1. PROJECT INFORMATION

Title	Webcam monitoring of marine/tsunami debris
Award period	*April 1, 2016 – March 31, 2017*
Amount of funding	*38,000 CAD*
Report submission date	*31 January 2017*
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: Charlie Plybon (Surfrider Foundation OR), Thomas Murphy (Hatfield Marine Research Center, OSU), Nir Barbea (NOAA), Nancy Wallace (NOAA)
Collaborators in Canada: Cathryn Clarke Murray (PICES)

2. YEAR 3 PROGRESS SUMMARY

a. Describe progress.

The webcam monitoring and aerial photography were both conducted as in the previous years, and estimated the JTMD abundance on the US and Canadian beaches by combining a particle tracking model.

b. Describe any concerns or challenges you may have about your project's progress.

We have not encountered any problems in the year 3.

3. ABSTRACT

We installed a webcam overlooking a beach in Newport, Oregon, directly facing the North Pacific. The webcam was set up to sequentially and automatically take photographs of a part of the beach, on which marine debris including driftwood and anthropogenic debris (which might include JTMD) were littered. In addition, we attempt

to develop an image analysis technique for quantifying the debris abundance from aerial photographs using a Cessna plane. The debris abundance was computed around Vancouver Island located in the southwest of British Columbia, Canada. First, it seems likely that the meridional wind component was responsible for the seasonal (summer to winter) increase of the debris abundance. It is likely that the onshore-ward Ekman transport carries marine debris toward the coast, and that the debris littered on the beach increases thereafter. Second, it is interesting that the marine debris decreased when the westerly (onshore-ward) winds prevailed in winter at the spring tides. It is therefore reasonable to consider that the wind setup resulted in the re-drifting of debris during the westerly (onshore-ward) winds at spring tides (particularly at flood tide). A straightforward sub-model was constructed to reproduce the above-mentioned two critical factors. We combined the sub-model with a particle tracking model (PTM) reproducing JTMD motion in the North Pacific. Our estimates were as follows: about 3% of JTMD (~45,000 tons) was accumulated on the US and Canadian beaches, and large amount of JTMD has been washed ashore on the relatively narrow area (<1000 km) around Vancouver Island.

4. PROJECT DESCRIPTION

a) Research Purpose

According to an estimate by the Ministry of the Environment, Government of Japan (https://www.env.go.jp/en/focus/docs/files/20120901-57.pdf), about 5 million tons of Japanese tsunami marine debris (JTMD) flowed out into the North Pacific on March 11, 2011. Part of this JTMD (estimated to 1.5 million tons) remained afloat, is still drifting in the North Pacific, and thus, there remain concerns about this debris to reach the North American and Pacific Islands' coasts even at present time. In particular, an attention is placed on coastal Japanese species carried by JTMD because these invasive species might damage the indigenous marine ecosystem: see the website of the Assessing the Debris-Related Impact of Tsunami project (ADRIFT; https://www.pices.int/projects/ADRIFT/main.aspx).

However, it is a difficult task to estimate the abundance of JTMD (hence, invasive species) washed ashore on the coasts. To date, there have been no published studies investigating temporal variations of marine debris abundance on beaches along the western United States and Canadian coasts over a period longer than one year (including seasonality), and with a monitoring interval shorter than a week. Consequently, there is no way of knowing "critical factors" governing the temporal variations of debris abundance on these beaches.

b) Objectives

In the present study, we installed a webcam system (Kako et al., 2010; Kataoka et al., 2012) on a beach along the western United States coast to hourly monitor the marine debris abundance over a one-year period. Using this one-year record, we attempt to establish a numerical model to estimate the abundance of the JTMD washed ashore on the western US and Canadian coasts.

In addition, we attempt to develop an image analysis technique for quantifying the debris abundance from aerial photographs using a Cessna plane. The debris abundance was computed around Vancouver Island (because of the intensive accumulation of debris as shown later) located in the southwest of British Columbia, Canada. To date, the debris abundance has been evaluated in line with a subjective and visual decision by an observer in the aerial photography. However, this abundance might be different by observers, and by altitudes and camera angles of the aerial photography. In the present study, however, areal coverage of marine debris on beaches are computed objectively, and thus, the estimated abundance of debris washed ashore on beaches will be capable of, for instance, predetermining the cost of beach clearance.

c) Methods

c-1 Webcam system

We installed a webcam overlooking a beach in Newport, Oregon, directly facing the North Pacific (Fig. 1). The webcam was set up to sequentially and automatically take photographs of a part of the beach, on which marine debris including driftwood and anthropogenic debris (which might include JTMD) were littered. In this study, beach photographs taken every 60 minutes during daytime (10 times from AM 9:00 to PM 6:00 in the Pacific Standard Time of the United States), from April 3, 2015 to the 31 March, 2016 were used (this survey is planned to continue to the end of March, 2017). The area of approximately of 60-m and 70-m length in the alongshore and the offshore directions within the entire panorama, respectively, was photographed by the webcam with a fixed angle. These photographs were transmitted to our web server via the Internet, and have been opened publicly on our website (http://nilim-camera1.eco.coocan.jp/webcam/index.html). In the present study, the marine debris found on the beach was not categorized into natural and anthropogenic debris because our objective is to establish the sub-model reproducing the critical factors to govern the abundance to the debris littered on the beach. In particular, we should note that the actual JTMD is difficult to distinguish on the beach, unless the debris source can be suggested by Japanese characters printed on the debris surface, and the characters are sufficiently large to be identified on the photographs.

As shown in an example of photographs taken by the webcam (Fig. 2a), it is found that the substantial amount of marine debris (mostly, driftwood and lumbers) was washed ashore on the beach over 1-year period from the beginning of the monitoring. Hereinafter, “the abundance of marine debris” was evaluated by counting their number on the beach photographs by visual observations. First, an observer selected a single photograph from all 10 photographs taken on each day so as to identify marine debris as much as possible during the daytime. Thus, the photographs taken at ebb tide (i.e., the broadest beach area) were likely to be selected, while those taken during foggy and/or rainy period were removed. Thereafter, the observer identified the marine debris regardless of their sizes as shown in red circles in Fig. 2b. If the small objects were difficult to distinguish from shadows of surface irregularity on the beach, the remaining nine photographs taken at different times (different incident angles of the sunlight) were used for the identification. To suppress human error in counting the marine debris, the visual observations were conducted twice by different observers for double-checking the omissions and/or duplications of the marine debris.

c-2 Aerial Photography Survey

Aerial surveys were conducted on October 7 and December 3, 2014 (January 30 and March 2, 2015) in the west coast of Vancouver Island (the central coast of British Columbia and Haida Gwaii) as parts of the Assessing the Debris Related Impact From Tsunami (ADRIFT) project, which started to assess the risk of invasive species carried by Japanese tsunami marine debris (JTMD) to North American and Hawaiian coastal ecosystem since 2014. The aerial surveys had covered over more than 1,500 km of British Columbia's coastline, and provided us with 6,228 photographs on the west coast of British Columbia. In these surveys, oblique aerial photographs had been taken by a camera (single-lens reflex digital camera with 24.3 megapixels of effective pixels, D750, Nikon) from a small fixed-wing airplane flying between 500 m and 1000 m above the beaches. Since the camera was not fixed to the airplane, the exposure angles were altered in different photographs. The flight track and altitude were recorded with a built-in GPS device over the course of the aerial photography.

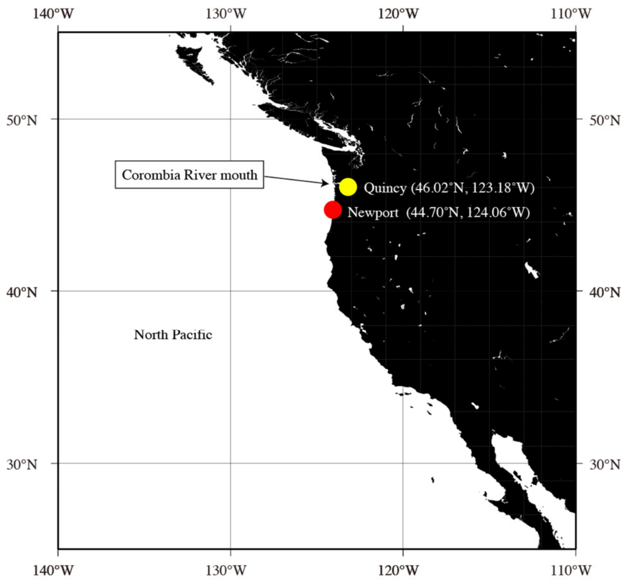


Fig. 1. Locations of the webcam monitoring site in Newport, and Quincy (observatory of river discharge) and Colombia River mouth.

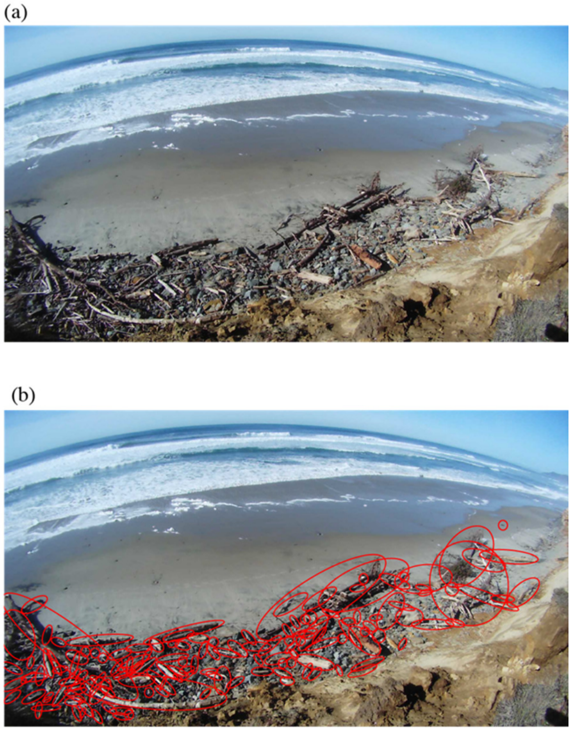


Fig 2. Photographs of the Newport beach on February 25, 2016, taken by the webcam.
(a) Original photograph and (b) the marine debris (surrounded by the red circles) identified on the photograph by the visual observation.

In the present study, the abundance of marine debris littered on the beaches was evaluated by ratios of the marine-debris areas projected on a horizontal plane to that of the beach (hereinafter referred to as "percent cover"). The procedures of image processing described below is based on Kataoka et al. (2012) where areas covered by anthropogenic plastic debris were computed using images taken by webcams installed on Japanese beaches. First, they defined a range of colors for anthropogenic plastic debris on a CIELUV color space (hereinafter, the range is referred to as "color reference"). Second, the pixels of marine debris (hereinafter, "debris pixel") were extracted from the webcam-derived images by computing the Euclidean distance on the color space between background (natural things such as sand and driftwood) and the anthropogenic debris defined by the predetermined color reference. However, it should be noted that, in general, the coverage of aerial photographs depends on both flight altitudes and exposure angles. Third, the extracted images were therefore converted to those on a geographic (Cartesian) coordinate, that is, images to which our sight line is perpendicular, by applying a projective transformation method (i.e., georeferencing described in Kako et al. (2012)); otherwise the aerial photographs are originally distorted, and thus, they are unsuitable for accurately computing the areas covered by marine debris. Last, areas of marine debris were calculated by multiplying the number of the debris pixels by the area of a single pixel (0.01 m^2 in the present application) determined uniquely by the projective transformation method (Kako et al., 2012). From the size of a single pixel, we can evaluate the amount of marine macro-debris larger than 0.01 m^2 of projected area.

The procedures mentioned above were applied to the aerial photographs taken over the British Columbia coasts, on which large quantities of logs and lumber were washed ashore in addition to the anthropogenic debris. The color references were first determined to avoid the extraction of the non-debris pixels from the aerial photographs. In the present application, the color of debris pixel is represented with the values (v) of three primary colors (red, green and blue: RGB). The average ($\bar{v}$) and standard deviation (σ) calculated from the RGB values of debris pixels are used as color references through trial and error. Namely, if each RGB value of a pixel is included within $\bar{v} \pm \sigma$, it can be determined as the debris pixel. In the British Columbia coasts, a difficulty for the projective transformation arises from the fact that reference points could not be set owing to the inaccessibility to the beaches. Thus, in lieu of setting the physical reference points, we used satellite image provided by the Google Earth. The satellite images of the Google Earth have been already geometrically corrected (i.e., ortho-corrected), and thus, the reference points with both latitude and longitude data can be chosen arbitrarily from the satellite image. Geographic markers such as headland, rocks, and trees that could be identified on both the satellite image and the aerial photograph were used as reference points. In the present study, five reference points were carefully selected in the aerial photographs through the comparison between the aerial photograph and satellite image of the Google Earth.

c-3 Winds and ocean currents

The temporal variation of the marine-debris numbers counted on the beach was compared with that of satellite-derived wind data to investigate the potential causes(s) of the variation. We used a global gridded wind vector dataset constructed by applying an optimum interpolation method (Kako et al., 2011) to the Level 2.0 Advanced Scatterometer (ASCAT) wind product (Verspeek et al., 2009).

d) Results

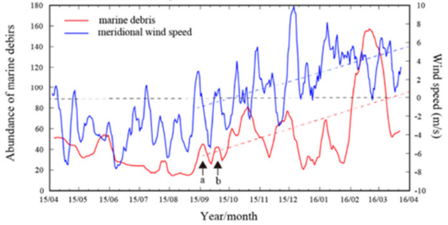
d-1 webcam monitoring

First, it seems likely that the meridional wind component was responsible for the seasonal (summer to winter) increase of the debris abundance. In fact, the seasonal increase was revealed when southerly winds prevailed because of the development of the Aleutian low over the North Pacific; compare the two linear trends between September to March in Fig. 3a. The seasonal increase of the marine debris during the southerly winds looking at the coast on their right-hand side suggests the dependence of the debris abundance on the occurrence of the coastal upwelling/downwelling and their associated cross-shore Ekman flows. In fact, it has been well known that the coastal upwelling (downwelling) occurs along the western US coasts especially during the summer (winter) (Duxbury et al., 2002). When the southerly (downwelling-favorable) winds prevail, it is likely that the onshore-ward Ekman transport carries marine debris toward the coast, and that the debris littered on the beach increases thereafter. Meanwhile, the beach litter decreases when drifting marine debris is prevented from approaching to the coast because of the offshore-ward Ekman transport induced by the northerly (upwelling-favorable) winds.

Second, a finding is the sub-monthly fluctuations of debris abundance (Fig. 3) superimposed on the seasonal increase, which seem to be related to those appeared in the zonal wind component especially in the latter half of the study period (from the mid-October to the end; Fig. 3b). It is interesting that the marine debris decreased when the westerly (onshore-ward) winds prevailed in winter. One may consider that the debris abundance varied in a non-intuitive manner, because onshore-ward winds were likely to carry floating objects onto the beach owing to wind-induced surface currents and leeway drift. It should be noted that the minimal abundance in the latter half appeared when westerly winds prevailed at spring tides (gray bars in Fig. 3b). It is therefore reasonable to consider that the wind setup resulted in the re-drifting of debris during the westerly (onshore-ward) winds at spring tides (particularly at flood tide). The photograph of the beach on December 11, 2015, when the westerly wind prevailed at the first spring tide, exhibits that the high-tide line moved landward over the entire beach (middle of Fig. 4). Thus, it is likely that the seawater occupied over the entire beach mostly "swept" the marine debris (December 13; lower in Fig. 4), which had been accumulated on the beach until the occurrence of the wind setup (upper in Fig. 4).

d-2 Aerial Photography Surveys

The map of percent covers estimated from the 167 photographs (Fig. 5) shows that debris abundance was estimated to be high in the northwest of Vancouver Island in comparison with the southeastern beaches. The highest percent cover of 38% was revealed around the northern tip of Vancouver Island.


(a) vs. meridional wind speed

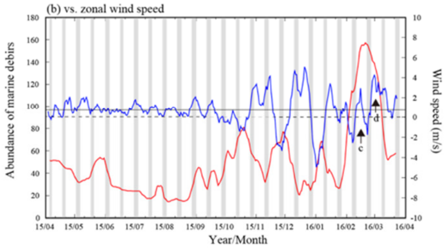

(b) vs. zonal wind speed

Fig. 3 Comparison of the marine debris abundance with wind speed components (7-day running mean). The debris abundance (red curves) are depicted with (a) the meridional wind speed, and (b) zonal wind speed, respectively. The red (blue) dotted line in (a) indicates the linear trend of marine debris abundance (meridional wind speed) between September to March. Gray bars in panel (b) indicate the period of the spring tides.

Fig. 4 Photographs of the day before (December 9, 2015), during which (December 11), and after (December 13) the westerly winds prevailed at the spring tide. The change of the ground form just below the webcam resulted from the land slide occurred due to the storm on December 11.

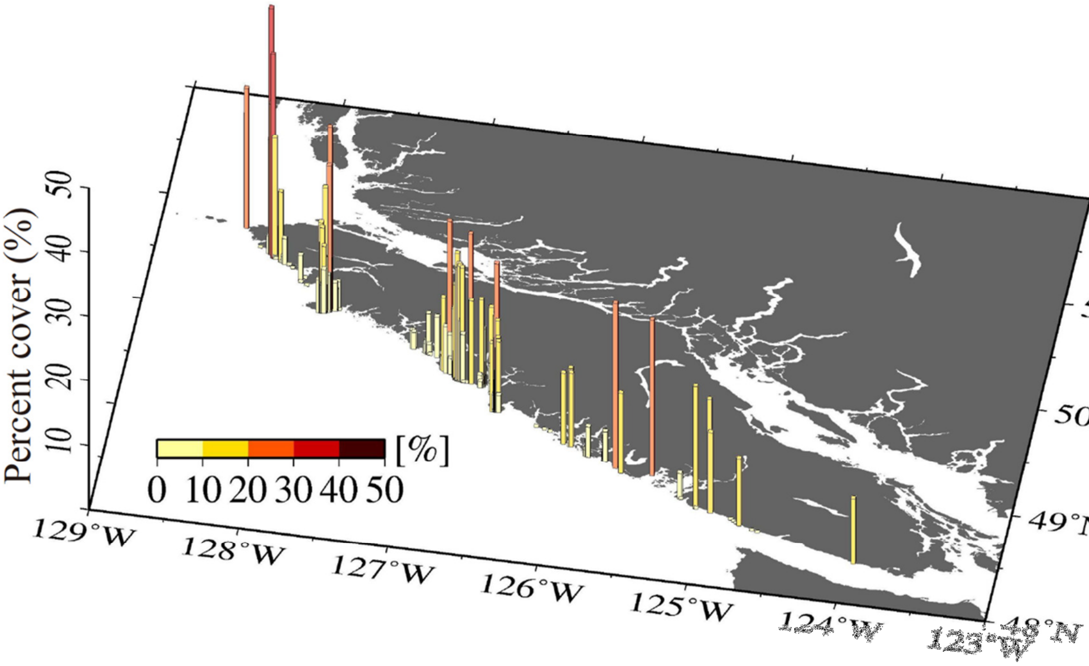


Fig. 5. Horizontal distribution of percent covers estimated by applying our image processing to the aerial photographs taken in Vacounver Island. The yellow-red gradation represents the percent cover, of which color scale is shown in the lower left of the panel.

e) Discussion

A straightforward model is constructed to validate whether or not the above-mentioned two critical factors (coastal upwelling / downwelling, and wind setup) certainly determine the variation of marine debris abundance on the beach. We assumed that the marine-debris abundance (N) on the beach depends on the meridional (V) and zonal (U) wind directions at grid cell nearest to Newport. The abundance increases by one when southerly winds occur ($N = N+1$ at $V > 0$; coastal downwelling), while the debris abundance on the beach vanishes when the onshore-ward wind speed becomes higher than its temporal average at spring tides ($N \rightarrow 0$ at $U >$ average over the entire period; wind setup). In spite of its simplicity, the model does a reasonable job of reproducing the abundance of marine debris on the beach (Fig. 6). The correlation coefficient between the webcam observation and the model run are 0.85, significant at the 99% confidence level. It is anticipated that the model is commonly capable of reproducing the marine-debris abundance on various beaches along the western US and Canadian coasts, because the above model is free of locality available only for the Newport beach, and because the coastal upwelling/downwelling as well as the wind setup at spring tides occurs anywhere over the western coasts.

Our idea is to combine the above "sub-model" with a particle tracking model (PTM) reproducing JTMD motion in the North Pacific. The sub-model gives the criterion whether modeled particles approaching coasts are washed ashore on the land grid cell, and whether they return to the oceanic domain from the land. The satellite-derived winds on the oceanic grid cells neighboring the land boundary were used for the criterion in the sub-model. The PTM uses surface ocean currents provided by the HYCOM (https://hycom.org), and ASCAT winds are used for both the PTM and sub-model. 50,000 particles were released off the Sanriku coast, Japan, on March 11, 2011, and thereafter five-year computation was conducted. An advantage of the combination of the sub-model over the conventional PTM is demonstrated in Fig. 7, where the abundance of particles washed ashore was computed on the beaches as well as particles carried in the ocean. It should be noted that the abundance of modeled particles on the Vancouver Island becomes larger in the north than that in the south. This pattern is consistent with the results of the aerial photography (Fig. 5), and well validates the capability of the combination of PTM and sub-model to compute the abundance of JTMD washed ashore actually on the beach.

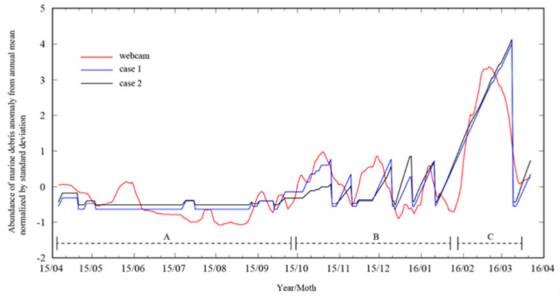


Fig. 6 Time series of abundance of the webcam-observed (red curve) and modeled (blue curve) marine debris. The case 2 (black curve) was not used in this report.

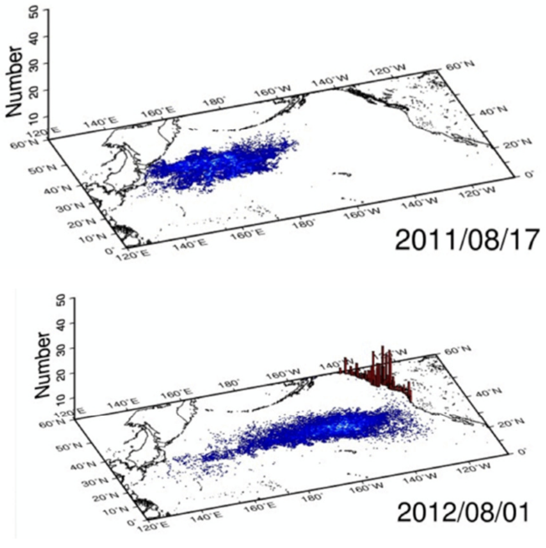


Fig. 7 Two snapshots of the PTM combined with the sub-model.

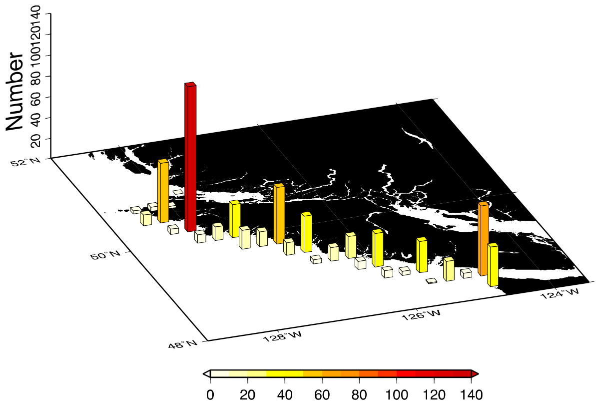


Fig. 8 Modeled particle abundance averaged on the same day of the aerial photography in Fig. 3.

In summary, the abundance integrated over the five years (Fig. 9) states that the JTMD (hence, invasive spices) has not washed ashore homogeneously on the entire West Coast of the US and Canadian beaches. Indeed, the JTMS have been found from Northern California to Alaska. It is however suggested that large amount of JTMD has been washed ashore on the relatively narrow area (<1000 km) around Vancouver Island, which might act as a "gate" of the invasive spices carried by the JTMD.

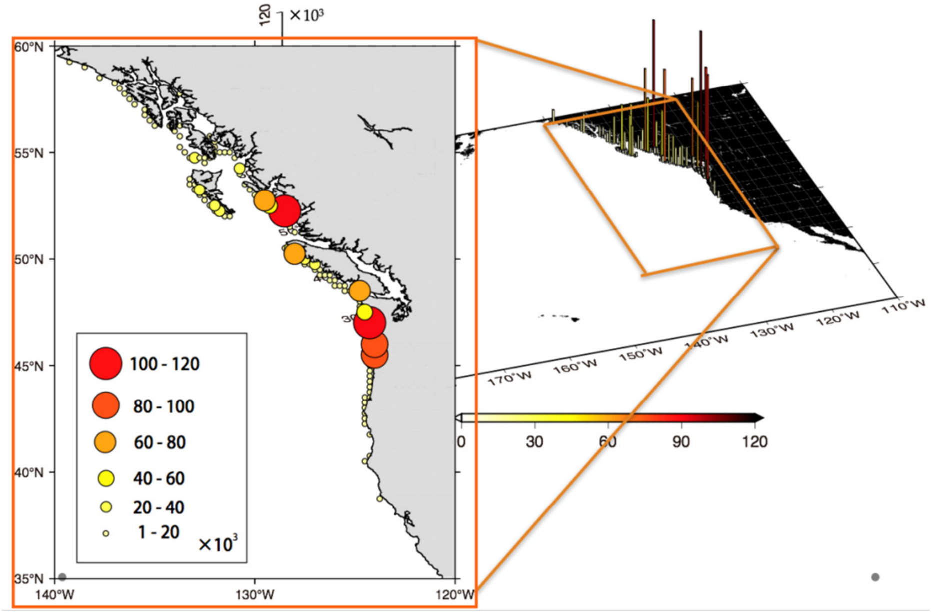


Fig. 9 Particle abundance integrated over 5-year computational period. Particle numbers washed ashore on the beach grid cells are represented by the bar height, and are also represented by circle diameters in the enlarged map in the left panel

f) Challenges

Setting a webcam monitoring system in the US was the first experience for us. We could not continue the monitoring without supports by our colleagues in Newport.

g) Achievements

To evaluate how the invasive species have been washed ashore on the US and Canadian coasts along with the JTMD, we have to estimate where and how much the JTMD has been washed ashore there. Based on the webcam monitoring, aerial photography, and PTM experiments, our estimates were as follows: about 3% of JTMD (~45,000 tons) was accumulated on the US and Canadian beaches, and large amount of JTMD has been washed ashore on the relatively narrow area (<1000 km) around Vancouver Island.

h) Literature Cited

Duxbury, N. and coauthors., 2002. Fundamentals of Oceanography, 4th edition. New York: McGraw Hill. pp. 344

Kako S, Isobe A, Kubota M., 2011. High resolution ASCAT wind vector dataset gridded by applying an optimum interpolation method to the global ocean. J Geophys Res. 116, D23107. doi: 10.1029/2010JD015484.

Kako, S., Isobe, A., Magome, S., 2010: Sequential monitoring of beach litter using webcams. Mar Pollut Bull. 60, 775-779.

Kataoka, T., Hinata, H., Kako, S., 2012. A new technique for detecting colored macro plastic debris on beaches using webcam images and CIELUV. Mar Pollut Bull. 64, 1829-1836.

Verspeek, J. A., Stoffelen, A., Portabella, M., Bonekamp, H., Anderson, C., Figa, J., 2009. Validation and calibration of ASCAT using CMOD5.n, IEEE Trans. Geosci. Remote Sens. 48(1), 386-395. doi:10.1109/TGRS.2009.2027896.

5. OUTPUTS

a. Completed and planned publications

(1) Kako, K., A. Isobe, T. Kataoka, K. Yufu, S. Sugizono, C. Plybon, and T. A. Murphy "Sequential webcam monitoring and modeling of Marine debris abundance on a beach of the western US coast", submitted to Marine Pollution Bulletin (special issue for JTMD)

(2) Kataoka, T., C. C. Murray, and A. Isobe "Quantification of marine macro-debris abundance around Vancouver Island, Canada, based on archived aerial photographs processes by the projective transformation", submitted to Marine Pollution Bulletin (special issue for JTMD).

(3) Isobe, A., S. Kako, T. Kataoka, S. Iwasaki, C. Plybon, and T. A. Murphy "Webcam monitoring and modeling of Japanese tsunami marine debris washed ashore on the western coast of the North America", PICES Press, 25(1), 32-35, 2017.

b. Poster and oral presentations at scientific conferences or seminars

Tomoya Kataoka, Shin'ichiro Kako, Cathryn C. Murray, Charlie Plybon, Thomas A. Murphy, Nir Barnea, Hirofumi Hinata, Atsuhiko Isobe (2016): Techniques for quantifying the accumulation of marine debris on beaches, Workshop on Mission Concepts for Marine Debris Sensing, 19-21 Jan. 2016, Honolulu, USA.

Shin'ichiro Kako, Shujin Sugizono, Tomoya Kataoka, Kei Yufum Atsuhiko Isobe (2016): webcam monitoring of marine debris on the western coast of US, Annual Meeting of Japan Oceanographic Society, 16S25-12, 15 Mar. 2016, Tokyo, Japan. (In Japanese)

Shin'ichiro Kako: Sequential monitoring of marine debris washed ashore on a western US beach using a webcam system, PICES annual meeting, 9 Nov., 2017, San Diego.

Tomoya Kataoka : Accumulation of beach litter in Vancouver Island, Canada, PICES annual meeting, 9 Nov., 2017, San Diego.

Atsuhiko Isobe: An estimate of the tsunami-debris quantity washed ashore on the US and Canadian beaches, based on a webcam monitoring and a particle tracking model experiment, PICES annual meeting, 9 Nov., 2017, San Diego.

c. Education and outreach

Science Seminar "Remote monitoring of Marine Debris", Mar 21, 2016, Hatfield Marine Science Center, Auditorium. (OSU and Surfrider Foundation OR region).
https://oregon.surfrider.org/monitoring-marine-debris-with-remote-web-cam-technology/

6. RESEARCH STATUS AND FUTURE STEPS/PLANS

We will remain the webcam monitoring system in Newport for further analyses that will be conducted by US researchers and NPO members.