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Innovative Improvement Method of Tidal Mud in Ariake Sea, Japan for Restoration of *Sinonovacula Constricta* Shell

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ABSTRACT. The Ariake Sea, which is one of the best-known semi-closed shallow seas in Japan, is famous for its various kinds of fisheries' products and seaweed cultivation. Recently, a dramatic decrease in the catch of shells has been observed in the Ariake Sea. This study discusses an innovative improvement method that was used in the tidal mud of the Ariake Sea to restore the *Sinonovacula constricta* shells. Field investigations were carried out in the Iida tidal flat area by creating an improvement area comprising of dikes, sand and recycled waste glass. Results indicate that in the improvement area, water content was reduced to less than 200% in the upper layers of the mud and compares favorably with the non-improvement area that had a water content of 250%. Additionally, the acid volatile sulphide (AVS) value in the improvement area declined significantly and was measured within the safe limit for both the benthos living in the tidal mud and the adult shells.

Keywords: Ariake sea, tidal mud, improvement area, benthos, sinonovacula constricta, survival rate, geo-environment

1. Introduction

The Ariake Sea is one of the best-known semi-closed shallow seas in Japan. The vast tidal flat mud of the Ariake Sea, which makes up nearly 40% of the total tidal flat area of Japan, is well known for its rich fishery products and Porphyra sp. cultivation. However, environmental issues related to the Ariake Sea have been of increasing interest recently and the analysis of the tidal flats' characteristics is of great interest to the regional population (Cyranoski, 2001; Ohtsubo et al., 1995; Zhang et al., 2004). Moreover, a dramatic decrease in the catch of shells, such as *Sinonovacula constricta*, *Atrina pectinata* and *Crassostrea gigas* has been observed in the tidal flat mud area over the last thirty years. The catch of *Crassostrea gigas*, which usually live near the mud surface, dropped from 7.99×10^5 kg in 1976 to only 1.26×10^5 kg in 1999; while that of *Atrina pectinata*, (found in the upper 0.10 ~ 0.15 m of the mud), declined from 1.34×10^7 kg in 1976 to 7.9×10^4 kg in 1999. The reduction in catch of *Sinonovacula constricta*, living at a depth of 0 ~ 0.70 m in the mud, was even more significant as it dropped from 1.7×10^5 kg in 1976 to practically zero by 1992 (Figure 1). Questionnaires completed by fisherman in the area reveal that most fishermen thought that the mud in the tidal flat areas of the Ariake Sea has deteriorated. The fishermen also feel that an unpleasant odor from the mud of Ariake sea tidal flats has accompanied this deterioration (Hayashi and Du, 2005). Ushihara et al., (2002) carried out preliminary investigations indicating that the acid treatment practice used in the Porphyra sp. cultivation is one of the most probable causes for mud deterioration. In short, the geo-environmental conditions of the Ariake Sea have become unfavorable for the benthos living in it (Kanayamal et al., 2000; Koga et al., 2003). The objective of this study, therefore, is to investigate the effectiveness of the new improvement method for developing favorable living conditions for the *Sinonovacula constricta* shells and consequently, the restoration of these shells in the Ariake Sea.

2. Study Area

A map of the study area along with the different types of *Porphyra sp.* cultivation areas is illustrated in Figure 2. The study area Iida (33º 57' N, 130º 40' E), located at Kashima city, Saga prefecture, was chosen as it has been most affected by the acid treatment practice (Kato and Seguchi, 2001). The field investigation shows that the acid volatile sulphide (AVS) value is significantly higher than the safe limit of 0.2 mg/g dry mud for the benthos living in the tidal mud at Iida site (Moqsud et al., 2007a). Also the mud samples at this site have a strong unpleasant odor due to the gas-phased hydrogen-sulphide (H_2S). Another study area located at Higashiyoka (in Saga City) was used as a control site as it has a quite healthy geo-environment and many living creatures are observed there (Araki et al., 2002; Yamanishi et al., 2002; Azad et al., 2005).

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3. Methods and Materials

Figure 3 shows the conceptual image of the improvement methodology by using a dike, sand and foamed waste glass in the Iida tidal flat mud. The dike was used to create tidal effects such as a whirlpool and to increase the water velocity in order to retard finer particles from settling inside the improvement area. The improvement area comprised of thoroughly mixing sand and the recycled waste glass with tidal mud to a depth of 1 meter. The quantity of materials in the improvement area was; tidal mud 70 cm, sand 25 cm and recycled waste glass 5 cm. An artificial fishing land (20 m × 20 m) was also created in the Iida tidal area to improve the tidal mud (Figure 4). The grain size distribution of the improvement materials is shown in Figure 5 and indicates that both the sea sand and recycled waste glass can be classified as sand based on their size. Put another away, the size of the recycled waste glass is not significantly different from the sea sand. The density of the recycled waste glass is 1.7 g/cm^3, which is less than the density of soil. These new improvement materials have two main roles in improving the tidal mud such as increasing the permeability of the total mud and declining the reduction in the oxygen content by increasing the amount of fresh sea-water, which is rich in dissolved oxygen (Moqsud et al., 2007b).

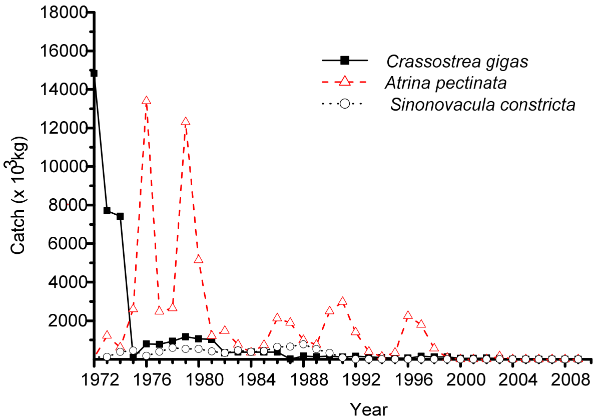

Figure 1. Decrease in the catch of shells in the Ariake Sea.

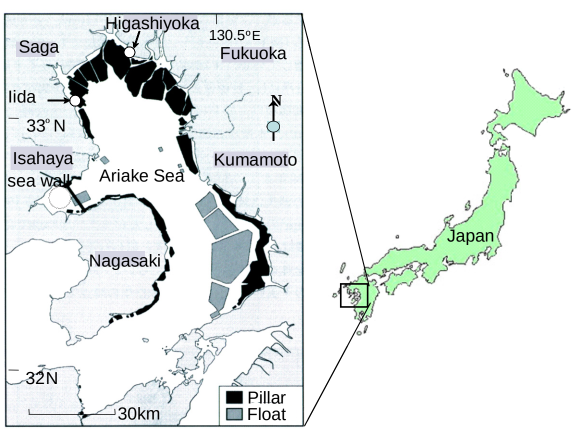

Figure 2. Map of the Ariake Sea & study areas.

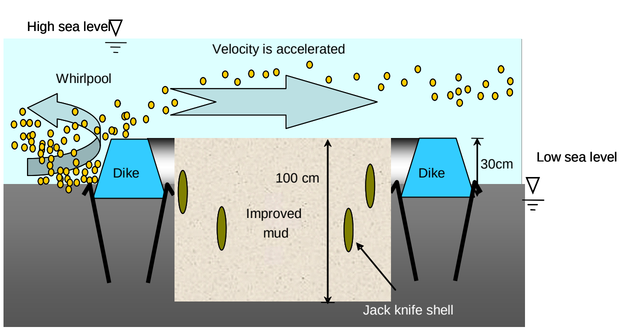

Figure 3. Conceptual image of the improvement method for restoring *Sinonovacula constricta* shells in the tidal flat area.

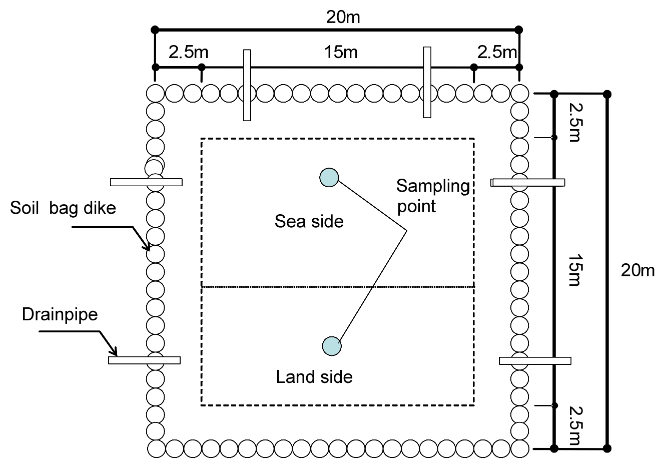

Figure 4. Sketch of the improvement area for restoring the *Sinonovacula constricta* shell in the Iida tidal flat.

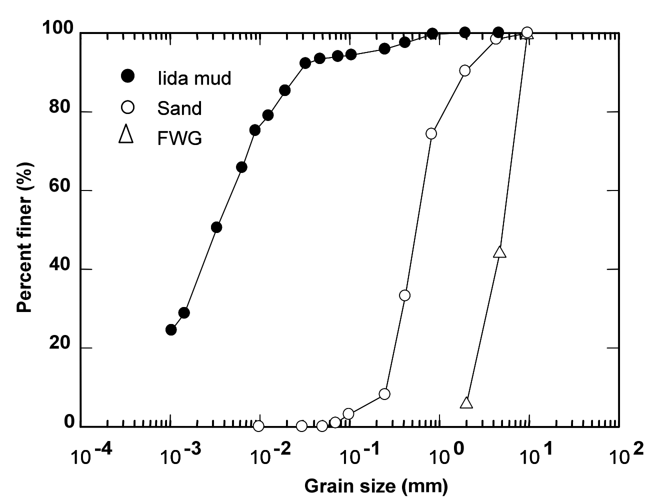

Figure 5. Grain size distribution of improvement materials used in the improvement area.

After preparing the Iida site improvement area, baby Sinonovacula constricta shells were discharged into the improvement area. In total there were four discharges of shells over a period of 14 months. The first discharge of 21,000 baby Sinonovacula constricta shells with an average size of 11 mm occurred in April, 2004. A second discharge in December, 2004, of 27,000 *Sinonovacula constricta* shells, averaging 7.3 mm was followed by a third discharge in March, 2005 and a fourth discharge two months later in June, 2005. The total number of *Sinonovacula constricta* shells discharged in March and June of 2005 was 18,500 and 4,500 respectively.

The size of the *Sinonovacula constricta* shells and their survival rate were monitored regularly by counting the living shells in the improvement area once every month. Samples were collected using a 90 cm long and 7 cm diameter steel tube sampler, which was inserted vertically into the tidal mud. The AVS content along with the other geo-environmental parameters was measured in pre-specified layers by using GASTEK 201 H/L methods (Moqsud et al., 2006; Wu et al., 2003). The AVS was measured because it is the most important geoenvironmental parameter for the benthos life (Jorgensen, 1990; Rickard and Morse, 2005; Sorensen and Jorgenson, 1987).

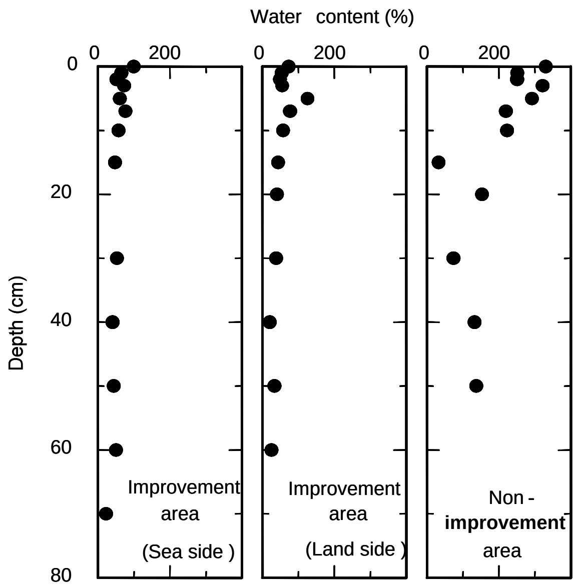

Figure 6. Water content variation at depth in the improvement area and in non-improvement area at the Iida tidal flats.

4. Results and Discussion

Figure 6 illustrates that the water content at different depths varied in both the sea side and land side of the improvement area. It also shows a lower value than the tidal flat area (non improvement area or Blank) during July, 2006. This is due to the effects of the improvement methodology of making a dike around the improvement areas. The dike caused an increase in the water velocity which then washed away the finer particles on the top of improvement area. Figure 7 also shows that the water content in the top 5 cm of mud also improved within the improvement area. The study showed that the water content was less than 200% in the improvement area while the water content collected from the non-improvement tidal flat area had a value significantly higher at 250%. This improvement is due to the combined effects of dike along with the mix of sand in the improvement area. In fact, the water content at both the sea side and land side in the improvement area is almost 50% lower than that in the non-improvement area.

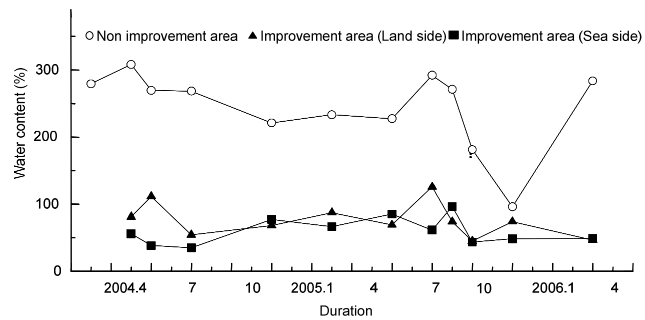

Figure 7. Variation of water content over time at 5 cm of depth at improvement area and the Iida tidal flats.

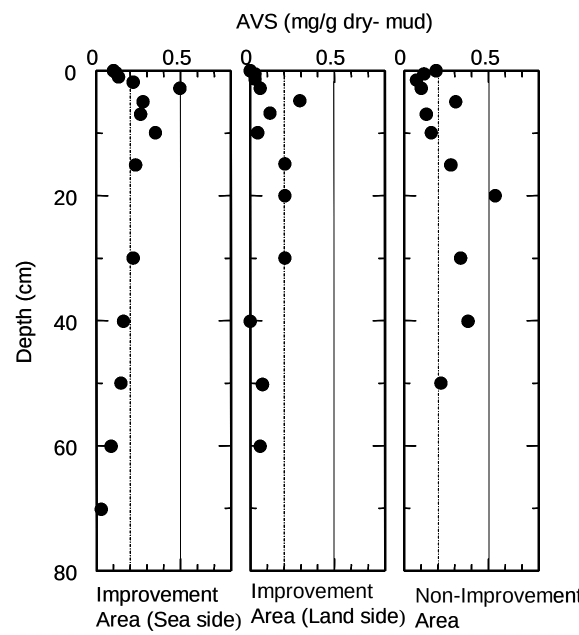

Figure 8. Variation of AVS with depth at improvement area and the Iida tidal flats. July, 2005.

The differences in the acid volatile sulphide (AVS) content at various depths between the improvement area and the non-improvement area in July 2006 is shown in Figure 8. The improvement area's AVS content was reduced to under 0.2 mg/g of dry mud at almost all depths whereas the AVS content in tidal mud of the non-improvement area gradually increased until it reached a maximum measurement of 0.55 mg/g of dry mud. This finding is significant as the safe limit of the acid volatile sulphide content for benthos living in the mud is 0.2 mg/g dry mud (Japan Fisheries Resource Conservation Association, 2000; Tsusumi, 2003).

Figure 9 illustrates that from 2002 to 2006, the variation of AVS content at a 10 cm depth at the Iida and Higashiyoka tidal flats as well as the seaside and the landside area of the improvement area decreased. The AVS content of the tidal mud was reduced due to the increased movement of fresh sea water caused by the dike. As was stated earlier in the paper, the increased water velocity made it impossible for the finer particles to settle inside the improvement area. This factor along with the mixture of sand and foamed waste glass provided an adequate supply of oxygen which helped minimize the acid volatile sulphide content and increased the geoenvironmental conditions favorable for benthos. Figure 9 shows that at both Higashiyoka and the improvement area, the AVS value is noticeably lower than the safe limit whereas the AVS value is above the safe limit at the Iida tidal mud area nearly the entire time. This indicates that the improvement methods greatly benefited the tidal mud habitat for the benthos from a geoenvironmental point of view.

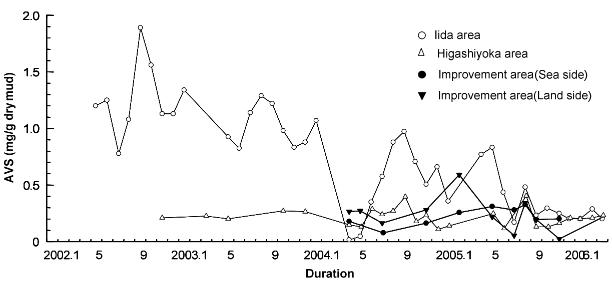

Figure 9. Variation of AVS at 10 cm depth in the improvement area, Iida tidal flats and Higashiyoka tidal flats.

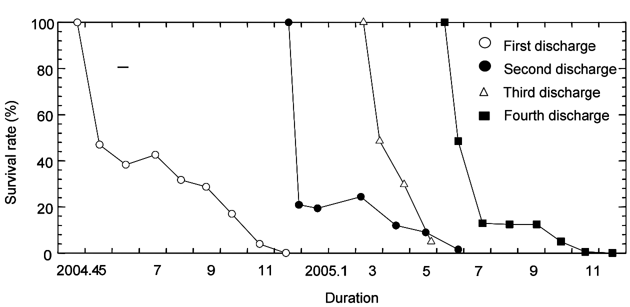

Figure 10. Variation of survival rate of *Sinonovacula constricta* shells over time at improvement area.

Figure 10 indicates that the survival rate of the *Sinonovacula constricta* shells was gradually decreasing during the study period in the improvement area. Shells from the first discharge died within 8 months after discharge. The survival rate of the *Sinonovacula constricta* shells was strongly affected by the increased turbulation caused by typhoons that hit the area. Additionally, the occurrence of a red tide in the Ariake Sea during summer also had a detritus affect on the survival rates of the *Sinonovacula constricta* shells.

The variation in size of the discharged *Sinonovacula constricta* shells in the improvement areas is shown in figure 11. The graph indicates that the size of the adult *Sinonovacula constricta* shells was almost 6 cm within 6 months. The average body weight of the *Sinonovacula constricta* shells gradually increased from 0.08 g to 12 g within the 6 month period. The maturation of the *Sinonovacula constricta* shells reached within this time allowed them to lay eggs in October to November. As such, the growth proves that the improvement area is effective in establishing a suitable living condition for the shells.

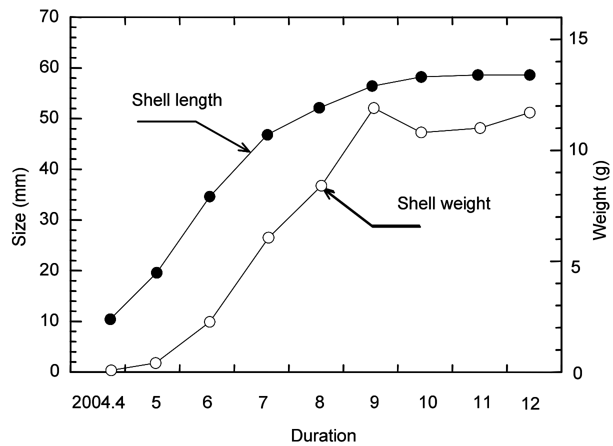

Figure 11. Variation of size and weight of *Sinonovacula constricta* shells over time at improvement area.

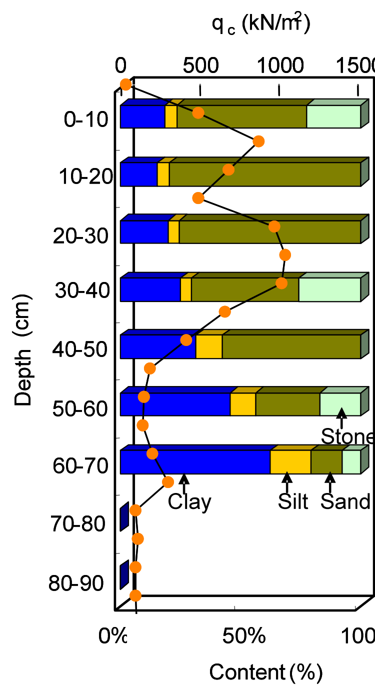

Figure 12. Grain size distribution and cone penetration test result at different depths at improvement area after typhoon.

Figure 12 depicts the grain size distribution at different layers in the improvement area after typhoon no. 14, which occurred on September 6, 2005. The rate of fine grain content is less than 20% at the depth of 20 cm after the typhoon and resulting wave turbulation. Normally, the fine particle content should be around 70% according to the initial mixing condition of the improvement area. Results of the cone penetration test show that the depth distribution within 10 cam was $q_c = 1000$ kN/cm^2 and was $q_c = 800$ kN/cm^2 at 30 cm depth. These two depths indicate the hard sand layers that caused unfavorable living conditions for the *Sinonovacula constricta* shells as they were not able to enter into the mud. During the typhoon, waves turbulated the soil surface washing away the finer particles from the top surface and consequently allowing the coarser particle to settle in the improvement area. This wave turbulation along with the toxic red tide during summer caused a serious declination in the survival rate of the *Sinonovacula constricta* shells in the improvement area.

5. Conclusions

This paper discusses the effective use of new improvement methods comprising of a dike, mixing sand and recycled waste glass in the tidal mud in developing favorable living conditions for *Sinonovacula constricta* shells. The Field tests carried out in the study area of the Ariake Sea prove the effectiveness of this method to improve the geoenvironmental condition of the tidal mud. Water content values were compared between the improvement area, which utilized a dike and the non improvement areas which did not. The AVS content of the improvement area mud was found to be within the favourable range at various depths and during all seasons. The growth and maturation of adult *Sinonovacula constricta* shells indicates that the improvement area was also a favourable living environment for them. As a result, the study shows that the new improvement method comprising of dikes, sand and foamed waste glass is an efficient way to restore populations of *Sinonovacula constricta* shells situated in contaminated tidal mud.

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