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Angela RIZZO [1,2], Angelo SOZIO [1*], Giorgio ANFUSO [3],
Marco LA SALANDRA [1] & Corrado SASSO [1]

THE USE OF UAV IMAGES TO ASSESS PRELIMINARY RELATIONSHIPS BETWEEN SPATIAL LITTER DISTRIBUTION AND BEACH MORPHODYNAMIC TRENDS: THE CASE STUDY OF TORRE GUACETO BEACH (APULIA REGION, SOUTHERN ITALY)

Abstract: Rizzo A., Sozio A., Anfuso G., La Salandra M. & Sasso C., *The use of UAV images to assess preliminary relationships between spatial litter distribution and beach morphodynamic trends: the case study of Torre Guaceto beach (Apulia Region, southern Italy).* (IT ISSN 0391-9838, 2022).

Beach litter (BL) represents one of the major threats to coastal areas and related ecosystems. Monitoring programs based on in situ visual surveys allow the identification and classification of BL items. Nevertheless, such activities are time-consuming and only cover limited coastal stretches. Due to the above limitations, recent studies are exploiting the use of Unmanned Aerial Vehicles (UAV) to collect photogrammetric images for the monitoring of litter-related pollution. In this study, the BL spatial distribution along the Torre Guaceto beach (southern Italy) is assessed by mapping macro (> 2.5 cm) items on the orthomosaic obtained through the post-processing of UAV images. Furthermore, in order to define the recent morphodynamic evolution and analyze the potential influence of coastal process in the dispersion and accumulation of BL along the beach profile, morphological changes that occurred in the last 20 years have been estimated in the GIS environment. From the manual image screening process, a total number of 382 items BL are identified. The highest number of items are composed of artificial polymers/plastic (88%), followed by glass and textiles (3.4%). What concern the morphodynamic evolution, the central part of the investigated sector has been interested by a general retreat trend, especially in the last two years. Recent erosion processes affected mostly the fixed vegetation, whose limit has been affected by a retreat up to 3 m. The highest density of BL has been estimated for the inner part of the investigated beach, which corresponds to the area from the embryo dune to the foredune limit. In conclusion, this study highlights how the use of UAV systems enhances the monitoring of wide coastal sectors and the analysis of beach morphodynamic characteristics, this way supporting the easy identification of hotspot areas for BL accumulation as well as the establishment of appropriate clean-ups works.

Key Words: Coastal monitoring, Coastal geomorphology, Drone, Shoreline evolution, Litter pollution

Riassunto: Rizzo A., Sozio A., Anfuso G., La Salandra M. & Sasso C., *L'utilizzo di immagini UAV per l'analisi preliminare della correlazione tra la distribuzione del* beach litter *e i processi morfodinamici costieri: il caso dell'area di Torre Guaceto (Puglia, Italia).* (IT ISSN 0391-9838, 2022).

La presenza di rifiuti spiaggiati (*beach litter* - BL) rappresenta una delle principali problematiche che interessano le aree costiere e i relativi ecosistemi. I programmi di monitoraggio basati su indagini visive in situ consentono di identificare e classificare in termini di dimensione e tipologia i rifiuti spiaggiati. Nonostante l'elevata accuratezza, tali attività richiedono intense attività di campo e consentono di analizzare tratti costieri di limitata estensione. A causa di queste limitazioni, studi più recenti sono volti a promuovere l'uso di veicoli aerei senza pilota (droni) per l'acquisizione di immagini fotogrammetriche da utilizzare per l'analisi della distribuzione spaziale del BL. In questo studio, la presenza e la densità del BL è stata valutata attraverso la mappatura di oggetti con dimensioni > 2,5 cm (*macro-litter*) sull'ortomosaico ottenuto attraverso il post-processing di immagini UAV acquisite lungo la spiaggia di Torre Guaceto (provincia di Brindisi, regione Puglia, Italia). Inoltre, al fine di valutare la potenziale influenza dei processi morfodinamici nella dispersione e nell'accumulo di BL lungo il profilo di spiaggia, i cambiamenti morfologici avvenuti negli ultimi 20 anni sono stati stimati in ambiente GIS. Dal processo di screening manuale delle immagini, è stato identificato un numero totale di 382 elementi di BL. I risultati ottenuti mostrano che il maggior numero di elementi è composto da polimeri artificiali/plastica (88%), seguiti da vetro e tessuti (3,4%). Per quanto riguarda l'e-

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voluzione morfodinamica, la parte centrale del settore indagato è stata interessata da un generale trend di arretramento, soprattutto negli ultimi due anni. I recenti processi erosivi hanno interessato soprattutto la vegetazione fissa, il cui limite ha registrato un arretramento massimo di 3 m. La densità più alta di BL è stata stimata per la parte interna della spiaggia indagata, che corrisponde all'area che va dalla duna embrionale al limite della duna primaria. In conclusione, questo studio evidenzia come l'uso di sistemi UAV possa supportare il monitoraggio di ampi settori costieri, favorendo in questo modo la facile identificazione di aree critiche per l'accumulo di BL e della loro tendenza nel tempo così come la definizione di appropriate strategie di ripristino ambientale.

Termini Chiave: Monitoraggio costiero, Geomorfologia costiera, Drone, Evoluzione del litorale, *Beach litter*

INTRODUCTION

Coastal areas constitute places of great ecological, aesthetic, scientific, recreational, social, economic, and cultural interest (Millennium Ecosystem Assessment – MEA, 2005; Council of Europe, 2012; Pilkey & Cooper, 2014). They provide several ecosystem services and related functions essential for human well-being (MEA, 2005), this is especially true for natural systems such as beaches, dunes, and salt marshes located in protected areas where such environments constitute privileged nesting places for birds, fishes, marine mammals, crustaceans, amphibians, and marine turtles (Fabbri, 2012; Costanza & *alii*, 2014). As an example, for the Mediterranean Sea – that only account for 0.82% of the global ocean surface, yearly benefits derived from ecosystem services are estimated to be over 26 billion (Timothy, 2012; Claudet & Fraschetti, 2010). Similarly, beaches have also a remarkable economic relevance, hosting facilities and amenities for recreational activities and attracting therefore a high number of visitors and tourists.

Due to the high ecological and social-economic values, the increasing abundance of litter items in coastal environments represents a major threat at both the local and regional levels. In this context, the Marine Strategy Framework Directive (MSFD) identifies macro and micro-litter as major threats to marine ecosystems.

According to international definitions, beach litter (BL) corresponds to all persistent, manufactured, and processed solid material discarded, disposed, or abandoned in the marine and coastal environment (OSPAR, 2010; United Nations Environment Programme – UNEP, 2005, 2021). BL is constituted by a wide range of materials, including glass, ceramics, paper, textiles, and many others. Nevertheless, plastics, which include polypropylene (PP), high- and low-density polyethylene (HDPE and LDPE), polyvinyl chloride (PVC), polyurethane (PUR), polyethylene terephthalate (PET) and polystyrene (PS), represent the most abundant and widespread category (Plastics Europe, 2019).

Due to the impacts that BL can have on natural ecosystems, anthropogenic activities, and human wellness, it is very important to monitor its presence, especially in areas hosting particular habitats and high biodiversity. Therefore, BL monitoring programs represent a valid tool to analyze the items' presence and their characteristics. In the last decade, an increasing number of studies have been focused on the analysis of BL assessment by carrying out *in-situ* surveys following the international procedures specifically proposed to collect information on BL typology (cf. "Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area" - OSPAR Commission, 2010; "Guidance on Monitoring of Marine Litter in European Seas" - Hanke & *alii*, 2013; "Methodology for Monitoring Marine Litter on Beaches" - Vlachogianni, 2017, "Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean" GESAMP, 2019). Such kinds of studies allowed for defining the environmental status of the investigated coastal sectors by evaluating the BL density, composition, and hazardousness by means of a number of environmental indices specifically proposed to this aim (Alkalay & *alii*, 2007; Rangel-Buitrago & *alii*, 2018, Rangel-Buitrago & *alii*, 2019, Rangel-Buitrago & *alii*, 2021).

More recently, an increasing number of studies is focusing on the exploitation of photogrammetric images acquired by means of UAVs (i.e., drones) to monitor coastal environments and related geo-environmental issues (e.g., flooding, pollution, land use modifications).

For what concerns the use of UAV images to assess litter distribution on coastal environments, the images post-processing can be carried out by means of both manual visual screening and algorithms developed for the automatic identification. Andriolo & *alii* (2020, 2021) have focused their analysis on the identification of macro-litter on dune systems, revealing the spatial relation between litter hotspots and dune blowouts. In this case, the orthophoto of the investigated area was visually screened and manually processed in a GIS environment to mark the litter items.

On the other hand, several studies have explored the application of ML techniques to identify BL items on orthomosaics. By way of example, Fallati & *alii* (2019) used a commercial deep-learning software to automatically quantify the litter debris, while Scarrica & *alii* (2022) proposed a Convolutional Neural Network model for the object segmentation.

From the accounted studies, it emerges that UAV images allow to cover a wider portion of the coastal sector without requiring extensive and time-consuming field activities.

Although the high number of studies (Cesarano & *alii*, 2021, 2023) published in the last 15 years, very few assessed the interactions between the BL spatial distribution and the site-specific morphodynamical characteristics. Asensio-Montesino & *alii* (2020) analyzed the cross-shore distribution of BL from the shoreline up to the landward limit of each investigated meso-tidal beach in Andalusia (Spain). In their study, the authors found out that the mean BL abundance per beach zone was higher for the high-tide water level and the backshore area. In addition, the authors highlighted that, differently from the meso-tidal conditions, in the Mediterranean beaches the higher BL density occurs along the beach landward limit (normally a wall, houses/buildings, dunes, vegetation line, etc.). These differences highlighted the remarkable role played by the tidal range, morphology of the beach, its size, and environment, in influencing the distribution and abundance of BL items.

In this study, a special focus is given to the analysis of BL spatial distribution along the Torre Guaceto beach, located in southern Italy along the Adriatic Sea, a micro-tidal coast. The investigated beach is included in the Marine Protected Area (MPA), established in 1991. Although its remarkable environmental importance, an analysis carried out in 2021 by applying an in-situ survey allowed highlighting that the area is characterized by a moderate litter magnitude (avg: 0.47 items/m^2) and that plastics dominate among all the litter items, representing almost 75% of the collected items (Rizzo & *alii*, 2021). Nevertheless, up to date, no information is available on the BL distribution along the beach profile and related influencing processes. To fix this gap, in this study, a first attempt to link the potential influence of coastal morphodynamic processes with the BL abundance is provided. Since actual beach litter distribution is due to morphodynamic processes that took place mainly in recent months, the relations between litter distribution and coastal evolution at short-term scale is analyzed. Then, a comparison with the coastal evolution at middle-term scale is also provided.

STUDY AREA

Torre Guaceto beach is located north of the city of Brindisi on the Adriatic coast of the Apulia Region in south-eastern Italy (fig. 1a). This coastal sector belongs to a natural protected area established with the aim of preserving the local habitat biodiversity and protecting a wide wetland separated from the sea by a well-established dune system. The area also belongs to the Natura 2000 ecological network under the features of Special Protection Area (IT9140008 "Torre Guaceto") and Site of Community Importance (IT9140005 "Torre Guaceto e Macchia San Giovanni"). The protected area includes marine and terrestrial zones: the Marine Protected Area (MPA) was established in 1991 by a Decree of the National Environmental Ministry. The Natural Terrestrial Reserve (NTR) was established in 2000. In 2007, the MPA and the NTR were Included in the "Specially Protected Areas of Mediterranean Importance" (SPAMIs) list, envisaged by the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention, 1995). The geological setting of the area is strongly related to the past sea-level oscillations that occurred during the Middle-Late Pleistocene that determined downward and seaward shifts of the shoreline position (Mastronuzzi & *alii*, 2011, 2018; De Giosa & *alii*, 2019). In particular, the present-day coastal morphology, which is characterized by the presence of a series of sub-circular inlets that host pocket beaches bordered by a polyphasic dune ridge, is the result of Holocene marine transgression (last 12 ka BP). Limited quantities of sediments delivered by streams

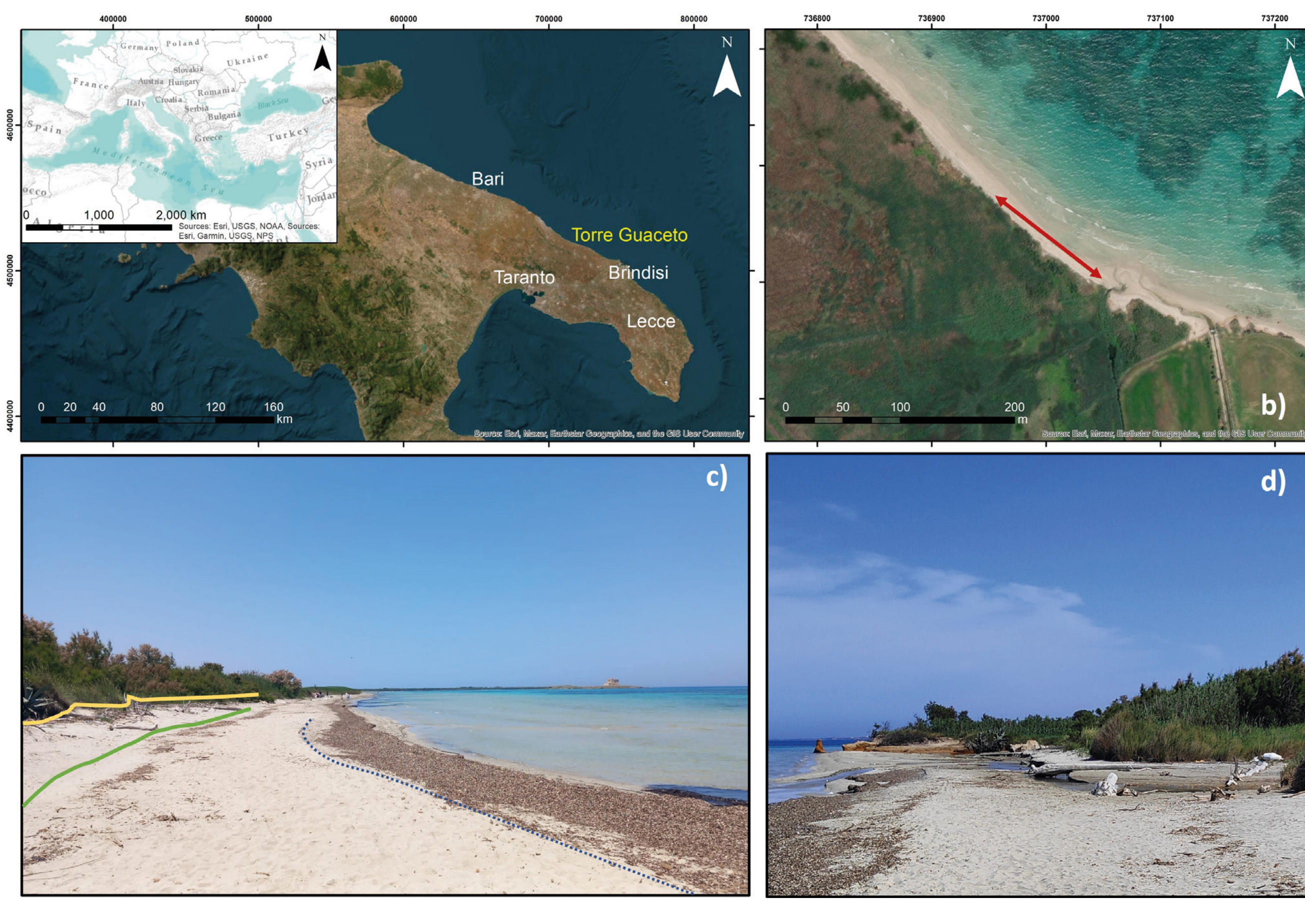

FIG. 1 - a) Study area location; b) Coastal area investigated in this study (red arrow); c) Morphologies identifiable in the study area: small berm (blue dotted line), embryo dune (green line), stabilized foredune (yellow line); d) Canale Reale mouth.

and torrents are redistributed along the coastal area by the predominant NW-SE longshore current. The investigated coastal sector (figs. 1b, 1d) is characterized by the presence of the "Canale Reale", which is a 48 kilometers long creek. After crossing the province of Brindisi almost longitudinally, it reaches the Adriatic Sea inside the MPA. From the geomorphological point of view, the investigated beach is characterized by a dissipative beach profile with, from sea to land:

a) a dissipative nearshore and beach face;
b) small berm and flat backshore (blue dotted line in fig. 1c);
c) embryo dunes (green line in fig. 1c), at places not observed;
d) stabilized foredune (yellow line in fig. 1c) with a well-developed vegetation cover.

METHODS

The field activities were conducted in May 2023, before the high-season touristic period started, this way avoiding the influence of beachgoers on litter abundances. Moreover, weather conditions were characterized by very low energy, as demonstrated by wind data measured before and during the survey (wind speed < 3 m/s) using a portable anemometer. Therefore, observed beach litter was essentially related to marine based sources and stranded on the beach during the last months, mostly during storm events. The identification of the areas where litter items accumulate along the beach profile is based on a two-phase procedure. In the first phase (blue box in fig. 2), the litter distribution map is created. To this aim, images acquired by UAVs are post-processed in order to obtain the orthomosaic of the investigated areas; then, orthomosaic is imported into the GIS environment and litter items are mapped. The second phase (green box in fig. 2) is aimed at assessing the morpho-evolutive trends that characterize the investigated coastal sector. This evaluation is based on the detection of the shoreline proxies and their analysis in the GIS environment. The overlay of the litter distribution map with the morphological trends allows the identification of predominant processes characterizing the coastal zones where BL density is higher as well as the potential hotspot areas, for which tailored management strategies can be proposed. In the following sub-paragraphs, each phase of data acquisition and elaboration is described in detail.

Phase 1: Litter distribution assessment -UAV images acquisition and post-processing

Aerial images were acquired by using a multirotor quadcopter UAV "DJI Inspire 2" equipped with a "DJI Zenmuse X5S" optical camera (20.8 MP, DJI MFT 15 mm/1.7 ASPH supported lens, 4/3" CMOS sensor, FOV 72° and image resolution 5280 × 3956 pixel) owned by the Department of Earth Sciences of the University of Bari (Italy). Following the survey characteristic applied in previous studies also dealing with UAV survey on sandy beaches in micro-tidal environments (Fallati & *alii*, 2019; Scarrica & *alii*, 2022), the drone flew at an altitude of 15 m AGL of take-off location with the camera set perpendicular to the main path of the flight (camera angle -90°). The aero-photogrammetric survey, carried out from 11 A.M. to 13 P.M. on the 25th of May, was planned using the software *Litchi flight* on which was possible to set the drone speed at 1.3 m/s, the ISO sensibility value at 100, the f-stop at f/9, the exposure time and the focal length of the camera at 1/800 s and 15 mm, respectively. Furthermore, to fulfill the international monitoring guidelines (as reported in the introduction section), the flight mission covered an area of 100 m in length with the flight path designed as a single grid of straight lines perpendicular to the shoreline.

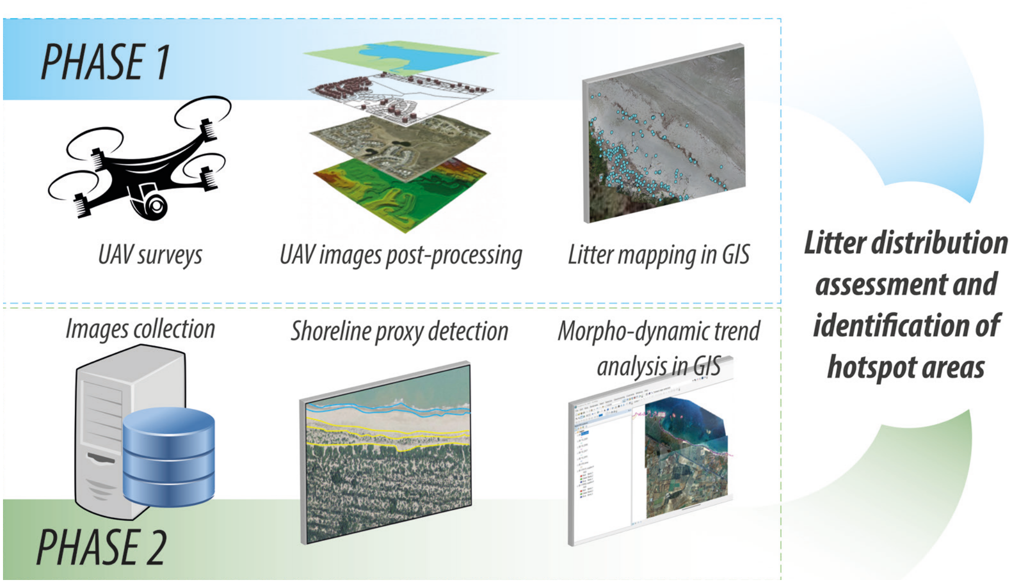

FIG. 2 - Flow chart of the methodological approach applied for the analysis of the BL distribution and the identification of hotspot areas.

Fig. 3 - Drone DJI Inspire 2 during the field survey carried out in May 2023.

In order to perform an accurate georeferencing process, a total number of 18 Ground Control Points (GCPs) were placed within the investigated area. To this aim, a Stonex S9III-N GNSS receiver in Real Time Kinematic (GNSS-RTK) mode was used to estimate the coordinates of each GCP with a vertical accuracy of about 0.02 m and horizontal accuracy of about 0.01 m.

Post-processing of the images was performed through Agisoft Metashape Professional (v. 1.6.5), which follows the principle of the Structure from Motion (SfM) process (Mancini & *alii*, 2013) and enabled the generation of the Digital Surface Model (DSM) and related RGB orthomosaic. Furthermore, the Ground Sampling Distance (GSD) was calculated following the formula proposed by Ventura & *alii*, (2018) based on pixel dimensions, camera focal length (mm), sensor width (mm), and flying height above the ground (m).

Beach litter mapping and spatial distribution analysis

The distribution of BL along the investigated area is analyzed by mapping all the items recognizable on the orthomosaic. To this end, a dedicated database was created as a point shapefile in the GIS environment. Each item was identified by a point manually inserted by the operator at the center of the item itself. Furthermore, each item was briefly described and classified based on the J-codes proposed by the European Commission in 2021 (Fleet & *alii*, 2021) for the application of a common classification system. According to this classification, the following litter categories are identified:

– artificial polymer materials/plastic;
– cloth/textiles;
– glass/ceramics;
– metal;
– paper/cardboard;
– processed/worked wood;
– rubber.

Nevertheless, when it was not possible to assign a specific class to a litter item, it was attributed to the other/unspecified category.

In order to evaluate the BL spatial distribution along the beach profile, the 100 m investigated area was divided in four sections, as it follows:

– the first section includes the upper part of the foreshore (beachface);
– the second section includes the area from the first strandline (i.e., the most recent one) to the last strandline (i.e. the inner one);
– the third sector includes the area from the last strandline up to the seaward limit of the embryo dune (here identified as the first line of incipient vegetation);
– the fourth sector includes the area from the embryo dune to the foredune limit.

Phase 2: Coastal morpho-dynamic trends assessment - Data collection and analysis

The analysis of the coastal morpho-dynamic trends is based on the evaluation of:

– short-term changes occurred from 2021 to 2023;
– middle-term changes occurred from 2006 to 2021.

The morpho-dynamic changes are evaluated using the Digital Shoreline Analysis System (DSAS) tool of Arc-GIS developed by the US Geological Survey (Thieler & *alii*, 2009). DSAS allows the calculation of the rate-of-change statistics for a time series of shoreline/dune proxies. In detail, the shoreline position for the years 2011 and 2006 was digitalized from orthophotos available on the Apulia Region geo-portal (*http://www.sit.puglia.it*, accessed in June 2023). The shorelines relative to the years 2021, 2020, 2018, 2017, and 2015 were digitalized from Google Earth Pro and imported as linear features in GIS environment. For the detection of short-term modifications, UAV images acquired in May 2023 are used. The high-water level (i.e., the wet/dry mark) was selected as the shoreline proxy while the first line of fixed vegetation was selected as the dune proxy (Boak & Turner, 2005).

Variation trends were evaluated along transects built with a distance of 10 m in terms of two statistics: the Net

Shoreline Movement (NSM) and the End Point Rate. The former provides the distance between the oldest and the youngest proxy and it is expressed in meters. The latter is determined by dividing the NSM by the time elapsed between the two shorelines and it is expressed in meters/year. In the case of middle-term analysis, the Linear Regression Rate (LRR) is also calculated. It is determined by fitting a least-squares regression line to all the available proxies and it is expressed in meters/year. The estimated positive or negative values indicate accretion or erosion processes, respectively.

RESULTS

Beach litter mapping and spatial distribution analysis

A total amount of 295 images were acquired during the UAV survey of the studied area and their post-processing resulted in two main products: an orthomosaic and a DSM. The former has an RGB color scale and a GSD value of 2.1 mm/pixel. The DSM reported orthometric heights referred to the local mean sea level (MSL) and has a horizontal spatial resolution value of 4.2 mm/pixel. Both products were exported in GeoTIFF format to be available and utilized in GIS software.

Once the orthomosaic has been imported into GIS, two operators carried out the manual image screening. This step has led to the identification of 382 BL items (figs. 4 and 5) in a total investigated area of 1300 m^2, which includes the four analyzed sections (cf. paragraph "Methods").

Each item was first classified according to the most recent classification codes (EC, 2021) and was than assigned to a specific category. Each operator executed the image screening using two different GIS software (ArcMap and QGIS) and without being aware of each other's work. Items > 2.5 cm (commonly used for beach litter monitoring) were classified according to the specific guidelines (GESAMP, 2019). Furthermore, litter items < 2.5 cm were also identified and reported as fragments because, due to the orthomosaic resolution, they were too small for their allocation within a particular litter category. The visual screening of litter items allowed to obtain a complete dataset composed by items with different sizes, and main identification problems concerned the items between 2.5 and 5 cm in length. In fig. 4, some examples of identified items are provided. In detail, a polystyrene piece (category J82), a drink glass bottle (J200), and a net for mussel/fishing activities (J45) are shown in figs. 4a, 4b, and 4c, respectively. Based on the manual image screening, it emerged that the higher number of items is represented by plastic (336 items), followed by the glass and textiles categories (13 items in each category), metals (8 items), wood and paper (5 and 4 items, respectively) and, finally, rubber and not identified items (2 items in both cases). As shown in fig. 6 (a), plastic items represented 88% of all the identified BL, being the most represented items included in the classes J79 (164 items), J45 (39 items), J8/J7 (37 items), J9 (30 items), J22/J23 (19 items). Items with percentage values ranging from 1 to 5 are included in classes J18, J82, J240, J63, J4. In fig. 6 (b) the percentage distribution of the plastic items is indicated. The class "others" includes all the plastic items with a percentage lower than 1% (J28, J228, J16, J65, J23, J12).

Considering all the items identified in the whole investigated area, a BL density of 0.29 items/m^2 was calculated. For what concerns the distribution of the BL along each section, the results showed that the highest number of items (243) characterizes the fourth section, which identifies the area from the embryonic dune to the foredune limit (fig. 7). The second and third sections were characterized by a quite similar distribution of BL, with 64 and 50 identified items, respectively. Based on these results, the corresponding density values were 1.24 items/m^2 (for section 4) and 0.19 (for sections 3 and 2). Finally, only three items were identified along the beachface (section 1). This means that, excluding the section 1 from the calculation, the density value estimated for the backshore area (which includes sections 2, 3, and 4) increased up to 0.48 items/m^2.

Quantitative analysis of the morpho-dynamic changes

The analysis of the morpho-dynamic changes was based on the calculation of the NSM, LRR, and EPR indicators, whose interpretation allows to define the predominant processes characterizing the investigated coastal sector.

In particular, regarding the short-term modifications (i.e., modifications that occurred in the last 2 years), the analysis was carried out by considering both the shoreline and the fixed vegetation proxies. In the case of the shoreline, EPR values ranged from -1.6 m/yr to 1.5 m/yr (fig. 8a) with a mean value of 0.20 m/yr while NSM value ranged from -2.8 to 2.7 m (fig. 8b) with a mean value of 0.35 m. For what concerns the modifications in the limit of the fixed vegetation, in the last two years, the study area was characterized by a general retreat process, with EPR values ranging between -1.9 and -1.0 m/yr, respectively. The corresponding NSM are -3.4 and -1.8 m, respectively (Table 2). The mean values are -1.4 m/yr (EPR) and -2.5 m (NSM).

For what concerns the middle-term modifications (i.e., shoreline displacements that occurred from 2006 to 2021), the results showed that the EPR ranges from a minimum value of -0.18 m/yr to a maximum value of 0.54 m/yr (fig. 9a) with an estimated mean value of 0.1 m/yr. For what concerns the NSM (fig. 9b), the investigated area was characterized by a maximum retreat value of -2.7 m and a maximum accretion value of 6 m (Table 2). The estimated mean NSM value is 0.7 m. Higher retreat values characterize the northern part of the investigated coastal sector (fig. 9b, from transect 1 to 5), while the southern part (fig. 9b, from transect 9 to 12) is characterized by high positive NSM values. Finally, by considering the LRR index, which is evaluated accounting for all the available shorelines, the values range from -0.14m/yr to 0.07 m/yr, with maximum values estimated for the same transects with maximum EPR values.

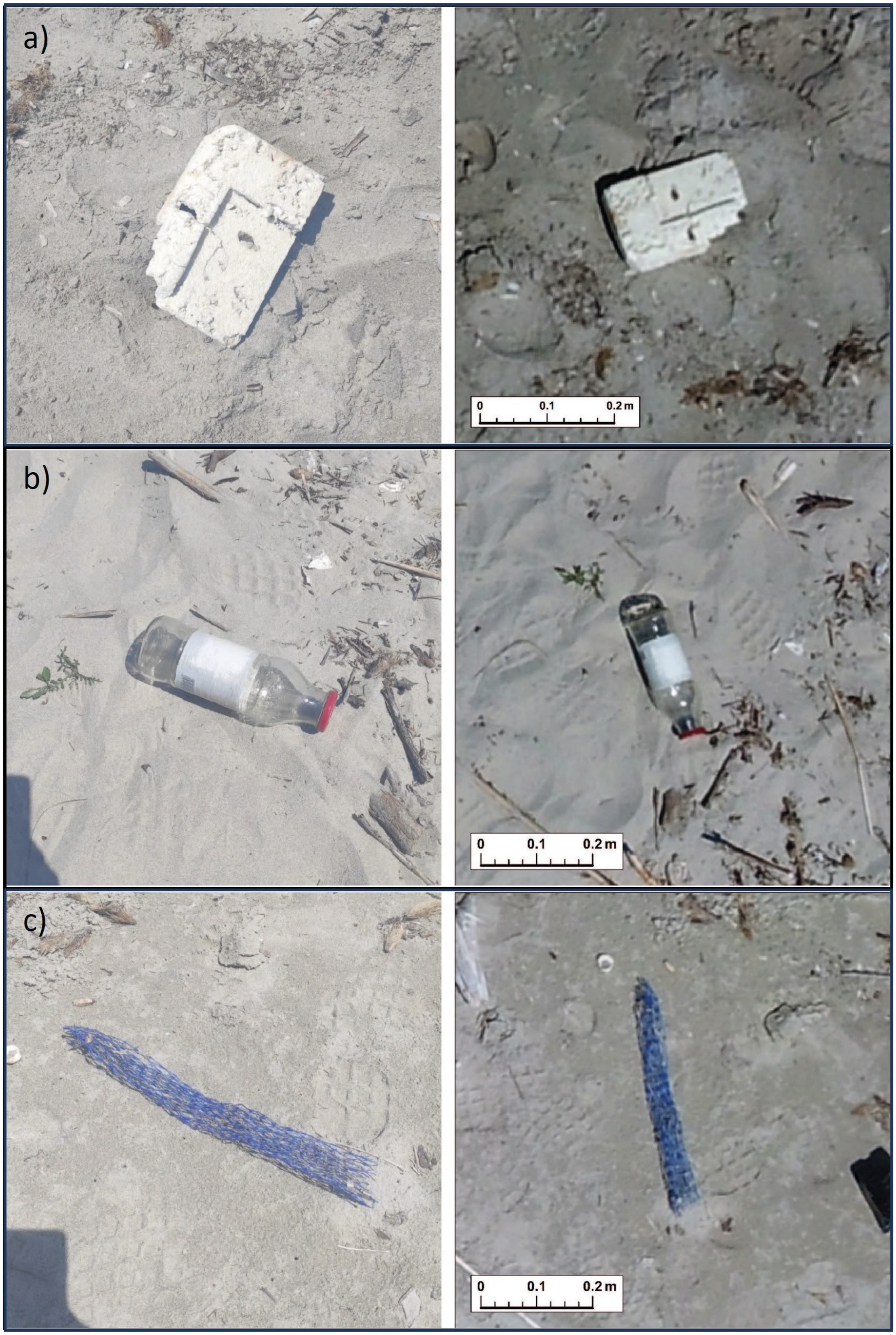

FIG. 4 - Examples of litter items identified during the in-situ survey and their corresponding identified by the manual image screening in GIS environment: a) polystyrene pieces (J82), b) drink glass bottle (J200), and c) net for mussel/fishing activities (J45).

TABLE 1 - BL items identified by the visual analysis that is performed in a GIS environment.

J-Code	*Description*	*Material*	*Number of items reported*
J9	plastic bottles and containers of cleaning products	Plastic	30
J82	fragments of foamed polystyrene 2.5 cm ≥ ≤ 50 cm	Plastic	8
J8/j7	plastic drink bottles ≤ 0.5 l/plastic drink bottles > 0.5 l	Plastic	37
J79	fragments of non-foamed plastic 2.5cm ≥ ≤ 50cm	Plastic	164
J63	plastic floats/buoys	Plastic	4
J65	plastic buckets	Plastic	2
J45	plastic mussels/oyster mesh bags, net sack	Plastic	39
J4	small plastic bags	Plastic	4
J28	plastic pens and pen lids	Plastic	3
J240	other identifiable foamed plastic items	Plastic	7
J228	plastic cutlery	Plastic	3
J22/J23	plastic caps/lids chemicals, detergents (non-food) / plastic caps/lids unidentified	Plastic	19
J18	plastic crates, boxes, baskets	Plastic	11
J16	plastic jerry cans	Plastic	3
J12	plastic non-beach use related body care and cosmetic bottles and containers	Plastic	1
J202	glass light bulbs	Glass	2
J200	glass bottles	Glass	11
J174/J175	metal aerosol/spray cans/metal drinks cans	Metal	6
J171/J172	other processed wooden items 2.5 cm ≥ ≤ 50 cm / other processed wooden items > 50cm	Wood	5
J148	cardboard boxes	Paper	3
J156	paper fragments	Paper	1
J145	other textiles	Textiles	6
J138/J102	shoes & sandals made of leather and/or textile / plastic flip-flops	Textiles	7
J134	other rubber pieces	Rubber	2

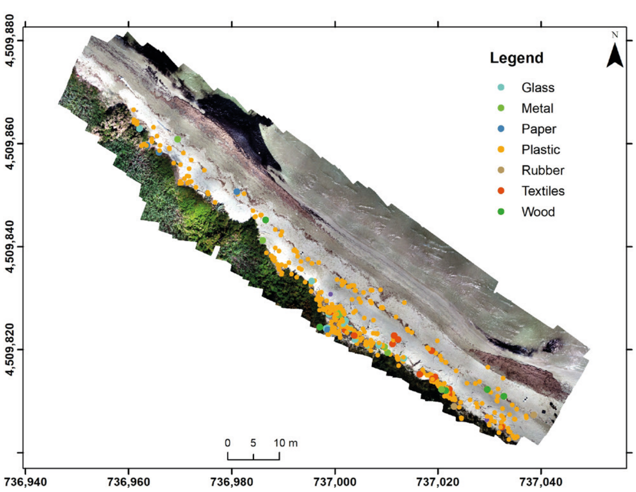

FIG. 5 - Distribution of BL items identified in the investigated area by the manual image screening process. BL items are classified according to their typology (EC, 2021).

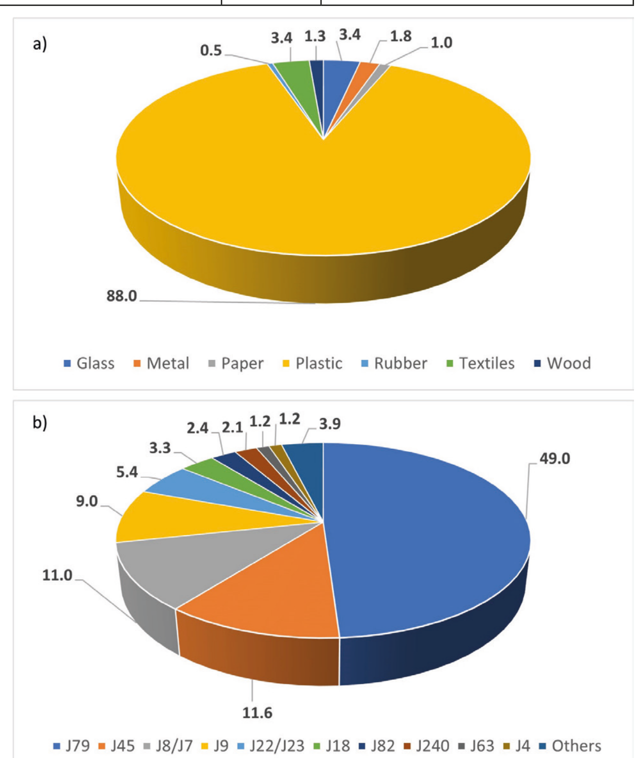

FIG. 6 - a) Percentage distribution of the BL items identified in the study area evaluated according to their composition; b) percentage of plastic BL items identified in the study area evaluated by accounting for their typology. Materials and codes reported in the graphs are in agreement with the classification provided by the European Commission in 2021 (EC, 2021), as also reported in Table 1.

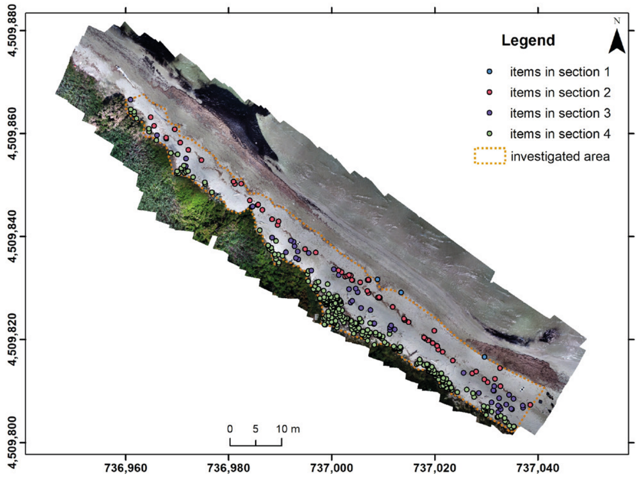

FIG. 7 - Distribution of BL items identified in the investigated area by a manual image screening process. BL items are classified according to their position along the backshore. Note that the section 1 limit is not shown in the figure.

From the morphologic short-term analysis, a "hotspot" area was identified (fig. 10d), located on the dune-foredune limit. Indeed, the analysis of the morpho-dynamic changes highlighted that this sector can be considered as the main storage zone along the analyzed coastal zone. There, a strong presence of vegetable whips was registered. From the comparison of the two beach profiles (fig. 10c) referred to the years 2021 and 2023, it can be inferred that this accumulation zone was built in the last two years (cf. fig. 9b). This phenomenon is probably connected to the high erosion rate concentrated in this area as a consequence of storm events, making it a highly dynamic zone.

DISCUSSION

The methodological approach applied in this study has allowed exploiting the use of images acquired by means of UAS for the detailed geo-environmental analysis of deter-

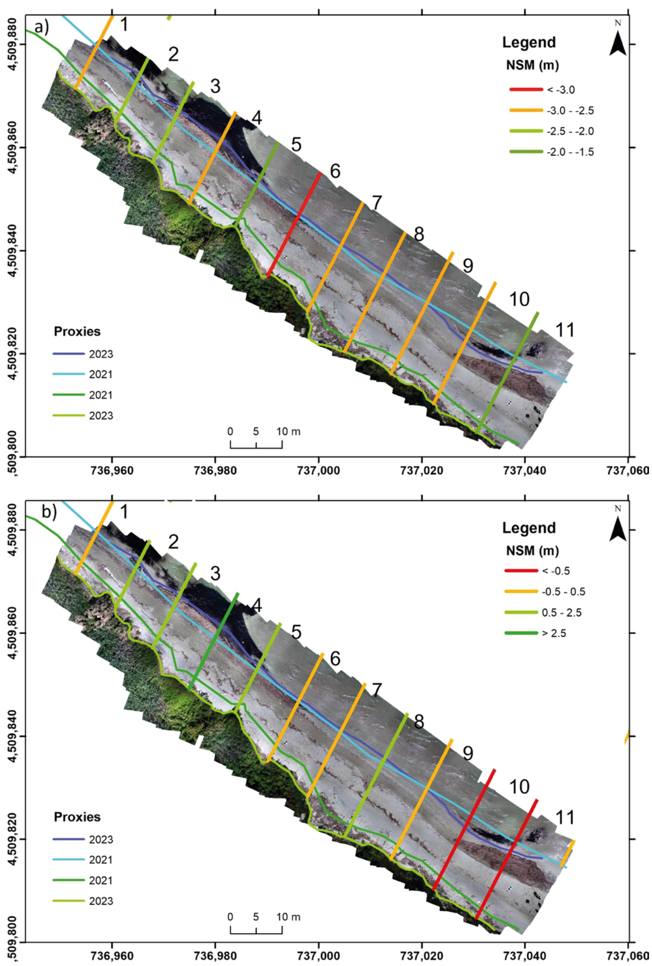

FIG. 8 - NSM evaluated for the short-term period considering as proxy a) the shoreline and b) the fixed vegetation.

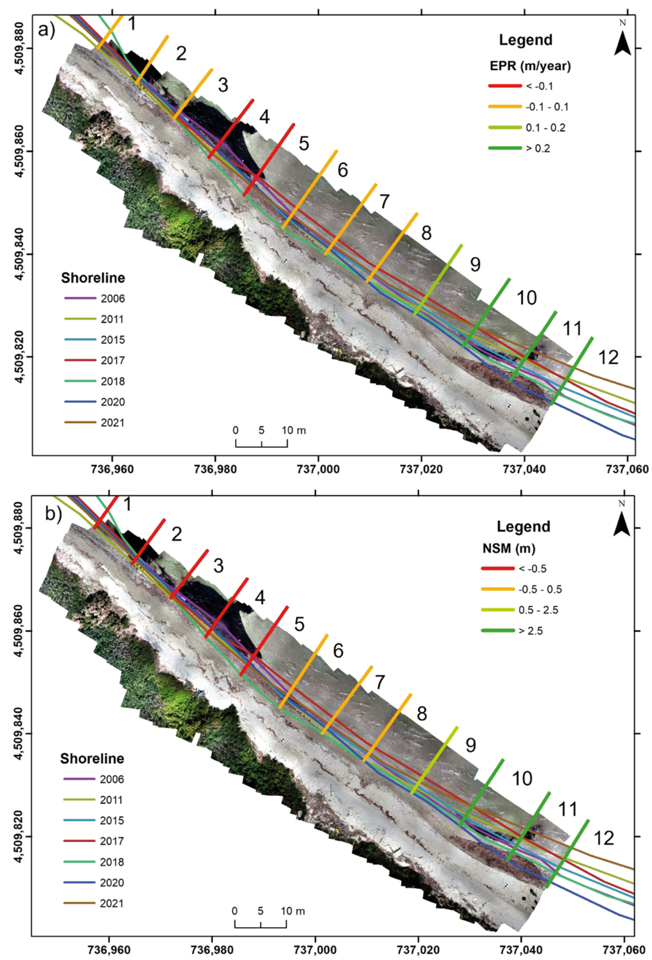

FIG. 9 - a) EPR and b) NSM evaluated for the middle-term period considering the shoreline as proxy.

TABLE 2 - NSM values (m) evaluated for the medium-term (2006-2021) and short-term (2021-2023) period. Values in bold refer to the maximum retreat values (erosion).

Transect id	*NSM (Medium-term)*	*NSM (Short-term shoreline)*	*NSM (Short-term vegetation)*
1	-0.59	-0.31	-2.67
2	-0.76	1.58	-2.13
3	-1.29	2.26	-2.19
4	-2.72	2.69	-2.46
5	-1.79	1.02	-1.80
6	-0.41	0.40	**-3.34**
7	0.26	0.55	-2.51
8	0.43	0.98	-2.58
9	1.55	-0.17	**-2.80**
10	3.37	**-2.78**	**-2.76**
11	4.38	**-1.99**	-1.94
12	6.03	-	-

mined coastal stretches. Such kind of applications are of remarkable importance since they facilitate the investigation of wide territorial sectors without requiring extensive field work activities, as already highlighted in similar studies carried out for both geo-morphological (Di Paola & *alii*, 2022; Minervino Amodio & *alii*, 2022; La Salandra & *alii*, 2022, 2023;) and environmental purposes (Martin & *alii*, 2018; Andriolo & *alii*, 2021; Taddia & *alii*, 2021; Kariminejad & *alii*, 2022). In the case of Torre Guaceto beach, it was possible to perform the UAV images and their post processing in the same day. In a following step, the identification of the BL items and their classification performed in a GIS environment allowed to obtain a georeferenced litter map and a detailed distribution of litter items along the investigated beach sections. The overall BL density value obtained by the manual image screening process (0.48 items/m^2) is in line with the value estimated from the data acquired during a previous in-situ survey carried out in proximity of the investigated area in 2021 (Rizzo & *alii*, 2021).

Furthermore, by considering similar studies, the density value obtained in this study is slightly higher than the ones obtained in other coastal areas. By way of example, Rangel-Buitrago & *alii* (2019) estimated a density value of 0.34 items/m^2 along the Las Salinas beach in Chile, Asensio-Montesinos & *alii* (2020) defined a density ranging from 0.003 to 0.26 based on in-situ investigations carried out along 40 coastal sites in the Atlantic coast of Cádiz and Battisti & *alii* (2023) defined a value of 0.35 items/m^2 in Lazio region (Central Italy). Considering the investigations carried out in micro-tidal environments, Asensio-Montesinos & *alii* (2019) assessed the amount and composition of BL at 56 sites along the coast of Alicante Province, on the western Mediterranean Sea., Authors highlighted as plastic represented the dominant material (82.6%) and as BL density values ranged from 0.05 to 0.373 items/m^2, depending on the site characteristics. On the contrary, a number of investigations have highlighted a more critical environmental situation. As an example, higher density values (ranging between 0.838 ± 0.33 and 4.01 ± 0.55 items/m^2 have been defined for beach stations in the southeastern Black Sea (Eruz & *alii*, 2023), and along a number of beaches in the Central Caribbean coast of Colombia (with mean value of 4.54 items/m^2 – Rangel-Buitrago & *alii*, 2021).

Considering that the study area is included in a natural protected area, where no beach concessions are established and there is not a great affluence of visitors, it is possible to state that BL is essentially transported by waves and currents and the high density of litter items can be due to the lack of scheduled cleaning activities, as highlighted also in the case of rural beaches in Asensio-Montesinos & *alii* (2020). Nevertheless, in general, high-density values are estimated for those coastal areas characterized by the presence of big river months (Chassignet & *alii*, 2021), as in the case of the Rio Magdalena in Colombia (Lebreton & *alii*, 2017, Bolivar-Anillo & *alii*, 2023) and Japaratuba River in Brazil (Santos & *alii*, 2020). The Adriatic flank of the Apulia region is not characterized by the presence of high-discharging rivers and therefore BL items mainly arrive from the sea and/or are linked to the discharge of local channels (e.g., Canale Reale), especially during the occurrence of heavy storm surges and rain events. These considerations are supported also by the typology of items that have been found. In fact, most of the identified items are represented by "containers of cleaning products" (J9) and plastic mussels/oyster mesh bags, and net sacks (J45). The source of such kinds of elements can not be attributed to beach users and recrerational activities but are mainly associated with solid waste discharged from recreational and commercial fishing/boating activities (i.e., marine sources). On the contrary, the number of beach users-related items (e.g., plastic cutlery and pens) and land-based sources is very low (6). This aspect has remarkable importance in terms of local coastal management. In fact, effective BL management activities need to be oriented firstly to the source removal. Due to the fact that in this case the main source is represented by marine activities, actions should be focused on the items' removal after their deposition in order to avoid BL accumulation and burial processes.

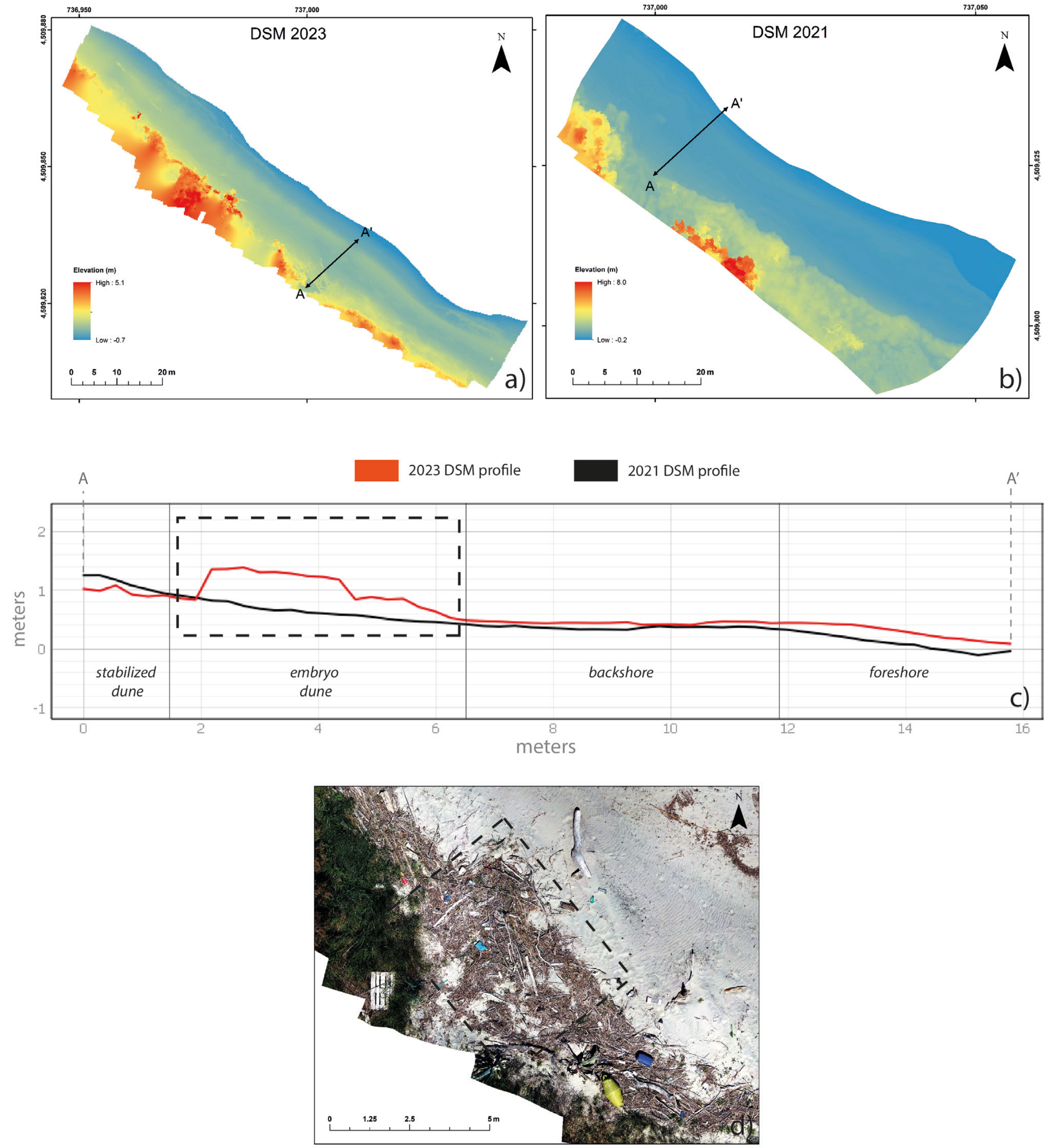

FIG. 10 - a) 2021 DSM and b) 2023 DSM of the investigated beach sector; c) comparison between the two models along the same beach profile. Relief highlighted with the dashed box is caused by the vegetable whips accumulation; d) focus of the accumulation zone.

To this aim, the identification of zones where elements accumulate plays a crucial role in the operative management of the coastal systems. In addition, raising awareness of the fishermen about the problem of marine litter could result in a change in attitudes and behaviour (Ronchi & *alii*, 2023) and therefore sustainable and low impacting practices could be implemented.

For what concerns the analysis of litter distribution along the beach profile, to date very few studies have been focused on this aspect. Asensio-Montesinos & *alii* (2020) have highlighted that litter accumulation strongly differs according to the beach zone, with the high tide line and the backshore being the most polluted, with almost 90% of the total litter amount identified in their study area (Cadiz coast, SW Spain). On the contrary, many studies have analyzed the litter distribution and related ecological impacts along the dune systems (Menicagli & *alii*, 2023, Šilc & *alii*, 2018, Andriolo & Gonçalves, 2022, Poeta & *alii*, 2014, De Francesco & *alii*, 2018).

The results of this study show that for what concerns the distribution of BL items along the profile of the Torre Guaceto beach, the section from the embryo dune to the foredune limit resulted in the most polluted, being characterized by the highest density value. Such kind of information can be coupled with data derived from the analysis of the morphological change that occurred in the investigated area in the last years. In fact, by overlaying the BL distribution map with the short-term morphodynamic variations that occurred in the investigated coastal sector, it is possible to provide the following preliminary considerations:

- the estimated short-term variations in the shoreline position poorly affect the short-term dynamics of the dune (fixed vegetation proxy), as it is possible to determine by comparing transects 8, 10, and 11 in fig. 8a, b);
- the short-term evolution of the dune (fixed vegetation), which highlights a strong erosion of the area included between transect 6 and 10, does not reflect the intense middle-term retreat that characterizes the northern part of the investigated area (c.f. transects 1-8 in fig. 9a, b);
- the high distribution of BL items can be expected along those coastal sectors characterized by recent high-erosion trends, with a special reference to the dune limit (c.f. transects 7-10 in fig. 8b).

As a general overview, the recent morphodynamic evolution of a coastal sector may influence the distribution of BL items and therefore their sound management according to the following conditions:

1. *Eroding beach sectors.* Coastal erosive processes may cause the retreat of the dune system. In such case, a flat beach can be formed and run-up processes linked to significant storm surge events are able to transport landward huge amounts of vegetation debris and large BL items that are accumulated at the beach edge, e.g., the beginning of the vegetated areas (on stabilized dunes and/or aeolian deposits). Such deposits, due to their distance from the shoreline and their accumulation modality, are not removed by marine or aeolic processes and, if good weather conditions are recorded, can be partially or totally buried. In general, despite the risk of burial is low, clean-up programs should be scheduled at a seasonal scale in order to remove the post-storm BL accumulation and avoid burial and degradation processes.

2. *Stable beach sectors.* Low embryo dunes are observed and debris and BL accumulations linked to very significant storms are placed at the embryo dune toe. The risk of BL burial is medium and clean-ups programs have to be carried out with a medium frequency, i.e., months.

3. *Accreting beach sectors.* Well-developed embryo dunes are observed and probably they grow up in weeks/months. The upper part of the beach shows a greater slope with respect to a beach presenting erosion. Probably several strand lines – linked to accretion phases, i.e., no erosion took place when they were formed – are recorded because they have not been "removed" by the occurrence of more recent marine processes. Vegetation debris and BL items are observed and show a high probability of be partially covered by sediments essentially due to aeolic processes, therefore the risk of burial is high and clean-ups programs should be carried out with a higher frequency, i.e., weeks.

Last, the results of the analysis proposed in this study highlight how the exploitation of UAVs images can support the characterization of the coastal sector in terms of both morphodinamic trends and beach litter pollution distribution. The integrated use of such tools and information represents a scientific base for a sustainable management of the coastal zone, as also highlighted in previous review papers (Adade & *alii*, 2021; Kandrot & *alii*, 2022).

CONCLUSIONS

In this study, the analysis of the distribution of litter items at Torre Guaceto beach (Brindisi province, southern Italy) has been carried out by the visual screening of the orthomosaic of the study area obtained from the post-processing of UAV images. To this aim, a drone flight survey, covering a beach sector of 100 m in length, has been performed in May 2023 with a flight altitude of 15 m. The analysis of BL items distribution along four different beach sections identified according to the main observed beach morphological features is expressed in terms of items density. Furthermore, in order to compare BL distribution with the main morphodynamic characteristics of the study area, the short- and middle-term variations in the shoreline proxies have been estimated by means of a specific GIS tool. The results showed that the estimated density value on the backshore was 0.48 items/m^2. In detail, the area from the embryo dune up to the foredune limit was characterized by a higher number of items, with a density of 1.24 items/m^2. Nevertheless, the shoreface sector showed a very limited distribution of BL items. Coupling these results with the analysis of the coastal evolution occurred in the last two years, it clearly emerged that the zone characterized by a retreat trend in the vegetation line corresponded to the area where the high number of items can accumulate. This last point lays the foundation for the definition of tailored and effective management actions, highlighting how the hotspot areas of litter can be defined by identifying the erosive focuses. This research provides a preliminary analysis of the correlation between coastal morphodinamic processes and litter spatial distribution. For this reason, we only used litter distribution assessed during the field activities carried out in May, when the high season period was not started yet and therefore litter items were mainly stranded on the beach by marine processes. Based on the highly promising obtained results, further applications will be aimed at extending such kind of evaluations to wider coastal sectors in order to assess litter quantitative accumulation rates. For this future step, periodic monitoring surveys will be planned to provide sound statistical evidence to these preliminary considerations.

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