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Beach litter in Mediterranean coastal dunes: an insight on the Adriatic coast (central Italy)

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Abstract
Beach litter is an increasingly important threat, causing a drastic loss of natural biodiversity and the associated ecosystem services. Even if beach litter accumulation in oceanic coasts has been analyzed quite well, new research efforts are still necessary to better understand this phenomenon along the Mediterranean coasts. This work sets out to analyze the sources of beach litter, the type of material, and the distribution and accumulation trend along the sandy coasts of the Adriatic Sea in central Italy (Abruzzo and Molise Regions, Italy). In particular, we focus on the following questions: (i) Which are the most frequent beach litter items and materials on sandy coasts? (ii) How is beach litter distributed on the different coastal dune habitats along the sea–inland gradient? Data were collected and categorized during spring 2014–2015 following the OSPAR guidelines in belts parallel to the shoreline and in transects perpendicular to the shoreline. Before analyzing litter abundance by classes of material, source types, and floating capacity, the spatial trends of waste accumulation along the dune zonation was also explored. Most of litter elements are in plastic, followed by styrofoam with good floating capacity. Majority of the debris derive from food packaging, fishing and recreational activities. The distribution of litter along the sea–land eco-morphological gradient is heterogeneous. The unequal accumulation amounts of debris on the upper beach, embryodunes, mobile dunes and fixed dunes threaten natural EC habitats in different ways. Our results stress the need of specific conservation and cleaning actions able to preserve the ecological value of EC coastal dune habitats.

Keywords Litter characteristics · Debris accumulation trends · Coastal dune eco-morphological zonation · EC habitat · Conservation actions

1 Introduction

Sandy coastal dunes are dynamic mosaics which host a remarkable ecological diversity (van der Maarel 2003; Acosta et al. 2009; Doody 2013). These systems comprise approximately three-quarters of the world's shorelines (Bascom 1980) and provide humans with important services (Millennium Ecosystem Assessment 2005) such as coastal protection, water catchment and purification, maintenance of wildlife, carbon sequestration, and tourism, recreation and education (Doody 1997; Everard et al. 2010; Jones et al. 2011; Drius et al. 2016). Regardless of the numerous benefits provided by coastal dunes, they are among the most fragile and threatened ecosystems worldwide (Schlacher et al. 2007. Doody (2013). In particular, during the last decades, the outbound tourism, the expansion of urban areas, the spread of agriculture and afforestation activities and the biological invasions have strongly shaped coastal landscapes (Hesp and Martinez 2007; Malavasi et al. 2013; Santoro et al. 2012; Carranza et al. 2018). Added to these, is the increasingly important threat of marine litter (Lippiatt et al. 2013; Galani et al. 2015). The marine litter, intended as persistent, manufactured or processed solid material discarded, disposed, or abandoned in the marine and coastal environment (CBD Technical Series 2012), has lately turned into a pollution problem in different places of the world (do Sul

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and do Costa 2007). The range of negative consequences of marine litter may include environmental, social and economic impact (Cheshire et al. 2009). Sandy shores are generally considered as important sinks for floating debris, which after stranding generally becomes trapped in/under sand or might be blown farther inland (Williams and Tudor 2001).

Even if beach litter accumulation on oceanic coasts have been analyzed quite well (do Sul and do Costa 2007; Eriksson et al. 2013), new research efforts are still necessary to better understand this phenomenon on Mediterranean coasts (Poeta et al. 2015a). Anyway, the accumulation of beach litter on the Mediterranean coastal dunes has not yet been sufficiently studied, and updated information about the trend of accumulation/distribution along the coastal dune mosaic is still incomplete and inappropriate (Munari et al. 2016). Recently, some authors (Benedict and Billeter 2004; Poeta et al. 2015b) have highlighted the threat represented by plastic and polystyrene materials on the native fauna of the dunes, in particular for macro- and micro-invertebrates and small vertebrates (Wright et al. 2013).

On this basis, this research sets out to analyze the sources of beach litter, the type of material, and the distribution and accumulation trends along the sandy coasts of the central Adriatic Sea (Abruzzo and Molise regions, Italy). In particular, we focus on the following questions: (i) Which are the most frequent beach litter items and materials on sandy coasts? (ii) How is beach litter distributed in the different coastal dune habitats along the sea–inland gradient?

2 Materials and methods

2.1 Study area

The study was carried out in a representative zone of the Adriatic coast in central Italy (Fig. 1), characterized by a narrow strip of recent dunes (Holocene) along the seashore. Such coastal dunes included in the Molise and Abruzzo regions are low and relatively simple in structure. Abiotic conditions vary greatly moving along the sea–inland ecotone shaping a typical vegetation zonation (Carranza et al. 2008), ranging from pioneer annual plant communities on the upper beach to the Mediterranean macchia on the landward fixed dunes (Izzi et al. 2007; Acosta et al. 2003, 2009). The analyzed coastal dunes host many EU habitat types (according to the Council Directive 92/43/EEC, the so-called Habitats Directive) (Feola et al. 2011; Stanisci et al. 2014; Fig. 1) and vertebrate species of European concern (Berardo et al. 2015; Foresta et al. 2016). Most of this coast is included into the Natura 2000 network and in the European Long-Term Ecological Research monitoring network (Drius et al. 2013; Stanisci et al. 2007; LTER IT20 code, www.lteritalia.it), thus representing an excellent training ground to develop methodologies for assessing beach litter on coastal dune ecosystems (Acosta and Ercole 2015).

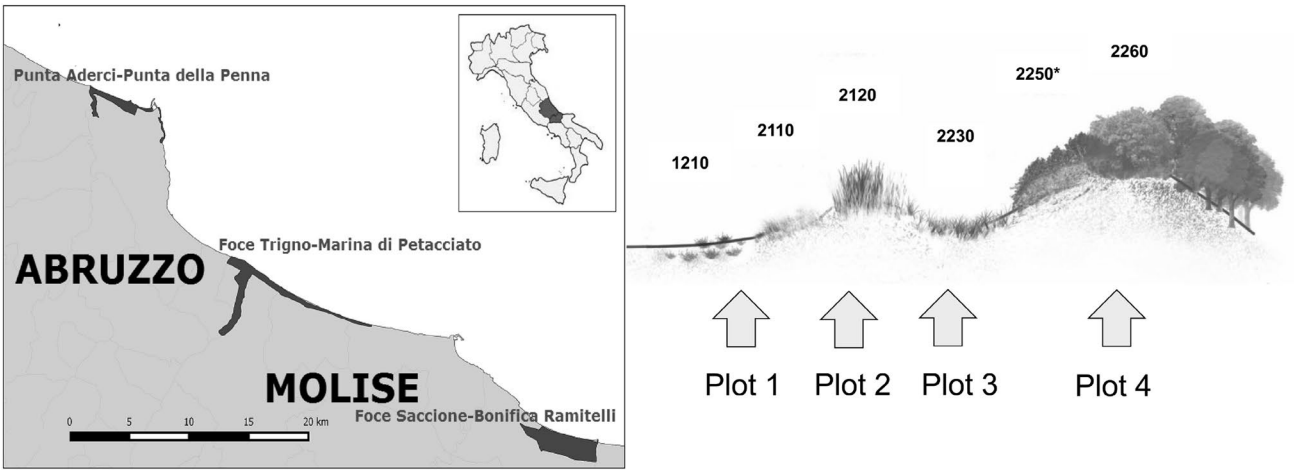

Fig. 1 Localization of study area along with the sites of Natura 2000 network in which litter data were collected (IT7140108 Punta Aderci—Punta della Penna, IT7228221 Foce Trigno—Marina di Petacciato and IT7222217 Foce Saccione—Bonifica Ramitelli). The profile schematically represents the distribution of sampling plots across the morpho-ecological dune zonation along with the EC habitats (sensu 92/43/EEC Habitat Directive). 1210: vegetation of the drift lines; 2110: embryonic shifting dunes; 2120: shifting dunes along the shoreline with *Ammophila arenaria*; 2230: Malcomietalia dune grasslands; 2250*: coastal dunes with Juniperus spp.; 2260: Cisto-Lavanduletalia dune sclerophyllous scrubs (profile form Bazzichetto et al. 2016 modified)

2.2 Litter sampling

The sampling was carried out following the OSPAR Guidelines (for the complete list of material types and relative codes see OSPAR Commission 2010).

Data were collected and categorized during a field campaign performed in spring 2014–2015 as follows:

- Small–medium litter with a diameter between 2 and 50 cm were sampled along two transects perpendicular to the coastline in four plots of about 200 m^2 (Fig. 1).
- Large litter with a diameter more than 50 cm was sampled along three transects (one for each SCI) parallel to the coastline from the shoreline to the dune habitats of 1 km in length.

For each sampled area, the following information was also registered:

- The abundance of the litter, that is the number of elements collected in each plot;
- The material (paper, plastic, polystyrene, glass, mixed, not available);
- The source (recreational, health, fishing and food business, not available);
- The floating capacity of each kind of litter (classified in three levels: high, medium, and low).

Before characterizing the material, source, and floating capacity of the collected debris, the spatial trends of litter accumulation along the coastal zonation were also explored (Poeta et al. 2015a, b).

3 Results

During the litter sampling campaign, at least one litter item was found in all the plots (Fig. 2). We collected 5330 elements with diameter between 2 and 50 cm, most of which was plastic (3024 elements) followed by polystyrene (1623 elements) and these debris mainly derive from food, fishing and recreational activities. Almost all small–medium-sized litter (97%) presents high–medium buoyancy and therefore they are transported by waves and wind on the coast even at considerable distances from the seashore (Fig. 2).

We collected 770 large litter elements mostly in plastic (417 elements, 54%), in polystyrene styrofoam (283 elements, 37%) and mixed (70 elements, 9%). The source of big litter was mostly related with fishing activities (87%), followed by recreational (11%) and food (2%) business. The floating capacity of big litter is also good with half of the elements having medium (54%) and the other half high (43%) buoyancy (Fig. 3).

Moreover, the results showed different accumulation trends across the dune eco-morphological zonation. We observed higher accumulation near to the seashore on the upper beach and embryodunes impinging the vegetation of the drift lines (EC: 1210) and embryonic shifting dunes (EC: 2110) (43% of the litter elements). Litter accumulation slightly decreases towards the mobile and transition dune sectors with *Ammophila arenaria* (EC: 2120) and Malcomietalia dune grasslands (EC: 2230) (35% of the litter), and also affects the fixed dunes with *Juniperus* spp. (EC: 2250*) and Cisto-Lavanduletalia dune sclerophyllous scrubs (EC: 2260) (18% of the litter) and here the polystyrene prevails due to its high volatility.

Fig. 2 Beach litter along the study area

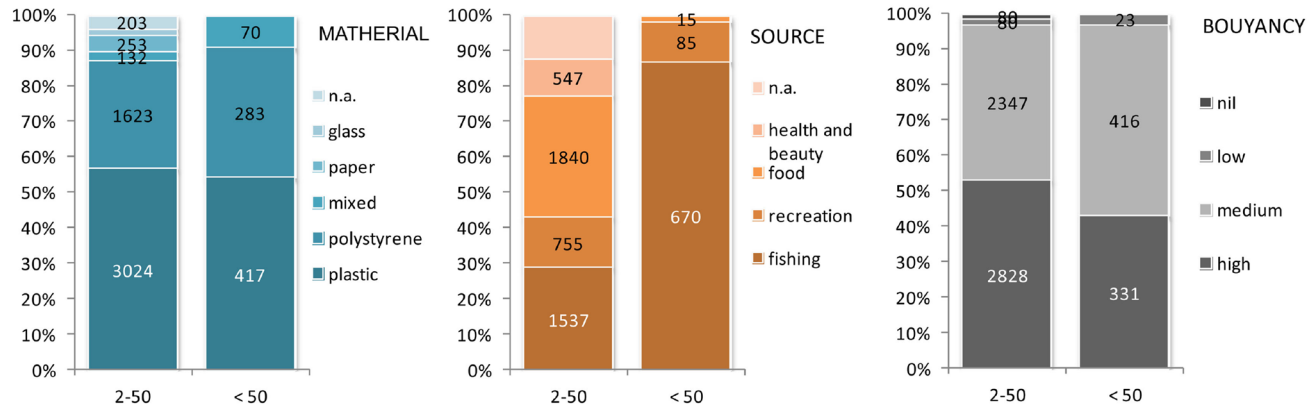

Fig. 3 Abundance of litter organized by material source and floating capacity. Medium–small litter: 2–50 cm in diameter and coarse litter: greater than 50 cm

4 Discussion

Similar to previous observations that reported plastic as the most widespread marine litter (do Sul and do Costa 2007; Eriksson et al. 2013), along the central Adriatic coast plastic and polystyrene styrofoam are also the most common litter items. Moreover, a higher density of litter was recorded in the Adriatic Sea than in other basins as seen by Arcangeli et al. (2017), who have analyzed the abundance and the distribution of floating marine litter across the Mediterranean Sea, while the artificial polymer materials are the most abundant litter fraction recorded (90% in the entire study area).

The distribution of litter along the sea–inland eco-morphological gradient is heterogeneous and a higher amount of litter was recorded in the vegetation of the drift lines (EC: 1210) and in embryonic shifting dunes (EC: 2110), followed by the mobile dunes with *Ammophila arenaria* (EC: 2120) and Malcomietalia dune grasslands (EC: 2230), and by the fixed dunes with *Juniperus* spp. (EC: 2250*) and Cisto-Lavanduletalia dune sclerophyllous scrubs (EC: 2260). The necessary cleaning actions must be carefully planned to avoid both sand extraction and dune morphology simplification (Poeta et al. 2015a, b). Indeed, Battisti et al. (2016) in an experimental work on cleaning up procedures of coastal dunes have observed that with the litter debris, a high amount of sand tends to be also removed. In view of such observations, the management measures aimed at beach cleaning should be aware of the possibility, when removing litter, of unintentional sand and natural dune herbaceous vegetation removal that would affect coastal dune habitats subsistence over time. Indeed, the persistence and the integrity of coastal dunes depend on preserving the vegetation zonation (Acosta et al. 2003; Drius et al. 2013) and the natural morphology (Bazzichetto et al. 2016), both threatened by the mechanical litter removal.

On the other hand, the lighter litter elements tend to remain trapped in the woody vegetation growing in the internal dune sectors. The great volatility of polystyrene and its structure characterized by tiny fragments, determine its accumulation in the fixed dunes that host one of the last relicts in the Adriatic coast of *Juniperus* spp. thickets (EC: 2250) (Acosta and Ercole 2015; Malavasi et al. 2013; Stanisci et al. 2014). The juniper maquis and Cisto-Lavanduletalia dune sclerophyllous scrubs (EC:2260) also are a refuge and a nesting site for *Testudo hermanni* (Berardo et al. 2015). While in previous works, a sort of adaptation of the natural fauna towards the utilization of new plastic elements in the coastal areas is reported, it should not be the case for terrestrial vertebrates living in the dunes. For instance, recent research reported that hermit crabs can use plastic debris as dwelling sites (Hamasaki et al. 2017) and that marine fouling organisms can stabilize in the floating litter and use its textured surfaces as living micro-habitats (Bravo et al. 2011). Instead, for some terrestrial vertebrates, such as *Testudo hermanni*, the presence of litter in nesting areas, may have negative consequences because of the ingestion of plastic debris and the 'trap effect' of plastic packaging that often lead to the death of animals (Kühn et al. 2015; Poeta et al. 2015b).

The ecological effects of the large presence of plastics and polystyrene show the need for further research efforts. Surely, the presence of large amounts of plastic litter has negative impact on the environment and causes the degradation and ecological integrity loss of natural habitats. Our results also reported the major role of food packaging, fishing and recreational activities as sources of the beach litter items. This reveals the paradox that, most often, tourism and related activities disturb and threaten local wildlife and their habitats, which attracted them to the area in the first instance (Williams 1992). Moreover, our results revealed that styrofoam box items come from fishing activities as already

assessed (Arcangeli et al. 2017). Actually, it is urgent to decrease its production and its persistent effect on the environment, making eco-friendly choices which enhance the products manufactured from renewable resources, containing biodegradable materials, and those that are easily recycled.

The presence of beach litter along the coastal dune habitats reduce the landscape value and the attractiveness for touristic and recreational activities, that are key resources for the local and regional economy (Malavasi et al. 2013; Drius et al. 2013; Carranza et al. 2018).

The obtained results revealing an heterogeneous distribution of waste along coastal dune zonation, confirm the urgent need of a differentiated management strategy, (by zones, Doody 2013) aimed at preventing, contrasting and mitigating the negative impact of beach litter on biodiversity and on the recreational and socio-economic values of sandy coasts (Ryan 2015).

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