since the 1970s on Arao Tidal Flat (unpublished data). We will report about the sedimentation rates on the tidal flats, together with the results of vertical profile of manganese in the sediment, elsewhere. These results will clarify the process of the increase of manganese concentration of the sediment on the tidal flats.

The determination of the concentration of manganese ion, which seems to exert a serious negative impact on the physiology of aquatic animals among various manganese forms (Baden & Eriksson 2006), from the interstitial water of the sediment on the tidal flat is always accompanied technical difficulties, particularly in the sampling process of the interstitial water, since some water tends to remain on the sediment surface even after the tidal flat is exposed at ebb tide, and the water lying on the sediment surface often contaminates and dilutes the interstitial water. However, in this study, I made small holes in the sediment with a plastic core sampler to collect the interstitial water exuded from the sediment, preventing the contamination of water from the sediment surface, and detected 5.8 to 9.1 mg L\(^{-1}\) of manganese ion from the interstitial water of the sediment on Midori River Tidal Flat (Table 2). These manganese ion concentrations of the water are equivalent to the toxic levels that influence significantly the survival rate of the small juveniles of *R. philippinarum* just after settlement (5.4 mg L\(^{-1}\)) (Tsukuda et al. 2008) and the levels that disturb the functions of the haemolymph, midgut gland, and central nervous system of various aquatic organisms (5 to 20 mg L\(^{-1}\)) (Baden & Eriksson 2006). On Arao Tidal Flat, the content of exchangeable form of manganese of the sediment was high at two sampling stations (28.8 and 28.1 mg kg\(^{-1}\) dry sediment), although the manganese ion concentration of the interstitial water was relatively low (1.4 to 2.8 mg L\(^{-1}\), Table 2). The exchangeable form of manganese adhering to the sediment particles tends to be released to the interstitial water as manganese ion, as pH levels of the interstitial water decrease due to reasons such as inflow of freshwater, development of reduced conditions in the sediment, etc. The content of exchangeable form of manganese of the surface sediment, therefore, indicates the potential maximum concentration of manganese ion of the interstitial water of the sediment. On Arao Tidal Flat, the manganese ion concentration of the interstitial water of the sediment might reach much higher levels (maximum approximately 70 mg L\(^{-1}\)) than those detected in this study, if pH levels of the interstitial water decreased to around 7.0.

Now, I am examining the seasonal fluctuations of the content of total manganese and exchangeable form of manganese of the sediment and the concentration of manganese ion of the interstitial water, together with other physicochemical conditions of the sediment and the interstitial water, on Arao Tidal Flat and Midori River Tidal Flat, conducting field experiments to decrease these manganese levels of the sediment and interstitial water by creating sand covers with common levels of total manganese content of less than 600 mg kg\(^{-1}\) dry sediment, and monitoring the survival rate of the clam juveniles that settled on the sand covers. Results of these field surveys and experiments will clarify how the sediment with extremely high content of manganese affect the survival of juveniles of clam on these two tidal flats.

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