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Original Articles

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

Lucia Fanini[a,*], Fabio Bozzeda[b]

[a] Institute for Marine Biology Biotechnology and Aquaculture, Hellenic Centre for Marine Research (IMBBC-HCMR), Crete, Greece
[b] Centro de Investigación Dinámica de Ecosistemas Marinos de Altas Latitudes (IDEAL), Universidad Austral de Chile, Punta Arenas, Chile

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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

* Corresponding author.
E-mail address: lucia@hcmr.gr (L. Fanini).

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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.

Prior sampling, a blank condition was obtained in the sampling area by sieving twice the transect for a depth of 10 cm and re-placing the sieved sand. In occasion of each sampling thereafter, the sieving was performed on site, with the sieved sand re-placed along the transect to minimize the bias due to depth variations in pellets distribution (Turra et al., 2014). Given the characteristics of the study site, subduction by beach cleaning and massive trampling was excluded as cause of variation in pellets numbers.

Along with each sampling, beach width (m), beach face slope (°), dominant winds (eight quadrants and two categories of strength based on the Beaufort scale) were reported. Seasonal samples of substrate were taken and mean grain size was determined after Folk and Ward (1957). Coarse fraction was reported as percentage in weight. These features were used as independent variables in modelling the density of plastic resin pellets and "new" plastic resin pellets.

The material retained by the sieve was first sorted to separate AL from other substrate, and then sorted again to separate pellets from other AL (Moreira et al., 2016). Color and condition of pellets were used to assess their permanence in the environment. A five-color scale was used by Turner and Holmes (2011) to categorize beached pellets, their age and history. The use of color as indicator of age of pellets was here used cautiously, retaining only two categories: pellets were discriminated between "new" and "old" depending on the time they spent in the environment, as inferred from their colour with respect to the virgin pellets. A scale for tooth color was used as reference (Fig. 1; the scale used as visual reference is a scale wider than the classical 16-shades one, and includes most colors of weathered pellets http://prodotti-speciali.it/wp-content/uploads/2015/02/gradazioni-300x204.jpg), based on the fact that tooth color scales use projections of yellowing and darkening through time and consider color scales related to ageing. Clear and slightly yellowed pellets were considered as newly present in the environment and assigned to the category "new" (shades 1–14 in Fig. 1B). Yellower and darker shades were assigned to the category "old" (shades 15–36 in Fig. 1B). Blue, green and black pellets (expected to be a minority, see Turner and Holmes, Shiber 1979; Shiber 1982 for the Mediterranean) were excluded from this analysis. Surface scratches and scales were also used as discriminant and their presence meant allocation to the category "old".

To obtain a descriptive conceptual model of 1) occurrence of total pellets and 2) occurrence of "new" pellets on the supralittoral, data were analysed with quantile regression (R software version 3.1.2 (R Core Team, 2015)) and the quantreg package (Koenker, 2018). The relationships among the environmental variables recorded and pellets densities were examined at different quantiles (from 0.70 to 0.95 with a 0.01 step width), to explore the boundaries of the relationships for the upper limits defined by the limiting factors. Since the range of values of

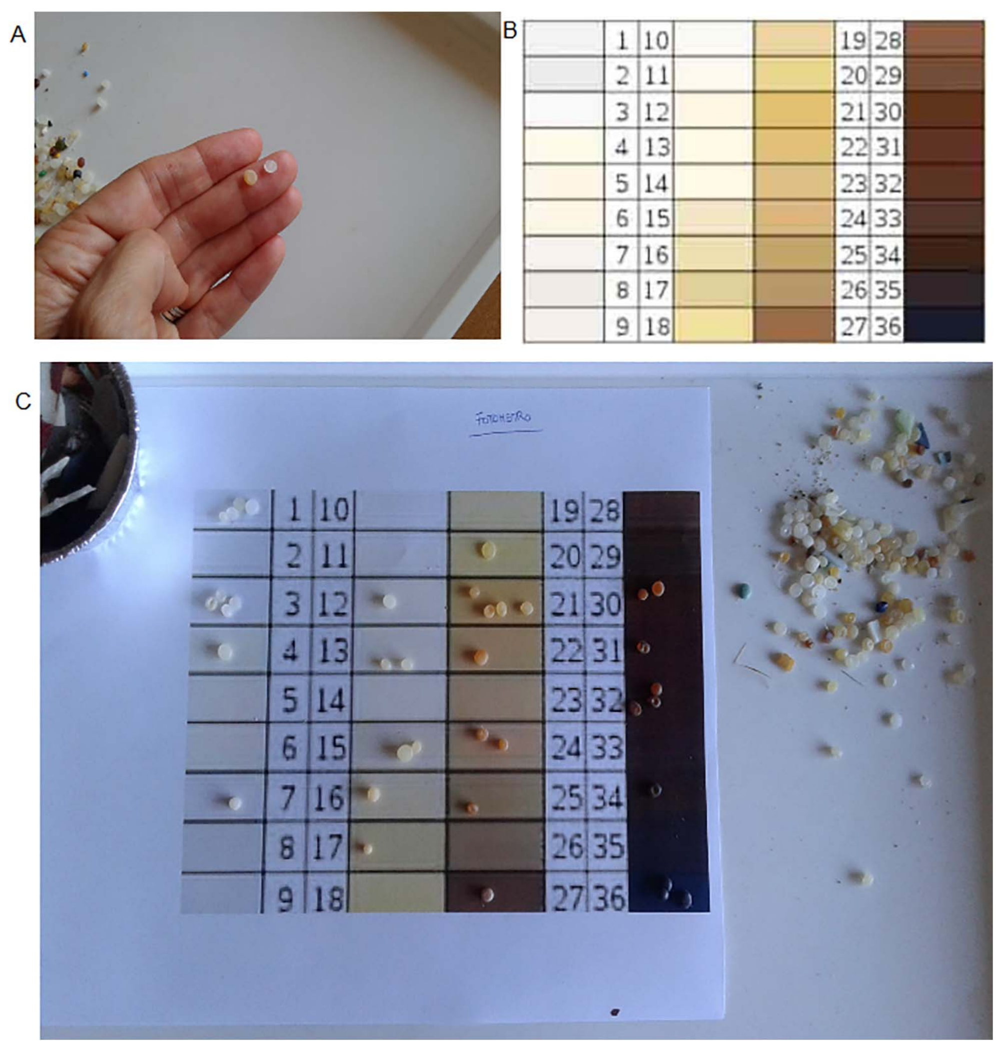

Fig. 1. Visual estimate of time-related pellets categories. A. Pellets sample (on the background) and comparison of virgin pellet with a weathered one. B. Color scale used to assess the two categories. Values 1–14 defined "new" pellets (translucent white to scarce yellowing; non-translucent white to scarce yellowing). Values 15–36 defined "old" pellets (yellowing to darkening). C. Example of visual census of pellets categories. After assigning a color to each pellet, the sample was divided into "new" and "old" as at point B. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

raw data varies widely, quantile regression functions will not work properly without normalization. All independent variables were hence unit-based normalized ($X' = X - X_{min}/X_{max} - X_{min}$). Best models were selected on the basis of the Akaike Information Criterium (AIC) as follows: for each model it was calculated 1) a τ-specific version of AIC, corrected for small sample size (AICc(τ)) for every quantile and 2) the Akaike weights (w_i), i.e. the relative model likelihood given a data set and a set of models (Burnham and Anderson 2002; Johnson and Omland 2004). Best models were determined across the 0.70–0.95 quantiles by averaging w_i for each model form and selecting the best performing one (Allen and Vaughn 2010; Fornaroli et al. 2016). To take into account non-linearity in the relationships, the response of variables was considered using different functions (Constant, Linear, Threshold, Exponential, Logarithmic and Quadratic). The performance of different models was estimated by selecting the best fitting model function for each environmental variable separately and then compare w_i of the resulting best models, to select the one best describing changes in plastic pellets densities ashore.

2.1. Visual vs. spectrophotometric census

The suitability of use of two time-related classes of pellets was tested as follows. Assuming the categories of "new" and "old" pellets depending on weathering/ageing, scales for tooth colors, using ageing-related projections of shades, were used as reference for the obtention of the two categories. The performance of human eye to discriminate the "new" from "old" pellets was tested against a dentistic spectrophotometer (Spectroshade micro MHT) and the correspondent standard color scale (Vita classical scale A1-D4, in which A1-A4 is reddish-brownish; B1-B4 is reddish-yellowish; C1-C4 is greyish; D2-D4 is reddish-grey. The standard color scale Vita Classical used for the spectrophotometer measures is available at https://www.vita-zahnfabrik.com/en/VITA-classical-A1-D4-shade-guide-39699,27568.html with groups A-D characteristics and https://vitanorthamerica.com/products/shade-management/vita-classical-previously-the-lumin-vacuum-shade-guide/ with repositioning color scale from light to dark). A first test was previously performed on the two extremes of the scale (virgin conditions and color shade 33). A total of 50 pellets ranging between colors 1–18 (Fig. 1B) were then randomly extracted from the samples and used for the test. The spectrophotometer measured both color (A1-D4) and translucency (high; high + low; low) of each item. Pellets resulting of shades A1; A2; B1; B2; C1; C2; D2 were assigned to the category "new", while other shades were assigned to the category "old". The same pellet was independently allocated to "new"/"old" categories after estimation by eye, using the color scale in Fig. 1B). The two results were compared notating concordance or discordance of the result. In case of discordant result, translucency values were checked as possible candidates to originate the bias. Prior the analysis, tests were made with a virgin pellet, resulting category B1 high translucency, and a dark brown pellet, resulting category C4 low translucency.

3. Results

Beach conditions were highly variable through time: beach width ranged from 3 to 14 meters, beach slope from 2.20 to 6.75 ° (there is a trend of linearly decreasing beach slope with increasing width, as expected on sandy beaches (McLachlan and Defeo, 2017) however this does not resulted significant; R2 = 0.128) and substrate size from medium (Winter 2016) to coarse (all other seasons). Events of no wind were distributed across summer, autumn and winter, while strong NW winds occurred across all seasons. Strong S winds occurred in spring. One isolated event of NW winds and rain occurred in late summer. All samples contained pellets (Fig. 2), ranging from a minimum density of 1233 to a maximum of 164,00 per square meter. A total amount of 7112 items was collected; of which, more than 50% were "new" pellets; this ratio was kept consistently among samples (Fig. 2).

Beach width resulted the only environmental variable related to pellets density. Namely, density of both total and "new" pellets categories increased with decreasing beach width. This relationship was found to be best described by a logarithmic function (Table 1; Table 2; Fig. 3). This reflects the data indicating a continuous input of pellets ashore: similar amount of beached pellets on a smaller area returns higher densities.

3.1. Notes and observations

A huge amount of stranded shells and shell fragments was found stranded on both the 11th of May and the 10th of October 2016. Storms in December 2016 and January 2017 resulted in clear deposition line/s of detritus and pellets -as those reported by Moreira et al. (2016). Such lines were not observed after other storms, when the stranded material was evenly spread on the littoral.

A heavy rainfall at the end of Summer (19th of September) was found associated with a sudden decrease of pellets, both new and old, found on the beach.

3.2. Eye vs. Spectrophotometer census

Full consistency was found in pellets allocation to "new" and "old" categories between human eye and spectrophotometer, with one exception: all pellets assigned to color 17 (Fig. 1B), i.e. allocated to "old" by human eye, were read by the spectrophotometer as B2, i.e. "new". The mismatch was likely due to the low saturation of this shade, perceived more gray to the eye and therefore interpreted as aged pellet. Hence, the eye proved to be more selective than the spectrophotometer when discriminating "new" pellets. This result supports the inclusion of an eye estimation of simple time-related categories such as "new" and "old" within studies of plastic resin pellets. Translucency was found high, high + low, and low for classes A1 and B1, and low in all other classes. This follows the general trend of loss of translucency with weathering, but does not affect the perceived neither the measured shade of the pellet.

4. Discussion and conclusions

The consistent finding of pellets throughout the whole sampling period was interpreted as an indication of the high mobility of pellets (McCormick and Hoellein, 2016). The scarce seasonal variation in terms of both total and new pellets amount also points to the fact that plastic resin pellets can be considered a pressure impact rather than a pulse or ephemeral condition. However the beach, characterized by a continuous turnover of depositional material, cannot be considered as the final resting place for stranded items (as reported by Bowman et al. (1998) for AL in general). Beaches are in fact shaped by physical factors, and the input of pellets by passive transportation is not an exception. The plastic resin's basis weight is making pellets more likely to be displaced than substrate, under the same current conditions. Pellets, as other debris, may be drifted by main surface currents (IPRC, 2008) and pushed ashore by the dominant currents, which in the microtidal, wave-dominated study site here considered are the main drivers (Theocharis et al., 1999). The observed relationship between beach width and density of pellets suggests that, in a continuous supply context, both wind and beach exposure are relevant to the definition of study sites (Bauer et al., 2009). Two other morphophysical beach features were proposed as related to mobility of plastic items: the dune as stabilising factor (McCormick and Hoellein, 2016) and the relative size of substrate with respect to the beached debris (Williams and Tudor, 2001). In the case-study, the lack of dune likely enhanced the mobility of pellets. The substrate size was below the pellets' diameter (> 1 and < 5 mm), however it is possible that incoming waves contributed to the exhumation of items and their displacement ashore from the swash zone, adding to the count of beached pellets in case of reduced

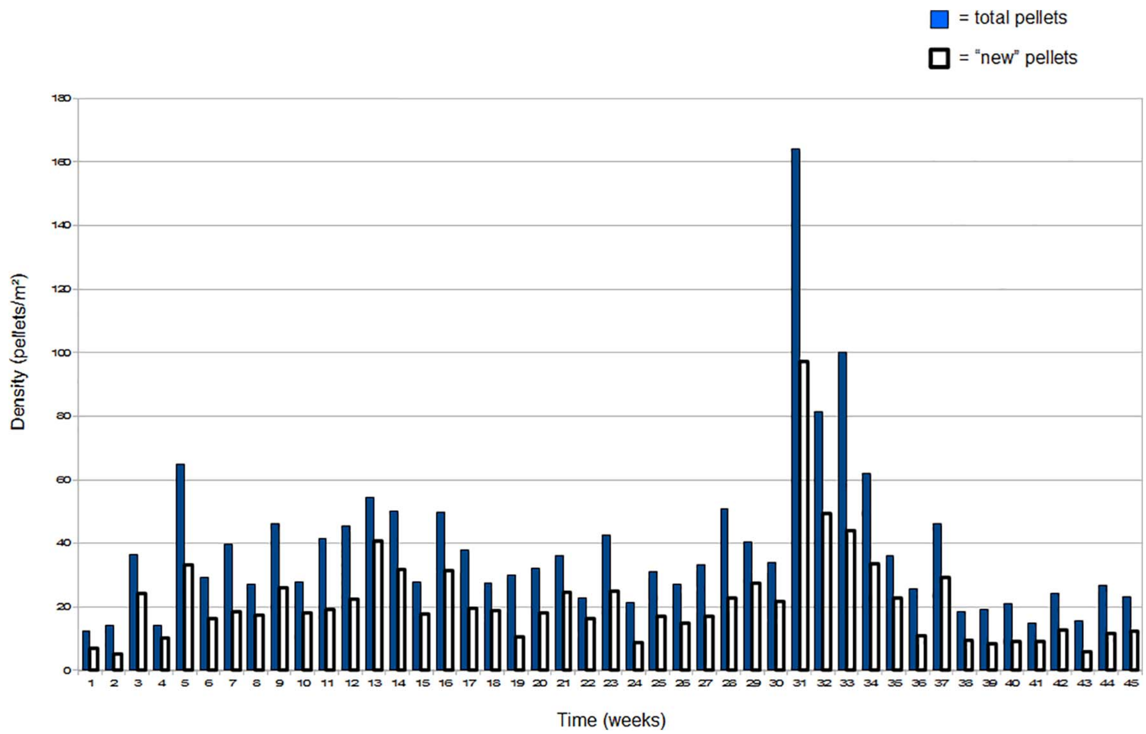

Fig. 2. Density of pellets (pellets/m^2) through time (weeks). Solid bars are total density of pellets; white bars are the fraction of "new" pellets density. Week 1 = 09 March 2016; Week 45 = 07 March 2017.

Table 1
Models fitting results for the density of total pellets. Best fitting is highlighted in bold. LOG: logarithmic function, QUA: quadratic function, EXP: exponential function, LIN: linear function, NL1 and NL2 non linear functions and null: null functions. Wi for LOG function describing beach width = 0.9999 (second best Wi = 2.9 E−05).

Pellets total density					
Beach width		Beach slope		Grain size	
LOG	0.9273	LOG	0.2312	NL2	0.4022
QUA	0.0321	QUA	0.2294	EXP	0.1795
LIN	0.0321	LIN	0.2294	Null	0.1613
NL2	0.0078	EXP	0.1937	QUA	0.0878
EXP	0.0005	NL2	0.0720	LIN	0.0878
Null	1.87E−08	Null	0.0226	LOG	0.0640
NL1	1.97E−09	NL1	0.0213	NL1	0.0170

Table 2
Models fitting results for the density of "new" pellets. Best fitting is highlighted in bold. LOG: logarithmic function, QUA: quadratic function, EXP: exponential function, LIN: linear function, NL1 and NL2 non linear functions and null: null functions. Wi for LOG function describing beach width = 0.9999 (second best Wi = 3.6 E−06).

"New" pellets density					
Beach width		Beach slope		Grain size	
LOG	0.6168	EXP	0.2512	NL2	0.3632
NL2	0.2241	QUA	0.2300	Null	0.1865
QUA	0.0781	LIN	0.2300	EXP	0.1584
LIN	0.0781	LOG	0.1709	QUA	0.0980
EXP	0.0026	NL2	0.0702	LIN	0.0980
Null	1.59E−09	NL1	0.0433	LOG	0.0757
NL1	1.68E−10	Null	0.0042	NL1	0.0197

beach width due to increasing swash.

Rainfall was found associated to a decrease in pellets, even if the event only occured once and it was not possible to perform statistical analysis on that. While water-saturated sand is not easy to move (Van Duk and Stroosnijder, 1996), pellets may instead have been swashed out by a water run-off. Crete does however not have a rainy climate and there was consequently no replication of rainy events between weeks of fine weather to further test this hypothesis. Measurements targeting rain events may be however be informative to tackle circulation of pellets.

The results allow to integrate studies targeting the interaction between beach resident fauna and microplastics (of which plastic resin pellets are a component), as follows: model species such as talitrid amphipods showed that the uptake and excretion, as well as behavioural changes due to microplastic presence in the stomach are temporary, with a gut resident time of about 24 h (Ugolini et al., 2013; Tosetto et al., 2016). However in constant condition of plastics presence in the substrate, these flows through organisms can be assumed as continuous, carrying along the continuous risk of biomagnification through the predation of both resident and visiting macrofauna. A review of references reporting direct feeding on amphipods by shorebirds (Baldwin and Lovvorn, 1994; Dugan, 2006; Colwell, 2010;), crabs (Buck et al., 2003), rats (Drummond, 1960), fish (Fox, et al., 2014) and conspecifics (Duarte et al., 2010) indicates potential paths.

The trends here depicted for density of pellets are opposite than the ones described by Bowman et al. (1998) for macroplastics, where wider beaches hosted higher amounts of AL. In the case of a reduced supralittoral area then, a higher concentration of both pellets (this study) and beach burrowing macrofauna is expected in the narrowed emerged zone (Brown, 1996; Fanini and Scapini 2008).

Also, the beach is the ecological compartment that most degrades pellets, due to their exposure to UV and physical breakdown (Corcoran et al., 2009). At the same time, the size of items makes difficult the formulation of potential strategies to be applied for removing beached pellets from the system: an eventual mechanical separation and removal of pellets to prevent their further circulation and interaction will likely harm the substrate-related arthropod fauna, which is in most cases of comparable size and shares the same zonation on the supralittoral (McLachlan and Defeo, 2017).

The use of a temporal dimension was found suitable to identify the amount of pellets recently spilled – in this case constantly more than

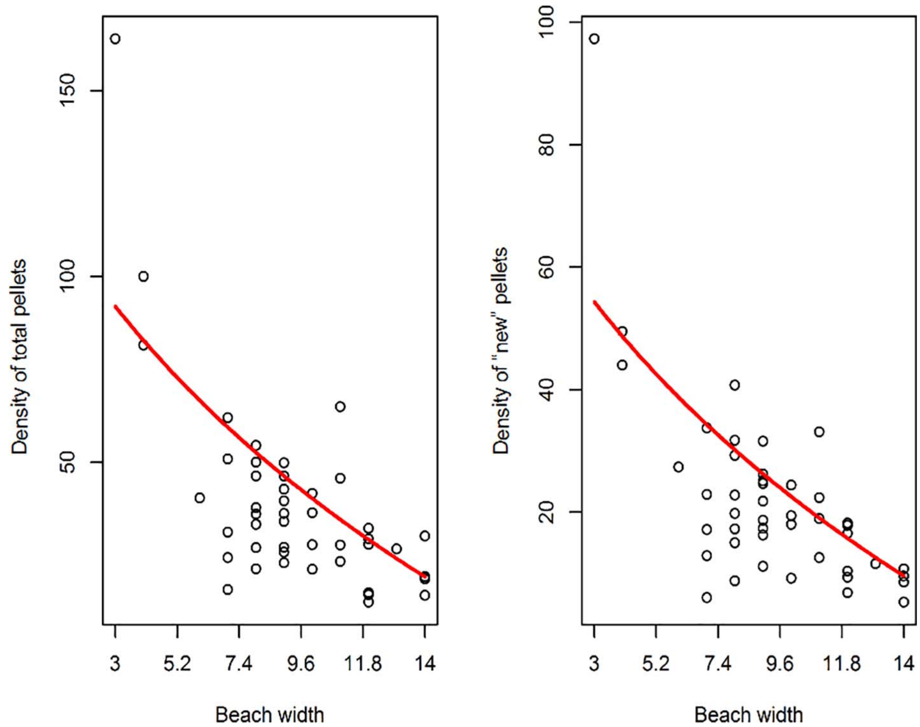

Fig. 3. Best models describing beached pellets densities. Fitting is reported in Table 2.

Table 3
Additional environmental information proposed for collection in occasion of studies regarding beached plastic resin pellets. Physical variables here listed are known to 1) describe the morphophysical status of beaches and 2) be major drivers of patterns and processes of resident beach fauna. Temporal variables also have an effect on 1) substrate characteristics and 2) resident fauna on periodic (daily, seasonal) and contingent (e.g. rainfalls) base.

Physical	Measurable without specific instruments	Proposed general categories	Additional references
Tidal regimen	Yes if general standard categories are considered Data can be retrieved from tide charts	Microtidal; Macrotidal	Local tide charts
Beach width (m)	Yes		Bascom (1951)
Beach exposure	Yes if general categories are considered	Pocket; Bay; Exposed; Sheltered	Bascom (1951)
Beach slope (°)	Yes if general categories are considered No if exact measurement is required	Flat; Steep	Bascom (1951) for beach face slope
Beach substrate	Yes if general categories are considered No if exact measurements are required Possibility of visual estimates and graphic analysis	Fine sand; Coarse sand; Mixed substrate; Pebbles; Cobbles	Bascom (1951), Blott and Pye (2001) and Guilherme et al. (2016)
Temporal	***Measurable without specific instruments***		
Season	Yes -implies replicates on the same beach	Record of the date, then allocated to the season on the base of the climatic zone	
Rainfall	Yes -implies replicates on the same beach	Before rainfall; After rainfall	
Weather	Yes as winds – Beaufort for strength and quadrants for direction Data can be retrieved from meteorological stations	Quadrants (N; NE; E; SE; S; SW; W; NW); 0–12 Beaufort	Explanations available online https://en.wikipedia.org/wiki/Beaufort_scale
Age of pellets	Yes if general categories are considered	New; Old	This paper

50%, likely to indicate not only a continuous input ashore, measurable at local, single-beach level, but also a continuous input in the environment (distal driver). The use of time-related categories ("old" and "new"), based on visual census, resulted 1) a potential contribution to the measurement of beach litter via common biodiversity metrics estimates (Battisti et al., 2017) and 2) to be reliable and viable to be proposed for monitoring actions by non-specialists.

4.1. Contribution to and from citizen science in the study of beached plastic pellets

Citizens could be successfully involved into the study of a broad range of topics, given that adequate background information is provided (as this was found to solve most of the issues related to the reliability of data proceeding from citizen science actions (Garcia-Soto and van der Meeren, 2017). The issue of beached plastic resin pellets is a good candidate for this kind of actions, and key elements for the depiction of environmental patterns can be easily gathered, returning a broader awareness to citizens and an integrated information to researchers (Table 3). The relevance of physical drivers on a beach is a key concept to explain both impacts related to beached plastics and the "personality" of a beach, including substrate, dunes, and resident biota characteristics – on which the plastics input will have an effect.

It is thought possible for both researchers and citizen scientists to recognise by eye "new" pellets from weathered ones and allocated them to two basic time-related categories. These simple categories can then be used to communicate the inputs of plastic pellets into the environment as a pulse vs. pressure impact. A budgetary approach (as for example estimated by Bowman et al. (1998) for AL) to plastic pellets can also be easy to communicate.

The information related to substrate characteristics and beach exposure (as explained by Bascom, 1951) is easy to gather and would greatly improve citizen science actions, providing awareness of the sandy beach environment as a whole. Substrate size estimates still lack standardization, but general categories can be proposed (Blott and Pye, 2001) and tested with specific questions regarding interaction of beached pellets with different substrate categories (see e.g. Williams and Tudor, 2001 for AL and cobble interactions). Also, the improvement of visual methods for substrate identification (Guilherme et al., 2016) could pave the way to a standardized, accurate yet non-expensive information. A basic set of parameters related to the LAZ and its dynamics, encompassing physical environment and biota is presented (Table 3). They are proposed as standard additional information to accompany and/or be collected in occasion of citizen science actions related to beached plastics. Most parameters are easy to record and require minimal (GPS; access to meteorological data) equipment and knowledge. A repartition in categories is also proposed for some variables, to facilitate their use. Along with those it is reported the detailed procedure for indexing and related reference.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2018.02.027.

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