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Beach litter dynamics on Mediterranean coasts: Distinguishing sources and pathways

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ABSTRACT

We assessed amounts, composition and net accumulation rates every ~15 days of beach macro litter (≥2.5 cm) on 4 Mediterranean beaches, on Corfu island, N. Ionian Sea, taking into account natural and anthropogenic drivers. Average net accumulation rate on all beaches was found 142 ± 115 N/100 m/15 d. By applying a Generalized Linear Model (GzLM) it was shown that sea transport is the dominant pathway affecting the amount and variability in beach litter loadings. Principal Component Analysis (PCA) on compositional data and indicator items discerned two more pathways of beach litter, i.e. in situ litter from beach goers and wind and/or runoff transport of litter from land. By comparing the PCA results to those from a simple item to source attribution, it is shown that regardless their source litter items arrive at beaches from various pathways. Our data provide baseline knowledge for designing monitoring strategies and for setting management targets.

1. Introduction

Marine pollution by anthropogenic litter is recognized as a global problem which impairs the ecosystems, wildlife and possible human health (UNEP, 2005; Papatheodorou, 2012; Rochman et al., 2013). Marine litter consists primary of plastics and follows an exponentially increasing trend during the last decades, parallel to the increasing production of plastic goods and packaging materials (Ryan, 2015; Plastics Europe, 2015). Marine litter can be found in all marine compartments (beaches, sea surface and water column, seafloor, ingested by biota) close to populated areas as well as at remote places of the world (Stefatos et al., 1999; Bergmann and Klages, 2012; Morishige et al., 2007; Koutsodendris et al., 2008; Eriksson et al., 2013). All human activities generate waste and it has been estimated that ~2–5% of produced plastic waste finds its way into the marine environment (Jambeck et al., 2015). Anthropogenic activities that take place outdoors, such as agriculture, fisheries, aquaculture, constructions, tourism, as well as inadequate waste management schemes are the main contributors to litter dispersion. As a result, litter found in the marine environment has a variety of sources and can be produced at sea or at the coastal zone, or even further inland and transported via streams and rivers. Once at sea, marine litter is redistributed due to natural drivers (wind, surface circulation, bottom currents, biofouling, photodegradation) which affect its lateral transport, buoyancy, residence time and degradation (Galgani et al., 2015). Many works have shown that marine litter accumulates close to densely populated areas (Leite et al., 2014; Vlachogianni et al., 2017) but also at distant areas away from its sources such as mid-ocean waters and deep canyons (Eriksen et al., 2014; Pham et al., 2014). Due to plastics' positive buoyancy, plastic litter items afloat and circulate on the ocean surface for long periods (Andrady, 2015). During this journey a large amount of litter is washed up on shores, which are considered a sink for marine litter (Williams and Tudor, 2001), the other being the seafloor (Galgani et al., 2000; Ioakeimidis et al., 2014). Nevertheless, several works have shown that litter washed ashore does not necessarily stay there (Bowman et al., 1998; Kataoka et al., 2013). Local beach dynamics in addition to human intervention play an important role in balancing inputs (litter washed ashore or stranded in situ) and outputs (litter exported back at sea, buried, blown by the wind or removed by humans) for a specific beach (Ryan et al., 2009).

In the Mediterranean Sea, the increased coastal population (160 million residents) and tourism (~350 million overnight stays per year) (UNEP/MAP, 2012) are considered the major causes of the high amounts of litter recorded (Suaria and Aliani, 2014; Cózar et al., 2015). The enclosed character of the Mediterranean Sea, the long coastline (46,000 km), the presence of numerous islands (~3000) as well as the

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specific sub-basin and mesoscale surface circulation features (Robinson et al., 2001), favor the entrapment of litter and the interplay between floating and beach litter. Understanding beach litter dynamics in this environment is therefore essential for waste management and future prediction scenarios and modeling.

Most studies dealing with beach litter are based on infrequent samplings (quarterly, annually or once) and report the standing stock of litter, i.e. the amount of litter that stays on the beach in the long term. Data obtained from standing stocks surveys are useful in determining compositional changes of marine litter, but cannot accurately monitor any changes in marine litter abundances and in particular cannot be related to changes in floating litter (Ryan et al., 2009). On the other hand regular frequent surveys (daily, weekly, monthly) that record and remove beach litter provide information on the amount of litter that arrives on the beach and can be used to determine the net accumulation rate of litter per unit of time. Such practice is considered more suitable for assessing trends in marine litter amounts (Ryan et al., 2009; OSPAR, 2010; Ribic et al., 2010, 2012). No such studies exist for the Mediterranean Sea and most beach litter data available come from single (Martinez-Ribes et al., 2007; Laglbauer et al., 2014; Munari et al., 2016) or monthly (Gabrielides et al., 1991) surveys aiming to report standing stocks and composition. More recently Pasternak et al. (2017) have conducted a detailed survey over 19 consecutive months, on Israeli coasts, focusing on the compositional changes and source identification with time. The only work conducted for the Mediterranean environment which investigates the role of the natural drivers on beach litter distribution is by Bowman et al. (1998), again on the Israeli coasts. These authors address the issue of beach litter dynamics but interpret their results only taking into account the impact of beach geomorphology.

The present study focuses on the understanding of beach macro litter (≥ 2.5 cm) dynamics on four Mediterranean coasts, taking into account natural (wind-wave regime, beach orientation) as well as anthropogenic drivers (proximity to urban centres and visiting periods). The accumulation of litter and its spatio-temporal variation in amounts and composition is investigated on four (4) beaches of Corfu Island in the N. Ionian Sea, during 16 consecutive months applying fine scale samplings (< 1 month). To our knowledge, this is the first time that an integrated study such as this one is conducted for Mediterranean beaches. The ultimate goal of this work is to provide baseline knowledge to policy makers and relevant stakeholders for an effective design of monitoring programmes and for the interpretation of the monitoring results. This has particular relevance for the implementation of the Marine Strategy Framework Directive (MSFD, 2008/56/EC) by the EU member states and the UNEP/MAP Regional Plan for Marine Litter Management in the Mediterranean (UNEP/MAP IG.21/9) by all Mediterranean countries.

2. Methods

2.1. Study sites

In the framework of the 'DeFishGear' project, we conducted surveys on four (4) beaches around Corfu isl. Greece, located in the North Ionian-Southern Adriatic Sea. Beach selection was based so as to cover different exposure to natural and anthropogenic drivers of litter deposition. The four beaches (Acharavi-A, Ipsos-B, Halikounas-C and Issos-D) selected for the present study are shown in Fig. 1. Shelf waters at all sites are fishing grounds for trawls, nets and lines.

Beach A (Acharavi) is located on the north coast of Corfu isl. facing the Adriatic Sea to the northwest. Beach A is 5107 m long and ~17 m wide, with a substrate consisting of medium sand. The prevailing winds were overall low (< 10 m/s) with a west–east direction during the sampling period. The beach is used for bathing during summer, has several small scale touristic settlements and tavernas and can be characterized as semi-rural (~657 inhabitants; population count 2001).

Beach B (Ipsos) is located on the east coast of Corfu isl. facing Kerkyraikos Gulf to the southeast. Beach B is 1440 m long and approximately 5 m wide, with pebbles and cobles. The prevailing winds had a northwest–southeast direction during the sampling period. The beach is a public bathing site from June to September. Touristic settlements are built along the whole length of the beach. The main traffic road passes between the beach and the building line. Additionally the beach is burdened by dense and frequent movement of vessels and ships, from the town of Corfu, from the port of Igoumenitsa and the Kalamas river outflow both situated on the mainland coast and the beach can be characterized as semi-urban.

Beach C (Issos) and the adjacent beach D (Halikounas) are located on the SW coast of Corfu isl. facing the Ionian Sea; beach C to the south and beach D to the southeast. The beaches are part of the ecosystem of the Korrissia Lagoon which is formed parallel to the coast ('Natura 2000' site; GR2230002). Beach C extends along the W–E direction and changes abruptly to the NW–SE direction forming beach D, thus a spit is formed which separates the two beaches. Beach C is 2360 m long and ~20 m wide, beach D is 2659 m long and ~20 m wide, while both beaches are consisted of fine sand. The prevailing winds were intense (10–15 m/s) with several incidents of wind blowing at 15–20 m/s with a northwest–southeast direction. Beach C is difficult to visit due to the presence of high dunes at the back. Beach D is visited throughout the year either by beach goers or visitors of the lagoon, but with low frequency. Both beaches can be characterized as remote.

2.2. Sampling and analyses

Over a period of 16 months, from July 2014 to October 2015 we sampled for beach litter (≥ 2.5 cm) twice a month (every 15 ± 5 days). All collections were done by the same person in order to achieve high degree of sampling objectivity. Three transects of 100 m long were monitored at each beach (Fig. 1). Transects were set parallel to the water line and extended to the back of the beach where vegetation or built constructions appear. Before starting our sampling programme, the sampling transects were cleared of all stranded litter items which were considered as the initial stock of litter. Individual items were identified and categorized according to the methodology proposed by the EU MSFD TGML D.10 'Guidance on Monitoring of Marine Litter in European Seas' (Galgani et al., 2013). The protocol classifies litter in 8 marine litter types (artificial polymers, rubber, textile, paper, metal, wood, glass, unidentified) and in 213 detailed item categories each having a unique identification code (G1-G213). All litter items were counted, cleaned from any sand and weighed to the nearest 0.01 g. Beach litter is expressed as number of items or mass per 100 m transect (N/100 m; kg/100 m). We choose to express our results per beach length unit (m) rather than per beach area unit (m^2) for three reasons: (i) Given that the whole width of the beach is sampled, then for equal litter counts (or mass), litter densities per area unit will increase as the width of the beach decreases, which means that data for narrow beaches will be always biased towards higher values and vice versa; (ii) comparisons on the global scale can only be made for the global coastline (~1.634,701 km) as there is no global coast area; (iii) beach litter data per length unit can be more easily related to floating litter fluxes washed ashore.

2.3. Meteorological data

Data on wind speed and direction were extracted from the Poseidon forecasting system (http://www.poseidon.hcmr.gr) and significant wave height data from the Triton wave forecasting system (http://www.oc.phys.uoa.gr). These data were collected for four positions closest to our sampling sites. The square of significant wave height [H^2] was used as an index of the wave energy flux (WMO, 1998), in order to check whether the waves control litter abundance on the studied beaches. The sum of wave height squared [$\Sigma_i H^2$], for the days (i) preceding