Marine Pollution Bulletin xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

# Sequential webcam monitoring and modeling of marine debris abundance☆

Shin'ichiro Kako[a,*], Atsuhiko Isobe[b], Tomoya Kataoka[c], Kei Yufu[b], Shuto Sugizono[d], Charlie Plybon[e], Thomas A. Murphy[f]

[a] *Graduate School of Science and Engineering, Department of Ocean Civil Engineering, Kagoshima University, Kagoshima, Japan*
[b] *Research Institute for Applied Mechanics, Kyushu University, Fukuoka, Japan*
[c] *Tokyo University of Science, Noda, Japan*
[d] *Faculty of Engineering, Department of Ocean Civil Engineering, Kagoshima University, Kagoshima, Japan*
[e] *Surfrider Foundation Oregon region, Oregon, USA*
[f] *Department of Fisheries and Wildlife, Oregon State University, Oregon, USA*

ARTICLE INFO

*Keywords:*
Webcam monitoring
Japanese tsunami debris
Coastal upwelling/downwelling
Wind setup
Surf zone model

ABSTRACT

The amount of marine debris washed ashore on a beach in Newport, Oregon, USA was observed automatically and sequentially using a webcam system. To investigate potential causes of the temporal variability of marine debris abundance, its time series was compared with those of satellite-derived wind speeds and sea surface height off the Oregon coast. Shoreward flow induced by downwelling-favorable southerly winds increases marine debris washed ashore on the beach in winter. We also found that local sea-level rise caused by westerly winds, especially at spring tide, moved the high-tide line toward the land, so that marine debris littered on the beach was likely to re-drift into the ocean. Seasonal and sub-monthly fluctuations of debris abundance were well reproduced using a simple numerical model driven by satellite-derived wind data, with significant correlation at 95% confidence level.

## 1. Introduction

Marine debris from various sources and activities such as agriculture, fisheries, tourism, and industry—as well as illegal dumping and accidental losses from vessels—has pervaded marine ecosystems in the global ocean (e.g., Jambeck et al., 2015). Most marine debris is carried by both ocean surface currents and winds from domestic and overseas sources over long distances (hence long periods), and is then washed ashore on beaches (Gall and Thompson, 2015). Many studies (e.g., Gregory and Ryan, 1997; Derraik, 2002; Nakashima et al., 2012) have indicated that plastics account for ~70% of all marine debris washed ashore on beaches.

The large amount of debris drifting in the ocean constitutes a grave threat to marine life and ecosystems through ingestion and entanglement (Gall and Thompson, 2015), as well as through transport of hydrophobic persistent organic pollutants that adsorb onto plastic marine debris from seawater (Mato et al., 2001). Marine debris washed ashore on beaches also has impacts on coastal intertidal and/or supralittoral environments through invasive species attached to debris surfaces (Barnes, 2002), and carries a potential risk of harmful substances such as toxic metals leaching from the debris (Derraik, 2002; Nakashima et al., 2012). In addition to the aforementioned environmental risks, it has been recognized that marine debris diminishes the tourism value of beaches because of an aesthetically offensive form of pollution (Kako et al., 2010a, 2010b, 2011a, and Nakashima et al., 2011).

Despite the above concerns with marine debris, it remains difficult to hindcast and/or forecast the abundance of such debris washed ashore on beaches to determine the most effective frequencies of beach survey and/or beach cleanup activities. Marine debris abundance on a beach is a function of three fundamental and interrelated components, i.e., the concentration of debris in nearby waters, deposition on the beach, and re-drifting from the beach. Thus, the beach can be both a sink and a source of marine debris, regardless of season. Recent advances in atmosphere/ocean general circulation models and reanalysis products have provided reliable modeled winds and ocean currents, which are capable of supporting particle-tracking numerical models (e.g., Isobe et al., 2009; Kako et al., 2010a, 2011a, 2014) that reproduce marine debris behavior in the oceans. Nonetheless, unresolved in these models are complex debris motions in surf zones forced by tides, coastal currents, waves and winds, and local topography. In addition, it is difficult to reproduce exchange processes (i.e., washing ashore and re-drifting) of marine debris between surf zones and beaches. Therefore, particle-

---

☆ This is one of the papers from the special issue of Marine Pollution Bulletin on “The effect of marine debris caused by the Great Tsunami of 2011.” The special issue was supported by funding provided by the Ministry of the Environment of Japan (MOE) through the North Pacific Marine Science Organization (PICES).

* Corresponding author at: Department of Ocean Civil Engineering, Kagoshima University, 1-21-40 Korimoto, Kagoshima 890-0065, Japan.
*E-mail address:* kako@oce.kagoshima-u.ac.jp (S. Kako).

https://doi.org/10.1016/j.marpolbul.2018.04.075
Received 26 January 2017; Received in revised form 19 April 2018; Accepted 30 April 2018

Please cite this article as: Kako, S., Marine Pollution Bulletin (2018), https://doi.org/10.1016/j.marpolbul.2018.04.075

tracking models are unlikely to reliably reproduce marine debris on beaches unless the above nearshore processes are incorporated appropriately.

A straightforward way to reproduce the nearshore processes is to establish a surf zone model that can be incorporated into particle-tracking models, which is the objective of the present study. The model is specialized to reproduce washing-ashore and re-drifting processes associated with atmospheric and oceanic conditions such as winds, waves and ocean currents, as well as the offshore abundance of marine debris. Therefore, it is necessary to identify the fundamental and interrelated components mentioned above (hereafter, “critical factors”) to reliably determine variability in marine debris abundance on beaches.

A number of methods have been developed to quantify debris abundance on shorelines (e.g., Kako et al., 2010b, 2012; Kataoka et al., 2012; Veenstra and Churnside, 2012). Aerial photography using small aircraft is useful to search and document long stretches of inaccessible coastlines to estimate the relative abundance of debris (Veenstra and Churnside, 2012). However, aerial photography provides only snapshots of beaches, although it can cover extensive remote areas quickly and relatively easily. To establish the surf-zone model, we used marine-debris monitoring with a webcam, which takes beach photographs once per hour. As with aerial photography, conventional beach surveys (e.g., once per month) are insufficient for capturing the temporal variability of debris abundance resulting from atmospheric and oceanic processes with typical timescales shorter than fortnightly spring/neap tidal cycles and/or sub-weekly passages of extratropical cyclones (Kako et al., 2011a). Our previous studies (Kako et al., 2010b; Kako et al., 2012, and Kataoka et al., 2012) demonstrated that the area covered by marine debris and its temporal variation can be computed from webcam photographs via the image processing methods proposed in those studies. The sequential (once every 60–90 min) webcam monitoring system established in these previous studies are capable of capturing the variation of marine debris abundance on time scales shorter than a month. Thus, webcam monitoring is likely more suitable for resolving temporal variations of marine debris abundance than in-situ visual and manual beach surveys.

The webcam monitoring was conducted on a beach along the western coast of the United Sates to monitor marine debris related to the Great Tohoku Earthquake, which triggered a massive tsunami on March 11, 2011. According to estimates 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 away from Japan into the North Pacific. Part of this JTMD (estimated at 1.5 million tons) remained afloat and is still drifting in the North Pacific. Thus, there is a concern for this debris reaching the North American and Hawaiian coasts. In particular, attention is given to coastal Japanese species carried by the JTMD. In fact, the National Oceanic and Atmospheric Administration reported that “in the case of a dock, it carried a biofouling community that included over 90 marine species that were not native to the West Coast of North America” (https://marinedebris.noaa.gov/sites/default/files/Japan_Tsunami_Marine_Debris_Report.pdf). Thus, these species have the potential to damage the indigenous marine ecosystem along beaches of North America and the Pacific islands (Murray et al., 2015).

Nevertheless, there have been no published studies investigating temporal variations of marine debris abundance on beaches along the western U.S. and Canadian coasts over a period longer than 1 year (including seasonality) and with monitoring intervals shorter than a week. Consequently, there is no way of knowing the critical factors governing temporal variations of debris abundance on these beaches. In the present study, using a dataset of marine-debris abundance monitored by the webcam system, we establish a simple but reliable surf zone model based on the critical factors to hindcast the temporal variation of debris abundance on the western U.S. and Canadian coasts.

## 2. Material and methods

### 2.1. Webcam

We installed a webcam on a beach in Newport, Oregon, USA (Fig. 1), because it directly faces the North Pacific and is free from complex topography, and because it has easy access for installing/maintaining the webcam. In addition, community residents told us that substantial marine debris washes ashore on the beach. The webcam was set up to sequentially and automatically take photographs of a part of the beach on which marine debris was littered, including driftwood and anthropogenic debris (possibly including JTMD). Beach photographs were taken every 60 min during daytime (10 times from 9:00 AM to 6:00 PM Pacific Standard Time in the USA) from April 3, 2015 to March 31, 2016 (this webcam observation ended in April 2017). The area, approximately 60 m × 70 m in the alongshore and offshore directions, respectively, was photographed within the entire panorama by the webcam with a fixed angle. An accurate angle was not required because we counted debris number visually. In addition, the camera angle was not required, even if we computed an accurate area covered by marine debris via image processing such as projection transformation. This is because reference positions are given on each photograph for georeferencing (Magome et al., 2007; Kako et al., 2012). These photographs were transmitted to our web server via the Internet. Actual JTMD was difficult to identify from the photographs, unless the debris source was suggested by Japanese characters printed on the debris surface and those characters were sufficiently large to be identified on the photographs.

It was found that a substantial amount of marine debris (mostly driftwood and lumber) was washed ashore on the beach over a 1-year period from the start of monitoring (Fig. 2a shows an example of photographs taken by the webcam). Nonetheless, anthropogenic debris such as plastic was difficult to identify on the photographs. It was also difficult to distinguish lumber from natural driftwood. However, nearshore processes determine the motion of drifting objects, regardless of whether they are artificial. Thus, marine debris monitored by the webcam was analyzed without discrimination between natural and anthropogenic debris, to elucidate critical factors governing the temporal variation of debris abundance on the beach.

The abundance of marine debris was evaluated by counting their number ($N$) on the beach photographs by visual observation. The camera angle (hence, the entire beach area covered by the webcam) was fixed over the survey period, so number per unit area was obtained by $N/(60\,\mathrm{m} \times 70\,\mathrm{m})$. Likewise, $N/100\,\mathrm{m}$ (frequently used in marine debris surveys; e.g., Ryan et al., 2009) is computed as $N \times 100/70$. It is indeed reasonable to compute the difference in brightness and colors of pixels to extract marine debris from the background beach (Kako et al., 2010b; Kako et al., 2012; Kataoka et al., 2012; Nakashima et al., 2012). However, these methods were not available for the present study, because there was little difference in both brightness and color between the sandy beach and driftwood/lumber (Fig. 2a).

First, an observer selected a single photograph from all 10 photographs taken on each day. The photograph was selected to identify marine debris to the extent possible during daytime. Thus, photographs at ebb tide (i.e., the broadest beach area) were likely to be selected, whereas those during foggy and/or rainy periods were removed. Thereafter, the observer identified the marine debris, irrespective of its size, as shown by red circles in Fig. 2b. This is because the motion (trajectory) of a floating object is determined only by the ratio between projected areas above and below the sea surface in conjunction with the speeds of ambient ocean currents and winds (rather than by object size). If small objects were difficult to distinguish from shadows of surface irregularity on the beach, the remaining nine photographs at various times (different incident angles of sunlight) were used for the