



Review

Environmental changes in Ariake Sea of Japan and their relationships with Isahaya Bay reclamation



Rui Jia^{a,b,*}, Huayang Lei^{a,b}, Takenori Hino^c, Arul Arulrajah^d

^a School of Civil Engineering, Tianjin University, 135 Yaguan Road, Jinnan District, Tianjin 300350, China

^b Key Laboratory of Coast Civil Structure Safety of Ministry of Education, Tianjin University, 135 Yaguan Road, Jinnan District, Tianjin 300350, China

^c Institute of Lowland and Marine Research, Saga University, 1 Honjo-machi, Saga-city, Saga 840-8502, Japan

^d Department of Civil and Construction Engineering, Swinburne University of Technology, Melbourne, Australia

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ABSTRACT

This paper reviews the recent environmental deterioration in Ariake Sea, Japan, including an increased frequency of red tides and hypoxic waters and decreased fishery production. Analysis of the mechanisms of environmental deterioration suggests that it is possibly induced by the decrease in tidal flat area, decreases in the tide and tidal current and changes in the sediment environment. The Isahaya Bay reclamation project resulted in the loss of 1550 ha of tidal flats, and is one of the possible reasons for the decreases in the tide and tidal current. Therefore, some fishermen and researchers believe that opening the reclamation project dike's floodgates is an effective environmental restoration countermeasure for Ariake Sea. However, the central government decided not to open the floodgates at present due to strong opposition from local farmers, and some researchers believe that the influences of the Isahaya Bay reclamation project on the environmental changes outside of Isahaya Bay are minor. Several lawsuits regarding these relationships and the opening of the dike's floodgates are currently under dispute. To revive Ariake Sea as a sustainable ecosystem, other countermeasures for environmental restoration are suggested and discussed in this paper.

1. Introduction

In association with socioeconomic development, many construction projects have been conducted in Asia to satisfy the requirements of urban, agricultural, and industrial use (Li et al., 2014; Ma et al., 2014; Shen et al., 2017). These projects have included urban construction, e.g., metro construction (Shen et al., 2014; H.-N. Wu et al., 2017; Liu et al., 2018; Ren et al., 2018), groundwater pumping (Wu et al., 2016; Xu et al., 2014; Y.-X. Wu et al., 2017), and reclamation in coastal regions (Du et al., 2008; Zhang et al., 2015). However, these projects may have caused environmental issues, such as water pollution, land contamination by heavy metals (Du et al., 2012, 2014b), land subsidence (Shen and Xu, 2011; Xu et al., 2016, 2017), flooding hazards (Lyu et al., 2017, 2018; Xu et al., 2018) and the deterioration of the ecosystem and the aquatic environment (Koriyama et al., 2011; Hayami and Hamada, 2016). These issues have affected the total environment in both urban and coastal regions. Isahaya Bay reclamation in Ariake Sea of Japan has involved the reclamation of Isahaya Bay using a double dike system (Fig. 1). There is much controversy about whether the reclamation project has had important impacts on the environment of Ariake Sea,

with the local fishermen claiming that a decrease in fish catches was mainly caused by the reclamation project (Ohkura, 2003; Hayami and Hamada, 2016).

Ariake Sea is located on the island of Kyushu, Japan, and is a typical semi-enclosed shallow bay surrounded by Fukuoka, Saga, Nagasaki and Kumamoto Prefectures (Fig. 1). Ariake Sea is approximately 1700 km² in area, measuring 100 km in length and having an average width of 18 km (Hayami and Hamada, 2016). The maximum depth of Ariake Sea is approximately 100 m, and the average water depth is approximately 20 m. The maximum tidal range of Ariake Sea can reach 6 m, which creates extensive tidal flats that account for approximately 40% of Japan's total tidal flats. The tidal flats provide a unique ecosystem for many different forms of marine and amphibious life, and the environment in Ariake Sea allows a wide range of marine products to be harvested. Ariake Sea is famous for nori (laver) cultivation using its large tidal range, providing approximately 50% of the total production in Japan. It is also famous for its fishery products, and it has been dubbed the “Sea of Treasure” due to its abundant fishery resources. However, Ariake Sea has displayed signs of environmental deterioration in recent years, such as an increasing incidence of red tides (Commission for the

* Corresponding author.

E-mail addresses: jiarui@tju.edu.cn (R. Jia), huayanglei@tju.edu.cn (H. Lei), hino@ilt.saga-u.ac.jp (T. Hino), arulrajah@swin.edu.au (A. Arulrajah).

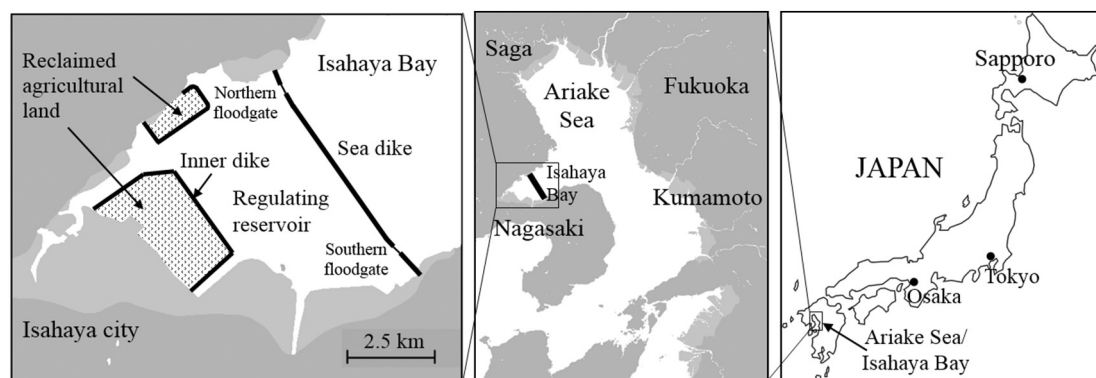


Fig. 1. Isahaya Bay reclamation project.

Assessment of Comprehensive Research on Ariake Sea and Yatsushiro Sea, 2017), the frequent occurrence of hypoxic water (Yamaguchi and Hayami, 2017), an increase in transparency (Hayami et al., 2015), a decreasing grain size of the sediments (Li and Matsunaga, 2010), a decrease in fishery products (Association of Researchers Calling for Opening the Floodgates in Isahaya Bay, 2016) and a discoloration of nori (Japan Fisheries cooperative, 2004).

Isahaya Bay is located in the western part of Ariake Sea. The Isahaya Bay reclamation project involves the reclamation of parts of the Isahaya Bay tidal flats using a double dike system (Fig. 1). The outer dam closes off the inner 1/3 of Isahaya Bay, totaling 3550 ha, and the inner one encloses the reclaimed land, which is 672 ha in total. The outer dam is a 7-km-long sea dike with a 200-m-wide northern gate and a 50-m-wide southern gate. The objectives of the Isahaya Bay reclamation project are to (1) prevent flooding due to high tides and provide easy daily drainage of the excess water from the rice paddies around the bay and (2) create a huge, flat and highly productive farmland. The water in the reservoir can be discharged into the sea at low tide because the river water keeps flowing into the regulating reservoir within the sea dike, and the water level is controlled at -1.0 m from the mean sea level. Because the water within the regulating reservoir must be fresh, as it is used for farming, the floodgates are closed to prevent the saline water from flowing into the reservoir at high tide. The project commenced in 1989, the bay was closed off by the sea dike in 1997, and the project was completed in 2008. There has been controversy over whether the project will damage the environment of Ariake Sea. A dispute has recently arisen between the local fishermen and farmers concerning the opening of the floodgates of the dike. The government is caught between two conflicting court decisions, one ordering it to open the floodgates of the dike and the other instructing it to keep them closed.

Therefore, it is an urgent issue to clarify the mechanism of environmental degradation in Ariake Sea and its relationship with the Isahaya Bay reclamation project. In this paper, the environmental deterioration of Ariake Sea, manifested by the frequent occurrence of red tide and hypoxic water, poor harvest of fishery products, and discoloration of nori, is reviewed first. Then, the possible mechanisms of environmental deterioration represented by a decrease in tidal flats, decreases in the tidal amplitude and current, and changes in the sediment environment are analyzed. Subsequently, the possible causes of environmental deterioration, especially the Isahaya Bay reclamation, are discussed. Finally, environmental restoration countermeasures for Ariake Sea are suggested.

2. Recent environmental changes in Ariake Sea

2.1. Increase in red tides

Red tides have occurred more frequently in Ariake Sea. Fig. 2 shows the variation in recorded red tides in the inner parts of Ariake Sea in

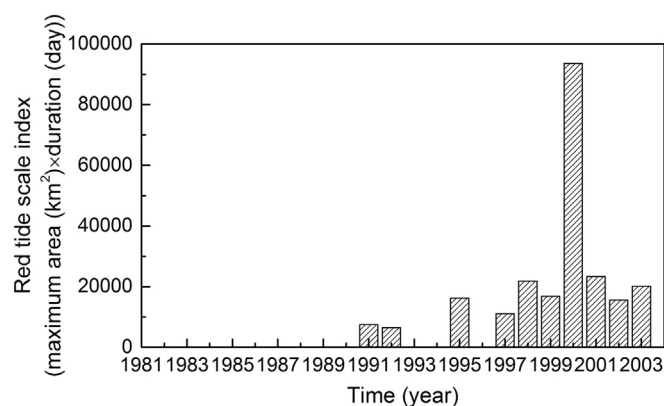


Fig. 2. Variation in the red tide scale index over time in the inner part of Ariake Sea. (Modified from Tsutsumi, 2006.)

autumn from 1981 to 2003 (modified from Tsutsumi, 2006). The “red tide scale index” is calculated as the maximum area of red tide multiplied by the duration of the red tide. In the figure, only the massive red tides with a red tide scale index of more than 5000 are plotted. It can be seen that in autumn in the inner parts of Ariake Sea, there were no massive red tides before 1991. From 1991 to 1997, four massive red tides occurred, with red tide scale indexes of 6449 to 16,200. Since 1998, massive red tides have occurred every year, and the scale of red tides has increased, with the red tide scale index ranging from 15,550 to 93,610.

Fig. 3 shows the variation in the annual occurrence of red tide in Ariake Sea (modified from the Commission for the Assessment of Comprehensive Research on Ariake Sea and Yatsushiro Sea, 2017). The number of occurrences of red tide in Ariake Sea has increased since 1998. The average number of occurrences of red tide from 2000 to 2015 (35.6 times per year) was approximately two times that from 1984 to 1999 (17.3 times per year). Red tide is generally defined as the coloration of the surface water due to the plankton bloom. However, since 1998–2000, cases without coloration of the surface water were also treated as red tide when there were damage to the fisheries (especially Nori farming) due to plankton blooms (Commission for the Assessment of Comprehensive Research on Ariake Sea and Yatsushiro Sea, 2017). Therefore, the number of annual occurrences of red tide in Ariake Sea may have been overestimated after 1998–2000. The red tide occurrence data should be compared with other data, such as those for chlorophyll a , plankton biomass, chemical oxygen demand (COD) and nutrient concentrations, to systematically investigate the reason for and analyze the mechanism of environmental deterioration in Ariake Sea, such as the discoloration of nori.

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