



## Spatio-temporal variability of beached macro-litter on remote islands of the North Atlantic

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### ABSTRACT

Marine litter has been identified as one of the major environmental problems that oceans are currently facing. Worldwide efforts are being made to reduce the input of litter into the oceans, and projects aimed at monitoring their quantities are key to evaluate their success. This study, provide baseline information on the quantities of marine litter found on 42 beaches spread throughout the nine islands of the Azores archipelago, North Atlantic Ocean. A total of 31,439 items were collected throughout the archipelago with an average density of  $0.62 \pm 0.15$  macro-litter items  $m^{-2}$ . Of this litter 87% were plastic and its majority (67%) plastic fragments. Six beaches were further monitored every three months for two years. Substrate type and wind exposure were important factors for explaining patterns of litter deposition. Our results highlight that marine litter have the tendency to accumulate in remote islands of the North Atlantic Ocean.

### 1. Introduction

Marine anthropogenic litter is one of the most pervasive environmental pollution problems that the oceans are currently facing, affecting directly and indirectly all marine ecosystems (Galloway and Lewis, 2016). Among the wide diversity of litter items found in the oceans, plastic is by far the most abundant and concerning material (GEF, 2012). Due to their physicochemical properties, plastic materials are suitable for a wide range of industrial and medical applications worldwide. However, when not properly disposed, they remain in the environment for long periods of time, eventually causing harmful effects to marine biota (Bergmann et al., 2015). The negative effects of marine litter are well known and include entanglement, a phenomenon that has been reported in 243 different species of marine organisms (Gall and Thompson, 2015) and ingestion, that has been documented in a wide variety of marine wildlife, from planktonic organisms up to baleen whales (Gall and Thompson, 2015).

Recent estimates suggest that ~8 million metric tons of plastic waste reach the oceans each year (Jambeck et al., 2015), and this figure will probably continue to increase as research into this field also

progresses. A recent study by Lebreton et al. (2018), shows evidences that the extent of plastic accumulation in the Great Pacific Garbage Patch in the North Pacific Ocean has been rapidly increasing. Furthermore, the northern hemisphere has historically been reporting higher marine pollution accumulation rates than southern hemisphere areas (Galvani et al., 2015; Eriksen et al., 2014; Van Sebille et al., 2015).

Marine litter has been described as ubiquitous and has been found in every compartment of the marine realm, including the coastal zone, floating at the sea surface and in the water column, deposited on the seabed and even in the Arctic sea ice (Barnes et al., 2009; Obbard et al., 2014; Pham et al., 2014; Woodall et al., 2014; Peeken et al., 2018).

Small and isolated islands, such as the case of the Azores archipelago, are not immune to this global problem, and could potentially act as important sinks for marine anthropogenic litter in the open ocean (Lavers and Bond, 2017; Lebreton et al., 2018). At the moment, there are only a few studies conducted in the Azores archipelago that focus on marine anthropogenic litter, particularly on coastal accumulation (Pieper et al., 2015), seafloor deposition and accumulation (Pham et al., 2013; Rodríguez and Pham, 2017) and impacts on sea turtles (Pham

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et al., 2017).

Beach surveys provide an important way to assess the abundance and sources of plastic pollution in the environment while also serving as a management tool to evaluate the efficiency of policies targeted at reducing their input into the oceans. Additionally, information collected by beach monitoring programs can facilitate EU member countries to assess their progress towards a “Good Environmental Status” (GES) under the framework of the Descriptor 10 “Properties and quantities of marine litter do not cause harm to the coastal and marine environment” of the Marine Strategy Framework Directive (MSFD).

Even with the efforts of organised clean-up actions conducted by different non-governmental organizations and local municipalities, information regarding deposition factors, quantities, and seasonal trends of coastal marine litter in the archipelago is still scarce, and this study aims to fill in knowledge gaps for this region.

In order to provide a detailed characterisation of litter on beaches of the Azores archipelago, this work aims to (1) provide a snapshot of the quantity of marine litter present in 42 different beaches across the nine islands; (2) assess seasonal variability in litter deposition across the archipelago; (3) provide insight on the potential factors that influence litter deposition.

## 2. Materials and methods

### 2.1. Study area and selected beaches

The Azores archipelago, located in the middle of the North Atlantic Ocean, consists of nine volcanic islands disposed in three separate groups (Eastern Group, Central Group and Western Group) (Fig. 1). The exceptional relevance of this archipelago is directly linked to the extension of the Portuguese Exclusive Economic Zone (EEZ; 953,633 km<sup>2</sup>), and to the environmental and socio-economic importance of this region to Portugal.

The present study focused on 42 beaches that are spread throughout the nine islands and that present a different set of characteristics

(detailed descriptions of each beach can be found as supplementary material (Table S1)). The locations included different types of substrate (sandy ( $n = 19$ ), rocky ( $n = 9$ ) and gravel ( $n = 14$ )), level of accessibility, presence/absence of artificial walls, width, length and orientation.

All beaches are regularly visited by tourists during the summer and only a few are commonly frequented during the winter. As a result, in the summer, most beaches are regularly cleaned by municipalities while during the winter litter removal is far less frequent. Beaches with clean-ups occurring all year-round include Porto Pim, Prainha de Angra and Praia das Milícias. Beaches only cleaned during the summer (and occasionally in the winter) include Conceição, São Mateus, Prainha de Vitória, São Lourenço, Água de Alto, Calhau da Areia, Praia dos Moinhos, Santa Barbara, Praia da Areia, Calheta. The remaining beaches are cleaned either sporadically or are very rarely cleaned.

In order to minimise bias that could be caused by beach clean-ups, all responsible entities were contacted one month prior the surveys (January 2016), to inquire about all cleaning activities on site and to ensure no removal of marine litter took place. This action was only performed during our initial large-scale survey (see details below) that took place between February and March 2016 (not all the municipalities were able to stop their cleaning activities).

### 2.2. Survey design and methodology

An initial survey was designed to cover the whole archipelago and included 42 beaches. Those beaches were sampled on a single occasion between February and March 2016 while a sub-sample ( $n = 6$ ) was subsequently monitored using the same methodology over a period of 24 months, once every three months (Table S1).

The beaches selected for the seasonal monitoring were all sandy beaches with a reduced cleaning activity and were located in all three groups of islands (Fig. 1).

For each beach, a fixed 100 m (whenever possible) section was delimited, covering the whole area between the water line to the beach

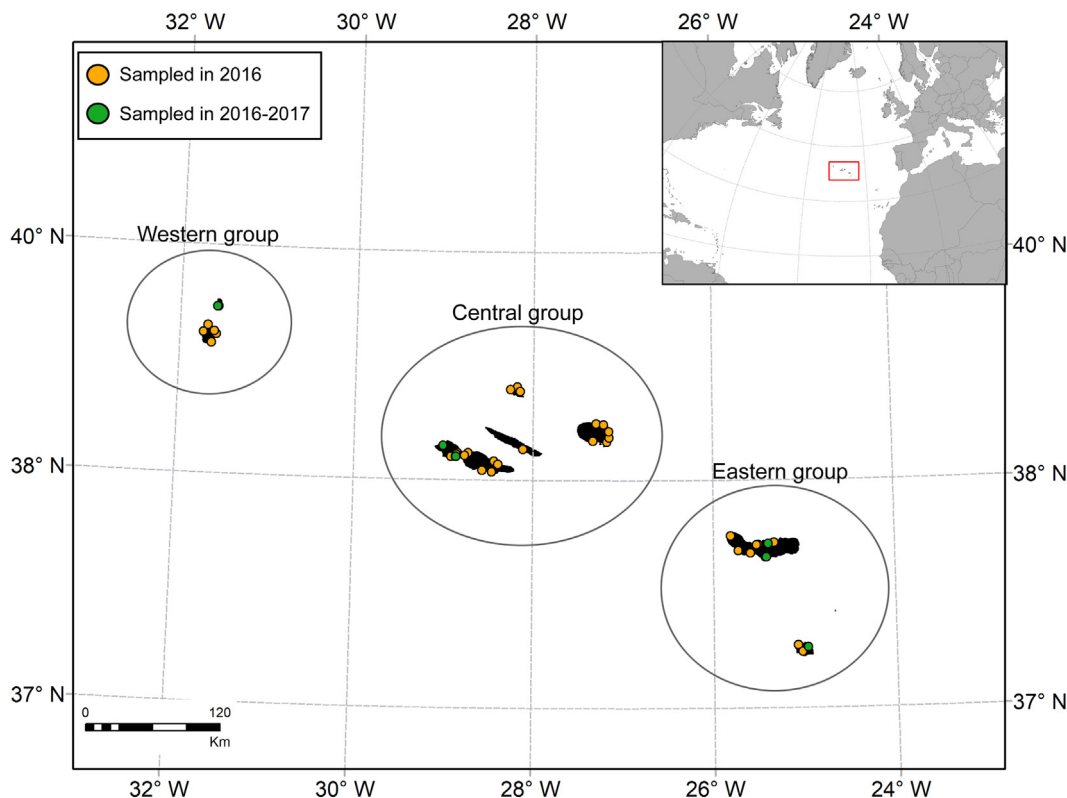


Fig. 1. Location of the selected beaches spread throughout the different islands of the Azores archipelago, subdivided into three main groups.

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