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Changes in abundance and composition of anthropogenic marine debris on the continental slope off the Pacific coast of northern Japan, after the March 2011 Tohoku earthquake

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ABSTRACT

Abundance and composition of anthropogenic marine debris were assessed on the basis of six bottom trawl surveys conducted on the continental slope off Iwate Prefecture, Pacific coast of northern Japan, in 2003, 2004 and 2011, and the temporal changes due to the Tohoku earthquake and tsunami in March 2011 evaluated. In 2003 and 2004, 54–94 items km^{-2} of marine debris, dominated by sea-base sourced items mainly comprising fishing gear and related items from adjacent fishing grounds on the continental shelf, were quantified. In the post-earthquake period, the density increased drastically to 233–332 items km^{-2}, due to an increase in land-base sourced items generated by the tsunami. However, a major increase in abundance after the disaster, compared to the total amount of tsunami debris swept into the sea, was not found. Additional sources of land-based debris from the adjacent continental shelf are suggested in the present waters.

1. Introduction

The National Academy of Sciences (1975) recognized marine debris as persistent materials of human origin, either discarded at sea or reaching the oceans through other avenues. Such anthropogenic debris, washed ashore on beaches (Pruter, 1987; Ribic et al., 1997), floating in the world's oceans (Day and Shaw, 1987) or occurring on the seafloor (Feder et al., 1978; Galgani et al., 1995, 1996; Moore and Allen, 2000; Lee et al., 2006), can be divided into that derived from sea-based or land-based sources, originating from fisheries, ships, pleasure crafts and aquaculture activities, and urban populations (Backhurst and Cole, 2000; Lee et al., 2006; Hinojosa and Thiel, 2009). Efforts to address concerns about marine debris have focused primarily on monitoring surveys and clean-up of the sea surface, shorelines and seafloor areas accessible to snorkelers (Watters et al., 2010). For deeper waters, abundance and composition of benthic debris have been assessed mainly using bottom trawl survey or echo data using acoustic devices in various fishing or non-fishing areas of Mediterranean, Bering, Pacific and Atlantic waters (Jewett, 1976; Feder et al., 1978; Bingel et al., 1987; June, 1990; Galgani et al., 1995, 1996; Hess et al., 1999; Stefatos et al., 1999; Backhurst and Cole, 2000; Galgani et al., 2000; Moore and Allen, 2000; Stevens et al., 2000; Acha et al., 2003; Kuriyama et al., 2003; Ohtomi et al., 2004; Lee et al., 2006). Studies on the abundance and distribution of deep water benthic debris were reviewed and applied in Spengler and Costa (2008), and subsequent studies based on bottom trawls and visual observations using video have increased as standard methods of large scale assessments covering extensive geographic areas (Keller et al., 2010; Ramirez-Llodra et al., 2011, 2013; Pham et al., 2013, 2014; Debrot et al., 2014; Vieira et al., 2014).

The Tohoku earthquake (magnitude 9.0) hit northeastern Japan on March 11, 2011. It triggered a massive tsunami, which impacted the Pacific coast of Japan from Hokkaido to Okinawa (UNEP, 2012), reaching a height of 40.5 m at Miyako, one of the most affected areas (Mori et al., 2011; UNEP, 2012). The tsunami inundated an area of about 561 km^2 (Geospacial Information Authority, 2011) and swept away an estimated five million tonnes of debris, including wood, sediment, plastics, industrial materials and various structural components (Ministry of Environment, Japanese Agency, 2012). Approximately 70% of the debris sank to the seabed off the coast in the immediate aftermath of the disaster (Ministry of Environment, Japanese Agency, 2012). Other debris was propelled by wind and currents into the Kuroshio-Oyashio Extension (KOE) region over the continental shelf (Bagulayan et al., 2012). The areas of floating debris have been well evaluated on the basis

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of satellite images and mathematical simulation models of water currents and winds (IPRC, 2011; Bagulayan et al., 2012; Lebreton et al., 2012; Lebreton and Borrero, 2013). Some of the drifting debris is thought to have gradually sunk and accumulated on the seafloor far from the coast (Bagulayan et al., 2012; Lebreton and Borrero, 2013). Although debris accumulated on seafloor might negatively affect not only benthic marine ecosystems but also fishing operations (Nash, 1992; Katsanevakis et al., 2007), the distribution and volume of the former are poorly known due to the difficulty of making quantitative assessments for widespread areas, although some fragmentary assessments have been made based on surveys using ROV and acoustic devices (Miyake et al., 2011; Japan Agency for Marine-Earth Science and Technology, 2013a,b). In Iwate and Miyagi Prefectures, which suffered the greatest damage to coastal fisheries due to the tsunami, a project to remove underwater marine debris from the fishing grounds has been conducted since 2011, utilizing commercial fishing vessels equipped for bottom trawl or seine net fisheries (Yamaoka, 2013). However, temporal fluctuations in the quantity and composition of post-tsunami debris and current status remain unknown to date.

The present study carried out an assessment of the abundance and composition of anthropogenic marine debris on the continental slope off Iwate, Pacific coast of northern Japan, on the basis of bottom trawl surveys conducted both before and after the Tohoku earthquake. The goal of this study was to evaluate temporal changes in seafloor marine debris on bottom trawl fishing grounds close to the areas most impacted by the tsunami.

2. Materials and methods

In this study, seafloor anthropogenic marine debris were collected from bottom trawl surveys carried out by the *R/V Iwate-maru* to assess demersal fish stocks, e.g., walleye Pollock (*Gadus chalcogramma*), Pacific cod (*Gadus macrocephalus*) and rockfish (*Sebastolobus macrochir*), off Iwate Prefecture, Pacific coast of northern Japan, in 2003, 2004 and 2011. The surveys were conducted on the upper continental slope ranging from 183 m to 521 m depth, between 39°N and 40°10′N (Fig. 1). Two survey programs were conducted per year, in April–June and November, May and November, and June and November in 2003, 2004 and 2011, respectively. Samples were collected using an otter trawl net with the following structural components and dimensions: stainless steel otter board, footrope composed of rubber bobbins and chain, 11.7 m opening width, 12.5 m body length and 4.0 cm cod-end mesh (Nichimo *co Ltd.*). Each tow was conducted for a period of 30 min from the contact of the foot-rope on the seafloor, the swept area (km^2) being calculated on the basis of the net opening width and towing distance recorded by SCANMAR sensors (Simrad *co Ltd.*) and a GPS tracking device (Nihon-musen *co Ltd.*). Anthropogenic marine debris collected was categorized as having originated from sea-based or land-based sources (UNEP, 2005; Macfadyen et al., 2009), and included fishing gear and items for fishery or vessel activities (i.e., waterproof wear, gloves and boots, ropes and metal oil cans), and plastic bags, plastic bottles, plastic pieces, metal beverage cans, metal pieces, glass bottles, clothing and "other items", respectively.

The debris collected was counted and weighed (kg) on board. To assess debris distribution, CPUE was calculated as mean density of debris for two bathymetrical strata, comprising shallower (<300 m) and deeper (⩾300 m) strata, for northern (area N) and southern (area S) areas, extending from 39°N to 39°30′N and 39°30′N to 40°10′N, respectively. Frequency of occurrence (*FO*: %) was calculated as follows: $FO = Nd \cdot N^{-1} \cdot 100$, where Nd and N are the number of tows with marine debris and the total number of tows, respectively. CPUE (items km^{-2}: Ribic et al., 1992) was calculated as follows: $\text{CPUE}_i = n_i \cdot A_i{}^{-1} \cdot F_i{}^{-1}$, where n_i, A_i and F_i are the number of debris items, towed area (km^2), and relative fishing power, respectively, for site i. In this study, F was taken as 1.0 (Ribic et al., 1992). Mean CPUE was calculated as follows: $\text{meanCPUE}_k = \overline{\text{CPUE}}_k = \frac{\sum_{k=1}^{N}(\text{CPUE}_k)}{N}$, where N is the number of tows at site k. Variance of CPUE (*var* CPUE) within each area (Ribic et al., 1992) was calculated as follows: $var\ \text{CPUE} = \frac{\sum_{i=1}^{N}\left(\text{CPUE}_i - \overline{\text{CPUE}}\right)^2}{N(N-1)}$, where N is the number of tows in each area. In this study, abundance of marine debris was assessed only on the basis of number of items collected, since debris weight, sometimes utilized as an index of

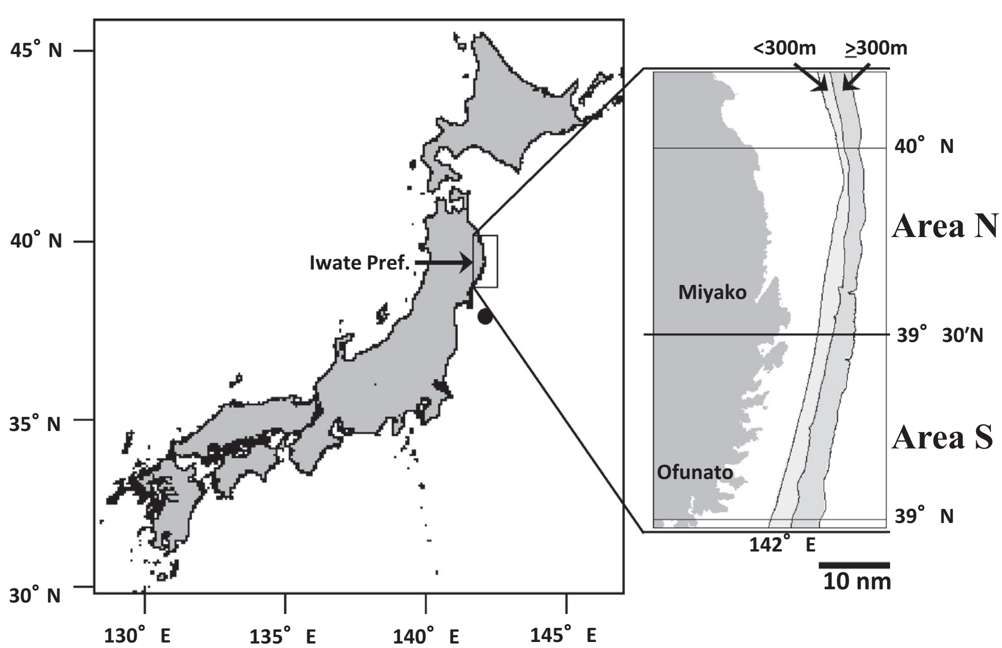

Fig. 1. Location of six bottom trawl surveys from April 2003 to November 2011 conducted on the upper continental slope off northeastern Japan, showing two bathymetric strata ("<300 m" and "⩾300 m" in depth) and areas N (39°30′–40°10′N) and S (39°00′N –39°30′N). ● Epicenter of Tohoku earthquake.