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Beach litter along various sand dune habitats in the southern Adriatic (E Mediterranean)

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ABSTRACT

Marine litter accumulates on sandy beaches and is an important environmental problem, as well as a threat to habitat types that are among the most endangered according to EU legislation. We sampled 120 random plots (2 × 2 m) in spring 2017 to determine the distribution pattern of beach litter along the zonation of habitat types from sea to the inland.

The most frequent litter items were plastic, polystyrene and glass. A clear increase of litter cover along the sea-inland gradient is evident, and foredunes and pine forests have the highest cover of litter. Almost no litter was present in humid dune slacks. Shoreline and recreational activities are the major source of beach litter, while ocean/waterway activities are more important in the aphytic zone and strandline.

1. Introduction

Coastal areas are one of the most human-impacted habitats in the world (Brown and McLachlan, 2002; Martínez et al., 2004). Changes of biota and loss of biodiversity are the result of excessive pressures on these fragile ecosystems. In addition to several other harmful activities, pollution and waste management have been considered among the most important environmental problems affecting coastal areas (Stanners and Bourdeau, 1995). Sandy beaches, as part of the marine environment, are particularly vulnerable and are among the most endangered habitats worldwide (Martínez et al., 2004).

Marine debris is any manufactured or processed solid waste material (typically inert) that enters the marine and coastal environment from any source (discarded, disposed, or abandoned) (Coe and Rogers, 1997; Galgani et al., 2010). Despite various methodologies used, general patterns about the composition, abundance and distribution of beach litter are known. Knowledge of the composition is important, since it gives information on individual litter items and their source (land or ocean-based). Plastics are the most abundant material in debris, and also the most persistent (Derraik, 2002). Marine litter is found on beaches, as floating marine debris, on the sea floor, in various depths of the water column and, recently, microplastics are becoming a serious threat (Galgani et al., 2015).

Zonation of dunal habitat types is well known and researched in all parts of the world (Acosta et al., 2007; Doing, 1985). Dune vegetation is arranged in distinct zones along a perpendicular gradient from sea to inland and zonation is very fixed without erosion and human disturbance (Attorre et al., 2013). The zonation includes the drift line, embryonic dunes, fore dunes, semi-fixed dunes, and fixed dunes. The human impact on sandy beaches is changing the species composition and sequential distribution of plant communities (Ciccarelli, 2014; Šilc et al., 2016).

Habitat (type) is a term used in nature policy for areas with a defined species composition (both fauna and flora) and associated physical factors (EEA, 2014) and usually habitat typologies have a direct link to plant communities and vegetation classification. The EUNIS habitat typology is widely used in the EU by practitioners and environmental policymakers and provides a standardised tool for nature conservation (EEA, 2014). The Habitat Directive, based on EUNIS habitats, is the basis of the EU's nature conservation policy. The European Red List of Habitats contains 13 coastal habitats (out of 30) and pollution is one of the main pressures and threats (Janssen et al., 2016).

There is a broad set of literature about the quantities, composition and source of marine litter (Ariza et al., 2008; Pasternak et al., 2017; Williams et al., 2017; Williams et al., 2016), recently also in the Adriatic Sea (Laglbauer et al., 2014; Munari et al., 2016; Peraš et al., 2017). The studies were done according to standardised methodologies that enable direct comparisons by using large sampling plots (Cheshire et al., 2009; EA/NALG, 2000). Such plots take into account the whole beach and several habitats. However, to our knowledge, only a study by

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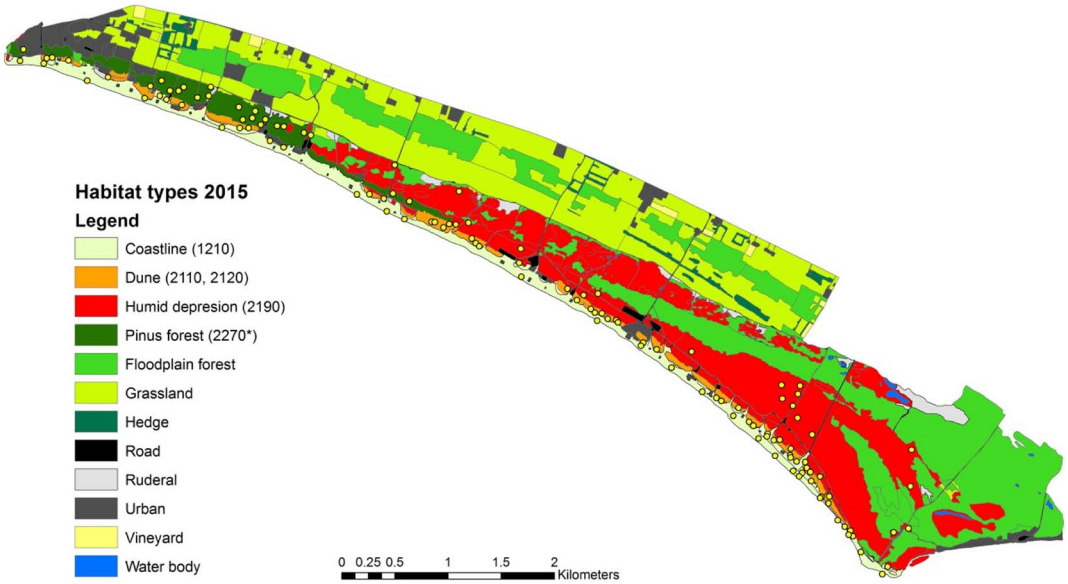

Fig. 1. Generalized habitat map of Velika plaža and hinterland with sampling plots. Dots represent individual sampling plots within dune habitats (Table 1).

Poeta et al. (2014) has considered different habitat types when sampling beach litter and studying the spatial pattern of beach litter according to various habitats.

The aims of our study were to detect: (i) the composition and source of beach litter on Velika plaža in Montenegro and (ii) the spatial distribution of beach litter in different habitat types along the sea-inland gradient.

2. Study area

The Adriatic Sea is a body of water (200 × 800 km) between the Apennine and Balkan Peninsulas and is the northernmost part of the Mediterranean Sea, which connects with the Ionian Sea at the Otranto Strait. The eastern Adriatic coast is mainly transgressive coast of carbonate substrate, with some areas of flysch and Quaternary deposits. It follows the Dinaric range in a NW to SE direction (Pikelj et al., 2013).

Our study site was Velika plaža near Ulcinj (Montenegro), the largest sandy beach along the north-eastern Adriatic coast. The sandy beach is located at the south-eastern end of Montenegro and is bordered by the channel of Port Milena to the west and the Bojana River to the east. It is 13 km long and, on average, 150 m wide (Pikelj et al., 2013). The River Bojana/Buna is the third main source of marine litter input into the Adriatic Sea, but currents take it mostly to north-western coasts and the concentration of floating debris on the Montenegrin coast is therefore low (Liubartseva et al., 2016).

The area is frequently exposed to very strong winds, which carry sand from the shore to the inland (Mijović, 1994). Wind directions are mainly N, NE and E (Deutscheinvestions- und entwicklungs Gesellschaft MBH, 2002). According to the Köppen-Geiger system, the climate of the nearby town of Ulcinj is classified as Csa type – a Mediterranean climate with hot summers (Burić et al., 2014).

Velika plaža is one of the most popular tourist destinations in Montenegro. According to official statistics for the municipality of Ulcinj, around 1 million overnight stays were recorded during the 2012 and 2013 tourist seasons. In terms of relative contribution of tourism to GDP, Montenegro ranks 22nd in the world (World Travel and Tourism Council, 2017).

Velika plaža is heavily impacted by tourism (large number of visitors, built permanent tourist facilities, such as restaurants and showers) and also by illegal dumping, illegal and non-planned sand exploitation, urbanization and a non-sustainable approach to tourist development (Petrović and Karaman, 2009). Contractors of beaches are obliged during summer to clean their own part of the beach daily and to collect waste. The beach is cleaned manually and also mechanically by a municipal company, with special machinery with rakes, but only the most extreme part of the beach. The part of the beach that is not leased is also not cleaned, except sometimes during the pre-season.

3. Methods

3.1. Sampling

We followed the example of Poeta et al. (2014) for the sampling methodology. The stratified random sampling procedure was made with Sampling Design Tool (Buja and Menza, 2012) in ArcGis 10.4 (ArcGIS 10.4, 2015). We used a habitat map of Velika plaža (made by the authors in 2015) (Fig. 1) and randomly sampled 20 plots in each habitat type (Table 1), so altogether 120 plots were recorded. Only dune habitats were sampled (Table 1). We used a standard plot size of 2 × 2 m for sampling sand dune vegetation, since this allows comparison of our results with similar vegetation (Carboni et al., 2009) and beach litter sampling studies (Poeta et al., 2014).

In the field, we located the randomly selected sampling plots using GPS and, in each of the plots, we recorded the number and type of litter items present (see below). Additionally, we visually estimated the cover of every litter category for each plot. Cover is a better estimator of abundance of litter than number when considering the impact on vegetation and the environment, and visual estimation on small plots (e.g., 4 m^2) is easy. Sampling was carried out during May 2017, when the vegetation is optimally developed, and the tourist season and cleaning of the beach have not yet started. Each plot was sampled only

Table 1
Habitat types present on Velika plaža (for further description see (Šilc et al., 2017)).

	EU habitat types (European Habitat Directive (92/43/CEE); European Commission, 1992).
Aphytic shore	Without vegetation
Strandline	1210 Annual vegetation on drift lines (*Cakiletea maritimae*)
Embryonic dune	2110 Embryonic shifting dunes
Foredune	2120 Shifting dunes along the shoreline with *Ammophila arenaria*
Dune slack	2190 Humid dune slacks
Woodland	2270* Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*