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)

TABLE OF CONTENTS

North Pacific Marine Science Organization (PICES)
Project on *"Effects of Marine Debris caused by the Great Tsunami of 2011"*

PROGRESS REPORT FOR YEAR 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 (such as 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.

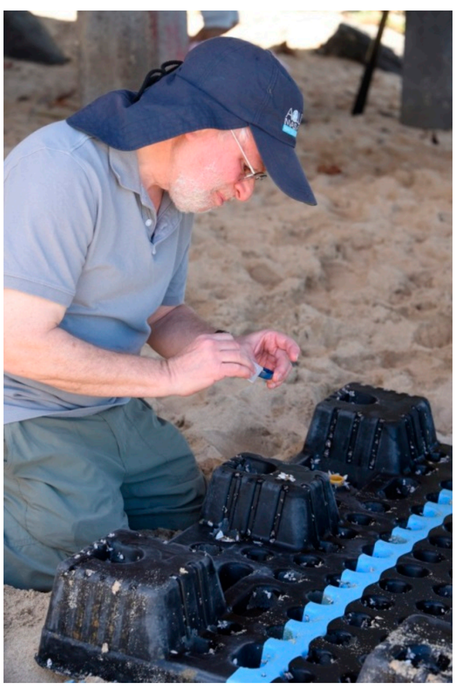
Hawaii received the most debris items over the post-tsunami study period (2012–2014). British Columbia, has the second highest debris influx in this time period (with high numbers of large polystyrene pieces), driven by a few surveys in Haida Gwaii (northern British Columbia). Alaska had few surveys 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 m^2) 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.

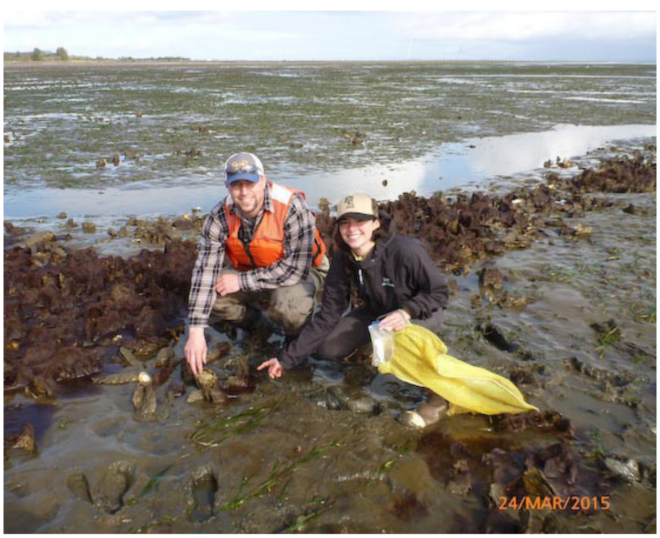
Hundreds of samples of JTMD from Alaska to California and the Hawaiian Islands have been acquired, processed, and carefully analyzed. This work consists of the taxonomic identification of the species on the debris, molecular genetic analyses, specimen image analyses, screening of over 1,500 mussels and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

Carlton, J.T. (2014) Invasive species, oceanic rafting, and Japanese Tsunami Marine Debris. Presentation at the University of Massachusetts, Dartmouth, MA, December 5, 2014.

Carlton, J.T. (2015) The story of the Japanese Tsunami Marine Debris. Presentation at the Mystic Seaport Museum Adventure Series, Mystic, CT, April 26, 2015.

Chapman, J. (2015) Multi-year ocean crossings by Asian coastal marine species on floating debris generated by the Great Japanese Tsunami of 2011. Presentation at the OSU Marine Biology 450 Special Seminar, Oregon State University, Newport, OR, April 6, 2015.

Clarke Murray, C., A. Bychkov, T. Therriault, H. Maki and N. Wallace. (2015) The impact of Japanese tsunami debris on North America. PICES Press, No. 23(1).

Geller, J. (2014) Metazoan barcoding to characterize biodiversity and invasive species in marine environments. Presentation at the California State University, Monterey Bay, CA. November 4, 2014.

Geller, J. (2014) Metagenetic studies of marine invertebrate communities. Presentation at Moss Landing Marine Laboratories, CA, November 20, 2014.

Hafner, J., N. Maximenko and G. Speidel (2014) Transport of marine debris from the 2011 tsunami in Japan: model simulations and observational evidence. PICES 2014 Annual Meeting, October 20–24, 2014, Yeosu, Korea. Oral presentation.

McCuller, M. and J.T. Carlton (2015) Oceanic rafting of coastal marine Bryozoa: Lessons from Japanese tsunami marine debris. 44th Annual Benthic Ecology Meeting, Université Laval, Québec, Canada, March 4–7, 2015. Oral presentation.

Therriault, T., C. Clarke Murray, N. Wallace, H. Maki and A. Bychkov (2014) Effect of marine debris caused by the great tsunami of 2011", 2nd International Ocean Research Conference, Barcelona, Spain, November 17–21, 2014. Poster presentation (Recipient of best presentation award).

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

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

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

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

Appendix 1

PROJECT SCIENCE TEAM MEMBERSHIP

Canada

Dr. Patrick F. Cummins
Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 W. Saanich Rd., P.O. Box 6000
Sidney, BC
Canada V8L 4B2
Phone: (1-250) 363-6553
Fax: (1-250) 363-6746
E-mail: Patrick.Cummins@dfo-mpo.gc.ca

Dr. Thomas W. Therriault (Co-Chairman)
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Rd.
Nanaimo, BC
Canada V9T 6N7
Phone: (1-250) 756-7394
Fax: (1-250) 756-7138
E-mail: Thomas.Therriault@dfo-mpo.gc.ca

Japan

Dr. Atsuhiko Isobe
Research Institute for Applied Mechanics
Kyushu University
6-1 Kasuga-koen
Kasuga, Fukuoka
Japan 816-8580
Phone: (81-92) 583-7726
Fax: (81-92) 573-1996
E-mail: aisobe@riam.kyushu-u.ac.jp

Dr. Hiroshi Kawai
Kobe University Research Center for Inland Seas
Rokkodai Nadaku
Kobe Hyogo
Japan 657-8501
Phone: (81-78) 803-5710
Fax: (81-78) 803-6699
E-mail: kawai@kobe-u.ac.jp

Dr. Hideaki Maki (Co-Chairman)
National Institute for Environmental Studies
16-2 Onogawa
Tsukuba, Ibaraki
Japan 305-8506
Phone: (81-29) 850-2394
Fax: (81-29) 850-2576
E-mail: hidemaki@nies.go.jp

USA

Dr. James Carlton
The Maritime Studies Program
Williams College
Mystic Seaport Museum
P.O. Box 6000, 75 Greenmanville Ave.
Mystic, CT
U.S.A. 06355
Phone: (1-860) 572-5359
Fax: (1-860) 572-5329
E-mail: james.t.carlton@williams.edu

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

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

PICES

Dr. Cathryn Clarke Murray (*ex-officio*)
Visiting Scientist
PICES Secretariat
9860 West Saanich Road
Sidney, BC,
Canada V8L 4B2
Phone: (1-250) 363-6911
Fax: (1-250) 363-6827
E-mail: cmurray@pices.int

Dr. Alexander Bychkov (*ex-officio*)
Project Coordinator
PICES Secretariat
9860 West Saanich Road
Sidney, BC,
Canada V8L 4B2
Phone: (1-250) 363-6346
Fax: (1-250) 363-6827
E-mail: bychkov@pices.int

Appendix 2

1. PROJECT INFORMATION

Title:	Modeling studies in support of research on impact of alien species transported by marine debris from the 2011 Great Tohoku Tsunami in Japan
Award period	August 1, 2014 – April 30, 2015
Amount of funding	91,900.00 US Dollars
Report submission date	April 30, 2015
Lead Author of Report*	Nikolai Maximenko

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

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

PI: Nikolai Maximenko <maximenk@hawaii.edu>

Recipient Organization: University of Hawaii

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

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

2. EXECUTIVE SUMMARY

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.

Appendix 3

1. PROJECT INFORMATION

Title:	Surveillance and Monitoring of Tsunami Debris
Award period	September 1, 2014 to March 31, 2015
Amount of funding	$97, 672.88
Report submission date	April 29, 2015
Lead Author of Report*	Cathryn Clarke Murray

**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.

<u>Surveillance</u>

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.

Appendix 4

1. PROJECT INFORMATION

Title:	Webcam monitoring of marine/tsunami debris
Award period	October 1, 2014-March, 31, 2015
Amount of funding	94,599 Canadian dollars
Report submission date	30 April 2015
Lead Author of Report*	Atsuhiko Isobe

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

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

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

Hirofumi Hinata (Ehime University, Japan)
Shin'ichiro Kako (Kagoshima University, Japan),
Tomoya Kataoka (Nat'l Inst. Land and Infrastructure Management, Japan)

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 m^2) 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). T he 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.

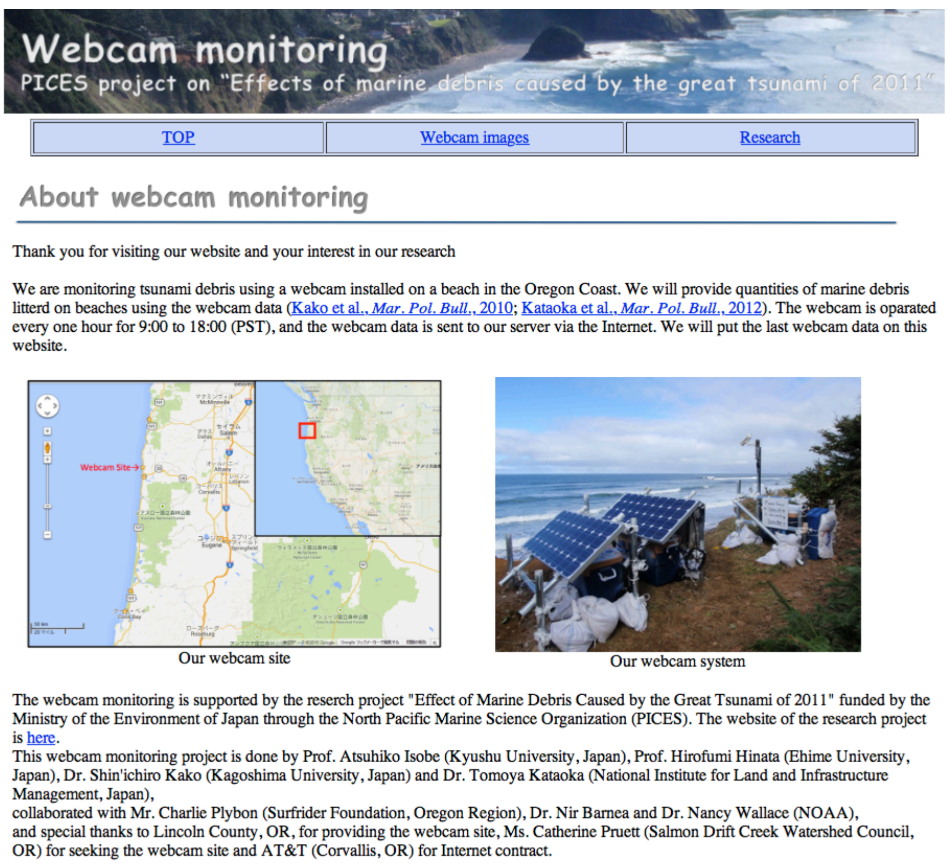
Also investigated is the efficiency of a near-infrared camera to monitor lumbers that are potentially carrying invasive species onto beaches. The near-infrared monitoring experiments are conducted on beaches in Japan this year.

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.


Webcam monitoring
PICES project on “Effects of marine debris caused by the great tsunami of 2011”

TOP	Webcam images	Research

About webcam monitoring

Thank you for visiting our website and your interest in our research

We are monitoring tsunami debris using a webcam installed on a beach in the Oregon Coast. We will provide quantities of marine debris litterd on beaches using the webcam data (Kako et al., *Mar. Pol. Bull.*, 2010; Kataoka et al., *Mar. Pol. Bull.*, 2012). The webcam is oparated every one hour for 9:00 to 18:00 (PST), and the webcam data is sent to our server via the Internet. We will put the last webcam data on this website.

Our webcam site

Our webcam system

The webcam monitoring is supported by the reserch project "Effect of Marine Debris Caused by the Great Tsunami of 2011" funded by the Ministry of the Environment of Japan through the North Pacific Marine Science Organization (PICES). The website of the research project is here.
This webcam monitoring project is done by Prof. Atsuhiko Isobe (Kyushu University, Japan), Prof. Hirofumi Hinata (Ehime University, Japan), Dr. Shin'ichiro Kako (Kagoshima University, Japan) and Dr. Tomoya Kataoka (National Institute for Land and Infrastructure Management, Japan),
collaborated with Mr. Charlie Plybon (Surfrider Foundation, Oregon Region), Dr. Nir Barnea and Dr. Nancy Wallace (NOAA),
and special thanks to Lincoln County, OR, for providing the webcam site, Ms. Catherine Pruett (Salmon Drift Creek Watershed Council, OR) for seeking the webcam site and AT&T (Corvallis, OR) for Internet contract.

Appendix 5

FINAL PROJECT REPORT

to the
North Pacific Marine Science Organization (PICES)

Title	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
Award period	October 1, 2014 - March 31, 2015
Amount of funding	US $282,013
Report submission date	April 30, 2015
Lead author of report	James T. Carlton
Principal Investigators	James T. Carlton — james.t. carlton@williams.edu, *Williams College* Jessica A. Miller — Jessica.Miller@oregonstate.edu, *Oregon State University* John W. Chapman — john.chapman@oregonstate.edu, *Oregon State University* Jonathan B. Geller — geller@mlml.calstate.edu, *Moss Landing Marine Laboratories* Gregory M. Ruiz — ruizg@si.edu, *Smithsonian Environmental Research Center*

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.

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.

Appendix 6

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

Title	Marine Algae arriving on JTMD (Japanese Tsunami Marine Debris) and their Invasion Threat to the Coasts of Oregon and Washington, USA
Award period	August 1, 2014 – March 31, 2015
Amount of funding	$39,921 (Hansen) + $10,000 (Kawai and Hanyuda)
Report submission date	April 30, 2015
Lead Author of Report	Hansen, Gayle I.

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.

Appendix 7

PROJECT ON "EFFECTS OF MARINE DEBRIS CAUSED BY THE GREAT TSUNAMI OF 2011"

JAPANESE COMPONENT
Year 1 Report by JAPAN NUS Co., Ltd.

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 the 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

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

Table 2 Japanese component organizations and researchers

Project	Organization	Researcher
Webcam monitoring	Kyushu University	Dr. Atsuhiko Isobe*
	National Institute for Land and Infrastructure Management (NILIM)	Dr. Tomoya Kataoka
	Ehime University	Dr. Hirofumi Hinata
	Kagoshima University	Dr. Shinichiro Kako
Climatological simulation	Meteorological Research Institute	Dr. Masafumi Kamachi*
	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	Dr. Yoichi Ishikawa Dr. Norihisa Usui
Marine algae	Kobe University	Dr. Hiroshi Kawai* Dr. Takeaki Hanyuda

*****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 m^2) 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 *rbc*L (-S), *psb*C, 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*)

Polyopes lancifolius? (*Grateloupia turuturu*); *Porphyra* sp. (*Pyropia yezoensis*) *Polysiphonia abscissa* (*P. morrowii*)

Chlorophyta
Bryopsis pennata (*B. plumose*); *Cladophora* sp. (*C. albida*); *Caldophora albida* (*C. vagabunda*); *Cldophora sericea* (*C. oligocladoidea*); *Caldophora* 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. lactuc*a)

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.