Ecological Indicators 89 (2018) 309–316

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Dynamics of plastic resin pellets deposition on a microtidal sandy beach: Informative variables and potential integration into sandy beach studies

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ARTICLE INFO

Keywords:
Sandy beaches
Plastics
Pellets
Mediterranean
Temporal dynamics

ABSTRACT

The study addressed temporal dynamics of plastic resin pellets input on a Mediterranean beach, paired with standard environmental variables known to be relevant to sandy beach ecology. Time-related component of the study were related to two levels: 1) weekly sampling along one year, and 2) allocation of beached pellets to categories "old" and "new" as proxy of the time spent in the environment. Pellets were collected by sieving along a fixed transect perpendicular to the shoreline. In correspondence of each sampling were measured beach width and beach face slope. Weekly records of main wind direction and strength, and seasonal substrate mean grain size estimates were added to the dataset. Both density of total pellets and density of "new" pellets were modelled with quantile regression analysis, and best models were selected by Akaike Information Criterion. Data indicate a constant input of pellets ashore, with about 50% evenly represented by "new" items. Beach width resulted the only variable significant to pellets' density, whether total or "new", with increasing densities of pellets related to narrower beach widths, best explained by a logarithmic fashion. Results hence point to plastic resin pellets as a pressure impact, rather than a spill-related, time-limited one. A list of simple and cost-effective measurements of sandy beach features is provided as a guidance to couple basic ecological information with a possible range of research (including citizen science) addressing beached anthropogenic litter -including plastic pellets. This would ideally enhance the relevance of both research on beached plastics and sandy beach biota, so far running along parallel paths.

1. Introduction

Among Anthropogenic Litter (AL), stranded plastic resin pellets are a common item found on sandy shores (Mato et al., 2001). They are highly interactive with the environment and were found to accumulate Persistent Organic Pollutants (POPs), among them dichlorodiphenyltrichloroethane (DDT) and its metabolites; polychlorinated biphenyl (PCB); hexachlorocyclohexane (HCH) from the surrounding environment (Mato et al., 2001); polycyclic aromatic hydrocarbons (PAH) (Fisner et al., 2013), and metal traces (Holmes et al., 2012). Being about or below 5 mm diameter, pellets are included within the category of microplastics. The release of pellets in the environment is accidental, with main spills related to processes of production and transportation, either via sea or via land. Plastic resin pellets are easily recognizable items, and are defined by different common names: pellets, nurdle, mermaid's tears. Names refer however generically to their size and shape, not to their composition, which is most commonly polyethylene, polypropylene, and nylon (Karapanagioti and Klontza, 2007).

Most studies have so far targeted composition, origin and loads of pollutants adsorbed by pellets, focussing on collections from vaste areas and limited collection time per site (most often a snapshot), including beach areas. The attention of research recently moved towards the inclusion of temporal dynamics of pellets deposition and occurrence ashore. Citizen science actions were found of great help in tackling the temporal dimension and providing key information related to processes and dynamics, for example in the case of citizen monitoring on the beaches of the Great Lakes Region (Vincent and Hoellein 2017; Vincent et al. 2017). The great nurdle hunt, a campaign by FIDRA (https://www.nurdlehunt.org.uk/), proposed a winter and a summer edition, combining a seasonal dimension with a geographical macroarea (Europewide).

Regarding finer temporal information, a study by Moreira et al. (2016) on a small geographical scale identified tide cycles as main driver of pellets deposition -and of eventual bias in their estimation. While such information might not be applicable in microtidal conditions (see e.g. the claim for data about the Mediterranean by Schulz et al., 2015), or on wave-dominated shores, yet it remains clear that

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https://doi.org/10.1016/j.ecolind.2018.02.027
Received 20 November 2017; Received in revised form 7 February 2018; Accepted 8 February 2018

retrieving information on temporal dynamics is relevant both to 1) the understanding of interactions between pellets, physical and biotic environment, and 2) the increase in effectivity of actions and campaigns, including citizen science ones. A focus on indicators related to dynamics is therefore needed to fill gaps and interpret patterns. Time-related indicators of pellets density and deposition ashore were consequently investigated in this study.

1.1. Integration of beached plastic resin pellets studies into sandy beach ecology

A vision encompassing key characteristics of the sandy beach ecosystem and study of beached plastic pellets is indeed essential to open new paths for the understanding of potential interaction between pellets, the beach environment and resident biota. On sandy beaches, fluxes of energy and material were indicated as the primary drivers of sandy beach ecology (McLachlan and Defeo, 2017). Beach morphotypes are shaped by different incoming energy and substrate characteristics (Masselink and Short, 1993). Morphophysical characteristics of a beach are in turn main drivers of resident fauna diversity patterns (Defeo and McLachlan, 2011), with biotic interaction only found relevant when the harshness of the environment allows for them (Habitat Safety Hypothesis and Habitat Harshness Hypothesis, summarized in Defeo and McLachlan, 2013). Beach resident fauna is finely adapted to such conditions, both in terms of population dynamics and behavioural plasticity (Brown, 1996). On the other hand, beach macrofauna was reported to be the key component for trophic functioning of the littoral system and a vital link between primary production and higher trophic levels such as pelagic fish and birds (Reyes-Martínez et al., 2015; Costa et al., 2017). Beach exposure, width and slope were found to be key parameters of sandy beach ecology (Defeo and McLachlan, 2013). Their analysis could also be linked to the analysis and depiction of resin pellets' deposition and potential interaction with the environment. So far, a relationship of POPs content and depth of the stranded pellets was found (Fisner et al., 2013), indicating an important interaction between stranded pellets and beach substrate characteristics. Several other insights could proceed from combined information from different disciplines.

In this respect it is important to remark once again the relevance of the temporal dimension, with regular (daily and seasonal) fluctuations defining changes of the morphophysical environment. Both features of resident and visiting fauna (e.g. nesting turtles, wadying birds) and human impacts (pressure and pulse is in fact a time-based classification of impacts) are characterized by temporal dynamics, particularly in the case of seasonal climates. The consideration of a temporal dimension in the study of beached pellets would then be a relevant step forward, towards the identification of potential synchronic/diachronic phenomena related to the system as a whole.

1.2. The potential of involving citizen scientists in the study of beached plastic resin pellets

Citizen science pilot actions and local campaigns to raise awareness about plastic resin pellets were successfully proposed (Duckett and Repaci, 2015). In fact, the characteristics of pellets (small size, easy to recognize and non-directly associable to AL) as well as their worldwide distribution (see www.pelletwatch.com for a map) makes them a good target for both citizen science and awareness-raising actions at global level (Yeo et al., 2015). Permanent observatories are active at international level (examples are www.pelletwatch.com and www.nurdlehunt.co.uk) and combine these two aspects. The use of a set of basic sandy beaches features, easy and cheap to record yet capable of depict the system and its status, would enhance the potential of such actions. While occurrence and amount of stranded pellets are obvious variables to be recorded, their pairing with a standard set of environmental variables could maximise at once the relevance of information proceeding from beach ecology, actions and campaigns involving citizens, and research on beached pellets. Key beach metrics are easy and non-expensive to measure, and at the same time highly informative to describe the system. The same applies to the temporal perspective: it would be keen to propose a suitable temporal pace, viable for citizen science actions, minimizing the effort and maximising the information.

In this context the weathering of pellets was considered an informative variable. The color of plastic resin pellets found ashore greatly varies in dependence of a suite of factors, and the range of resulting colors depends on the history of every single pellet. Nevertheless, a rough repartition into time-related categories such as "new" and "old" pellets with respect to their presence in the environment (please see detailed explanation in methods below) could provide information related to patterns and dynamics of pellets spills.

1.3. Goal of the study

On these premises, stranded pellets were collected and linked to a set of environmental variables known to be drivers of sandy beach fauna diversity patterns and dynamics. The question to be answered was whether and to which extent these variables are relevant to pellets deposition and stay on the beach. A dense temporal data set and the allocation of pellets to time-related categories allowed the consideration of temporal dynamics in the analysis of both independent and response variables.

Even if this study was not based on citizen science, specific attention was paid to select and test a set of key environmental variables relevant to sandy beach ecology, easy and cheap to retrieve hence suitable to 1) be used in association with campaigns and/or awareness raising actions involving citizens participation 2) enhance the use of common parameters across disciplines.

2. Materials and methods

The approach of model-site was used (Turner and Holmes, 2011; Geng et al., 2016). A microtidal, wave-dominated beach with fine-to-medium sand was targeted to this aim: the sandy beach of Kokkini Chani (N35°19.925′ E25°15.374′ map in supplementary material – Fig. 1) was selected as representative of the stretch of coast of NE Crete: it is exposed to NW winds and currents (Theocharis et al., 1999), characterised by sandy substrate ranging from fine to coarse, and subject to erosion. To counteract erosion, groynes were built decades ago and appear now almost destroyed, yet defining beach units. Also, the presence of groynes ashore prevents the mechanical beach cleaning, which is occasionally (seasonally) performed by hand. Samples were taken in the center of the beach unit, which is where dynamics are expected to be less affected by the presence of groynes (Nordstrom, 2000). A road built immediately behind the littoral interrupts the Littoral Active Zone (the geomorphic system characterized by wind and wave physical control of sand budget, *sensu* Tinley 1985); on the beach it is consequently found pioneer vegetation but no dune. On the same beach there is relatively scarce human frequentation: due to the presence of slippery stones in the water the site is not preferred by swimmers. A mark on the wall behind the supralittoral was used to recognise the sampling site, kept fix throughout the study. Each sampling consisted in sieving along a transect perpendicular to the shoreline with a sieve bag of 25 cm opening and 1 mm mesh size for 5 cm depth. The length of such perpendicular transect was determined by the beach width, i.e. from the water mark to the first dune vegetation, hence variable depending on the meteorological conditions. The area sampled was therefore obtained as the area of the rectangle with 0.25 × length of the transect (m), and used for the density estimates of the items collected. Sampling was repeated weekly, whenever possible, from March 9, 2016 to March 4, 2017. With such sampling frequency, the mark left from the previous week was visible and allowed to easily recognise the transect.