Executive Summary

The Great East Japan Earthquake on March 11, 2011 created a massive tsunami that washed millions of tons of debris into the Pacific Ocean. The overall goal of this PICES project, funded by the Ministry of the Environment of Japan (MoE), was to assess and forecast the effects of this debris (termed Japanese Tsunami Marine Debris or JTMD), especially those related to non-indigenous species (NIS), on ecosystem structure and function, the coastlines, and communities of the Pacific coast of North America and in Hawaii, and to suggest research and management actions to mitigate any impacts.

The project, referred to as ADRIFT (**A**ssessing the **D**ebris-**R**elated **I**mpact **F**rom **T**sunami) focused on three main areas of research: (1) modeling movement of JTMD in the North Pacific, (2) surveillance and monitoring of JTMD landfall and accumulation, and (3) potential impacts from JTMD and associated NIS to coastal ecosystems in Pacific North America.

The modeling group utilized a suite of general circulation models to simulate movement of marine debris arising from the Great Tsunami of 2011. The team developed, refined, and calibrated these models using available observational reports to forecast the distribution of JTMD and timelines of its potential arrival on the Pacific Coast of North America and in Hawaii. These results illustrated how different types of JTMD were transported – light-weight and/or floating debris are transported rapidly and may be removed from the ocean within a year following the tsunami (*e.g.*, polystyrene), while heavy-weight and/or submerged/sunken debris can remain in the ocean considerably longer, with the potential to become entrained in the North Pacific gyre (*i.e.*, garbage patch). Simulated particles reaching the coasts of Washington and Oregon showed a strong seasonal cycle. The models were used to calculate probable trajectories of individual JTMD items to highlight areas where debris was likely to accumulate, as well as probable oceanographic conditions (temperature, salinity, and chlorophyll) along the JTMD trajectories to facilitate NIS risk assessments.

The surveillance and monitoring team characterized the temporal and spatial variability in JTMD landfall in North America and Hawaii and its relationship to the reported debris resulting from the Great Tsunami of 2011. Aerial photographic surveys were conducted for the main Hawaiian Islands and the outer coastline of British Columbia, Canada. Analysis of the monitoring data showed a sharp increase in the influx of debris items beginning in May 2012; indicator items, such as beverage containers and other consumer items, increased 10 times over records prior to the tsunami. A webcam system was installed at a site in Oregon during February 2015 to track beach-specific debris landings and removals to better understand temporal dynamics of debris on coastal beaches.

The NIS team characterized the invasion potential of species associated with JTMD by 1) documenting the biodiversity allied with arriving JTMD objects, 2) formally evaluating the risk of the species and JTMD as a vector for NIS overall, and 3) conducting detection surveys in Pacific

North America and Hawaii. Over the course of the project, 650 JTMD items have been intercepted and sampled, from which more than 380 species of algae, invertebrates and fish have been identified. With time, fewer species are arriving alive, but even as recently as spring 2017 live Japanese species were still documented arriving on JTMD objects in North America and Hawaii.

The risk of each species was formally evaluated, and lists of higher-risk species were generated for each Pacific North American and Hawaiian ecoregion (a biogeographic area with relatively homogenous species composition clearly distinct from adjacent systems due to similar oceanographic and topographic features) that received debris. Some of these species are well-known global invaders, such as the mussel *Mytilus galloprovincialis*, the ascidian *Didemnum vexillum*, the large pink barnacle *Megabalanus rosa*, and the seaweed *Undaria pinnatifida*. On average, the highest median risk was to Northern California, an area that already hosts a number of NIS from historical vectors like shellfish aquaculture and commercial shipping. Hawaii had the highest number of JTMD NIS that would be novel to the Hawaiian Islands. Detection surveys were carried out in each affected ecoregion: from Alaska to California, and Hawaii. Fouling panel deployment, mussel parasite screening and visual surveys were conducted in an effort to detect the establishment of invertebrate and algae species associated with JTMD. Thus far, surveys at more than 60 sites have not detected a single establishment event but serve as important baselines for future monitoring efforts as NIS introductions can take years to decades to detect. Perhaps the one exception is the striped beakfish *Oplegnathus fasciatus*, a Japanese species associated with JTMD which was observed independent from marine debris along the coast of Oregon and Washington, but we could not find evidence of an established population.

Based on this impressive body of research a number of conclusions can be drawn about the impact of marine debris from the Great Tsunami of 2011. A significant and substantial pulse of marine debris arrived on the shorelines of North America and Hawaii from 2012 to 2017 that can be directly attributed to this 2011 event. An unknown proportion of JTMD remains afloat in the North Pacific Ocean and may continue to arrive for years to come. The volume of this original pulse of debris is of a similar magnitude to that entering the oceans from other sources on an annual basis, although the type of debris differs.

The biodiversity of Japanese coastal species associated with JTMD was varied and documented on recovered debris items. This has been the most intensely scrutinized group of species associated with a vector, with more than 65 taxonomists contributing to the identification effort. Overall, there is little doubt that JTMD may serve as a vector of potentially invasive species. However, when compared to other historical and contemporary vectors as mentioned above, JTMD is relatively low risk. JTMD represents a unique NIS vector compared to ongoing vectors like commercial shipping.

The ADRIFT project produced a remarkable number of publications and legacy products. Two journal special issues are in production (the expected publication date is late 2017); papers focused on the taxonomy of the JTMD species will be published in *Aquatic Invasions*, and papers on modeling, surveillance, monitoring, ecology and risk of species will be published in *Marine Pollution Bulletin*.

The following legacy products from the project are available to the public and scientific community: 1) the PICES JTMD species database on the Smithsonian Institution online portal NEMESIS (National Exotic Marine and Estuarine Species Information System), 2) the archival collection of specimens (marine invertebrates) from JTMD lodged at the Royal British Columbia Museum, 3) aerial photographs of more than 1,500 km of the exposed outer coast of British Columbia (BC), debris ranking segments and maps through the BC Provincial Government online mapping portal (PICES Tsunami Debris Aerial Photo Survey), 4) ortho-rectified aerial photographs of the eight main Hawaiian Islands and maps through ArcGIS Story Map, and through the State of Hawaii Office of Planning Service Directory, and 5) the field identification guide on NIS algae associated with JTMD at the Kobe University website; and morphological documentation on benthic marine algae found on JTMD through Oregon State University's online library; to be posted in July 2017.