Estuarine, Coastal and Shelf Science 181 (2016) 231–237

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Beach litter occurrence in sandy littorals: The potential role of urban areas, rivers and beach users in central Italy

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ARTICLE INFO

Article history:
Received 12 January 2016
Received in revised form
18 May 2016
Accepted 29 August 2016
Available online 31 August 2016

Keywords:
Marine litter
Plastics
Central Italy
Litter sampling
Spatial scale
Coastal zone

ABSTRACT

Litter washed ashore on the coastline, also called beach litter, constitutes one of the most obvious signs of marine litter pollution. Surveys of beach litter represent a fundamental tool for monitoring pollution in the marine environment and have been used world-wide to classify and quantify marine litter. Identifying the sources of marine and beach litter is, together with education, the prime weapon in combating this type of pollution. This work investigates the impact of three main potential land sources on litter occurrence: urban areas, rivers and beach users. Three sources were analyzed simultaneously on a broad scale (Lazio region, central Italy) using a random sampling design and fitting a generalized linear mixed-effect model. The results show that urban areas are the main drivers for the occurrence of marine litter along central Italy's coastal ecosystems, suggesting that the presence of such litter on Lazio beaches could be effectively reduced by identifying failings in recycling and waste collection procedures and by improving waste processing systems and sewage treatment in urban areas.

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1. Introduction

Since the influential work of Carpenter and Smith (1972) who predicted the increase in the amount of plastic on the sea surface, marine and beach litter has become an environmental threat on a global scale (Andrady, 2003; Barnes et al., 2009; European Commission, 2011; United Nations Environmental Programme, 2011). In 2008, together with other environmental disturbances, marine litter was included in the Marine Strategy Framework Directive ("2008/56/EC MSFD; EEC, 2008) as one of the descriptors for European marine waters' environmental status.

Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment" (CBD Technical Series, 2012) and "ubiquitous in all marine compartments ranging from the pelagic and benthic zones to intertidal regions and beaches" (Schulz and Matthies, 2014). Litter washed ashore on the coastline is called beach litter and is one of the most obvious signs of marine litter pollution (Cheshire et al., 2009).

Beaches are dynamic systems where litter can be washed ashore by the sea, dumped by beach users, buried and exhumed, exported inland, offshore or along-shore by wind, wave or tidal action or removed by formal or informal beach cleaning (Williams and Tudor, 2001; Araùjo and Costa, 2007; Ryan et al., 2009). Surveys of beach litter, aimed to classify and quantify litter, represent a fundamental tool for monitoring the load of litter in the marine environment (Gago et al., 2014). There are numerous methods used to sample beach litter and they can depend on the objectives of the study: some methods sample only the tidal or fresh litter areas, others sample the accumulation litter only, while still others sample both (Velander and Mocogni, 1999). They can be also useful to identify the causes or the sources leading to litter accumulation, to measure the effectiveness of management or mitigation measures, and to identify threats to marine biota and ecosystems (Martinez-Ribes et al., 2007; Cheshire et al., 2009). Determining the type, the distribution timeline and, most of all, the origin of litter on beaches are key factors for developing strategies aimed at minimizing the presence of marine litter (Araùjo et al., 2011). Therefore, identifying the sources of marine litter is, together with education,

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http://dx.doi.org/10.1016/j.ecss.2016.08.041
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a prime weapon in fighting this type of pollution. Measures to address and subsequently prevent the problem can be taken only if a source is identified, and those perpetrating the pollution can be targeted (Williams et al., 2003).

Despite the importance of finding sources of litter, most scientific articles on this issue mostly concern the abundance, distribution and composition of marine litter or its impact on animal species (e.g. Oliveira et al., 2015). Different studies have suggested that abiotic or biotic drivers such as vegetation structure, wind, wave-action, tide and density of plastic materials have a role in influencing spatial patterns of accumulation on beaches or in the open ocean (Browne et al., 2010; Poeta et al., 2014). However, only a restricted number of studies have considered the possible sources of litter or developed methods to identify it (Tudor and Williams, 2002; Williams et al., 2003); in most cases such studies were carried out at local scale considering only a single possible source (Araùjo and Costa, 2007). Moreover, it should be noted that results of fine scale studies may be misleading if extended to a wider region: for example Laglbauer et al. (2014) found that the amounts and types of debris appear to differ along the 46.7 km of Slovenian coast, suggesting that human populations may have distinct impacts in each beach location; in Australia, Jones (1995) found that comparisons of sources were difficult, and provided examples from O'Callaghan (1993) showing that the bulk of beach litter came from cities, and from Wace (1994) who demonstrated that fishing was a major source of debris on an isolated beach.

Nevertheless, previous studies confirmed that marine litter mainly originates from land-based sources (Jung et al., 2010; MSFD GES Technical Subgroup on Marine Litter, 2011; Topçu et al., 2013) and that sources are principally rivers (Williams and Simmons, 1997; Araùjo and Costa, 2007; Neto and da Fonseca, 2011), urban areas (Garrity and Levings, 1993; Willoughby et al., 1997) and beach users (Gabrielides et al., 1991; Frost and Cullen, 1997).

On this basis, this study aims to understand the role of urban areas, rivers and beach users as potential sources of beach litter on a broad scale, considering these three different potential sources simultaneously and to analyze how distance from urban areas, rivers and beach users could influence the presence of beach litter by using a detailed spatial analyses approach in a wide coastal area of central Italy.

2. Materials and methods

2.1. Study area

The study was carried out on the Tyrrhenian coast of Central Italy. The surveyed area includes five study sites (for a total length of 21 km) along the coast of the Lazio region (350 km, Fig. 1); these five sites represent most of this region's remaining contiguous and best conserved dune systems. All beaches of the study area shared the same characteristics: South/South-west orientation, Mediterranean climate, relatively simple and low (<10 m) dunes (upper beaches ranging from a few meters to around 40 m, followed by a section of low embryo-dunes, generally only one mobile dune ridge, and lastly a stabilized dune zone) (Acosta et al., 2003; Carboni et al., 2011) and the presence of tourist activity during the bathing season; all five sites studied are characterized by cleaning activities which are carried out before the beginning of the bathing season (end of May).

2.2. Litter sampling

The choice of method for monitoring beach litter may depend on many factors (Velander and Mocogni, 1999). In order to study how distance from different sources could influence the presence of beach litter a fast sampling approach considering only the occurrence of different litter items (presence-absence) was applied. Indeed, to account uniquely for the influence of the three major sources in such a wide coastal area of central Italy (five different sites along 350 km of coast) it was particularly relevant to sample in a relatively short time period in order to ensure similar environmental conditions.

To this purpose, georeferenced random points distributed in the study area were generated in GIS environment within the sandy dunal strip. With the help of a high precision GPS the georeferenced random points were visited and at each point the litter occurrence was recorded within a 2 m × 2 m (4 m^2) plot, without digging or removing sand or plants; the sampling design did not include litter removing. Although results may be very variable depending on the amount of litter, this method is not influenced by location or distribution of litter and represents a statistical valid and fast sampling approach (Velander and Mocogni, 1999). The classification of litter followed the guidelines proposed by the MSFD Technical Subgroup on Marine Litter (Galgani et al., 2013). Sampling was carried out before the start of the clean-up actions and in a single week between April and May 2012 by the same individual to avoid bias of detectability. A total of 153 plots were sampled allocated according to each site's length (A = 32 plots, B = 10 plots, C = 35 plots, D = 43 plots, E = 33 plots).

2.3. Potential sources of marine litter

For each random plot the distances to the main land-based sources were calculated, which according to literature are affecting the presence of beach litter at broad scale: urban areas, rivers and beach users (Table 1, Figs. 1 and 2). Even though several processes may modify the beaching rate of litter and affect its spatial distribution along the sandy littorals (wind, waves, sea currents, etc.; Kako et al., 2010; Lippiatt et al., 2013; Isobe et al., 2014), the former 3 sources are acknowledged as the most important, with shorter distances to the potential source reasonably corresponding to a higher litter occurrence.

In order to estimate the impact of urban areas on beach litter occurrence, the shortest point to edge distance from urban areas (D_Urban) was calculated considering only those urban centers with more than 20,000 inhabitants (UNESCO/MAB, 1973). Data on urban areas were obtained from the Archives of National Institute of Statistics (http://www.istat.it/it/archivio/104317).

To quantify the impact of rivers as a potential source of beach litter, the distance of each plot from the nearest river mouth (D_River) was calculated and only the major river courses along the Lazio coast with an active watercourse during all the four seasons were selected. In the study area 5 rivers matched this criteria: Fiora, Marta, Tevere, Astura and Arrone. River data were obtained from National Archives of ISPRA, the technical Agency of the Italian Ministry of Environment (http://www.sinanet.isprambiente.it/it/sia-ispra/download-mais).

Finally, distances to artificial structures such as roads, local infrastructures or bathhouses were used as a proxy of the relationship between beach litter occurrence and beach users. Beach user contribution to beach litter is assumed to increase inversely to the distance to these man-made infrastructures, which normally facilitate beach access and therefore beach frequentation. Moreover, in this area of the Mediterranean Sea and due to the mild climate, beach users frequent coastal environments not only in summer but during the whole year, which makes this measure the only good approximation of beach frequentation. Indeed, in the study area roads run along the whole coastline with beach users stopping randomly. Therefore the shortest point to edge distance from the nearest land cover artificial areas (D_Artificial) was

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