Fisheries and Oceans Canada Pêches et Océans Canada
Science Sciences
Pacific Region
Canadian Science Advisory Secretariat
Science Response 2012/006

TRANSPORT OF MARINE DEBRIS FROM THE 2011 TŌHOKU TSUNAMI TO THE WEST COAST OF CANADA

Context

On December 9, 2011, Fisheries and Oceans Canada's (DFO) Ocean Sciences Division (OSD) in Pacific Region requested that DFO Science, Pacific Region, provide information and advice regarding the transport of debris to the west coast of Canada from the March 2011 earthquake and tsunami in Japan. This request arose because the OSD has received multiple requests from other federal government departments and agencies, the Province of British Columbia, and the media for information on the timing, location and quantity of debris generated by the earthquake and tsunami that might reach Canadian waters and shorelines. The OSD requested responses to the following:

1. **When and where is debris from the 2011 Tōhoku tsunami expected to reach Canadian waters and shorelines?**
2. **What types of material are expected in the debris and what is the estimated quantity of material likely to enter Canadian waters and/or reach shorelines?**
3. **What monitoring of the debris is occurring while it drifts at sea from a Canadian/international perspective?**
4. **What risks, if any, does this debris pose for species, habitats, and ecosystems in Canadian waters? and,**
5. **What are the potential navigational impacts in Canadian waters?**

This Science Special Response Process (SSRP) was based on existing information on the debris and two independent ocean circulation models of simulating debris movements and drift rates in the North Pacific Ocean, both of which are subject to considerable uncertainty due to the minimal observation and tracking of debris, the diffuse nature of the debris field, and the absence of formal testing of the models. A SSRP was used because DFO Science was asked only to review the information available on the issue rather than data collection methods or the simulation models and their results.

The responses/conclusions of the SSRP are:

1. **When and where is debris from the 2011 Tōhoku tsunami expected to reach Canadian waters and shorelines?** Based on model forecasts, debris from the March 2011 tsunami is expected to begin arriving in waters off North America in 2013 and will likely continue to arrive over a large spatial area from Alaska to California for several years. Most of this debris will consist of small pieces rather than large objects or debris fields owing to the effects of surface currents, winds, and waves. It is important to note that the debris generated by the tsunami will be an addition to the existing debris load floating into Canadian waters and washing ashore in British Columbia every day. Existing patterns of debris deposition on shorelines are not expected to change when debris from the tsunami begins arriving. Since the origin of the most debris washing ashore is not identifiable, the only indicator of tsunami debris may be an increase in the quantity of debris (by weight)

Canada

washing ashore relative to the long-term average. It is unlikely that debris from the tsunami will enter the Strait of Georgia due to surface water properties and currents at the mouth of the Strait of Juan de Fuca.

2. **What types of material are expected in the debris and what is the estimated quantity of material likely to enter Canadian waters and/or reach shorelines?** Both the quantity and composition of tsunami debris expected to reach North America are highly uncertain. Initial estimates of the mass of debris swept into the ocean ranged between 20 and 25 million tonnes. However, an updated estimate from the Government of Japan is that 1.54 million tonnes of tsunami-generated debris remains afloat as of March 2012. Independent confirmation of these figures is lacking at present and the composition of the debris is poorly known. Based on existing knowledge of oceanographic processes and marine debris transport, only the most buoyant and durable objects will survive the trans-Pacific crossing and reach North America. Models used to forecast debris movements show that most of the tsunami debris will remain in the ocean for many years and collect in the North Pacific Garbage Patch. It is unlikely that debris caught in the Garbage Patch will subsequently reach the coast of British Columbia.

3. **What monitoring of the debris is occurring while it drifts at sea from a Canadian/international perspective?** Debris swept into the Pacific Ocean was tracked by satellite for about one month after the tsunami. An attempt to locate debris with high resolution satellite imagery in December 2011 was unsuccessful. In the absence of systematic monitoring of debris by satellites, opportunistic sightings by passing vessels have been compiled and catalogued by the Government of Japan. Shoreline monitoring to collect baseline data on the quantity and composition of marine debris washing ashore in Washington is occurring and may expand to Oregon and California. At present, there is no formal systematic shoreline monitoring program in British Columbia, although some baseline data may be available from annual beach clean-up days coordinated by environmental non-governmental organizations.

4. **What risks, if any, does this debris pose for species, habitats, and ecosystems in Canadian waters?** It is impossible to quantify the risk to marine species, habitats or ecosystems in British Columbia associated with tsunami debris and whether this risk surpasses any thresholds for effects. The baseline risks to marine habitats, species and ecosystems in Canadian waters from the existing marine debris load are poorly understood and documented and as a result the expected incremental increase in risks associated with the arrival of tsunami debris cannot be estimated at present. However, the risks from radioactivity on the debris associated with ^{131}I and ^{137}Cs originating from the Fukushima nuclear plant are believed to be low. Limited testing of tsunami debris collected by a Russian research vessel in September 2011 found that radioactivity levels were below detection limits.

5. **What are the potential navigational impacts in Canadian waters?** Navigational impacts in Canadian waters associated with marine debris are poorly known. The highest risk to navigation is likely related to large objects (e.g., shipping containers, houses, etc.) arriving in coastal waters, but the probability of these objects surviving a trans-Pacific crossing intact is believed to be low. Although drifting nets, ropes and other entangling debris from the tsunami pose a risk, this risk and the resulting impacts are likely incremental increases on the current navigational risks associated with entangling debris. Small objects (e.g., logs or small pieces of wood) are not believed to pose any additional risk to vessel traffic off the west coast of Vancouver Island. Tsunami debris, when it arrives, is unlikely to pose a risk to

vessel traffic in the Straits of Juan de Fuca or Georgia since water properties and current patterns will inhibit the movement of debris into these water bodies.

Although some of the debris from the 2011 Japanese tsunami will eventually reach North America, there remains considerable uncertainty with respect to the quantity and composition of debris still floating, the location of the debris, the pathway of the debris, and the timing and quantity of debris that will arrive. To address these uncertainties, recommendations to update this advice as new information becomes available from other Government agencies and to coordinate monitoring and surveillance are provided.

This Science Response report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat, Regional Science Special Response Process (SSRP) of March 6, 2012 on the Transport of Marine Debris from the 2011 Tōhoku Tsunami to the west coast of Canada.

Background

The magnitude 9.0 mega-thrust earthquake that occurred under the ocean about 70 km off the east coast of Japan on 11 March 2011 generated a tsunami that caused widespread destruction and loss of life in Japan. The tsunami inundated low lying coastal areas of the Tōhoku region of northeast Honshu Island and, in several instances, entire villages were swept away by the surging waters. A large quantity of debris was produced by the tsunami, much of which was swept into the ocean by the retreating waters. This marine debris is presently being transported and dispersed by ocean currents and some of this debris is expected to enter Canadian waters. The following report provides a brief overview of present knowledge regarding the transport of marine debris from the Tōhoku tsunami.

Analysis

Marine debris

The debris that was swept to sea by the tsunami is composed of a very wide variety of objects of different materials and sizes, some as large as entire houses. The actual mass or volume of this material is not known accurately. The Ministry of the Environment of Japan initially estimated that the tsunami produced some 25 million tons of debris, which included both material that remained on land and material that was transported out to sea (NOAA 2012a). The most recent estimates from the Government of Japan (GoJ) are that the tsunami swept approximately 4.8 million tonnes of debris into the ocean, of which 70% of the debris, consisting of the heavier objects, sank to the bottom within a relatively short distance of its point of entry, and that 1.54 million tonnes remains afloat in the north Pacific Ocean as of March 2012 (GoJ 2012). These figures have not been independently confirmed, nor is the composition of the floating debris known with certainty. However, lighter materials that float at or close to the surface such as plastic, wood, metal containers, and as well as fishing gear (nets, lines, buoys, etc.), can be expected to remain afloat for a long time. Wind and waves will exert forces on these floating objects, with the relative effects determined by the degree of windage (fraction of the area of an object that protrudes above the water surface). Larger objects, such as houses, are expected to break up into many smaller pieces.

The Tōhoku tsunami inundated the Fukushima nuclear power plant, damaging reactors and stored spent fuel rods, and subsequently leading to leaks of radioactive material, specifically iodine-131 (^{131}I, half-life 8.02 days) and cesium-137 (^{137}Cs, half-life 30.17 years) into the atmosphere and ocean. The discharge of radioactive water into the ocean occurred well after the vast bulk of the debris had been transported seaward by the ocean currents. Plumes of radioactive material escaped from the reactors into the atmosphere shortly after the tsunami, and some of this material may have been deposited onto floating debris. Since ^{131}I has a short-half life and ^{137}Cs is water soluble, radioactivity deposited on the debris is likely to either have degraded below detection limits or have washed off during the prolonged exposure in the ocean. Given these considerations, there is only a remote possibility that the marine debris is contaminated by radioactive materials (NOAA 2012a).

Transport and dispersal by ocean currents

Marine debris is subject to transport and dispersal by ocean currents and by oceanic winds and their attendant waves. Large-scale ocean currents are responsible for transport over large distances. The ocean is also a very turbulent environment, and smaller scale motions and eddies will gradually disperse an initially compact debris cluster into a diffuse cloud of objects spread over a large area.

The Tōhoku tsunami deposited debris into the ocean along the northern coast of Honshu Island. The Oyashio and Kuroshio Currents merge together in this region to form the Kuroshio Extension, a swift eastward-flowing current which will have carried some of the debris away from the coast of Japan towards the central North Pacific (see Figure 1). In the central North Pacific, the flow becomes very broad and sluggish and is referred to as the North Pacific Current (or the West Wind Drift). It is expected that marine debris from the Tōhoku tsunami will be transported by this relatively slow moving current system across the Pacific Ocean towards the west coast of North America.

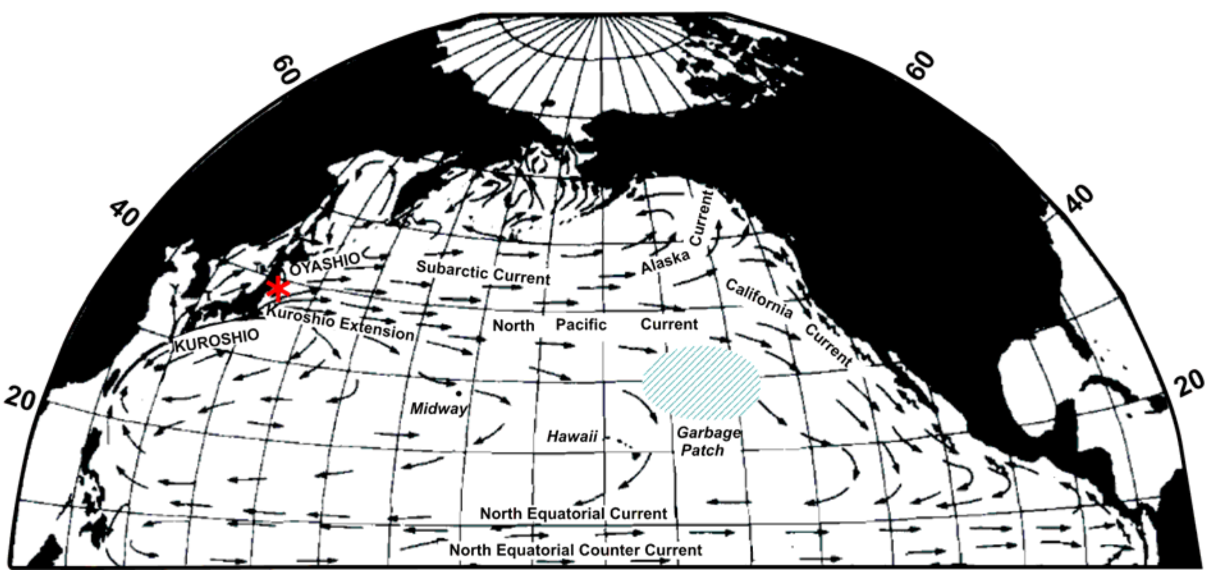

Figure 1. Schematic diagram showing major currents of the North Pacific. The red symbol indicates the approximate location where debris generated by March 2011 tsunami entered the ocean. The hatched blue area indicates the approximate location of the Great North Pacific Garbage Patch. Adapted from Figure 3 in Tabata (1975).

Near the North American coast, the North Pacific Current splits (bifurcates) into northeastward and southeastward flowing current systems, referred to as the Alaska Current and California Current, respectively. It is expected that the tsunami debris will be transported into both of these current systems as it approaches North America. Debris flowing northward into the Alaska

Current is more likely to enter Canadian waters, while debris transported in the southward flowing branch is more likely to impact the U.S. west coast and Hawaii.

Studies of the motion of near-surface drifters have found that the latitude of bifurcation is about 50°N (Bograd et al. 1999), although there is some year-to-year variability in this latitude. To reach the British Columbia shoreline, debris must traverse a region of variable flow located eastward of the bifurcation zone. Here generally westerly winds will drive segments of the debris field onto the coast. Currents can only bring debris close to the shore. Debris is then deposited on the shoreline by the action of retreating tides, onshore winds, and waves.

The major currents depicted in Figure 1 represent an idealized view of the large-scale circulation in the North Pacific. Highly variable, energetic motions occurring over a range of smaller scales are also present at any given time. These motions, referred to as 'eddies', are ocean analogues to the atmospheric systems that produce familiar day-to-day weather patterns. The main effect of eddy variability on the marine debris is to spread the debris out over an increasingly large area. For example, consider the following estimate of dispersion in which the length scale of dispersion of a cluster is

$$d = \sqrt{2Kt} \ ,$$

where t is the elapsed time and K is the lateral eddy diffusivity based on single particle dispersion. Zhurbas and Oh (2003) reported that values of 5,000 - 10,000 $m^2\ s^{-1}$ are representative of single particle diffusivity within the Kuroshio Extension. Taking a value at the lower end of the diffusivity range results in a dispersion scale of $d \approx 400$ km after 6 months. A circle with a radius of 400 km encompasses an area of about 500,000 km^2, which is comparable to the area of the province of Alberta (660,000 km^2) or the state of California (424,000 km^2). Thus, based on this simple calculation, tsunami debris is likely to be dispersed into a very diffuse cloud that extends over hundreds of thousands of square kilometers after only 6 months. Within this large expanse, the debris is not expected to be uniformly distributed. Rather patchy clumps and elongated filaments of debris are likely to be observed.

Present status

Offshore transport of the tsunami debris was observed very soon after deposition into the ocean. The debris was tracked for a short time by satellite (NOAA 2012b), and patches of debris could be seen in satellite imagery for about a month following the tsunami. However, by 14 April 2011 the cloud of debris had dispersed to the point that it ceased to be visible in satellite imagery (NOAA 2012b). In December 2011, researchers at the United States National Oceanic and Atmospheric Administration (NOAA) examined high resolution satellite imagery of a 50 km by 60 km patch of ocean where model simulations suggested debris would be located, but failed to detect any debris. This result means either that scale of the debris was smaller than the 1–2 meter resolution of the satellite imagery, or that debris was not in the forecasted location. Regardless of the explanation, this result underscores the limits of existing knowledge of the distribution of tsunami debris at this time (N. Barnea, NOAA Marine Debris Program, pers. comm.). Presently, there is no tracking of the tsunami debris by satellite and as a result, comprehensive monitoring of the movement of the tsunami debris has become essentially impossible.

Reports of direct observations of debris at sea are being collected by the GoJ and NOAA and sightings from commercial vessels have been compiled and catalogued (GoJ 2012b). This record now consists of some 97 sightings from April 2011 through November 2011. All of these sightings were from a region of the Pacific that is west of the dateline and south of 45°N and most of the sightings consist of small vessels and/or containers. The vessels are frequently reported to be either capsized or partially submerged. The last reported sighting occurred in November 2011.

NOAA has received to date only two reports of debris with origins that are confirmed to be from the tsunami. One of these reports consists of extensive observations made in the open ocean from the *STS Pallada*, a Russian sailing vessel that was travelling west across the Pacific to Vladivostok (IPRC 2011a). As it was heading past Midway Atoll, the crew of the *Pallada* noticed many floating objects in the water. On 22 September 2011, about 800 km northwest of Midway Atoll, the *Pallada* encountered a small fishing boat, registered in Fukushima, Japan. Tests of the boat found that radiation levels were below detection limits. Observations of additional debris were made from the *Pallada* as it continued on a north-westward course towards Japan.

Forecasts of debris location

Forecasts of the future movement of the tsunami debris depend on models predictions and carry a considerable degree of uncertainty. Results from model simulations conducted at NOAA (NOAA 2012a) and at the University of Hawaii (IPRC 2011b) are in the public domain. It is not clear how much confidence can be placed in the models since they have not been well tested against observations, particularly for a once-in-a-lifetime event such as the March 2011 tsunami. Nevertheless, it is somewhat encouraging that these two differently formulated models yield results that are generally consistent with each other. Figure 2 shows the distribution of the tsunami debris at a series of different times as predicted by the University of Hawaii model.

The following are some of the salient results from this simulation.

- As anticipated, the simulation shows dispersion of the debris over a large area as it is being transported across the Pacific toward the west coast of North America.
- The leading edge of the debris cloud is predicted to reach the North American continent about two years after deposition into the ocean. Based on this prediction, the debris can be expected to start arriving along the coast by spring 2013 or shortly afterwards.
- Following its initial appearance, the rate at which debris arrives along the coast should increase gradually. Tsunami debris will continue to be transported by ocean currents close to the coast for a number of years, and it is possible that debris will continue to be deposited along the British Columbia shoreline during this time.
- In the simulation, most of the debris is transported south into the California Current system, with a much smaller amount entering the Alaska Current. Based on this finding, the U.S. west coast can expect to receive a larger fraction of the debris than the west coast of Canada.
- The simulation shows most of the debris (> 90%) remaining in the ocean after 5 years. In particular, the simulation shows a large fraction of the debris accumulating in a region known as the Great North Pacific Garbage Patch (Figure 1). This is a large expanse of ocean northeast of Hawaii where floating debris, especially plastics, has accumulated over time due to the convergence of surface wind-driven currents (Ekman transport) (Maximenko et al. 2012). The simulation shows debris remaining trapped within the Garbage Patch for many years.

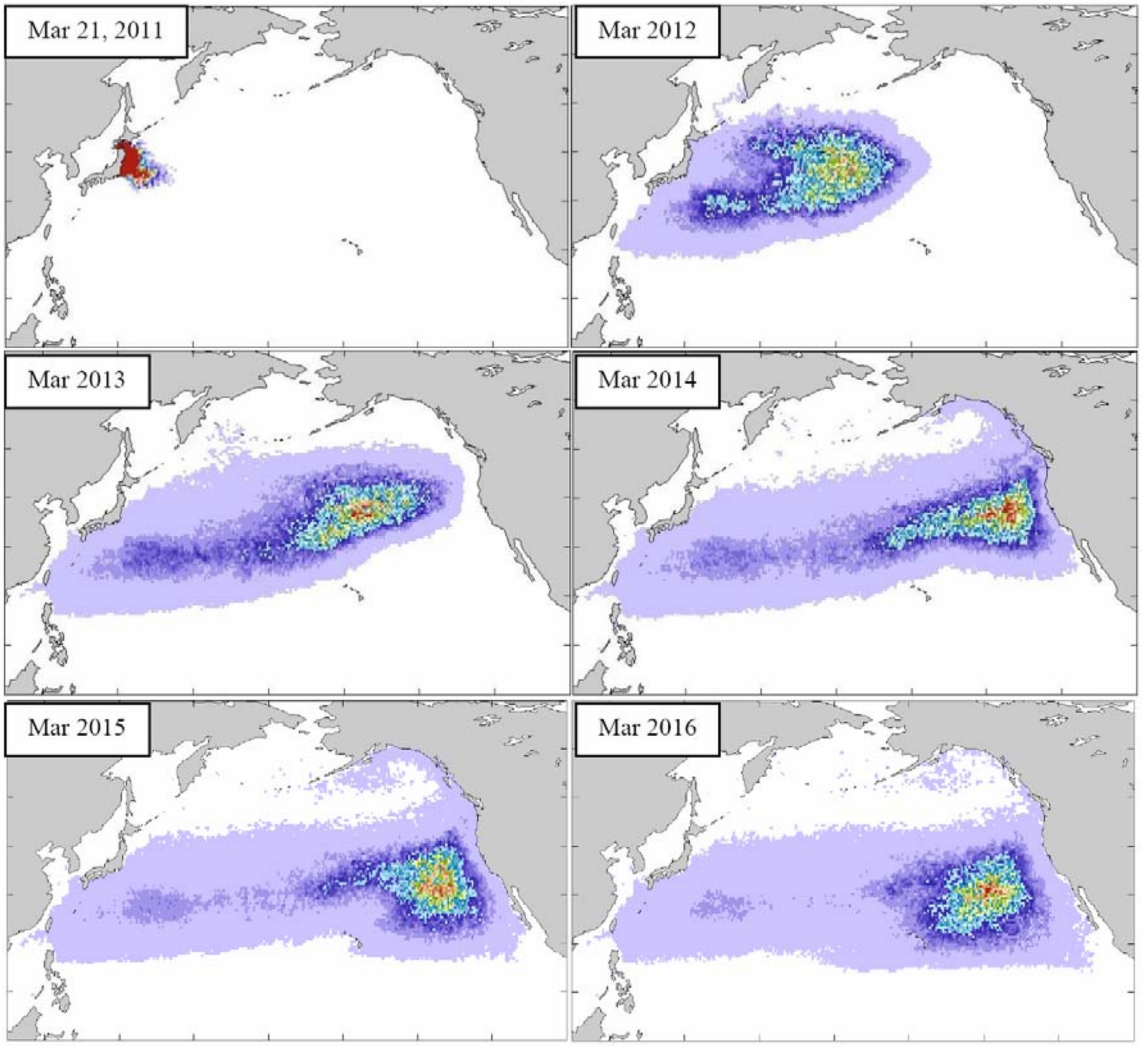

Figure 2. Distribution of the tsunami debris at yearly intervals in a model simulation by N. Maximenko and J. Hafner of the University of Hawaii. In this simulation, the concentration of debris found in proximity to the coast of British Columbia peaks by about March 2014, some three years after its release into the ocean. Debris remains present along the British Columbia coast for at least five years, albeit at reduced level. This figure is drawn from (IPRC 2012b).

Results from this model simulation are derived from the trajectories of a large number of drifters deployed in the ocean over a 30 year period (Maximenko et al. 2012). These trajectories are representative of the motion of objects that move with the top layer of the water column. They may be less representative of the motion of high windage objects that float well above the water surface and are directly exposed to wind forcing. High windage objects may be driven by the prevailing westerly winds and move more quickly towards the North American coast than the surface waters that are likely transporting most of the debris. Thus, high windage objects may begin arriving along the coast of British Columbia earlier than the bulk of the debris, which is forecasted to begin arriving in the first half of 2013.

Environmental impacts and hazards to navigation

The potential environmental impacts of the tsunami debris on the coastal waters and shoreline of British Columbia are difficult to ascertain with confidence. Presently, the volume of debris likely to reach the coast cannot be estimated, and the composition of the debris is poorly known. Consequently, the risks to habitat, species and ecosystems cannot be identified at this time.

Likewise the possible hazards to navigation presented by the debris are difficult to determine. There may be a few large objects amidst the debris that arrives in British Columbia waters (e.g., containers from shipping), and it is at least conceivable that there is a risk of collision at sea. However, perhaps the greatest navigation risk presented by the debris may be due to entanglement in floating fishing gear, ropes and nets, but the magnitude of this risk is unknown relative to existing risks which are poorly documented.

Conclusions

While many relevant questions can be posed regarding the marine debris produced by the Tōhoku tsunami, only tentative answers can be given, amid considerable uncertainty. What is known is that a large mass of debris was swept into the Pacific Ocean and was transported offshore by ocean currents. The spatial extent and composition of this debris field is not well known, although it is likely to be highly diffuse, with the debris dispersed into numerous small patches over a large expanse of ocean. There have been a few isolated reports indicating that, as expected, debris is being transported across the Pacific and has reached the central Pacific. No systematic monitoring of the motion of the debris is occurring at this time.

Projections for the future must depend on the use of inadequately tested models. These models produce qualitatively similar results forecasting that the bulk of the debris will begin to arrive along the west coast of North America during the first half of 2013, although some high-windage objects may arrive sooner. Most of the debris that reaches North America will move south into the California Current where some of it may wash ashore in Washington, Oregon, and California before moving towards the Hawaiian Islands. A smaller portion of the debris will move north into the Alaska Current and it is from this load that debris is most likely to wash ashore in British Columbia. The models also show the great bulk of tsunami debris remaining in the ocean for many years and collecting in the North Pacific Garbage Patch. It is unlikely that much of the debris caught in the Garbage Patch will subsequently reach the coast of British Columbia.

It is important to note that marine debris from a variety of domestic and foreign sources floats into Canadian waters and is deposited on British Columbia shorelines every day and that most of this debris consists small pieces with no identifiable markings. Identifying specific shoreline locations in British Columbia for tsunami debris deposition is not possible because the models used to forecast debris movement do not consider factors such as tides, wind/waves, and local geography which are important for washing debris onto a shoreline. However, existing patterns of marine debris deposition on shorelines are not expected to change when debris from the tsunami begins arriving. Therefore, shorelines that receive debris at present (e.g., collector beaches) are also likely to receive tsunami debris.

It is unlikely that marine debris from the tsunami will enter the Strait of Georgia due to a strong surface outflow of fresher water through the Strait of Juan de Fuca and a counter-clockwise eddy at the mouth that traps surface debris and moves it back into coastal areas off the west coast of Vancouver Island.

Although the March 2011 tsunami was probably one of the largest single-source loadings of marine debris to the north Pacific Ocean, the significance of this addition is uncertain because the existing load of marine debris is not well quantified. The Government of Japan estimates that about 70% of the debris swept into the ocean sank on the continental shelf and that 1.54

million tonnes of debris remains afloat in the north Pacific Ocean as of March 2012 (GoJ 2012a), although these figures have not been independently verified yet. Based on existing knowledge of oceanographic processes and marine debris transport, only the most buoyant and durable objects will survive the trans-Pacific crossing and reach North America and this pattern is unlikely to change with the tsunami debris. Most large objects swept into the ocean by the tsunami (e.g., shipping containers, houses, small vessels) are not expected to survive a crossing of the North Pacific intact.

Movements of tsunami debris fields were tracked by satellite for approximately one month, after which the debris field was too widely dispersed and debris pieces too small to be resolved in satellite imagery. An attempt to verify the University of Hawaii model forecast of debris location in December 2011 was unsuccessful. Opportunistic sightings of debris recorded by passing vessels have been compiled and catalogued by both NOAA and the Government of Japan. Since there is no tracking of the tsunami debris by satellite, reliable data on the location, pathways, and drift rates of tsunami debris in the North Pacific Ocean are currently lacking.

Shoreline monitoring has been conducted for several years in the Olympic Coast National Marine Sanctuary of Washington using a well documented protocol established by the NOAA Marine Debris Program (http://marinedebris.noaa.gov/). There is no formal systematic shoreline monitoring program in British Columbia. Some baseline information on debris may be available from annual beach clean-up days coordinated by environmental non-governmental organizations, but follow-up is needed to assess the quality of these data.

Neither the existing risks to habitats, species and ecosystems in British Columbia from marine debris nor the incremental increase in risks associated with the arrival of tsunami debris are quantifiable because existing risk from marine debris loads in Canadian waters are poorly understood and documented. Although there may be an increased risk to species in British Columbia associated with entanglement in drifting nets, ropes, and plastics, the magnitude of this increase relative to the existing entangling risk from marine debris is unknown at present. The risks from radioactivity associated with ^{131}I and ^{137}Cs on the debris originating from the Fukushima nuclear power plant are believed to be very low. ^{131}I has a half-life of about 8-days and by March 2012 activity levels on debris would be well below the most sensitive detection limits and any known effect threshold and ^{137}Cs salts are water-soluble and can be washed off debris during prolonged exposure while at sea. Testing of tsunami debris collected by a Russian research vessel in September 2011 found that radioactivity levels were below detection limits. There is some potential for bioaccumulation of ^{137}Cs in aquatic food webs, but the risk to marine species and ecosystems in British Columbia through biological transport is likely low because ^{137}Cs is rapidly eliminated from organisms, resulting in a short biological half-life of 2-3 months.

Baseline navigational impacts in Canadian waters associated with marine debris are poorly known and, therefore, the additional impacts associated with tsunami debris arriving in Canadian waters cannot be quantified at present. Although the highest risk to navigation is likely related to large objects (e.g., shipping containers, houses, etc.) arriving in coastal waters, the probability of these objects surviving a trans-Pacific crossing intact is believed to be very low and the number of large objects deposited in the sea off the coast of Japan may not have been high. Drifting nets and ropes and other entangling debris from the tsunami may incrementally increase the current risk of navigational impacts associated with entangling debris in Canadian waters. Small objects (e.g., logs or small pieces of wood) are not believed to pose any additional risk to vessel traffic off the west coast of Vancouver Island. Tsunami debris, when it arrives, is unlikely to pose a risk to navigation in the Straits of Juan de Fuca or Georgia since water properties and current patterns will ensure that little, if any, debris enters these areas.

Additional recommendations concerning further measures that could be considered to respond to the tsunami debris issue are listed below.

1. The Government of Japan released new estimates of the quantity and composition of debris that was swept into the sea and remains afloat in March 2012. Since these data were not available during the SSRP meeting, it may be prudent to re-evaluate the conclusions and advice in this SRR following independent confirmation of the new estimates.
2. DFO has the expertise to liaise with other science organizations dealing with marine debris and transfer information on debris movements, observations at sea, and other scientific issues to relevant agencies in Canada responsible for creating contingency plans to respond to tsunami debris when it begins arriving in Canadian waters and washes ashore on British Columbia shorelines.
3. Since large floating objects have a higher probability of detection and likely have a higher risk of navigational impacts, other opportunities for the early detection of large objects should be explored, including aerial surveillance flights for fisheries enforcement, commercial shipping, Radarsat, and land-based coastal radar installations.
4. There is no systematic shoreline monitoring program in British Columbia at present. If a formal shoreline monitoring program is contemplated, then the NOAA Marine Debris protocol used in Washington should be considered for consistency in data collection methods and analysis.

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Date March 23rd, 2012

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This Report is Available from the:

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Internet address: www.dfo-mpo.gc.ca/csas-sccs

ISSN 1919-3750 (Print)
ISSN 1919-3769 (Online)

La version française est disponible à l'adresse ci-dessus.

Correct Citation For This Publication:

DFO. 2012. Transport of marine debris from the 2011 Tōhoku tsunami to the west coast of Canada. DFO Can. Sci. Advis. Sec. Sci. Resp. 2012/006.