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Effects of Marine Debris Caused by the Great Tsunami of 2011

ADRIFT Research Team | <http://www.pices.int/projects/adrift>

The Great East Japan Earthquake, with magnitude 9.1, struck off Tōhoku coast on March 11, 2011, and triggered a massive tsunami wave that surged inland across kilometres of shoreline. This event was a natural disaster of staggering proportions, causing loss of human life, property destruction and environmental damage. The tsunami swept about 5 million tons of debris from terrestrial and coastal environments into the Pacific Ocean (Ministry of the Environment, Japan, 2012) – an amount in the range of the global debris input to the ocean per year. It was estimated that 70% of that debris sank close to shore, leaving 1.5 million tons floating in the North Pacific with the potential to arrive on North American and Hawaiian coastlines. The ecological and biogeographic significance of this event was initially unforeseen for the Eastern North Pacific. The first confirmed instances of Japanese Tsunami Marine Debris (JTMD) washing up on the shores of North America occurred in March 2012, but possible impacts were not evident until June 5, 2012, when a massive floating dock from the port of Misawa (Aomori, Japan) landed on the central Oregon coast with nearly 130 living species, including highly invasive plants and animals.



Photo: BLOOMBERG

The PICES project (2014–2017), funded by the Japanese Ministry of Environment and referred to as **ADRIFT – Assessing the Debris-Related Impact From Tsunami**, brought together researchers across multiple scientific disciplines to document and evaluate the potential impacts from JTMD and associated nonindigenous species (NIS) to coastal ecosystems in Pacific North America and Hawaii.

The project focused on three major themes:

1. modeling movement of marine debris in the North Pacific to forecast and hindcast JTMD trajectories and landings;
2. surveillance and detection of JTMD landfall and accumulation, and
3. characterizing and assessing the invasion risk of NIS transported on JTMD.

The ADRIFT Research Team (photo at right) was able to study marine debris under unique conditions — researchers knew exactly when and where tsunami debris entered the ocean and, for the first time, were able to track debris over long distances.

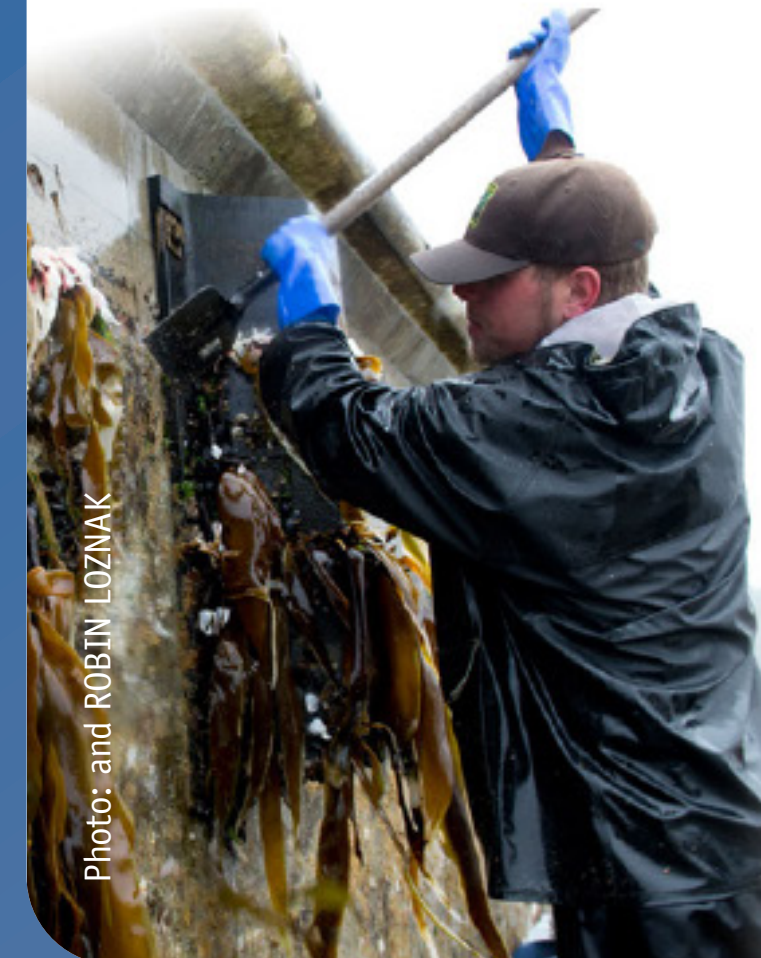


Photo: ROBIN LOVNAK



Modeling Movement of Tsunami Debris

- A suite of 5 numerical ocean models, validated and scaled using available observational data, was developed to simulate the movement of JTMD. Model solutions suggest that during the eastward drift across the North Pacific the debris was “stratified” by the wind such that objects with different windages took different paths: light-weight and/or floating debris items were transported rapidly and may be removed from the ocean within a year following the tsunami, while heavy-weight and/or submerged/sunken debris could remain in the ocean considerably longer, with the potential to become trapped in the part of the Subtropical Gyre known as a North Pacific Garbage Patch (Fig. M-1). Model predictions agree with types of JTMD reported from different areas and timelines of its arrival on the North American and Hawaiian coasts, exhibiting strong seasonal and interannual variations.
- New techniques were developed to derive probable drift trajectories of individual JTMD items. They allowed us to assess the oceanographic conditions (temperature, salinity, etc.) to which these items were exposed to thereby informing the potential for Japanese coastal species to survive transit and facilitating NIS risk assessments.
- Analysis of the climatological conditions in the North Pacific demonstrated that species off eastern Honshu are likely to encounter favourable conditions on the entire North America west coast north of 30°N, whereas warmer-water species from southern Japan that may have been picked by JTMD in the Kuroshio Extension are likely to meet more favourable conditions in Hawaii (Fig. M-2). These conclusions agree with biological samples collected from JTMD.

Complete set of model solution maps and data is available at: <http://iprc.soest.hawaii.edu/MarineDebrisModels>.

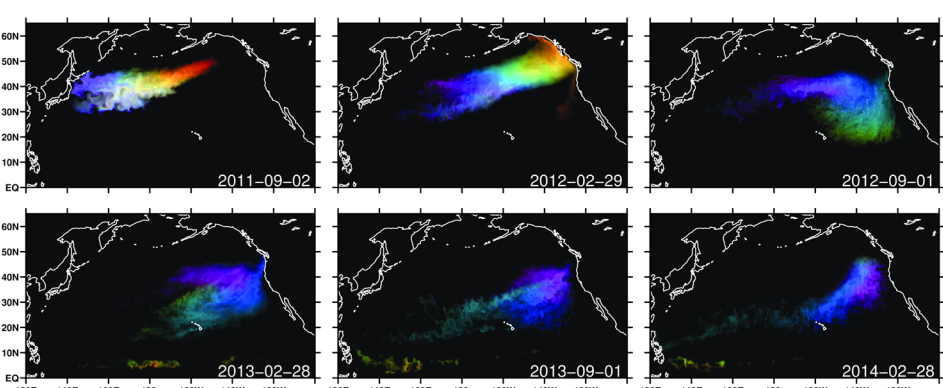


Figure M-1: Motion of JTMD in SCUD model simulations from 2011–2014. Colors indicate windage of the debris.

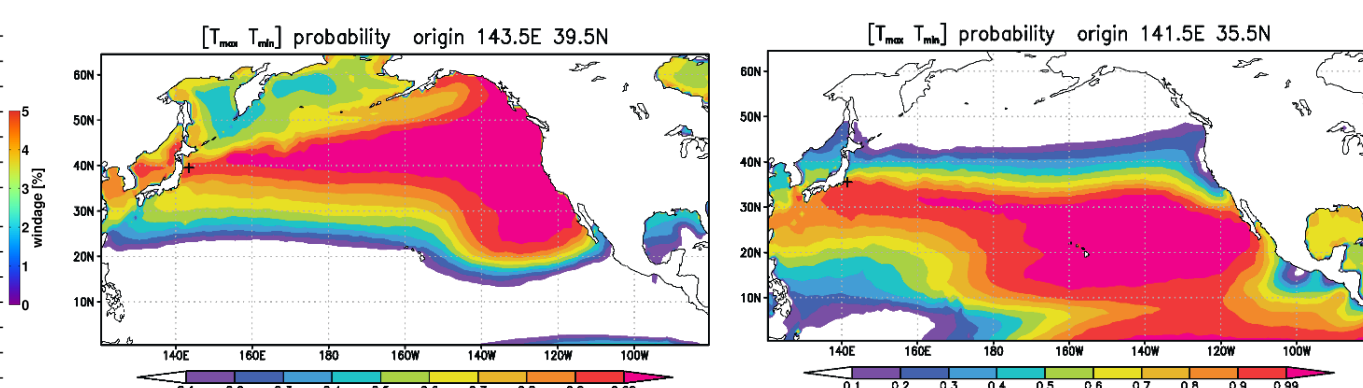


Figure M-2: Degree of the sea surface temperature (SST) match with the climatology at select locations east of Japan (marked with crosses), calculated using AMR satellite data. Model origin locations: 143.5E, 39.5N, and 141.5E, 35.5N.

Surveillance and Monitoring

- Analysis of the temporal and spatial variability in JTMD landfall indicated that the Great Japan Tsunami of 2011 produced a significant and substantial increase in debris influx to the shorelines of North America and Hawaii, representing a 10-fold increase over baseline in northern Washington State where a long-term dataset was available. (Fig. S-1). Debris influx differed by coastline, with higher-windage debris in higher latitudes. Recorded cumulative debris landings to North America were close to 100,000 items in the four year study period. The temporal peaks in measured debris landings align with drift model solutions (Fig. S-2).
- Recognizing the existence of vast, uninhabited shorelines where JTMD could have made landfall, systematic aerial photographic surveys were conducted to search for, and quantify, JTMD arriving on the coastlines of British Columbia (more than 1,500 km of the exposed outer BC coast) and Hawaii (~1600 km of shoreline of the eight main Hawaiian Islands) (Fig. S-3). These surveys were the first comprehensive debris evaluation in these two regions, providing important baselines of marine debris and complementing previous similar efforts in Alaska. In both British Columbia and the Hawaiian Islands, the aspect of shorelines and prevailing wind conditions combined to produce debris “hot spots.”

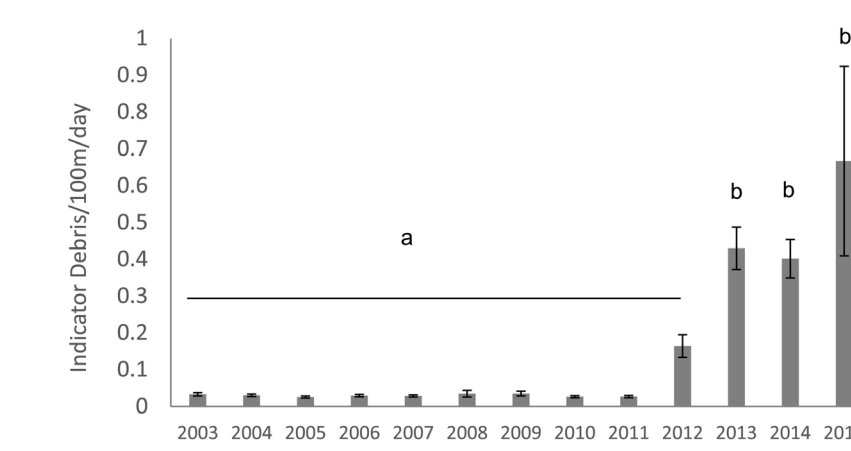


Figure S-1: Mean yearly debris influx of indicator items from 2003 to 2015 at sites in northern Washington State, USA. Letters denote significantly different groups using Tukeys HSD posthoc comparisons.

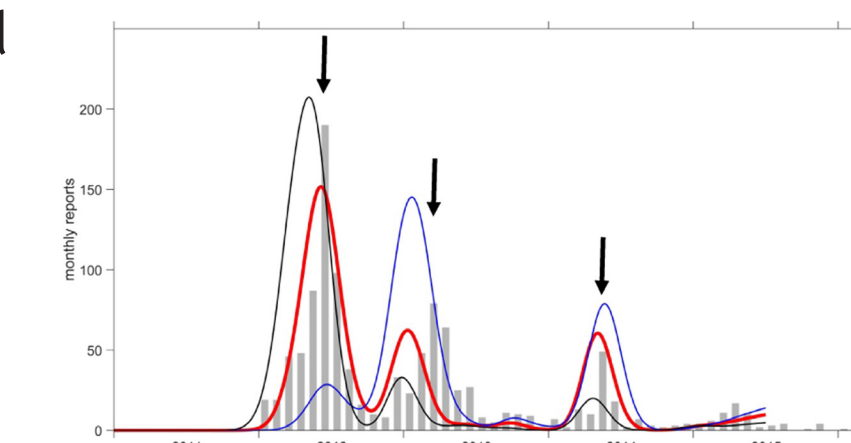


Figure S-2: Timeline of monthly disaster debris reports for North American landfall (grey bars), as of April 13, 2016, and simulated monthly debris arrival from SCUD model.



Figure S-3: Three sample vessels (A, B, and C) identified from the aerial imagery of the Hawaiian Islands (top) and their corresponding in situ ground truth images (bottom).

Species/Risk Assessment

- First opportunity in the history of marine science to track a multi-year large-scale (7000+ km) transoceanic rafting event of marine life originating from a known source and sea-entry time.
- Living Japanese species were transported across the ocean to North America and Hawaii: >650 JTMD items were intercepted and sampled, containing ~400 identified species of invertebrates, algae, and fish.
- Non-biodegradable anthropogenic JTMD provides permanent, long-term rafts, leading to the discovery that coastal species can survive, and even reproduce, far longer in an open ocean than known before (>7 years in some cases - 5 years longer than previously documented for any coastal species).
- Trans-oceanic movement of species on marine debris is now an emerging issue in invasion research, as human-mediated amplification of marine debris provides new opportunities for species to surmount historic ocean barriers.
- JTMD carried many globally-recognized marine invaders. Species invasion risk was characterized using a screening-level risk assessment tool – the Canadian Marine Invasive Screening Tool (CMIST). Higher-risk invertebrate invaders were identified for each of five ecoregions that received debris. Risk varied by region, with the highest median risk to Northern California (an area that already hosts a number of NIS from historical vectors) and the highest cumulative risk to Hawaii (an area that has the largest number of novel JTMD species). A Top 10 Watch List for each ecoregion was produced (see examples in Fig. R-1).
- Detection surveys (fouling panel deployment, mussel parasite screening and visual inspections) were carried out at >60 sites in each affected ecoregion to determine potential establishment of invertebrate and algae species associated with JTMD. No survey has yet detected a single establishment event, but the surveys are important monitoring baselines as NIS introductions can take many years to detect.
- JTMD represents a novel NIS transport vector. However, despite the large amount of debris generated, it could be considered a lower risk given the unique, one-time nature of JTMD compared to other historical and contemporary vectors.

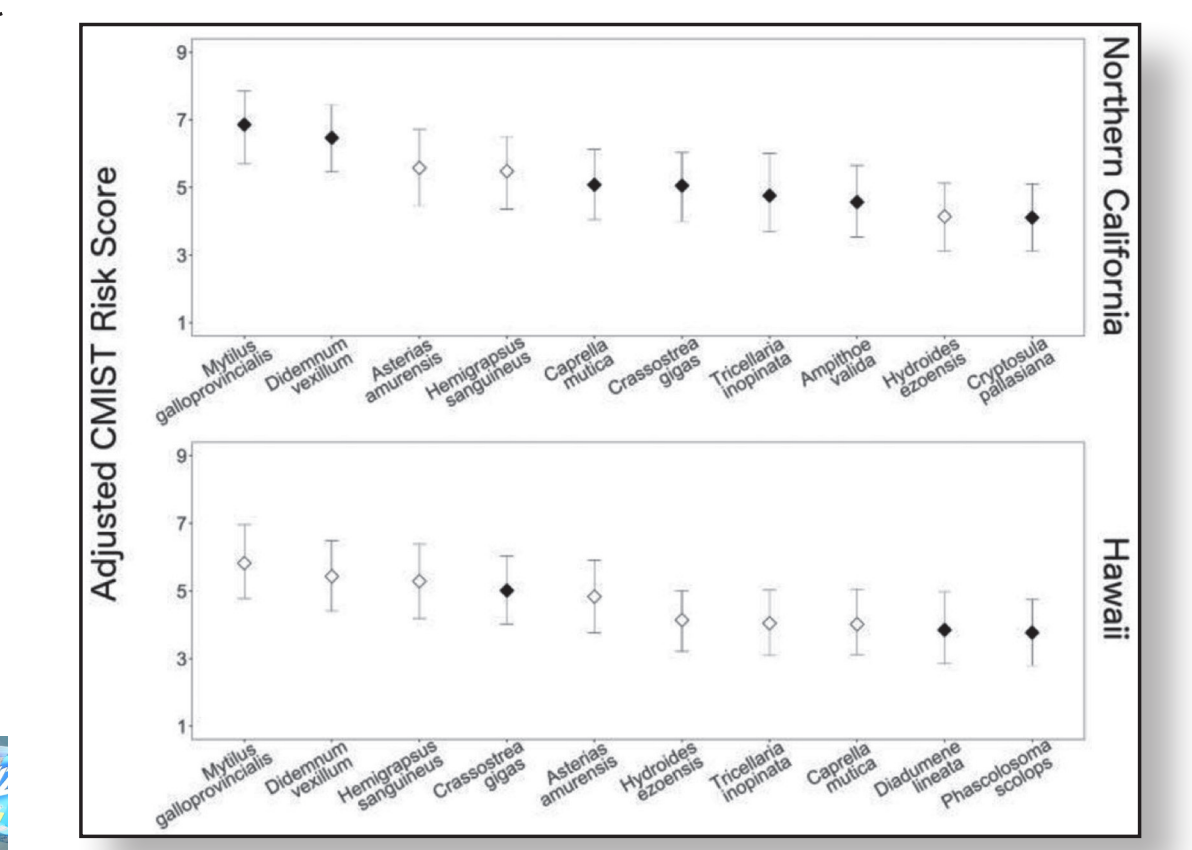
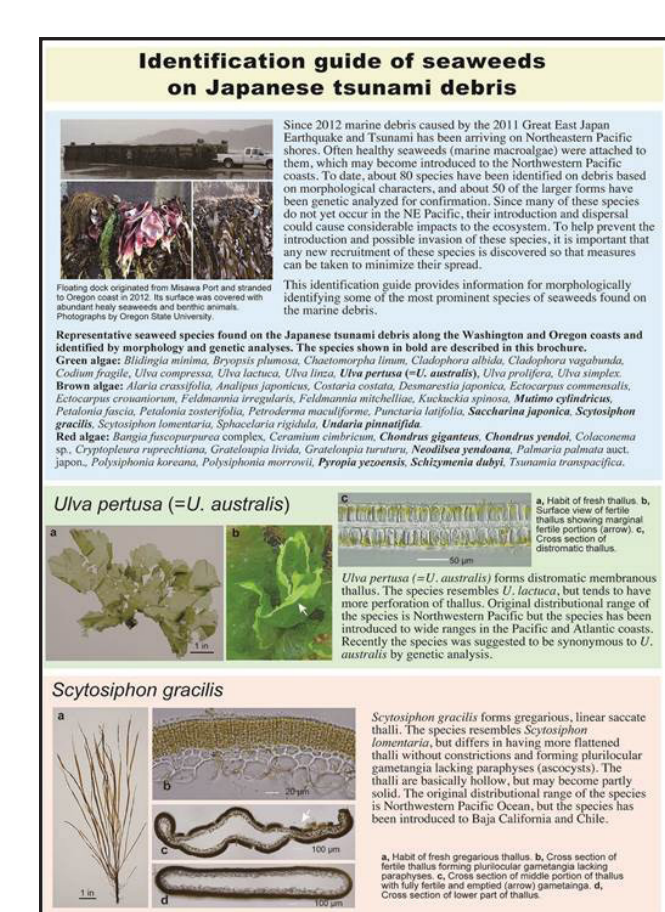


Figure R-1: The ten highest risk invertebrate species for Northern California and Hawaii. Error bars are 95% confidence intervals. Filled diamonds denote NIS already present in the ecoregion prior to JTMD arrival, while open diamonds denote NIS not yet present in the ecoregion.



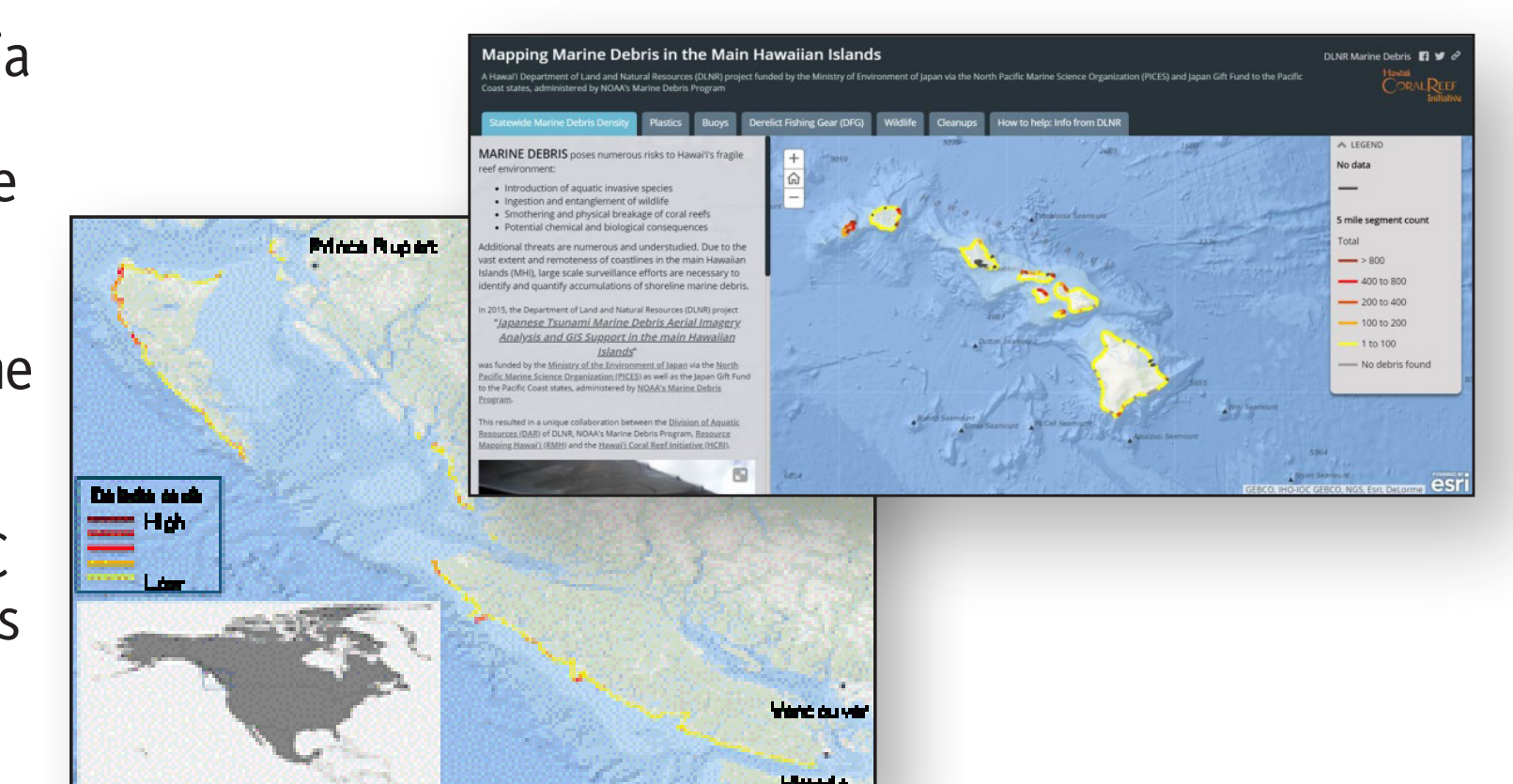
Publications

- A paper in *Science* titled “Tsunami-driven rafting: Transoceanic species dispersal and implications for marine biogeography” by J. Carlton et al. (29 September 2017, Vol. 357, Is. 6358, pp. 1402–1406) was chosen as the “journal cover article” and was accompanied by the “perspective” essay and science video. As of October 8, 2017, this research paper has an Altmetric Attention Score of top 5% of all research outputs (8.5 million) ever tracked by Altmetric and was in #1 position for all Science papers over the last 6 weeks and one of the top 5 research stories of the month of September tracked globally by Altmetric (<https://www.altmetric.com/>).
- A special issue of *Aquatic Invasions* on “Transoceanic dispersal of marine life from Japan to North America and the Hawaiian Islands as a result of the Japanese Earthquake and Tsunami of 2011” (February 2018, Vol. 13, Is. 1, pp. 1–186 (> 220 pages with supplementary files); Guest Editors: J. Carlton and A. Fowler) includes the Introduction, Co-Editors’ Preface and 12 scientific papers (all Open Access) by 30+ researchers, and provides an impressive amount of information on JTMD and on invasion biology globally.
- A special issue of *Marine Pollution Bulletin* on “The effect of marine debris caused by the Great Tsunami of 2011” (May 2018; Guest Editors: C. Murray, H. Maki, T. Therriault and N. Wallace) includes the Introduction and 11 scientific papers (all Open Access) by 30+ researchers on modeling, surveillance, monitoring, ecology and risk of species from the ADRIFT project.
- *PICES Special Publication No.5* on “The effects of marine debris caused by the Great Tsunami of 2011” (June 2018; Editors: C. Murray, H. Maki, T. Therriault and A. Bychkov) summarizes the outcomes from the ADRIFT project.
- Two publications by H. Kawai, T. Hanyuda and G. Hansen (2017), “Identification guide of seaweeds on Japanese Tsunami debris”, available at <http://www.research.kobe-u.ac.jp/rcis-kurcis/KURCIS/FieldGuide2017may14LR.pdf>, and “Benthic marine algae on Japanese tsunami marine debris” (Part 1: Project overview and the red algae, Part 2: The brown algae, and Part 3: The green algae and cyanobacteria), available at <https://ir.library.oregonstate.edu/>, are prepared to assist in detecting JTMD algal species and help prevent future invasions by these species in the Eastern North Pacific.



Legacy Products

- **JTMD specimen archive** – the biological collection of over 1,000 individual samples (marine invertebrates) from 650 registered JTMD objects landed in North America and Hawaii, housed at the Royal British Columbia Museum (Victoria, Canada) for long-term stewardship, will allow researchers world-wide to access this unique resource in years to come, especially with the advance of new analytical techniques. Additional funding for this effort was provided by Fisheries and Oceans Canada through a grant from the Priorities and Partnership Fund to PICES.
- **JTMD species database**, available through the Smithsonian Institution online portal NEMESIS (National Exotic Marine and Estuarine Species Information System; <https://invasions.si.edu/nemesis/databases.html>), provides information on the distribution, biology, ecology, life history traits and invasion history for selected species of marine invertebrates and algae from the northwestern Pacific Ocean, including those associated with JTMD that arrived to the coasts of North America and Hawaii. The database is an important resource for improving our basic understanding of species transport and attributes related to invasion success, and can contribute to risk assessments.
- **Products from aerial surveys** of the British Columbia outer coast and the main Hawaiian Islands (aerial photographs, debris ranking segments and maps) are available for other researchers and managers to use through publicly-accessible online sources: the BC Provincial Government online mapping portal and the State of Hawaii Office of Planning Service Directory. Additional funding for this effort was provided by the Japan Tsunami Gift Fund administered by the BC Ministry of Environment and by NOAA’s Marine Debris Program.



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Japan