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

Year 2 Final Report

1. PROJECT INFORMATION

Title:	Webcam monitoring of marine/tsunami debris
Award period	April 1, 2015 – March 31, 2016
Amount of funding	$55,000 CAD
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2. EXECUTIVE SUMMARY

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

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

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

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

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

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

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

The timetable in year 2 was as follows.

- April 2015: The webcam-monitoring started at Newport OR;
- December 2015: Analyses of webcam data started;
- March 21, 2016: Science seminar (opened publicly) at the Hatfield Marine Science Center at Newport, OR; talks by Atsuhiko Isobe and Tomoya Kataoka.

3. PROGRESS SUMMARY

a. Describe original proposed research and planned outputs

Webcam monitoring

As mentioned above, photographs of the beach have been taken automatically every 60 min over a 9-month period using the webcam, with the aim of elucidating temporal variations of debris quantities and the possible factors responsible for these changes. The time series of the beach litter quantity was derived from webcam observations, and it was found that the quantity of marine debris vary largely in time, with a period shorter than one month or less superimposed on seasonality. In addition, the results of a comparison between satellite-observations and the quantity of marine debris reveled that the coastal upwelling related to the offshore-ward Ekman flow induced by the northerly winds prevents the increase of the quantity of marine debris washed ashore on the beach.

Image analysis of aerial photographs

To monitor beach litter on the western coast of North America with a high spatio-temporal resolution, we have proposed a combination of the webcam monitoring and aerial photography in the preliminary report of Year 1. The webcam has an advantage in monitoring marine debris continuously in time, although it has a disadvantage that this monitoring provides marine debris quantities only at a local site. On the other hand, the aerial photography can synoptically monitor the accumulation of marine debris over broad areas, although it also has a disadvantage that surveys are conducted sporadically, so that difficulty arises in considering the temporal variability of marine debris quantities with a high temporal resolution. Probably, the most reasonable approach for monitoring the marine debris with a fine resolution is a combination between the webcam monitoring and aerial photography. Therefore, a new technique was developed for marine debris monitoring with a high spatial-temporal resolution by using webcam and aerial photography.

Image analysis of multispectral images

In the webcam monitoring and aerial photograph surveys, quantification of marine debris is based on the image analysis in the RGB color space. If the color of marine debris is similar to that of beach sediments, it is difficult to distinguish marine debris from beach sediments by the image analysis (Kataoka *et al.*, *MPB*, 2012). Additionally, to calculate quantities of marine debris from the webcam and aerial photographs, the geometric distortion of the original photographs should be removed by applying a projective transformation method (see section c2). To apply this method, we need to measure geographic locations of at least four reference points using GPS on the beach (Kako *et al.*, *MPB*, 2012). However, it is a difficult task, if the beaches are hard to access.

To solve these issues, we attempted to develop a technique for evaluating the accumulation of marine debris by applying the image analysis to multispectral satellite image, such as WorldView-2 (WV-2). We expect to successfully distinguish marine debris from beach sediments with similar color using the intensity of various wavelength bands. In addition, we do not need to apply the projective transformation method because of ortho-rectified satellite images. We therefore attempted to develop a technique for extracting pixels of beach litter from multispectral satellite images.

b. Describe progress

Webcam monitoring

Webcam monitoring of beach litter has been conducted on the beach near Newport (Oregon, USA) from April 2015 to the present to elucidate the temporal variation of debris quantities and the possible factors responsible for these changes. Beach photographs taken by the webcam 10 times a day (from 9:00 – 18:00) are transmitted to a webserver every 60 min *via* the Internet and are freely available on our project website at http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html. These observations clearly indicate that the quantity of marine debris on the beach fluctuates largely in time. The main finding of this study is that the coastal upwelling associated with the offshore-ward Ekman flow induced by the intensification of the northerly winds contributes significantly to a decrease of the quantity of marine debris washed ashore on the beach.

<u>Image analysis of aerial photographs</u>

We have begun to collaborate with the project aerial surveillance team since the end of Year 1. In the Year 1 preliminary report, we have described a technical issue for estimating a ratio of an area covered by marine debris to the area of entire beach (hereinafter, "percent cover") from aerial photographs: we should apply a projective transformation method (*e.g*., Kako *et al*., *MPB*, 2012) to the aerial photographs to remove the geometric distortion of the original photographs.

In this year, we established an effective way to apply the projective transformation method to the aerial photographs (with some limitations shown later). This approach enables us to successfully remove the geometric distortion from the aerial photographs. In addition, the percent covers were estimated by extracting the pixels of marine debris from the images after applying the projective transformation method. The percent covers were consistent with the results of shoreline cleanup survey conducted by the aerial surveillance team. Furthermore, the accumulation of marine debris on beaches of Vancouver Island was estimated by applying our image analysis to aerial photographs. It was found that beach litter accumulated to a greater extent on the south- and southeast-facing beaches of Vancouver Island and, consequently, concluded that the accumulation of beach litter depends on the cross-shore direction of the beach interacting with the major direction of offshore ocean currents.

<u>Image analysis of multispectral images</u>

Preparing for analysis of multispectral satellite images, we have demonstrated the effectiveness of an 8-band multispectral image by a photographing experiment using a hyperspectral camera (NH-7, EBA JAPAN). In this experiment, the hyperspectral reflectance was obtained for two types of plastics (*i.e*., polyepropylene (PP) and polystyrene (PS)) set on the ground with its similar color, and then converted the hyperspectral imagery into an 8-band multispectral imagery corresponding to WV-2 satellite image by averaging the hyperspectral reflectance of the plastics in the range of each wavelength band. When the 8-band spectra were used, we successfully extracted the pixels of the plastics without the misdetection of pixels of the ground with those similar colors. This demonstrated that the usage of the 8-band multispectral image enables us to more accurately calculate the accumulation of marine debris over wide areas. In the near future, we will apply the technique to the WV-2 satellite image.

c. Describe results

<u>Webcam monitoring</u>

The location of the webcam monitoring site and the webcam monitoring system used in this study are shown in Figure 1. An example of the original webcam photograph is presented in Figure 2 (left), in which a lot of driftwood washed ashore on the beach can be observed, although the artifact debris such as fishery floats and polystyrene, among others were not washed ashore. The original image is rotated to an image on a Cartesian coordinate (Fig. 2, right) using the positions measured by GPS on the beach (projective transformation method). Since the details of this method are published by Magome *et al*. (2007) and Kako *et al*. (2012), it is not discuss it further here.

By webcam monitoring during the 9-month period, we could not capture the marine debris associated with the 2011 Great Tohoku Earthquake and subsequent tsunami (because we could not identify beach litter with large Japanese characters, and large litter specifically used in Japan), although a large amount of drifting wood washed ashore on the beach has been taken by the webcam and its quantity fluctuated substantially through time. It is expected that the understanding of possible factors affecting these variations is useful in estimating total amount of beach litter (possibly including tsunami debris unidentified by cameras) washed ashore on the beach. Thus, in the present study, the number of drifting wood is used as an index of the marine debris quantities on the beach. Hereinafter, "the quantity of marine debris" means the number of drifting wood washed ashore on the beach.

Fig. 1 Location of the webcam monitoring site near Newport, Oregon, USA (left) and webcam system used in this study (right).

Fig. 2 Original photograph taken by webcam (left) and photograph after applying the projection transformation method (right).

Next, to obtain the quantity of marine debris using the photographs, the lightness was computed at each pixel as a function of RGB color coordinate values. However, lightness values derived from both beach and driftwoods are very similar, so that we cannot objectively deduce the quantity of marine debris using the method proposed by Kako *et al*. (2010). Therefore, to investigate the quantity of marine debris, we counted those in each photograph by visual observation. The time series of the quantity of marine debris (Fig. 3) demonstrates the remarkable variations with a period shorter than a month, superimposed on a seasonal variation.

To examine what factors might influence these temporal variations, the time series of the beach litter quantity were compared with the sea surface wind speed observed by Advanced scatterometer (ASCAT; Kako *et al*., 2011) at the nearest grid point. This datasets are freely available at http://mepl1.riam.kyushu-u.ac.jp/~kako/ASCAT.

Figure 3 shows the results of comparison, demonstrating that the number of marine debris vary largely in accordance with meridional (north-south) wind speed (Fig. 3b), but there is no relationship with the zonal (east-west) wind speed except for winter (Fig. 3a), *i.e.*, the quantity of beach litter decreased when the northerly winds prevailed. These results suggested that the offshore-ward flow induced by the northerly wind (*i.e.*, the coastal upwelling in accordance with the offshore-ward Ekman flow) prevents the increase of marine debris washed ashore on the beach. To investigate the relationship between the occurrence of the coastal upwelling and beach-litter quantity more precisely, the quantity of marine debris was compared with the sea surface dynamic heights (SSDH) produced by AVISO (Archiving, Validation and interpretation of Satellite Oceanographic data). AVISO data is also free available at http://www.aviso.altimetry.fr/en/home.html.

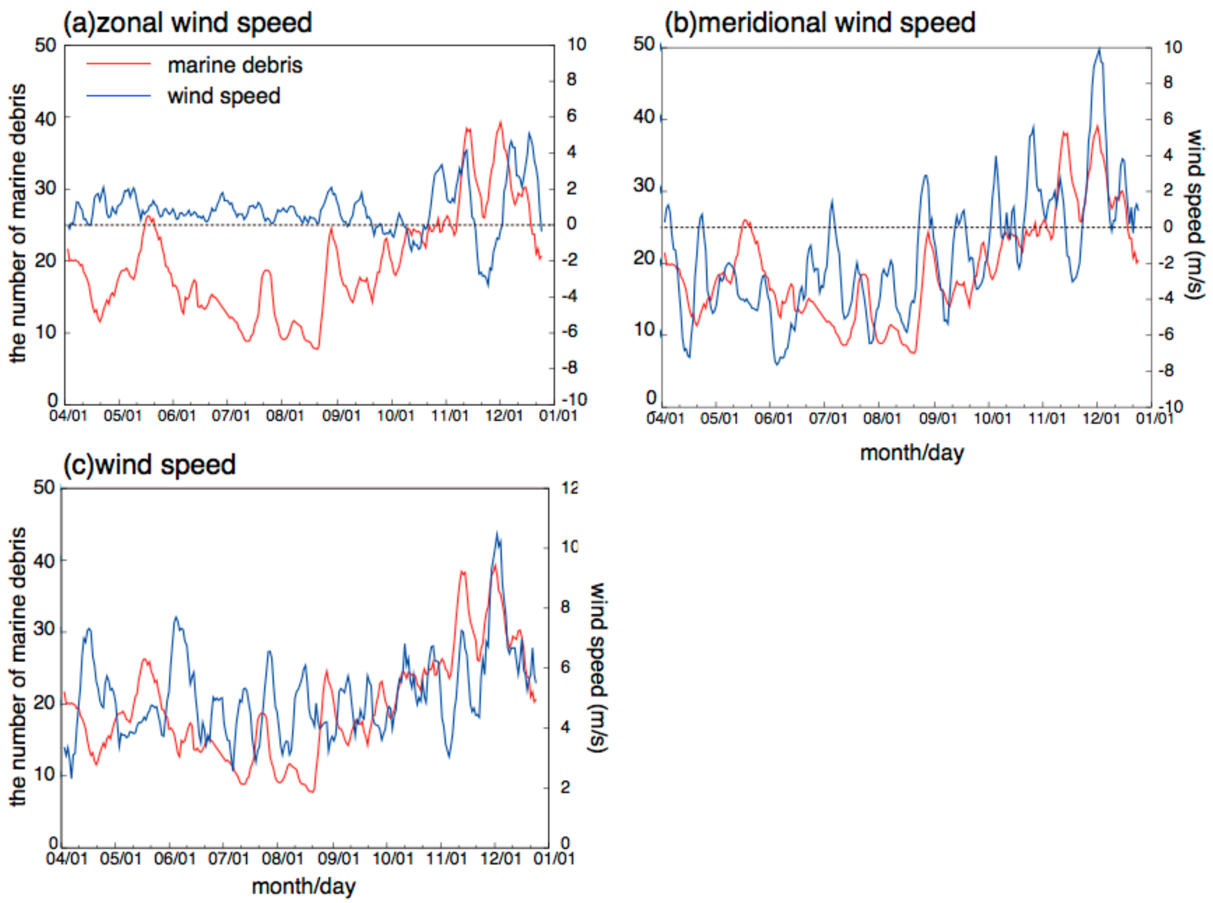

Fig. 3 Comparison between the quantity of marine debris and (a) zonal wind speed, (b) meridional wind speed, and (c) wind speed.

Figure 4 shows that the quantity of beach litter varies largely with SSDH. Namely, this quantity decreases (increases) when SSDH is low (high) [note that the low (high) SSH means the presence of cool (warm) water]. This indicates that the coastal upwelling (hence, appearance of cool water in the surface layer) induced by the northerly winds along the Oregon coast plays an important role in inhibiting the increase of marine debris on the beach. Thus, offshore-ward flow related to the northerly wind (*i.e.*, Ekman drift) inhibits the increase of marine debris on the beach. The result of comparison after removal of seasonal variation from both the quantity of marine debris and SSDH reveals that, in contrast to spring to summer seasons, the correlation coefficient between the quantity of marine debris and SSDH becomes negative in winter (November to December; Fig. 4b). This is because the westerly winds, in accordance with a cyclone passage in winter, bring the large amount of marine debris on the beach, as Newport beach is located under the storm path in the winter as shown in Figure 5.

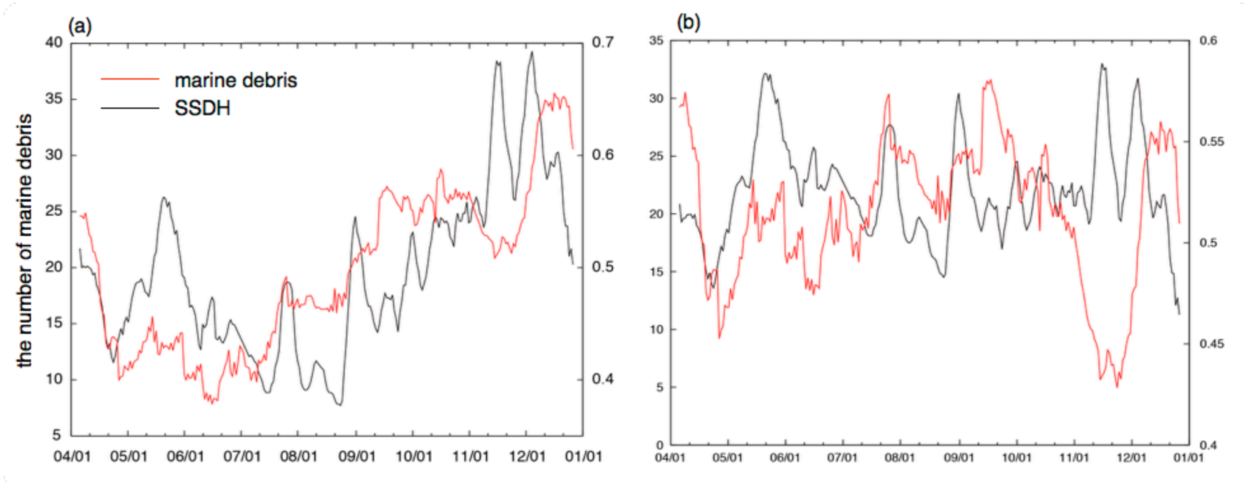

Fig. 4 Comparison of the quantity of beach litter with SSDH (a) and after removing the seasonal variation (b).

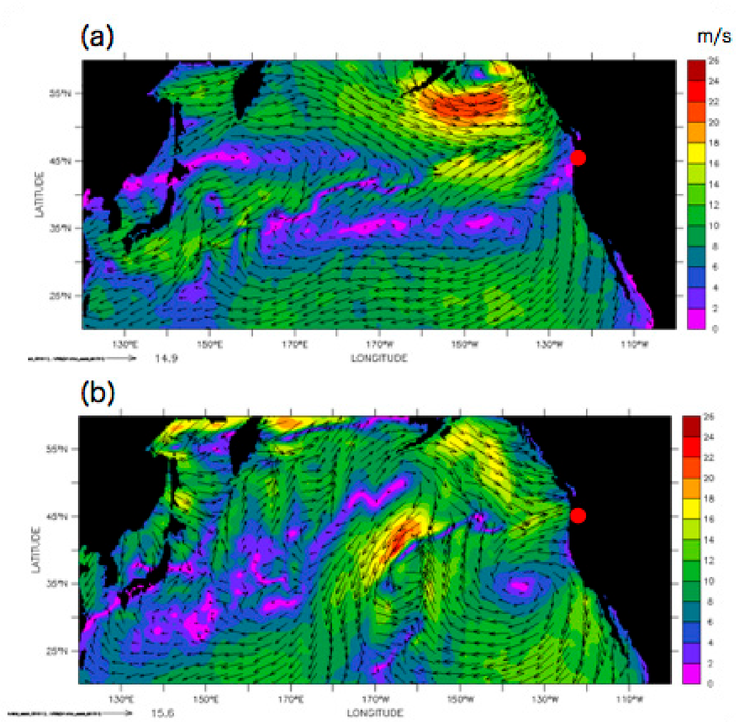

Fig. 5 Horizontal distribution of daily averaged wind speed/direction (color/vector) on November 12, 2015 (a) and November 17, 2015 (b).

<u>Image analysis of aerial photographs</u>

We have analyzed the aerial images provided by the project surveillance team. The locations where all aerial photographs were taken are shown in Figure 6(a). In Year 1, the surveillance team had photographed Vancouver Island during the aerial surveys conducted two times on October 7 and December 3, 2014 (Fig. 7(a)). In Year 2, they simultaneously carried out the aerial survey and shoreline cleanup surveys on the Cheewat Beach and Clo-ose Beach located southwest in Vancouver Island on July 28–29, 2015 (Fig. 7(b)), and measured the densities of marine debris on these beaches based on the number of marine debris collected by the shoreline cleanup surveys. The densities of marine debris can be used to validate the percent covers calculated from the aerial photographs.

To remove the geometric distortion of the original aerial photographs taken in the oblique angle from aircrafts, we attempted to apply a projective transformation method established by Kako *et al*. (2012) to the aerial photographs. According to Kako *et al*. (2012), a geometric relationship between geographic (corrected) and photographic (original) coordinates is represented as follows:

$$X = \frac{b_1 x + b_2 y + b_3}{b_4 x + b_5 y + 1}, \quad Y = \frac{c_1 x + c_2 y + c_3}{c_4 x + c_5 y + 1} \tag{1}$$

where (X, Y) and (x, y) mean geographic and photographic coordinates, respectively. b_i and c_i $(i = 1, 2, \cdots, 5)$ mean the coefficients for rotating the photograph in both horizontal and vertical directions to the Cartesian plane. If the GPS-derived geographic positions for at least four reference points are available in the coverage of the aerial photographs, we can determine the coefficients in the Eq. (1) by applying a least square method (Kako *et al*., *MPB*, 2012). However, the surveillance team did not set the reference points over the coverage area for each photograph. Thus, *in lieu* of setting the reference points by ourselves, we used the satellite image provided by the Google Earth. In the Google Earth, the satellite images have been already geometrically corrected, and thus, the reference points with both latitude and longitude data can be chosen arbitrarily. When remarkable geographic markers such as headland, rocks, and trees could be identified on both of the satellite image of the Google Earth and the aerial photograph, they can be used as reference points in the present application. The five reference points were carefully selected in the aerial photographs through the comparison between the aerial photograph and satellite image of the Google Earth. For each aerial photograph, we determined the coefficient of b_i and c_i of Eq. (1) by the least square method using the geographic and photographic coordinates.

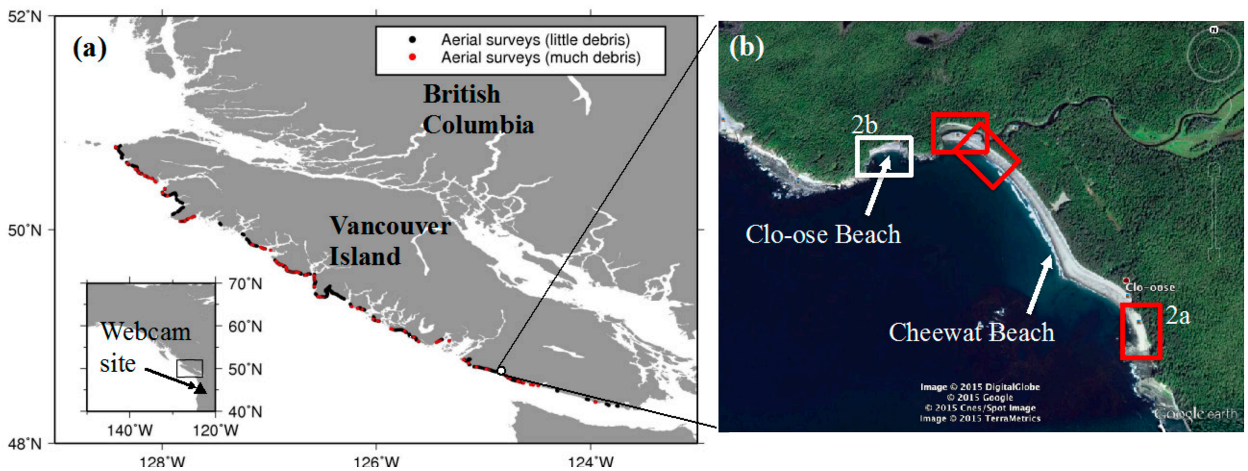

Fig. 6 (a) Locations where the aerial photographs were taken. Black and red dots indicate the photographing locations, and the legend of the symbols is shown in the right-upper box. (b) The enlarged map of the shoreline cleanup sites. The white and red boxes show the coverage of the aerial photographs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

Figure 7(c) and (d) are the images corrected by the projective transformation (hereinafter "converted image") to Figures 7(a) and (b), respectively. An area corresponding to a single pixel on the converted images (*e.g*., Figures 7(c) and (d)) is 0.01 m^2, which can be arbitrarily determined by the projective transformation method (Kako *et al*., *MPB*, 2012). Hence, we estimated the area covered by beach litter by counting the number of pixels of marine debris on the converted image. The areas calculated from the converted image were validated by comparing with those calculated from the geographic positions of the five reference points, and the error was less than 1%. Next, we estimated the percent covers of marine debris using the converted images. Driftwoods are the most common beach litter in Vancouver Island. In this study, driftwoods as well as anthropogenic debris were chosen as target objects, and we extracted their pixels (hereinafter "debris pixel") from aerial photographs using the difference of their colors based on Kataoka *et al*. (2012). The area covered by marine debris was calculated by counting the number of debris pixels extracted from the converted images.

Thereafter, we specify the sandy beach in each converted image by eyes (red outlines of Fig. 7(c) and (d)), and computed its area by counting the number of pixels inside the outlines. The percent covers were computed by taking the ratios of these two areas.

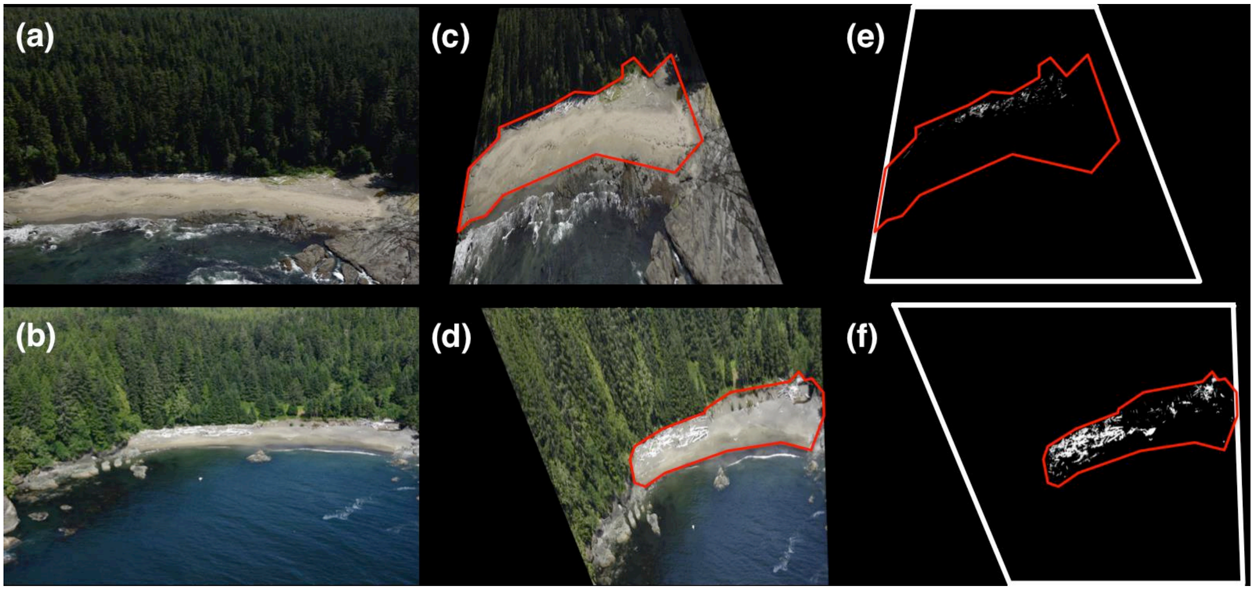

Fig. 7 The panels (a) and (b) are the original aerial photographs on Cheewat Beach and Clo-ose Beach, respectively (see 2a and 2b in Fig. 6(b)). The panels (c) and (d) are the converted images on these beaches. The panels (e) and (f) are the images that marine debris was detected from the converted image on each beach by the image analysis. The white pixels mean marine debris on the panels (e) and (f). The red outlines denote the area of the sandy beach on the panels (c)-(f).

To investigate the accuracy of the beach litter accumulation evaluated by image analysis of aerial photographs, we compared the percent covers estimated from the aerial photographs with the densities of beach litter measured by the shoreline clean-up surveys on the Clo-ose Beach and Cheewat Beach (Table 1). The percent cover on the Clo-ose Beach was estimated using the converted image (*i.e.*, Fig. 7(d)) because the entire beach was captured on a single aerial photograph (white box of Fig. 6(b)). On the other hand, the percent cover on the Cheewat Beach was estimated using three converted images (red boxes of Fig. 6(b)). Although the entire Cheewat Beach was captured on eleven aerial photographs, eight of them were unable to be converted by the projective transformation because of the lack of the appropriate five reference points. The accumulation of beach litter on these two beaches indicated by the percent covers was consistent with the densities of beach litter measured by the shoreline clean-up surveys. Namely, both the percent cover and density on the Clo-ose Beach were greater than those on the Cheewat Beach, and also a ratio of the percent cover on the Clo-ose Beach (*i.e.*, 14.0/4.0 = 3.5) was identical to the density the Cheewat Beach (*i.e.*, 0.049/0.014 = 3.5). Consequently, this result demonstrated that our image analysis would enable us to estimate the percent cover using the aerial photographs.

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

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

Next, we evaluated the accumulation of marine debris on Vancouver Island by applying the image analysis to the aerial photographs. From all aerial photographs (black dots in Fig. 6(a)), 116 aerial photographs in which beach litter seems to be denser than others were chosen as target photographs. Figure 8 shows the accumulation map of beach litter based on the analysis of these photographs. We found the several beaches on which marine debris highly accumulated. The highest percent cover was 38% (black arrow in Fig. 8). To investigate the factors determining the accumulation of beach litter, the aerial photographs were classified by the cross-shore direction of the beach. On Vancouver Island, the south- and southwest-facing beaches are predominant, while there are no north-, northeast- and east-facing beaches (Fig. 9(a)). The mean percent covers were the highest on the south-facing beach (Fig. 9(b)). This accumulation pattern of marine debris might reflect the ocean current pattern west of Vancouver Island. Basically, the northward and northwestward Alaska Current is predominant in the offshore region. The Alaska Current could frequently strike the south-facing beach. Therefore, it is likely that the accumulation of marine debris would depend on the ocean current pattern in the offshore region.

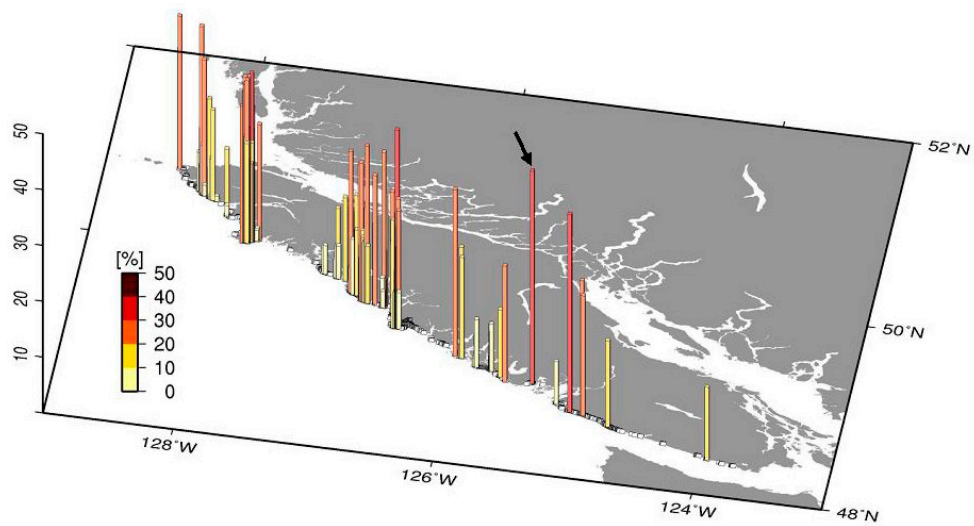

Fig. 8 Accumulation map of marine debris in the western side of Vancouver Island. The height and color denote percent covers estimated from the aerial photographs. Black arrow means the beach where marine debris accumulated most highly.

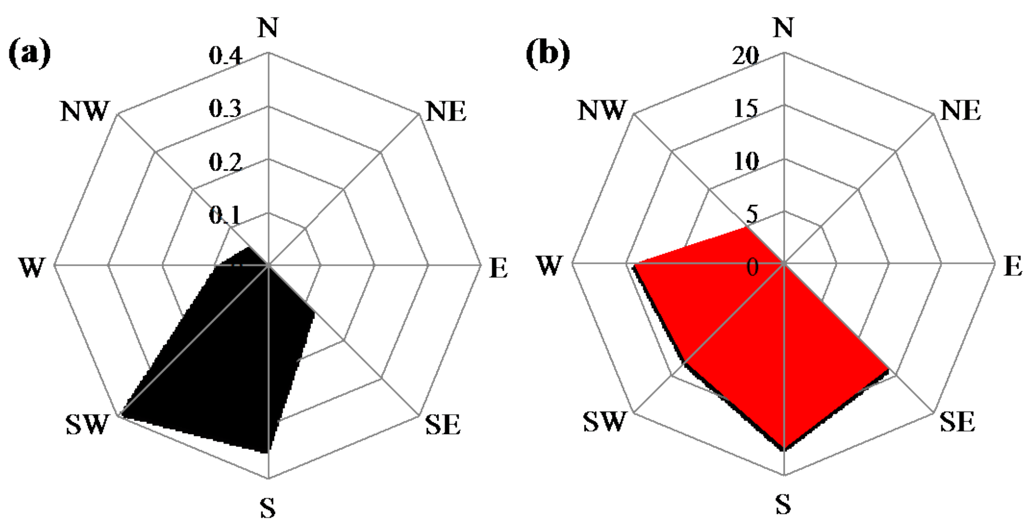

Fig. 9 Dependence of the number of beaches (a) and mean percent cover (b) on the cross-shore direction of the beach in Vancouver Island.

Image analysis of multispectral images

As the first step to develop the algorithm for extracting pixels of marine debris from WorldView-2 (WV-2) satellite images, we conducted a photographing experiment using a hyperspectral camera (NH-7, EBA Japan Co. Ltd.), which covers from 350 nm to 1100 nm bands, with a wavelength sampling interval of 5 nm. The WV-2 is the 8-band multispectral commercial satellite owned by DigitalGlobe, and has eight spectral sensors in the visible light to near-infrared ranges corresponding to the wavelength band of the hyperspectral camera (Table 2). In the photographing experiment, we set the object on white pebbles, and then took it by the hyperspectral camera installed on the building roof of National Institute for Land and Infrastructure Management (NILIM). The two types of the representative marine plastics (*i.e.*, polyepropylene (PP) and polystyrene (PS)) were selected as the objects, and set up on the board and beach sand (Fig. 10(a)). The spectral reflectance curves of PP and PS are shown in Figure 10. The spectral reflectance of PS was constant from 400 nm to 1050 nm of wavelength. On the other hand, the spectral reflectance of PP degrades significantly around 770 nm and 940 nm of wavelength.

Table 2 Multispectral sensors bands of WV-2

Symbol	Name	Band	Symbol	Name	Band
V1	Coastal	400−450 nm	V5	Red	630−690 nm
V2	Blue	450−510 nm	V6	Red edge	705−745 nm
V3	Green	510−580 nm	N1	Near-IR1	770−895 nm
V4	Yellow	585−625 nm	N2	Near-IR2	860−1040 nm

* V: Visible light range, N: Near-infrared range

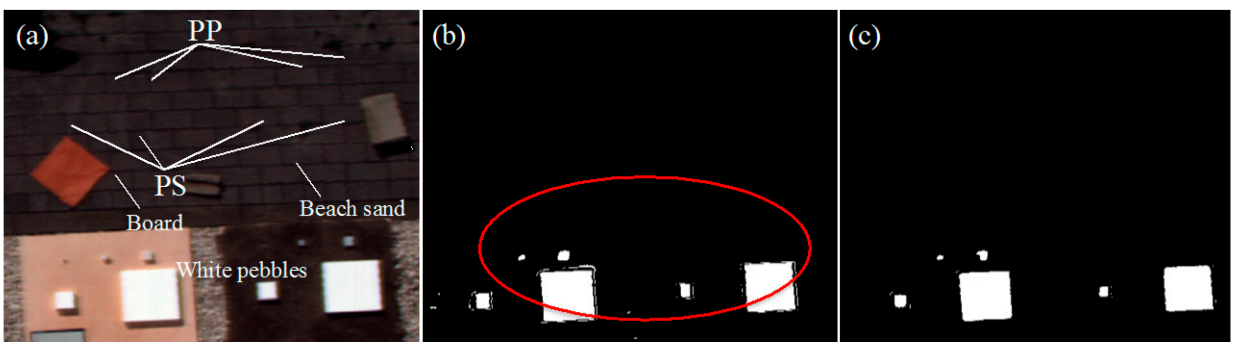

Fig. 10 Results of the photographing experiment (original image of the objects (a), result that the objects were extracted using the references of three bands (b), result that the objects were extracted using the references of all eight bands (c)). Red ellipse in panel (b) denotes misdetection of white pebbles.

Considering the applicability of the image analysis to WV-2 satellite imagery, we created multispectral imagery by averaging the spectral reflectance in each wavelength range of WorldView-2 as follow.

$$S_m = \int_{\lambda_{min}}^{\lambda_{max}} S(x,y,\lambda)\,d\lambda \Big/ \Delta\lambda \qquad (2)$$

where S_m means the multispectral value corresponding to the intensity of WV-2 imagery in each band, $S(x,y,\lambda)$ means the hyperspectral reflectance obtained by the photographing experiment. x and y are the photographic coordinates, and λ is the wavelength. λ_{max} and λ_{min} are maximum and minimum of wavelength in each band, and $\Delta\lambda$ is its band width (i.e., $\Delta\lambda = \lambda_{max} - \lambda_{min}$). Then, to define references for extracting pixels of PP and PS from the multispectral image, we calculated the average ($\bar{S}_m$) and standard deviation (σ_m) of S_m. If S_m of several certain bands is the range between $\bar{S}_m \pm \sigma_m$, its pixel is defined by PP and PS.

When the references of three bands (Red: V5, Green: V3 and Blue: V2; see Table 2) were used, PP and PS could successfully be extracted, while the white pebbles were misdetected (red ellipse in Fig. 10(b)). This causes that the hyperspectral reflectance curve of the white pebbles is similar to that of PP (Fig. 10). When the references of all eight bands (Table 2) were used, we can successfully be extracted PP and PS without the misdetection of pebbles. Therefore, we can effectively extract the pixels of the target objects by using the references of eight bands, even if the color of target objects is similar to that of the other materials.

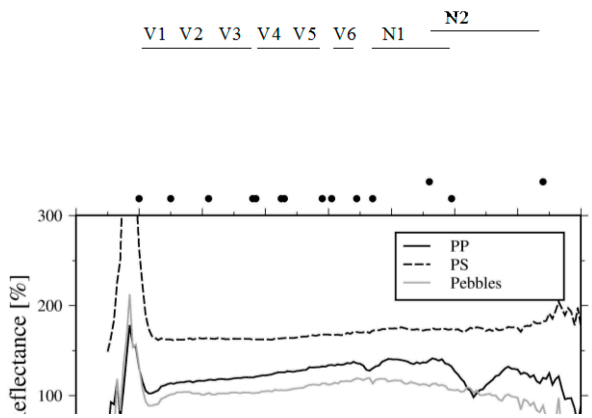

Fig. 11 Hyperspectral reflectance curves of PP, PS and Pebbles. The legend is shown in the right-upper box. The 8-bands of WV-2 is shown in the top of the figure. Note that the symbol is shown in Table 2.

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

We have the following suggestions for taking aerial photographs from aircrafts to improve the accuracy of percent cover estimates. Firstly, the camera should be fixed on the aircraft (not held by hands). Secondly, aerial photographs should be taken from the aircraft normally to the ground to the degree possible. In this study, aerial photographs were geometrically corrected based on the reference points using the Google Earth. Unfortunately, we missed the percent covers from the eight aerial photographs on the Cheewat Beach because we were unable to determine the five reference points (see section c.2). If the camera was fixed and its direction was normal to the ground, we would be able to remove the geometric distortion more precisely.

Due to the budget decrease, the analyses of the multispectral images cannot be financially supported in Year 3 of the project.

e. Completed and planned publications

We are now preparing the manuscripts with respect to the two presentations listed below (see **f**).

f. 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, January 19–21, 2016, Honolulu, USA (oral presentation).

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, March 15, 2016, Tokyo, Japan (oral presentation in Japanese).

g. Education and outreach

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

4. PROGRESS STATUS

In Year 1, a webcam was installed on a beach at Newport (Oregon, USA) and continues to be maintained. All photos taken by the camera are now opened publicly at http://mepl1.riam.kyushu-u.ac.jp/home/works/gomi/webcam.html. In Year 2, research was focused on the critical factors that determine the temporal variation of beach litter at the webcam site (and hence, US and Canadian coasts). The analysed images indicate that the temporal dynamics of debris on coastal beaches is strongly related to onshore winds and coastal upwelling. An effective way was developed to apply the projective transformation method to the aerial photographs. This approach enables to successfully remove the geometric distortion and quantify percent covers in the aerial photographs in the broad area. In Year 3 (final year of the project), we will attempt to estimate the total tsunami debris that has been washed ashore on the western coast of North America by combining webcam monitoring, aerial photography, and numerical tsunami debris modeling.