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Estuarine morphology recovery after the 2011 Great East Japan earthquake tsunami

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ABSTRACT

The 2011 Great East Japan Tsunami caused severe morphological changes along the affected coastline on the northeast part of Japan. This study investigates the recovery of river mouths and breaching of sandy coast at the place used to be river mouth in Miyagi Prefecture, Japan after severe erosion induced by the tsunami through analyzing aerial photograph and investigating field data. After several years since the tsunami took place, the morphology of some river mouths has mostly recovered while others still have some damage. Results on the analysis of aerial photograph clearly indicate that the total length of sandy coast on both sides of river mouth plays important role in the recovery process. Moreover, the relevant phenomenon occurring during the morphological recovery process is also investigated. The findings demonstrated the intrusion of sand spit into river mouths due to the tsunami having scoured river mouth deeper than the depth of closure. Interestingly, the intrusion distance was found to be positively correlated with the width of river mouth. In addition, there is an important finding on the practical problem which is related to the intrusion upstream of sand spit. That intrusion shifts the boundary of fresh-sea water upstream, therefore external wave forces must be considered when implementing the design of river structures.

1. Introduction

On March 11, 2011, the Great East Japan earthquake tsunami swept large areas on the coast along Iwate, Miyagi, and Fukushima Prefectures. In addition to devastating damages of infrastructure, the tsunami also resulted in significant changes in coastal and estuarine morphology in the northeastern part of Japan.

Before the 2011 tsunami occasion, there had been the 2004 Indian Ocean tsunami which was of almost the same magnitude and also resulted in a heavy damage. The significant changes and recovery process of the coastal and estuarine morphology of the affected areas in Indonesia, Thailand, and Sri Lanka were the topics of studies such as Ali and Narayana (2015); Choowong et al. (2009); Liew et al. (2010) and Koiwa et al. (2017). These studies investigated the damages and the recovery of coastal area after the tsunami based on average resolution satellite images (yearly or longer interval) and field observation data. In addition, some other works on the change of bathymetry and sediment transportation induce by the tsunami waves have been done (e.g., Wijetunge, 2009; Goto et al., 2011). After the 2011 tsunami event, there have been studies on the damages and recovery process of morphology in Sendai Bay area such as Tanaka et al. (2012, 2014a); Tappin et al. (2012) and Udo et al. (2012). Among them, Tanaka et al. (2012) detailed the significant changes of coastal and riverine morphology in Miyagi Prefecture such as erosion of sandy beaches, disappearance of sand barrier in front lagoon, flushing of sand spit in front of these river mouth and the breaching of sandy beach at the location of old river mouth. In addition, the subsequent recovery in the early stage has also been discussed. Besides that, there have been many studies based on field survey data and numerical modeling to report the changes of morphology relating to landward/seaward sediment deposition induced by the 2011 tsunami (e.g., Sugawara and Goto, 2012; Goto et al., 2014a, 2014b; Udo et al., 2015;). These studies provide more information and connection to the alongshore morphological changes and recovery process.

Six years has passed since the tsunami occurrence, the damages of morphology after such huge tsunami at the river mouths of many areas are still remnant, while at some other river mouths morphology has largely recovered. The occurrence frequency of such 2011 tsunami is extremely low. Therefore, findings on the recovery of riverine morphology and relevant phenomenon are not only important for coastal

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Fig. 1. Location map of the study areas.

Table 1
Summary of river characteristics.

River name	River class*	River length (km)	Catchment area (km^2)	River mouth structure
Kitakami	A	249	10,150	no structure
Naruse	A	89	1133	2 jetties
Nanakita	B	45	229	1 jetty
Natori	A	55	933	2 jetties
Abukuma	A	239	5400	no structure
Arahama	breaching of sandy coast			old river mouth
Akaiko	breaching of sandy coast			old river mouth

* Class A: managed by the national government.
Class B: managed by the prefectural government.

and riverine management in short-term or long-term periods but also very useful for many other activities such as navigation, fishery, river mouth environmental concerns especially the ones adjacent to the lagoon.

Accordingly, this study attempts to present the recovery of morphology at the river mouths and breaching of sandy coast at the old river mouth in Miyagi Prefecture, and the relevant phenomenon, that followed the recovery process, is also evaluated through analysis of aerial photograph and field observation data.

2. Study areas and data collection

Although the tsunami caused severe damages to the northeast coast of Japan, this study only focuses on the recovery process of the estuarine morphology in Miyagi Prefecture (Fig. 1) where the tsunami inundation was reported up to 19.5 m (Mori et al., 2011).

The recovery of morphology at five river mouths (the Kitakami, Naruse, Nanakita, Natori, and Abukuma) and at two sandy coast breaching (Arahama and Akaiko) in order from north to south is investigated.

The rivers in Japan are classified into Class A and Class B depending on their dimension and importance for land conservation and national economy. Class A rivers are managed by the national government, while Class B rivers are under management of the prefectural government. The characteristics of the first four river mouths listed in Table 1 were described in term of river class, river length, catchment area, and river mouth structures by Tanaka et al. (2012). This study supplements the characteristics of the Abukuma River and two breaching.

Breaching of two sandy coasts, Arahama and Akaiko, which were formed by the incident tsunami waves and return flows at the locations of river mouths, were also taken as the study areas. Although these areas were not initially river mouths, the breaching of sandy coast made them temporarily converting to river mouth or lagoon.

Another river mouth, Mogami River mouth, which was not subjected to the tsunami damages, is also taken into account for the comparative study on the intrusion of sand spit into river mouth. Mogami River is a river in Yamagata Prefecture which borders the west side of Miyagi Prefecture (Fig. 1). It is about 224 km in length with the river basin of about 7040 km^2. This river pours into the Sea of Japan at Sakata City, Yamagata Prefecture. The sand spit started to intrude upstream after the construction of jetties at the river mouth.

In order to achieve the objectives of the study, many required data sets including the series of aerial photographs and bathymetry of river mouth were collected. Aerial photographs of the study area, especially for the areas of the Nanakita, Natori River mouths, and Arahama breaching were being taken frequently in every one or two months before and after the tsunami. Besides, many sets of aerial photographs of the study areas were also collected from other sources such as