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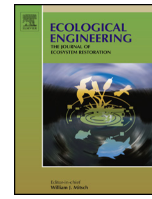

Research paper

Numerical analysis of convective dispersion of pen shell *Atrina pectinata* larvae to support seabed restoration and resource recovery in the Ariake Sea, Japan

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ABSTRACT

In this study, numerical simulation of convective dispersion of the larvae of the pen shell *Atrina pectinata* was conducted to support effective seabed restoration in the Ariake Sea, Japan. A two-dimensional depth-averaged model consisting of a continuity equation and Navier–Stokes momentum equations was developed to reproduce tidal currents in the Ariake Sea. This larval transport model was then used to predict migration of larvae drifting on tidal currents. To determine effective areas for seabed restoration, 14 release points were defined in the model as potential new spawning grounds for the pen shell. The number of larvae that migrated from these points to habitable areas for pen shells (depth: $2 < h < 20$ m, grain size median diameter: >62.5 μm) was calculated for each release point. Because of the anticlockwise tidal residual flow in the inner bay of the Ariake Sea, pen shell larvae also had anticlockwise trajectories. Larvae originating from the northeast area spread out over a large area, while larvae originating from the northwest area reached only the western area. Most of the larvae originating from Isahaya Bay flowed out through the mouth of the Ariake Sea. Consequently, larvae released from the northeast area (particularly from Point 13, Noku 210) reached the largest habitable area. In addition, most of the larvae ultimately drifted to Isahaya Bay, suggesting that seabed restoration in the northeast area and Isahaya Bay would be the most effective approach to recovery of pen shell resources.

1. Introduction

The Ariake Sea is a typical semi-enclosed inner bay located near Kyushu Island, Japan (Fig. 1; area, 1700 km^2; average depth, 20 m; volume, 34 billion m^3). The western portion of Isahaya Bay is closed off for tidal basin reclamation. Because the area of the Ariake Sea is large compared to its depth and the width of its mouth at Kuchinotsu, the oscillation period of the inner bay of the Ariake Sea (12.4 h) resonates with the semidiurnal tide in the outer sea (Inoue, 1980). Thus, the Ariake Sea has the largest tidal range in Japan, up to 6 m. Because the tidal range is so large, >200 km^2 of tide flats emerge at the spring ebb tide in the Ariake Sea. Many rivers flow into the Ariake Sea (Fig. 1); its entire watershed is 8420 km^2 and the annual volume of freshwater inflow is about 8×10^9 m^3. Vast quantities of nutrients flow into the sea and the detention period is long due to its shape. Hence, the Ariake Sea is a homeostatic eutrophic area with high biological productivity. A wide variety of fisheries, such as seaweed (Nori) aquafarming and shellfisheries, have been active in the Ariake Sea for many years.

The pen shell *Atrina pectinata* is a well-known bivalve harvested in the Ariake Sea. Its adductor muscle and mantle are marketable as edible shellfish. Pen shells adhere to the seabed point downward and have a triangular shell reaching about 40 cm in length. The nursery grounds of the pen shell are in the inner bay, with suitable water temperatures of 22.0–28.5 °C. In the summer, pen shells spawn and the ova are fertilized in the water. After hatching, the fertilized ova become suspended larvae with a shell length of 150–585 μm (Koga and Yamashita, 1986). After a floating period of 30–40 days, the floating larvae become full-grown larvae, which then settle onto the bottom and transform into juvenile bivalves. The juvenile bivalves grow into adults in that location.

Production of pen shells in the Ariake Sea increased dramatically until the 1970s. However, environmental deterioration of the Ariake Sea has become a serious social problem. Since 1985, the number of red tide outbreaks has exceeded 20/year. During 1998–2002, red tides occurred >30 times/year. Numerous studies

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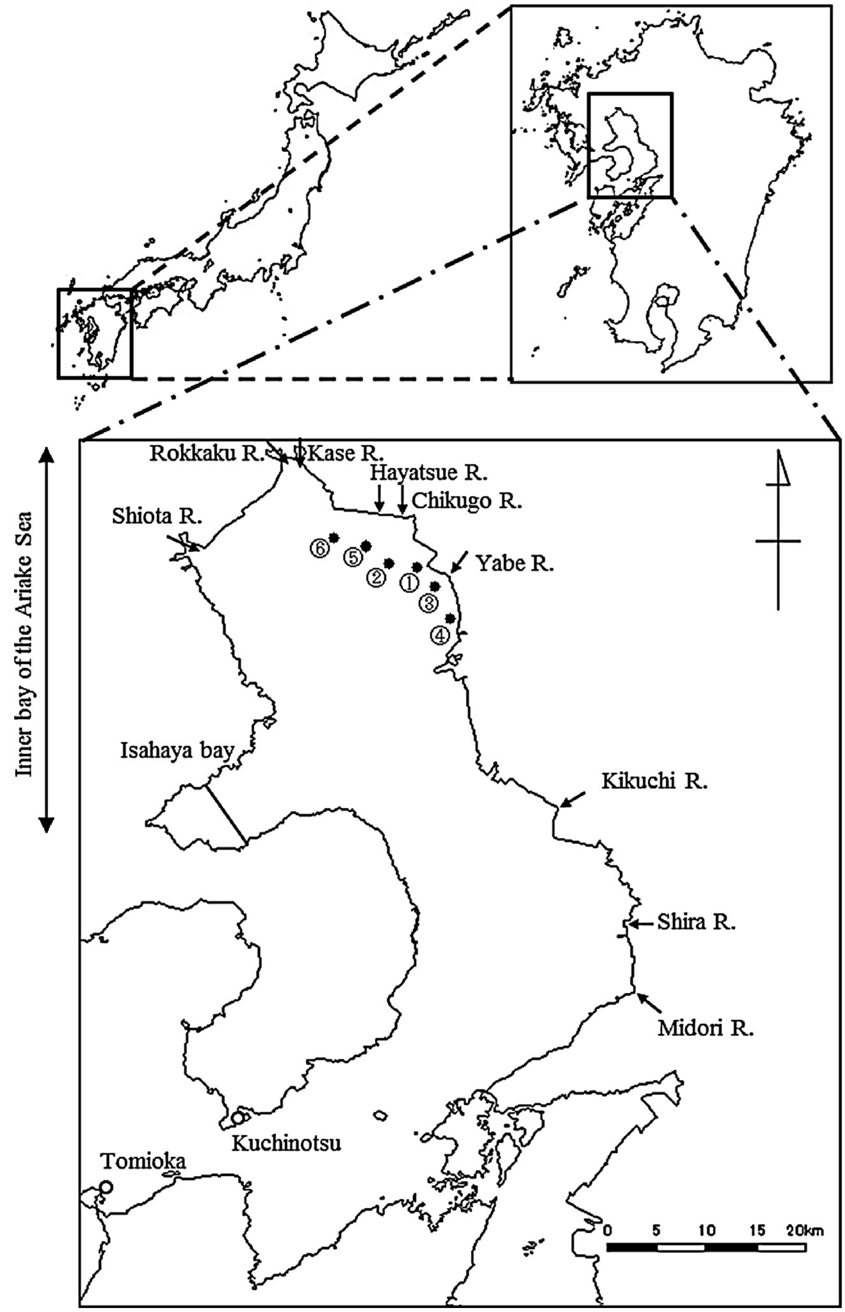

Fig. 1. Location of the Ariake Sea, river inflow, and the six observation stations for tidal currents.

have been conducted of a large anoxic water mass, which has also become a serious issue in the Ariake Sea (e.g., Hamada et al., 2008; Kajiwara et al., 2003; Tsutsumi et al., 2003). Pen shells have been affected by this environmental deterioration in the Ariake Sea. Peak production years were 1942, 1961, and 1979, in which production was 9330, 30,935, and 29,305 tons, respectively. However, in 1996, which was expected to be a peak year, production substantially decreased to only 3786 tons. Production of pen shells in the Ariake Sea has been continuously low since then. Of additional concern, pen shell resources have significantly declined because of pen shell mortality (Kawahara and Ito, 2003; Kawahara et al., 2004a), attributed to the anoxic water mass and degradation of the quality of the seabed. Hence, recovery of pen shell resources is one of the most urgent issues in the Ariake Sea.

For this study, we considered degradation of the quality of the seabed to be a potential cause of low harvest of pen shells. Yurimoto et al. (2008) conducted an experiment on the effect of resuspended mud on pen shells and reported that deposits of resuspended mud caused critical damage to pen shells. Kondo et al. (2003) surveyed the seabed environment and reported that a reduction in grain size was occurring in the northwest portion of the Ariake Sea, where mortality of pen shells has frequently occurred. Restoration of the seabed in the Ariake Sea will contribute to recovery of pen shell resources. However, the area is so large that it would be impossible to conduct seabed restoration throughout the entire Ariake Sea. Thus, in this study, we used numerical simulation to predict the settling areas of pen shell larvae to identify effective areas to implement seabed restoration for pen shell resource recovery.