North Pacific Marine Science Organization (PICES)

PICES-MoE project on "Effects of marine debris caused by the Great Tsunami of 2011"

PROGRESS REPORT FOR YEAR 2 (April 1, 2015 – March 31, 2016)

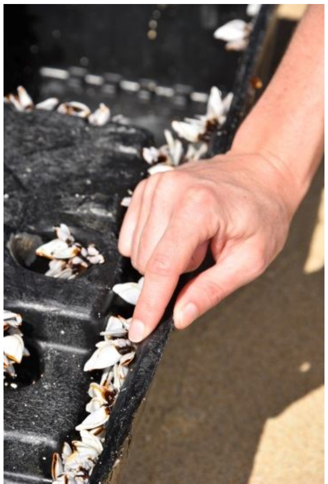




TABLE OF CONTENTS

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

PROGRESS REPORT FOR YEAR 2 (APRIL 1, 2015 – MARCH 31, 2016)

YEAR TWO IN REVIEW

The Great Tsunami of 2011 washed an estimated 5 million tons of debris into the Pacific Ocean. The overall goal of this PICES project, funded by the Ministry of the Environment of Japan (MoE), is to assess and forecast the effects of this debris (so-called Japanese-Tsunami Marine Debris, JTMD), especially those related to non-indigenous species (NIS) on ecosystem structure and function, the coastlines and communities of the west coast of North America and in Hawaii, and to suggest research and management actions to mitigate any impacts. The duration of the project is 3 years, from April 15, 2014 to March 31, 2017.

The project is directed by a Project Science Team (PST), co-chaired by three PICES members: one each from Canada (Dr. Thomas Therriault), Japan (Dr. Hideaki Maki) and the USA (Ms. Nancy Wallace). All PST members are listed in *Appendix 1*. The PST Co-Chairmen are responsible for the scientific implementation of the project and annual reporting to MoE and PICES Science Board. These reports should be submitted to MoE within 90 days after the close of each project year ending March 31, and include a summary of the activities carried out that year, with an evaluation on the progress made, and a work plan for the following year. The Project Coordinator, Dr. Alexander Bychkov, is responsible for the management of the fund and annual reporting on its disposition to MoE and PICES Governing Council within 90 days after the close of each project year.

The project continues to focus 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) assessing risk and potential impacts from JTMD-associated invasive species to coastal ecosystems in North America and Hawaii. In Year 2, significant progress was made in each of these three research themes.

The modeling research has been applying different numerical models to simulate JTMD movement. In Year 2, the team refined and further calibrated their models using observations from the monitoring and surveillance teams. The optimized models successfully reproduce the seasonality and the main peaks of JTMD arrivals in 2012–2015, and predict much of the remaining floating debris is, most likely, entrained in the Pacific gyre and may continue to arrive for decades. The models were then used to estimate the trajectories of individual debris items, such as the large floating docks, and the accompanying environmental conditions that the JTMD-associated biota would have experienced during the journey.

The surveillance and monitoring team continued its activities for British Columbia, Canada (aerial surveys for less accessible areas on the Pacific coast of North America were initiated in Year 1 and completed in Year 2), and began work in Hawaii. The Hawaiian Islands receive a large amount of baseline marine debris, and the unique flora and fauna of the region makes the potential introduction of NIS a concern for state authorities. In Year 2, high-resolution aerial surveys were conducted for the main Hawaiian Islands, and image analysis was completed. The results highlight which islands and shorelines accumulate large amounts of debris, thereby providing guidance to managers for increased mitigation and monitoring efforts. The additional data collected in 2015 allowed a re-analysis of the shoreline monitoring data which showed a sharp increase in the influx of debris items in 2015. Novel approaches to image analyses have been undertaken to enable qualification and quantification of JTMD stranded on beaches. The webcam system installed at a site in Newport

(Oregon, USA) continues to be maintained, and the analysed images indicate that the temporal dynamics of debris on coastal beaches is strongly related to onshore winds and coastal upwelling.

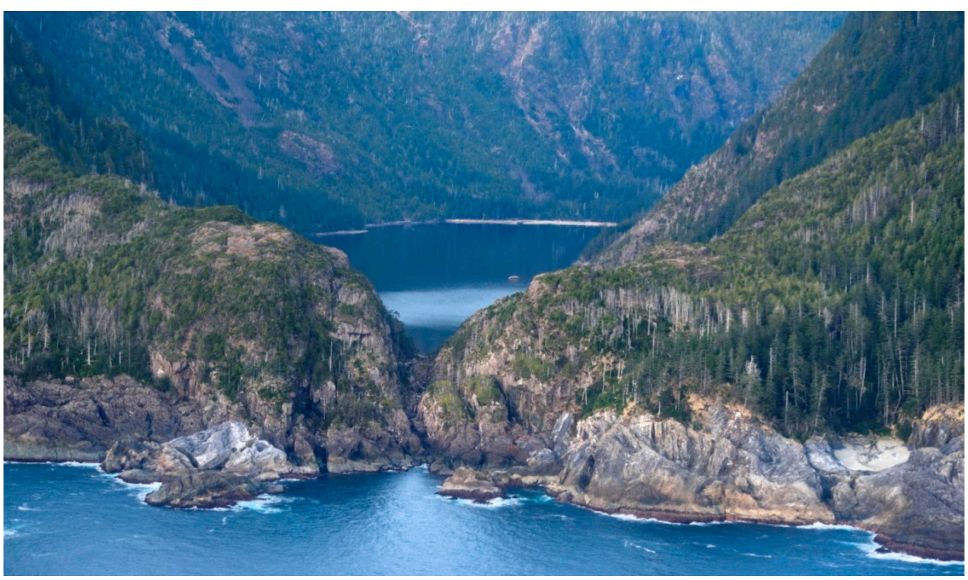
The invasive species team continues to characterize the biodiversity associated with landed JTMD items. By the end of Year 2, more than 500 debris items attributed to the tsunami have been intercepted, and from those items 352 species of algae, invertebrates and fish have been identified. Some of these species are well-known invasive species elsewhere in the world (such as the large pink barnacle *Megabalanus rosa*, the bryozoan *Tricellaria inopinata*, the seaweed *Undaria pinnatifida*, and the serpulid tube worm *Hydroides ezoensis*), but other Japanese species are unique – JTMD is the only vector they have been associated with. In Year 2, new species were found that had not been seen in previous years; for example, two species of sea anemones (*Anthopleura asiatica* and *Diadumene lineata*) were detected which have global invasion histories. These discoveries highlight the need to continue research on the incoming debris items to better understand their potential for facilitating invasions of North American and Hawaiian coastlines.

Field surveys to detect established populations of JTMD species in North America and Hawaii continued in Year 2. Intertidal surveys for algae were conducted in Washington and Oregon, and submerged fouling panels targeting settling invertebrates were deployed in each ecoregion of North America and Hawaii in order to search for potential JTMD species. Mussel samples from more than 20 sites on the Pacific coast of North America were obtained and screened for parasites and pathogens using morphological and genetic methods. The parasite, *Eutima*, detected in JTMD mussels, has not been detected in North American mussels, and no new introductions attributed to JTMD have been detected to date. Haplotype analyses of some JTMD algae have confirmed they originated from the Tohoku coastal area of Japan hit by the tsunami. Fouling panels have been also deployed in the Tohoku region in order to characterize the suite of available species at origin sites.

The risk assessment team has begun to build upon and incorporate the results of the modeling, monitoring and biodiversity research. Two workshops were held in Year 2 to develop a risk assessment framework to evaluate the risk of JTMD as a vector for invasive species. The risk of individual species will be assessed by using a database of life history traits and invasion histories compiled for all species associated with JTMD. A screening-level risk assessment tool will be applied to each species in Year 3, and the supporting information made available *via* an online resource.

Broader dissemination of our research occurred in Year 2, and project activities have been increasingly highlighted by the media. This year, scientists involved in the project gave more than 30 presentations on their ongoing research and results in both scientific fora and public settings (see Publications, Presentations and Outreach section).

A more detailed summary of the Year 2 research progress is available in the following Research Activities section, and the full submitted reports for each funded activity are attached as Appendices.



RESEARCH ACTIVITIES

In Year 2, the PICES team continues to focus 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) characterizing the biodiversity of species associated with landed JTMD items. Additionally, the team has begun to utilize the knowledge gained from these three themes in conducting risk assessments.

MODELING

Numerical models are used to provide information on the general context, large-scale patterns, and past and future timelines of JTMD concentration at particular locations and in larger regions. Modeling support for the project relies on simulations with three different models: SCUD (International Pacific Research Center (IPRC), University of Hawaii), GNOME (NOAA), and SEA-GEARN/MOVE-K7 (Japan). In Year 1 of the project, these models were applied to study particle and tracer motions within a broad range of windage parameters, which describe the direct effect of the wind on items floating at the ocean surface.

In Year 2, a number of methods have been developed that addressed multiple uncertainties by grouping them under a joint wind-related drift component and improving simulations by selecting the optimal windage parameter. Such optimization was first applied to the timeline of JTMD boats/skiffs reported from the US/Canada coastline. Using the optimal windage parameters, models successfully reproduced main peaks of JTMD arrivals from 2012–2014. They also suggested that 60–70% of JTMD boats were still floating in the ocean by the end of year 2014. The models predicted a long-term residence of boats in the "garbage patch"; the area in the eastern North Pacific between Hawaii and the US west coast where sea surface currents converge and collect objects having moderate or no exposure to the wind. The remaining boats and other debris items are expected to be regular arrivals on shore over the next several years. This prediction was confirmed by another influx of small boats to North American coastlines in 2015 and again in early 2016.

New modeling techniques have been developed that allow the selection of optimal windage values for objects that were observed more than once and/or whose start and end positions and arrival times are known. For example, the three Misawa docks, found in 2012 in Oregon, Washington and north of Hawaii are estimated to have taken three very different routes across the North Pacific (Fig. 1).

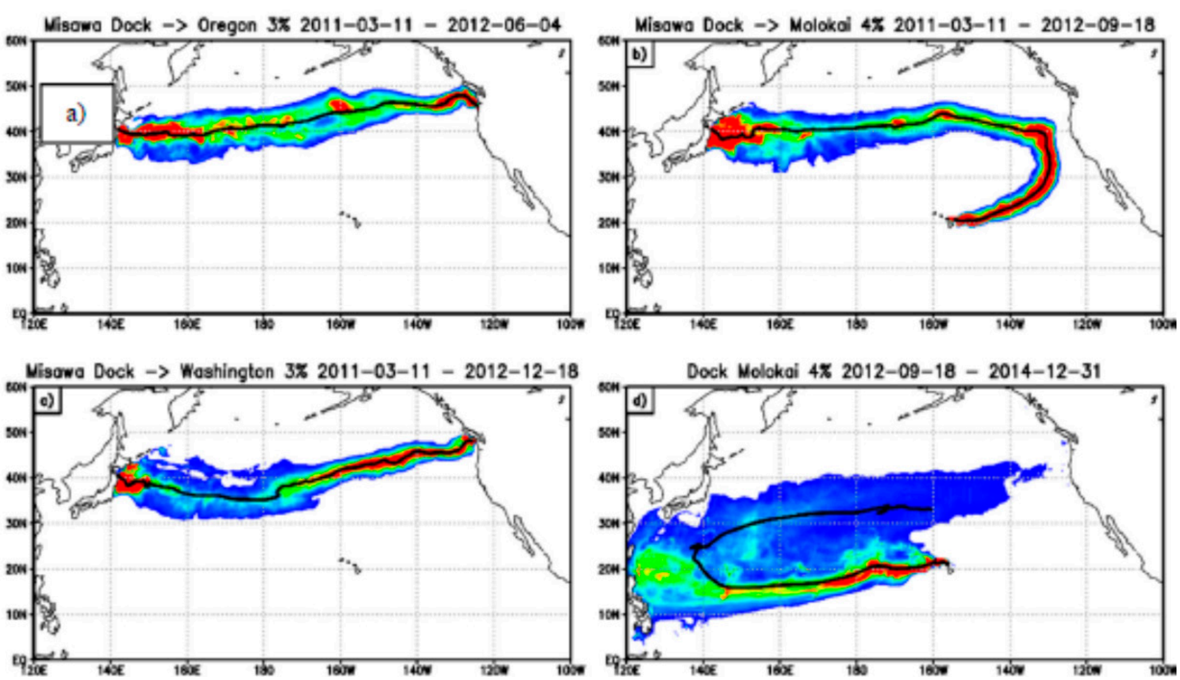


Fig. 1 Probable pathways and trajectories of Misawa docks found in a) Oregon on June 4, 2012, b) north of Molokai on September 18, 2012 and c) Washington on December 18, 2012; d) Probable pathway of Molokai dock after Hawaiian sighting. Image provided by Nikolai Maximenko, University of Hawaii.

Initial experiments with model particles later evolved into tracer simulations that allowed researchers to treat uncertainties in a probabilistic way. As a result, a novel technique is now available to describe probable trajectories of individual debris objects and the probable oceanographic conditions they experienced along these paths, such as temperature (Fig. 2). This information is critical for understanding the history and fate of biota colonizing JTMD and will significantly contribute to our understanding of the risk of invasion of species associated with these objects. The ultimate goal of the modeling activity in this project is the conversion of limited point-observations of debris items into a larger-scale understanding of the phenomenon (*e.g.*, spatial patterns, timelines and relative estimates of arrivals to the affected ecoregions).

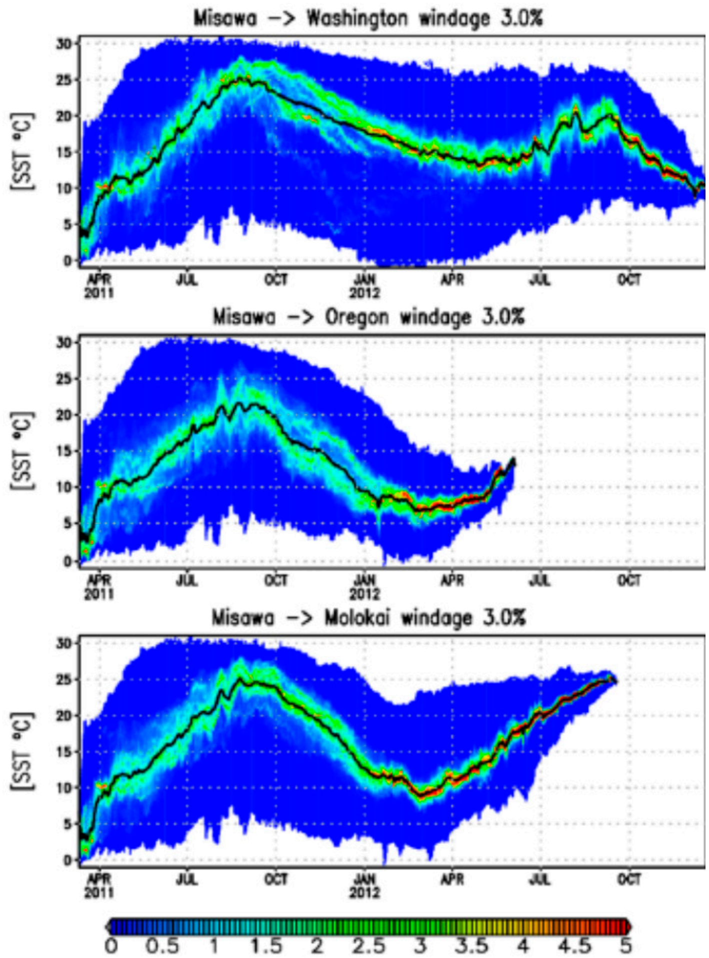


Fig. 2 Sea surface temperature (SST) probability timelines along pathways of three Misawa docks. Image provided by Nikolai Maximenko, University of Hawaii.

SURVEILLANCE AND MONITORING

Surveillance

Surveillance activities are being undertaken in order to search for large debris items (vessels, skiffs, docks) and to detect "hot spots" of debris accumulation. Aerial surveys are cost-effective ways to monitor vast, largely uninhabited coastlines. In Year 2, we conducted aerial surveys of the main Hawaiian Islands and completed surveying the exposed coastlines of British Columbia, Canada, initiated in Year 1.

Hawaii, USA

The Hawaiian Islands have been a major landing site for JTMD generated in 2011. The debris has served as a potential rafting mechanism for NIS to the Hawaiian Islands. In collaboration with the PICES team, Hawaiian managers and researchers are actively monitoring marine debris landing sites for the presence of NIS. In order to portray the potential ecological consequences of tsunami debris, it is important to characterize the debris itself. Understanding the type, size, and location of debris accumulating on Hawaiian coastlines is crucial in developing plans to streamline the removal process and mitigate any negative impacts this debris may have on the islands and their inhabitants. Therefore, in Year 2 a remote sensing firm, Resource Mapping Hawai'i (RMH), was contracted to collect imagery of more than 2,000 km of coastline as part of the effort to identify JTMD on the Hawaiian Islands. RMH collected aerial imagery of the coastlines of the main Hawaiian Islands at 2-cm horizontal ground resolution, covering a swath of 200–300 m that included shoreline and nearshore water (Fig. 3). The coastlines of the eight Main Hawaiian Islands (Maui, Moloka‘i, Kaho‘olawe, O‘ahu, Lāna‘i, Ni‘ihau, Kaua‘i, and Hawai‘i) were surveyed using high resolution aerial photography.

Fig. 3 Aerial ortho-photograph from the Hawaiian Islands survey. Image provided by Resource Mapping Hawai'i.

This imagery was then used to develop ortho-mosaic image datasets for analysis in ArcGIS. Prior to beginning analysis, coastlines were divided into segments, and debris categories were developed to classify debris by type and size. While there are limitations on the ability to determine debris types at this scale, categorization of identifiable debris is useful to determine possible ecological consequences; for example, nets and lines pose a serious entanglement hazard, while small plastics and foam are more likely to be mistakenly ingested by wildlife. Imagery was analyzed by 1-mile coastline segment for systematic coverage of each island's coastline, and each piece of debris observed was identified in ArcGIS on a point shapefile and given a unique, sequential identification number, starting at 1 within each 1-mile segment. For each data point, attributes such as debris type (material), size (object area), and observer information and comments were recorded. Size was approximated using the measurement tool within ArcGIS, and was estimated in meters squared and sorted into size classes. Once analysis for a segment was completed, the segment was given a rating based on density and distribution of debris. Other attributes, including total item count, dates analyzed, and observer information were also recorded for each segment. Original data was used to generate maps in ArcGIS to display debris density and distribution along Hawai‘i's coastlines.

A total of 20,658 marine debris items were identified across the Main Hawaiian Islands. Ni‘ihau was determined to have the highest density of marine debris statewide, containing 38% of the total debris identified. Marine debris was found to be most dense on northern and eastern facing shores for all islands, with western facing shores being the least dense. Maps generated in ArcGIS provided visual representation of debris density and distribution on the coastlines of Hawai‘i (Fig. 4). The data and maps will be used to plan further monitoring efforts for NIS associated with JTMD and for removal efforts at debris accumulation sites.

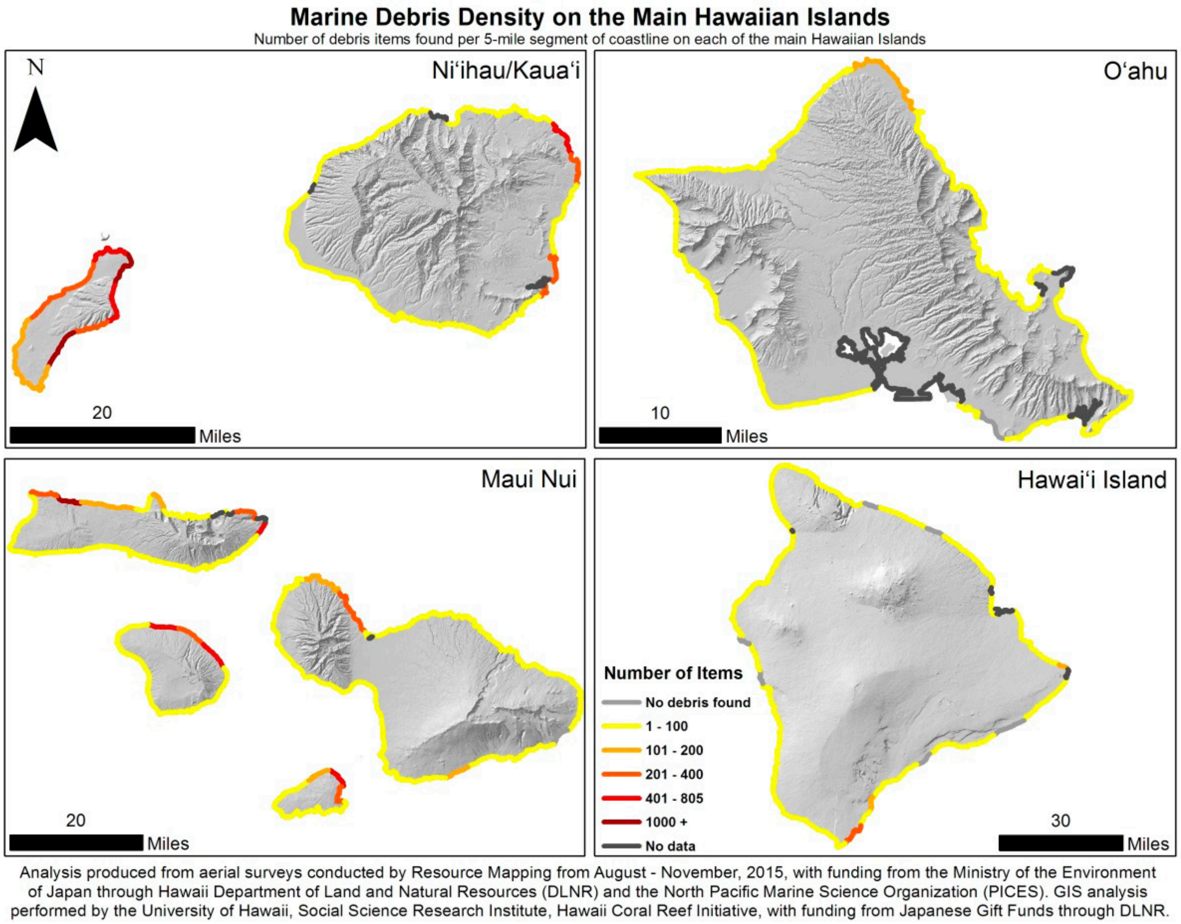


Fig. 4 Marine debris density across the main Hawaiian Islands in 5-mile segments. Darker colours represent higher densities. Image provided by Social Science Research Institute, University of Hawaii.

British Columbia, Canada

In Year 1, PICES funded aerial surveys of the entire exposed outer coast of British Columbia (BC), including the west coast of Vancouver Island, the Central Coast and the west coast of Haida Gwaii. In Year 2, the northern coast of Haida Gwaii, the only remaining section of the exposed outer coast of BC, was photographed and added to the existing inventory (Fig. 5). All surveys were conducted by the local aerial photography company, Lightspeed Digital. Additionally, funding provided by the Japanese Gift Fund through the BC Ministry of Environment (BC-MoE) was used to conduct GIS analysis of the photographs and make them publicly available.

A total of over 6,500 images covering more than 1,500 kilometers of the BC coast were taken. Post-survey processing assigned unique identifiers (tags) for specific types of debris and quantified the amount of debris on a qualitative scale from 0–5. GIS analysis was then conducted on the ranked photographs. The full set of aerial photographs was processed to extract key information and create geospatial data to be used for identifying high-priority sections of the coastline for clean-up. The photographs from five areas of interest were processed into 1-km, 5-km, 1-mile, and 5-mile segments (Fig. 6). Each segment contained the average debris rating from the photographs occurring on that segment. Working with the BC provincial government, PICES completed GIS analysis of the photographs and rankings in order to show “hot spots” of debris accumulation. The debris ranking segments, maps and photographs are now available to the public through an online mapping portal designed and hosted by the BC-MoE.

Fig. 5 Aerial photograph example from the northern coast of Haida Gwaii survey. Image provided by Lightspeed Digital.

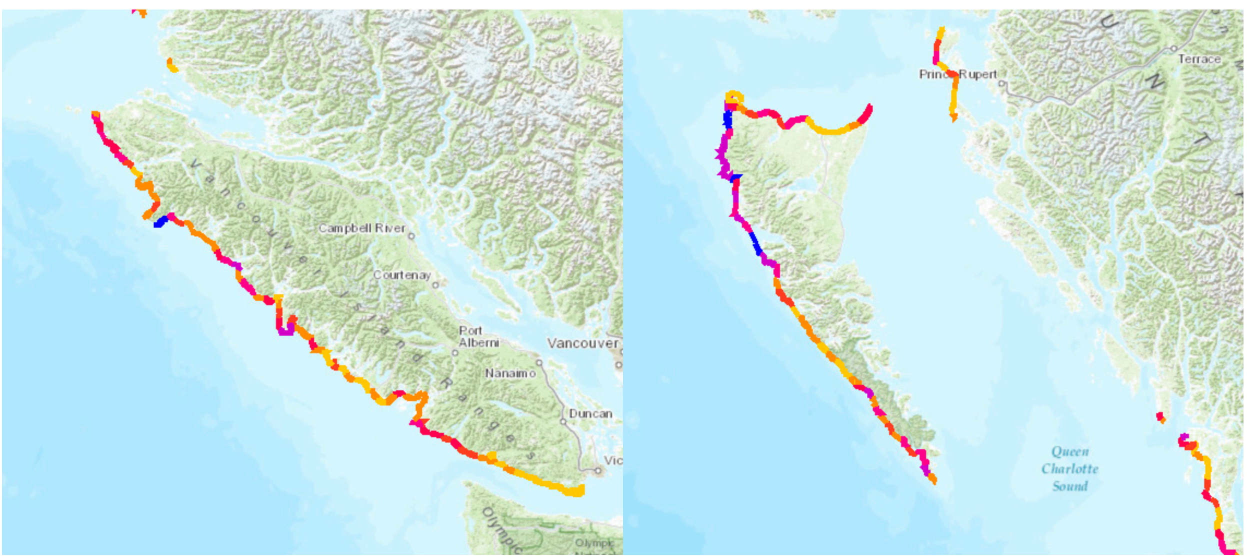


Fig. 6 Debris ranking segments of Vancouver Island (left) and Haida Gwaii and North Coast (right). Darker colours indicate higher debris density. Image provided by Cathryn Clarke Murray, PICES.

In Year 2, working with colleagues at Kyushu University (Japan), image analysis techniques have been refined to gain further data from aerial survey images. The projective transformation method used in webcam monitoring was applied to the oblique aerial photographs from BC (Fig. 7). This successfully removes the geometric distortion from the aerial photographs. Thereafter, ratios of areas with and without beach litter (later referred to as “percent covers”) were computed by extracting the pixels of beach litter from the images using the projective transformation method. The accumulation of marine debris on beaches of Vancouver Island was estimated by applying our image analysis to aerial photographs. It was found that beach litter accumulated to a greater extent on the south- and southeast-facing beaches of Vancouver Island and, consequently, concluded that the accumulation of beach litter depends on the cross-shore direction of the beach interacting with the major direction of offshore ocean currents.

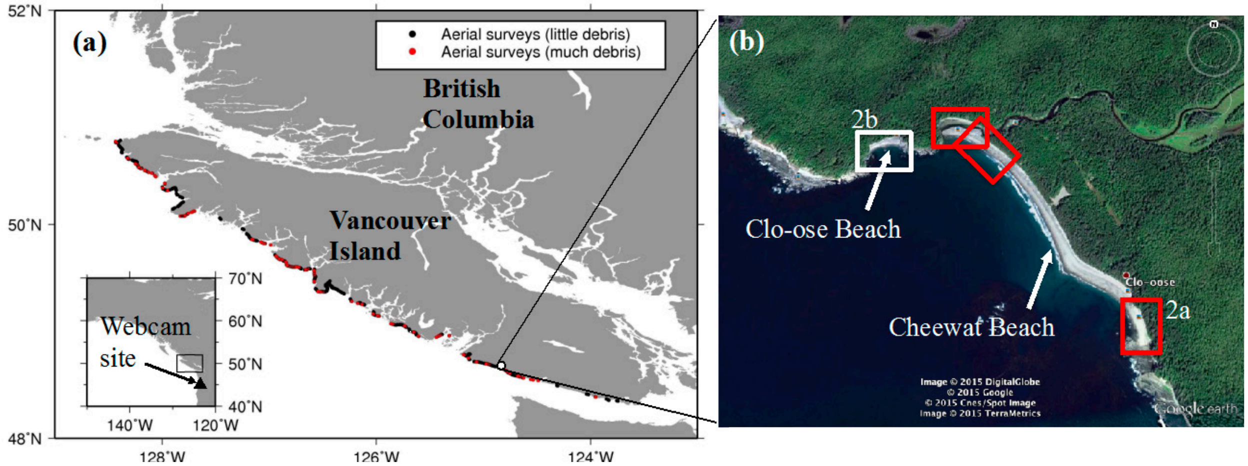


Fig. 7 (a) Locations where the aerial photographs were taken. Black and red dots indicate the photographing locations, and the legend of the symbols is shown in the right-upper box. (b) The enlarged map of the shoreline cleanup sites. The white and red boxes show the coverage of the aerial photographs used to estimate the percent cover on Cheewat Beach and Clo-ose Beach, respectively. The aerial photographs of 2a and 2b are shown in Figs. 6(a) and 6(b), respectively. Image provided by Tomoya Kataoka, National Institute for Land and Infrastructure Management, Japan.

To investigate the accuracy of the beach litter accumulation measured by image analysis of aerial photographs, the percent covers estimated from the aerial photographs were compared with the densities of beach litter measured by the shoreline clean-up surveys on the Clo-ose Beach and Cheewat Beach (Table 1). The results of these analyses were further compared to three small aerial surveys conducted in conjunction with shoreline surveys in order to compare the effectiveness of the three survey types (qualitative rankings, quantitative image analysis and shoreline surveys).

Table 1 Comparison of the percent covers of beach litter calculated from the converted images with the densities measured by the shoreline cleanup surveys.

Beach	Percent cover of marine debris (%)	Density of marine debris (items/m^2)
Cheewat Beach	4.0	0.014
Clo-ose Beach	14.0	0.049

Shoreline Monitoring

Monitoring research activities aimed to quantify the amount, distribution and timing of debris landfall attributable to the 2011 tsunami compared to baseline amounts. Three data sources were made available to PICES to examine the influx of marine debris after the 2011 tsunami (Fig. 8): (1) NOAA (National Oceanic and Atmospheric Administration) shoreline monitoring surveys, (2) OCNMS (Olympic Coast National Marine Sanctuary) shoreline surveys, and (3) NOAA's disaster debris reports.

In Year 2, the NOAA shoreline debris monitoring analysis was updated with data from 2015 and reanalyzed. The peaks in debris landfall on the west coast of North America after the tsunami are similar to the peaks in disaster debris reported to NOAA, and these peaks are consistent with the modeling predictions from the University of Hawaii (Fig. 9). It was concluded from this analysis that the increase in debris on Washington State, Oregon and California shorelines is attributable to the 2011 tsunami and represents a minimum 10-fold increase in debris above baseline levels. Alaska and British Columbia have few ongoing monitoring surveys and therefore it is difficult to document the influx of debris beyond anecdotal reports. Hawaii receives the most debris of all the study regions on an ongoing basis, and it has not been possible to distinguish the influence of JTMD compared to the baseline amounts.

The alignment between the influx of marine debris over time documented in the shoreline surveys, the disaster debris reports and oceanographic modeling is a striking and interesting result (Fig. 9).

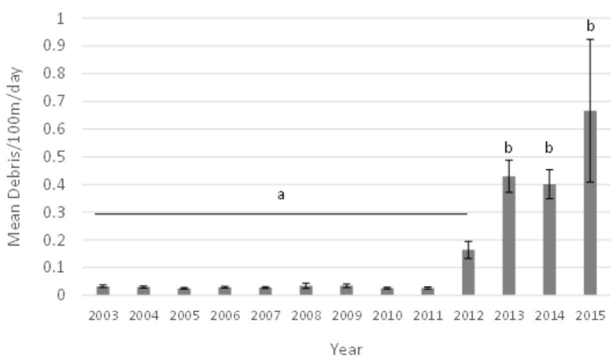


Fig. 8 Increase in marine debris indicator items beginning in 2012. Letters denote statistically significant sub-groups. Data from NOAA and OCNMS. Image provided by Cathryn Clarke Murray, PICES.

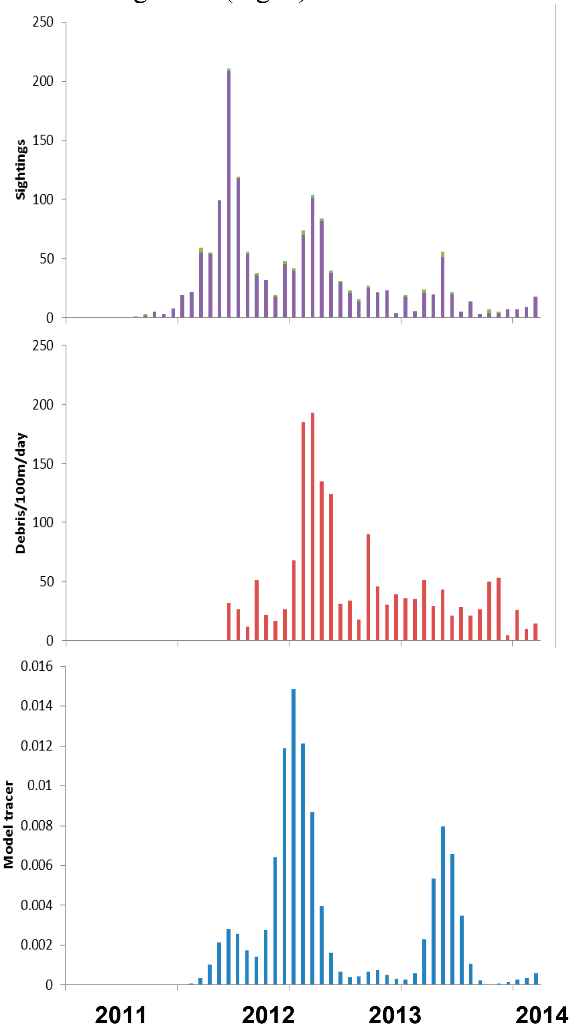


Fig. 9 Temporal variation in disaster debris reporting for North American landfall (top), and beach debris accumulation for Washington, Oregon and California (middle) and University of Hawaii's SCUD model tracer predictions with 1.5% windage (bottom). Image provided by Cathryn Clarke Murray, PICES.

Webcam Monitoring

In Year 1, a webcam was installed on a beach at Newport (Oregon, USA) to automatically take sequential photographs of beach litter in order to quantify the variability through time of landings of JTMD. Photographs of the study beach have been taken every 60 minutes from April 2015 to the present to elucidate the temporal variation of debris quantities and the possible factors responsible for these changes (Fig. 10). However, JTMD is difficult to distinguish from baseline beach litter, unless specific items can be uniquely identified (*e.g.*, Japanese characters printed on the litter surface large enough to be detected in the photographs). During 9 months (our analyzed period in Year 2), no JTMD was identified by webcam monitoring. All photos taken by the camera are now opened to the public at http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html.

In Year 2, research was focused on the critical factors that determine the temporal variation of beach litter at the webcam site (and hence, US and Canadian coasts.) A large amount of drifting wood was washed ashore on the study beach, and its quantity fluctuated substantially through time. The number of drifting wood was used as an index of the marine debris quantities on the beach. To investigate the natural (oceanic and atmospheric) factors affecting the temporal variability, the time series of the beach litter quantity (mostly drifting wood) was compared with time series of satellite-derived wind speed and sea surface dynamic height. It was found that the quantity of marine debris fluctuated largely in accordance with variations of meridional (north-south) wind component – the beach litter quantity on the webcam site increased (decreased) when the southerly (northerly) winds prevailed. This is because the offshore-ward Ekman flow (hence, coastal upwelling) induced by the northerly winds prevents offshore marine debris from approaching the beach, and thus, decreased the amount of debris washed ashore. Thus, the winds off the beach and the occurrence of coastal upwelling along the west coast of North America act as the stimulus for marine (and tsunami) debris to be washed ashore on the beaches.

Fig. 10 Original photograph taken by webcam (left panel) and photograph after applying the projection transformation method (right panel). Image provided by Atsuhiko Isobe, Kyushu University.

RISK OF INVASIVE SPECIES

Biodiversity Assessment

To date, over 500 samples of JTMD have been acquired from Alaska, British Columbia, Washington, Oregon, California, and the Hawaiian Islands, and have either been analyzed or are in the process of being studied. The majority of intercepted items is from Washington, Oregon, and the Hawaiian Islands, and includes vessels, post-and-beam lumber, floats (buoys), pallets, baskets, and a wide variety of additional objects. The invasive species team focuses on the identification of the species associated with JTMD, utilizing both morphological and genetic approaches, as well as the screening of mussels for the presence of endoparasites. A total of 58 taxonomic experts from Australia, Canada, China, Germany, Japan, Mexico, Norway, Russia, Singapore, and the United States have been engaged in the research. Overall, 352 Japanese species have been identified as surviving transoceanic rafting, including 80 species of algae. About 77% of the invertebrate diversity is represented by 4 major phyla (Bryozoa – 69 species; Mollusca – 55; Crustacea – 54; Annelida – 37).

In Year 2, JTMD items continued to arrive on North American and Hawaiian shorelines. For example, at least eight vessels landed on the Oregon and Washington coasts between March 22 and April 15, 2016. JTMD objects intercepted in March 2016 included new Japanese species such as the sea anemones, *Anthopleura asiatica* and *Diadumene lineata*, not observed in previous years (Fig. 11). These recoveries of new objects and new drift species indicate that quantities of JTMD, with associated Japanese species, remain in the North Pacific Ocean and will continue to arrive. They also highlight the need to continue research on the incoming debris items to better understand their potential for facilitating invasions of North American and Hawaiian coastlines.

In addition, a survey of the fouling invertebrates and intertidal algae species has been conducted in the Tohoku region of Japan. Fouling panels have been deployed at three different sites in Japan; a subset of panels was retrieved after one month and the remainder after three months (Fig. 12). After the panels were processed and the attached species were morphologically identified, specimens were sent for genetic bar-coding analysis in the United States. This research aims to obtain a thorough collection of fouling organisms to morphologically and genetically complement the existing collection of JTMD species to those present in Japan. A total of

195 species were identified across the three sites. These species will be cross-referenced with those detected on JTMD and used to inform the risk assessments. A second survey will be conducted early in Year 3 to more closely align with the timing of the 2011 tsunami event. Intertidal surveys for algae were conducted in the same region of Japan, and 82 specimens were gathered for genetic sequencing and comparison to samples collected from JTMD items in North America and Hawaii. At least 25 of the sampled species have been found on JTMD and their morphology and DNA sequences will be compared.

Fig. 11 Examples of sea anemone species found associated with JTMD items in Year 2: Anthopleura asiatic *(left) and* Diadumene lineata *(right).*

Fig. 12 Map of fouling panel deployment sites in the Tohoku area of Japan (middle), site photographs (left) and examples of the fouling panels from each site after a 1-month deployment (right). Image provided by Karin Baba, Japan NUS Co.

Detection of Invasions

In Year 2, a series of surveys using a number of different field methods were used in order to detect the potential presence of JTMD species in North America and Hawaii. To survey for biofouling species, standardized surveys using collector plates were conducted in the bays of Alaska, British Columbia, Washington, Oregon, California, and Hawaii (Table 2). Panels were retrieved and processed, and the morphological and genetic analyses are in progress.

Table 2 The number and location of fouling panels deployed in Year 2.

Region	Location	Sites	Total Panels
Alaska	Ketchikan	3	30
British Columbia	Prince Rupert	10	50
British Columbia	Ucluelet/Tofino	2	20
Washington	Neah Bay	2	10
Washington	Grays Harbor	2	20
Washington	Willapa Bay	2	20
Oregon	Yaquina Bay	10	50
California	Humboldt Bay	10	50
California	San Francisco Bay	10	100
Hawaii	Oahu	11	110
Japan	Tohoku	3	70
Total		65	530

Intertidal algae surveys to search for new invasions and to collect specimens to compare with JTMD species were conducted in Washington State and Oregon in Year 2. Over 300 specimens from 100 species were collected in Grays Harbor, Washington and near Hatfield Marine Science Center, Oregon. DNA sequences have been obtained from over 200 of these specimens, and the morphological and genetic analysis of these specimens will continue in Year 3. Biogeographical analyses of representative taxa from JTMD have yielded interesting and useful results. For example, *Petalonia fascia* is a common ephemeral brown alga growing on diverse substrates including artificial structures in the intertidal zone, and is frequently found on JTMD. The species has broad distributional ranges in temperate and cold water seas. The haplotypes of the specimens on JTMD were all of group-a, whereas field-collected specimens from Washington, Oregon and California were all of group-b (Fig. 13) suggesting an earlier arrival in North America by some other vector(s). Therefore, the *P. fascia* specimens were considered to have originated from Japan.

To survey for NIS parasites and pathogens in mussels on the Pacific coast of North America, mussels were collected from bays in Alaska to California (Fig. 14). To date, more than 3,800 mussels have been processed for visual surveys of macroparasites and to preserve target tissues samples to screen genetically for protistan parasites (especially haplosporidians). The screening for parasites is focused on those taxa detected in mussels on JTMD, including the endoparasitic hydroid *Eutima*. To date, no *Eutima* have been detected in the surveyed mussels.

Despite the increased sampling effort spanning the full range of affected ecoregions, there has been no evidence of successful invasions of JTMD species. Our detection research will continue in Year 3.

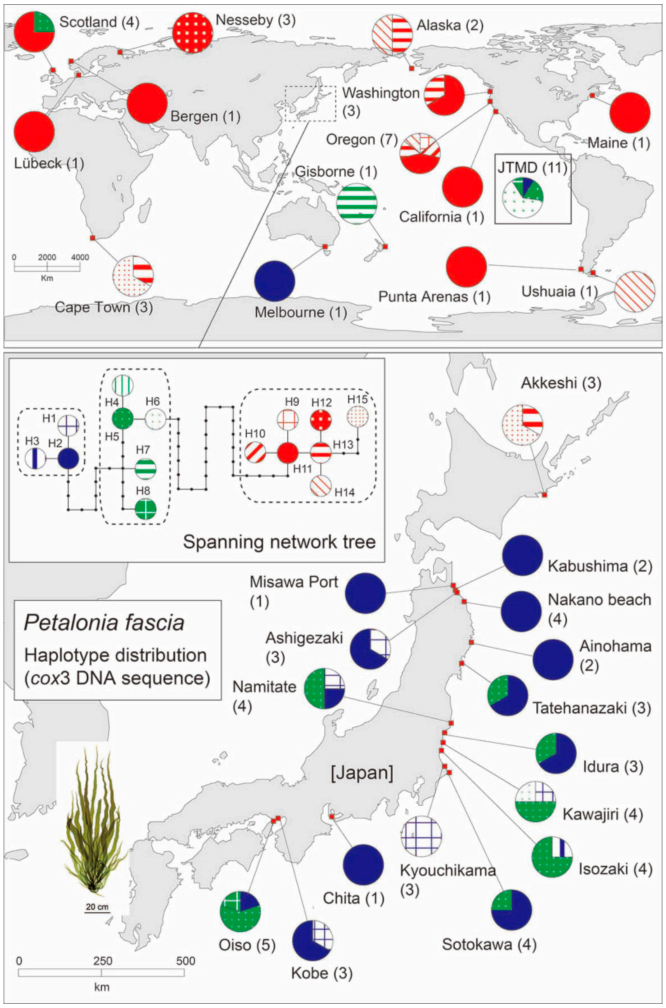


Fig. 13 Haplotype distribution and spanning network tree for the JTMD brown algal species Petalonia fascia*. Group a (red) and Group b (blue and green). Image provided by Hiroshi Kawai, Kobe University.*

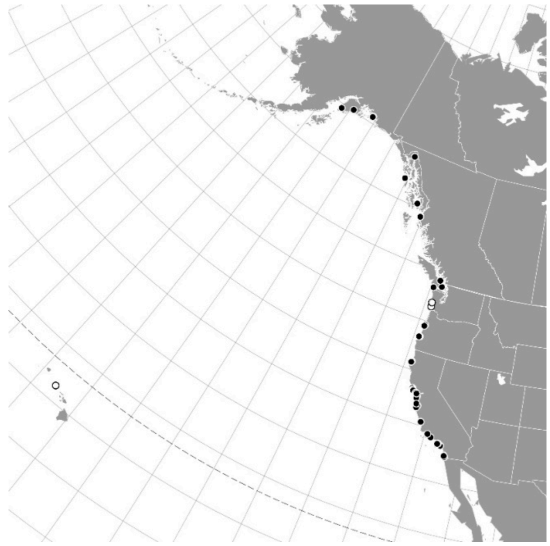


Fig. 14 Mussel survey locations surveyed to date (dark circles) and planned (open circles). Image provided by Gregory Ruiz, Smithsonian Environmental Research Center.

Risk Assessment

Species-level risk assessment

In order to evaluate and prioritize higher-risk species associated with JTMD, a screening-level risk assessment is being conducted. In Year 2, a database of species-specific traits and tolerances was designed to synthesize published literature on global invasion history, potential impacts, environmental tolerance, reproductive and growth strategies (Table 3). As of April 30, 2016, the database is complete for 238 of 274 invertebrate species. Once finalized (early in Year 3), the database will be housed by the Smithsonian Environmental Research Center as part of its National Exotic Marine and Estuarine Species Information System (NEMESIS), which will provide a comprehensive and valuable source of information on JTMD species to a variety of potential users.

Based on the information contained in the database, a species risk assessments will be conducted in Year 3 using a qualitative screening tool (Drolet *et al*. 2016), and a list of higher-risk invaders will be provided for North America and Hawaii.

Vector risk assessment

In order to evaluate the overall risk from tsunami debris, a vector risk assessment is being conducted. The risk assessment incorporates data from the invasive species, surveillance and monitoring, and modeling research activities. The invasive species research will provide data on cumulative species richness, species richness per debris item, and abundance. The surveillance and monitoring research will provide estimates of the number of debris items that made landfall in each region. The modeling research will provide data on the likely voyage routes and voyage durations of debris items. Finally, life history and environmental matching data from the invasive species team will be used to estimate the likelihood of establishment of species on debris items. When combined, there will be an estimate of relative risk to each region from JTMD and the relative risk of different types of debris items.

Table 3 Selected traits and definitions for the species-specific database.

Trait or Characteristic		Definition
Geographic Range	Native Range	Native range
		Latitudinal range
		Reproductive range
		Known genetic diversity
	Invasion History	Non-native range
		Prior invasion propensity
		Vectors of initial introduction
		Date of first recorded observation in Japan
		Date of first recorded observation in NA/Hawaii
	Impacts of non-native species	Impact in Japan
		Global impact
Life History Data	Reproduction	Internal vs. external fertilization
		Division of sexes (monoecious, dioecious)
		Type of spawning
		Type of larval development
		Method of asexual reproduction
	Mobility of adult stage	Mobile vs. sessile
	Reproductive cues	Temperature thresholds, wave action, stressors, *etc*.
	Reproductive timing	Days of year reproduction reportedly occurs
	Fecundity and egg size	Approximate brood size, number of broods/year
Ecological and Biological Data	Temperature survival	Water temperature regime for survival
	Temperature reproduction	Water temperature regime for reproduction
	Salinity survival	Salinity regime (Oligohaline, Euryhaline, *etc.*)
	Salinity reproduction	Salinity regime (Oligohaline, Euryhaline, *etc.*)
	Depth	Depth regime
	Habitat	Ecosystem that the species occupies
		Preferred Habitat types, Substrate types
		Level of exposure that the species prefers or occupies
	Trophic level	Trophic group
	Foraging Strategy	Foraging strategy: specialized prey diet *vs* generalist
	Natural control agents	Predators, competitors, disease, disturbance
	Associated species	Diseases, parasites, or pathogens

Two workshops were convened to develop the framework to evaluate the risk of JTMD as a vector. The first workshop was held November 16–18, 2015, at the Smithsonian Environmental Research Center in Annapolis, Maryland, USA, and the second took place on January 17, 2016, in association with the 9th International Conference on Marine Bioinvasions in Sydney, Australia (Fig. 15). The framework is now being applied in a probabilistic risk assessment model using data from the biodiversity and modeling research teams (Fig. 16). Results will be reviewed at a small workshop in August 2016. A manuscript detailing the framework and model results is expected to be submitted to a peer-reviewed journal in Year 3.

Fig. 15 Workshop attendees in Annapolis, Maryland (left): back row – Tara Holtz (USA), Greg Ruiz (USA), Glenn Fowler (USA), Gordon Copp (UK), Stephan Gollasch (Germany), Cathryn Clarke Murray (PICES), Claudio DiBacco (Canada) and Thomas Therriault (Canada); front row – Jim Carlton (USA), Claire Wilson (Canada) and Alisha Dahlstrom (USA), and in Sydney, Australia (right): Marnie Campbell (Australia/New Zealand), Chad Hewitt (Australia/New Zealand), Sonia Gorgola (Australia), Chris McKindsey (Canada), Thomas Therriault (Canada), Oliver Floerl (New Zealand), Grant Hopkins (New Zealand), Cathryn Clarke Murray (PICES).

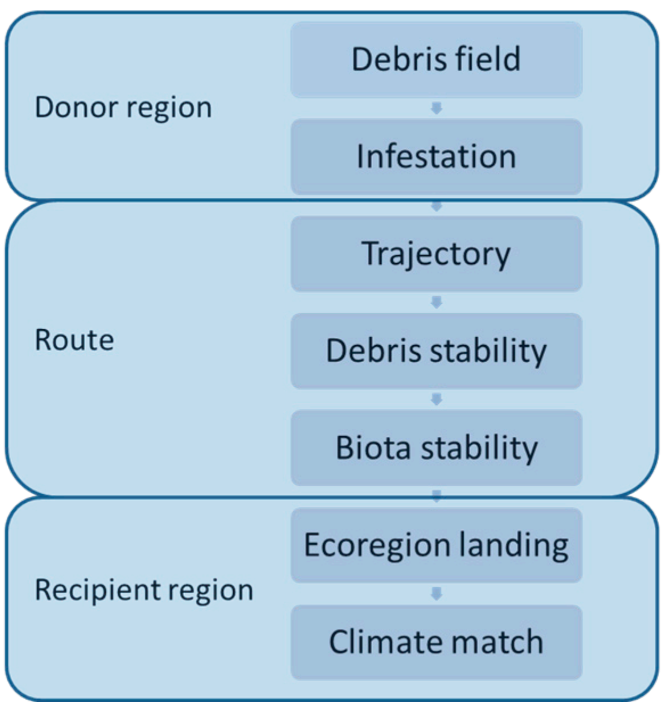


Fig. 16 Framework for the risk assessment of the JTMD invasion vector. Image provided by Cathryn Clarke Murray, PICES.

Publications, Presentations and Outreach

Publications

Miller, J.A., Carlton, J.T., Chapman, J.W., Geller, J.B., and G. Ruiz. 2015. The mussel *Mytilus galloprovincialis* on Japanese tsunami marine debris: A potential model species to characterize a novel transport vector. PICES Press 24(1): 24–28.

Maximenko, N., MacFadyen, A., and M. Kamachi. 2015. Modeling the drift of marine debris generated by the 2011 tsunami in Japan, PICES Press 23(2): 32–36.

Presentations

Bychkov, A., Clarke Murray, C., Therriault, T., Wallace, N., and H. Maki. Effects of marine debris caused by the Great Tsunami of 2011. 42nd Session of GESAMP (GESAMP-42), UNESCO Headquarters, Paris, France, August 31–September 3, 2015 (poster and oral presentations).

Carlton, J., Chapman, J., Geller, J., Miller, J., Ruiz, G., Carlton, D., and M. McCuller. The invasion process model and the long-distance transoceanic dispersal of coastal marine organisms by Japanese tsunami marine debris. 9th International Conference on Marine Bioinvasions, Sydney, Australia, January 19–21, 2016 (oral presentation).

Clarke Murray, C. Connections and challenges: Lessons learned five years after the Great Japanese Tsunami of 2011. Special Seminar, Institute for Resources, Environment and Sustainability, University of British Columbia, Vancouver, Canada, March 8, 2016 (oral presentation).

Clarke Murray, C., Therriault, T., Wallace, N., Maki, H., and A. Bychkov. Effects of marine debris caused by the Great Tsunami of 2011. 9th International Conference on Marine Bioinvasions, Sydney, Australia, January 19–21, 2016 (poster presentation).

Geller, J.B., Campbell, T., Carlton, J.T., Chapman, J.W., Heller, P., Miller, J., and G.M. Ruiz. DNA barcode and metagenetic approaches for monitoring and surveillance of marine invasive species in North American waters, with focus on 2011 Japanese Tsunami Marine Debris-associated species. 9th International Conference on Marine Bioinvasions, Sydney, Australia, January 19–21, 2016 (oral presentation).

Hafner, J., Maximenko, N., and G. Speidel. Transport of JTMD in IPRC model simulations and observations. Hilo Symposium on Marine Debris and Tsunami Driftage, Hilo, Hawaii, USA, December 3, 2015 (oral presentation).

Hafner, J., Maximenko, N., Speidel, G., and K.L. Wang. 'Waves' of tsunami debris: Effect of the windage. Workshop on Mission Concepts for Marine Debris Sensing, Honolulu, Hawaii, USA, January 19–21, 2016 (oral presentation).

Hafner, J., Maximenko, N., Speidel, G. and K.L. Wang. 'Waves' of tsunami debris in Hawaii: Effect of the windage. IPRC Annual Symposium, Honolulu, Hawaii, March 29, 2016 (oral presentation).

Hansen, G.I., Hanyuda, T., and H. Kawai. Marine Algae arriving on Japanese Tsunami Marine Debris (JTMD) and their invasion threat to the coasts of Oregon and Washington, USA. 9th International Conference on Marine Bioinvasions, Sydney, Australia, January 19–21 2016 (poster presentation).

Kako, S., Sugizono, S., Kataoka, T., Yufum, K. and A. Isobe. Webcam monitoring of marine debris on the western coast of the US. Annual Meeting of the Japanese Oceanographic Society, 16S25-12, Tokyo, Japan, March 15, 2016 (oral presentation in Japanese).

Kataoka, T., Kako, S., Clarke Murray, C., Plybon, C., Murphy, T.A., Barnea, N., Hinata, H., and A. Isobe. Techniques for quantifying the accumulation of marine debris on beaches. Workshop on Mission Concepts for Marine Debris Sensing, Honolulu, Hawaii, USA, January 19–21, 2016 (oral presentation).

Miller, J., Carlton, J., Chapman, J., Geller, J., and G. Ruiz. The Mussel *Mytilus galloprovincialis* on Japanese Tsunami Marine Debris: A Potential model species to characterize a novel transport vector. 9th International Conference on Marine Bioinvasions, Sydney, Australia, January 19–21, 2016 (poster presentation).

Maximenko, N. Modeling the drift of marine debris generated by the 2011 Tsunami in Japan. Oceania Regional Response Team Meeting, Pearl Harbor, Hawaii, USA, September 17, 2015 (oral presentation).

Maximenko, N. Surface currents and the motion of marine debris. The 2nd GlobCurrent User Training and Development Meeting, Brest, France, November 4–6, 2016 (pre-recorded presentation).

Maximenko, N., Hafner, J., MacFadyen, A., and M. Kamachi. Predictability of marine debris motion simulated with numerical models and diagnosed using oceanographic satellite data. Ocean Surface Topography Science Team Meeting, Reston, Virginia, USA, October 20–23, 2015 (oral presentation).

Maximenko, N., Hafner, J., MacFadyen, A., Kamachi, M. and C. Clarke Murray. Using the data from accidents and natural disasters to improve marine debris modeling. Ocean Sciences Meeting, New Orleans, Louisiana, USA, February 21–26, 2016 (oral presentation).

Maximenko, N., Hafner, J., MacFadyen, A., Kamachi, M., and G. Speidel. Synthesis of numerical drift models and JTMD boat reports: first signs of quantitative consistency. Hilo Symposium on Marine Debris and Tsunami Driftage, Hilo, Hawaii, USA, December 3, 2015 (oral presentation).

Maximenko, N., Hafner, J., MacFadyen, A., and M. Kamachi. Using disaster debris data to train dynamical models. Workshop on Mission Concepts for Marine Debris Sensing, Honolulu, Hawaii, USA, January 19–21, 2016 (oral presentation).

Maximenko, N., Hafner, J., Speidel, G., and K.L. Wang. Oceanography of marine litter. IPRC Annual Symposium, Honolulu, Hawaii, USA, March 29, 2016 (oral presentation).

Maximenko, N., Hafner, J., MacFadyen, A., Kamachi, M., and G. Speidel. Synthesis of marine debris modeling and observations: Recent progress in understanding and applications. 2016 New Year Symposium on Marine Litter, Tokyo, Japan, January 23–24, 2016 (oral presentation).

Maximenko, N., MacFadyen, A., and M. Kamachi. Modeling the drift of marine debris generated by the 2011 tsunami in Japan. 42nd session of GESAMP, IOC-UNESCO Headquarters, Paris, France, August 31–September 3, 2015 (poster presentation).

Ruiz, G., Geller, J., Carlton, J., Chapman, J., Miller, J., Di Maria, R., Lohan, K., and R. Barnard. Japanese Tsunami Marine Debris: Potential transoceanic rafting of bivalve parasites and pathogens. 9th International Conference on Marine Bioinvasions, Sydney, Australia, January 19–21, 2016 (oral presentation).

Speidel, G., Maximenko, N., Hafner, J., and K.L. Wang. The science behind the Japan tsunami marine debris in Hawaii. Hilo Symposium on Marine Debris and Tsunami Driftage, Hilo, Hawaii, USA, December 3, 2015 (oral presentation).

Treneman, N., Carlton, J., Borges, L., Shipway, J.R., Raupach, M., and B. Altermark. Shipworms (Bivalvia: Teredinidae) in Japanese Tsunami Marine Debris (JTMD). Coastal and Estuarine Research Federation (CERF) conference, Portland, Oregon, USA, November 12, 2015 (oral presentation).

OUTREACH

Carlton, J. Tsunamigenic Megarafting: The Invasion process model and the long-distance transoceanic dispersal of coastal marine organisms by Japanese Tsunami Marine Debris. Special Seminar hosted by the Sessile Organisms Society of Japan, Tokyo, Japan, February 24, 2016 (oral presentation).

Clarke Murray, C. Effects of Marine Debris. Talk to Grade 6 elementary school students at Tong'an Road Primary School in Qingdao, China, in association with the 2015 PICES Annual Meeting (oral presentation).

Clarke Murray, C. Art, Aliens, and Radiation. Vancouver Aquarium public event, Vancouver, BC, Canada, March 7, 2016 (https://www.youtube.com/watch?v=wo7L6quifpk).

Hansen, G.I., Hanyuda T., and H. Kawai. Marine Algae arriving on Japanese Tsunami Marine Debris (JTMD) and their invasion threat to the coasts of Oregon and Washington, USA. Marine Science Day, Hatfield Marine Science Center, Newport, Oregon, USA, April 9, 2016 (poster presentation).

Hansen, G.I., West, J., Zuccarello, J., and T. Hanyuda. The pink crust, a new-to-science algae on hard plastic debris. Marine Science Day, Hatfield Marine Science Center, Newport, Oregon, USA, April 9, 2016 (poster presentation).

Hansen, G.I. Some marine algae on Japanese Tsunami Debris. Marine Science Day, Hatfield Marine Science Center, Newport, Oregon, USA, April 9, 2016 (poster presentation).

Hansen, G.I. Determining the source of the Seal Rock debris boat. Marine Science Day, Hatfield Marine Science Center, Newport, Oregon, USA, April 9, 2016 (poster presentation).

Isobe, A. Remote monitoring of marine debris. Science Seminar hosted by the Oregon State University and Surfrider Foundation, Hatfield Marine Science Center, Newport, Oregon, USA, March 21, 2016 (https://oregon.surfrider.org/monitoring-marine-debris-with-remote-web-cam-technology/).

Treneman N. Shipworms and tsunami debris. Presentation at the Museum of the North Beach, Moclips, Washington, USA, April 7, 2015 (oral presentation).

Radio Interview: Marine life taken global by tsunami trash. Radio New Zealand. Nine to Noon, March 30, 2016 (http://www.radionz.co.nz/national/programmes/ninetonoon/audio/201795022/japanese-earthquake-debris).

ONLINE RESOURCES

Tsunami debris diagnostic and forecasts are available at http://iprc.soest.hawaii.edu/users/hafner/NIKOLAI/SCUD/TSUNAMI/DEBRIS/PICES/Tsunam_diagnostic_and_forecast.html.

All photos taken by the web camera installed and maintained at a site in Oregon (USA) are now available to the public at http://nilim-camera1.eco.coocan.jp/webcam/newport/index.php.

The debris ranking segments, maps and photographs for debris accumulation hot spots in British Columbia, Canada, using PICES aerial survey, are now available to the public through an online mapping portal at http://www.arcgis.com/home/webmap/viewer.html?webmap=3c5fb88b7f3f4d97974615acad67af3e.

Details on collaboration with Province of British Columbia to map debris accumulation for removal efforts can be viewed at http://www2.gov.bc.ca/gov/content/environment/waste-management/recycling/tsunami-debris-removal-recycling.

MEETINGS AND WORKSHOPS

Event	Location	Dates
3rd Project Co-Chairs meeting	Silver Spring, Maryland, USA	May 11–12, 2015
4th Project Co-Chairs meeting at PICES-2015	Qingdao, China	October 16, 2015
First Vector Risk Assessment workshop	Annapolis, Maryland, USA	November 16–18, 2015
Second Vector Risk Assessment workshop (in conjunction with 9th International Conference on Marine Bioinvasions)	Sydney, Australia	January 17, 2016
5th Project Co-Chairs meeting and 3rd Project Science Team meeting, followed by the Tohoku coast field expedition	Tokyo, Japan	February 22–26, 2016

Fig. 17 Attendees at the 4th Project Co-Chairs meeting in Qingdao, China. Left to right: Taichi Yonezawa (Japan), Karin Baba (Japan), Hideaki Maki (Japan), Robin Brown (PICES), Thomas Therriault (Canada), Cathryn Clarke Murray (PICES) and Alexander Bychkov (PICES).

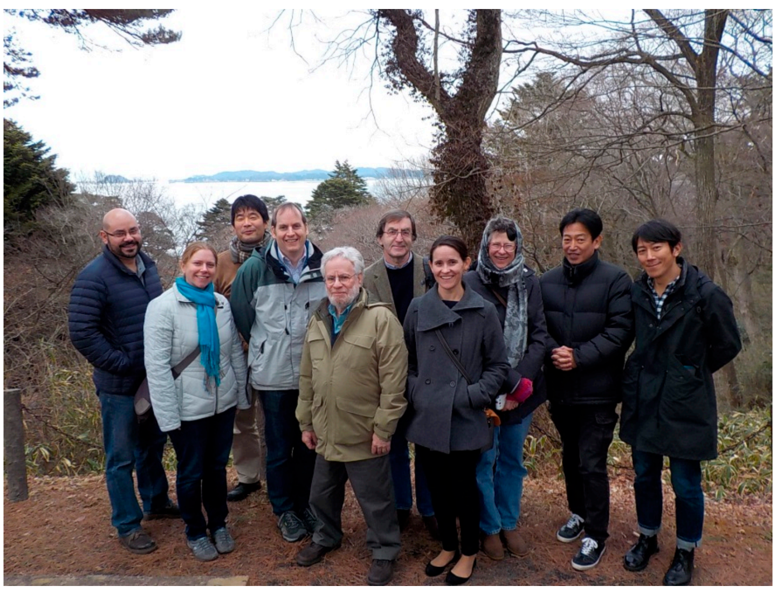


Fig. 68 Attendees at the Tohoku coast field expedition associated with the 3rd Project Science Team meeting in Tokyo, Japan. Left to right: Leo Zuckerman, Nancy Wallace (USA), Hideaki Maki (Japan), Thomas Therriault (Canada), Jim Carlton (USA), Alexander Bychkov (PICES), Cathryn Clarke Murray (PICES) Nancy Treneman (USA), Hideki Takami (Tohoku National Fisheries Research Institute (TNFRI), Japan) and Kazuaki Tadokoro (TNFRI, Japan).

APPENDICES

For more details on specific research, please contact the lead authors.

Appendix 1

PROJECT SCIENCE TEAM MEMBERSHIP

Canada

Dr. Patrick F. Cummins
Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 W. Saanich Rd.,
Sidney, BC
Canada V8L 4B2
Phone: (1-250) 363-6553
E-mail: Patrick.Cummins@dfo-mpo.gc.ca

Dr. Thomas W. Therriault (Co-Chairman)
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Rd.
Nanaimo, BC
Canada V9T 6N7
Phone: (1-250) 756-7394
E-mail: Thomas.Therriault@dfo-mpo.gc.ca

Japan

Dr. Atsuhiko Isobe
Research Institute for Applied Mechanics
Kyushu University
6-1 Kasuga-koen
Kasuga, Fukuoka
Japan 816-8580
Phone: (81-92) 583-7726
E-mail: aisobe@riam.kyushu-u.ac.jp

Dr. Hiroshi Kawai
Kobe University
Research Center for Inland Seas
Rokkodai Nadaku
Kobe Hyogo
Japan 657-8501
Phone: (81-78) 803-5710
E-mail: kawai@kobe-u.ac.jp

Dr. Hideaki Maki (Co-Chairman)
National Institute for Environmental Studies
16-2 Onogawa
Tsukuba, Ibaraki
Japan 305-8506
Phone: (81-29) 850-2394
E-mail: hidemaki@nies.go.jp

USA

Dr. James Carlton
Williams College
P.O. Box 6000,
75 Greenmanville Ave.
Mystic, CT
U.S.A. 06355
Phone: (1-860) 572-5359
E-mail: james.t.carlton@williams.edu

Dr. Amoreena (Amy) MacFadyen
Emergency Response Division
NOAA Office of Response and Restoration
Building 3, 7600 Sand Point Way NE
Seattle, WA
U.S.A. 98115-6349P
Phone: (1-206) 526-6954
E-mail: amy.macfadyen@noaa.gov

Ms. Nancy Wallace (Co-Chairman)
Marine Debris Division
NOAA Office of Response and Restoration
N/ORR, SSMC4, Rm. 10201
1305 East-West Hwy
Silver Spring, MD
U.S.A. 20910
Phone: (1-301) 713-2989 x125
E-mail: nancy.wallace@noaa.gov

PICES

Dr. Cathryn Clarke Murray (*ex-officio*)
Visiting Scientist
PICES Secretariat
9860 West Saanich Road
Sidney, BC,
Canada V8L 4B2
Phone: (1-250) 363-6911
E-mail: cmurray@pices.int

Dr. Alexander Bychkov (*ex-officio*)
Project Coordinator
PICES Secretariat
9860 West Saanich Road
Sidney, BC,
Canada V8L 4B2
Phone: (1-250) 363-6346
E-mail: bychkov@pices.int

Appendix 2

North Pacific Marine Science Organization (PICES)
PICES-MoE project on "*Effects of marine debris caused by the Great Tsunami of 2011*"
Year 2 Final Report

1. PROJECT INFORMATION

Title:	Modeling studies in support of research on impact of alien species transported by marine debris from the 2011 Great Tohoku Tsunami in Japan (Year 2)
Award period	April 1, 2015 – March 31, 2016
Amount of funding	US$63,976.22
Report submission date	April 30,2016
Lead Author of Report*	Nikolai Maximenko

**Although there may be only one lead author of the report, all PIs and co-PIs of the project, as identified in the approved statement of work and listed below, are responsible for the content of the Final Report in terms of completeness and accuracy.*

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

PI: Nikolai Maximenko <maximenk@hawaii.edu>

Recipient Organization: University of Hawaii

Co-PI: Amy MacFadyen <amy.macfadyen@noaa.gov>

Co-PI: Masafumi Kamachi <mkamachi@mri-jma.go.jp>

2. EXECUTIVE SUMMARY

The Great Tohoku Tsunami of March 11, 2011 created an unprecedented amount of marine debris, having a great potential of floating in the ocean for a very long time. After the Japan tsunami marine debris (thereafter JTMD) started arriving on the US/Canada west coast and later in Hawaii, surprising discoveries have been made: numerous Asian species were first found on two of the four docks that were washed from Misawa harbor, then on an increasing number of skiffs, and later on progressively smaller and diversified objects, including objects originating not only from coastal waters but also from the land.

Marine debris has a large effect on the marine life. Every tiny solid piece, floating on the sea surface, becomes colonized and creates a local eco-system. The ability of debris to attract sea life is well known to fishers, who broadly use fish aggregating devices (FADs), floating rafts, which

are essentially artificial marine debris. While materials of natural origin (e.g., driftwood) degrade relatively fast, man-made materials (plastic, glass, metal) can last in the marine environment for many years, decades, or even centuries. Species, living on such debris, can therefore travel over long distances and may become alien or even invasive species at their final destination. Driftage was one of the ways how volcanic islands (such as Hawaii) have got their flora. At the same time, great differences between coastal species living on opposite sides of the ocean suggest that surviving such long-distance travel is difficult. It is an open question whether in the era of man-made materials a single strong tsunami can have a stronger effect on the Asia-America exchange than natural marine debris over previous millions of years.

The current state of the observing systems does not allow basin scale monitoring of the ecosystem or the marine debris, and field surveys are limited to episodic inspections of particular locations, mainly of the shore. In this situation, numerical models are used to uniquely provide the information on the general context, bigger picture, large-scale patterns, and past and future timelines of JTMD concentration at particular locations and in larger regions. Modeling support for this PICES-MoE project relies on simulations with three different models: IPRC (UH), GNOME (NOAA), and SEA-GEARN/MOVE-K7 (Japan). These models were used to study particle and tracer motions within a broad range of windage parameters, which describe the direct effect of the wind on items floating on the ocean surface.

Numerical models have own limitations. They do excellent work in simulating the ocean dynamics that is well understood and monitored by the global observing system but they have to rely on assumptions and parameterizations on scales and in variable that are not observed. One of such variable that plays a critical role in the drift of marine debris is surface currents. However paradoxical may it sound, surface currents are not measured directly or by satellites and they differ between commonly used numerical models. This creates tremendous difficulties for simulating trajectories of marine debris, floating on the sea surface. To add to the complexity, debris interaction with wind, waves and currents is very individual for each item and changes with time as the item gets bio-fouled or degrades.

To resolve these difficult problems, a number of methods have been developed in this project that allowed to address multiple 'unknowns' and uncertainties by grouping them under a joint wind-related drift component and optimizing simulations by selecting the "best" windage parameter. Such optimization has been first applied to the timeline of reports from the US/Canada coastline on JTMD boats/skiffs. Using the optimal windage parameters, models successfully reproduced main peaks of JTMD arrivals in 2012-2014. They also suggested that the initial number of JTMD boats was close to 1000, of which 60-70% were still floating in the ocean by the end of year 2014. Models predicted a long-term residence of boats in the "garbage patch" (the area in the eastern North Pacific between Hawaii and the US west coast where sea surface currents converge and collect objects having moderate or no exposure to the wind) and their regular arrivals on shore in the next several years. This prediction was confirmed by coastline observations in 2015.

New techniques have been also developed that allow to select optimal windage value using sparse at-sea reports, commonly biased toward regions of active navigation, and also for objects that were observed more than once or whose start and end positions/times are known (for example, Misawa docks, found in 2012 in Oregon, Washington and north of Hawaii).

Initial experiments with model particles later evolved into tracer simulations that allow to treat all kinds of uncertainties in a probabilistic way. As a result, an original technique is now available to describe probable trajectories of individual objects and probable oceanographic conditions along these paths. This information is critical for understanding the history and the fate of the biota, colonizing JTMD. The ultimate goal of the modeling activity in this project is conversion of limited point-observations into a ‘bigger picture’ (spatial patterns, timelines and integral estimates). This task includes using the fundamental knowledge of the ocean processes and filling gaps by analyzing the JTMD data.

While the present-day risks of invasion can be estimated by processing JTMD arrivals in previous years, future predictions also require understanding the state of the eco-system of the garbage patch where much of JTMD is floating. The project results have a potential of not only improving our scientific understanding of the ocean dynamics, but can also help to advance ocean management by articulating needs for better marine debris observing system, education and environmental policy.

Appendix 3

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

Year 2 Final Report

1. PROJECT INFORMATION

Title:	Hawaiian Islands Marine Debris Aerial Imagery Survey
Award period	June 1, 2015-January 31, 2016
Amount of funding	$85,000 CAD
Report submission date	March 24, 2016
Lead Author of Report*	Brian Neilson

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Brian Neilson, Hawaii Department of Land and Natural Resources (Brian.J.Neilson@hawaii.gov)

2. EXECUTIVE SUMMARY

The Hawaiian Islands have been a major landing site for marine debris from the Great Japanese Tsunami of 2011. The debris has served as a rafting mechanism for non-native species to the Hawaiian Islands. Managers and researchers are monitoring marine debris landing sites for the presence of non-native species. As part of the effort to identify Japanese tsunami marine debris (JTMD) on the Hawaiian Islands, a remote sensing firm, Resource Mapping Hawaii, was contracted to collect imagery of approximately 2,000 km of coastline. The imagery was then analyzed using remote sensing techniques to locate, categorize, and quantify marine debris in the main Hawaiian Islands in a separate PICES project.

Appendix 4

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

Year 2 Final Report

1. PROJECT INFORMATION

Title:	Japanese Marine Debris Aerial Imagery Analysis and GIS Support
Award period	January 1, 2016 – April 30, 2016
Amount of funding	$14,995.00
Report submission date	April 29, 2016
Lead Author of Report*	Kristine Davidson

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Michael P. Hamnett, Principal Investigator, Executive Director, RCUH (mhamnett@rcuh.com)
Kristine Davidson, Co-Principal Investigator, Program Director, HCRI-RP (KristineDavidson@hawaii.rr.com)

2. EXECUTIVE SUMMARY

Purpose and Objectives

After the Tohoku earthquake and resulting tsunami devastated Japan in 2011, marine debris from the event has found its way across the Pacific through oceanic currents and processes, and has been arriving on coastlines of the Hawaiian Islands since 2012. This debris introduces many potential hazards to the natural environment, including wildlife entanglement and ingestion as well as the possible establishment of invasive species that raft on debris items. In addition, debris can damage fragile reef infrastructure and coastal habitat, and can be a deterrent to the tourism that sustains much of Hawaiʻi's economy.

In order to characterize the potential ecological consequence of tsunami debris, it is important to characterize the debris itself. Understanding the type, size, and location of debris accumulating on Hawaiian coastlines is crucial in developing plans to streamline the removal process and mitigate any negative impacts this debris may have on the islands and their inhabitants. Given the vast extent and remoteness of coastlines in the Hawaiian Islands, large scale surveillance efforts are needed to identify and describe these accumulations. Capture and analysis of high-resolution aerial imagery allows for rapid qualitative and quantitative assessments at this scale, providing data that can be used to plan further management actions and evaluate marine debris accumulation patterns in Hawaiʻi. During the previous project period, four of the eight Main Hawaiian Islands (Lānaʻi, Niʻihau, Kauaʻi, and Hawaiʻi Island) were surveyed using these methods. The goal of this project period was to continue analysis of the remaining islands (Maui, Molokaʻi, Kahoʻolawe, and Oʻahu) and combine this data with results from the previous analysis to provide a comprehensive assessment of debris accumulations for all of the Main Hawaiian Islands. This baseline data will support future investigations into effective management and removal strategies that aim to minimize the negative impact of this debris on the environment.

Objectives of the overall project were to locate, categorize, and quantify debris accumulations that may be associated with the Japanese tsunami of 2011 on coastlines of all eight Main Hawaiian Islands through analysis of high-resolution aerial imagery paired with ArcGIS mapping software. Production of maps, figures, and reports detailing findings were included in this objective, in order to provide useful data to community groups, research organizations, and government agencies across the islands with the capacity to develop management plans and conduct removal operations.

Methods

A remote sensing firm, Resource Mapping Hawai‘I (RMH), on a separate grant, collected aerial imagery of the coastlines of the Main Hawaiian Islands at 2-cm horizontal ground resolution, covering a swath of 200-300 meters that included shoreline and near-shore water. This imagery was then used to develop ortho-mosaic image datasets for analysis in ArcGIS. Prior to beginning analysis, coastlines were divided into segments, and debris categories were developed to classify debris by type and size. While there are limitations on the ability to determine debris types at this scale, categorization of identifiable debris is useful to determine possible ecological consequences; for example, nets and lines pose a serious entanglement hazard, while small plastics and foam are more likely to be mistakenly ingested by wildlife.

Imagery was analyzed by 1-mile coastline segment for systematic coverage of each island’s coastline, and each piece of debris observed was identified in ArcGIS on a point shapefile and given a unique, sequential identification number, starting at 1 within each one-mile segment. For each data point, attributes such as debris type (material), size (object area), and observer information and comments were also recorded. Size was approximated using the measurement tool within ArcGIS, and was estimated in meters squared and sorted into size classes. Once analysis for a segment was completed, the segment was given a rating based on density and distribution of debris. Other attributes, including total item count, dates analyzed, and observer information were also recorded for each segment. Once all segments from an island were complete, 20% of the total number of segments were chosen at random for quality control, which involved re-analysis by a different observer in order to assess accuracy and precision of data collection. Data from quality control analysis was used to refine and standardize the data collection process. Original data was used to generate maps in ArcGIS to display debris density and distribution along Hawai‘i’s coastlines. Data analyses to determine composition and size distributions of debris were also conducted and used to create figures.

Results

A total of 6,909 pieces of marine debris were identified on the coastlines of Maui, Moloka‘i, Kaho‘olawe, and O‘ahu. When combined with previous data for the remaining islands, a total of 20,658 marine debris items were identified across the Main Hawaiian Islands. Of the four islands surveyed during this project period, Moloka‘i had the highest concentration of marine debris, while O‘ahu had the lowest. When compared with results from the previous project period, Ni‘ihau was determined to have the highest density of marine debris statewide, containing 38% of the total debris identified. Moloka‘i was the next most dense overall, containing 14% of the total debris count, with O‘ahu remaining the least dense, at 5% of the total debris count. On all islands, marine debris was primarily concentrated on north and east facing shores, with western facing shores containing the least amount of debris.

Composition of debris varied between islands, but the most common type of debris on all islands was plastic, making up 47% of the overall composition of debris identified and between 37% and 63% on any individual island. When comparing total counts statewide, he next most common debris types were buoys and floats and derelict fishing gear, at 22% and 11%, respectively. The remaining categories each made up 7% or less of the total debris composition, varying up to 14% on individual islands.

Marine debris size was found to be less variable than type composition, with regards to the defined size classes. 86% of the total debris found statewide fell into the smallest category of less than 0.5 m^2, with similar concentrations on individual islands (84% to 89%). The three remaining size classes each made up 7% or less of the composition on any island, with 6% of all debris items being classified as small (0.1 – 1 m^2), and 8% of all items being divided equally between the medium (1 – 2 m^2) and large (> 2 m^2) size classes.

Achievements and Challenges

During the project period, aerial imagery analysis was completed for four of the Main Hawaiian Islands, identifying nearly 7,000 marine debris items potentially linked to the Japanese tsunami of 2011. This data was paired with previous data for the remaining islands, resulting in a comprehensive assessment of marine debris on coastlines of all eight Main Hawaiian Islands that identified over 20,000 data points of potential Japanese tsunami marine debris. Data analysis also provided a breakdown of composition and size of debris found, and maps generated in ArcGIS provided visual representation of debris density and distribution on the coastlines of Hawai‘i. Various additional analyses were also conducted in the remaining time, providing size sampling data and comparisons over time for the Kahuku area of O‘ahu using historical imagery datasets, though this data is not yet fully processed.

Challenges to this project included imagery issues such as missing or fuzzy imagery, or difficulty determining item type or origin (*i.e.*, natural versus man-made). Issues with image quality can be attributed to the various conditions that affect the in-flight imagery collection process, such as variation in terrain and weather conditions. Gaps in imagery may also be a result of these factors, as well as flight restrictions over areas such as airports and military bases. Segments that could not be analyzed due to missing imagery are noted on maps and displayed as “No data” areas. Difficulty classifying debris items decreased over time, as analysts gained experience and became familiar with examples of debris encountered during the analysis process. Quality control procedures also helped to simplify the classification process through the development of standardized rules to enhance accuracy and precision of data collection between observers.

Timelines and Milestones

The aerial imagery collection process was conducted between August and November, 2015, and the image processing to create ArcGIS compatible files was conducted concurrently and continuously during this time. Aerial imagery analysis for the previous project period began in October 2015 and was concluded in December 2015. Aerial imagery analysis for this project period began in December 2015 and was concluded in February 2016. Data analysis and processing, final report writing, and additional tasks (size sampling, O‘ahu through time, *etc*.) were continued to present.

Appendix 5

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

Year 2 Final Report

1. PROJECT INFORMATION

Title:	Webcam monitoring of marine/tsunami debris
Award period	April 1, 2015 – March 31, 2016
Amount of funding	$55,000 CAD
Report submission date	April 30, 2016
Lead Author of Report*	Atsuhiko Isobe

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

PI: Atsuhiko Isobe, Kyushu University, Japan (aisobe@riam.kyushu-u.ac.jp)

Collaborators in Japan:
Hirofumi Hinata, Ehime University, Japan (hinata@cee.ehime-u.ac.jp)
Shin'ichiro Kako, Kagoshima University, Japan (kako@oce.kagoshima-u.ac.jp)
Tomoya Kataoka (Tokyo University of Science, Japan (tkata@rs.tus.ac.jp)

Collaborators in North America:
Charlie Plybon (Surfrider Foundation OR), Thomas Murphy (Hatfield Marine Research Center, OSU), Nir Barbea (NOAA), Nancy Wallace (NOAA), Cathryn Clarke Murray (PICES)

2. EXECUTIVE SUMMARY

To date, there are few published studies investigating temporal variations of beach litter quantity for a long time with monitoring intervals shorter than one month. Consequently, temporal variations of litter quantity on beaches, and critical factors for determining these variations have remained obscure. Thus, there is no way of knowing the appropriate and most-efficient frequencies of beach surveys and/or beach clean-up activity. An attempt was made to quantify the amount of tsunami debris that has continuously washed ashore on beaches on the west coast of North America. As a part of the project, a webcam was installed in Year 1 on a beach at Newport (Oregon, USA), to automatically take sequentially photographs of beach litter, which might include tsunami debris.

Kako *et al*. (2010) and Kataoka *et al*. (2012) established a sequential webcam monitoring system, and demonstrated that webcam monitoring is indeed more suitable for resolving temporal variation of beach litter quantity than *in-situ* observations conducted by eyes and hands. In this study, photographs of beach have been taken by the webcam every 60 min from April 2015 to the present (and now on-going) to elucidate the temporal variation of debris quantities and the possible factors responsible for these changes. However, it is

difficult to be distinguished tsunami debris from beach litter, unless specific items can be uniquely identified (*e.g.*, Japanese characters printed on the litter surface large enough to be detected in the photographs). Unfortunately, during 9 months (our analyzed period in Year 2), no tsunami debris was identified by webcam monitoring. To quantify the tsunami debris washed ashore on the beaches, our webcam monitoring was combined with other methods such as numerical modeling of tsunami debris from March 11, 2011 and/or aerial photography (see section 3 for detail) in Year 3.

In Year 2, our attention was focused on the critical factor to determine the temporal variation of beach litter on the webcam site (and hence, US and Canada coasts). A large amount of drifting woods was washed ashore on the beach, and its quantity fluctuated substantially in time. In the present study, the number of drifting wood was used as an index of the marine debris quantities on the beach. To investigate the natural (oceanic and atmospheric) factors determining the temporal variability, the time series of the beach litter quantity (mostly drifting woods) was compared with time series of satellite-derived wind speed and sea surface dynamic height. It was found that the quantity of marine debris fluctuated largely in accordance with variations of meridional (north-south) wind component – the beach litter quantity on the webcam site increased (decreased) when the southerly (northerly) winds prevailed. This is because the offshore-ward Ekman flow (hence, coastal upwelling) induced by the northerly winds prevents offshore marine debris from approaching the beach, and thus, decreased the amount of debris washed ashore. The conclusion is that the winds off the beach and the occurrence of coastal upwelling along the west coast of North America might act as a "key to open the gate" for marine (and tsunami) debris to be washed ashore on the beaches. All photos taken by the camera are now opened publicly on the website http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html.

To quantify marine debris on the west coast of North America, one of efficient combinations will be the webcam monitoring and aerial photography. The webcam has an advantage in monitoring marine debris continuously in time, although it has a disadvantage that this monitoring provides marine debris quantities only at a local site. On the other hand, the aerial photography can synoptically monitor the accumulation of marine debris over broad areas, although it also has a disadvantage that surveys are conducted sporadically, so that difficulty arises in considering the temporal variability of marine debris quantities with a high temporal resolution. Probably, the most reasonable approach for monitoring the marine debris with a fine resolution is a combination between the webcam monitoring and aerial photography. Therefore, a new technique was developed for marine debris monitoring with a high spatial-temporal resolution by using webcam and aerial photography.

In Year 2, an effective way was found to apply the projective transformation method to the aerial photographs. This way enables to successfully remove the geometric distortion from the aerial photographs. Thereafter, ratios of areas with and without beach litter (later referred to as "percent covers") were computed by extracting the pixels of beach litter from the images using the projective transformation method. The accumulation of marine debris on beaches of Vancouver Island was estimated by applying our image analysis to aerial photographs obtained by the aerial surveillance team of the ADRIFT project. It was found that beach litter accumulated to a greater extent on the south- and southeast-facing beaches of Vancouver Island and, consequently, concluded that the accumulation of beach litter depends on the cross-shore direction of the beach interacting with the major direction of offshore ocean currents.

Also investigated is the efficiency of a near-infrared camera to monitor lumbers that are potentially carrying invasive species onto beaches. The near-infrared monitoring experiments were successfully conducted on beaches in Japan this year. However, due to the budget decrease, this research cannot be financially supported in Year 3 of the project.

Appendix 6

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

Year 2 Final Report

Title:	Japanese Tsunami Marine Debris (JTMD) and Alien Species Invasions: PICES Year 2: Continued Interception of Non-Native Species on JTMD and Detection in North America to Understand Invasion Risk
Award Period:	April 1, 2015 - March 31, 2016
Amount of Funding:	US $341,944
Supplemental Funding:	US $9,532.89 (received March 2016)
Report Submission Date:	29 April 2016
Lead Author of Report:	James T. Carlton

Principal Investigators:

James T. Carlton james.t. carlton@williams.edu
Williams College

John W. Chapman john.chapman@oregonstate.edu
Oregon State University

Jonathan B. Geller geller@mlml.calstate.edu
Moss Landing Marine Laboratories

Gregory M. Ruiz ruizg@si.edu
Smithsonian Environmental Research Center

EXECUTIVE SUMMARY

Our research is focused on characterizing the biodiversity of marine protists, invertebrates and fish associated with Japanese Tsunami Marine Debris (JTMD) generated on March 11, 2011 by the Great East Japan Earthquake. An important rationale is to understand the invasion potential of non-indigenous species, and thus which non-native species should be on high-profile target search agendas. Over 500 samples of JTMD have been acquired from Alaska, British Columbia, Washington, Oregon, California, and the Hawaiian Islands, and have either been analyzed or are in the process of being studied. This work consists in large part of the identification of the species on the debris, utilizing both morphology and genetic approaches, as well as the screening of 1000s of mussels for the presence of endoparasites.

As of March 31, 2016, the majority of items intercepted and analyzed are from Washington, Oregon, and the Hawaiian Islands, and include vessels, post-and-beam lumber, floats (buoys), pallets, baskets, and a wide variety of additional objects. Items are corroborated and verified as JTMD -- that is, items believed to have been ejected into the ocean on March 11, 2011 -- by a combination of a broad spectrum of evidence, including formal confirmation of original owner by means of registration numbers or other identification as traced by the Japanese Consulate, unique Japanese manufactory, bioforensics (linking foundation JTMD biota to the fauna

typical of the Honshu tsunami epicenter), pulse event timing (a unique pulse of Japanese vessels and other debris with no landing history prior to 2012 in North America or Hawaii), and homogeneity of object identification (for example, 100% of all vessels identified by registration number have come solely from the four prefectures impacted by the tsunami). To date, 58 scientists from Japan, China, Russia, Singapore, the United States, Canada, Mexico, Australia, Norway, and Germany have been engaged in identifying JTMD species. Both morphological and genetic analyses remain in progress. In addition, we have worked closely with our Japanese PICES colleagues to assist in their survey of biofouling invertebrates in Japan. The primary aim of this survey is to provide identified specimens, using expertise in Japan, for DNA barcoding, to match and verify JTMD species.

Overall, 352 Japanese species have been identified as surviving transoceanic rafting, including approximately 80 algal taxa (the latter work under the aegis of G. Hansen and colleagues). 77% of the invertebrate diversity is represented by 4 major phyla (Bryozoa – 69 species; Mollusca – 55; Crustacea – 54; Annelida – 37). In the winter of 2015–16 and in the early spring of 2016, JTMD continued to arrive. For example, at least 8 JTMD vessels landed on the Oregon and Washington coasts between March 22 and April 15, 2016. JTMD objects intercepted in March 2016 included new Japanese species such as the sea anemones *Anthopleura asiatica* and *Diadumene lineata*, not observed in previous years. These recoveries of new objects and new drift species indicate that quantities of JTMD with associated Japanese species remain in the North Pacific Ocean and will continue to arrive.

JTMD wood debris in the ocean has been colonized by shipworms, which are bivalve mollusks. More than 150 woody items (largely consisting of the highly recognizable post-and-beam building wood from Japan) have been analyzed for shipworm species diversity, abundance, and frequency. Six species of non-native shipworms have been discovered in JTMD: 3 subtropical to tropical pelagic species, 2 Japanese coastal species and 1 cosmopolitan species. Of the other 5 species, at least two have established invasive populations elsewhere in the world.

Many of these species are not yet present on the North American Pacific Northwest coast or in Hawaii where the majority of JTMD has come ashore. Some of these, such as the large barnacle *Megabalanus rosa,* the bryozoan *Tricellaria inopinata*, and the tube worm *Hydroides ezoensis*, are well-known invasive species elsewhere around the world. We have also detected the endoparasitic hydroid *Eutima japonica* (known to cause shellfish mortalities) and the pathogenic protist *Haplosporidium* in JTMD mussels.

To detect the potential presence of JTMD a series of epibenthic sublittoral surveys (*via* deployed panels to analyze fouling communities) were conducted, and plankton samples and/or mussels were collected.

To survey for parasites and pathogens in mussels on the Pacific coast of North America, mussels were collected and processed from bays in California to Alaska. To date, we have processed more than 3,800 mussels for visual surveys of macroparasites and to preserve target tissues samples to screen genetically for protistan parasites (especially haplosporidians). The screening for parasites is focused on those taxa detected in mussels on JTMD, including the endoparasitic hydroid *Eutima*. To date, no *Eutima* have been detected in the surveyed mussels.

To survey for biofouling species, and working with our Canadian PICES colleagues, we implemented standardized surveys of biofouling communities for bays in California, Oregon, Washington, British Columbia, and Alaska. Fouling panels were deployed in each state or province, and a subset of these was collected for analyses. In Year 2, panels were retrieved and processed at most sites, and morphological and genetic analyses are in progress.

Zooplankton samples were collected at 10 sites from California to Alaska, and preserved for potential screening of JTMD species. To date, 99 plankton samples, 39 from British Columbia and 60 from Oregon and Washington, were received at MLML for DNA extractions for potential future PCR and sequencing-based detection of JTMD-associated species. Samples from Yaquina Bay were sequenced as a demonstration of concept, revealing introduced species long-known to be in the region, but not detecting any new JTMD-associated invasions.

In mussel (Mytilus) surveys, 250 mussels collected from Yaquina Bay were genetically identified. We used *Mytilus galloprovincialis* from San Diego as a positive control and to test sensitivity of the assay. All mussels tested were identified as the native Pacific coast species *Mytilus trossulus*; no *Mytilus galloprovincialis* were detected at this one bay based on late 2014 samples.

We worked intensively with colleagues in Hawaii to implement an identical biofouling survey to those along western North America. We provided protocols and staff time to advance this work. In Year 2, we focused on Oahu, with panels deployed at 11 sites (110 panels total). These were retrieved and processed by SERC staff in December 2015. This survey generated a similar set of vouchers for morphological and genetic analyses to those in North America. Hawaii has funded independent taxonomists for identification of some vouchers, and Williams College and SERC are continuing to provide assistance with detection of non-native species and data management and analysis. Voucher samples and whole-plate biomass was received at MLML for genetic analysis in April 2016.

We are now actively engaged in data vetting and analyses. We are standardizing data quality at the object (item) level for evenness, to address identifications that may be uneven in resolution (with some identifications still in progress) and to incorporate barcode results, in order to produce high quality resolution on frequency of different species or unique taxa per object across many hundreds of items. As part of the vetting process, we are also using the graphical and statistical analysis of the spatial and temporal patterns (object x date x location x taxa) to provide the critical QA/QC filtering step in verifying the robustness of the data (the standard approach to data vetting -- testing for outliers, unexplained deviations, etc.). Our goal is to provide a robust data set that will feed into the ADRIFT risk assessment components.

We are preparing a photo and data catalogue of JTMD for permanent online posting to assist individuals and agencies from around the Pacific Rim with identifications and classifications of JTMD objects and species.

Appendix 7

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*
Year 2 Final Report

1. PROJECT INFORMATION

Title:	Marine Algae arriving on JTMD (Japanese Tsunami Marine Debris) and their invasion threat to the coasts of Oregon and Washington, USA – Year 2
Award period	April 1, 2015 – March 31, 2016
Amount of funding	US $ 48,092.77
Report submission date	April 30, 2016
Author of the Report	Gayle I. Hansen

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

American Researcher:
Gayle I. Hansen, Oregon State University (hansengi@outlook.com)

Japanese Researchers (separate grant):
Takeaki Hanyuda, Kobe University (hanyut@kobe-u.ac.jp)
Hiroshi Kawai, Kobe University (kawai@kobe-u.ac.jp)

2. EXECUTIVE SUMMARY

Carried across the North Pacific on currents from Japan, marine debris from the Great Tohoku Tsunami of 2011 continues to arrive on Oregon and Washington shores, even 5 years after the tsunami has occurred. Therefore, our goals for Year 2 of the PICES-ADRIFT algal project have continued to be:

1) To identify and characterize the algae arriving on Japanese Tsunami Marine Debris (JTMD), particularly the new debris items. Our counts of the algae now reach around 80 species, and, of these, about 66% were already present in the NE Pacific before the tsunami.
2) To carefully examine the 66% of the species that are already on both coasts of the North Pacific so that we can verify their molecular and morphological differences and obtain clues to their spread in the North Pacific and to other areas around the world.

Both of these goals have involved collecting and morphologically studying the species as well as using molecular methods to determine and compare their DNA in populations on both coasts of the North Pacific and on debris. In addition to collecting the species from debris, all 3 researchers have now also collected and observed material of our JTMD algal species in their native habitats in the field during trips to the Tohoku coast of Japan and to selected sites along the Washington and Oregon coast (particularly our targeted site at Grays Harbor, Washington).

Methods

This year we continued using the same methods as in Year 1 to collect, sort, and preserve the material both from debris and from the field.

1) Collections are made by hand *via* scraping the material with a spatula or knife from the substrate, placing the material in plastic bags on ice, and then returning it to our laboratories for processing.
2) The algae (often mats of algae) are sorted using a microscope to separate out the individual species.
3) Each species collection is then pressed as a voucher (if large enough) and also preserved in 5% formalin in seawater (for morphological study and photography) and in silica gel (for DNA sequencing).
4) At the laboratory of GIH in Oregon, preliminary morphological identifications and species characterizations are carried out using a microscope and the available literature, and microscope slides are prepared for later photography.
5) Silica-gelled specimens of the problematic species are then delivered to the laboratory of HK and TH in Japan for sequencing and final DNA determinations using 1–3 genes.
6) After our determinations are complete: (a) GIH carries out anatomical studies and photography on the species, and (b) HK and TH conduct comparative sequencing analyses of our sequences with data at Kobe University and in the International Nucleotide Sequence Database (INSD).

The data from these studies will then be used for:

1) A paper that provides a checklist of the debris species and an analysis of their invasion threat to Oregon and Washington
2) A paper on our comparative haplotype survey that shows the world-wide distribution of the major debris species occurring on both Pacific coasts and also speculates on their methods of global spread.
3) An illustrated web-based accounting of the debris species that will eventually be incorporated into a hard copy guide to the debris species.
4) Papers will also be prepared that describe the new species we have found.

Results

Our studies and papers are still in progress, but we do have some updated information for this year.

During Year 1, our checklist of the species on tsunami debris was based on 28 documented debris items and included 64 species. Our Year 2 results are more tentative, but we have worked up 26 additional debris items and have increased our species numbers to 80. However, for Year 2, we have not yet determined that the source of all of the debris items was the tsunami and have not yet completed DNA determinations on all of the new-to-debris species. So, these numbers are likely to change.

Our search for "native" species conspecific with those on tsunami debris was also quite successful. In Japan, we collected 82 species from the Tohoku coast, and 1/3 of these were species also found on debris. This material is now being sequenced in Japan. In Washington and Oregon, we collected about 100 species from Grays Harbor alone (300 specimens). These species will be sequenced during the coming year.

Although we have uncovered many interesting projects from our studies, two come to mind as important to mention here.

1) **The origin of the Seal Rock debris boat:** In April 2015, an 8-meter-long debris boat was spotted off shore at Seal Rock, Oregon, near the Hatfield Marine Science Center. After much discussion, enough support was obtained for John Chapman (PICES support) and Jim Burke (Oregon Coast Aquarium) to visit and collect the boat offshore. The authorities were unsure of its origin but were convinced by the original collections to tow the boat into the South Beach Marina where it was sampled. The boat had none of the normal invertebrates that indicated JTMD, but it was coated with a wide variety of algal species. Where was it from? On the top deck of the boat was a dark green *Ulva* species that I knew my colleagues in Japan were very familiar with. Years earlier, TH had mapped the distribution of the haplotypes of this

alga, *Ulva pertusa*, in Japan. When I sent him the material from the boat, he was able to use his data to pin-point the exact source of the boat as from the Tohoku coast at Iwate and definitely from the tsunami. It was truly a remarkable study, and it is now in press for publication.

2) **The new-to-science pink crust:** For the past year, an unusual gelatinous pink crust has been arriving on plastic debris along the Washington and Oregon coast. Although I could guess, I had no real idea of what it might be, so I sent the material to Hanyuda-san to get in-line for sequencing. Months later, he sent me his results -- the alga was in the red algal class Stylonematophyceae, but it could not be identified from his sequence. Since, the pink crust continued to arrive here on numerous light-colored plastic debris items, I knew it was important to identify. By surveying the literature for papers on the Stylonematophyceae, I discovered that the world expert on the group was an old friend of mine in Australia. After several e-mails back and forth, he agreed to help me out with its identification. I sent material of the crust to his laboratory for culturing and study, and they have now determined that it is a new species. We are now in the process of naming and describing it and hope to have that paper out by this summer.

<u>Field observations on the 2015-2016 debris and its algal biota</u>

This fiscal year, the amount of debris arriving on Oregon and Washington shores has kept us extraordinarily busy, and it might be useful to provide a brief discussion of my observations on the debris that I have seen and its algal biota and also to pose questions to the zoologists about what is actually happening.

During much of the year, smaller debris items such as personal items, plastic floats, containers and large fish crates have arrived, but during the spring (and occasionally at other times) large derelict boats, often 15 feet or greater in length, have been arriving. This past month, 6 Japanese boats have arrived on our shores. Many of the debris items are coated by abundant pelagic animals, such as *Lepas anatifera* (the pelagic goose neck barnacle) and hydroids, and, on some items, filter feeders (mussels and oysters) and small herbivores have survived the trip. But, most of the other invertebrates, originally common on debris, now arrive dead (see J. Chapman's press interviews). Perhaps not so surprising is the fact that many of the larger debris items are still arriving populated by a wide variety of living, healthy, and highly reproductive algae. Moreover, on the items I have examined, nearly all of the algae (with a few exceptions) appear to be from Japan, and our DNA fingerprinting to date has shown this to be true.

The change in the balance of species on debris during their years at sea is a subject that I can only begin to approach, but I suspect that the diminished number of some animal species on debris is due to the limited availability of food and also, perhaps, to their reproductive methods. The continued abundance of algal species on some debris seems to be a testament to the fact that they derive their nutrition directly from the water column and that, as long as their other requirements are met (*e.g.*, submergence level, sunlight, nutrients, and available space) and they are not consumed by herbivores, they can survive and often thrive for long periods of time on the debris – actively reproducing and renewing their populations.

Another factor that I consider to be important is the longevity or life span of the species. The algae can be categorized into 3 groups: perennials, annuals, and ephemerals (the latter are short-lived and continually recycle themselves). The definitions vary a bit, but basically they are your garden plant definitions. Most likely, all of the algal species on debris are able to reproduce and recolonize their host since their propagules (spores and gametes) do not need to travel far and can settle immediately as long as hard substrata is available. However, the various developmental stages of the species do have specific requirements and these might not be available on debris. We have some clues as to survival strategies by the fact that the diversity of algae on debris occurs in the following order: ephemerals>annuals>perennials. The requirements of the ephemeral species appear to be mainly available, while this may not be true for the others. And, indeed, many of the larger annual species found on debris during the first year were not seen later. This included the large brown algae *Undaria pinnatifida, Alaria crassifolia, Costaria costata*, and *Desmarestia japonica* and *Desmarestia viridis*. One 2-year perennial species, *Saccharina japonica*, was discovered on debris during our first collecting year and one progeny was found in year 2, but then it disappeared from debris altogether.

Competition for space between the algae and the animals on debris is always apparent. For example, heavy populations of *Lepas anatifera* force most algae to live at or above the waterline or in flooded compartments on the derelict boats. However, during the winter when the *Lepas* populations fall off, some of their space becomes available to the algae, and ephemeral and crustose algal species colonize the substrate. Then, in early spring, recruitment of *Lepas* is often seen on the winter crustose algal species, and the competitive cycle for space resumes. As would be expected, seasonality of the algae is very apparent on debris. In the winter, the populations of algae greatly diminish as the annuals and many of the ephemeral species are in their microscopic overwintering stage.

Certainly the size of debris also influences what species survive. Larger debris items like docks and boats seem to float steadily at a specific level in the water column. Unless they are disturbed or turned over by storms, this provides a steady habitat for sessile organisms like algae. The highest diversity of algae occurs on some of these items. Obviously, other factors enter into the diversity formula, many dealing with the animals. But, I will leave this discussion to the zoologists. Perhaps the Carlton's group will help to explain if what I am seeing occurs on all debris (they see many more debris items than I do) and its true cause.

Appendix 8

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*
Year 2 Final Report

1. PROJECT INFORMATION

Title:	Marine Algae arriving on JTMD (Japanese Tsunami Marine Debris) and their invasion threat to the Northwestern Pacific coasts
Award period	April 1, 2015 – March 31, 2016
Amount of funding	1,724,220 yen
Report submission date	May 3, 2016
Lead Author of Report*	Hiroshi Kawai

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Hiroshi Kawai, Kobe University, Japan (kawai@kobe-u.ac.jp)
Takeaki Hanyuda, Kobe University, Japan (hanyut@kobe-u.ac.jp)
Gayle Hansen, Oregon State University (hansengi@outlook.com)

2. EXECUTIVE SUMMARY

(1) A field survey has been carried out from June 5–7, 2015, at several locations in Aomori and Iwate Prefectures on the Pacific coast of Tohoku, including the reinstalled floating docks in Misawa Fishing Port. Approximately 40 species of macroalgae have been collected during this trip from natural and artificial habitats, covering about half of the species found on JTMD.

(2) The specimens on JTMD have been genetically analyzed and compared with those from natural habitats in Tohoku, and NW America (mostly Washington and Oregon coast, sent by Gayle Hansen). For the genetic study, the following gene DNA sequences have been used depending on taxa: chloroplast *rbc*L and *rbc*S, mitochondrial *cox*1 and *cox*3, and nuclear 18S rDNA and rDNA ITS. The examined taxa are as follow – **Green algae:** *Ulva* spp. (*U. compressa*, *U. lactuca*, *U. linza*, etc.), *Blidingia* spp.; **Brown algae:** *Feldmannia mitchelliae*, *Ectocarpus* spp., Kuckuckia sp., *Desmarestia japonica*, *Desmarestia* sp. *D. viridis*, *Petalonia* spp. (*P. fascia*, *P. zosterifolia*)**,** *Saccharina japonica***,** *Scytosiphon* spp. (*S. lomentaria, S. gracilis*); and **Red algae:** *Chondrus* spp. (*C. giganteus, C. yendoi*)**,** *Grateloupia* spp.(*G. giganteus*, *G. turuturu*, etc.)**,** *Palmaria palmate and Palmaria* cf. *mollis.*

(3) Based on the genetic results, the species level morphological identifications have been re-examined and the list of taxa has been updated.

(4) In the genetic study, the geographic distributions of representative haplotypes (genetic types) have been shown for the following taxa: Ulva pertusa., Blidingia spp. (Ulvophyceae); Petalonia fascia, *Desmarestia* spp. *Ectocarpus* spp. (Phaeophyceae); *Palmaria palmata*/*P. mollis*.

(5) A poster was presented at ICMB-2016 (Sydney, Australia) – Gayle I. Hansen, Takeaki Hanyuda and Hiroshi Kawai: Marine Algae arriving on Japanese Tsunami Marine Debris (JTMD) and their invasion threat to the coasts of Oregon and Washington, USA.

(6) In March 2016, Takeaki Hanyuda and Gayle Hansen carried out a field survey in Washington and Oregon and collected ca. 40 species of macroalgae from natural and artificial habitats, including the floating dock in Grays Harbor, the monitoring site to detect new introductions.

Appendix 9

North Pacific Marine Science Organization (PICES) PICES-MoE project on "Effects of marine debris caused by the Great Tsunami of 2011" Year 2 Final Report

1. PROJECT INFORMATION

Title:	Development of life history database for Japanese Tsunami Marine Debris (JTMD) biota
Award period	15 May 2015 to 31 March 2016
Amount of funding	$14,620 US direct funds ($1,370 indirect)
Report submission date	April 30, 2016
Lead Author of Report*	Jessica Miller

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Jessica Miller (Jessica.Miller@oregonstate.edu), Oregon State University, Coastal Oregon Marine Experiment Station, Hatfield Marine Science Center, 2030 SE Marine Science Dr., Newport, Oregon 97365

2. EXECUTIVE SUMMARY

The overall goal of the PICES project, Assessing the Debris Related Impact From Tsunami (ADRIFT), funded by Ministry of the Environment of Japan, is to assess and forecast the effects of debris generated by the tsunami that followed the 2011 Great East Japan Earthquake. The assessment is focused on the coastlines and communities along the west coast of North America and Hawaii. Prior grants from Oregon Sea Grant, the US National Science Foundation, and the North Pacific Marine Science Organization (PICES) resulted in substantial progress on documenting the biota arriving on JTMD and evaluating the growth and condition of some commonly occurring species. To date, over 500 JTMD items with >250 invertebrate taxa have been documented arriving along the west coast of the US and Canada and in Hawaii and other NW Pacific Islands.

The establishment of and impacts from the biota transported on JTMD may not be known for years to decades after their arrival and could, hopefully, be small to non-existent. While we do not know if any of these species will establish in the NE Pacific, it is important to build upon our current knowledge base. A logical and important step in addition to understanding the arrival phase is to compile existing information on these JTMD species for a variety of purposes, including formal risk assessment, life history and ecological analyses, and comparison with other marine invasive species and vectors. Such information is not only an opportunity to learn more about the dispersal and transport of marine species but also critical for a robust risk assessment and addressing key ecological questions about the JTMD species pool.

The approach to address this information need was to collaborate with PICES researcher (Clarke Murray) and staff to develop a database on JTMD species attributes, including information on geographic distribution, temperature and salinity ranges, invasion history, reproductive mode, etc. In spring 2015, we designed and distributed a template to other researchers who provided input on its design. With the assistance of Jocelyn Nelson (PICES contractor), the database, which includes descriptive and categorical fields, was finalized. Literature acquisition, interpretation, and data entry continued throughout the grant year. Due to the time required to populate the database, additional staff were hired by PICES in late 2015 and early 2016. After coordinating with Clarke Murray, Miller distributed a position description to identify a likely candidate to assist with database entry. Ms. Reva Gillman, a MS student at Oregon State University, was hired by PICES to assist with data entry and focused on Molluscan taxa. Information on many of the JTMD taxa that were identified to genus or species, as well as some higher order taxonomic groupings, have been compiled. There are some additional taxa to be added during spring 2016. Once finalized, the database will be housed by the Smithsonian Environmental Research Center as part of its National Exotic Marine and Estuarine Species Information System (NEMESIS), which will provide a comprehensive and valuable source of information on JTMD species to a variety of potential users.

Appendix 10

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

Year 2 Final Report

1. PROJECT INFORMATION

Title:	Surveillance, Monitoring and Risk of Tsunami Debris
Award period	April 1, 2015 to March 31, 2016
Amount of funding	Salary only
Report submission date	April 29, 2016
Lead Author of Report*	Cathryn Clarke Murray

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Cathryn Clarke Murray, PICES (cmurray@pices.int)

2. EXECUTIVE SUMMARY

Understanding the overall risk of invasion associated with Japanese Tsunami Marine Debris (JTMD) requires surveillance, monitoring, biological and ecological research. Ongoing monitoring research yields information on the tsunami debris field including the amount, type, and timing of debris landings. In some cases, large debris items require rapid response in order to avoid navigation hazards for maritime traffic, such as that needed for derelict fishing vessels and the large floating concrete docks. Rapid response to debris sightings is also required to obtain fresh biological samples of any species attached to debris items. Biological research details the biota associated with debris items and their abundance. Ecological research focuses on the interactions between JTMD species, and their population and community dynamics. The body of knowledge gained from the project will be used in risk assessment to generate a list of high risk species and to evaluate tsunami debris as a vector of potentially invasive species.

Surveillance

Surveillance activities were undertaken in order to search for large debris items (vessels, skiffs, docks) and to identify hot spots of debris accumulation. PICES contracted a local aerial photography company, Lightspeed Digital, to complete aerial surveys of British Columbia (BC), Canada. Aerial surveys were also conducted for the main Hawaiian Islands (see Neilsen report for more details). The BC survey complements aerial surveys completed by the State of Alaska in 2013 and 2014 as part of their debris response and removal activities, and uses the same survey methodology. These surveys consist of overlapping oblique photographs taken from a small plane, flying between 500 m and 1000 m above the beach.

Aerial surveys of BC coastlines began in October 2014 and were completed in October 2016. The entire outer exposed coast of British Columbia (over 1500 kilometers) has been captured; on the west coast of Vancouver

Island from Port Renfrew to Cape Scott, the Central Coast region, outer coast of Haida Gwaii and Chatham Sound. There are over 6,500 images of the shorelines. The surveys have located at least six skiffs and vessels as well as a number of other large debris items on remote beaches of BC and provided rankings of debris accumulation for the outer coast shorelines.

Post-survey processing assigned unique identifiers (tags) for specific types of debris and quantified the amount of debris on a qualitative scale from 0-5. Working with the BC provincial government, PICES completed GIS analysis of the photographs and their rankings in order to show hot spots of debris accumulation. The provincial government has provided the debris ranking maps and photographs to the public through an online mapping portal.

Working with colleagues at Kyushu University, image analysis techniques have been refined to gain further data from aerial survey images. The results of these analyses were compared to three small aerial surveys conducted in conjunction with shoreline surveys in order to compare the effectiveness of the three survey types (qualitative rankings, quantitative image analysis and shoreline surveys).

Monitoring

Monitoring research activities aimed to quantify the amount, distribution and timing of debris landfall and estimate debris landfall attributable to the 2011 tsunami, compared to baseline amounts. Three data sources were made available to PICES to examine the influx of marine debris after the 2011 tsunami: 1) NOAA (National Oceanic and Atmospheric Administration) shoreline monitoring surveys, 2) OCNMS (Olympic Coast National Marine Sanctuary) shoreline surveys, and 3) NOAA's disaster debris reports.

The ongoing NOAA marine debris shoreline survey is a rapid, quantitative beach survey which uses trained community volunteer organizations to collect standardized and consistent data. NOAA's current shoreline monitoring program began in 2011 and continues through the present. In the wake of the 2011 tsunami, this ongoing research provided an opportunity to evaluate the amount of debris. The NOAA dataset was analyzed for trends in distribution and abundance of debris concentration and type over time and across the Pacific coast of North America and Hawaii. An additional dataset maintained by OCNMS was used to establish a baseline of marine debris influx for northern Washington State. This survey was initiated in 2001 to record marine debris indicator items and continued until the new survey methodology began in 2012, which records all marine debris items.

There was a sharp increase in the influx of indicator debris items, from 0.03 items per 100 m per day to 0.29 debris items per 100 m per day. This is a 10-fold increase in debris over that recorded in the 9-year period prior to the tsunami event. The increase of all debris items, not just indicator items, cannot be calculated, but the increase over the indicator baseline is almost 600,000%. Therefore, the North American coastline experienced an influx of tsunami debris items that was significantly and substantially higher than the baseline amount.

After the tsunami event, there were peaks in all debris items (not just indicator items) in May 2012, early in 2013, and smaller peaks in May 2014 and late 2014. In May 2012, the mean debris influx recorded was over 180 debris items per 100 m per day. Reports of disaster debris peaked in May 2012, March 2013 and May 2014, with at least one confirmed 2011 Japan tsunami debris item in each of the temporal peaks. The three peaks in debris landfall after the tsunami are similar to the peaks in disaster debris reported to NOAA, and are consistent with modeling predictions.

Across the states and provinces of study, Hawaii received the most debris items over the post-tsunami study period (2012–2015). BC has the second highest debris influx in this time period, driven by a few surveys in Haida Gwaii (northern BC) with high numbers of large Styrofoam pieces. Alaska had few surveys to analyze, and we are investigating other data sources for this region. The incidence of large debris items (larger than

30 cm) was highest in Washington State, followed by California, and the highest arrival of large items occurred in 2013 and 2014.

The congruence between the influx of marine debris documented in the shoreline surveys, the disaster debris reports and oceanographic modeling is a striking and interesting result. The analysis will be documented in a manuscript and submitted to a peer-reviewed journal in 2016.

<u>Risk Assessment</u>

Risk assessments are an important tool that can inform policy and management decisions about non-native species. In order to evaluate the overall risk from potential invasive species transported by JTMD, a vector risk assessment is being conducted. There are an abundance of risk assessment models available for species-specific evaluation and prioritization (reviewed in Dahlstrom *et al*., 2011). However, the evaluation of an entire vector has been limited to largely descriptive and qualitative risk assessment models. Our goal is to develop a vector risk assessment model that can be used to categorize risk from tsunami debris to ecoregions in the Northeast Pacific and Hawaii. The process aims to generate a numerical estimate of relative risk to each affected region. Specifically, the model can be used to inform and prioritize the monitoring, research and cleanup efforts in response to the debris resulting from the Great Tsunami of 2011. In Year 2, the framework for the vector risk assessment was developed over the course of two workshops held in November 2015 in Annapolis, USA, and in January 2016 in Sydney, Australia. The framework will be applied to a probabilistic mathematical model in Year 3, and the results discussed at a small workshop in August 2016. A manuscript detailing the framework and the model results is expected to be submitted to a peer reviewed journal by the end of Year 3.

The risk of individual species associated with JTMD will be evaluated using an established screening tool (Drolet *et al*., 2016). To support the risk assessment, a database of species traits and tolerances is currently under development and will be completed early in Year 3. Once completed, this database will become a permanent online resource as part of the National Exotic Marine and Estuarine Species Information System (NEMESIS). The application of the risk assessment screening tool will produce a ranked list of JTMD species and their potential invasion risk. High-risk species are good candidates for further research and monitoring activities at the local, state and federal levels. Field guides to the high risk species will be produced.

Appendix 11

NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON *"EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"*

Year 2 Final Report

1. PROJECT INFORMATION

Title:	PICES Tohoku coast field survey (fouling plate) – supplemental study for U.S. tsunami debris spp. list
Award period	July 15, 2015 – March 31, 2016
Amount of funding	$ 68,965 CAD
Report submission date	December 12, 2015
Lead Author of Report*	Hisatsugu Kato (JANUS), Michio Otani, Karin Baba (JANUS)

Principal Investigator(s), Co-Principal Investigators and Recipient Organization(s):

Dr. Hisatsugu Kato
Karin Baba

Japan NUS Co., LTD.
Nishi-Shinjuku Kimuraya Building 5F,
7-5-25 Nishi-Shinjuku, Shinjuku-Ku, Tokyo
160-0023, Japan
Phone: (81)-3-5925-6866 (Direct)
Email: baba-k@janus.co.jp

Dr. Michio Otani
Rokujo Midori-machi 3-9-10,
Nara City, Japan, 630-8045
Tel & Fax: 81-742-48-8552

2. EXECUTIVE SUMMARY

Introduction

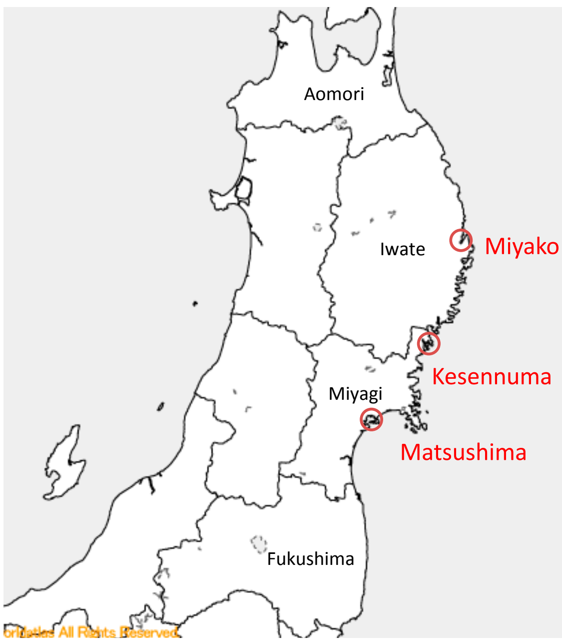
During the Great East Japan Earthquake and tsunami in 2011, vast amount of debris got washed out from land and some became Japanese Tsunami Marine Debris (JTMD) and reached Hawaii and west coast of the U.S. and Canada with many coastal fouling organisms attached. It is uncertain amount and species of fouling organisms which were transferred from Japan to the U.S. and Canada. This research is the survey which is aimed to obtain a thorough collection of fouling organisms to morphologically and genetically complement the existing collection of JTMD species in Japan.

Materials and method

The survey was conducted at several locations in the Tohoku coast. Fouling plates of 14 cm square were placed in 3 different locations; Miyako (Iwate prefecture), Kesennuma and Matsushima (Miyagi prefecture) in July or August, 2015 (Figure 1).

Tohoku coast is a ria coast and each survey site is in the inlet. The inlets have the brackish-water inputs which make the areas suitable for coastal fishery and the aquaculture. In the ria coasts, shallow and narrow inlets trapped and focused incoming tsunami waves and created destructive swells and currents that pushed large volumes of water far inland. All survey sites suffered serious damage by the tsunami after the Great East Japan Earthquake.

The fouling plates were retrieved after about 1 month (the first survey) and 3 months (the second survey) at each site (Table 1).



Tohoku area

Miyako

Kesennuma

Matsushima

Figure 1 Fouling plate deployment sites.

Table 1 Schedule of the field survey

	Placement (# of plates)	1 month (# plates) First survey	3 month (# plates) Second survey
Miyako	Aug. 12th (30)	Sep. 8th (15)	Nov. 10th (15)
Kesennuma	Aug. 4th (10*)	Sep. 8th (5)	Nov. 11th (5)
Matsushima	Jul. 24th (30)	Sep. 10th (15)	Nov. 12th (15)

*In Kesennuma, due to limited availability of space, minimum # of plates were deployed

The species of fouling organisms on the fouling plates were identified, and morphological specimens and samples for DNA analysis were prepared. The morphological specimens were stored in 70% ethanol, and the samples for DNA analysis were stored in pure ethanol (99.5%). In case where only small number of samples was available, preparation of samples for DNA analysis was prioritized to preserving for morphological analysis. The DNA samples are to be sequenced by Dr. Jonathan Geller at Moss Landing Marine Laboratories.

Results

The appearance of fouling plates in each location is illustrated in Table 2. The numbers of morphological specimen and samples for DNA analysis are shown in Table 3. The number of the samples for DNA analysis means the number of identified species. The state of the fouling species varies depending on the location. The number of species found was the highest in Matsushima, and the fewest in Miyako. More species were detected in the second survey than the first survey in all sites. Phylum Arthropoda (especially Class Malacostraca) dominated at all sites (Table 4).

Table 2 Retrieved fouling plates

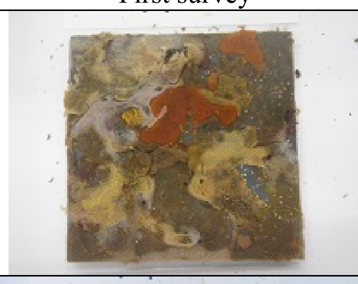
	First survey	Second survey
Miyako		
Kesennuma		
Matsushima		

Table 3 Number of the prepared specimens.

	First survey		Second survey	
	Samples for DNA analysis	Morphological specimens	Samples for DNA analysis	Morphological specimens
Miyako	31	15	51	16
Kesennuma	35	9	65	14
Matsushima	63	22	79	26

Table 4 Number of the appearance species.

PHYLUM	Miyako		Kesennuma		Matsushima	
	1st survey	2nd survey	1st survey	2nd survey	1st survey	2nd survey
PORIFERA	0	1	0	2	1	3
CNIDARIA	1	1	1	1	3	2
NEMERTINEA	0	1	0	1	0	1
KAMPTOZOA	0	0	0	0	0	1
TENTACULATA	1	5	3	5	3	7
MOLLUSCA	0	3	3	4	6	9
ANNELIDA	2	9	3	15	15	10
ARTHROPODA	21	22	21	30	27	35
CHORDATA	6	9	4	7	8	11
Total	31	51	35	65	63	79

The complete lists of species found in each survey are shown in section 3(c). Most of fouling organisms identified in this survey are native to Japanese coasts. Several non-native species were found such as *Amphibalanus eburneus* and *Amphibalanus amphitrite*. According to the result of this survey, *Crassostrea gigas* was not detected in Miyako. On the other hand, *Caprella mutica,* which is northern species, was detected only in Miyako. Although *Nemertellina yamaokai* was detected only in Hokkaido in the past surveys, it was found in Miyako and Kisennuma in this survey.