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 1 (April 15, 2014 – March 31, 2015)
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NORTH PACIFIC MARINE SCIENCE ORGANIZATION (PICES)
PROJECT ON “EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011”

PROGRESS REPORT FOR YEAR 1 (APRIL 15, 2014 – MARCH 31, 2015)

YEAR 1 IN REVIEW

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 debris generated by the Great Tsunami of 2011, especially those related to non-indigenous species (NIS) and potentially invasive species on ecosystem structure and function, the coastlines and communities of the west coast of North America and Hawaii, and to suggest research and management actions to mitigate any impacts. Non-indigenous or alien species are those not historically present in a region, and those NIS that establish, spread and have an ecological, economic or social impact in the new region are then called “invasive”. The duration of the project is 3 years, from April 15, 2014 to March 31, 2017.

In accordance with the organizational principles agreed to by MoE and PICES, 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). The Co-Chairmen can select PST members from within or outside of PICES expert groups, as deemed appropriate (current PST members are listed in Appendix 1), and are responsible for the scientific implementation of the project and annual reporting to MoE and PICES Science Board. This report 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 in the year, with an evaluation on the progress made, and a workplan for the next year. The Project Coordinator, Dr. Alexander Bychkov (PICES), is responsible for the management of the fund and for reporting annually on its disposition to MoE and PICES Governing Council within 90 days after the close of each project year ending March 31.

The project focuses on three main areas of research: (1) modeling movement of marine debris in the North Pacific, (2) surveillance and monitoring of tsunami-generated marine debris landfall, and (3) risk (including potential impacts) from potentially invasive species to coastal ecosystems. In Year 1, significant progress has been made in each of these research themes.

The modeling group utilized a suite of general circulation models to simulate movement of marine debris arising from the Great Tsunami of 2011. The team developed, refined and calibrated these models using available observational reports to forecast distributions of Japanese Tsunami Marine Debris (JTMD) and timelines of its potential arrival on the west coast of North America and Hawaii. These results illustrated how different types of JTMD are transported -- light-weight and/or floating debris are transported rapidly and can be removed from the ocean within a year of the tsunami event (e.g., polystyrene), while heavy-weight and/or submerged/sunken debris may remain in the ocean for a very long period with the potential to become entrained in the North Pacific Gyre. Also, simulated particles reaching the coasts of Washington and Oregon showed a strong seasonal cycle.

The surveillance and monitoring team characterized the temporal and spatial variability in JTMD landfall in North America and Hawaii and its relationship to the reported debris resulting from the Great Tsunami of 2011. Analysis of the monitoring data showed a sharp increase in the influx of debris items beginning in May 2012; indicator items increased 10 times over records prior to the tsunami, and general items increased more than 100 times. A webcam system was installed at a site on the Oregon coast in February 2015 to track beach-specific debris landings and removals to better understand the temporal dynamics of debris on coastal beaches. Aerial photographic surveys were conducted for the entire outer coastline of British Columbia, Canada (more than 1500 km) which included the west coast of Vancouver Island and Haida Gwaii where JTMD has been reported.

The invasive species team continued to characterize the invasion potential of NIS associated with tsunami debris. Currently, 296 items attributed to tsunami debris have been intercepted, and from those items 326 species of algae, invertebrates and fish have been identified. Some of these species are well known global
invaders such as the large pink barnacle *Megabalanus rosa*, the bryozoan *Tricellaria inopinata*, the seaweed *Undaria pinnatifida*, and the serpulid tube worm *Hydroides ezoensis*.

A more detailed summary of Year 1 research progress is available in the following Research Activities section, and the full submitted reports for each funded activity are included as Appendices.

**RESEARCH ACTIVITIES**

The ability of debris to attract sea life is well known to fishers who broadly use fish aggregating devices (floating rafts), which are essentially 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 invasive species at their final destination.

The Great Tsunami of 2011 created an unprecedented amount of marine debris, having a great potential to float in the ocean for a very long time. After JTMD started arriving on the US/Canada west coast and later in Hawaii, amazing discoveries were made: numerous species were found on two large Misawa docks, an increasing number of skiffs, as well as smaller and diversified objects, including objects originating from the land.

**MODELING**

The current state of satellite observing systems does not allow basin-scale monitoring of the ecosystem or marine debris, and field surveys are limited to episodic inspections of particular locations, mainly of the shore. In this situation, models are used to 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 the project relies on simulations with three different models: SCUD (University of Hawaii), 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.

Model calibration was completed using reports collected by the NOAA Marine Debris Program and other groups providing and collecting JTMD reports. A combined JTMD database shows three peaks in reports of boats washed ashore on the west coast of North America in 2012–2014. These peaks are also present in the model simulations. This allows converting model units into boat counts and providing practical estimates of JTMD density, volume, and fluxes. Based on the three peaks, the SCUD solution at 1.6% of windage is best correlated with observations. Estimates using this solution indicate that the original number of boats lost to the Great Tsunami of 2011 was at least 500–1000, and the number currently afloat is at least 400–700. The number of boats initially lost is likely to be an underestimate because of boats that came ashore but were not reported, boats that sank, and boats that originally had higher windage. The model does not account for loss of boats due to sinking – eventually some of these items are likely to break up or lose buoyancy due to seawater immersion and/or increasing biofouling. However, recent sighting of JTMD items in Washington, Oregon and Hawaii coastal waters more than 4 years after the tsunami indicates the persistence of many of these items. Models estimate that only 10–20% of the tracer with the relevant windage ends up on shore every year, which means that the number of arriving boats may remain elevated for some years.

JTMD provides a unique opportunity to develop and test a forecasting system which could help in planning future activities and predict the long-term fate of the main mass of JTMD. Experiments with such a system resulted in a website available to the PICES-MoE team (see the Publications and Presentations section). Work on validation and improvement of this system will continue in collaboration with other participants of the project and will include evaluations of available wind and current products in addition to exploring the relationships between seasonal cycles and the interannual signal of JTMD fluxes and indices of the processes governing the North Pacific Ocean (*e.g.*, the Pacific Decadal Oscillation, North Pacific Gyre Oscillation, El Niño-Southern Oscillation, *etc*.).

While the survival of the trans-Pacific drift by some species is amazing, careful analysis of biological samples suggests that pathways of some items could be very complex. For example, samples from two Misawa docks,
which both started from the north of Honshu and landed in Oregon and Washington, contained (among others) subtropical species not common at the place of origin. This indicates that at certain point, the docks drifted south and spent some time in or south of the Kuroshio Extension. The models are positioned for evaluating probable scenarios of JTMD items drift and NIS colonization/survival. Newly developed techniques will help to synthesize biological data using expertise in ocean circulation and with oceanographic data, such as sea surface temperature, salinity, sea state, and chlorophyll to produce a coherent and consistent description of the dynamics of the colonization and the survival of NIS.

**SURVEILLANCE AND MONITORING**

Characterizing the impact of debris from the Great Tsunami of 2011 requires an understanding of the amount, type and timing of debris landing on North American and Hawaiian coastlines. In some cases, large debris items may require rapid response in order to avoid navigation hazards for maritime traffic, such as that needed for derelict fishing vessels or large floating concrete docks. Rapid response to debris sightings is also required to obtain fresh biological samples of any species attached to debris that may pose an invasion risk. Watching for new debris landings on the North American and Hawaiian coastlines as well as monitoring the landfall of tsunami debris compared to the normal influx of marine debris necessitates ongoing surveillance and monitoring activities.

**Surveillance**

Surveillance activities were undertaken in order to search for large debris items (vessels, skiffs, docks) and to detect “hot spots” of debris accumulation. Data gaps were identified for the surveillance of the Canadian west coast. While beaches in Washington, Oregon and California are regularly visited, cleaned and monitored, little surveillance and monitoring occurs on the remote western-facing beaches of British Columbia and Alaska at risk of tsunami-debris landfall. Aerial surveys are cost-effective ways to monitor these vast, largely uninhabited coastlines where debris may be accumulating and to pinpoint potential “hot spots”.

Aerial surveys have been conducted by the State of Alaska in 2013 and 2014 as part of their debris response and removal activities. PICES carried out aerial surveys of the exposed outer coastlines of British Columbia as a complement to the Alaskan surveys by using 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.
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.

Aerial surveys of British Columbian coastlines began in October 2014 and were completed in March 2015. The entire exposed outer coast of British Columbia (over 1500 kilometers) has been captured: 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 British Columbia and provided rankings of debris accumulation for the outer coast shorelines.

**Shoreline Monitoring**

Monitoring research activities aimed to quantify the amount, distribution and timing of debris landfall and to estimate debris landfall attributable to the Great Tsunami of 2011 compared to baseline amounts. Three data sources were made available to PICES to examine the influx of marine debris after the 2011 tsunami: (1) the National Oceanic and Atmospheric Administration (NOAA) shoreline monitoring surveys, (2) Olympic Coast National Marine Sanctuary (OCNMS) 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 samples using standardized procedures. NOAA’s current shoreline monitoring program began in 2011 and is continuing. This ongoing research provides an opportunity to analyze the timing and distribution of debris landings in the wake of the Great Tsunami of 2011. The NOAA dataset was examined for trends in distribution and abundance of debris concentration and type over time and across the west 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, which recorded marine debris indicator items, was initiated in 2001 and continued until the new survey methodology, which records all marine debris items, was introduced in 2012.

The analysis of these two datasets first identified common sites between the two survey timelines, matched the two sets of categories (removing and combining categories as needed) and then examined the spatial and temporal trends in marine debris influx. 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 an 867% increase in debris over that recorded during the 9-year period prior to Great Tsunami of 2011. 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 higher than the baseline amount.

After the Great Tsunami of 2011, 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 items per 100 m per day. Reports of disaster debris peaked in May 2012, March 2013 and May 2014, with at least one confirmed debris item from the Great Tsunami of 2011 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 these peaks are consistent with modeling predictions.

Hawaii received the most debris items over the post-tsunami study period (2012–2014). British Columbia, has the second highest debris influx in this time period (with high numbers of large polystyrene pieces), driven by a few surveys in Haida Gwaii (northern British Columbia). Alaska had few surveys to analyze, so we are investigating other data sources for this region. The incidence of large (larger than 30 cm) debris items was highest in Washington, followed by Alaska and California, and the greatest 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 the next year. Shorelines that accumulate debris in general and tsunami debris in particular (hot spots) will be identified based on the data from the aerial and beach monitoring surveys and webcam monitoring and used to direct field surveys for potential invasive species introductions related to tsunami debris.
Webcam Monitoring

To date, there are few published studies that have investigated variations in the quantities of long-term beach litter for intervals shorter than one month. Consequently, there is no way of knowing the “true” temporal scale of the variations in the quantity of litter on beaches, or the factors responsible for them. Furthermore, there is no way of knowing the appropriate time scales for beach surveys and/or cleaning services. In this study, photographs of beach litter were taken automatically every 60 min over a 1.5-year period using webcams, with the aim of elucidating the temporal variations of litter quantities and the possible factors responsible for these changes. To measure the quantities of marine debris littered on beaches, monitoring using a webcam is adopted in line with Kako et al. (2010) and Kataoka et al. (2012). Photographs of beaches are taken every 1–2 hours for 1 to 2 years and, after image processing, are converted to time series of areas (in m²) covered by marine debris. The projection transformation method is used for this geo-referencing (Kako et al., 2010), and extraction of anthropogenic objects from the beaches is conducted on a CIELUV color space (Kataoka et al., 2012). The photographs, uploaded to laboratories via the Internet, are also open to the public. In this experiment, the efficiency of the webcam system for automatically monitoring tsunami debris was tested, and relationships between the quantities of marine debris on beaches and atmospheric/oceanic conditions were examined. Additionally, the effectiveness of using a near-infrared camera to monitor lumber that is potentially carrying invasive species onto beaches was studied. Near-infrared monitoring experiments were conducted on beaches in Japan this past year.

Risk of Invasive Species

This research focused on characterizing the biodiversity on JTMD generated by the Great Tsunami of 2011. Non-indigenous species on JTMD items that are not known to be already established in North American and Hawaiian ecosystems are of particular interest. A fundamental rationale is to understand the invasion potential of NIS and thus which species should be on high-profile target search agendas. In order to accomplish this we have pursued an assessment of the diversity, reproductive potential, and other critical aspects of the biology and ecology of species on JTMD that have arrived and continue to arrive on North American and Hawaiian shores. Species such as the mussel *Mytilus galloprovincialis* and the barnacles *Megabalanus rosa* and *Semibalanus cariosus* have now survived trans-oceanic voyages of over 4 years in duration. These types of observations, combined with the consistent arrival of a number of the same species since 2012, may provide a foundation for assessing the types of organisms that are particularly robust and may have higher invasive potential.

Hundreds of samples of JTMD from Alaska to California and the Hawaiian Islands have been acquired, processed, and carefully analyzed. This work consists of the taxonomic identification of the species on the debris, molecular genetic analyses, specimen image analyses, screening of over 1,500 mussels and other mollusks for the presence of endoparasites, and chemical analyses of mussel shells.
As of March 31, 2015, of 331 intercepted JTMD items, 92% are from Washington, Oregon, and the Hawaiian Archipelago. Approximately 18% are vessels (n = 60) and 35% post-and-beam lumber (n = 117), with the remaining items representing a diversity of marine-origin debris (floats, buoys, ropes, etc.) and terrestrial-origin debris (pallets, cylinders, boxes, coolers, tanks, etc.), the latter colonized by marine species after they entered the ocean, and often identified by a unique Japanese biotic signature.

On this debris 350 species of marine animals and plants, including 304 species originating from Japanese waters and additional species acquired during the oceanic transit or upon arrival in the Eastern Pacific, have been found. Of the 304 species, more than half represent four groups of organisms: algae (71 species; 23% of the biota), bryozoans (51 species, 17%), polychaete worms (35 species, 12%) and bivalve mollusks (28 species, 9%). Mollusks and crustaceans combined account for slightly more than one-quarter of the biota (14% each). A large number of species are not yet reported in North American or Hawaiian waters, 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 global invasive species. The endoparasitic hydroid *Eutima japonica* (known to cause shellfish mortalities) and the pathogenic protist *Haplosporidium* in mussels associated with JTMD have also been detected.

JTMD wood debris in the ocean has been colonized by shipworms (bivalve mollusks). More than 120 woody items (largely consisting of the highly recognizable post-and-beam building timber 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, 1 Japanese coastal species, 1 cosmopolitan species, and 1 probable new species. Genetic sequencing has aided in confirming species identity, as well as the probable existence of a previously undescribed species. Of the other 5 species, at least 2 have established invasive populations elsewhere in the world.

Algal material was obtained from 28 JTMD items, and 64 algae species have been identified so far. About 86% of algal species from the debris have been found to be reproductive on arrival, displaying active spore and gamete release. Of the 64 algal species on JTMD, 21 (33%) are Asian only or known Asian exports (non-indigenous species), 35 species (55%) are cryptogenic, and 7 (11%) occur on both sides of the Pacific Ocean.

Further, population growth and reproductive condition in several abundant species, including mussels (*Mytilus*) and small amphipod crustaceans, have been studied. A large majority of the mussels arriving on JTMD are *Mytilus galloprovincialis*, a Mediterranean species that was introduced to Japan. From the onset of the arrival of biofouled JTMD along the Northeast Pacific coast in June 2012, relatively large mussels (>70 mm total length) have been present on many items. As this species is a predominantly intertidal filter-feeder known to grow well in relatively warm and saline waters, it is noteworthy that so many individuals arrived in apparently good condition at relatively large sizes 15+ months after the tsunami. Thus, this species has been used as a model to explore size, reproduction, growth and dispersal patterns of the JTMD biota. Size and reproduction assessment on >1000 individuals were completed. Mean size of arriving mussels was smallest in Hawaii, with no significant variation between 2012 and 2013 collections. However, shell size increased in Oregon and Washington waters between 2012 and 2013, but appears to have stabilized, as the sizes of 2014 collections were similar to 2013. Furthermore, reproductive individuals consistently arrived during collections from 2012 to 2014. The lowest occurrence of individuals with mature or maturing gametes was observed in mussels collected in Hawaii (<17%) on debris that may have passed through lower productivity waters, whereas >60% of the individuals arriving on debris landing within Oregon...
and Washington waters (and with potential transits through higher productivity water masses) were reproductive and may have released gametes along the coast.

Variation in chemical ratios (such as barium (Ba)/calcium (Ca)) in mussel shells can provide information on ocean versus coastal residency and shell growth, which in turn can provide key information on conditions experienced by JTMD items and the duration of an item's residency in different water bodies. Coastal waters typically display higher concentrations of many trace metals, including Ba, than open ocean waters. In 2012 and 2013, JTMD mussels had elevated Ba/Ca levels observed, indicating presumed residence in coastal waters. Trace metal composition of mussel shells may thus be used to identify shell growth that occurred in Japanese coastal waters (relatively high Ba), open ocean waters (relatively low Ba), and potentially Northeast Pacific coastal waters (relatively high Ba) if adequate shell growth occurred. A peak (usually more than 2 times background level) in Ba/Ca was detected in many mussels, followed by a period of low Ba/Ca, and finally a gradual elevation of Ba/Ca at the outer shell edge. It is possible that the peaks observed in so many JTMD mussels are directly related to the tsunami, which was associated with the delivery of a large amount of Ba-rich terrestrial sediments into the coastal zone and the disturbance of vast areas of high-Ba sediment pore water. Of interest is that the shell chemistry of the spring 2014 mussel arrivals was different from earlier collections. No distinct spikes of Ba/Ca were observed indicative of the tsunami. For several mussels there was a consistently greater amount of shell growth displaying moderate Ba/Ca levels, potentially indicating multiple coastal interceptions prior to coming ashore. This pattern may reflect longer coastal residence times, greater growth, and potential reproduction in Northeast Pacific coastal waters.

**PUBLICATIONS AND PRESENTATIONS**

**Selected Year 1 publications and scientific presentations:**


A webpage has been set up to distribute to the PICES-MoE Project Team biweekly and bimonthly forecasts: http://iprc.soest.hawaii.edu/users/hafner/NIKOLAI/SCUD/TSUNAMI/DEBRIS/PICES/Tsunam_diagnostic_and_forecast.html

All webcam photos taken by the camera are now available to the public on the website: http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html
APPENDICES

APPENDIX 1
Project Science Team membership.............................................................................................................. A1 – 1

YEAR 1 REPORTS FROM RESEARCH ACTIVITIES FUNDED BY THE PICES-MoE PROJECT

APPENDIX 2
Modeling studies in support of research on impact of alien species transported by marine debris from the 2011 Great Tohoku Tsunami in Japan
Lead author of the report: Nikolai Maximenko, University of Hawaii, USA............................................... A2 – 1

APPENDIX 3
Surveillance and monitoring of tsunami debris
Lead author of the report: Cathryn Clarke Murray, PICES................................................................. A3 – 1

APPENDIX 4
Webcam monitoring of marine/tsunami debris
Lead author of the report: Atsuhiro Isobe, Kyushu University, Japan..................................................... A4 – 1

APPENDIX 5
Japanese Tsunami Marine Debris (JTMD) and alien species invasions: PICES Year 1: Invasive species biodiversity, genetics, population biology and reproductive status, and debris interception and characterization
Lead author of the report: James Carlton, Mystic Williams College, USA............................................... A5 – 1

APPENDIX 6
Marine algae arriving on JTMD and their invasion threat to the coasts of Oregon and Washington, USA
Lead author of the report: Gayle Hansen, Oregon State University, USA.................................................. A6 – 1

APPENDIX 7
PICES-MoE project: Japanese component
Lead author of the report: Karin Baba, JANUS, Japan ................................................................................ A7 – 1
Appendix 1

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1. PROJECT INFORMATION

<table>
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<th>Modeling studies in support of research on impact of alien species transported by marine debris from the 2011 Great Tohoku Tsunami in Japan</th>
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<td>91,900.00 US Dollars</td>
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<td>Report submission date</td>
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</tr>
<tr>
<td>Lead Author of Report*</td>
<td>Nikolai Maximenko</td>
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*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.

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2. EXECUTIVE SUMMARY

Describe both the research purpose, objectives, methods, results, achievements and challenges, timelines and milestones (2-3 pages)

Marine debris has a large effect on the ocean. Every tiny solid piece, floating on the sea surface, gets colonized and in many cases eaten. 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 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.

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, amazing discoveries were made: numerous Asian species were first found on two large Misawa docks, then on an increasing number of skiffs, and later on progressively smaller and diversified objects, including objects originating from the land.
The current state of the observing system 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, 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: SCUD (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.

To calibrate the models we collaborated with the NOAA Disaster Debris team and other groups providing and collecting reports. A combined JTMD database shows three peaks in reports of boats washed ashore on the US/Canada west coast in 2012-2014. These peaks are also present in the model simulations. That allows us to convert model units into boat counts and provide practical estimates of JTMD density, volume, and fluxes. Based on the three peaks, the SCUD solution at 1.6% is best correlated with observations. Estimates using this solution indicate that the original number of boats lost to the 2011 tsunami was at least 500-1000 and the number currently afloat is at least 400-700. The number of boats initially lost is likely to be an underestimate because of boats that came ashore but weren’t reported, boats that sank, and boats that originally had higher windage. The model does not account for loss of boats due to sinking – eventually some of these items are likely to break up or lose buoyancy due to increasing biofouling. However, recent sighting of potential JTMD boats in Oregon coastal waters more than four years after the tsunami indicates the resilience of many of these items. Models estimate that only 10-20% of the tracer with the relevant windage ends up on shore every year, which means that the number of arriving boats may remain significant for some years.

Robustness of the observational timeline of JTMD on the US/Canada west coast in the presence of limited number of reports (79 boats and 76 wood items) is demonstrated by high correlation between timing of reports from BC, WA, OR, and CA. This large scale structure of the phenomenon justifies the use of the models. Unfortunately, reports from the Hawaiian Islands are very patchy and combined with the lack of resolution in global or basin scale models around small islands currently do not offer a meaningful opportunity for model calibration/validation. The at-sea observing system is developed even less. At-sea observations are very small in number and biased towards routes of participating ships. Because “no debris sighted” reports are missing, it is practically impossible to discriminate between “clean” areas and areas not covered with observations. Establishment of an adequate marine debris observing system is necessary for a radical improvement of future drift models. In the meantime, it is important to continue collecting JTMD data from all available sources and combining them into a unified database.

JTMD provides a unique opportunity to develop and test a JTMD forecasting system, which could help in planning next year activities and also predict the long-term fate of the main mass of JTMD. Experiments with such system resulted into a website available to the PICES-MoE team. Work on validation and improvement of this system will continue in collaboration with other participants of the project and will include evaluations of available wind and currents products in addition to investigation of relations between the seasonal cycle and the interannual signal of JTMD fluxes and indices of the processes, governing the North Pacific Ocean (such as Pacific Decadal Oscillation, North Pacific Gyre Oscillation, El Nino-Southern Oscillation, etc.).
While the survival of the Trans-Pacific drift by some species is amazing, careful analysis of biological samples suggests that pathways of some items could very complex. For example, samples from two Misawa docks, which both started from the north of Honshu and landed in Oregon and Washington, contained (among others) subtropical species not common in the start area. This indicates that at some point, the docks drifted south and spent some time in or south of the Kuroshio Extension. Our models are perfectly positioned for evaluating probable scenarios of JTMD items drift and colonization. Newly developed techniques will help us to synthesize biological data with expertise in ocean circulation and with oceanographic data, such as sea surface temperature, salinity, sea state, and chlorophyll to produce a coherent and consistent description of the dynamics of the colonization and the survival.

3. PROGRESS SUMMARY

a. Describe original proposed research and planned outputs

Year 1 plan included two tasks:

Task 1. Estimate the current location and amount of JTMD in the North Pacific. This task will start with systemizing reports, collected by different agencies and organizations into a uniform data base and evaluating the range of the windage parameter of the debris of interest. This evaluation will be done using reports of arrivals of debris on the US/Canada west coast and in Hawaii and their comparison with model simulations under different scenarios. Then, careful numerical experiments with a suite of models will be conducted to determine the pattern of debris density at sea and on the coastline. The latter will allow us to calibrate model solutions and estimate the total amount of still-floating debris.

Task 2. Predict times and locations of JTMD influx on the shore to help plan coastal surveys. This task will be approached from three different directions. Firstly, atmospheric and ocean forecasts such as NCEP CFS (Climate Forecast System) and products of the Japan Task Team will be used to calculate model tracer motions during the winter/spring season of 2014/2015. Reanalysis and Reforecast data, collocated with the model data in space and time will be used to inter-calibrate model results. Secondly, similarity of the year 2014 with previous years during the satellite era (QuikSCAT was launched in 1999) will be analyzed. Hindcast simulations in the year, following the “analogue” year will provide an alternative “forecast”. Finally, the seasonal cycle in different years will be studied with respect to interannual differences and sensitivity to the phases of ENSO, PDO, and other climate indices. Because winter conditions are favorable for the debris collected in the gyre to start washing ashore along the US/Canada west coast and also in Hawaii, prediction of this-year’s transition to the winter condition will help to predict the next wave of the JTMD.

The tasks were focusing on two main types of JTMD: boats/skiffs and wood/lumber. The study was proposed to start with compiling a sufficiently large dataset, calibrating the models with respect to the optimal windage parameters, and running model simulations under the most probable setup. As a result, estimates of the total amount of particular types of JTMD would be estimated and predictions would be made for the next year.
b. **Describe progress.**

The following tasks have been completed in year 1 of the project.

3.b.1 **JTMD database**

Observational reports collected from various sources by the University of Hawaii (UH), NOAA’s Marine Debris Program (special thanks to Peter Murphy, Nir Barnea, and Lester Tapawan), and other groups have been compiled into a homogeneous database, combining a spreadsheet (that can be processed for statistics in an automated way) and wealth of auxiliary information (photographs, emails, webpages, etc.).

The UH subset, made easily accessible for the PICES-MoE Project Team, includes 196 reports, 106 of which are on boats/skiffs/ships and 87 on wood/lumber. The NOAA Disaster Debris subset includes 293 reports, 161 of which are vessels and 105 wood. The two subsets greatly complement each other without overlaps (Fig. 1).

**Figure 1.** Locations of JTMD reports in UH (red) and NOAA (blue) subsets. Circles indicate boats/skiffs/ships/vessels and crosses indicate wood/lumber/trees.

**Figure 2.** Monthly number of JTMD reports in UH (red) and NOAA (blue) subsets. Circles and solid lines indicate boats/skiffs/ships/vessels and crosses and dashed lines indicate wood/lumber/trees.
Figure 3. Locations and times (shown in colors) of JTMD reports in the combined database for boats (left) and wood (right).

UH data are biased towards the western North Pacific and Hawaii while the NOAA Disaster Debris dataset has more reports from the eastern North Pacific and the west coast of the US and Canada (hereafter, WC denotes a stretch on the coastline between latitudes 40N and 51N, including Northern California and Vancouver Island). The timing of at-sea reports (Fig. 3) illustrate debris drift from west to east (color change from deep blue to yellow) in 2011-2013 and enhanced role of mixing in 2014 (red and brown). The combined database was used to produce preliminary timelines of debris arrival on the in Hawaii and WC (Fig. 4). The latter was used for the comparison with model simulations.

Figure 4. Monthly number of JTMD reports in the combined database in Hawaii (left) and on the WC (right) for boats (red circles and solid lines) and wood (blue crosses and dashed lines).
There were three significant peaks in reports of boats: during the summer of 2012, the winter-spring of 2013, and the spring-summer of 2014 (Figs. 4 and 5d). *(Note the absence of a robust seasonal cycle and important interannual differences.)* The peaks are remarkably correlated practically at all latitudes (i.e. the timing of peaks on Vancouver Island was nearly identical to peaks in WA, OR, and Northern CA). The maximum density of reports is found near the WA-OR boundary between 46N and 47N. The second maximum is found in central OR, between 44 and 45N. Similar analysis of reports on wood revealed only one significant peak (Fig. 4 and 6d), coinciding with the second peak in boats in 2013. We suspect that much of the JTMD wood was not reported and the observational timeline doesn’t provide a reliable index for comparison with models. Therefore, further analysis was based on boats only.

**Figure 5.** Distribution of boats/skiffs reports on the WC. (a) Coastline data locations. (b) Time-latitude diagram of the arrivals, supporting the large-scale structure of the signal. (c) Total number of reports in 1-degree boxes. (d) Monthly number of reports.

**Figure 6.** Same as Figure 5 but for wood/lumber/trees.
Simulations of SCUD (UH), GNOME (NOAA), and SEA-GEARN/MOVE-K7 (Japan) models were used to study particle and tracer motions within a range of windage parameters, describing the direct effect of the wind on items floating on the ocean surface.

SCUD is an empirical, diagnostic model, developed at IPRC/UH and forced with data from satellite altimetry and scatterometry and calibrated on a ½-degree global grid using trajectories of satellite-tracked drifting buoys. The model calculates tracer evolution released on March 11, 2011 in the model domains along the east coast of Honshu for 61 values of windage ranging between 0 and 6%.

NOAA/ERD has also continued to update and refine their “hindcast” model run, which simulates the movement of tsunami debris from March 11, 2011 through the present. The debris is modeled as particles initialized at 8 sites along the Japan coast spanning a distance of ~700 km. There is limited information about the distribution of debris that entered the ocean, therefore, the particles are distributed equally among these 8 sites. Particle simulations are performed using the NOAA GNOME model – a particle tracking model initially designed for forecasting movement of oil spills. GNOME inputs include modeled currents and winds which assimilated satellite data:

- Currents: Global 1/12° operational HYCOM from Naval Research Lab
- Winds: NOAA Blended Sea Winds 0.25° global

The most recent set of the experiments included 23 windages ranging between 0 and 5.5%. In each experiment a total of 40,000 particles were released.

MRI experiments with partners in Japan included the following:

- Calculation of ocean current from March 2011 to August 2013 using a data assimilation model with an eddy-resolving general ocean circulation model (MOVE system by JMA/MRI).
- Forecasting current and wind fields from September 2013 to May 2016 by an atmosphere-ocean-land coupled data assimilation system (K-7 system by JAMSTEC)
- Calculation of dispersion of marine debris using the above-mentioned current and wind fields with a dispersion model (SEA-GEARN by JAEA).

Four values of windage were used in the SEA-GEARN/MOVE-K7 model: 0, 2.5, 3.5, and 5%.

The low-pass filtered timelines of model tracer and particle fluxes on the WC are shown in Figure 7 for different values of model windage parameter. To extract the signal from observational reports containing a high level of noise we experimented with a variety of low-pass filters (Fig.8, left). As a result of these experiments, we selected a 1.5-month Gaussian filter (black line), which successfully preserved the main peaks while eliminating noisy, secondary
peaks. Figure 8 (right) illustrates the filter effects on the SCUD solution at 1.5% windage. An identical filter was applied to timelines from all windage values simulated with the three models.

Figure 7. Fluxes of model (a) SCUD tracer (61 windage values), (b) GNOME particles (23 windages), and (c) SEA-GEARN/MOVE-K7 particles (4 windages) on WC (the US/Canada west coast between 40 and 51N) as functions of time (since Jan 1, 2011) and windage parameter. Red dots, positioned at the time of the tsunami, mark windage values used in the model simulations. Three vertical magenta lines correspond to the observational peaks in boats. White dots mark the model maxima. (d) Fraction of tracer, remaining in the ocean in the SCUD model as a function of time.

Generally, the models demonstrated an impressive correspondence with observations by capturing all three main peaks. The SEA-GEARN/MOVE-K7 model captured correctly timing of the 1st peak but did not produce the 3rd peak -- this may be because since August 2013 it was run as a forecast and updated calculations will be inspected in year 2. Both SCUD and GNOME capture correctly all three peaks although disagree somewhat with the magnitude of the peaks. They also systematically lead the observations by 2-3 months. These differences are not necessarily due to problems with the models. Lags in observations may reflect delays in item identification and reporting resulting from the delay in developing public concern and awareness.
**Figure 8.** Timelines of reports of boats (left) and 1.5% windage SCUD tracer fluxes (right) on WC, smoothed with a low-pass Gaussian filter of various widths. A 1-1/2 month filter was selected to be used for the further analyses.

**Figure 9.** Timelines of boat fluxes on WC in observations (magenta) and model experiments with different windages: 1.6% for SCUD (blue) and 2.5-3.5% averages for GNOME (green) and SEAGEARN/MOVE-K7 (red).
Table. Estimate of total number of boats floating at central times of the peaks and total initial number, derived through observations comparison with the SCUD solution at 1.6% optimal windage and (in brackets) GNOME solution averaged between 2.5 and 3.5%.

<table>
<thead>
<tr>
<th>Peak date</th>
<th>Peak #1</th>
<th>Peak #2</th>
<th>Peak #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of boats</td>
<td>13</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Tracer washed ashore</td>
<td>1.9% (5.3%)</td>
<td>5.9% (2.1%)</td>
<td>3.1% (18.1%)</td>
</tr>
<tr>
<td>Tracer fraction per single boat</td>
<td>0.15%/boat (0.41%/boat)</td>
<td>0.19%/boat (0.07%/boat)</td>
<td>0.10%/boat (0.60%/boat)</td>
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<tr>
<td>Tracer in water (initially 100%)</td>
<td>87.4% (92.7%)</td>
<td>79.4% (87.1%)</td>
<td>71.6% (50.0%)</td>
</tr>
<tr>
<td>Boats in water</td>
<td>583 (227)</td>
<td>418 (1244)</td>
<td>716 (83)</td>
</tr>
<tr>
<td>Estimate of initial number of boats</td>
<td>667 (243)</td>
<td>526 (1428)</td>
<td>1000 (167)</td>
</tr>
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</table>

3.3.3 Forecast

A webpage has been set up to distribute to the PICES-MoE Project Team biweekly and bimonthly forecasts: http://iprc.soest.hawaii.edu/users/hafner/NIKOLAI/SCUD/TSUNAMI/DEBRIS/PICES/Tsunami_diagnostic_and_forecast.html

The webpage is based on the SCUD model forced with satellite data to update the hindcast and forced by the NCEP CFS1 winds and currents to extend the solution into the future. The webpage is updated automatically every week for the biweekly forecast and every month for the bimonthly forecast. Sample output available on the webpage are illustrated in Figure 10. These include:
- Maps of model tracer concentration in the past, present and future and
- Timelines of on-shore fluxes in 12 selected regions of the North Pacific.

We will also study relations between seasonal cycle and interannual signal of JTMD flux and indices of the processes, governing the North Pacific Ocean (such as PDO, NPGO, ENSO, etc.). This study will be based on an assumption that after some years JTMD “forgets” its source and mixes with a general MD. Model simulations of onshore tracer fluxes will be compared with the oceanographic indices.

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1 http://cfs.ncep.noaa.gov/cfsv2.info/
c. Describe results.

The following main results have been achieved in year 1 of the project:

- A JTMD database has been created, analyzed, and made available to the team (section 3.b.1, Figure 1).
- The database revealed three main peaks in the onshore fluxes of boats/skiffs on the US/Canada west coast in 2012-2014 (Figs. 4, 5). The peaks were observed in different months of different year and were synchronous along the coast between Vancouver Island, British Columbia and northern California.
- Similar peaks were identified in the model solutions and were used to calibrate/validate the models (section 3.b.2, Fig. 9). Optimal values of windage were derived as 1.6% for SCUD, 2.5-3.5% for GNOME, and 2.5-3.5% for SEA-GEARN/MOVE-K7. According to SCUD and GNOME models, at least one half of the original amount of JTMD with such windage is still floating in the ocean that warrants significant fluxes in the following years.
- By comparing model results with observations, the total numbers of boats washed away by the tsunami is estimated to be 526-1000 in SCUD and 167-1428 in GNOME. The number of boats still floating during the 2014 peak is estimated to be 700 in SCUD and 167 in GNOME (see Table). These values may be still underestimated because of boats missing from the database, boats that sank, and boats that originally had higher windage.
• An online near-real time forecast system has been built and provided to the team (section 3.b.3, Fig. 10).
• Mathematical formalism has been developed combining the forward and reverse model solution to estimate probable oceanographic conditions along the pathway of a debris item with known start and end points.

d. **Describe any concerns you may have about your project’s progress.**

- Because of scarce observational reports and tremendously complex dynamics, comparison between model results and observations is difficult for the Hawaiian Islands. This issue will be addressed in the future. For now, all the analysis has focused on the WC.
- When interpreting the observational reports, it is hard to estimate what fraction of JTMD was not reported. Awareness and preparedness of the reporters could significantly affect documented timelines. In some remote areas, estimate of the correspondence of report time to the item arrival time is difficult. Sensitivity of results to this effect should be accounted for in future estimates.
- A particular limitation is the limited utility of at-sea data, which has huge gaps and biases. More advanced techniques need to be developed to make these data useful. Future observing system should expand to much larger areas and provide not only debris reports but also reports from “clean” regions.
- In 2013 wood/lumber, rich with biological riders, was a dominant type of JTMD. It is not clear if the fast decay of reports in 2014-15 is due to the loss of interest or due to actual degradation of wooden debris. There may be a missed (or almost missed) important opportunity of research.
- The forecast of JTMD fluxes, based on NOAA CFS winds and currents suffers from the low quality of the latter. Alternative products should be used. Forecast products should be calibrated against nowcast and real time data.

e. **Completed and planned publications**

2. Research paper about JTMD data-model comparison (planned in year 2 in the Marine Pollution Bulletin or a similar journal).

f. **Poster and oral presentations at scientific conferences or seminars**


Maximenko, N., A. MacFadyen, M. Kamachi, J. Hafner, G. Speidel, C. Curto, N. Usui, and Y. Ishikawa, 2015: Modeling studies in support of research on impact of alien species transported
by marine debris from the 2011 Great Tohoku Tsunami in Japan, PICES MoE Project Science Team Meeting, March 16-18, 2015, Honolulu, Hawaii (oral)

g. Education and outreach

Much of the UH team activity was overlapping with the PICES MoE project:

2014-09-14: Plastic, Plastic Everywhere. Jan Hafner participated as a guest in "Green Code" video show hosted by Howard Wiig. The topic of the show was plastic in marine environment, transport, impacts and its impact on Hawaii. The show can be viewed on: https://www.youtube.com/watch?v=9osj1ThRkMI&index=3&list=PLQpkwcNJny6mQgRi089s4dXbwfJAkT6X8

2014-11-07: Makalapa Elementary School - informal lecture on ocean currents in the North Pacific and their relevance to marine debris. The lecture was presented to 5th grade students.

2014-11-30: Interview to Millersville University Weather Watch TV regarding the tsunami debris. Jan Hafner was interviewed by Amber Liggett for the episode about Great Pacific Garbage Patch. The episode can be viewed on: https://www.youtube.com/watch?v=_04GC4BTk_I&feature=youtu.be&t=2m


2015-03-05: 90 minute lecture presented by Jan Hafner to a group of Japanese high school students from Morioka Daisan High School. Title of the lecture: "Ocean currents, global circulation, and the 2011 tsunami in Japan: modeling and observations".

2015-04: Consultations to Yuki Yamamoto, University of Hokkaido student, visiting UH.


4. PROGRESS STATUS

Year 1 plan has been accomplished in full and products and results exceeded expectations. Even limited initial number of reports, included in the JTMD database, provided meaningful timeline for debris arrivals on the US/Canada west coast. Model solutions demonstrated excellent correspondence with observational peaks and were calibrated to provide practical information and estimates. Collaborations with other members of the team has been established and will help to synthesize various types of observational data with model experiments.
1. PROJECT INFORMATION

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<th>Surveillance and Monitoring of Tsunami Debris</th>
</tr>
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<tr>
<td>Award period</td>
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<tr>
<td>Amount of funding</td>
<td>$97,672.88</td>
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<tr>
<td>Report submission date</td>
<td>April 29, 2015</td>
</tr>
<tr>
<td>Lead Author of Report*</td>
<td>Cathryn Clarke Murray</td>
</tr>
</tbody>
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*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):
Cathryn Clarke Murray, PICES Secretariat (cmurray@pices.int)
Nancy Wallace, NOAA Marine Debris Program (nancy.wallace@noaa.gov)

2. EXECUTIVE SUMMARY

Describe the research purpose, objectives, methods, results, achievements and challenges, timelines and milestones (2-3 pages)

Characterizing the impact of debris from the 2011 Great Tōhoku Earthquake and tsunami requires an understanding of the amount, type and timing of debris landing on North American and Hawaiian coastlines. 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. Watching for new debris landings on the North American and Hawaiian coastlines as well as monitoring the landfall of tsunami debris compared to the normal influx of marine debris requires ongoing surveillance and monitoring activities.

Surveillance

Surveillance activities were undertaken in order to search for large debris items (vessels, skiffs, docks) and to identify hot spots of debris accumulation. Data gaps were identified for the surveillance of the Canadian Pacific coast. While beaches in Washington State, Oregon and California are regularly visited, cleaned and monitored, little surveillance and monitoring occurs on the remote western-facing beaches of British Columbia and Alaska at risk of tsunami-debris landfall. Aerial surveys are cost-effective ways to monitor these vast, largely uninhabited coastlines where debris may be accumulating and to identify potential “hot spots”. Aerial surveys have been conducted in Alaska to identify hot spots of debris accumulation and prioritize clean ups.
PICES contracted a local aerial photography company, Lightspeed Digital, to complete aerial surveys of British Columbia, Canada. The British Columbia 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 500m and 1000m above the beach. 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.

In October 2014, aerial surveys of British Columbian coastlines began and were completed in March 2015. 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 British Columbia and provided rankings of debris accumulation for the outer coast shorelines.

Conducting aerial surveys in winter is not ideal but the surveys were completed on time in spite of the conditions. Future research will focus on identifying any remaining regions that would benefit from aerial surveys, developing image analysis techniques to gain further data from aerial survey images, and hot spot analysis to direct invasive species monitoring field research.

**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) the National Oceanic and Atmospheric Administration (NOAA) shoreline monitoring surveys, 2) Olympic Coast National Marine Sanctuary (OCNMS) 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 analyze 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 recorded marine debris indicator items and began in 2001 and continued until the new survey methodology began in 2012 which records all marine debris items.

The analysis of these two datasets first identified common sites between the two survey timelines, matched the two sets of categories (removing and combining categories as needed) and then analyzed the spatial and temporal trends in marine debris influx. There was a sharp increase in the influx of indicator debris items, from 0.03 items per 100m per day to 0.29 debris items/100m/day. This is an 867% increase in debris over that recorded in the nine 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/100m/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 these peaks are consistent with modeling predictions.

Across the states and provinces of study, Hawaii received the most debris items over the post-tsunami study period (2012-2014). British Columbia, Canada 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 30cm) was highest in Washington State, followed by Alaska and 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 the next year. Shorelines that accumulate debris in general and tsunami debris in particular (hot spots) will be identified using the data from the aerial surveys, beach monitoring surveys and webcam monitoring and used to direct field surveys for tsunami-debris related invasive species introductions.

3. PROGRESS SUMMARY

a. Describe original proposed research and planned outputs

Provide a summary of the research you proposed to PICES and the outcomes and deliverables you planned to produce.

Surveillance: We were tasked with conducting aerial surveys of British Columbia coast, following the State of Alaska protocol in collaboration with NOAA scientists.

Monitoring: We were tasked with analyzing marine debris beach monitoring data provided by NOAA in order to document the trends in marine debris arrival in North America and Hawaii.

b. Describe progress.

Provide a narrative of your activities and accomplishments (Including samples collected, data analysis completed, etc.), being as clear and concise as possible. If no progress was achieved on a particular objective during this reporting period, state why and, if applicable, describe how you plan to address the objective in the future.

Surveillance

PICES contracted a local aerial photography company, Lightspeed Digital, to complete the aerial survey of British Columbia, Canada. In October 2014, aerial surveys of British Columbian coastlines began and were completed in March 2015. The British Columbia 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 and 1000 m from the beach. Post-survey processing assigns unique identifiers (tags) for specific types of debris and quantifies the amount of debris on a qualitative scale from 0-5.
Monitoring

The PICES project is analyzing the data for trends in distribution and abundance of debris concentration and type over time and across the Pacific coast of North America and Hawaii. The goal of the analysis is to characterize the signal of the tsunami debris pulse against the background of ongoing ocean and land-based debris and determine how much the tsunami debris increased or changed the influx of marine debris to North American and Hawaiian coastlines. Since 2011, over 421 surveys have been conducted at 123 sites in California, Oregon, Washington, Alaska and Hawaii as well as British Columbia, Canada.

Because the current monitoring program began in 2012, it is difficult to establish a baseline level of marine debris before the tsunami occurred. We were given access to the Olympic Coast National Marine Sanctuary (OCNMS) beach monitoring data. These surveys were carried out over a longer time series although there is a slightly different survey method that must be taken into account during the analysis. The OCNMS data ranges from 2003-2012 and there are 11 sites in common with the monitoring dataset begun in 2011.

c. Describe results.

Surveillance

The entire outer exposed coast of British Columbia (over 2,000 kilometers) has been captured, the west coast of Vancouver Island from Port Renfrew north to Cape Scott, the Central Coast region, outer coast of Haida Gwaii and Chatham Sound (Figure 1). The surveys have located a number of skiffs and a number of other large debris items on remote beaches of British Columbia. These will be cross-referenced with the disaster debris reports and other sightings. The photographs have been assigned rankings of debris accumulation for the outer coast shorelines. There are over 6,500 images of the shorelines (Figure 2) that will be made available directly to the project science team and online through an interactive map.

Figure 1: Aerial surveys of British Columbia, Canada (green) completed.
Monitoring

The beach monitoring dataset post-2011 has a high degree of variability between sites and years so the influx of tsunami debris is difficult to detect. When adding the longer OCNMS dataset, our analyses show a sharp increase in the influx of indicator debris items, from 0.03 items per 100m per day to 0.29 debris items/100m/day. This is a 10-fold increase in debris over that recorded previous to the tsunami (Figure 3). Disaster debris reports were also analyzed for temporal variation and there were peaks in May 2012, March 2013 and May 2014. 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 (Figure 5a). In May 2012, the mean debris influx recorded was over 180 debris items/100m/day.

The peaks in debris landfall after the tsunami are similar to the peaks in disaster debris reported to NOAA (Figure 5) and these peaks are consistent with the modeling predictions from the University of Hawaii (N. Maximenko pers. comm.). We conclude from this analysis that the increase in debris on Washington State, Oregon and California shorelines are attributable to the 2011 tsunami and represent a minimum 10 times as much debris as baseline and as much as 6000 times more debris.
Figure 3: Increase in marine debris indicator items beginning in 2012. Letters denote statistically significant subgroups. Data from NOAA and OCNMS.

Figure 4: Number of landfall disaster debris reports (NOAA) between 2011 and 2014 for all regions (AK, BC, CA, HI, OR, and WA).
d. Describe any concerns you may have about your project’s progress.

No problems were encountered during this reporting period.

e. Completed and planned publications


Clarke Murray et al. (In preparation) “Spatial and temporal distribution of marine debris resulting from the 2011 Great Japan tsunami”
f. Poster and oral presentations at scientific conferences or seminars


g. Education and outreach


4. PROGRESS STATUS

Overall progress was excellent. The aerial surveys for British Columbia were successfully completed on schedule and on budget. This will prove an important contribution to the project and the photographs will be further analyzed by Japanese colleagues to estimate percent cover of marine debris. The monitoring data analysis is largely complete and will be written as a manuscript for publication in collaboration with the monitoring contacts at NOAA and the modelling team.
1. PROJECT INFORMATION

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<tr>
<td>Lead Author of Report*</td>
<td>Atsuhiko Isobe</td>
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*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):

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Collaborators in US: Dr. Nancy Wallace (NOAA), Dr. Nir Barbea (NOAA), Mr. Charlie Plybon (Surfrider Foundation OR), Ms. Catherine Pruett (Salmon Drift Creek Watershed Council, OR), Prof. Nikolai Maximenko (Univ. Hawaii), Prof. Rob Holman (OSU CEOAS Coastal Imaging Lab)

Collaborators in Canada: Dr. Cathryn Clarke Murray (PICES)

2. EXECUTIVE SUMMARY

Describe both the research purpose, objectives, methods, results, achievements and challenges, timelines and milestones (2-3 pages)

To date, there are few published studies that have investigated variations in the quantities of long-term beach litter for intervals shorter than one month. Consequently, there is no way of knowing the “true” temporal scale of the variations in the quantity of litter on beaches, or the factors responsible for them. Furthermore, there is no way of knowing the appropriate time scales for beach surveys and/or cleaning services. Thus in this study, for monitoring tsunami debris, photographs of beach littering were taken automatically every 60 min over a one and half year period using webcams, with the aim of elucidating the temporal variations of litter quantities and the possible factors responsible for these changes. To provide quantities of marine debris littered on beaches, monitoring using webcams is adopted in line with Kako et al. (2010) and Kataoka et al. (2012). Photographs of beaches are taken every 1-hour during 1-2 years sequentially, and are converted to time series of areas (in the unit of m²) covered by marine debris after an image processing. The projection transformation method is used for this geo-referencing (Kako et al., 2010), and extraction of anthropogenic objects from the beaches is conducted on a CIELUV color space (Kataoka et al., 2012). The photographs are sent via the Internet to laboratories, and are also opened publicly. In the above experiment, we examine the efficiency of the above system for automatically monitoring tsunami debris, and elucidate relationships between the quantities of marine debris on beaches and atmospheric/oceanic conditions.
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 are conducted on beaches in Japan this year.

The webcam data are provided to the research project “Effect of Marine Debris Caused by the Great Tsunami of 2011” to combine with data obtained by other research groups (aerial photography and beach severance). This potentially provided us with a quantitative estimate of invasive species washed ashore onto western US and Canada coasts along with tsunami debris.

The timetable this year is as follows.

- **January 15-21, 2015**
  - Seeking the webcam-monitoring site around Newport OR

- **By the mid-February**
  - Purchase of equipment required for webcam monitoring
  - Shipping them to the webcam site

- **February 15-21, 2015**
  - Installing the webcam monitoring site
  - Operating test for the webcam monitoring
  - Near infra-red camera experiments

The details of the webcam system are as follows. The VIVOTEK IP8362 network camera is driven by two solar panels, and takes a photo every one-hour during the daytime (0900-1800 EST). The photo data are sent using the AT&T mobile communication service, and using Verizon 4D LTE USB Modem (UML295) and the CradlePoint MBR1400 Mission Critical Broadband Router to establish the Internet communication. 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.
3. PROGRESS SUMMARY

a. Describe original proposed research and planned outputs

As mentioned above, photographs of beach littering were taken automatically every 60 min over a one and half year period using webcams, with the aim of elucidating the temporal variations of litter quantities and the possible factors responsible for these changes. Thus, we had to complete to install the webcam this year, and this has done successfully. All image data are sent our laboratory through the Internet. The image processing is now ongoing, and will provide the time series of marine debris during the next year.

b. Describe progress

The most telling on our accomplishments is our website. This provides us photos of the OR beach littered by marine debris every one hour during the daytime (0900-1800 EST). The photos are processes by the projective transformation to convert images on the Cartesian coordinate in order to measure the areas covered by marine debris. Part of the processed images is shown in the next section.

c. Describe results

(1) Choice of webcam site at Newport OR

Candidates suitable for the webcam site were investigated along Oregon coasts close to Newport during the period 11th through 15th January 2015 (Fig. 1). The bottom lines to be satisfied for monitoring are capability of the mobile communication, soil condition, areas sufficiently large for setting a webcam equipment, accessibility from major roads, and surroundings without vandalism. The results of the in situ examination are listed on check sheets for each candidate.

As a result, we chose the site#2 (Fig. 1) for the webcam monitoring of marine debris at the west coast in US. This is because this site is located on the place higher than other sites (see photos in the check sheet), and because higher places always have an advantage in watching the debris littered on beaches. Also, the site#2 seems to be free from vandalism compared to other sites because of a careful management by county officials. In addition, the capability of the AT&T mobile service, the soil condition suitable for setting the webcam system, and accessibility from the major road all meet our criteria.

Fig. 1 Four candidates of the webcam site investigated in January 2015
(2) Installing a webcam at the Oregon coast

We stayed at Newport to install a webcam system at the site#2 during the period 15 through 21 February 2015. Figure 2 shows the webcam system that we have a plan to set at the site#2. The electricity for driving the camera is provided using solar panels. The area of 2.5 m x 2.5 m at least is required for the webcam system to set stably, and the site#2 well meets this criterion. By the end of February 2015, photo images taken by the camera was opened publicly via the Internet using the Verizon 4D LTE USB Modem (UML295) and the CradlePoint MBR1400 Mission Critical Broadband Router.

Fig. 2 Overview of the webcam system looking offshore-ward (westward) at the Oregon coast near Newport. The side views from south (upper panel) and west (middle panel), and plane view (lower panel) are shown in the figure.

(3) Providing webcam images through the Internet

The webcam images are first sent from the Oregon coast onto a FTP site at Kagoshima University, Japan. Thereafter, the images are opened publicly on the website http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html. When installing the webcam at the OR coast, the reference points for georeferencing were chosen in the area taken by the camera. The webcam images (Fig. 3a) are rotated to the images (Fig. 3b) on the Cartesian coordinate using the positions measured by GPS on the coast.
(4) Collaboration with aerial photography

The webcam monitoring has an advantage in monitoring marine debris continuously in time. The webcam however has a disadvantage that this monitoring provides us with quantities of marine debris only at a local site. On the other hand, aerial photography can synoptically monitor the accumulation of marine debris over areas broader than webcam monitoring. Nonetheless, the aerial photography also has a disadvantage that the surveys are conducted sporadically, so difficulty arises in considering the temporal variability of the quantities of marine debris with a fine resolution. Probably, the most reasonable method to monitor the marine debris with a high spatio-temporal resolution is a combination between webcam monitoring and aerial photography. In this year, as the first step of the combination, we attempt to quantify the marine debris on aerial photographs using the same image processing method as we applied to webcam images.

To investigate the accumulation of marine debris in the British Columbia and Alaska coasts, PICES and NOAA have been conducting aerial photographic surveys. We attempted to estimate a ratio of areas covered by marine debris to areas of entire beach (hereinafter, “percent cover”) by applying the image processing established by Kataoka et al. (2012) to the aerial photographs.

Fig. 3  Photo taken by the webcam at 1000EST on 4 April 2015 (a: left) and processed images by rotating the same photo onto the Cartesian coordinate with the projective transformation technique (b: right).

(4) Collaboration with aerial photography

The webcam monitoring has an advantage in monitoring marine debris continuously in time. The webcam however has a disadvantage that this monitoring provides us with quantities of marine debris only at a local site. On the other hand, aerial photography can synoptically monitor the accumulation of marine debris over areas broader than webcam monitoring. Nonetheless, the aerial photography also has a disadvantage that the surveys are conducted sporadically, so difficulty arises in considering the temporal variability of the quantities of marine debris with a fine resolution. Probably, the most reasonable method to monitor the marine debris with a high spatio-temporal resolution is a combination between webcam monitoring and aerial photography. In this year, as the first step of the combination, we attempt to quantify the marine debris on aerial photographs using the same image processing method as we applied to webcam images.

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Fig. 4  Comparison between original aerial photographs (a-c) and images that are extracted debris pixels by image processing (d-f). The red curves denote the beach area for calculating the percent cover.
Driftwoods are the most remarkable marine debris along the British Columbia coasts (Fig. 4, upper panels). In the present analyses, we chose driftwoods and anthropogenic debris as target objects, and extract their pixels (hereinafter, “debris pixel”) from aerial photographs using the difference of their colors. The lower panels of Fig. 4 show the images in which we extracted debris pixels from the three sample photos by the image processing. Most of debris pixels are likely to be successfully extracted although the whitecaps along the shoreline are erroneously extracted. Next, to calculate the percent cover of marine debris, we define the area of the beach every sample photographs (areas surrounded by red curves in Fig. 4 (a)-(c)). The percent covers were estimated for panels (a), (b) and (c) in Fig.4 as 4.8%, 0.1% and 6.0%, respectively.

At the present time, we have to override two technical issues to enhance the accuracy of the percent cover as follows:

i. The geo-referencing process is needed. The percent cover remains uncertainty because of the geometric distortion of the photographs. Hence, we have to convert the photos to those on a geographic coordinate using several references (more than four positions should be measured by GPS). Applying a projective transformation technique to the aerial photographs is thereafter required (e.g., Kako et al., 2012 and Kataoka et al., 2012).

ii. The areas littered by marine debris should be identified automatically. In the present analysis, we had to compute the percent covers from many photographs by eyes because the beach areas were defined by each photograph. In Year 2 (April, 2015 to March, 2016), we will establish the method for extracting the pixels of the beach from aerial photographs based on their colors.

(5) Experiments of near-infrared monitoring

The accuracy in monitoring marine debris with invasive species should be validated using alternative methods different from webcams; otherwise we cannot justify the estimate of the marine-debris amount. We attempt to identify driftwoods and anthropogenic debris covered partly by biological things (e.g., shells) using a near-infrared camera (Hyperspectral Camera; NH-7, EBA Japan Co. Ltd.). The camera has ability to distinguish the marine debris, driftwood, and other biological things from sands using reflectance spectra (Fig. 5) backscattered from objects on images. The comparison between images of near-infrared camera and webcam is conducted to investigate if the webcam images accurately capture marine debris with invasive species.

Fig. 5 Normalized reflectance spectra of polystyrene (PS), polyethylene (PE) and wood measured by NH-7.

(6) Potential research to be carried out in Year 2.

(6)-1 Comparison among webcam monitoring data, aerial photography, near-infrared images, and results of particle-tracking model

The photo image data are dumped every one or two hours into a data server via the Internet, and the areas covered by marine debris littered on the beach are computed using pixel numbers after geo-
referencing (Kako et al., 2010; Kataoka et al. 2012). The time series of the area is regarded as that of the amount of marine debris washed ashore on the beach over the entire project period. The accuracy of the debris estimate will be validated using near infrared images as mentioned above. In addition, the spatial-temporal variability of marine debris washed ashore on the US and Canadian coasts will be deduced by the combination with aerial photography. The cause(s) of the temporal variation of the debris amount will be investigated using a particle-tracking model into which ocean currents and winds are given. The model details are described below.

The gridded ocean surface current data from National Oceanic and Atmospheric Administration/Ocean surface Current Analyses – Real time (NOAA/OSCAR) is used for the ocean currents in this study (Fig. 6). The surface currents are computed directly from the gridded surface topography and surface wind analyses data derived from the various types of satellite observations such as TOPEX/Poseison, Jason-1, Geosat Fllow-On, European Remote Sensing 1/2, Environmental satellite, QuikSCAT, and so forth. The data derived from these satellites are interpolated into 1˚ by 1˚ grid box for every 5 days by using objective analysis method proposed by Lagerloef et al., (1999). This employs a straightforward linear combination of geostrophic and wind-driven (Ekman) motion. The technique is tuned to best represent the ageostrophic motion of the WOCE/TOGA 15 m drogue drifters relative to the surface wind stress. Geostrophic velocities are computed with sea level gradients derived from satellite sea surface height analyses. The mean altimeter surface height field is also subtracted and replaced by the mean annual 0-1000 dbar dynamic height derived from the NOAA/NODC (Levitus et al., 1994a,b) to preclude the influence of marine geoid errors on the altimeter data.

The difficulty of computing near equatorial geostrophic currents was treated by devising a weighted blend of the equatorial beta-plane and conventional f-plane geostrophic equations (Lagerloef et al., 1999). Ekman currents were derived from a two-parameter linear model fitted to drifter data. This provided a formulation that allowed smooth transitions across the equator without the problem of the equatorial singularity where the Coriolis acceleration crosses zero. The gridded surface current and sea surface height datasets for global oceans have been opened on NOAA website: http://www.oscar.noaa.gov/index.html. The period for which NOAA/OSCAR datasets are available is from 15 October 1992 to present.

Fig. 6  Horizontal distribution of long-term averaged (1993-2014) ocean surface currents in the North Pacific derived from NOAA/OSCAR. The unit is cm/s.

(6)-2 Additional webcam monitoring

We have a plan to install an additional webcam site in Year 2. Two candidates are now considered to monitor marine debris effectively, and we will choose one of two because of limitations of financial and human resources. The OR coast where we are installing the webcam is located at the boundary between subtropical and subarctic gyres of ocean currents in the North Pacific. A new site should be located in either subtropical gyre or subarctic gyre. The webcam data on the beaches provide us with an amount of debris “integrated” in time, and so it will be useful to compare with results of the particle-tracking model of
the subsection (6)-1 and the models used by MoE/PICES project researchers. In addition, the comparison with winds and ocean currents with webcam data should be conducted in various places to draw the firm conclusions.

One candidate is Pacific Islands such as Hawaiian Islands in the subtropical gyre. The other is Alaskan coast in the subarctic gyre. Both places are littered intensely by marine debris, and NPOs’ activities are anticipated to help us seek and maintain the webcam monitoring site.

**References**


d. Describe any concerns you may have about your project’s progress

We met some difficulties in making a contract of the Internet connection because of the limitation due to non-US inhabitants (without social security numbers, and without residential address in US). Our collaborators in US (Dr. Nir Barne) provided us with great helps to make the contract. We will need a counterpart in installing the webcam at additional places except in Japan.

e. Completed and planned publications

We just installed the webcam one month before, so that much more times are needed to process the images for preparing publications.

f. Poster and oral presentations at scientific conferences or seminars

We just installed the webcam one month before, so that much more times are needed to process the images for preparing presentations.

g. Education and outreach

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.

4. **PROGRESS STATUS**

Overall, In Year 1 the webcam project progressed on schedule. The webcam was installed by March 2015 and is now providing images through the Internet. Image processing has already started and will continue in Year 2 as suggested in the proposal submitted to PICES.
FINAL PROJECT REPORT

to the
North Pacific Marine Science Organization (PICES)

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<td>Lead author of report</td>
<td>James T. Carlton</td>
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Submitted to:

Dr. Alexander Bychkov  
Project Coordinator  
Effects of Marine Debris Caused by the Great Tsunami of 2011  
North Pacific Marine Science Organization (PICES)  
P. O. Box 6000, Sidney, British Columbia, Canada
EXECUTIVE SUMMARY

This research focused on characterizing the biodiversity on Japanese Tsunami Marine Debris (JTMD) generated on March 11, 2011 by the Great East Japan Earthquake. A fundamental 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. In order to accomplish this we have pursued an assessment of the diversity, reproductive potential, and other critical aspects of the biology and ecology of Japanese species on JTMD that have arrived and continue to arrive on North American and Hawaiian shores. Species such as the mussel *Mytilus galloprovincialis* and the barnacles *Megabalanus rosa* and *Semibalanus cariosus* have now survived transoceanic voyages of over 4 years in length. These types of observations, combined with the consistent arrival of a number of the same species since 2012, may provide a foundation for assessing the types of organisms that are particularly robust and may have higher invasive potential.

Hundreds of samples of JTMD from Alaska to California and the Hawaiian Islands have been acquired, processed, and carefully analyzed. This work consists of the taxonomic identification of the species on the debris, molecular genetic analyses, specimen image analyses, screening of over 1,500 mussels and other mollusks for the presence of endoparasites and chemical analyses of mussel shells.

As of March 31, 2015, of 331 intercepted JTMD items, 92% are from Washington, Oregon, and the Hawaiian Archipelago. Approximately 18% are vessels (n=60) and 35% post-and-beam lumber (n=117), with the remaining items representing a diversity of marine-origin debris (floats, buoys, ropes, etc.) and terrestrial-origin debris (pallets, cylinders, boxes, coolers, tanks, etc.), the latter colonized by marine species after they entered the ocean, and often identified by a unique Japanese biotic signature.

On this debris field we have found 350 species of marine animals and plants, including 304 species originating from Japanese waters and additional species acquired in the oceanic transit or upon arrival in the Eastern Pacific. Of the 304 species, more than half are represented by four groups of organisms: *algae* (71 species; 23% of the biota), *bryozoans* (51 species, 17%), *polychaete worms* (35 species, 12%) and *bivalve mollusks* (28 species, 9%). Mollusks and crustaceans combined account for slightly more than one-quarter of the biota (14% each). A large number of species are not yet present on the North American Pacific Northwest coast (or in Hawaii), where the majority of JTMD have 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. We have further obtained genetic sequences of a large number of JTMD invertebrate specimens, providing portions of the information required for detection of Japanese species and genomes in North American waters.

The large JTMD wood debris in the ocean has been colonized by shipworms, which are bivalve mollusks. More than 120 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, 1 Japanese coastal species, 1 cosmopolitan species, and 1 probable new species. Genetic sequencing has aided in confirming species identification, as well as the probable existence of a previously undescribed species. Of the other 5 species, at least two have established invasive populations elsewhere in the world.

We have further studied aspects of population growth and reproductive condition in several abundant species, including mussels (*Mytilus*) and small amphipod crustaceans. A large majority of the mussels arriving on JTMD are *Mytilus galloprovincialis*, a Mediterranean species that was introduced to Japan. From the onset of the arrival of biofouled JTMD along the Northeast Pacific coast in June 2012, relatively large mussels (>70 mm total length) have been present on many items. As this species is a predominantly intertidal filter-feeder known to grow well in relatively warm and saline waters, it is noteworthy that so many individuals arrived in apparently good condition at relatively large sizes 15+ months after the
tsunami. We thus used this species as a model to explore size, reproduction, growth and dispersal patterns of the JTMD biota. We completed size and reproduction assessment on >1000 individuals. Mean size of arriving mussels was smallest in Hawaii with no significant variation between 2012 and 2013 collections. However, shell size increased in Oregon and Washington between 2012 and 2013 but appears to have stabilized, as the sizes of 2014 collections were similar to 2013. Furthermore, reproductive individuals consistently arrived throughout our collections from 2012 to 2014. The lowest occurrence of individuals with mature or maturing gametes was observed in mussels collected in Hawaii (<17%), on debris that may have passed through lower productivity waters, whereas >60% of the individuals arriving on debris landing within Oregon and Washington (and with potential transits through higher productivity water masses) were reproductive and may have released gametes along the NE Pacific coast.

Variation in chemical ratios (such as barium (Ba) to calcium (Ca)) in mussel shells can provide information on ocean versus coastal residency and shell growth, which in turn can provide key information on conditions experienced by JTMD items and the duration of an item's residency in different water bodies. Coastal waters typically display higher concentrations of many trace metals, including Ba, than open ocean waters. In JTMD mussel in 2012 and 2013 elevated Ba/Ca levels were observed, indicating presumed residence in coastal waters. Trace metal composition of mussel shells may thus identify shell growth that occurred in Japanese coastal waters (relatively high Ba), open ocean waters (relatively low Ba), and potentially US coastal waters (relatively high Ba) if adequate shell growth occurred. In many mussels we detected a peak (usually >2x background) in Ba/Ca, followed by a period of low Ba/Ca, and finally a gradual elevation of Ba/Ca at the outer shell edge. It is possible that the peaks observed in so many JTMD mussels are directly related to the tsunami, which was associated with the delivery of a tremendous amount of Ba-rich terrestrial sediments into the coastal zone and the disturbance of large areas of high-Ba sediment pore water. Of interest is that the shell chemistry of the spring 2014 mussel arrivals was different from earlier collections. No distinct spikes of Ba/Ca were observed indicative of the tsunami. For several mussels there was consistently a greater amount of shell growth displaying moderate Ba/Ca levels, potentially indicating multiple coastal interceptions prior to coming ashore. This pattern may reflect longer coastal residence times, greater growth, and potentially reproduction in Northeast Pacific coastal waters.

Population analyses of the marine gammarid amphipod *Jassa marmorata*, analyzed by image analysis, help resolve the ocean history of JTMD communities and the trophic conditions linked to surviving JTMD species. It appears, for example, that the gammarid amphipod *Jassa marmorata*, had stable age distributions which may reflect continuous reproduction on JTMD as items crossed the ocean from Japan. In turn, *Jassa* appears to be the most common gammaridean amphipod on JTMD.

Population analyses of crustaceans and marine insects further aid in resolving the ocean history of JTMD communities. Small crustaceans that reproduce at sea have stable age populations; those that reproduce at irregular or recent periods have unstable populations, often lacking juveniles or reproductive adults. Understanding whether species with different reproduction and population histories are more or less persistent in ocean rafting may assist with predicting invasion success. Species survive ocean transits by either individual survival (e.g., mussels and barnacles) or by recruitment and replacement (e.g., mobile crustaceans). These strategies require competence to feed in either low production ocean waters, a debris pathway in high production waters, or competence to survive near-starvation. Stable isotopic analyses of tissues in common JTMD species arriving on American shores can assist in resolving these potential patterns, again with a focus on predicting species with lower vs. higher probabilities of invasion success.

There is a critical lack of information on JTMD composition and structure required for risk analyses of the volume of inbound debris and thus potential propagule pressure. Post-and-beam wood comprises one of the largest fraction of JTMD transporting species to North America. Mark-and-recapture tagging methods on JTMD wood potentially aids in resolving JTMD movements and residency times, permitting hindsight calculations leading to more accurate assessments of the condition and abundance of JTMD in general.
PROGRESS SUMMARY

A. ORIGINAL PROPOSED RESEARCH AND PLANNED OUTPUTS

Our original proposed research was as follows:

* Complete Biodiversity Characterization of the JTMD Biota: Rafting Years 1-4, including:
  § Analysis of Bivalve Parasites and Pathogens Associated with JTMD
  § DNA Barcoding of JTMD Vouchers and Initial Creation of JTMD Barcode Database
* Species Survival, Population Growth, and Reproductive Condition
* Early Detection of JTMD-Related Invasions, including:
  § Initiate Surveys of Pacific Coast Mussels for Detection of Japanese Endoparasitic Hydroid Eutima
  § Initiate Collections of Environmental DNA (Plankton and Fouling) from North American Waters
* JTMD Abundance and Structure

In turn, our outcomes and deliverables that we planned to produce were as follows:

* JTMD Biodiversity Assessment Report & Summary: An overall summary of JTMD biodiversity, emphasizing data acquired in sample analyzed from September 2014 to March 2015, including summary of detected parasites and pathogens in JTMD biota.
* Detailed progress report on DNA barcoding of JTMD vouchers and on the initial creation of JTMD barcode database.
* A summary of population growth and reproductive condition of prominent, abundant, JTMD biota.
* Early results of initial surveys of Pacific North American mussels (and other bivalves) for the Japanese endoparasitic hydroid Eutima.
* JTMD Abundance and Structure

B. PROGRESS

Our activities and accomplishments were as follows. Samples collected and data analyses are detailed in (C) RESULTS, below. We were pleased to be able to significantly expand our proposed research goals and objectives. While we had planned on initiating collections of e-DNA (plankton and fouling) from North American waters, time and circumstances did not permit our doing so, and this work has been moved to our proposed Year 2 studies.

* Completed Biodiversity Characterization of the JTMD Biota: Rafting Years 1-4, including:
  § Expanded and Refined our Understanding of Overall JTMD biodiversity
  § Characterized Shipworm Diversity
  § Analyzed Bivalve Parasites and Pathogens Associated with JTMD
  § Began DNA Barcoding of JTMD Vouchers and Initial Creation of JTMD Barcode Database
  § Analyzed population structure, reproductive condition and abundance of selected JTMD species
  § Analyzed trophic structure of selected JTMD communities (through stable isotope analyses)
* Assessed selected Species Survival, Population Growth, and Reproductive Condition
* Early Detection of JTMD-Related Invasions, including:
  § Initiated Surveys of Pacific Coast Mussels for Detection of Japanese Endoparasitic Hydroid Eutima
  § Designs for Collections of Environmental DNA (Plankton and Fouling) from Pacific North American Waters
* Assessed JTMD Abundance and Composition
C. RESULTS
In this report institutional codes are as follows:

<table>
<thead>
<tr>
<th>Code</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC</td>
<td>Williams College</td>
</tr>
<tr>
<td>OSU</td>
<td>Oregon State University</td>
</tr>
<tr>
<td>MLML</td>
<td>Moss Landing Marine Laboratories</td>
</tr>
<tr>
<td>SERC</td>
<td>Smithsonian Environmental Research Center</td>
</tr>
</tbody>
</table>

**Biodiversity Assessment**

**All PIs (WC, OSU, SERC, MLML)**

A primary focus of our activities since fall 2014 was to continue processing for biodiversity analysis the existing JTMD samples in hand as of October 2014, and curate new incoming biota associated with JTMD. We have completed the initial processing of 100% of all JTMD samples acquired prior to October 2014. Initial processing includes fine-scale sorting of biota, identification to species level when possible with resident expertise, and preparation of samples for provision to additional taxonomic experts. Further processing consists of the enumeration and measurement (as detailed below) of selected crustaceans, as well as of all mussels (*Mytilus*), extraction of tissue from all or a subset (up to 100) of *Mytilus* for genetic analysis, and delivery of remaining *Mytilus* tissue for parasite and pathogen analysis. We have completed processing of biotic samples from an additional >75 JTMD items. Over 1,200 individual *Mytilus* have been processed and are in various stages of analysis. Additionally we have completed or assisted in the acquisition since October 2014 of more than 40 newly-acquired JTMD items from Washington, Oregon, and Hawaii, working with personnel at the Hawaiian Department of Natural Resources, the Washington Department of Fisheries and Wildlife, and individual workers including Russell Lewis and Nancy Treneman.

**Species Diversity as of March 31, 2015**

As of March 31, 2015, we and colleagues have intercepted 331 items attributed to Japanese Tsunami Marine Debris (**Appendix I**). Approximately 92% of these items were accessioned from Oregon, the Hawaiian Archipelago, and Washington; approximately 18% are vessels (n=60) and 35% post-and-beam lumber (n=117) with the remaining being a wide diversity of marine-origin items (floats, buoys, ropes, etc.) or terrestrial-origin debris (pallets, cylinders, pipes, boxes, boards, coolers, tanks, etc.) that were biofouled upon entering the ocean.

On this debris field we have enumerated a fauna and flora of approximately 350 species (please see **APPENDIX II**). Of these, we currently recognize 304 species as originating from Japanese waters, with an additional 14 species acquired by JTMD in the oceanic transit, and 21 species acquired upon arrival in the Eastern Pacific. Of the 304 species, more than half are represented by four groups: algae (approximately 71 species; 23% of the biota), bryozoans (51 species, 17%), polychaete worms (35 species, 12%) and bivalve mollusks (28 species, 9%) (**APPENDIX II**). Overall, mollusks and crustaceans account for slightly more than one-quarter of the biota (13.8% and 13.8%, respectively).

Examples of some of the more common invertebrate species are shown in the table below, including taxa representing a wide range of cnidarian, annelid, molluscan, and crustacean groups. Not surprisingly, a number of species are not yet present on the North American Pacific Northwest coast (or in Hawaii), where the majority of JTMD have come ashore, with some of these, such as the large pink barnacle *Megabalanus rosa*, the bryozoan *Tricellaria inopinata*, and the serpulid tube worm *Hydroides ezoensis*, being well-known invasive species elsewhere around the world.
### Selected Common Invertebrate Species Encountered on or in JTDM 2012 - 2015, and their Invasion History

<table>
<thead>
<tr>
<th>Group</th>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Invasion History</th>
<th>Already Present on Pacific Northwest coast?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrozoa</td>
<td>hydroids</td>
<td><em>Obelia</em> spp.</td>
<td>Widespread in ports and harbors</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Sertularella mutuensis</em></td>
<td>Restricted to Japan at this time</td>
<td>No</td>
</tr>
<tr>
<td>Polychaeta</td>
<td>marine worms</td>
<td><em>Syllidae</em> (multiple species)</td>
<td>Poorly known</td>
<td>No (some species)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Hydroides ezoensis</em></td>
<td><strong>Known invader in Australia and Europe</strong></td>
<td>No</td>
</tr>
<tr>
<td>Bivalvia</td>
<td>mussels</td>
<td><em>Mytilus galloprovincialis</em></td>
<td><strong>Known invader in Asia, Eastern Pacific, So. Africa</strong></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Hiattella arctica</em></td>
<td>Widespread in northern hemisphere</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Teredinidae</em> (multiple species)</td>
<td><strong>Some species known invaders</strong></td>
<td>No (none of the 6)</td>
</tr>
<tr>
<td>Cirripedia</td>
<td>barnacles</td>
<td><em>Semiaulanus cariosus</em></td>
<td>Widespread in North Pacific</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Megabalanus rosa</em></td>
<td><strong>Known invader in New Zealand and Australia</strong></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Balanus trigonius</em></td>
<td>Widespread in warmer waters of Pacific Basin; <strong>known invader in Atlantic</strong></td>
<td>No</td>
</tr>
<tr>
<td>Amphipoda</td>
<td>amphipods</td>
<td><em>Jassa marmorata</em></td>
<td><strong>Widespread invader</strong> in ports and harbors, along with other possible JTMD <em>Jassa</em> species</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Stenothoe valida</em></td>
<td><strong>Widespread invader</strong></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Caprella mutica</em></td>
<td><strong>Widespread invader</strong></td>
<td>Yes</td>
</tr>
<tr>
<td>Isopoda</td>
<td>isopods</td>
<td><em>Ianiropsis serricaudis</em></td>
<td><strong>Widespread invader</strong></td>
<td>Yes</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>bryozoans</td>
<td><em>Aetea</em> spp.</td>
<td>Poorly known</td>
<td>No (A. truncata)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Scruparia</em> sp.</td>
<td>Not known</td>
<td>Rare if present; may not be same species</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Tricellaria inopinata</em></td>
<td><strong>Known invader in the Atlantic Ocean</strong></td>
<td>No</td>
</tr>
</tbody>
</table>

### Analysis of Bivalve Parasites and Pathogens Associated with JTMD
Gregory Ruiz (SERC)

There are two related goals focused on parasites and pathogens that we advanced in Year 1:
1. Analysis of mussels and oysters on JTMD arriving in the eastern Pacific, and,
2. Initiating surveys of the endoparasitic hydroid *Eutima* and other target parasites in resident host mollusk species along the eastern Pacific.

We summarize our work on (2) initial surveys below in the section on Early Detection of JTMD-Related Invasions. Relative to (1), we processed > 1,200 mussels arriving on JTMD to screen for parasites and pathogens. These have all been screened visually for the parasitic hydroid *Eutima* sp. and other macroparasites, which can occur on the gills or within the mantle cavity. In addition, a subset (>250 mussels) were screened using molecular genetic analyses for protistan parasites in the genera *Perkinsus*, *Bonamia*, and *Haplosporidium*, which are known to cause diseases in bivalve mollusks. This work was conducted with funding from the National Science Foundation (until 2014) and PICES funding thereafter (2014-2015). In particular, the PICES funds allowed us to increase the total sample size --- adding > 300 mussels --- for parasite analyses and also include mussels from additional JTMD objects, which have arrived in North America and Hawaii.
To date, we have detected *Eutima* and novel (previously unknown) lineages for *Haplosporidium* in mussels from JTMD. With Year 1 PICES funds, we continued to expand the sample size and scope of analyses of parasites for mussels on JTMD. In addition, we (a) screened all available oysters from JTMD for the above parasites and (b) screened > 200 mussels for copepod parasites, using standard enzyme digestion methods. The latter two components are novel to the PICES project and were not included in the earlier NSF effort.

**DNA Barcoding of JTMD Vouchers and Initial Creation of JTMD Barcode Database**

Jonathan Geller (MLML)

Year 1 goals included DNA barcoding of JTMD voucher specimens and genetic detection of JTMD-associated DNA sequences in North American waters. Upon receipt of funds a graduate student assistant and technician position were filled and DNA barcoding work commenced. Two approaches were taken: a limited subset of 96 specimens were sequenced conventionally by the Sanger method, and while two loci from all specimens (313) that were available for genetics were sequenced on the Ion Torrent platform. The accompanying Table below and Appendix III present summaries of work performed.

High quality Sanger sequences were queried against Genbank and our internal research database of invasive species in California. Preliminary assessment was based on a 95% threshold; final analysis will include phylogenetic analyses where sufficient data are available. Provisional genetic identifications were compared to morphological identifications provided by the Carlton Laboratory. The table below presents an overview of agreement and disagreement between genetic and morphological identifications, as well as refinements of morphological identification provided by genetics. In several cases, sequences were bacterial or algal in origin. In other cases, no record in Genbank was closely matching and the morphological identification cannot be independently tested.

Species refinements (where a species name is added to a morphologically identified genus or family) included the bivalve *Septifer virgatus*, the bryozoan *Watersipora subtorquata*, and the amphipod *Ampithoe lacertosa*. The amphipod *Jassa* was refined to *Jassa marmorata* or *J. slatteryi*. Of interest is that our sequences match either equally well and it appears that the two species are conspecific or not resolved by COI. One JTMD sequence for *J. marmorata*, on the other hand, was only 86% matched to any *J. slatteryi* sequence, suggesting the presence of a cryptic species or misidentification in Genbank. Confirmation was made for the barnacle *Semibalanus cariosus*. Cases for further morphological investigation include those bryozoans identified as *Bugula*, as these did not match existing records in Genbank or our local database.

Two cases of striking incongruence between morphological and genetic identification were seen. In one, an "anemone" sequence was similar to those from isopods, although there was no very close match in Genbank (as noted in the table, it may be that the anemone had consumed isopods; the isopod *Ianiropsis* is often common in JTMD samples). A sequence from the native oceanic bryozoan *Jellyella tuberculata* was found to strongly resemble that from a nudibranch, possibly the native oceanic seaslug *Fiona pinnata*. *Jellyella* and *Fiona* often occur together on the same floating substrates at sea. Most specimens of *Jellyella* yielded sequences that had no close match in Genbank. It is plausible that a nudibranch egg on a bryozoan colony could be the source of the anomalous sequence. Other *Jellyella* specimens produced sequences with no match in Genbank.

In many cases, there were no records in Genbank that matched a JTMD sequence at >85-95%, and lower matching records are relatively uninformative, as phylogenetic signal in COI degrades quickly as the evolutionary distance between taxa increases. For example, JTMD specimens morphologically identified as Capitellidae had no match in Genbank, but poor matches included other annelids. For other sequences, there was no correspondence between observed morphology and the taxon of low similarity Genbank matches.
In addition to specimens sequenced by conventional Sanger sequencing, which produces long read lengths, all templates were sequenced for both COI and 28S on the Ion Torrent platform (see APPENDIX III). PCR products that fail to sequence by the Sanger method will often yield useful sequences on the Ion Torrent platform due to its single-molecule sequencing approach that performs better with weakly amplifying templates. With combined Sanger and Ion Torrent sequencing, we have obtained sequences for the majority of specimens, providing necessary information for detection of Japanese genomes in North American waters.

### Summary of Morphology vs Genetic Identifications. Multiple similar results are binned in rows.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Morphological ID</th>
<th>Genbank Match</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryozoa</td>
<td>Celleporina sp.</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Anthozoa</td>
<td>Unidentified</td>
<td>Ianiropsis epilitoralis or Sphaeramene polytylotos</td>
<td>Weak hits, both 93% similar; possible dietary source of crustaceans</td>
</tr>
<tr>
<td>Cirripedia</td>
<td>Semibalanus cariosus</td>
<td>No hit</td>
<td>Semibalanus cariosus</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Membranipora sp.</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Watersipora sp.</td>
<td>Watersipora subtorquata</td>
<td>95% similar</td>
</tr>
<tr>
<td>Amphipoda</td>
<td>Unidentified</td>
<td>Ampithoe lacertosa</td>
<td>95% similar</td>
</tr>
<tr>
<td>Bivalvia</td>
<td>Septifer sp.</td>
<td>Septifer virgatus</td>
<td>99% similar</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Jellyella tuberculata</td>
<td>No hit</td>
<td></td>
</tr>
<tr>
<td>Annelida</td>
<td>Capitellidae</td>
<td>No hit</td>
<td>Closest to nemertein</td>
</tr>
<tr>
<td>Annelida</td>
<td>Capitellidae</td>
<td>No hit</td>
<td>Consistent with Annelida</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Scruparia sp.</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Amphipoda</td>
<td>Jassa sp.</td>
<td>Jassa marmorata/slattery</td>
<td>Both 99% similar; only 86% similar to slattery</td>
</tr>
<tr>
<td>Amphipoda</td>
<td>Jassa sp.</td>
<td>Jassa marmorata</td>
<td>Both 100% similar</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Bugula sp.</td>
<td>No hit</td>
<td>Bryozoa, very weak on B. migottoi and B. neritina (84%)</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Tricellaria sp.</td>
<td>No hit</td>
<td>Weak Tricellaria occidentalis 86%</td>
</tr>
<tr>
<td>Hydrozoa</td>
<td>Unidentified</td>
<td>No hit</td>
<td>Consistent with Bryozoa, not Hydrozoa</td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Aetea sp. B</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Hydrozoa</td>
<td>Unidentified</td>
<td>No hit</td>
<td></td>
</tr>
<tr>
<td>Porifera</td>
<td>Unidentified</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Porifera</td>
<td>Unidentified</td>
<td>No hit</td>
<td></td>
</tr>
<tr>
<td>Bryozoa</td>
<td>Jellyella tuberculata</td>
<td>Fiona pinnata</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Porifera</td>
<td>Unidentified</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
<tr>
<td>Hydrozoa</td>
<td>Unidentified</td>
<td>No hit</td>
<td>Possible algal source</td>
</tr>
<tr>
<td>Ascidiacea</td>
<td>Unidentified</td>
<td>No hit</td>
<td>Possible bacterial source</td>
</tr>
</tbody>
</table>

**JTMD Wood and Shipworm (Teredinidae) Survey**

**In cooperation with Nancy Treneman**

JTMD wood debris in the ocean is colonized by shipworms, which are bivalve mollusks in the family Teredinidae. As of March 31, more than 120 JTMD woody items (largely consisting of highly recognizable post-and-beam (mortise and tenon) building wood from Japan) from latitudes 42.1° to 49.9° N have been analyzed for shipworm species diversity, abundance, and frequency. Currently 6 species of non-native shipworms have been discovered in JTMD: 3 subtropical to tropical pelagic species, 1 Japanese coastal species, and 1 cosmopolitan species, and one probable new species. The native Eastern
Pacific shipworm, Bankia setacea, has not been found in JTMD. JTMD with living or freshly dead shipworms has been intercepted, permitting collection of tissue for DNA sequencing (18S and COI genes) in cooperation with the laboratories of L. Borges and M. Raupach (Germany) and R. Shipway (Massachusetts). Sequencing has confirmed species identification, and the probable existence of a previously undescribed shipworm species. It will be important to study the natural history and biogeography of this new species to determine the risk of it becoming established in the eastern Pacific. Of the other 5 species, at least two have established invasive populations elsewhere in the world.

**Early Detection of JTMD-Related Invasions: Initiate Surveys of Pacific Coast Mussels for Detection of Japanese Endoparasitic Hydroid Eutima**

Gregory Ruiz and Jonathan Geller (SERC, MLML)

We have initiated field surveys for parasites in resident bivalve populations along the coast of western North America. Mussel (*Mytilus*) populations were sampled from 4 bays in Oregon and California, using a standardized (stratified) sampling design. Mussels (1,248) were collected and screened visually for *Eutima* and other macroparasites, and tissue samples were preserved for molecular genetic assays (detection) of protistan parasites.

**Designs for Collections of Environmental DNA (Plankton and Fouling) from Pacific North American Waters**

Gregory Ruiz and Jonathan Geller (SERC, MLML)

The main goal of this research component focuses on testing for the presence (detection) of non-native species that may have established with JTMD from Japan. We have established protocols for surveys in plankton and fouling communities, in addition to those for parasites associated with bivalves (see above, Analysis of Bivalve Parasites and Pathogens). This includes surveys of fouling communities using settling panels and surveys of plankton communities using pump samples, yielding both morphological and molecular data. We have implemented these protocols at California sites in order to establish and refine our methods for Year 2 work.

**Species Survival, Population Growth, and Reproductive Condition**

**Model System: Japanese mussel Mytilus galloprovincialis**

Jessica Miller (OSU)

Based on our genetic work, a large majority of the mussels arriving on JTMD are *Mytilus galloprovincialis*, a Mediterranean species that was introduced to Japan and other geographic areas. From the onset of the arrival of biofouled JTMD along the NE Pacific coast in June 2012, relatively large *Mytilus* (>70 mm total length) have been present on many of the items. As this species is a predominantly intertidal filter-feeder known to grow well in relatively warm and saline waters, it is noteworthy that so many individuals arrived in apparently good condition at relatively large sizes 15+ months after the Japanese tsunami. Therefore, we used this species as a model to further explore size, reproduction, growth and dispersal patterns of the JTMD biota.

In Year I, we collected and synthesized information on size and reproductive state of the mussel *Mytilus* on JTMD items that have adequate numbers of individuals (>15) for analysis. We completed the size and reproduction assessment on >1000 individuals. Interestingly, mean size of arriving *Mytilus* was smallest in Hawaii with no significant variation between 2012 and 2013 collections. However, shell size increased in Oregon and Washington between 2012 and 2013 but appears to have stabilized, as the sizes of 2014 collections were similar to 2013 (see figure below). Furthermore, reproductive individuals consistently arrived throughout our collections from 2012 to 2014. The lowest occurrence of individuals with mature or maturing gametes was observed on samples collected in Hawaii (<17%) whereas >60% of the individuals arriving on debris landing within Oregon and Washington were reproductive (see figure below) and may have released gametes along the NE Pacific coast.
In Year 1, we also expanded our structural and chemical analyses on the *Mytilus* shells of a subset of individuals across the observed size range from representative debris items collected during the Spring 2014 pulse of JTMD skiffs. These efforts built upon prior work in which we have quantified variation in the barium:calcium (Ba:Ca) profiles across the growth axis of the mussels and thus add to our relatively comprehensive picture of the size, growth, and dispersal history of *Mytilus* arriving on selected JTMD items from June 2012 through June 2014. These data provide information on water mass residency (coastal vs. open ocean waters) and associated shell growth, which in turn provide key information on growth conditions experienced by different JTMD items and the duration of an item’s residence in coastal waters.

The premise of this analysis relies on the fact that coastal waters typically display higher concentrations of many trace metals, including barium (Ba), than offshore, open ocean waters. Therefore, the hypothesis was that trace metal composition of the mussel shells could be used to identify shell growth that occurred in Japanese coastal waters (relatively high Ba), open ocean waters (relatively low Ba), and potentially US coastal waters (relatively high Ba) if adequate shell growth occurred. Within the shells of *Mytilus* collected in 2012 and 2013, we observed the hypothesized pattern of elevated Ba/Ca during presumed residence in coastal waters (see figure below). The patterns of shell Ba/Ca were remarkably consistent within individuals of similar sizes on the same JTMD item. Interestingly, for many JTMD items, we also detected a peak (usually >2x background) in Ba/Ca, followed by a period of low Ba/Ca, and finally a gradual elevation of Ba/Ca at the outer shell edge. Although peaks in bivalve shell Ba/Ca have been observed in several taxa, the causes of these peaks remains unclear. Potential hypotheses include consumption of large amounts of senescent phytoplankton post-bloom and/or the consumption of barite particles. However, background water Ba/Ca are well correlated with water Ba/Ca levels. In this instance, it is possible that the peaks observed in so many JTMD *Mytilus* were directly related to the tsunami. The tsunami was associated with the delivery a tremendous amount of Ba-rich terrestrial sediments and debris into the coastal zone, the disturbance of large regions of high-Ba pore water, and potentially facilitated an enhanced spring bloom in NW Pacific coastal waters off Japan.

The shell chemistry of the Spring 2014 arrivals was different from earlier *Mytilus* collections (see figures below). We did not observe distinct spikes of Ba:Ca that could be indicative of the tsunami but for several BF items there was consistently a greater amount of shell growth that displayed moderate Ba/Ca levels, potentially indicative of multiple coastal interceptions prior to landfall. This pattern likely reflects longer coastal residence times, greater growth, and potentially reproduction in NE Pacific coastal waters.
Overall, the JTMD Mytilus that arrived in 2014 displayed patterns of settlement and growth that is distinct from earlier arrivals.

Based on the Ba/Ca profiles, we separated shell growth into two categories: 1) “oceanic growth” identified as shell growth during periods of low Ba/Ca between the earlier Ba/Ca peak, if present, and gradual increase in shell Ba/Ca at the outer edge of each shell and 2) NE Pacific coastal water growth identified as the region with a gradual increase in Ba/Ca at the outer edge of each shell. We then estimated the total shell length at distinct points in time based on back-calculation models of umbo width and total shell length ($R^2 > 0.75$). This approach allowed us to generate growth estimates (mm/day) for certain Mytilus shells during oceanic transit (low shell Ba/Ca). Additionally, we estimated total shell deposition during residence in coastal waters of the NE Pacific (i.e., shell deposition during the gradually increasing shell Ba/Ca at the outer shell edge) (see figures below). As we have no specific estimates of days of coastal residency, these growth values are presented as total shell deposition.
Figure 1. Length frequencies of males, females, and juveniles of the gammaridean amphipod crustaceans, *Ampithoe*, *Gammaropsis*, *Jassa* and *Stenothoe* on the biofouled JTMD objects BF-23 and BF-40 revealing higher frequencies of small and young size classes on BF-23.

**Challenges Encountered**

We also proposed to complete a laboratory experiment in which small individuals (10-50 mm shell length) of a congeneric native mussel species (*Mytilus californianus*) from the Oregon coast. We completed a 24-hour exposure to of barium enrichment (ambient, 5x, and 10x) and then allowed the *Mytilus* to grow under ambient conditions for 4 weeks. Unfortunately, there were unanticipated effects of the algal cultures used to feed the *Mytilus* on the water chemistry within the experimental treatments. Therefore, this experiment was not a robust evaluation of the hypothesis.

**Model System: Crustaceans and Marine Insects**

**John Chapman (with Andrea Burton and Maria Barton) (OSU)**

We used Year 1 support to measure structures of JTMD species populations that arrived up through 2014. These population analyses help to resolve the ocean history of JTMD communities and the trophic responses of surviving JTMD species. Our population analyses include distributions of size frequency and reproductive development of short and long-lived vagile and sessile species, including peracaridan crustaceans and marine insects (especially the marine chironomid fly *Telmatogeton*), and sedentary crustaceans such as acorn barnacles. We hope to extend these analyses to wood boring shipworms as major subjects of our analyses with N. Treneman in Year 2.

**Image analyses and processing of small crustacean populations**

We used PICES support to develop more efficient analyses of small species from digital images that can be produced quickly and permanently archived and reanalyzed. Peracaridan crustaceans (amphipods, isopods and tanaidaceans) populations that continue to reproduce at sea or in relatively low production waters are more likely to have stable age distributions (SAD). These species include the amphipod genera *Jassa* and *Stenothoe* which more commonly have stable age distributions (SAD), with multiple overlapping cohorts within sexes (Figure 1). Populations that are reproductive at irregular or recent periods are expected to have unstable age distributions (UAD) within sexes and are often lacking in
either juveniles or reproductive adults (Figure 1, *Ampithoe* and *Gammaropsis*). Coinciding UAD or SAD populations on the same debris objects are likely to reflect trophic conditions surrounding that object. The general differences (Figure 1) between items BF-23 (a small Japanese vessel coming ashore in Oregon in February 2013) and BF-40 (a vessel landing in Washington in March 2013) indicate that the recent history of BF-23 included less time in high trophic availability conditions than BF-40.

UAD species might have restricted reproduction in transit and thus reduced potential for long term survival on JTMD, but may be more likely to adapt, with increased reproduction and survival risk, to North American waters. Thus, the potential for JTMD species to survive the transit may be poorly related to their invasion risk in North America. We hope to use Year 2 analyses of the growth rates of UAD to test whether they have different invasion histories than SAD species.

Distinct size/age cohorts are less likely within SAD populations. The amphipod *Jassa marmorata* populations (see figure above) were resolved by the new image analyses. Their populations, in contrast to the amphipod *Caprella muticum*, measured microscopically, do not have clear size modes. The (SAD) among *Jassa* populations could result from continued reproduction on the JTMD as it crossed the North Pacific from Japan. *Jassa* may be the most common gammaridean amphipod on JTMD (recovered from at least 11 JTMD items since June 2012). The male and female *Jassa* size distributions are not significantly different. We propose to test in Year 2 whether short-lived SAD species can be more persistent in open ocean (JTMD conditions) than short-lived UAD species, to assist with predicting invasion success.

**Stable Isotope Analyses of Rafting community trophic sources and survival at sea.**

**John Chapman (OSU)**

Rafting species survive North Pacific Ocean transits by extended individual survival without replacement (e.g., mussels and barnacles) or by new recruitment and replacement during transit (e.g., mobile crustaceans). Both survival strategies required competence to feed since March 2011 in either (a) low production mid-ocean waters during transit, (b) a debris pathway restricted to high production waters farther north, or (c) competence to survive years of near-starvation. In Year 2 we will extend our stable isotopic analyses of the tissues in common JTMD species arriving on North American shores over longer periods to resolve these patterns, with, again, a focus on predicting species with lower vs. higher probabilities of invasion success.

Carbon (C) and nitrogen (N) stable isotope analyses of JTMD species began with NSF funding. The trophic histories of JTMD species can be partially resolved from comparisons of isotopic ratios in taxa from coastal Asia, the open ocean and coastal North America. This work is performed in the COAS Stable Isotope Laboratory (http://stable-isotope.coas.oregonstate.edu/) on samples that are prepared at the Hatfield Marine Science Center. Samples for these analyses have been collected from northeasten Japan, including Misawa Fishing Port (collected in collaboration with Dr. Toshio Furota), the source of the "Misawa 1" dock (JTMD-BF-1). These isotope samples also include populations and samples of North American taxa that are similar to JTMD taxa.

**JTMD Abundance Composition and Distributions**

**Beach Survey and Monitoring of JTMD Post-and-Beam Japanese Building Wood**

**John Chapman (OSU) (with Nancy Treneman)**

JTMD collection, processing and analyses revealed a critical lack of information on JTMD composition, diversity and structure needed for risk analyses. To address this, we allocated a small amount of Year 1 funding to tag and survey JTMD wood (Japanese building materials) relative to all other wood and other debris in beach deposits.

Dimensional building materials, consisting largely of post-and-beam wood construction, comprise the largest fraction of JTMD that transports Asian species to North America. We developed mark and recapture tagging methods targeted to resolve JTMD movements, residency times, and losses from beach deposits. Hindsight calculations of wood JTMD accumulation may lead to more accurate assessments of the condition and abundance of JTMD in general. Labeled tags are attached to beach debris, including JTMD wood. The tags, in combination with photographic records of the debris objects, will increase opportunities to monitor JTMD accumulation and movements in Year 2. Knowledge of the volume, accumulation, movement and decay of JTMD will be critical for risk assessment. Fortunately,
wooden JTMD is seldom removed from Oregon and Washington beaches, forming a foundation for this research.

**Aerial / Vessel JTMD Search and Recovery Activity**

**John Chapman (OSU)**

We used Year 1 funding to test aerial and shipboard search and vessel location protocols for finding and sampling or recovering at-sea JTMD. An unknown fraction of mobile species abandon the debris (or are otherwise lost) at sea. However, most samples of JTMD are from beach landed objects. An important goal has therefore been to measure at-sea communities on JTMD, but open ocean debris has proven difficult to locate directly from vessels.

We performed a trial plane search for this purpose on 30 January 2015 within a 30 km length by 20 km wide section of ocean between Lincoln City and Waldport, Oregon where fresh JTMD had landed on beaches within the preceding two weeks. Pilot Bill Frank (Aeromax Avionic) carried us in a twin engine plane for the survey from the Newport, Oregon Airport. The twin engines provide a safety factor that permits ocean searches beyond the normal 1 mile glide distance from shore. We searched at 1000 feet (300 meters) and 125 knots (232 km/hr) for 1.5 hours. Our observation angle from 1000 feet at 60 degrees out of the right side of the plane permitted a search path width of approximately 0.53 km. We marked each point of change in course by GPS and summarized the overall distance of the survey by the flight distance among the turning points. Our search within the 30x20 km area was 173 km$^2$ (327 km * 0.53 km). Seabirds and other small floating objects, within the size range of observable JTMD, were readily apparent at the airplane altitude and velocity. We are unlikely to have overlooked JTMD within our search area but nevertheless no JTMD objects were found.

We partially tested the flight search effectiveness on 1 February 2015. Lincoln County Commissioner Terry Thompson and John Chapman searched for JTMD from a 4 m vessel in the Depoe Bay area within the above flight search area. Relevant sized objects were apparent from an 0.3 km search width from the boat. The boat track, also measured from waypoints, was 32 km and thus the search area was 9.8 km$^2$ (32 km * 0.3 km). Consistent with the flight observations, no debris was found in the vessel survey. These surveys can be used to estimate the maximum densities of JTMD that would be missed with 95% confidence limits under a range of search efforts. The airplane and vessel times for these initial tests were donated; no special PICES funds approved for these two searches were used. We hope Year 2 funds will be available for intercepting any new debris.

**D. CONCERNS OR PROBLEMS RELATIVE TO PROGRESS**

No significant problems were encountered during this reporting period. During our mussel work, we encountered experimental challenges in a barium exposure experiment with native mussels, noted above.

**E. PUBLICATIONS** (planned and in preparation)


*Megarafting, megadispersal and megatsunamis: Implications for marine biogeography and long-distance oceanic species transport.*

Doug Eernisse

*Rare Trans-Pacific Invasions contribute to high species diversity in North Pacific chitons and limpets (Mollusca).*

Megan McCuller *et al.*

*Transoceanic rafting of Marine Bryozoa in the North Pacific Ocean*

John Chapman *et al.*

*Population structure of the Asian marine insect Telmatogoton japonica on a oceanic raft*

*Transoceanic Rafting of Marine Gammarid Amphipoda in the North Pacific Ocean*

Nancy Treneman, James T. Carlson, Louisa Borges, and Rueben Shipway

*Shipworm (Bivalvia: Teredinidae) diversity in wood generated by the 2011 Japanese tsunami*

Jessica Miller *et al.*

*Population structure, dispersal and growth history of the blue mussel, Mytilus galloprovincialis, on Japanese Tsunami Marine Debris*
F. POSTER AND ORAL SCIENTIFIC PRESENTATIONS


Abstract
The Tohoku Earthquake and Tsunami of March 11, 2011 ejected into the North Pacific Ocean a vast debris field which began drifting toward North America and Hawaii. The size (number of objects, weight, and volume) of the field is unknown. This is the first such event in marine biological history permitting multi-year tracking of transoceanic rafting based upon a debris field generated from a known source at a known time. Since 2012 approximately 300 Japanese Tsunami Marine Debris (JTMD) objects (forensically identified) with living biofouling have been intercepted from Alaska to California and Hawaii and are being analyzed for their species composition (morpho- and genotaxonomy), reproductive status, and other phenomena. Of 250 coastal species determined to date, 16% are represented by 41 species of shallow-water and near-shore bryozoans with living tissue, brown bodies (regressed tissue) and/or embryos. Two additional species of oceanic bryozoa also recruited to the debris. The JTMD event has permitted a rare window into understanding the potential for the role of high seas rafting in creating intrabasin biogeographic patterns. The list of JTMD bryozoa further provides a target inventory of non-native species to be searched for in North America and Hawaii.


G. EDUCATION AND OUTREACH (fall 2014 and spring 2015)
Numerous television, radio, and print media interviews and articles featuring Chapman, Carlton, Geller, Miller, and Ruiz.
Nancy Treneman. Shipworms and tsunami debris. Presentation at the Museum of the North Beach, Moclips WA, April 7, 2015.

PROGRESS STATUS

Our assessment is that we have made significant progress in the current reporting period, accomplishing our objectives and setting the stage for productive Year 2 work. We completed analyses of all samples acquired from 2012 to 2014, assessed the population structure, reproduction, and survival of selected JTMD species (including mussels, crustaceans, and marine insects), made significant progress on molecular genetics, including initiating a JTMD barcode library, and formalized potential assessments of the nature and abundance of JTMD.
APPENDIX I

JTMD: INTERCEPT GEOGRAPHY and COMPOSITION
(as of March 31, 2015)

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Items</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>7</td>
<td>2.1</td>
</tr>
<tr>
<td>BC</td>
<td>15</td>
<td>4.5</td>
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<tr>
<td>Wash</td>
<td>70</td>
<td>21.2</td>
</tr>
<tr>
<td>Oregon</td>
<td>170</td>
<td>51.4</td>
</tr>
<tr>
<td>California</td>
<td>6</td>
<td>1.8</td>
</tr>
<tr>
<td>Hawaiian Archipelago</td>
<td>63</td>
<td>19.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessels (skiffs, pandas, boats; entire or pieces)</td>
<td>60</td>
<td>18.1</td>
</tr>
<tr>
<td>Post-and-beam lumber</td>
<td>117</td>
<td>35.3</td>
</tr>
<tr>
<td>Other (floats, buoys, boxes, tanks, baskets, lids, cylinders, et al.)</td>
<td>154</td>
<td>46.6</td>
</tr>
</tbody>
</table>
APPENDIX II.
Japanese Tsunami Marine Debris:
SPECIES LIST as of March 31, 2015: Taxonomic Summary

<table>
<thead>
<tr>
<th>TAXON</th>
<th>Number of taxa</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I) Japanese or Presumptive Japanese Species</td>
<td></td>
</tr>
<tr>
<td>CYANOBACTERIA</td>
<td>1</td>
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<tr>
<td>RHIZARIA</td>
<td>14</td>
</tr>
<tr>
<td>CILIOPHORA</td>
<td>1</td>
</tr>
<tr>
<td>PORIFERA</td>
<td>5</td>
</tr>
<tr>
<td>CNIDARIA</td>
<td></td>
</tr>
<tr>
<td>Hydrozoa</td>
<td>16</td>
</tr>
<tr>
<td>Anthozoa</td>
<td>1</td>
</tr>
<tr>
<td>NEMATODA</td>
<td>3</td>
</tr>
<tr>
<td>NEMERTEA</td>
<td>3</td>
</tr>
<tr>
<td>SIPUNCULA</td>
<td>1</td>
</tr>
<tr>
<td>ANNELIDA</td>
<td>35</td>
</tr>
<tr>
<td>MOLLUSCA</td>
<td></td>
</tr>
<tr>
<td>Gastropoda</td>
<td>11</td>
</tr>
<tr>
<td>Bivalvia</td>
<td>28</td>
</tr>
<tr>
<td>Polyplacophora</td>
<td>3</td>
</tr>
<tr>
<td>CRUSTACEA</td>
<td></td>
</tr>
<tr>
<td>Copepoda</td>
<td>9</td>
</tr>
<tr>
<td>Ostracoda</td>
<td>3</td>
</tr>
<tr>
<td>Cirripedia</td>
<td>6</td>
</tr>
<tr>
<td>Amphipoda</td>
<td>15</td>
</tr>
<tr>
<td>Tanaidacea</td>
<td>1</td>
</tr>
<tr>
<td>Isopoda</td>
<td>6</td>
</tr>
<tr>
<td>Decapoda</td>
<td>2</td>
</tr>
<tr>
<td>PYCNOGONIDA</td>
<td>1</td>
</tr>
<tr>
<td>INSECTA</td>
<td>1</td>
</tr>
<tr>
<td>ACARINA</td>
<td>1</td>
</tr>
<tr>
<td>BRYOZOA</td>
<td>51</td>
</tr>
<tr>
<td>KAMPTOZOA</td>
<td>1</td>
</tr>
<tr>
<td>ECHINODERMATA</td>
<td>6</td>
</tr>
<tr>
<td>CHORDATA</td>
<td>5</td>
</tr>
<tr>
<td>ALGAE (fide G. Hansen)</td>
<td>(71)</td>
</tr>
<tr>
<td>DIATOMS</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>233 +algae:304</strong></td>
</tr>
</tbody>
</table>

(II) Oceanic – Neustonic Acquisitions by JTMD

| (II-A) Oceanic – Neustonic Acquisitions by JTMD: Entrainment | 8 |
| (III) Eastern Pacific Acquisitions by JTMD | 21 |
| (IV) Provenance Unknown | 3 |
| **TOTAL** | **279 +algae:350** |
Japanese Tsunami Marine Debris:  
Working SPECIES LIST as of March 31, 2015

The list is divided into four categories of living species:

(I) **Japanese or Presumptive Japanese Species**  
Taxa interpreted as having settled on debris in Japan or in nearshore Japanese waters, including the ocean well south of the Tohoku region.

(II) **Oceanic – Neustonic Acquisitions**  
Taxa interpreted as having settled on JTMD in the open ocean.

(II-A) **Oceanic – Neustonic Acquisitions: Entrainment**  
Planktonic taxa interpreted as having been entrained by JTMD in the open ocean.

(III) **Eastern Pacific Acquisitions**  
Taxa interpreted as having been acquired by the JTMD after entering the Eastern Pacific nearshore or shore region.

(IV) **Provenance Unknown**  
Taxa directly associated with JTMD but geographic provenance unknown to date.

---

**I) Japanese or Presumptive Japanese Species**

<table>
<thead>
<tr>
<th>CYANOBACTERIA</th>
<th>CILIOPHORA</th>
<th>Hydrozoa (continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanobacteria</td>
<td>Folliculinidae (1)</td>
<td>Plumularia setacea</td>
</tr>
<tr>
<td>Rhizaria</td>
<td></td>
<td>Plumularia sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sertularella sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sertularella matsuensis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stylasteria sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Anthozoa</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metridium senile</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Nematoda</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unidentified species (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Nemertea</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lineidae, unidentified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tetrastemma nigrifrons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oerstedia dorsalis</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Sipuncula</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unidentified species (1)</td>
</tr>
</tbody>
</table>

---

**RHIZARIA**

- Suctoria  
  - Species A yellow  
  - Species B white

**Foraminifera**

- Cibicides lobatulus
- "Quinqueloculina" sp.  
- "Elphidium" sp.  
- Elphidiella sp.?  
- Cyclogyra sp.?  
- "Bolivina" sp.

Unidentified taxa (3)

Arenaceous species (1)

**Cercozoa** (1)

- Gromia "oviformis"

**Protista**

- Unidentified (1)
ANNElIDA: Polychaeta
Nereidae
Nereis pelagica
Unidentified species (1)
Phyllodocidae
Eulalia quadrioculata
Nereiphylia sp.
Unidentified species (1)
Polynoidae
Halosydna brevisetosa
Harmothoe imbricata
Lepidonotus sp.
Syllidae
Syllis elongata-complex
Syllis hyalina-complex
Syllis spp. (6 species)
Sphaerosyllis sp.
Trypanosyllis zebra?
Amblyosyllis speciosa-complex
Terebellidae
Amphitrite sp.
Terebella sp.
Oenoidae
Arabella semimaculata
Spionidae
Polydora sp.
Capitellidae?
Unidentified species (1)
Orbinidae
Naineris sp.
Ctenodrilidae?
Unidentified species (1)
Chrysopteridae?
Unidentified species (1)
Acrocirridae
Acrocirrus sp.
Nerillidae
Mesonerilla sp.
Sabellidae
"Fabricia" sp.
Serpulidae
Hydroides ezoensis
Spirorbidae
Unidentified species (2)
Unidentified Families
Unidentified species (2)

MOLLUSCA
Gastropoda
Lottiidae
Nipponacmea habeii
Cellana radiata
Lottia sp.
Tectura emydia
Lottiid sp.
Calyptraeidae
Crepidula onyx
Columbellidae
Mitrella moleculara
Muricidae
Reishia sp., cf. clavigera
Nudibranchia
Aplysiidae
Dolabella auricularia
Other
Unidentified species (2)
Bivalvia
Mytilidae
Mytilus galloprovincialis
Mytilus coruscus
Mytilus trossulus
Modiolus sp. cf. nipponicus
Modiolus sp. (not nipponicus)
Modiolus sp.
Musculus cupreus
Sepifer virgatus
Lithophaga curta
Anomiidae
Anomia cytherea
Ostreidae
Crassostrea gigas
Ostrea denselamellosa
Arcidae
Arca navicularis
Barbatia sp.
Lyonsiidae
Entodesma navicula
Pectinidae
Chlamys sp.
Patinopunctum yessoensis
Pteriidae
Pinctada imbricata (cf. clade fucata)
Chamidae
Chama sp. cf. ambigua/brassica
Chama sp. cf. asperella
Myidae
Sphena coreanica?
Hiatellidae
Hiatella arctica
Teredinidae
Psiloteredo sp.
Teredothyra smithi
Bankia carinata
Bankia bipennata
Lyrodus takanosimensis
Teredo navalis
Polyplacophora
Mopalia seta
Mopalia sp.
Acanthochitona sp.
CRUSTACEA
Copepoda
Harpacticus sp.
Parastenhelia spinosa
Miracridae, unidentified (1)
Thalasstridae, unidentified (1)
Harpacticus obscurus-group
Tisbe (2 spp.)
Paralaoephonte congenera
Microsetella norvegica
Ostracoda
Unidentified species (3)
Cirripedia
Megalabalanus rosa
Semibalanus cariosus
Balanus glandula
Balanus trigonus
Chthamalus challengeri
Pseudoctomeris sulcata
Amphipoda
Jassa marmorata
Jassa slatteryi
Ampithoe valida
Ampithoe lacertosa
Ptihyale "littoralis"
Laticorphium sp., cf. baconi
Stenothoe valida
Gammaropsis japonicus
Calliopius sp.
Maera sp.
Caprella mutica
Caprella "cristibrachium"
Caprella penantis
Caprella sp. cf. brevirostris
Caprella sp.
Tanaidacea
Zeuxo normani
Isopoda
Ianiropsis serricaudis
Ianiropsis sp.
Dynoides sp.
Dynoides spinipodus
Dynamene sp.
Munnidae
Decapoda
Hemigrapsus sanguineus
Oedignathus inermis

PYCNOGONIDA
Unidentified species (1)

INSECTA
Diptera
Telmatogoton japonicus (1)

ACARINA
Halacaridae
Halacarellus schefferi

BRYOZOA
Cheilostomata
Aetea cf. anguina
Aetea cf. truncata
Arbocuspis bellula
Biflustra grandicella
Biflustra savartii
Biflustra cf. irregulata
Bugula sp.
Callopora craticula
Cauloramphus cf. cryptoarmatus
Celleporaria sp.
Celleporella hyalina
Celleporina porosissima
Celleporina sp. A
Celleporina sp. B
Crisia sp.
Cryptosula pallasiana
Cryptosula zavjalovensis
Electra tenella
Electra cf. devinensis
Escharella hozawai
Exochella longirostris?
Exochella tricuspis
Fenestrulina sp.
Filicrisia sp. A
Filicrisia sp. B
Hippothoa imperforata
Lichenopora radiata
Lichenopora sp. A
Membranipora conjunctiva
Membranipora cf. raymondi
Microporella borealis
Microporella sp.
Proboscina sp.
Schizoporella japonica
Schizoporella sp.
Scruparia sp.
Scrupocellaria? sp.

Smittoidea prolifica
Smittoidea spinigera
Tricellaria cf. inopinata
Tricellaria sp. A
Tubulipora cf. masakiensis
Tubulipora pulchra
Tubulipora sp. A
Tubulipora sp. B
Tubulipora sp. C
Walkeria uva
Watersipora mawatarii
Watersipora subatra

Ctenostomata
Alcyonidium sp.
Bowerbankia sp.

KAMPTOZOA
Barentsia sp.

ECHINODERMATA
Asteroidea
Asterias amurensis
Aphelasterias japonica
Patiria pectinifera
Echinoidea
Temnotrema sculptum
Holothuroidea
Unidentified species (1)
Ophiuroidea
Ophionereis porrecta

CHORDATA
Ascidiacea
Styela sp.
Didemnum vexillum
Diplosoma sp.
Pyura sp.

Pisces
Oplegnathus fasciatus

ALGAE
[about 71+ species, fide G. Hansen
March 2015]

DIATOMS
Licmophora sp.
Melosira ? sp.
Epizoic, unidentified (1)
(II) Oceanic – Neustonic
Acquisitions by JTMD:
Settlement

ANNELIDA
Polychaeta
Amphinome rostrata

CRUSTACEA
Amphipoda
Caprella andreae
Cirripedia
Lepas spp.
Conchoderma auritum
Decapoda
Planes major
Plagusia immaculata
Plagusia squamosa

MOLLUSCA
Gastropoda
Fiona pinnata
Bivalvia
Teredora princesae

BRYOZOA
Jellyella tuberculata
Jellyella eburnea

ALGAE
Kuckuckia spinosa
Colaconema daviesii

(II-A) Oceanic – Neustonic
Acquisitions by JTMD:
Entrainment

RHIZARIA
Foraminifera
Globigerina sp.
Radiolaria
Unidentified species (1)

CNIDARIA
Hydrozoa
Velella velella

MOLLUSCA
Gastropoda
Pteropoda (4)

CRUSTACEA
Euphausiacea
Unidentified species (1)

(III) Eastern Pacific
Acquisitions by JTMD

ANNELIDA
Polychaeta
Polynoidae

CRUSTACEA
Cirripedia
Balanus sp., cf. glandula
Pollicipes polymerus

Isopoda
Gnorimosphaeroma sp.
Idotea wosnesenskii
Excirrolana sp. (beach)

Amphipoda
Megelorcheistia sp. (beach)
Traskorchestia sp. ((beach)

INSECTA
Diptera
Unidentified (not Telmatogoton)
Unidentified (adult, not Telmatogoton
or Clunio)
Brachycera
Coleoptera
Staphylinidae (beach)

ACARINA
Copidognathus curtus (from beach)
Thinoseius brevisternalis (beach)
Zachvatkinia larica (from a gull)

MOLLUSCA
Bivalvia
Mytilus sp.
Crassadoma gigantea
Adula californiensis

Gastropoda
Littorina sp.
Alia carinata
Nucella sp.

(IV) Provenance Unknown

HAPLOSPORIDA
Unidentified taxa (3) in
Mytilus galloprovincialis
### APPENDIX III
Specimens sequenced by Ion Torrent PGM for Cytochrome c oxidase subunit I (COI) and 28S ribosomal RNA, with lowest identified taxon

<table>
<thead>
<tr>
<th>Kingdom</th>
<th>Order/Species</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protista</td>
<td>Folliculinidae</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Foraminifera</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Suctoria</td>
<td>2</td>
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Urochordata

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Total Number of Specimens: 313
Minimum number of taxa: 63
North Pacific Marine Science Organization (PICES)

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

Year 1 Final Report

1. PROJECT INFORMATION

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

Gayle I. Hansen, Oregon State University, USA – gaylehansen@q.com
Takeaki Hanyuda, Kobe University, Japan -- hanyut@kobe-u.ac.jp
Hiroshi Kawai, Kobe University, Japan -- 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 has frequently arrived in Oregon and Washington laden with Japanese marine algae and invertebrates. The algal species are often healthy and reproductive, and many could recruit to invade our shores. In order to monitor and evaluate the invasion threat of these species, we are conducting a 3-year, 5-part project that involves: (1) Identifying and characterizing the algal species found on JTMD (Japanese Tsunami Marine Debris, including their genetic structure, (2) Surveying sites along the shore of WA & OR for new invasions of these species, (3) Determining the pre-tsunami distribution of the JTMD species both globally and locally and mapping their WA & OR distributions so that new invasions are not confused with earlier colonizations, (4) Using comparative molecular sequencing to examine the relationship between JTMD species present in N. America before the tsunami and the Asian marine algal flora -- providing insight into the source and frequency of earlier invasions, and lastly, (5) preparing an electronic Guide to the Algae on Japanese Tsunami Marine Debris for both professionals and the public so that they can recognize JTMD algal invasions and alert experts so that control measures can be taken.

All parts of our project are moving ahead concurrently, but some parts are farther along than others. We have nearly completed parts 1 and 3, are continually working on parts 2 and 5, and now are concentrating heavily on part 4 as we feel our comparative genetic studies will provide an essential, but often overlooked, contribution to the assessment of risk of new algal species invasions in the NE Pacific from JTMD.
Methods

Part 1 Identifying and characterizing the JTMD algal species
A. Since the 2012 landing of the initial dock, a variety of state workers, volunteers, and scientists, have helped us to collect algal samples for the project. These samples have most often been provided alive, and, for these, processing must begin immediately since the algae deteriorate quickly.
B. Unique species in each collection are sorted and prepared for study.
C. Vouchers of the species are made (via pressings and permanent microscope slides) and the material is preserved (1) in 5% formalin/seawater (for later anatomical study and photography), and (2) in silica gel (for DNA analysis).
D. Preliminary morphological identifications are made in Oregon and the species is characterized. Since many of the species mimic one another in external appearance, the diagnostic features are most often anatomical and microscopic. Hence, for each sample, repetitive sectioning and microscopic observation is necessary to determine the species. During this process we also:
   1) Score the species for fertility (if they are actively reproductive and dropping spores)
   2) Score for the frequency or occurrence of each species on the debris items
   3) Determine their seasonality and also longevity on debris
E. Final DNA identifications of the species are made in Kobe, Japan, via sequencing 1-3 genes in each species and comparing the DNA with the sequences stored in the DNA Data Bank of Japan (DDBJ) and the National Center for Biotechnology information (Gen Bank), and with personal data.

Part 2 Surveying probable sites and habitats along the coast of WA & OR for new algal invasions
A. These sites include floating docks (6 sites), jetties (2 sites) and bays (2 major invasion bays) that are close to numerous debris landings and have relatively easy access
B. Sampling is done 2-4 times/year through visual searches and collections, and new invasions are noted
C. Baseline species lists are compiled so that new introductions are recognized.

Part 3 Determining the pre-tsunami distributions of JTMD algal species both globally and locally
A. We use www.algae-base.org to determine the world-wide distribution of the JTMD species, including the general extent of their ranges (widespread, North Pacific, or Asian).
B. To gather the local information, we use public and private herbarium databases, checklists compiled by state and national surveys, and also new collection data.
C. We have already used our local information to prepare a map the occurrence of those JTMD species already present in WA & OR, and are using this data to determine the probable habitats of new invasions -- and also as baseline so we do not confuse new invasions with earlier colonizations.

Part 4 Examining the relationship between those algal species present on JTMD, in North America before the tsunami, and in Asia
A. We are now beginning to carry out comparative DNA sequence studies on the genes/haplotypes of individual JTMD species that occur: (1) on JTMD, (2) in OR & WA, and (3) in Asia and elsewhere.
B. For a species to be included in the study, (1) its DNA must be available from all 3 sources, and (2) the selected gene/haplotype must be genetically variable between some of the sites.
C. By comparing the sequences (and knowing their source), we are able to match the identical sequences and determine a probable source for the species (possibly from an earlier invasion).
D. Additional material from each coast is needed to strengthen our study. The sequences in the DNA databanks are available for only some of the species and for few areas. We are badly in need of additional collections from both the Tohoku coast and from OR & WA – and we are hoping to make these during year 2 of our study.
Part 5  Preparing an electronic Guide to the Algae on Japanese Tsunami Marine Debris

A. A richly illustrated electronic guide to JTMD algae is planned for publication in Year 3 of our project. The Guide would enable both professionals and the public in North America to recognize future JTMD algal invasions so that experts can be alerted and control measures can be taken.

B. Its preparation would require: writing an introduction and species descriptions and preparing composite pictures for each species of (1) their appearance in the field, (2) their overall morphology, and (3) their diagnostic features of anatomy. Some pictures are already available, but we are hoping to obtain better material for anatomy and field pictures of the species in their native habitat during an upcoming trip to the Tohoku coast.

Results

The results for our project to date are based on algal material from 28 JTMD items that have been collected and/or made available to our project for analysis. The items have ranged from the Agate Beach (OR) floating dock in June 2012, to Panga fishing boats and lumber in 2013 & 2014, and, most recently, to plastic totes in December 2014 and January 2015.

Our counts change slightly with each new debris item and changing taxonomy, but the overall results remain nearly the same. In total ~64 algal species have been identified from these JTMD, including 40% brown algae, 28% green, and 32% red algae. This dominance of brown algae differs considerably from the Oregon algal checklist where red algae dominate the flora at 60% and brown algae consist of only 20% of the species. On debris, we did see a seasonal change in the group proportions: green algae and blue-green bacteria increased in the winter while brown and red algae decreased.

About 86% of the debris algal species have been found to be reproductive on arrival, displaying active spore and gamete release. Increasing nutrients on reaching shore could have stimulated this occurrence. Another reason seemed to be that the greatest proportion of the algal species on JTMD were ephemeral (~53%) and opportunistic/early successional forms (~76%), both groups typified by species that reproduce rapidly, grow quickly and invade new habitats. Ephemeral species are also capable of producing many generations per year, a feature that enables their populations to bounce back from a wide variety of environmental stresses such as those they might have encountered at sea.

The long trip across the Pacific through areas low in nutrients undoubtedly impacted the species that survived. However, the impact did not appear to be uniform. About 33% of all of the surviving species occurred on only one of the various debris items, possibly due, in part, to differential impact. Only 8% occurred on 10 or more items, and these widespread-on-debris species were all early successional forms (e.g., Feldmannia mitchelliae and Petalonia fascia).

Our global distribution study of the 64 algal species on JTMD revealed that 35 species (55%) are cryptogenic, 21 (33%) are Asian only or known Asian exports, and 7 (11%) occur both in the NE and NW Pacific. Of the cryptogenic species, 97% were early successional forms and 80% were ephemeral. The rapid reproduction and colonization features of these groups appear to contribute to the broad distribution of the species.

By reviewing publications, web-posted data, checklists and making new collections, we have also been able to determine that 43 JTMD species (67%) are already resident in the NE Pacific due to natural dispersal or earlier invasions. Of these 43 species, only 32 are present in Oregon, the least developed of the 3 NE Pacific states. We are now in the process of mapping the sites along the WA & OR coast where these pre-tsunami JTMD algal species have been found to occur. This enables us to: (1) be certain that these occurrences are not confused with new JTMD invasions, (2) characterize their habitats since these sites are likely to also host new JTMD invasions, and also (3) to collect material for our genetic study.

Currently, we are targeting the bays in SW Washington where numerous debris items have landed. To date, our collections have revealed that 23 of 77 species in Willapa Bay and 20 of 122 species in Grays
Harbor are species that are on our JTMD algal species checklist – and, hence, are pre-tsunami JTMD species. We have begun to analyze the genes of these species and are finding that, in many cases, their DNA of these species varies enough from their “identical” species on JTMD to have found that, in many DNA varies enough from the “identical” species on JTMD that we can use the DNA to recognize the new invasions – even among the “identical” species. Moreover, these comparative DNA studies are helping us to understand the genetic relationship between the NE Pacific and Asian marine algal floras and often to determine the source of earlier invasions.

The 64 marine algal species found on JTMD may indeed invade the NE Pacific flora. Water temperatures in the NE Pacific are within the range of those in the tsunami region of Japan, and most of the species were reproductive on arrival. The 21 species not yet present in the NE Pacific certainly pose the greatest threat to our native species, but the 43 species that are on JTMD and already here are also of concern as they may interbreed with the native populations and modify their gene structure. Perhaps even more indicative of the invasion potential from JTMD are the 6 JTMD algal species that have been included on the Global and/or Mediterranean Worst Invasive Species lists. These extreme-risk species are: Undaria pinnatifida, Codium fragile subsp. fragile, Grateloupia turuturu, Anthithamnion nipponicum, Polysiphonia morrowii, and Desmarestia viridis. All except P. morrowii are already known in California.

To date, (as detailed in section F) we have given numerous talks on our study, provided posters and displays on the algae, and have prepared and distributed handouts on (1) methods of collecting and preserving algae for taxonomic study, and (2) want-ads describing the most dangerous of the JTMD algae. This summer we will write our final checklist and risk assessment paper for publication. Then, we hope to (1) delve more deeply into our comparative sequencing study of the species found on both coasts, exploring their implications to risk, (2) prepare our Guide for the identification of the JTMD species, and (3) describe the new species found on both coasts as a result of this study.

3. PROGRESS SUMMARY

A. Original proposed research and planned outputs

In our original proposal, we provided a 3-year summary of our proposed work that we divided into 4 parts. For clarity, these 4 parts have been re-organized and split into 5 parts in the Executive Summary above. Parts 2 & 3 of the original proposal are now parts 2, 3, and 4 in the Summary.

As planned in our original proposal, all parts of our 3-year proposed project are being conducted concurrently. All of these areas are moving ahead, but some parts are progressing at different rates than we expected and our deliverables have not been on schedule. Below we list the 4 original parts of our proposal along with their proposed deliverables and target dates and also our newly proposed completion dates.

Part 1 Identifying, characterizing, and vouchering JTMD marine algal species
Morphological and molecular methods have been used to identify and characterize the JTMD species that continue to arrive on our shores. The deliverables for this part of the project were originally planned for the end of a 12 month Year 1 (Aug. 1) – so many are still in progress. They include:

1) Preliminary algal species lists for each JTMD item provided to J Carlton – Mostly complete
2) 1-2 published papers (including our checklist of species and evaluation of the risk). Not yet finished but submission plans are for late summer 2015 (after completing DNA identifications of the problematic species and our low tide survey collections).
3) DNA sequences of problematic species deposited in the DNA Databank of Japan (DDBJ). Partially complete with final submissions now also targeting later in 2015.
4) All voucher specimens (pressings and some slides) curated. About half complete
5) All voucher specimens deposited at Oregon State University, Corvallis. These will now not be deposited until the end of the project since the specimens are needed for reference and photography in Newport.

**Part 2** Using existing databases and new collections to detect and map JTMD algal species already occurring along the coast of OR and WA (Part 3 above)
Data have already been gathered from numerous herbarium databases, state and federal checklists, and new collections, and new information is continually being collected. The deliverables, due in Year 2, are partially complete but are on-going.

1) A report or map of the occurrence and distribution of JTMD algal species already occurring along the coasts of OR & WA. A preliminary updatable map of these species has been prepared.
2) Provision of healthy JTMD (conspecific) material for molecular and morphological study. Our collections from Grays Harbor, WA, have partially fulfilled this need.

**Part 3** Detecting new JTMD algal invasions at anticipated sites along the coast -- via visual surveys for new-to-America species and comparative sequencing of JTMD species that are already here
Deliverables were anticipated for year 2. All have been initiated.

1) Surveys (2-4x/year) were to be set up. We have selected our sites and 3 survey trips were carried out in Year 1. These will be on-going for the term of the project.
2) Screening for variable haplotypes and comparative sequencing to detect JTMD specific haplotypes. 3-5 species have already proven to be useful for this, but new species are being added and further collections and sequencing are needed before publication can take place.

**Part 4** An electronic guide to the marine algae on JTMD
The deliverable was listed for Year 3. Numerous pictures have already been collected for this and more are planned for the coming year.

**B. Describe the progress and problems encountered in each major part of the project**

1) The preparation of our Checklist and Invasion Threat paper
Since calculations involving the total number of JTMD algal species on our checklist are necessary for this paper, we have had to stop working on the manuscript until the final sequencing and identification of the problematic and new JTMD species is complete. Some of the new collections and their species are described in #2 below, but we particularly want to add to our list several problematic species that are particularly abundant on debris. These include species in the genera: *Ectocarpus, Sphacelaria, Cladophora*, and *Bryopsis*. We are hoping to finalize our determinations of these species so that we can complete the analyses of the species and preparation of the manuscript by the end of the summer.

2) New algae obtained from JTMD items available during Year 1
Comparatively few items containing algae have arrived this past year. In the Fall, only 1 debris items containing algae was found – and it supported only 3 algae. In January, tote boxes and boat fragments began arriving on the beaches in OR, but each of these contained only up to 3-4 species of algae. Then in late January and early March, we received 10 collections of JTMD from Manzanita (OR) and Long Beach (WA) collected primarily by volunteers. Although many of the samples were partially disintegrated, there appeared to be about 16 different algal species present. I am still awaiting the DNA results on these, but 2 very interesting species were common: *Ulva simplex* (now known from about 4 JTMD items), and a unicellular gelatinous red algae resembling the genus *Bulboplastis*. In order to accurately identify the *Bulboplastis*, we are hoping to obtain additional material for culturing.
Since the arrivals of JTMD have been so scarce, we thought they were almost over. Then on April 9, after our funding had ended, a 25-30 foot derelict boat arrived offshore at Seal Rock, OR. John Chapman sampled the boat offshore and our State Dept of Fish and Wildlife towed it into port for additional sampling (by me) and for destruction. It was laden with marine algal cover, including the very beautiful red alga, Chondrus giganteus (see the picture), found before on only 1 other JTMD item. I pressed and preserved numerous specimens from this boat and estimate that there will be about 26-30 algal species present. We will work on the identities of these after our funding resumes.

3) Surveying for new JTMD invasions and for those JTMD species already present in WA & OR
Since I have been collecting algae on the Oregon and Washington coasts since 1989, I was already familiar with potential sites for our survey. So for this purpose, I selected 6 floating docks, 2 jetties, and 2 major bays -- all close to numerous debris landings and with easy access. I had some baseline data for all of these sites and knew they had interesting macro-algal floras--often with \textit{Saccharina} species, \textit{Sargassum muticum} and numerous red algae (species similar to those on JTMD). Each site seemed likely to be an invasion candidate for JTMD species and some appeared to be perfect sites for the high ecosystem-risk species like \textit{Saccharina japonica}, \textit{Undaria pinnatifida}, and \textit{Pyropia yezoensis}.

With funding finally available for our project, I began my surveys of the coast on my way back from the Seattle group meeting, stopping at the floating docks in Ilwaco. For many of the WA & OR sites, good daytime low tides are needed for sampling, but these are seasonal in this region. In the winter, the lowest tides are always at night. The good daytime low tides only occur from late April to the beginning of September. So, to catch the last good low tides of the year, I carried out surveys of the coast in mid-August (Aug. 11-12) and early September (Sept. 6-8). I visited (1) Grays Harbor, (2) Willapa Bay, (3) Ilwaco, (4) Nehalem, (5) Yaquina Bay, and (6) Charleston. From these trips alone, I was able to process 410 pressings and preserve 70 specimens each in formalin and silica gel. Most of these specimens have been identified morphologically and many have already been sequenced. To date, the collections have resulted in the identification of approximately 125 species that can be used as baseline species for the project. Many are JTMD species, resident in WA & OR before the tsunami. For these, we now have excellent material for photography and for detailed comparative sequencing.

On March 24-27, 2015, I was also able to make a trip to Grays Harbor accompanied by my co-PI, Hiroshi Kawai, who flew over from Japan for the trip. During that trip, we collected the floating docks, jetty, and also the commercial oyster beds in that bay (with the help of a boat supplied by the Dept. of Fish and Wildlife). The early spring algal flora was remarkably different from the fall flora. About 210 specimens were collected & processed, and after they are identified, they will be added to our lists. In order to capture the full seasonality of this bay, I plan to make a late spring-early summer collection there sometime during May or June.

4) Gathering distribution information on JTMD algal species present in WA & OR before the tsunami
Information from our new collections, on-line herbarium databases and Olympic National Park checklists has already been compiled for this dataset, and I continue to update it as more information comes on line. A preliminary map of the distribution of these species, prepared for the meeting in Hawaii, is shown in C-2 of this Report.

5) Comparative sequencing studies of JTMD algal species on debris, in the NE Pacific and in Asia
My co-PIs in Japan have already completed comparative studies on several JTMD algal species that they found to have variable enough haplotypes for the study. These include \textit{Petalonia fascia} and \textit{Palmaria mollis}, both discussed in C-3. It is interesting that their screening for the variable haplotypes has also revealed a number of cryptic species that are genetically distinct but otherwise indistinguishable in the populations on both coasts. To strengthen our comparative studies, we require
additional samples for all of the species. We plan to make these collections this coming year from multiple sites in OR & WA and also in Japan.

6) **Preparing a Guide to the Marine Algae on JTMD**

We have already started writing descriptions and collecting pictures for this project – mainly of the anatomy of the species. However, my microscope camera ceased to work this year so photography has not been possible. During the coming year, I hope to purchase a new microscope camera to complete my anatomical pictures -- and also a small waterproof camera that I can use to obtain pictures of the algae in the field.

C. **Describe your results**

Our abbreviated overall results are included in the Executive Summary above. However, some of the more important lists and discoveries are provided here.

1) **Working List of the Marine Algae found on JTMD**

We have included as Appendix 1 our most current species checklist at the end of this Report. Note that we have included synonymies in the listing. Some of these are recently published synonymies and others are ones we suspect will happen in the future. In the latter case, extensive molecular study would be necessary to document the synonymies outside the time-limitations of this project.

We have coded the list to show: those species that have been verified through sequencing (*) and also those that require further sequencing (**). In a few cases, we have written to the authors of recent monographs and had them verify our identifications (#). We have also coded the list to show the known occurrence of the species in the NE Pacific (NEP) and in Oregon (OR). The NEP category includes BC, WA, OR & CAL. We have avoided AK for this as we consider it North Pacific. Our NEP data comes from AlgaeBase.net while our OR data comes from a personal database.

Our listing includes the algal species gathered from 28 JTMD items. Material from another 12 JTMD items is still being sequenced and identified and this will be added later. To date, we have identified a total of 64 algal species of which 25 (39%) are brown algae, 20 (31%) are red algae, 18 (28%) are green algae, and 1 is a bluegreen. Of the 64 species, 43 (67%) are already known to occur in the NE Pacific. In Oregon alone, only 32 (50%) are present.

The length of our species list has varied over the past year due to several causes: (1) new species have been added from new debris, (2) names have changed due to sequencing, and (3) new taxonomic data has been published on the species. Monographic papers that employ sequencing for identifications are published frequently – and we are striving to keep our list up-to-date.

From our checklist, we have also scored our species for their reproduction, life history, and distribution characteristics. These will be detailed in our upcoming paper.

2) **Map of the distribution of the JTMD algal species already present in WA & OR**

A preliminary map of these pre-tsunami occurrences serves an important purpose. By illustrating where the major numbers of these species occur, it can be used to: (a) Determine the sites and habitats most desirable to the largest number of pre-tsunami JTMD species--and most likely those for new invasions. These “hotspots” can then be marked for intensive NIS monitoring. (b) Know the distribution sites best for obtaining fresh JTMD algal species in the field for comparative sequencing, photography, and other studies. The map will be updated as new data becomes available.
3) Genetic analyses of the JTMD macro-algal specimens

Our final identifications of the macro-algal species on Tsunami debris have been made using molecular techniques. We employ genetic markers for these identifications and also explore the genetic diversity of the species. Different genetic markers were selected based on the taxa: nuclear 18S rDNA, ITS rDNA, chloroplast rbcL (-S), psbC, mitochondrial cox1 and cox3. To date, we have been able to obtain sequence data from 53 of the 88 JTMD samples provided, obtaining a total of 96 sequences. Our genetic determinations considerably improved our taxonomic knowledge of the species since we were able to provide names for many specimens that were not morphologically identifiable (sterile, young, fragments, misshapen, etc.) or were morphologically misinterpreted. In several cases, new monographs helped us with the identifications. On JTMD alone, some of the tentative algal names we were able to correct included the following:

**Rhodophyta:** *Chondrus* sp. (*C. yendo*); *Grateloupia* cf. *chaingii* (*Chondrus giganteus*); *Grateloupia* cf. *setchellii* (*G. livida*); *Porphyra* sp. (*Pyropia yezoensis*).

**Chlorophyta:** *Bryopsis pennata* var. minor (*B. plumosa*); *Cladophora* sp. (*C. albida*); *Ulva* cf. *japonica* (*U. lactuca*); *Ulva prolifera* (*U. simplex, compressa, & cf. linza*); *Ulva* sp. (*U. australis*).

**Phaeophyceae:** *Alaria marginata* (*A. crassifolia*); *Desmarestia ligulata* (*D. japonica*); *Ectocarpus* sp. (*Kuckuckia spinosa & Ectocarpus crouaniorum*); *Punctaria projecta* (*Punctaria latifolia*); *Saccharina* cf. *longissima* (*S. japonica*).

Our study of the genetic diversity of the individual JTMD species on debris, in Asia, and in N. America (our comparative sequencing study) has just begun, but two of the species we have selected are good examples of the types of results we hope to obtain:

a) **Petalonia fascia.** We sequenced the ITS-1 and Cox-3 genes in this species from numerous samples and the comparative results are illustrated in the TCS spanning network tree below. For the most part, the JTMD & Asian samples (B&C) are clearly separated by >20 base pairs from the NE Pacific samples and new NEP invasions could easily be recognized. But note that on each side of the tree there is an additional site: the JTMD & Asian samples are also in France, and the NE Pacific samples are in Korea. Secondary invasions have occurred in both cases.
**Petalonia fascia** - preliminary comparative sequence study

<table>
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<tr>
<th>KU No.</th>
<th>GH No.</th>
<th>GenBank</th>
<th>Site</th>
<th>Col. Date</th>
<th>ITS1</th>
<th>cox3</th>
<th>Occurrence</th>
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<td>KU-d12829</td>
<td>9</td>
<td>-</td>
<td>Boiler Bay</td>
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<td>○ (H3)</td>
<td>NE Pacific</td>
</tr>
<tr>
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<td>-</td>
<td>Seaview Rusty Pipe</td>
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<td>○ (H2)</td>
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<tr>
<td>KU-d12831</td>
<td>11</td>
<td>-</td>
<td>Gleneden Beach boat</td>
<td>2/6/2013</td>
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<td>○ (H2)</td>
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<td>-</td>
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<td>3/14/2013</td>
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<tr>
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<td>#66</td>
<td>-</td>
<td>Brighton Marina</td>
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<td>○ (H3)</td>
<td>NE Pacific</td>
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<td>-</td>
<td>Jetty Fishery</td>
<td>9/8/2014</td>
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<td>○ (H5)</td>
<td>NE Pacific</td>
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<tr>
<td>KU-d13327</td>
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<td>-</td>
<td>GH Jetty Channel</td>
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<tr>
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<td>-</td>
<td>-</td>
<td>Lost Creek black float</td>
<td>4/29/2014</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>HQ833766 Korea</td>
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<td>○</td>
<td>○ (H4)</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>EU681456 France</td>
<td></td>
<td>○</td>
<td>○ (H2)</td>
<td>Asia - France</td>
</tr>
</tbody>
</table>

Spanning Network Tree for Cox3 gene:
A = NE Pacific & Korea; B = JTMD & China; C = JTMD & France

**b) Palmaria palmata (=P. mollis).** Comparison of the haplotypes of Japanese and JTMD derived specimens of this species has revealed that Japanese *Palmaria palmata* (=P. mollis) collected from tsunami debris is genetically also distant from native populations of this species in North America. New invasions of Japanese Palmaria in the OR or WA would also be genetically recognizable. If the genetic distance between any of these species is great enough, a new species name is required. However, when the distance is not great enough, the populations are still considered to be the same species. In situations like Palmaria and Petalonia, the populations on both coasts are still the same species, but, if introductions occur, there is danger that interbreeding will occur, and this would cause genetic contamination of the local populations.
Currently, we are working on studies of *Feldmannia mitchelliae*, *Ptilota filicina*, and *Cladophora albida* and hope to do other JTMD species that occur in North America as well. However, in each case, the tree that we create is improved considerably if there are more collections. For *Petalonia*, we need Japanese material. For *Feldmannia*, we need Washington and additional Japanese material. And the list goes on. For this study to be truly effective, we need additional collections. We have outlined our proposed collecting trips for next year in our Year 2 proposal.

D. **Describe any concerns, problems, and solutions that you may have about your progress**
There are several factors that have slowed our progress, but they are out of our control.

1) **Our PI’s are on different coasts and each of us is busy** with other responsibilities as well as this grant. Therefore e-mail responses, the processing of specimens, and the writing of papers can only be completed when there is time. Since our methodologies for this project are complicated and require considerable background, hiring help is not possible for most of our work. When we meet in Japan this June, we will discuss this problem and set up a schedule that should help to resolve this problem.

2) **Problems impeding the identification and molecular verification of the algal species names**
   (a) The algal specimens from JTMD often arrive to my lab in poor shape – disintegrated, dried out, or heavily contaminated with diatoms. Often they have spent days on the beach—or in an office waiting to be sent to my lab. This destroys the chloroplasts, often necessary for identification, and often the integrity of the thallus. Some of the time I can still identify the “skeletons” or the reproductive structures of these species, but the DNA cannot be extracted or sequenced for verification. Only after it has been sent to Japan can this be discovered. We have sent out a “collecting methods” sheet to assist people with the best procedure for collecting from debris – but our directions are not always followed and the problem still occurs.
(b) The smaller JTMD species are often too tiny or dirty for sequencing. Adequate quantities of clean material are imperative for sequencing. For tiny species, I try to select material without diatoms and of a respectable size (1-2 mm for some), but once dried out in silica gel, they are very small. This has prevented the extraction and genetic verification of a number of the species.

3) **Collections for ecology and the time commitment.** It is important to realize that nearly all JTMD samples of algae must be examined microscopically for the species to be sorted and identified. We want to receive enough material to identify and characterize the species, but when samples are taken from e.g., 6 different areas or habitats on a debris item, the time commitment is the same as that for 6 different debris items. The sample numbers can quickly become very large. For the June 9 JTMD boat I now have 153 samples of which 44 must be sequenced. If an ecological paper arises from these studies, I think it is worth our time, but otherwise I hope that only qualitative collections of the species on each entire debris item will be necessary in the future.

4) **Japanese translations into English.** Although not essential for this project at this point, it would have been useful for a project like this to have PICES employ a part-time Japanese translator. Most of the technical identification guides for algae (and I think invertebrates) are hard copy Japanese volumes that are not available on-line for electronic translation. I can struggle through the identification keys slightly myself and search for scientific articles in English, but it would be much easier to send short paragraphs or taxonomic keys to a translator. I have noticed that most Japanese scientists (including my co-PIs) do not like to translate – they are too busy with other things. So, I hope PICES will consider this for future cross-Pacific projects and possibly for the last 2 years of our PICES-MoE study.

E. **Planned publications**

1) **Marine algae arriving on Japanese Tsunami Marine Debris and their invasion threat to the coasts of Oregon and Washington.** We plan to submit our major paper on the project to a peer-reviewed journal by the end of this coming summer (after our genetic identifications are complete). It will include our species checklist to date and the life history and distribution analyses that we presented at our talk in Hawaii.

2) **Tracking the invasion of marine algae from Asia to the North America: the impact of Japanese tsunami marine debris.** Our ideas for this paper are just being formed, but we hope to use our comparative sequencing study to prepare a manuscript that will be completed in the Spring of 2016.

3) **An illustrated guide to the marine algae on Japanese Tsunami Marine Debris.** We will develop this on-line or as an e-book and plan to finish it in Year 3.

F. **Oral conference presentations and seminars**

- The 3 most invasive algal species on marine debris. Power Point slides given to Sea Grant and NSF sponsored J. Miller, J. Chapman, S. Chan, and J. Carlton for their numerous presentations on Biofouling on JTMD.
- Japan US Marine Debris Public Workshop. Lincoln City and Newport, OR. February 15 & 16, 2013. Sponsored by SOLVE. Power Point Presentation and Display by Hansen, G1, Hanyuda, T, and H. Kawai. Marine Algae on Tsunami Debris, a study in progress. ~100 people attending
G. Education and outreach

- Watch for Invasive Wakame on Tsunami Debris! June 15, 2012. A Flyer by G. Hansen on Undaria pinnatifida that has been widely distributed, posted on the CoastWatch website, and incorporated into the training program for Oregon Parks and Recreation volunteers.


- Some Marine Algae from Japanese Tsunami Debris. April 13, 2013 on. A poster by G. Hansen for Oregon Sea Grant, used many times.

- Japanese Tsunami Marine Debris, Key Aquatic Invasive Species Watch. Summer 2013. A handout by Samuel Chan for Oregon Sea Grant. Algal pictures and edits by G. Hansen


H. Early grant reports & products

- Hansen, G. I. 4/15/2013. Identification and Biology of Seaweeds of the Japanese Tsunami Floating Dock. Oregon Sea Grant Project Completion Report for Grant # NA10OAR4170059 NA223C R693
• 2012 Algal Herbarium collections from the Agate Beach Dock. For deposit at the OSU Hebarium

I. Newspaper, radio and television interviews:
• Coos County Public Radio-- Phone interview on potential introductions from the Agate Beach Dock. Jessica Miller & Gayle Hansen. 9/2012.
• Japan Broadcasting Corporation -- TV Interview on the introductions -- Gayle Hansen and John Chapman 10/27/12
• BBC on-line. Video-Interview on the beach on the risks of invasive seaweeds 8/2/12. (just before the Agate Beach Dock removal)
• News-Times, Newport – Interview & photos by Larry Coonrod on preserving & cataloging the dock algal species for future study - 6/6/12 (article on 6/8/12)
• Numerous others in 2012 – not documented, including several in Japan
• KEZI television, Eugene, Oregon. 4/10/2015. Marine algae on the Seal Rock off-shore derelict boat
• News-Times, Newport. Interview & photos by Dennis Anstine. 4/10/2015 (article on 5/15/2015). Arrival of a slow boat from Japan. .
• Undocumented radio interviews via phone. 4/10–4/16/2015. On the new derelict boat & its algae.

J. JTMD-related Awards
• Ten Fingers in the Dike Award -- presented to several of us for our work on the Agate Beach Floating Dock -- by the Oregon Invasive Species Council, February 12, 2013, in Salem.

NOTE: The conference presentations, posters, and interviews given by Kawai and Hanyuda in Japan will be included in the Year 1 Report that they provide to JANUS.

4. PROGRESS STATUS

We are happy with our progress since all 5 parts of our project have been moving ahead. We are planning to complete our paper on “The marine algae arriving on Japanese Tsunami Marine Debris (JTMD) and their invasion threat to the coasts of Oregon and Washington, USA” by the end of the summer after we complete sequencing and genetically identifying the final problematic and new JTMD species. We have started surveying for new invasions and have already completed a preliminary map of the distribution of those JTMD marine algal species that are already in Washington and Oregon. We have completed several initial comparative sequencing studies, and we are now aware of how these studies will help to reveal the true genetic identity of the JTMD species (on both coasts) and also the source or sink of earlier invasions in the NE Pacific.

If our research continues to go as planned, we anticipate that will be able to complete all of our proposed products and planned surveys during the term of the grant.
Appendix 1

### Working List of the Marine Algae found on JTMD
- including true and probable synonymies -

<table>
<thead>
<tr>
<th>Group</th>
<th>Identified Species</th>
<th>NEP/OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td><em>Alaria crassifolia</em></td>
<td>n/n</td>
</tr>
<tr>
<td>B</td>
<td><em>Analipus japonicus</em></td>
<td>y/y</td>
</tr>
<tr>
<td>B</td>
<td><em>Costaria costata</em></td>
<td>y/y</td>
</tr>
<tr>
<td>B</td>
<td><em>Desmarestia japonica</em></td>
<td>n/n</td>
</tr>
<tr>
<td>B</td>
<td><em>Desmarestia viridis</em></td>
<td>y/n</td>
</tr>
<tr>
<td>B</td>
<td><em>Ectocarpus commensalis/parvus</em></td>
<td>y/y</td>
</tr>
<tr>
<td>B</td>
<td><em>Ectocarpus corticulatus/Jpn. arctus</em></td>
<td>y/y</td>
</tr>
<tr>
<td>B</td>
<td><em>Ectocarpus crouaniorum/crouanii</em></td>
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</tr>
<tr>
<td>B</td>
<td><em>Ectocarpus fasciculatus/acutus</em></td>
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</tr>
<tr>
<td>B</td>
<td><em>Ectocarpus penicillatus</em></td>
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</tr>
<tr>
<td>B</td>
<td><em>Feldmannia mitchelliae</em></td>
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<td><em>Hincksia granulosa</em></td>
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</tr>
<tr>
<td>B</td>
<td><em>Hincksia sandriana</em></td>
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</tr>
<tr>
<td>B</td>
<td><em>Kuckuckia spinosa</em></td>
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<td>B</td>
<td><em>Petalonia fascia</em></td>
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<tr>
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<td><em>Petalonia zosterifolia</em></td>
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<td><em>Protectocarpus speciosus</em></td>
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<td><em>Punctaria latifolia/projecta</em></td>
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<td><em>Saccharina japonica/angustata</em></td>
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<td><em>Scytosiphon gracilis</em></td>
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<td><em>Sphacelaria solitaria</em></td>
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<td><em>Bryopsis hypnoides</em></td>
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<td>Pyropia yezoensis *</td>
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**Excluded species**

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<tr>
<td>B</td>
<td>Composonema sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Sphacelaria sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Cladophora sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Bulboplastis sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total 6+ species</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Key**

B=Brown Algae, G=Green Algae, R=Red Algae, BG=Bluegreen Bacteria; NEP=CA, OR, & WA; *= sequenced species; **= requires further sequencing; #= expert identification

**Note**

Combined species names may be true or probable synonymies; species without coding are too small for DNA and/or have indisputable taxonomic features
The overall goal of this PICES project, funded by the Ministry of the Environment of Japan, is to assess and forecast the effects of debris generated by the Great Tsunami of 2011, especially those related to non-indigenous and potentially invasive species on ecosystem structure and function, the coastlines and communities of the west coast of North America and Hawaii, and to suggest research and management actions to mitigate any impacts.

The Japanese component of the project for Year 1 (September 15, 2014–March 31, 2015) included: (1) webcam monitoring of marine/tsunami debris, (2) climatological marine debris dispersion simulations, and (3) potential invasions of marine algae arriving on tsunami marine debris (Table 1). Organizations and researchers involved in each task are shown in Table 2. JAPAN NUS Co., Ltd was assigned to manage funding allocated for Japanese collaborators and to prepare a summary report to PICES at the fiscal year end.

### Table 1  Japanese component research projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Allocated funding (CAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webcam monitoring of marine/tsunami debris</td>
<td>94,599</td>
</tr>
<tr>
<td>Climatological debris dispersion simulations and forcing fields error estimation</td>
<td>21,633</td>
</tr>
<tr>
<td>Marine algae arriving on JTMD (Japanese Tsunami Marine Debris) and their invasion threat to the Northwestern Pacific coast</td>
<td>11,633</td>
</tr>
</tbody>
</table>

### Table 2  Japanese component organizations and researchers

<table>
<thead>
<tr>
<th>Project</th>
<th>Organization</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Webcam monitoring</td>
<td>Kyushu University</td>
<td>Dr. Atsuhioko Isobe*</td>
</tr>
<tr>
<td></td>
<td>National Institute for Land and Infrastructure Management (NILIM)</td>
<td>Dr. Tomoya Kataoka</td>
</tr>
<tr>
<td></td>
<td>Ehime University</td>
<td>Dr. Hirofumi Hinata</td>
</tr>
<tr>
<td></td>
<td>Kagoshima University</td>
<td>Dr. Shinichiro Kako</td>
</tr>
<tr>
<td>Climatological simulation</td>
<td>Meteorological Research Institute</td>
<td>Dr. Masafumi Kamachi*</td>
</tr>
<tr>
<td></td>
<td>Japan Agency for Marine-Earth Science and Technology (JAMSTEC)</td>
<td>Dr. Yoichi Ishikawa&lt;br&gt;Dr. Norihisa Usui</td>
</tr>
<tr>
<td>Marine algae</td>
<td>Kobe University</td>
<td>Dr. Hiroshi Kawai*&lt;br&gt;Dr. Takeaki Hanyuda</td>
</tr>
</tbody>
</table>

*Project Science Team member

### SUMMARY OF ACTIVITIES IN YEAR 1

**Project on “Webcam monitoring of marine/tsunami debris”**

To measure the quantities of marine debris littered on beaches, monitoring using a webcam is adopted in line with Kako *et al.* (2010) and Kataoka *et al.* (2012). Photographs of beaches are taken every 1–2 hours for 1 to 2 years and, after image processing, are converted to time series of areas (in m²) covered by marine debris. The
projection transformation method is used for this geo-referencing (Kako et al., 2010), and extraction of anthropogenic objects from the beaches is conducted on a CIELUV color space (Kataoka et al., 2012). The photographs, uploaded to laboratories via the Internet, are also open to the public.

In this experiment, the efficiency of the webcam system for automatically monitoring tsunami debris was tested, and relationships between the quantities of marine debris on beaches and atmospheric/oceanic conditions were examined. Additionally, the effectiveness of using a near-infrared camera to monitor lumber that is potentially carrying invasive species onto beaches was studied. Near-infrared monitoring experiments were conducted on beaches in Japan under a different funding scheme.

The requirements for the webcam monitoring sites include: robust soil conditions, sufficient area for the webcam equipment, availability of mobile communication, accessibility from major roads, and surroundings without vandalism. Candidate sites were investigated along the Oregon coast during the period from January 11–15, 2015. A site close to Newport was chosen for the webcam monitoring of marine debris because of its higher elevation compared to other sites – the higher is the site, the more advantageous it is in monitoring debris littered on beaches. The site seemed also to be free from vandalism, with a careful management by the county officials. In addition, the soil condition, availability of the AT&T mobile service, and accessibility from the major road were all favorable for webcam monitoring. The installation of the webcam was completed in March 2015, and the images are open to the public through the following website: http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html.

Project on “Climatological debris dispersion simulations and forcing fields error estimation”

The group discussed data needs and gaps for marine debris modeling with researchers at the International Pacific Research Center (IPRC), University of Hawaii and the US NOAA Office of Response and Restoration. The group provided: (1) the results of the former Japanese tsunami-debris modeling task team for dispersion simulations run by the IPRC group to study particle and tracer motions within a broad range of windage parameters (different debris types), which describe the direct effect of the wind on items floating on the ocean surface, and (2) the sighting observation data by the Japan Coast Guard through the webpage of the Secretariat of the Headquarters of the Ocean Policy (SHOP) for calibration and validation of the US simulation results.

The group considered and discussed with colleagues from the US and Canada methods for error estimation of the forcing fields for debris dispersion simulation and methods for assessing the debris trajectory using temperature fields for the second year of the project.

Project on “Marine algae arriving on JTMD (Japanese Tsunami Marine Debris) and their invasion threat to the Northwestern Pacific coast”

1. Genetic analyses of JTMD macroalgal specimens

The group identified the macroalgal specimens collected from the probable tsunami debris using molecular techniques, and examined the genetic diversity of the species. Different genetic markers were used depending on taxa: nuclear 18S rDNA, ITS rDNA, chloroplast rbcL (-S), psbC, mitochondrial cox1 and cox3. A total of 96 sequence data for 72 specimens has been obtained. Taxonomic study for identifying the specimens is still ongoing, but genetic determinations have allowed to considerably improve the identification made solely on morphology and to provide names for many specimens that were not morphologically identifiable (sterile, young, fragments, misshapen, etc.) or were morphologically misinterpreted. Examples of macroalgal species for which morphological identification has been revised using genetic data are listed below (species name based on genetic identification is given in brackets):

**Rhodophyta**

*Chondrus* sp. (*C. yendo*); *Grateloupia* cf. *chaingii* (*Chondrus* giganteus); *Grateloupia* cf. *setchellii* (*G. livida*); *Palmaria* palmata (*P. mollis*)

*Polysiphonia* abscissa? (*Grateloupia* turuturu); *Porphyra* sp. (*Pyropia yezoensis*) *Polysiphonia* abscissa (*P. morrowii*)
Chlorophyta
Bryopsis pennata (B. plumose); Cladophora sp. (C. albida); Cladophora albida (C. vagabunda); Cladophora sericea (C. oligocladoidea); Cladophora cf. microcladioides (C. glomerata); Bryopsis cf. hypnoides (B. cf. plumose); Ulva linza (U. compressa); Ulva cf. lobata (U. lactuca); Ulva cf. lactuca (U. rigida/laetevirens); Ulva lobata? (U. lactuca); Ulva prolifera (U. cf. linza); Ulva prolifera (U. compressa); Ulva flexuosa (U. cf. linza); Ulva paradoxa? (U. cf. linza); Ulva procera/prolifera (U. simplex); Ulva procera/prolifera (U. cf. linza); Ulva procera/prolifera (U. compressa); Ulva sp. (U. pertusa/australis); Ulva cf. japonica (U. lactuca)

Phaeophyceae
Alaria sp. (A. crassifolia); Desmarestia ligulata (D. japonica); Ectocarpus sp. (E. crouaniorum); Ectocarpus sp. (Kuckuckia spinosa); Punctaria sp. (P. latifolia); Punctaria sp. (Petalonia fascia); Punctaria sp. (P. latifolia); Saccharina sp. (S. japonica/angustata); Scytosiphon gracilis? (Petalonia zosterifolia)

The comparisons of haplotypes of Japanese and JTMD-derived specimens indicated that Japanese Palmaria palmata (= P. mollis) collected on the tsunami debris was genetically considerably distant from the native (local) population of the species in North America. Therefore, it was suggested that a possible invasion of the JTMD specimens can cause genetic contaminations to the local populations.

2. Monitoring for detecting new invasions by JTMD

In order to detect the settlement and spread of JTMD-originated macroalgae on the west coast of North America, the group investigated candidate sites suitable for monitoring. Floating docks in Grays Harbor, Washington, were selected as the site, because of the relatively rich macroalgal flora, including endemic Saccharina species, Sargassum muticum, and large red algae found on these structures. With the endemic nature of the site, if any JTMD with high risk for ecosystem, such as Undaria pinnatifida, Saccharina japonica, Pyropia yezoensis arrives, they are expected to be detected at the site, in the early stage of settlement.