Marine Pollution Bulletin 81 (2014) 174–184

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

A decadal prediction of the quantity of plastic marine debris littered on beaches of the East Asian marginal seas

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ARTICLE INFO

Keywords:
Plastic beach litter
Decadal numerical prediction
Particle tracking model
Inverse method
Web camera
East Asian marginal seas

ABSTRACT

Large quantities of plastic litter are expected to wash ashore along the beaches of the East Asian marginal seas in the coming decade. Litter quantities were predicted using three techniques: a particle tracking model (PTM) used in conjunction with two-way PTM experiments designed to reveal litter sources, an inverse method used to compute litter outflows at each source, and a sequential monitoring system designed to monitor existing beach litter using webcams. Modeled year-to-year variation in litter quantities indicated that the amount of litter would continue to increase in the East Asian marginal seas if the level of outflow remains constant in the coming decade. The study confirms that about 3% of all East Asian beaches may potentially experience a 250-fold increase in the amount of plastic beach litter washed ashore in the next 10 years.

1. Introduction

1.1. Plastic debris

Beach litter (i.e., marine litter, marine debris) along the world's coasts originates from many sources, and creates a serious and worsening environmental problem (Kako et al., 2010a). Beach litter threatens marine life when animals ingest it or become entangled in drift nets (Derraik, 2002); it also creates an eyesore that has detrimental effects on tourism. Many previous studies have investigated quantities, materials, and types of beach litter washing onto shore, based mostly on monthly or longer than monthly *in situ* beach surveys (Madzena and Lasiak, 1997; Ribic, 1998; Velander and Mocogni, 1998; Whiting, 1998; Stefatos et al., 1999; Williams and Tudor, 2001; Aliani et al., 2003; Bravo et al., 2003; Otley and Ingham, 2003; Edyvane et al., 2004; Kako et al., 2010a). Even with a variety of methods being used, all of these studies clearly indicate that plastic beach litter usually comprises between 60% and 80% of total beach litter. In addition to the above-mentioned *in situ* beach surveys, Kako et al. (2010b) and Kataoka et al. (2012) set up a beach litter monitoring system using webcams to capture sequential photographs every 90 or 120 min. These observations confirm the findings of previous studies worldwide showing that a large quantity of such litter is washed ashore on beaches, even on remote islands such as the Japanese islands of Goto and Tobishima.

1.2. Potential risk of toxic metals leaching from plastic litter into beach environments

Recently, Aston et al. (2010) and Holmes et al. (2012) detected relatively high concentrations of toxic metals on the surfaces of plastic litter on beaches, suggesting that metals from the seawater accumulate in the litter. In addition, toxic metals are often used as additive agents functioning as catalysts, pigments and plastic stabilizers in the production of plastic containers and other commonly discarded material. For example, lead stearate ($Pb(C_{18}H_{35}O_2)_2$) enhances the smoothness and stability of plastic products made from polyvinyl chloride (PVC) polymers. Specifically, the durable and lightweight nature of plastic marine debris causes it to act as a vector carrying toxic metals and allows the debris to float over long distances (Nakashima et al., 2012).

Toxic metals may leach from plastic litter into beach environments; however, this topic has received little attention despite the threats that these toxins pose to coastal ecosystems. However, Nakashima et al. (2012) recently evaluated the environmental risk to beaches posed by toxic metals derived from fishery floats made from PVC (hereafter referred to as PVC floats as defined by Nakashima et al. (2012)); they computed both the annual leaching flux

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http://dx.doi.org/10.1016/j.marpolbul.2014.01.057
0025-326X/

($0.1–1.0 \times 10^{-3}$ g/kg/year) and the resultant concentration of Pb in beach soil. Their analysis demonstrated that even when the worst estimate using a closed "box model" for the computation is used, the concentration of Pb in the beach soil caused by a single piece of PVC debris washing ashore repeatedly will not exceed the standards (250×10^{-3} g/kg) of the US Environmental Protection Agency (EPA) within the next 250 years. Therefore, they concluded that Pb leaching from PVC plastic litter is not an immediate risk to the beach environment. However, the authors assumed that the quantities of plastic litter reaching beaches will remain stable, and these quantities will probably increase even if litter outflows at various sources remain unchanged.

Importantly, floating plastic marine debris will never completely disappear from the environment because of its durability, although macro-plastic debris may gradually be changed to meso-, micro-, or nano-plastics as a result of various degradation processes (e.g., Barnes et al. (2009)). As long as humans continue to produce plastics, the volume of plastic marine debris (and plastic litter on beaches) will continue to increase in the environment.

The present study analyzed conditions along the shores of the East Asian marginal seas (Yellow Sea, East China Sea, and Japan Sea), which are surrounded by countries that continue to see rapid economic expansion and generate large amounts of plastic debris. The inflow of the plastic debris will continue to exceed the outflow from these semi-enclosed oceans, creating a particular concern; the quantities of litter drifting in these "cul-de-sac" oceans, and consequently, plastic litter washed ashore on surrounding beaches, is expected to increase each year even if outflow from the beach-litter sources is maintained at current levels. As a result, toxic metals leaching from plastic litter may create an environmental risk on beaches even in the near future.

At present, knowing exactly when the potential risk of toxic metals leaching from beach litter will be realized in the beach environment is impossible. The objective of this study is to provide a short-term prediction of the quantities of plastic litter expected to wash ashore in the region using recently developed state-of-the-art beach-litter research techniques. By combining an inverse method technique (Kako et al., 2010a), a two-way particle tracking numerical model (PTM; Isobe et al., 2009), and webcam observations (Kataoka et al., 2012), we aim to make a plausible estimate of the timing and quantities of beach litter expected to wash ashore.

The calculations used to estimate the outflows of plastic litter from various sources assume that those outflows will remain constant because an analysis of the long-term variation of litter outflows at each source is beyond the scope of the present study. Rather, this issue should be addressed from an economic and/or social science viewpoint. Accordingly, the estimate provided here is likely to be overly optimistic because actual litter outflows can be expected to increase as East Asian countries continue to experience economic growth.

2. Methods

2.1. Webcams

Quantities of current beach litter should be monitored precisely if we are to accurately predict the expected future risks derived from the presence of plastic litter. In the present study, a PTM was used to predict the quantity of beach litter (hereafter, litter prediction) on various beaches around the East Asian marginal seas. However, prior to the PTM experiment, we determined the locations of both litter sources and outflows at each source using an inverse method with a Lagrange multiplier (Kako et al., 2010a), which requires data on the current and actual quantities of beach litter (see Section 2.2 or Kako et al., 2010a).

Webcams provide a novel technique used to measure quantities of beach litter. Kako et al. (2010b) and Kataoka et al. (2012) established a sequential webcam monitoring system; they demonstrated that webcam monitoring is more suitable for resolving the temporal variation of beach-litter quantities than *in situ* beach surveys conducted by hand; estimates of the latter may be confounded because of fluctuations shorter than the sampling intervals used in the surveys. In the present study, we used four webcams with one webcam placed on beaches in the cities of Wakkanai and Wajima, as well as on the islands of Tobishima and Tsushima (Fig. 1) around the East Asian marginal seas (Kataoka et al.,

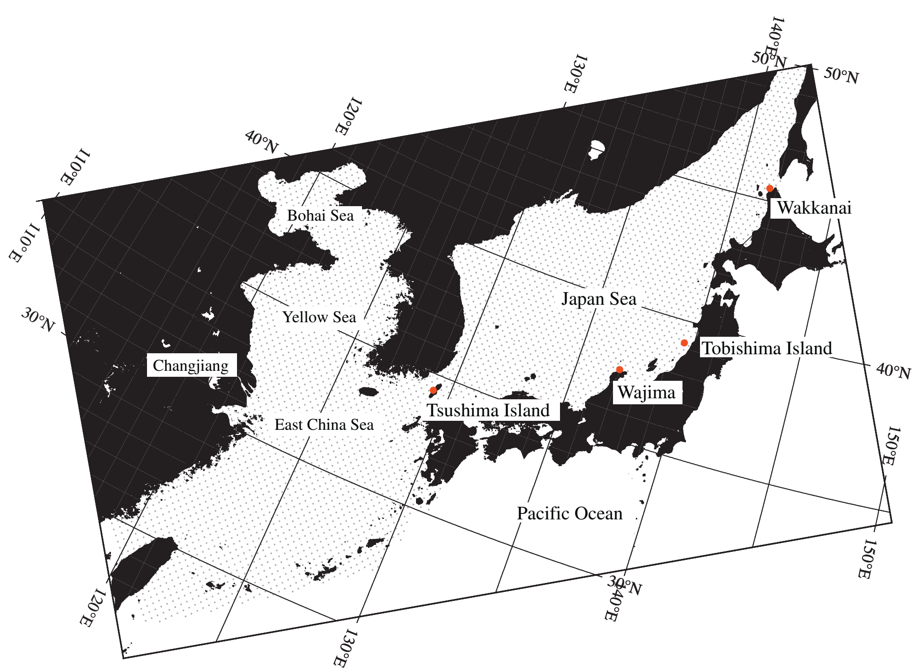

Fig. 1. Locations of the webcams (red circles) and the model basin (stippled) in the PTM experiments. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)