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Mechanisms leading to the decline in Pacific oyster seedlings in Matsushima Bay, Japan

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Introduction

The Pacific oyster *Crassostrea gigas* is an important bivalve for the aquaculture industry in Japan [1]. Miyagi Prefecture, located in the Tohoku region of Japan on the Pacific coast, has the largest production of oyster spat in Japan. Matsushima Bay, located in central Miyagi Prefecture, is a key area for the production of oyster seedlings.

The Tohoku earthquake and subsequent major tsunami off the Pacific coast of Japan on March 11, 2011 caused extensive damage to the coastal area [2]. Although the majority of mature oyster culture beds were lost in and around the bay as a result of the tsunami, 57% and 114% of the typical oyster seedling yield were collected in the bay in 2011 and 2012, respectively [3]. However, in 2013, the density of pre-attachment stage larvae was lower than in past years and seedling collection was characterized by an unusually low yield (34% of a typical yield). In this study, we elucidate the mechanism(s) leading to the low oyster seedling yields in Matsushima Bay in 2013, and focus specifically on the role of hydrographic conditions in the bay.

Materials and methods

Temperature and salinity at 0 m depth and 0.5 m above the seafloor at 18 stations in Matsushima Bay were obtained every 1 or 2 months in 2009–2014. The vertical distributions of temperature and salinity were measured both in and immediately outside the bay in 2013–2015. Oyster larvae were collected in 2011–2016. A Kitahara plankton net was hauled vertically from 2.5 m depth to the sea surface. Larvae with shell heights of <250 and ≥250 μm were classified as early stage and pre-attachment stage, respectively. Mooring systems with an electric current meter and a temperature-salinity sensor were deployed from June to September in 2014–2016.

Results

Early stage larval density was relatively high in 2013 compared with other years. Pre-attachment stage larval density of >10 individuals m^{-3} occurred at least once between mid-July and mid-August in 2008–2012 (Fig. 1). In contrast, in 2013, only 0.1–0.6 individuals m^{-3} were observed from mid-July to mid-August. Although higher densities of early stage larvae occurred in 2013 compared with previous years, pre-attachment stage larvae were rare. These results indicate that the early

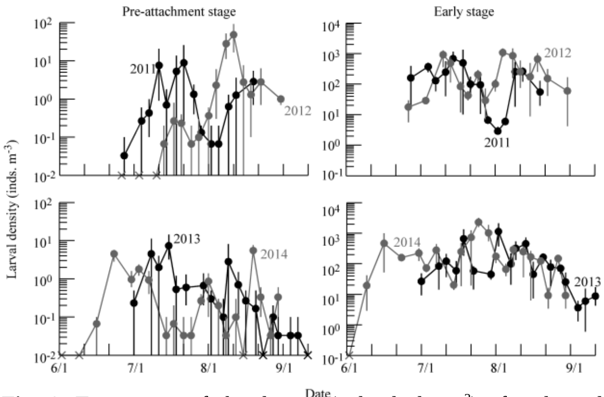

Fig. 1. Time series of the density (individuals m^{-3}) of early and pre-attachment and early stage larvae from 2008 to 2014. Circles and bars indicate the averages and ranges of observed density for each observation, respectively. Crosses indicate absence of larvae.

stage larvae abruptly decreased in number before they reached the pre-attachment stage.

The salinity ranges in the bay in August 2013 were 6.8–24.9, which was lower than in other years. The salinity range in July of 2013 was 20.8–29.4, indicating that a large inflow of freshwater into Matsushima Bay occurred between July 4 and August 1, 2013 (Fig. 2). The integrated precipitation in the catchment area of Matsushima Bay from July 15 to 31, 2013 was 196 mm and was the third highest amount since 1976, and was responsible for the low-salinity water distribution in the bay.

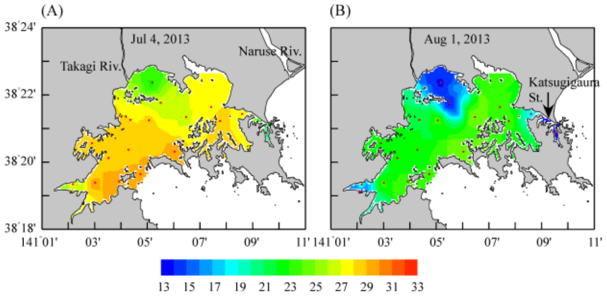

Fig. 2. Horizontal distributions of salinity at 0 m depth in (A) July 4 and (B) August 1, 2013. Dots indicate the stations where salinity was measured.

The time series of the vertical distribution of driving force *D* in the Kaneshima Strait was estimated from the density profiles. The value of *D* was almost constantly positive; that is, the direction of the driving force was out of the bay. Higher *D* values were observed from mid-June to mid-August 2013.

Mooring observations conducted in 2015 revealed that freshwater discharged from the Naruse River, which discharges outside Matsushima Bay, flowed into the bay via Katsugigaura strait, which is the nearest strait to the river, and that the freshwater transport increased when the river was flooding. From the box model analysis, during flood events, the salt and water budgets in the bay were maintained by horizontal circulation: inflow occurred mainly via Katsugigaura Strait, and outflow was mainly via other straits.

Discussion

In August 2013, when there was an exceptionally low oyster seedling yield in Matsushima Bay, pre-attachment stage larvae were rare despite the density of early stage larvae being higher than in previous years. The sea surface salinity was unusually low in August 2013, which generated a strong outward driving force. Therefore, we propose that early stage oyster larvae were transported out of the bay in the outflow driven by low-density (salinity) water before they reached the pre-attachment stage.

The low-salinity water distribution was formed by both the direct input of precipitation via the catchment area of the bay and the freshwater input derived from the river outside the bay. The latter is especially important to the formation of the outflow of the bay, which induces the outflow of oyster larvae. The magnitude of the freshwater input derived from the river is considered to have increased after the 2011 Tohoku earthquake and tsunami because the topography of the strait was changed by the disaster; a sandy beach and a shallow seashore that had previously existed disappeared as a result of the disaster (Fig. 3). Details are described in Kakehi et al. (2016) [4] and Kakehi et al. (2017) [5]

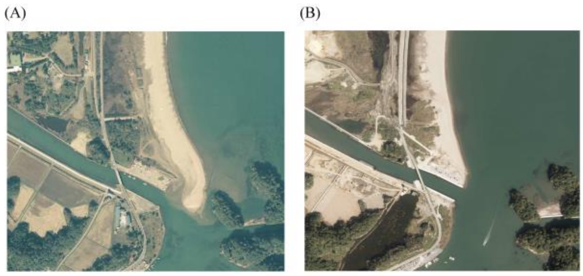

Fig. 3. Aerial photographs showing the topography (A) before (October 31, 2006) and (B) after (October 14, 2013) the 2011 Tohoku earthquake and subsequent major tsunami. The photographs were obtained from the Geospatial Information Authority of Japan (http://mapps.gsi.go.jp/maplibSearch.do#1).

Acknowledgements

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