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Effect of the 2011 Tohoku Earthquake on deep-sea meiofaunal assemblages inhabiting the landward slope of the Japan Trench

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ABSTRACT

Meiofaunal assemblages inhabiting the landward slope of the Japan Trench (water depth, 120–5600 m) were examined 4.5 months and 1.5 years after the 2011 Tohoku Earthquake off Sanriku, Miyagi Prefecture, northeast Japan. Two key parameters were compared before (24–30 years) and after (4.5 months in 2011 and 1.5 years in 2012) the earthquake: (a) the bathymetric pattern and (b) the vertical distribution of meiofauna in the sediments. Differences in meiofaunal densities and associated bathymetric patterns were not detected before and after the earthquake. However, the vertical profiles of meiofauna in the sediments differed at some stations. The highest meiofaunal densities occurred in the subsurface layers in 2011 at some stations, with these subsurface peaks being no longer present in 2012. At these stations, the assemblage structure at the higher taxon level differed between 2011 and 2012, with copepod density increasing in 2012. Therefore, copepod abundance appeared to decrease because of the effect of earthquake-related events (e.g. rapid sedimentation induced by the turbidity current). These changes in meiofaunal vertical profiles and assemblage structures detected after the earthquake were probably caused by an increase in organic matter content in the topmost layers. These results indicate that major disturbances to deep-sea sediments mainly influenced the vertical distribution and assemblage structure of meiofauna after the 2011 Tohoku Earthquake, whereas meiofaunal densities remained similar or quickly recovered within 4.5 months of the event.

1. Introduction

On 11 March 2011, an earthquake termed 'the 2011 off the Pacific coast of Tohoku Earthquake (M9.0)' occurred near Miyagi Prefecture, northeast Japan. Aftershocks caused by this earthquake were distributed across the Japan Trench, covering an area of about 500 km in length and 200 km in width (Asano et al., 2011). In addition, the fault rupture created during this earthquake reached the axis of the Japan Trench (Kodaira et al., 2012), with the earthquake causing the sea floor of the landward slope of the trench to move >50 m horizontally towards the trench axis and 10 m upward (Fujiwara et al., 2011). These movements would have induced turbidity currents. In fact, sedimentation caused by such turbidity currents was documented over an extensive area on the landward slope of the Japan Trench (Ikehara et al., 2011; Arai et al., 2013). Therefore, the 2011 Tohoku Earthquake probably impacted both shallow-water (e.g. Kanaya et al., 2012; Seike et al., 2013; Urabe et al., 2013) and deep-sea ecosystems. However, the generated turbidity would have mixed with short-term bioturbation processes over time.

Meiofauna are usually defined as benthic animals that pass through a 500–1000 μm sieve and are retained on a 32–63 μm sieve. They are recognized as biodeformers of the original stratigraphic record (Cullen, 1973; Ekdale et al., 1984), with this process being termed cryptobioturbation (Pike et al., 2001; Pemberton et al., 2008; Greene et al., 2012). The density and biomass of meiofauna exceed those of megafauna and macrofauna in the deep-sea environment (e.g. Rex et al., 2006; Wei et al., 2010). In addition, meiofauna influence major ecological processes, such as nutrient cycling and sediment stability (Snelgrove et al., 1997). Therefore, the pattern of meiofaunal distribution in the sediments after earthquake activity might serve as an indicator of the rate of recovery of the seafloor environment. For instance, several studies assessed the recovery of meiofaunal assemblages in shallow water environments after the 2004 Indian Ocean tsunami (Altaff et al., 2005; Kotwicki and Szczuciński, 2006; Grzelak et al., 2009). However, similar research has not been performed for the deep-sea environment.

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In this study, we evaluated the effect of large-scale disturbance on the deep-sea benthic assemblages inhabiting the landward slope of the Japan Trench. Shirayama and Kojima (1994) investigated the meiofaunal assemblages in this region in 1981, 1985 and 1987. Here, we assumed that the data collected by Shirayama and Kojima (1994) presented the conditions before the earthquake, allowing us to compare the meiofaunal assemblages before (24–30 years) and immediately after (4.5 months and 1.5 years) the event. We primarily focused on addressing the following three questions:

(1) Did the meiofaunal density change after the earthquake compared to before the earthquake? If so, did meiofaunal density recover within the 1.5 year period following the earthquake? Before the earthquake, meiofaunal density was documented to decrease with increasing water depth down to 1500 m, after which it stabilized (Shirayama and Kojima, 1994). Here, we examined whether the bathymetric pattern of meiofaunal density changed after the earthquake.
(2) Did the vertical distribution of meiofauna change after the earthquake compared to before the earthquake? In general, meiofauna aggregate in the topmost layers of deep-sea sediments (Shirayama, 1984; Itoh et al., 2011), as found in some stations before the earthquake (Shirayama and Kojima, 1994). Here, we examined whether this 'general pattern' was maintained or changed within a 1.5 year period of the earthquake.
(3) Did the assemblage structure of higher meiofaunal taxa level change after the earthquake? If so, which taxon caused the change in assemblage structure 4.5 months and 1.5 years after the earthquake? In addition, which environmental variable caused this change?

2. Materials and methods

2.1. Sampling and sample processing

Meiofaunal samples were collected at 14 stations on the landward slope of the Japan Trench off Sanriku during 3 cruises (Fig. 1; Table 1). Two cruises were conducted from late July to early August 2011 (4.5 months after the 2011 Tohoku Earthquake); specifically the KT11-17 cruise of the R.V. *Tansei Maru* and the YK11-E06 cruise of the R.V. *Yokosuka*. The third cruise, KT12-18 of the R.V. *Tansei Maru*, was conducted in late July 2012 (1.5 years after the earthquake). Samples were collected from the same locations during the KT11-17 and KT12-18 cruises in 2011 and 2012, respectively (Table 1). Sediment samples at 12 stations were collected using a multiple corer (Barnett et al., 1984; Table 1), which collects up to 8 sediment cores simultaneously. Each core covers 52.8 cm^2 of seafloor surface area. One multiple corer deployment was conducted at each station (except for St. 11 in 2011), with 3 cores per deployment being used for the meiofaunal analysis because of limited ship time and high demand for cores. The 3 cores were treated as pseudo-replicates, since different cores from the same deployment do not meet the criteria of random sampling (Hurlbert, 1984), with mean densities being assumed to be representative for each station. In 2011, two multiple corer deployments were conducted at St. 11, of which 1 was used in this study (referred to as St. 11A). Sediment samples at 2 stations (Stns 4 and 2) during the YK11-E06 cruise were collected using a push corer (covering 52.8 cm^2 seafloor surface area), which was operated by the manipulator of the manned submersible *Shinkai 6500*. One core from each station was used for the meiofaunal analysis.

On the ship, core samples were sliced horizontally into 0–0.5, 0.5–1, 1–2, 2–3 and 3–5 cm layers for the KT11-17 and KT12-18 samples and 0–0.5, 0.5–1, 1–1.5, 1.5–2, 2–2.5, 2.5–3, 3–4 and 4–5 cm layers for the YK11-E06 samples. Within a few hours of collection, the samples were fixed and separately preserved in 5% buffered seawater formalin and were stained with Rose Bengal (final concentration, 0.05 g/L). At Stn 4, the entire sediment sample was used for the meiofaunal analysis. However, at all other stations, half of the sediment samples were used, with the samples being quantitatively divided with a plankton splitter (Table 1).

In the laboratory, all of the sediment samples were treated according to the procedure described by Danovaro (2010). The samples were passed through a 1 mm mesh sieve (0.5 mm mesh sieve for the KT12-18 sample) and retained on a 63 μm mesh sieve. The sediment that remained on the latter mesh sieve was resuspended and centrifuged for 10 min 3 times at 3000 rpm with colloidal silica (Ludox HS40, Sigma-Aldrich). The supernatants were transferred to flat-bottomed petri dishes. Rose Bengal-stained organisms were then collected using an Irwin loop (Westheide and Purschke, 1988), sorted into higher taxa and counted under a binocular stereoscopic microscope. The

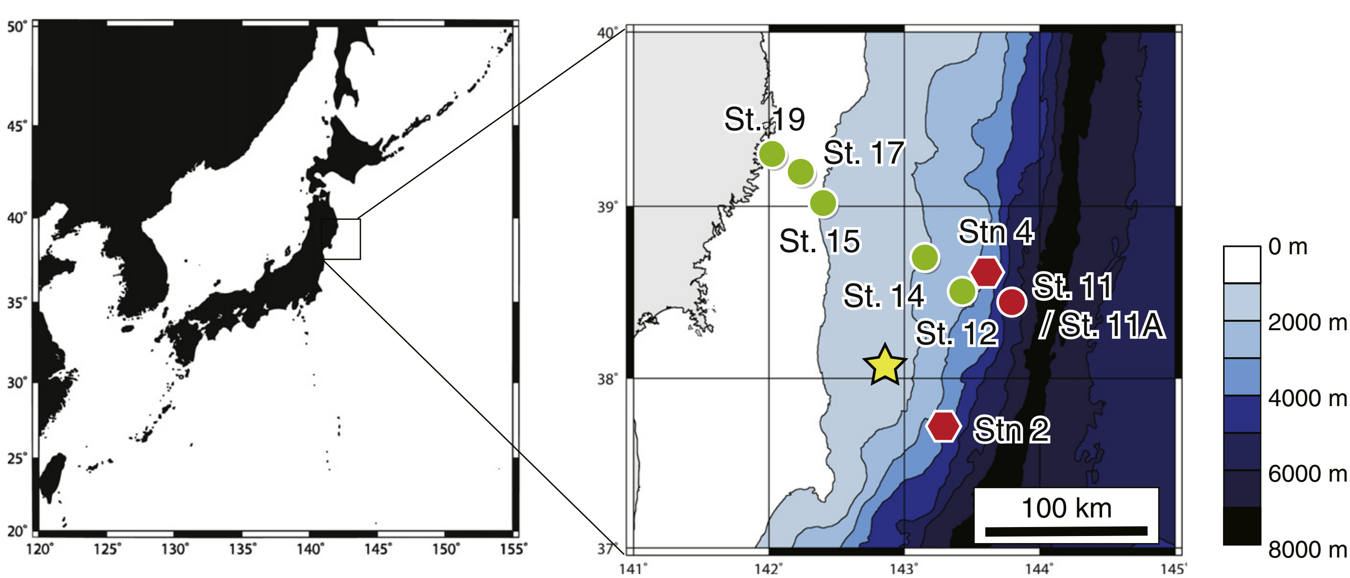

Fig. 1. Sampling stations on the landward slope of the Japan Trench off Sanriku, northeast Japan. The star indicates the epicenter of the 2011 Tohoku Earthquake. Circle symbols indicate the stations where samples were collected during the KT11-17 and KT12–18 cruises. Hexagonal symbols indicate where samples were collected during the YK11-E06 cruise. Green fill indicates the stations for which data was available from 24–30 years before the earthquake (Shirayama and Kojima, 1994).