Marine Pollution Bulletin 136 (2018) 435–447

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

# Abundance and distribution of beach litter along the Atlantico Department, Caribbean coast of Colombia

Nelson Rangel-Buitrago[a,b,*], Adriana Gracia C.[b], Anubis Vélez-Mendoza[b], Egna Mantilla-Barbosa[c], Victoria Andrea Arana[c,d], Jorge Trilleras[c,d], Harry Arroyo-Olarte[c]

[a] *Programa de Física, Facultad de Ciencias Básicas, Universidad del Atlántico, Puerto Colombia, Atlántico, Colombia*
[b] *Programa de Biología, Facultad de Ciencias Básicas, Universidad del Atlántico, Puerto Colombia, Atlántico, Colombia*
[c] *Programa de Maestría en Ciencias Ambientales, Facultad de Ciencias Básicas, Universidad del Atlántico, Puerto Colombia, Atlántico, Colombia*
[d] *Programa de Química, Facultad de Ciencias Básicas, Universidad del Atlántico, Puerto Colombia, Atlántico, Colombia*

ARTICLE INFO

*Keywords:*
Beach litter
Agglomerative Hierarchical Clustering (AHC)
Multidimensional Scaling (MDS)
Principal Components Analysis (PCA)
Atlantico
Colombia

ABSTRACT

A total of 5993 litter items divided into 13 categories were found at 25 beaches located along the Atlantico Department coastline, Caribbean of Colombia, with an average litter abundance of 7 items/m. Agglomerative Hierarchical Clustering (AHC), Multidimensional Scaling (MDS) and Principal Components Analysis (PCA) were applied with the objective of highlighting similarities and contrasts between litter categories and abundances. Results indicated two specific groups of beaches in terms of amounts of litter. The first group is composed of 17 "dirty beaches" (urban, resort and village) while the second group includes 8 "clean beaches" (village and resort). This division was confirmed by means of the EA/NALG (2000) grading system, which highlighted that 68% of beaches belonging to the Atlantico Department coastline are in an unacceptable condition of cleanness. Current patterns of litter abundance and accumulation are related to sources as well as beach characteristics such as degree of exposition and morphodynamic state.

## 1. Introduction

Beaches are unique areas of the planet Earth. They are defined as an accumulation of sediment, ranging in size (sand to boulders), formed by waves, tides and currents along a coastline (Woodroffe, 2002; Pilkey et al., 2011). From a geomorphologic and biological point of view, beaches are one of the most dynamic and changing geomorphologic features, serving as home to environments of extraordinary biodiversity, and they are also areas of significant importance due to their diversity of ecological functions (French, 1997).

Beaches are also strategic areas that provide multiple environmental services such as provision of raw materials, geochemical regulation (e.g., carbon sequestration), ecologic support (e.g., primary production), and cultural services (e.g., recreation).

From ancient times beaches have played a significant role as a place for human settlement (Barragan and Andreis, 2015; Rangel-Buitrago et al., 2017). However, during the last century, there has been overexploitation of these areas, leading to environmental degradation due to a large number of threats, one of them being: litter (Coe and Rogers, 1996; Bergmann et al., 2015; Tudor and Williams, 2018).

Beach litter includes all persistent, manufactured, or processed solid material disposed or abandoned over beach environments (Coe and Rogers, 1996; Bergmann et al., 2015; Tudor and Williams, 2018). Litter has a widespread negative influence over the entire beach system, affecting all its structure (swash, surf, and nearshore zones), and even extending to the inner continental shelf. Its impact is of global significance, and awareness of the threats posed by beach litter to humans and environment has been recognized for around 60 years (Ryan, 2015).

Currently, beach litter is an issue that has gotten out of hand. Its environmental and societal costs are immeasurable and irreversible. Related impacts encompass local, regional, national and global scales, and include adverse implications to biologic interactions (Rech et al., 2016; Carvalho-Souza et al., 2018; Gracia et al., 2018), direct effects on human health (Campbell et al., 2016; Antao Barbosa et al., 2018), degradation of aesthetic quality and public perceptions (Williams et al., 2016a, b; Rangel-Buitrago et al., 2017, 2018) and economic effects (Gilbert, 1996; Perez et al., 2018).

On beach systems, litter can derive from land-based sources (e.g., direct from rivers), as well as sea-based sources (e.g., waste disposal from shipping). Its magnitudes and composition are related to land uses, socio-economic activities, and littering behaviors (Lechner et al.,

* Corresponding author at: Programa de Física, Facultad de Ciencias Básicas, Universidad del Atlántico, Barranquilla, Atlántico, Colombia.
*E-mail address:* nelsonrangel@mail.uniatlantico.edu.co (N. Rangel-Buitrago).

https://doi.org/10.1016/j.marpolbul.2018.09.040
Received 5 August 2018; Received in revised form 19 September 2018; Accepted 20 September 2018

2014; Willis et al., 2017). In the same way, transport and accumulation regimes are related to hydrodynamic and climatic conditions (Carson et al., 2013), as well as beach characteristics, such as typology morphodynamic state and level of sheltering (Araujo and Costa, 2007; Williams et al., 2016a, b).

Within beach litter, plastics typically constitute the dominant pollutant item and sometimes account for up to 100% of marine litter pollution in a specific area (Galgani et al., 2015). Processed wood and rubber are also common beach litter types that usually are transported by rivers before deposition (Williams and Simmons, 1997; Viehman et al., 2011; Rangel-Buitrago et al., 2017). Some non-buoyant or non-persistent litter items, such as glass, metal, and organic litter, are frequently attributed to non-riverine sources, e.g., direct litter dumping over the beach (Bravo et al., 2009; Williams et al., 2016a, b; Rangel-Buitrago et al., 2018).

The Atlantico Department coastline is a developing area with 1,378,800 inhabitants (Gracia et al., 2018). This population represents close to 4% of Colombia's total and is primarily located at Barranquilla city, the largest and most populated urban concentration on Colombia's Caribbean coast. Preliminary studies developed by Gracia et al. (2018), Rangel-Buitrago et al. (2013, 2016, 2017, 2018), and Williams et al. (2016a, b), point out that the Atlantico Department coast has a critical environmental issue related to a high abundance of litter, as well as other environmental problems.

This paper presents the existing relations between beach characteristics (typology, morphodynamic state, and level of exposure) and litter magnitudes observed along the Atlantico Department coastline, Caribbean of Colombia. The analysis of these variables as indicators of pollution, from a management point of view, provides opportunities for optimal management of this essential coastal zone of the country. Results provide the baseline data necessary to adopt reasoned management decisions in regard to the current litter issue. The results presented here should be beneficial to local and national coastal managers and planners, who need to improve the baseline information for optimal litter monitoring and control.

## 2. Materials and methods

### 2.1. Location

The study area includes 25 beaches located along a 72 km coastline belong the Atlantico Department, Caribbean of Colombia (Fig. 1 and Table 1). This coast lies predominantly in a NE–SW orientation with some sectors oriented E–W that generate alternate stretches of *Z*-curved bays with medium-long linear segments.

The Atlantico coastline is a complex area where tectonic processes have defined the actual geomorphology with landscape units that include terrigenous sandy beaches, sand spits, rocky coasts, coastal plains and coastal lagoons, dunes and some mangrove swamps (Rangel-Buitrago et al., 2018). Sand from rivers is the major sediment component of local beaches, and availability is partially controlled by seasonal wave regimens. The supply of coarse terrigenous sediments to the study-area beaches comes mainly from the Magdalena River and 26 small distributaries which drain the Atlantico Department coastline (Gracia et al., 2018). A lesser percentage of sediment comes from erosion of Tertiary sandstone rock-shore segments, outcropping along the entire coast.

This coastline lies in a semi-arid tropical environment with mean temperatures of < 28 °C and maximum precipitation values of 2500 mm/yr, making the coastal climate attractive for tourism development (Rangel-Buitrago et al., 2013). Seasonal variations show two rainy periods (April–May and October–November) and two dry periods (December–March and July–September). Winds present mean velocity values lower than 13 m/s. Higher velocity values are associated with winds blowing from the NE during the dry period. Lower values are observed between September and November related to winds blowing from E (Anfuso et al., 2015).

The average significant wave height is 1.5 m and peak period average is 7.5 s. From November to July, the wave system along the area is dominated by NE swells; for the remainder of the time waves from NW, WSW, and even SW occur (Gracia et al., 2018). Tides are mixed semi-diurnal, with maximum amplitudes of 65 cm typical of a microtidal environment (Rangel-Buitrago et al., 2017). Longshore sand drift has a dominant south-westward component, but a minor reversal to the northeast occurs during rainy periods when southerly winds prevail in some areas and set up short, high-frequency waves able to generate significant erosion along sandy beaches (Anfuso et al., 2015).

### 2.2. Beach typology and characteristics

As a first step, each beach was classified using the typology definition expressed in the Bathing Area Registration and Evaluation (BARE) system (For more details see: Williams and Micallef, 2009). This classification allows the categorization of beaches into five different classes (remote, village, rural, urban and resort) taking into account their accessibility, environment, facilities, accommodation grade, and safety equipment.

In a second step, beaches were categorized according to their level of exposure to waves on:

- Exposed beaches.
- Sheltered beaches (e.g., beaches located on bays).

Also, the morphodynamic state of the beach foreshore was evaluated according to the Wright and Short (1984) classification that divides beaches into three types:

- Dissipative conditions: flat beaches composed of fine sand.
- Intermediate conditions: beaches with intermediate slope values composed of medium-coarse sand.
- Reflective conditions: beaches with low-tide terraces and relatively steep upper foreshore composed of coarse sand.

Regular cleaning operations are carried out by local authorities and inhabitants along 17 of the 25 beaches surveyed. These beaches were usually cleaned manually (urban and village) and mechanically (resort) at least three times per week throughout the year. Conversely, due its localization and access, the following eight beaches never have been subjected to clean up operations: A1 Punta Roca, A7 Puerto Velero — Exposed, A15 Tubara, A17 Playa Linda, A20 Salinas del Rey, A21 Loma de Piedra, A23 Bocatocinos, and A25 Salinas de Galerazamba.

### 2.3. Litter quantification and grading

The OSPAR (2010) methodology was used to determine the abundance and distribution of beach litter along the Atlantico department. In each of the 25 beaches, a 100 m long linear segment ("sampling unit") located in the middle of the beach between the low tide mark and the backshore was selected. Within this sampling unit, all litter was collected and separated based on the type of material and its buoyancy properties according to the classification presented by Rech et al. (2014). All litter items were counted in order to measure and compare the total amount of litter available on each beach surveyed. Densities were calculated as the number of items collected along the sampling unit divided by its length (100 m).

Also, beach litter grade was determined by counting the number and type of items collected along each sampling unit according to the EA/NALG (2000) methodology. This method classifies a beach on a scale from "excellent" ("A") to "poor" ("D") taking into account the score of the lowest grade scored in any of the seven categories shown in Table 2. The use of EA/NALG (2000) methodology allowed more detailed information on beach typology and quantities.