
Distribution of the Marine Debris on Seafloor from the Primary Report of Five Cruises After the Great East Japan Earthquake 2011

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Abstract

The Tohoku Ecosystem-Associated Marine Science (TEAMS) project started from 2011 with the aim of revealing the impacts of the 2011 tsunami and to assess the present state of the marine ecosystem in affected areas over time during the next decade. TEAMS collected various data such as bathymetry, geography, oceanography, benthos, and tsunami debris not only from our project but also from the archived data at our respective institutes and in public databases. Integration of data and creation of habitat maps are expected to contribute to our understanding of the effects of large tsunamis, present the status of marine biodiversity in the area, and lead to the identification of key areas for ensuring ecosystem resilience. Here we focus on information of marine debris identified from deep-sea images and sonar data. We conducted data integration and collated information in a GIS database.

Our preliminary results suggest that the impact of the tsunami debris in deep-sea areas (ca. 200–500 m) was not as severe as in coastal environments. Accumulations of tsunami debris were found mainly in submarine canyons. Although different types of debris occur so far in mixed aggregations, differences in the movement and decomposition patterns of these different materials are expected to lead to both positive and negative effects on the environment in different ways.

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1 Introduction

The Great East Japan Earthquake 2011 (2011 Tohoku-Oki Earthquake) occurred on the 11th of March 2011. After the earthquake, tsunami waves washed over the Pacific side of the Tohoku area – the northern part of the main island of Japan. Tsunamis destroyed many coastal towns, even those protected by seawalls of 10 m in height, and damaged and disabled a nuclear power plant as well. The Japanese government directed efforts to help the area recover from earthquake and tsunami damage, and several programs were conducted in terrestrial areas. During this time, surveys of marine ecosystems were conducted separately.

An initiative called the Tohoku Ecosystem-Associated Marine Science (TEAMS) project was launched at the end of the fiscal year 2011 with the support of the Ministry of Education, Culture, Sports, Science and Technology. The TEAMS project is required to contribute to the following in the ocean areas off Tohoku: (a) elucidate the effects of earthquakes and tsunamis; (b) with a view to assessing recovery, reveal the dynamics of organisms and their environment; (c) suggest fisheries that could be sustainably exploited; and (d) assess the safety of such products in terms of anthropogenic chemical compound content. As part of this project, multidisciplinary surveys of the environmental conditions and state of the ecosystem have been conducted from coastal areas to the continental slope, where fisheries are conducted, in order to assess the effect of earthquakes and tsunamis.

Previous research suggested heavy damage by the earthquake and tsunami in coastal and shallow ocean areas. Large amounts of sedimentation (Goto et al. 2012), increases in marine debris (Shibata et al. 2013), decrease in ground level/seafloor depth (Ozawa et al. 2011), and changes in the distribution of benthic organisms (Seike et al. 2013; Urabe et al. 2013) are considered to be the main changes in the ecosystem. Although extensive research and cleanup activities have been conducted in shallow waters, research results from deep-sea areas are scarce. A few

reports, some sedimentation studies, suggested difficulty in identifying the effects of the earthquake and the tsunami event in the upper part of the deep sea (such as shallower than 750 m) because of bioturbation (Arai et al. 2013). Nonetheless, marine debris is expected to have either positive or negative effects in deep-sea areas (Goto 2012; Ramirez-Llodra et al. 2011).

In the present paper, we introduce preliminary results on the distribution of debris in the datasets collected from deep-sea surveys by TEAMS-related cruises and from archived data from other studies. We focus in particular on the spatial distribution of marine debris and the types of marine debris to assess the positive or negative effects of marine debris originating from the earthquake on ecosystems in the upper part of the deep sea.

2 Methods

2.1 Study Area

The Tohoku offing is located on the northern Pacific side of the main island of Japan and is well-known as a frontal area where the warm, northward-flowing Kuroshio current encounters the cold, southward-flowing Oyashio current. Since 2011, we have surveyed the deep-sea area using a side-scan sonar, deep-tow submersible cameras, and an ROV (remotely operated vehicle) system. The target region for the TEAMS surveys encompassed the area from the coast to the continental slope, and this study focused on the offshore region of Miyagi and Iwate Prefectures. The survey areas and sites are plotted in Fig. 1.

2.2 Data Collection

We examined the data from five different surveys to evaluate quantitatively the occurrence of marine debris in each survey area or along each survey transect. Details of each survey are as follows: towed camera surveys by the 4KC (4,000 m camera deep-tow camera) and YKDT (Yokosuka deep-tow camera) were conducted from May 16

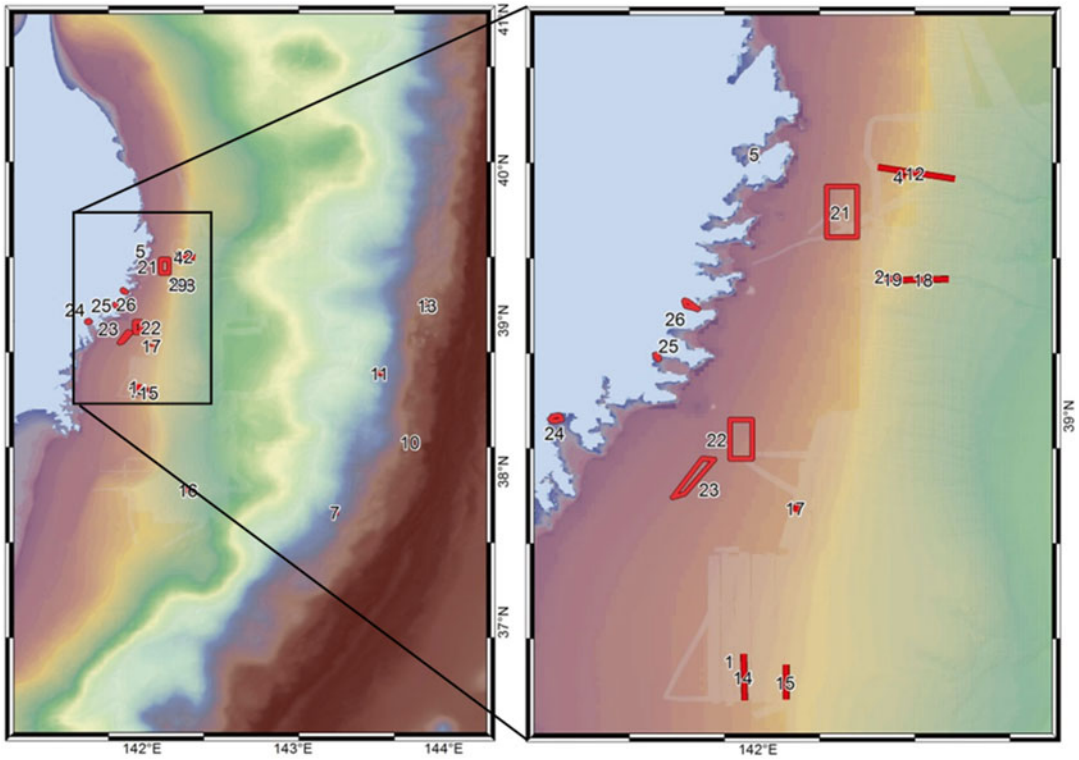


Fig. 1 Location of study sites for research on species and/or marine debris. Site numbers correspond with those in Table 1

to May 20 and July 31 to August 7, 2012. The 4KC was equipped with a Super-HARP (high-gain avalanche rushing photoconductor) video camera recording in NTSC (National Television System Committee specification) format for downward-facing seafloor observations, and this allowed observation of an area of approximately 3×3 m at an altitude of 3 m above the seafloor. The YKDT was equipped with a similar camera configuration but with a less light-sensitive CCD (charge-coupled device) camera and also recording in NTSC format. An ROV (remotely operated vehicle) survey was carried out during June 30 to July 5 in 2013. The ROV *Crambon* was equipped with a pan-tiltable, forward-facing, high-definition (1080i) video camera with a 67° view field angle and with video recorded onto a hard disk cartridge (AJA WZZ-KiPro2400) at ProRes 4:2:2HQ resolution via HD-SDI and saved in QuickTime format (.mov). Video and other data were time-stamped and recorded synchronously

using an Ethernet-enabled logging/playback system based on that developed by Lindsay et al. (2012). We assumed 2 m as the observation width for the calculation of the approximate number of debris items per km^2 . Side-scan sonar (EdgeTech 4200MP, 400/100 kHz) was used to obtain topographic data and marine debris occurrence information. In the case of coastal areas, another side-scan sonar system (System 3000, Klein Inc., 500/100 kHz) was deployed from a fishing boat.

3 Results

The deep-tow camera survey from May 16 to May 20, 2012, revealed a broad distribution of the brittle star *Ophiura sarsii* (Lütken 1855). It was especially dense during transect DT-6C but not during DT-7C (nos. 14 and 15 in Table 1 and Fig. 1). During transects DT-6C to DT-9C, several small items of debris, such as splinters of

Table 1 Survey point information

Cruise no. / platform	ID	Site name	Latitude	Longitude	Depth [m]	Distance from shore [km]	Date	Dive no.	Survey area [km ²]	Survey length [m]
KK-13-1	1	Off Minamisannriku-cho	38.56540	141.95063	289	27.3	2013/6/30	CRM005		267
ROV (<i>Crambon</i>)	2	Off Kamaishi (canyon)	39.24870	142.21763	477	16.9	2013/7/1	CRM006		622
	4	Off Otsuchi (canyon)	39.42470	142.25160	457	13.4	2013/7/2	CRM008		1,660
	5	Yamada Bay	39.46550	141.99539	46	0.7	2013/7/3	CRM009		42
	6	Yamada Bay	39.46580	141.99550	46	0.6	2013/7/3	CRM010		53
YK12_12	7	Bacterial mat site, trench	37.73170	143.28459	3,503	126.6	2012/7/31	YKDT147		3,056
Deep-tow (YKDT)	9	39 N site, Japan Trench	39.10900	143.88912	5,221	132.3	2012/8/2	YKDT148		3,002
	10	Crack site, Japan Trench	38.19850	143.78230	5,665	147.5	2012/8/3	YKDT149		3,816
	11	Animal site, Japan Trench	38.65600	143.57869	3,101	121.4	2012/8/4	YKDT150		2,808
	12	Submarine canyon off Miyako	39.43170	142.28046	551	11.1	2012/8/5	YKDT151		12,008
	13	39 N site, Japan Trench	39.10420	143.89455	5,152	133.3	2012/8/7	YKDT152		1,596
MR12_E2	14	Off Oshika Peninsula	38.53640	141.97525	320	27.6	2012/3/16	DT-6C		8,618
Deep-tow (4KC)	15	Off Oshika Peninsula	38.52760	142.04983	440	32.7	2012/3/17	DT-7C		6,333
	16	Off Sendai Bay	37.88120	142.31117	890	57.5	2012/3/18	DT-8C		3,830
	17	Off Kesenuma	38.83690	142.06783	349	20.5	2012/3/19	DT-9C		1,080
	18	Off Kamaishi (canyon)	39.24240	142.29475	727	19.5	2012/3/20	DT-10C		7,167
	19	Off Kamaishi (canyon)	39.24390	142.24025	567	17.6	2012/3/20	DT-11C		2,257
Chartered ship	21	Off Iwate	39.36259	142.14869	240	7.2	2013/3/12-13		46.0	
Side-scan sonar	22	Off Miyagi	38.95898	141.96978	190	9.8	2013/3/15-17		26.0	
	23	Off Miyagi	38.89315	141.88641	160	12.2	2013/3/15-17		12.0	
Chartered ship	24	Hirota Bay	39.10483	141.82088	15	0.0	2012/7/31-8/2, 8/6-11, 9/3-8		1.5	
Side-scan sonar	25	Okirai Bay	38.99597	141.64145	15	0.2	2012/7/26-30, 9/9-13		0.3	
	26	Tōni Bay	39.19732	141.87830	20	0.3	2012/7/23-25, 9/13-16		1.4	

Depths in bold-type letters were our main study depths

Fig. 2 Accumulated marine debris in a submarine valley (Deep Tow 10C image)



Fig. 3 Cans observed near the trench



wood and plastic bags, were found. During transects DT-10C and DT-11C, near a submarine valley off Iwate, many differently sized items of debris were observed clumped together as shown in Fig. 2.

During the cruise from July 31 to August 7, 2012, marine debris were found at 3000 m depth

in the Japan Trench area, more than 200 km from land, using the YKDT deep-tow camera (nos. 7–13 in Table 1). A fishing net, cans, plastic bags, and sunken wood were scattered over an area of seafloor (Fig. 3). The origin of these debris could not be determined as to whether it was related to the tsunami event or not. At a shallower study site

(depth 551 m, no. 12 in Table 2), we discovered high abundances of invertebrates and fish (such as *Ophiura sarsii*, sea stars, Anguilliformes sp., and *Sebastolobus macrochir* (Günther 1877)) in a submarine canyon area where much debris had accumulated. An extremely large number of the anthomedusan jellyfish *Euphysa japonica* were observed near the seafloor at some stations, but the identity and substrate habitat preferences of its benthic polyp stages have not yet been determined (Lindsay et al. 2008), so an analysis of correlations with debris distributions was not possible at the present time.

During the ROV survey in 2013, high densities of brittle stars were observed at stations 1 and 2 (Table 1 and 2) but not as many occurred at station 4. At station 2, the body sizes of brittle stars were significantly different from those occurring at the other stations. At station 4, we found drag marks made by trawl nets and a lower diversity and population size of macrofauna.

Although the area surveyed by the ROV *Crambon* was limited, detailed information on debris could be collected (Fig. 4). The number of debris items was obviously higher within the bay area (no. 5; the Yamada Bay) on the July of 4th. Eight debris items were observed in an approximately 50×50 m area.

Surveys by side-scan sonar were able to investigate broader areas of the deep-sea floor, although the resolution of acoustic images was lower than that of the video images obtained during the ROV survey (nos. 21 to 23 in Table 2). The acoustic survey off Miyagi found a large debris item of approximately 10–15 m in length (no. 23). In coastal areas, numerous small debris items, mostly less than 1 m in length, were able to be distinguished in the acoustic images (Fig. 5; nos. 24–26 in Table 2).

As shown in Tables 1 and 2, the amount of debris decreased substantially with increasing water depth and/or distance from the coastline. The average number of debris items at the ten main, video-surveyed study sites (1, 2, 4, 12, 14–19) at depths from 289 to 890 m and at distances from 11 to 57 km from the coastline, was 5,195 (standard deviation [SD]=5,133) per km² (Tables 1 and 2). It was 1,116 per km² (SD=961)

at the five sites (7, 9–11, 13) in deeper areas near the trench (>1,000 m depth), which were over 100 km from the coastline. In canyon areas (2, 4, 12, 18, 19), the average number of debris items per km² was 6,761 (SD=3,528), and this was higher than at other areas of similar depth that we studied (mean=3,629, SD=6,381). Of the observed debris categories, “plastics” were most numerous (113), followed by “wood and paper” (85). A large subset of the debris (over 237 items) were unclassifiable.

4 Discussion

Our preliminary results suggest that the direct impact of tsunami-derived debris in deep-sea areas off the Sanriku region (ca. 200–800 m depth) is not as severe as in coastal environments (Seike et al. 2013; Urabe et al. 2013). Accumulations of tsunami-derived debris were found mainly within submarine canyons in deep-sea areas, while in coastal areas the debris was scattered across the seafloor. The transportation power of tsunamis, turbidity currents, and the geomorphological features of the seafloor appear to greatly affect the distribution pattern of marine debris (Arai et al. 2013).

Our observations also showed that different kinds of debris, such as wood, plastics, and construction materials, still occur in mixed aggregations. These debris items accumulate sessile species that need hard substrates on which to attach. This is assumed to be because of the lack of such surfaces on the largely muddy deep-sea floor, as was observed in the canyon area. Different materials are expected to move and decompose in different ways, and the composition of the debris aggregations is therefore expected to change over time due to transportation and decomposition. For example, plastics can be harmful when accidentally ingested (Ramirez-Llodra et al. 2011). Flustering of plastics is also suspected to contribute to the accumulation of harmful substances in organisms, where micro-plastics are known to be a problem (Andrady 2011). In the case of wood or mixtures of wood and fabric materials, such debris attracts

Table 2 Properties of marine debris items extracted by the primary analysis

ID	Site name	Dive no.	No. of debris items	Debris per km ²	Types of debris (%)	Wood, paper	Cans, bottles	Plastics, packages	Steel, concrete	Fabrics, cloth	Nets, cables	Others
1	Off Minamisannriku-cho	CRM005	8	15,009	50	13	13	0	13	0	0	13
2	Off Kamaishi (canyon)	CRM006	7	5,627	29	14	29	0	0	0	0	29
4	Off Otsuchi (canyon)	CRM008	9	2,710	78	0	11	0	0	0	0	11
5	Yamada Bay	CRM009	2	954	0	0	0	0	0	0	100	0
6	Yamada Bay	CRM010	6	2,267	17	17	0	0	33	0	17	17
7	Bacterial mat site	YKDT147	24	2,618	21	4	17	0	8	0	0	50
9	39 N site, Japan Trench	YKDT148	9	999	0	0	33	0	0	0	11	56
10	Crack site, Japan Trench	YKDT149	0	0	-							
11	Animal site, Japan Trench	YKDT150	6	712	50	17	0	0	0	0	0	33
12	Submarine canyon off Miyako	YKDT151	226	6,274	15	12	17	1	2	8	46	
13	39 N site, Japan Trench	YKDT152	6	1,253	33	0	17	0	0	0	0	50
14	Off Oshika peninsula	DT-6C	31	1,199	29	10	0	23	0	3	35	
15	Off Oshika Peninsula	DT-7C	26	1,368	31	0	12	8	8	0	42	
16	Off Sendai Bay	DT-8C	3	261	0	0	33	0	0	0	67	
17	Off Kesennuma	DT-9C	1	309	0	0	0	0	0	0	100	
18	Off Kamaishi (canyon)	DT-10C	146	6,790	6	20	22	4	4	3	41	
19	Off Kamaishi (canyon)	DT-11C	84	12,406	2	19	33	4	15	0	26	
21	Off Iwate		0	0	-							
22	Off Miyagi		0	0	-							
23	Off Miyagi		2	0	Not distinguishable							
24	Hirota Bay		1,148	765	Not distinguishable							
25	Okirai Bay		506	1,687	Not distinguishable							
26	Toni Bay		530	379	Not distinguishable							

IDs of bold-type letters are our main focus

Fig. 4 Wood observed by the ROV

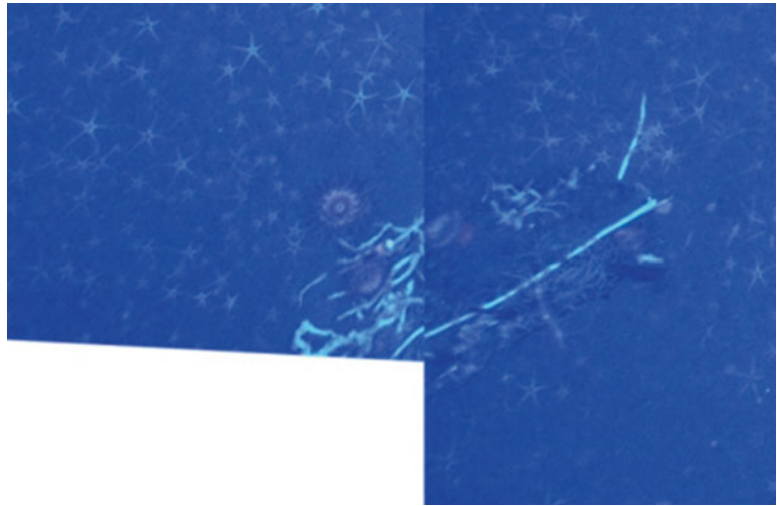
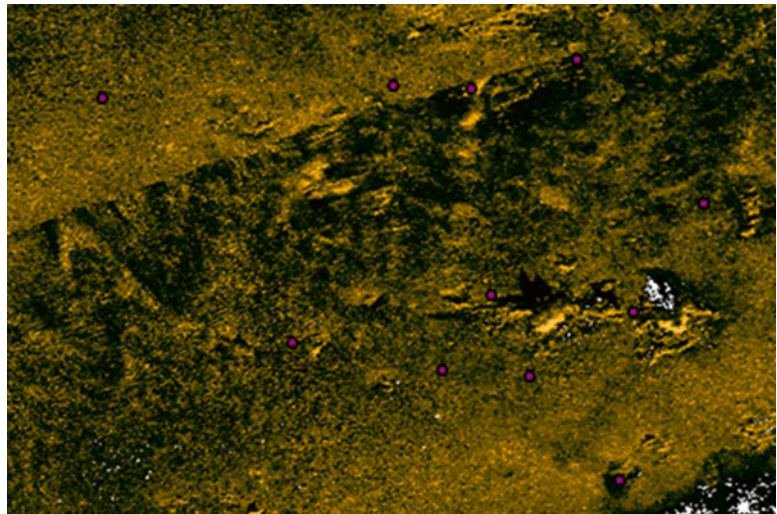


Fig. 5 Marine debris observed by the side-scan sonar



species that can decompose cellulose materials, such as members of the wood-boring mussel subfamily Xylophagidae, which were retrieved in a sample from this area. In the case of nets or wire debris, a negative effect on fisheries has already been reported by Goto (2012). For sustainable fisheries, as a first step the number of ghost fishing nets and plastics of ingestible sizes should be reduced. The next step should be to track the stage/status of flustering in plastics and determine the distribution of various marine debris materials.

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