Marine Pollution Bulletin 69 (2013) 128–136

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

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

A simple technique for counting marine debris at sea reveals steep litter gradients between the Straits of Malacca and the Bay of Bengal

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ARTICLE INFO

Keywords:
Marine debris
Survey
Detection range
Distance sampling
Plastic
Debris size

ABSTRACT

A size and distance-based technique was used to assess the distribution, abundance and composition of floating marine debris in the northeast Indian Ocean. Densities of floating litter (>1 cm) were greater and more variable in the Straits of Malacca (578 ± 219 items km^{-2}) than in oceanic waters of the Bay of Bengal (8.8 ± 1.4 items km^{-2}). The density of debris in the Straits was correlated with terrestrial vegetation, and peaked close to urban centres, indicating the predominance of land-based sources. In the Bay of Bengal, debris density increased north of 17°N mainly due to small fragments probably carried in run-off from the Ganges Delta. The low densities in the Bay of Bengal relative to model predictions may result from biofouling-induced sinking and wind-driven export of debris items. Standardised data collection protocols are needed for counts of floating debris, particularly as regards the size classes used, to facilitate comparisons among studies.

1. Introduction

Despite increasing concerns about the environmental impacts of plastics on the environment, especially in marine systems (e.g. Thompson et al., 2009; Gregory, 2009; Teuten et al., 2009), surprisingly little is known about the abundance and distribution of floating plastic debris at sea (Ryan et al., 2009). Our understanding of spatial and temporal patterns in the abundance of marine debris has been inferred mainly from surveys of stranded litter, or from the frequency of interactions with wildlife (see Barnes et al., 2009; Ryan et al., 2009 for reviews). Most at sea surveys of floating litter sample small debris items using fine-meshed nets, often linked to plankton surveys (e.g. Colton et al., 1974; Gregory et al., 1984; Ryan, 1988; Day et al., 1990; Shaw and Day, 1994; Moore et al., 2001; Yamashita and Tanimura, 2007; Zhou et al., 2011). Such surveys typically require dedicated ships' time, making them costly, and sample small areas, making it difficult to obtain sufficiently large samples to average out the inherently patchy distribution of floating litter (Ryan et al., 2009). Aerial surveys (e.g. Ryan, 1988; Lecke-Mitchell and Mullin, 1997; Pichel et al., 2007) can sample large areas rapidly, but only provide information on large litter items and it is hard to estimate the proportion of items detected. Remote sensing might be useful to assess the distribution of litter at sea (Mace, 2012; Veenstra and Churnside, 2012), but such studies are in their infancy and are unlikely to yield information on litter composition.

Studies that count debris items from ships at sea (e.g. Venrick et al., 1973; Morris, 1980; Day and Shaw, 1987; Mio et al., 1990; Matsumura and Nasu, 1997; Aliani et al., 2003; Thiel et al., 2003; Hinojosa and Thiel, 2009; Titmus and Hyrenbach, 2011) bridge the gap between net surveys and aerial counts or remote sensing. They can sample substantial areas, count smaller items than are visible from the air, and are able to exploit ships of opportunity. However, most studies have been hampered by biases resulting from differences in the detectability of litter items linked to the size and type of litter, and assumptions (often untested) about effective transect width. Other factors that might influence detection of floating marine debris from ships or boats include sea state, light conditions, observer height above the water and observer experience (Dahlberg and Day, 1985; Ryan et al., 2009). Some of these problems can be overcome by using distance-based sampling, which allows detection functions to be estimated for different conditions (Mio et al., 1990; Matsumura and Nasu, 1997; Thiel et al., 2003). However, it is difficult to record the distance to each litter item accurately, especially at even moderate litter densities, and few studies have considered the effect of litter size, type or colour on detection probabilities (Dahlberg and Day, 1985; McCoy, 1988; Mio et al., 1990; Titmus and Hyrenbach, 2011). Most studies simply assume that all floating debris within a fixed distance of the ship is detected, but with transect widths ranging from 10 m (Morris, 1980; Thiel et al., 2003) to 100 m (Shiomoto and Kameda, 2005) the extent to which this assumption is violated is bound to vary among studies.

Such differences in count techniques greatly compromise the value of comparisons of density estimates derived by different

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0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.01.016

studies. Differences in the minimum size of litter items counted are especially problematic, given the much greater abundance of small litter items than large litter items (e.g. Titmus and Hyrenbach, 2011; Zhou et al., 2011). Some surveys of floating debris exclude items smaller than 5 cm (e.g. Mio et al., 1990; Matsumura and Nasu, 1997; Shiomoto and Kameda, 2005) or even 10 cm (Barnes and Milner, 2005), whereas other surveys count items as small as 1.5–2 cm across (e.g. Morris, 1980; Thiel et al., 2003; Hinojosa and Thiel, 2009; Titmus and Hyrenbach, 2011). This difference has major implications for the resultant estimates of debris density, which typically are expressed as the number of items per km^2, irrespective of item size. Future direct counts of floating marine debris should standardize data collection protocols so that estimates of litter densities can be compared among studies, thus improving our understanding of spatial and temporal changes in the abundance of marine debris.

In this paper I use a simple size and distance-based sampling protocol to estimate the density of marine debris at sea through direct observations. The technique was used to assess the distribution, abundance and composition of marine debris from a vessel that made an out and back survey through the Straits of Malacca into oceanic waters in the Bay of Bengal. There are no published estimates of the densities of floating marine debris in these waters. Neither area is a 'sink' where drifting debris accumulates over very long periods (Maximenko et al., 2012; van Sebille et al., 2012), but the Straits of Malacca are one of the busiest shipping lanes on Earth, and the Bay of Bengal has high coastal population densities coupled with large urban run-off (Lebreton et al., 2012). As a result, this region is expected to have high concentrations of floating marine debris, comparable with accumulation zones in the mid-ocean gyres (Lebreton et al., 2012).

2. Materials and methods

Floating marine debris was counted during a research cruise aboard the R.V. *Marion Dufresne* from 24 May to 15 June 2012. The ship travelled from Singapore through the Straits of Malacca to the central Bay of Bengal, where a series of coring stations was conducted in international waters, then returned to Singapore via the Straits of Malacca (Fig. 1). Observations were conducted throughout daylight hours while the ship was underway, and were made from the bridge wing or from the deck above the bridge, 10–13 m above sea level and 57 m from the ship's bow. Only debris on one side of the bow was counted. In addition, scans of the waters in a 330° arc around the vessel were made from the ship's helideck (elevation 8 m) every 30 min while on station (cf. Aliani et al., 2003). Litter was mostly detected with the naked eye, but regular scans of waters away from the ship were made with 10×32 binoculars to detect more distant debris. Binoculars or images taken with a digital SLR camera with a 500 mm telephoto lens were used to identify litter items, but some submerged items could not be identified.

Observations were recorded continuously in 10-min bins for up to 12 h, with location and environmental parameters (wind speed, direction, sea surface temperature, salinity) recorded from the ship's data logger at the start and end of each hour. The ship's position also was recorded whenever a course-change occurred, and the track length calculated to measure the distance covered during observations. To compensate for the patchy nature of floating debris at sea, data were pooled into transects of roughly 50 km, which sample 2.5 km^2 of sea surface given an effective transect width of 50 m. Inspection of the crude density data suggested that this was sufficient to average out small-scale heterogeneity in the distribution of floating debris created by local convergence features. The duration of each transect block varied with the ship's speed, linked to sea state and other activities on the vessel, and typically lasted 2–3 h. Scans while on station gave a semi-quantitative index of litter abundance from the number of litter items observed per scan (cf. McCoy, 1988; Aliani et al., 2003). Most litter items were individually distinct, and it was easy to exclude the few items that were counted in successive scans.

In most areas I estimated the size of items and their distance from the side of the ship, but this was impractical in parts of the Straits of Malacca where there were very high densities of debris (e.g. Fig. 2), so in these areas I simply estimated the numbers of

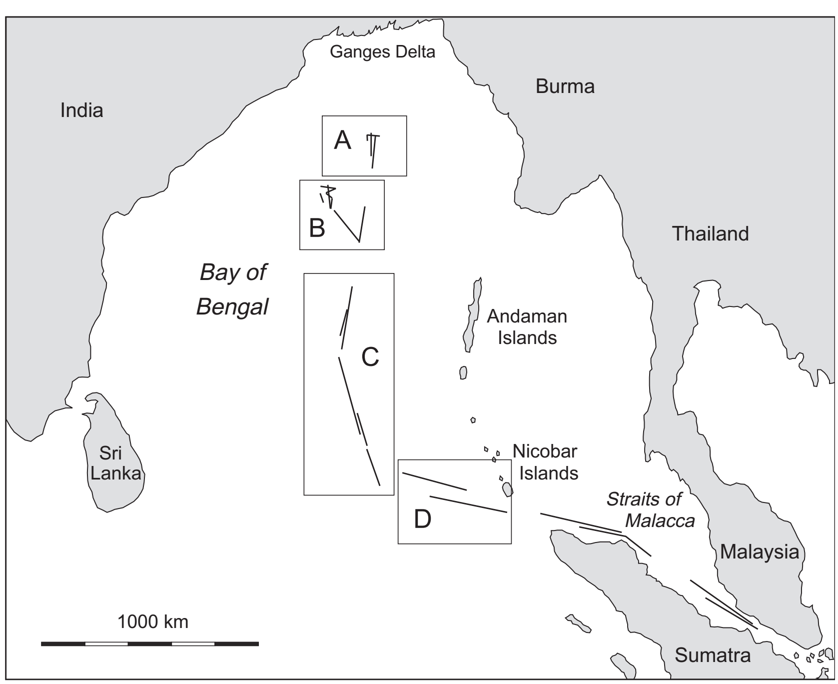

Fig. 1. Map of the northeast Indian Ocean showing the location of transects in the Straits of Malacca and four regions within the Bay of Bengal (A–D).