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Psammophytes as traps for beach litter in the Strait of Messina (Mediterranean Sea)

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ABSTRACT

In the present paper, for the first time, the presence of beach litter in dunal plants has been verified in a Strait area in an island. The aims of the present study were to evaluate if the psammophytes can act as a trap for the beached litter, to compare beach litter in plants located in beaches with different anthropogenic impacts, and to describe a new approach (namely clean patch index, CPI) to evaluated the cleanliness of dunal plants. In total 738 macro litter items, belonging to 7 litter categories were found in the study area. The main litter category collected was plastic, followed by ceramic, glass, paper/cardboard, metal, sanitary waste, and medical waste. Our results showed that psammophytes acted as a sink for the beach litter by trapping it. The CPI was higher in the dunal plants than in the relative control patches. The average dissimilarity between "Montorsoli" and "Pylon" beaches was 88.7%. The highest contribution to the dissimilarity between the two beaches was the construction material, followed by polystyrene and plastic pieces. Our data could be important for the implementation of the monitoring program within the Marine Strategy Framework Directive, and may also contribute to the development of specific management of the clean-up measures as well as implement National and Regional action plans.

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1. Introduction

Marine litter (ML) is defined as "any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment" (CBD Technical Series No. 67, 2012). The ocean pollution caused by anthropogenic litter has been recognized as a worldwide issue. (Ryan, 2015; Suaria et al., 2016). Also, the Mediterranean Sea is very impacted by anthropogenic litter and, in particular, by the accumulation of plastic litter in surface water, sediments, and beaches (Cózar et al.; 2015). ML consists mostly of plastics, which may affect marine ecosystems by transporting very hazardous chemicals, such as organic contaminants, heavy metals, pharmaceuticals, and persistent organic pollutants (Mathalon and Hill, 2014). ML can act as a vector also for alien species (Barnes, 2002) and can cause negative effects such as poisoning, suffocation, and entanglement on marine organisms (Markic et al., 2020; Ryan, 2019; Santos et al., 2021). Moreover, ML impacts the marine trophic web (Carbery et al., 2018; Nelms et al., 2018) since litter is also ingested by marine organisms (Bottari et al., 2022; Mancuso et al., 2022; Porcino et al., 2023a). Moreover, some ML types such as fishing lines, hooks, and nets can entrap plover birds nesting on sandy beaches (Battisti et al., 2023). ML affecting the coastal water quality can induce multi-scale ecological impacts on biodiversity components, and ecological processes, both when occurring in the sea or when stranded on the beaches (Battisti et al., 2020b; Poeta et al., 2017; Soto-Navarro et al., 2021; Porcino et al., 2023b). In this regard, sandy shores are generally considered important sinks for floating debris (Asensio-Montesinos et al. (2019), Benaissa et al. (2021), Camedda et al. (2021), Fortibuoni et al. (2021), Gündoğdu and Çevik (2019), Laglbauer et al. (2014), Mandić et al. (2022), Mghili et al. (2020), Munari et al. (2016), Orthodoxou et al. (2022), Vlachogianni et al. (2018), see Table S1), with consequences also at socio-economic and aesthetic levels (de Araújo and da Costa, 2007). The EU Marine Strategy Framework Directive – (MSFD) recognizes macro- and micro-litter as major threats to

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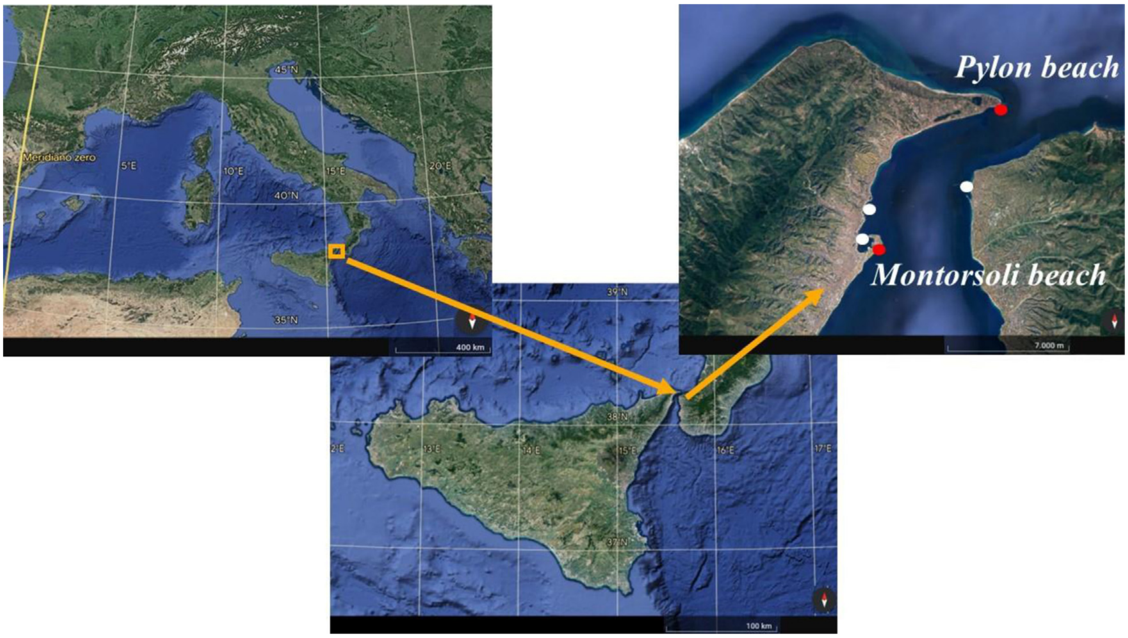

Fig. 1. Study area. Strait of Messina. The investigated beaches are indicated in red dots while ports with white dots. https://earth.google.com/web/@38.211644,15.60740628,9.38798353a,43889.60649222d,35y,0h,0t,0r/data=MikKJwolCiExTk5Fei1GZ1BoZzBnN2hfMnBuMV9NeEh5ZmdpR1NCUjYgAQ?utm_source=earth7&utm_campaign=vine&hl=it. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

marine ecosystems that may prevent the achievement of Good Environmental Status (GES). The ultimate goal of the MSFD is to protect the marine environment against harm caused by marine litter through Descriptor 10 ("Properties and quantities of marine litter do not cause harm to the coastal and marine environment"). Provisions include monitoring, assessment, and measures in order to achieve or maintain GES (Hanke et al., 2019).

Coastal dunes are an important and unique ecosystem, they are environments of great naturalistic and ecological interest (especially in the presence of the Mediterranean maquis), and as transitional environment, they play a fundamental role in the coastal protection against the coastal erosion (Andriolo and Gonçalves, 2022; Cesarini et al., 2021). The presence of ML, and in particular of plastics, entrapped in the dunal plants can be considered an ecosystem service (Andriolo et al., 2021; Calderisi et al., 2023; Gallitelli et al., 2021). This is because these plants blocking the plastics act as a sink of beach litter and can help to preserve the environment, and the biodiversity of the beach itself (Cresta and Battisti, 2021; Menicagli et al., 2022). The presence of ML was reported in several beach plants such as *Arundo donax, Carpobrotus* sp., and *Cakile maritima* (Andriolo et al., 2021; Battisti et al., 2020b; Ben-Haddad et al., 2023; Gallitelli et al., 2021), highlighting that these plants are an important sink of plastics.

A key challenge in addressing the environmental and economic impacts of plastic pollution is to understand where it comes from and which are the potential accumulation sinks. In the Mediterranean context, the Strait of Messina is a convergence region, where upwelling currents and surface fronts may concentrate rafting litter in a relatively narrow area. For this reason, the Strait of Messina has been recently proposed for monitoring purposes of floating and beached litter (Battaglia et al., 2019). The peculiar features of the waters of the Strait of Messina and the ecological and biological importance of the coastal area, representing the interface between sea and land, make the strait a very interesting site in the context of litter pollution. Thus, the aims of the present study were: (i) to evaluate the beach litter entrapped in the dunal plants (psammophytes) of the Strait Messina, (ii) to compare beach litter in plants in two beaches with different anthropogenic impacts, and (iii) to describe a new approach (namely clean patch index) to evaluate the cleanliness of dunal plants.

2. Methods and materials

2.1. Study area

The funnel-shaped Strait of Messina, which separates Sicily from the Italian peninsula and unites the Tyrrhenian and the Ionian Seas (Fig. 1), is considered a hot spot of biodiversity (Spanò and Domenico, 2017). The intense hydrodynamism of the waters of the strait creates an ecosystem unique that also affects the Ionian and Tyrrhenian basins (Azzaro et al., 2007; Bottari et al., 2014; Busalacchi et al., 2014; Zaccone et al., 2010). The Strait of Messina is a crucial point for the migration of many species, such as large pelagic fish (*Thunnus thynnus, T. alalunga, Sarda sarda, Tetrapturus belone,* and *Xiphias gladius*), sharks, rays, and cetaceans (Di Natale et al., 2014).

The city of Messina is a highly anthropized area with several human activities, such as commercial, tourist, and military harbors, commerce, and agriculture. For this study, two beaches were selected here named "Montorsoli" and "Pylon" beaches. The investigated areas are different in terms of anthropogenic impact (Fig. S1; Table 1). The first one covers an area of 1,223 m^2 in the so called "San Raineri Arm" of the harbor of Messina. The second beach covers an area of 3,848 m^2, situated in the Oriented Natural Reserve of Capo Peloro SCI (ITA030008), Site of Community Importance and Special Protection Area under the Council Directives 92/43 EEC on the "Conservation of natural habitats and of wild fauna and flora" and 79/409/EEC on the "Conservation of wild birds.

The investigated beaches are different in terms of the anthropogenic impact. "Montorsoli" beach is closed to visitors and used seldom for recreational fishing, "Pylon" beach is a tourist beach (see Table 2). "Montorsoli" and "Pylon" beaches are very close to each other (about 10 km) although they are exposed to different winds and sea currents. Montorsoli beach is exposed to

Table 1
Description of the two investigated beaches.

	"Montorsoli" beach	"Pylon" beach
GPS Coordinates	38°11'41"N; 15°34'25"E	38°16'0" N; 15°39'10" E
Total length of the beach	182 m	452 m
Length study area	100 m	100 m
Total area without plants	1,223 m^2	1,318 m^2
Total area including plants	1,687 m^2	3,848 m^2
Prevailing currents on sampling day	Montante (S→N)	Scendente (N→S)
Prevailing winds on sampling day	Mistral	Mistral
Beach composition	95% sand; 5% pebbles and gravel	90% sand; 10% pebbles
Access to the beach	Pedestrian	Pedestrian, boat
Major usage beach	Occasional fishing	Local people, swimming, sun bathing, fishing, surfing
Distance Km from the nearest town	0	10 km
Seasonal population size of this town	residential all the year	Residential all the year, tourist spring and summer
Distance m from the nearest harbor	0	3500 m; Villa S. Giovanni (Calabria) harbor
Position of the harbor in relation to survey area	South	Nord
Type of harbor	Touristic, commercial	Touristic, commercial
Distance Km from nearest river mouth	1.5 km; Boccetta stream	4.4 km; Papardo stream
Position nearest river	North	South
How often is the beach cleaned	Never	Once a year, during spring (may)
Used method	–	Manual

Table 2
List of plants identified in the investigated beaches.

Species	Family	"Montorsoli" beach	"Pylon" beach
Anethum foeniculum L.	Apiaceae	X	X
Anisantha diandra (Roth) Tutin ex Tzvelev	Poaceae	X	X
Arundo donax L.	Poaceae	X	X
Chondrilla juncea L.	Asteraceae		X
Convolvulus soldanella L.	Convolvulaceae	X	
Crithmum maritimum L.	Apiaceae	X	
Cuscuta cesattiana Bertol.	Apiaceae	X	
Cynodon dactylon (L.) Pers.	Poaceae	X	X
Daucus carota L.	Apiaceae		X
Dittrichia viscosa (L.) Greuter subsp. *viscosa*	Asteraceae	X	X
Echinophora spinosa L.	Apiaceae		X
Eryngium maritimum L.	Apiaceae		X
Euphorbia terracina L.	Euphorbiaceae	X	X
Festuca ligustica (All.) Bertol.	Poaceae		X
Glaucium flavum Crantz	Papaveraceae	X	
Hedypnois rhagadioloides (L.) F.W. Schmidt	Asteraceae	X	
Lobularia maritima (L.) Desv.	Brassicaceae	X	
Lotus creticus L.	Fabaceae	X	X
Matthiola sinuata (L.) W.T. Aiton	Brassicaceae		X
Matthiola tricuspidata (L.) W.T. Aiton	Brassicaceae	X	
Medicago marina L.	Fabaceae		X
Olea oleaster Hoffmanns. et Link	Oleaceae		X
Pancratium maritimum L.	Amaryllidaceae	X	X
Reichardia picroides (L.) Roth	Asteraceae	X	X
Scolymus hispanicus L.	Asteraceae	X	X
Sonchus tenerrimus L.	Asteraceae	X	
Sporobolus virginicus (L.) Kunth	Poaceae	X	X
Thinopyrum junceum (L.) Á. Löve	Poaceae	X	X
Tragopogon porrifolius L.	Asteraceae		X
Tricholaena teneriffae (L. f.) Link	Poaceae		X

North, Northeast winds and South–North current (namely scendente), Pylon beach is exposed to South – Southwest winds and South-North current (namely montante).

The plant communities present in the study area are herbaceous formations with psammophytes attributable to the classes *Cakiletea maritimae* Tüxen & Preising ex Br.-Bl. & Tüxen 1952 and *Euphorbio paraliae-Ammophiletea australis* Géhu & Rivas-Martínez in Rivas-Martínez, Asensi, Díaz-Garretas, Molero, Valle, Cano, Costa & Díaz 2011 (Biondi and Blasi, 2013); in the first case it regards formations of annuals or representatives of annuals and perennials closest to the sea, occupying accumulations of drift material and gravel rich in nitrogenous organic matter (di Blasi, 2008). In the back stretch of emerged beach there are formations of the coast representing the first stages of dune construction, constituted by ripples or raised sand surfaces of the upper beach or by a seaward fringe at the foot of the tall dunes (di Blasi, 2008). These plant communities constitute habitats protected by the Directive 43/92 and are included in the Annex 1, which contains "natural habitat types of community interest whose conservation requires the designation of special areas of conservation"; the therophytic communities of the *Cakiletea maritimae* can be placed into "Annual Vegetation of drift lines (cod. 1210), while the remaining perennial psammophyte formations (*Euphorbio paraliae - Ammophiletea australis)* are attributable to the habitat "Embryonic shifting dunes (cod. 2110)"

2.2. Samplings

Macro litter sampling was carried out on May 2022, before the annual "Pylon" beach clean-up, following the protocol of paired sampling of Gallitelli et al. (2021). Overall, 10 patches, in which psammophytes were present, and 10 control patches without plants or with very little vegetation (less than 30% of area), contiguous to the former ones, were examined for the

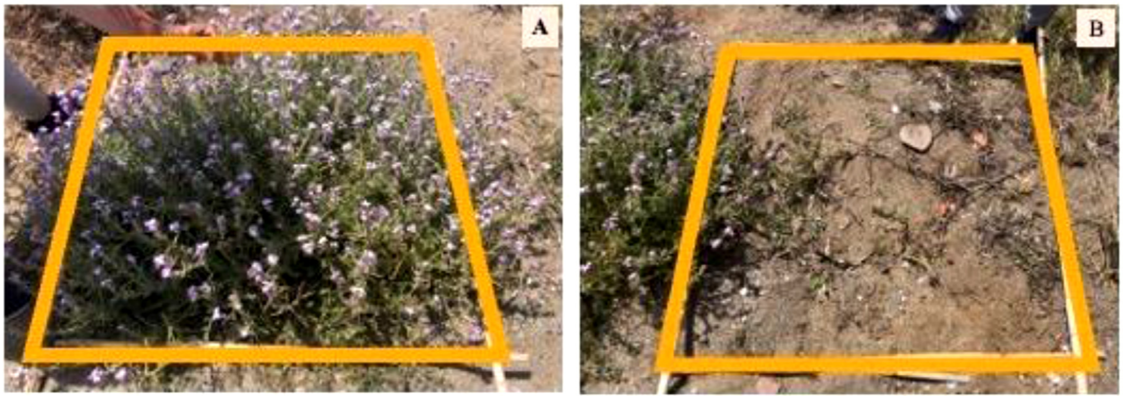

Fig. 2. Psammophytes (A) and control patch (B) along the "Montorsoli" beach coastal dunes.

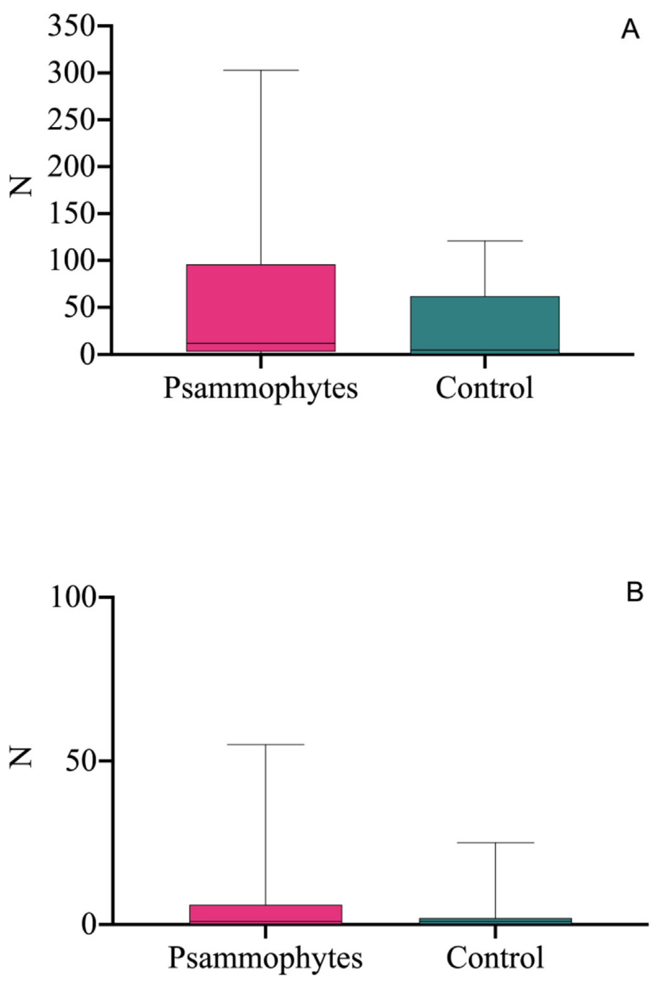

Fig. 3. Number of beach litter items retained by Psammophytes and control patches of the "Montorsoli" beach (A) and the "Pylon" beach (B).

presence of macro litter (Fig. 2). In both beaches, the vegetation distribution did not allow to sample patches totally free of vegetation A total of 20 patches for each beach were randomly chosen (corresponding to a surface equal to 20 m^2) along a linear transect (100 m). The distance between plots ranged from 6 to 10 m. In Montorsoli beach the plots were located to a mean distance of 10 m from the tidal line. In Pylon beach the plots were more far from the tidal line, about 40 m. For each patch (1 × 1 m), to obtain the number of litter items, we performed a macro litter removal sampling. In the laboratory, each litter item was classified into categories according to the Plastic Busters Guidelines (Fossi et al., 2019). Psammophytes present in each patch were collected and transported in plastic bags to the laboratory. Following Gallitelli et al. (2021) we considered only items >0.5 cm for anthropogenic macro litter, therefore excluding all items <0.5 cm.

For each sample, a voucher specimen was prepared as an herbarium sheet. Vouchers are housed in the Phycological Lab Herbarium (PhL) of the University of Messina, Italy (https://sweetgum.nybg.org/science/ih/herbarium-details/?irn=253162). For the taxonomic identification and the nomenclature of species, reference was made to the analytical keys and to the treatment contained in Pignatti et al. (2017, 2019) and Acta Plantarum (from 2007).

2.3. Data analysis

We classified each patch on the basis of the percentage of coverture of psammophytes. An increasing score from 0 to 3 was assigned to each patch (0: no vegetation; 1: 15%; 2: 30%; 3: 100%). For each macro litter type, the frequency of occurrence (FO%) was estimated as the percentage of the patches that contained litter type. Litter and plastic densities expressed as items/m^2 were estimated for psammophytes and control patches.

A new modified index, the clean-patch index (CPI) was estimated to evaluate the cleanliness of the dunal plants. It measures the total litter of dunal plants and represents a cleanliness indicator. It is based on the density of total litter (not only plastic items), occurring in the monitored patch. The index has been calculated starting from the clean coastal index of Alkalay et al. (2007). This index was calculated as $CPI = L_D \cdot K$ where L_D is the litter density (items/m^2) and K is a constant equal to 0.5. The coefficient $K = 0.5$ was inserted into the equation for convenience i.e. to make the values scale more easily comparable with the scale proposed by Alkalay et al. (2007) for beach litter. In accordance with the clean coast index (Alkalay et al., 2007) scale values from 0 to 20 indicate patches from very clean (0–2 CPI), clean (2–5 CPI), moderately clean (5–10 CPI), dirty (10–20 CPI) to extremely dirty (>20 CPI).

Wilcoxon Signed Rank Test was applied to compare total litter entangled in psammophytes and control patches. The Kruskal–Wallis test was applied to compare the plastic density (items/m2) between psammophytes and control patches. All the statistical analyses and graphs were performed using GraphPad Prism 8.4.2.3.

To compare litter composition between beaches data were also analyzed in terms of multivariate analysis using the package Primer 6 (Clarke and Gorley, 2006). The dataset (items/m^2), after log transformation, was used to evaluate the Bray-Curtis

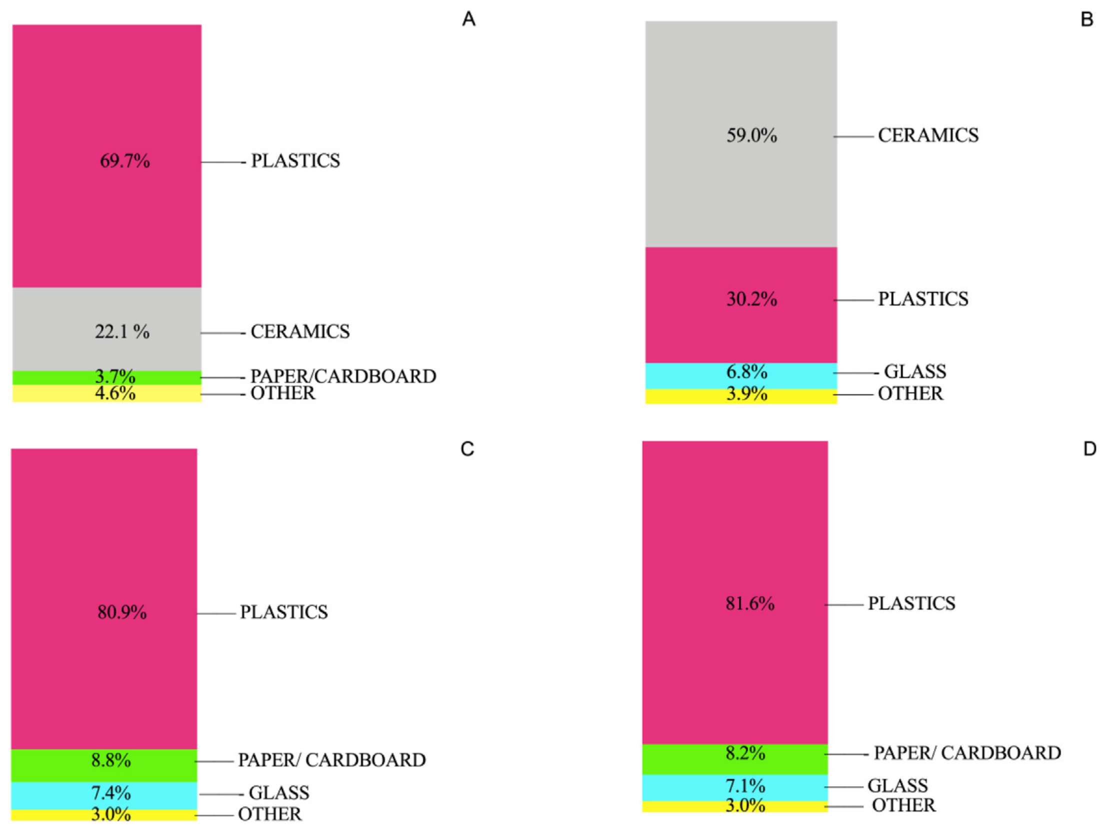

Fig. 4. Marine litter composition of the Psammophytes (A) and control patches (B) in the "Montorsoli" beach, and of the Psammophytes (C) and control patches (D) in the "Pylon" beach.

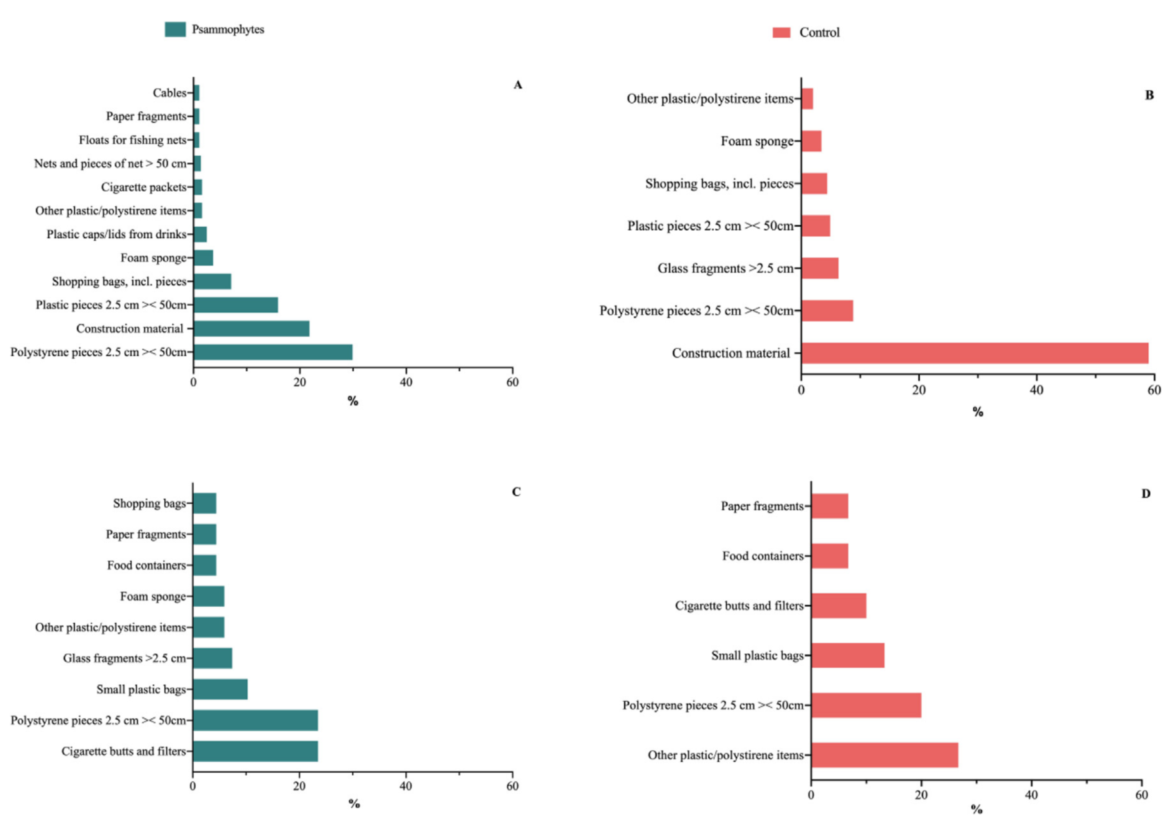

Fig. 5. Marine litter composition of the Psammophytes and control patches in the "Montorsoli" beach (A, B), and in the "Pylon" beach (C, D).

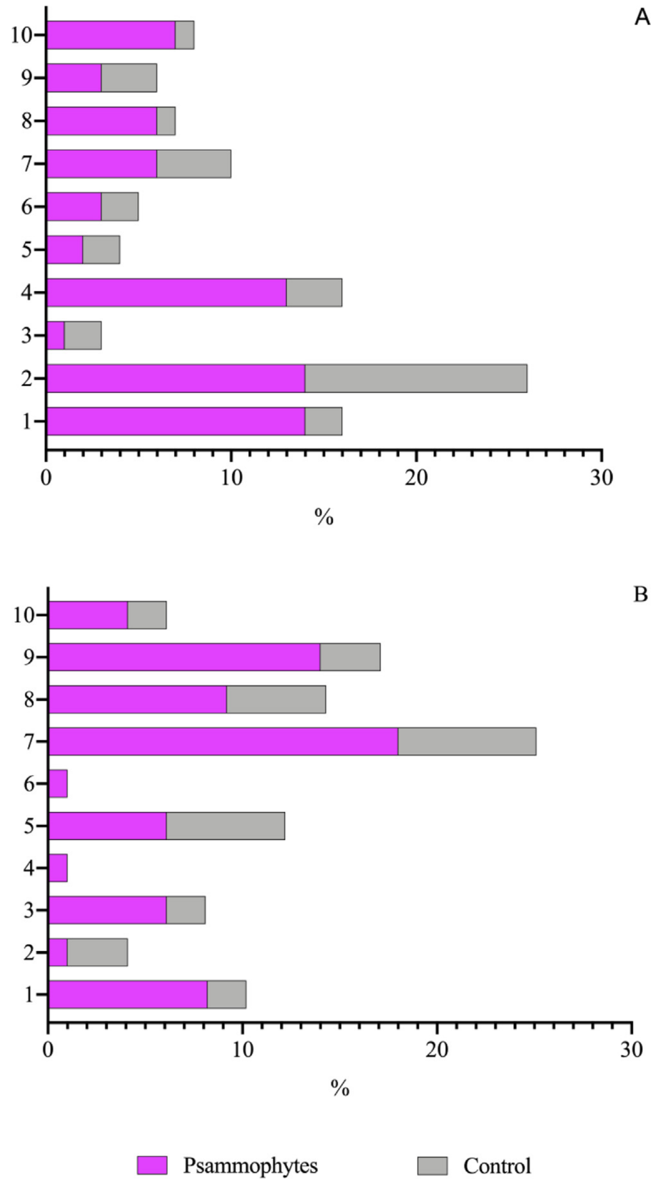

Fig. 6. Macro litter frequency of occurrence (%) retained by psammophytes and control patches in the "Montorsoli" beach (A) and in the "Pylon" beach (B).

resemblance matrix (Bray and Curtis, 1957). Analysis of similarity (ANOSIM) was used to determine the significance of differences in litter composition among beaches, based on litter density data. In order to visualize the litter distribution in relation to space, the Multi-Dimensional Scaling (MDS) ordination method was employed. The Similarity Percentage Analysis (SIMPER) was carried out to identify the litter type contributing mainly to the dissimilarity between beaches (Clarke, 1993).

3. Results

3.1. Macro litter composition

In total 738 litter items, belonging to 7 macro litter categories were found in the investigated area. The main litter category collected was plastic (60.3%) followed by ceramic (29.4%), glass (3.3%), paper/cardboard (3.9%), metal (2.2%), sanitary waste (0.8%), and medical waste (0.1%).

In total in the Montorsoli beach, 640 items belonging to 7 macro litter categories, were found. Plastic was the most abundant macro litter category (57%), followed by ceramic (33.9%). Other macro litter categories (glass, metal, paper/cardboard, sanitary waste, and medical waste) represented 9.1% of the total litter. As concern the total litter distribution, psammophytes patches trapped 68% (435 items), the control ones trapped only 32% of items (205 items). A significative difference between total litter entangled in psammophytes and control patches was observed (Wilcoxon Signed Rank Test – $Z = 3.4$: $p < 0.01$) (Figs 3, S2). The main ML category collected in psammophytes patches was plastic (69.7%), followed by ceramic almost represented by brick and tile residues (22.1%), paper/cardboard (3.7%), metal (2.8%), glass (0.7%), sanitary waste (0.9%), and medical waste (0.2%) (Fig. 4A). In the psammophytes patches 40 different types of litter were found, polystyrene pieces (from 2.5 cm to 50 cm) were the most abundant litter items (29.9%), followed by construction material (21.8%), plastic pieces (2.5 cm > < 50 cm, 15.9%), shopping bags, incl. pieces (7.1%), foam sponge (3.7%), plastic caps/lids from drinks, and cigarette packets (1.6%), nets and pieces of net (>50 cm, 1.4%), cables, paper fragments and floats for fishing nets (1.1%). All other items represented 11% of the total litter (Fig. 5A).

The main litter category collected in the control patches was plastic (30.2%), followed by ceramic (18.9%), glass (2.2%), paper/cardboard (0.8%), and metal (0.5%) (Fig. 4B). In the control patches, 25 different types of litter were found, construction material (pieces of brick) was the most common litter type (59%), followed by polystyrene pieces (2.5 cm > < 50 cm) (8.8%), glass fragments (6.3%), plastic pieces (2.5 cm > < 50 cm, 4.9%), foam sponge (3.4%). Other plastic/polystyrene items (2%), cartons/tetra pack, metal pieces <50 cm, plastic construction waste, shoes/sandals, straws, and stirrers (1%). All other litter types were found in the control patches, representing 6.3% of the total litter (Fig. 5B).

Among all patches, the number 2 with psammophytes (*Crithmum maritimum*) entangled the greatest amount of litter items as well as the corresponding control patch (Fig. 6a). The litter density index in relation to percentage of coverture and height of psammophytes is shown in Figure S2. The frequency of occurrence (FO %) for each litter type has been reported (Figure S3). Polystyrene pieces were found in all psammophytes patches and in 40% of the control patches. The construction material occurred in 90% of both psammophytes and control patches.

In the "Pylon" beach, 98 items belonging to 5 litter categories, were collected; plastic (81.6%) was the most abundant litter category, followed by paper/cardboard (8.2%), and glass (7.1%), sanitary waste (2%), and metals (1%). As concern the total litter distribution, psammophytes patches trapped 69% ($N = 68$), while in the controls 31% of items ($N = 30$) were found. A significant difference between total litter entangled in psammophytes and control patches (Wilcoxon Signed Rank Test – $Z = 2.4$: $p < 0.05$) was observed (Fig. 3B).

The main litter category collected in psammophytes patches was plastic (80.9%), followed by paper/cardboard (8.8%), glass (7.4%), metal, and sanitary waste (1.0%) (Fig. 4C). In the psammophytes patches, 16 different types of litter were found, polystyrene pieces (2.5 cm > < 50 cm), cigarette butts and filters were the most abundant litter items (23.5%), followed by small plastic bags (10.3%), other plastic/polystyrene items and foam sponges (5.9%), shopping bags, food containers and paper fragments (4.4%), drink bottles (>0.5l), cups and cup lids, cartons/tetra pack, cigarette packets foil wrappers and aluminum foil, and toilet fresheners (1.5%) (Fig. 5C).

In the control patches, 9 different types of litter were found, "Other plastic/polystyrene items" were the most common litter types (26.7%), followed by polystyrene pieces (2.5 cm > < 50 cm) (20%), small plastic bags (13.3%), cigarette butts (10%), glass bottle

Table 3
Simper analysis results. Items with the highest contribution to the dissimilarity between the two beaches are in bold.

Litter type	Montorsoli beach Av. Abundance	Pylon beach Av. Abundance	Av.Diss	Diss/SD	Contrib%	Cum.%
Construction material (brick, cement, pipes)	1.86	0.00	18.23	1.50	**20.54**	20.54
Polystyrene pieces 2.5 cm > < 50 cm	1.38	0.54	10.78	1.49	**12.15**	32.69
Plastic pieces 2.5 cm > < 50 cm	0.81	0.00	7.62	0.80	**8.59**	41.28
Shopping bags, incl. pieces	0.68	0.08	5.30	0.93	5.97	47.26
Other plastic/polystirene items	0.32	0.34	5.03	0.75	5.66	52.92
Foam sponge	0.47	0.12	4.34	0.86	4.9	57.82
Cigarette butts and filters	0.04	0.37	3.37	0.60	3.8	61.62
Paper fragments	0.13	0.19	3.06	0.57	3.44	65.06
Glass fragments >2.5 cm	0.32	0.13	3.03	0.55	3.41	68.47
Small plastic bags, e.g. freezer bags, including pieces	0.00	0.32	2.88	0.59	3.25	71.72
Food containers incl. fast food containers	0.04	0.19	2.04	0.60	2.30	74.01
Plastic construction waste	0.15	0.00	1.63	0.50	1.83	75.85
Cups and cup lids	0.06	0.10	1.45	0.37	1.63	77.48
Nets and pieces of net > 50 cm	0.13	0.00	1.42	0.33	1.60	79.08
Shoes/sandals	0.15	0.00	1.42	0.50	1.60	80.68
Plastic caps/lids from drinks	0.20	0.00	1.36	0.51	1.54	82.21
Other metal pieces < 50 cm	0.12	0.00	1.24	0.31	1.40	83.62
Floats for fishing nets	0.17	0.00	1.23	0.52	1.38	85.00
Toilet fresheners	0.04	0.08	1.22	0.40	1.37	86.37
Cigarette packets	0.12	0.04	1.05	0.39	1.18	87.55
Drink bottles >0.5l	0.12	0.04	1.05	0.40	1.18	88.73
Cartons/Tetrapack (others)	0.11	0.04	1.03	0.43	1.16	89.89
Straws and stirrers	0.09	0.00	0.76	0.28	0.86	90.75

(pieces), paper fragments, cups and cup lids, food containers (6.7%), and toilet fresheners (3.3%) (Fig. 5D).

Among all patches, the number 7 (including *Reichardia* spp., *Lotus creticus, Daucus* spp., *Arundo donax, Festuca ligustica*) entangled the greatest amount of litter items as well as the relative control patch (Fig. 6B). In Figure S3 the FO for each litter type has been reported. Polystyrene pieces were found in half of psammophytes patches and in 40% of the control ones. The plastic bags occurred in 40% of psammophytes and in 30% of the control patches.

3.2. Beaches comparison

In the "Montorsoli" beach, litter density was 43.5 and 20.5 items/m^2 in the psammophytes and control patches, respectively (Fig. 7A). In the "Pylon" beach, plastic density was 6.8 items/m^2 in the psammophytes and 3.0 items/m^2 in the control patches (Fig. 7B).

In the "Pylon" beach, litter density was 30.3 and 6.2 items/m^2 in the psammophytes and control patches, respectively. In the "Pylon" beach, plastic density was 5.5 items/m^2 in the psammophytes and 2.5 items/m^2 in the control patches. Total litter density and plastic density were significantly higher in the Montorsoli beach than the Pylon one (H=13.4, p<0.01; H=10.8, p<0.01).

ANOSIM was applied to test the potential geographic effect. The global R was equal to 0.49 (p < 0.01) indicating a significative difference. The relative nMDS is shown in Fig. 8. The average dissimilarity between the "Montorsoli" and the "Pylon" beach was 88.7%. The highest contribution to the dissimilarity between the two beaches was the construction material (20%), followed by polystyrene pieces (12%), and plastic pieces (7%) (Table 3).

3.3. Clean patch index (CPI)

In the "Montorsoli" beach the psammophytes patches were the dirtiest, CPI ranged from 4.5 to 45 with a mean value of 21.8 (Fig. 7C). In the control patches CPI ranged from of 4.0 to 39.5 with a mean value of 10.3. In the "Pylon" beach, psammophytes patches were clean, CPI ranged from 0.5 to 9.0 with a mean value of 3.4. The control patches were very clean, CPI ranged from 0.0 to 3.5 with a mean value of 1.5 (Fig. 7C).

4. Discussion

4.1. Litter composition in psammophytes of the Strait of Messina

In this study we assessed the role of psammophytes as a trap for macro litter in two beaches located along a strait. Results showed that psammophytes patches were more efficient in entangling ML than the control patches. This is due to the height, shape, and abundance of psammophytes present in the studied patches. In this study the vegetation distribution did not always allow to sample patches totally free of vegetation, but despite this limitation a significative difference in litter density was observed. Litter items also occurred in the control patches but to a less extend due to the absence of vegetation or, in some cases, plants with minimum height and limited distribution.

ML accumulation on the beaches is closely related to both human intervention and natural variables. The factors that determine the amount, type, and distribution of ML are both environmental and socio-economic variables. Among the environmental variables, there are winds, currents, tides, river flows, and beach morphology while the socio-economic variables are the municipal infrastructure (e.g., collection and destination of solid wastes, controlled urban drainage, etc.), the beach use, the social behavior (i.e., the level of environmental education among the local populations and tourists) (de Araújo and Costa, 2006; Thiel et al., 2013). In addition to the factors listed above, vegetation can interfere with the litter deposition dynamics in dune environments (Battisti et al., 2020b; Cresta and Battisti, 2021; Debrot et al., 2013; Gallitelli et al., 2023; Mo et al., 2021).

More particularly, coastal dune vegetation, playing a crucial role in trapping sediment for the embryo-dune establishment and hosting several invertebrates and vertebrate species (Battisti and Gippoliti, 2019), can be also impacted by ML (Menicagli et al., 2019), or may use ML opportunistically (e.g., polystyrene and plant germination (Menicagli et al., 2020; Poeta et al., 2017). Finally, plants can facilitate ML deposition, conditioning its distribution along the coasts e.g., (Debrot et al., 2013; Martin et al., 2019).

Data from literature (Gallitelli et al., 2023, and references therein) show that psammophytes in dunes progressively intercept the marine litter, similarly to all types of litter in other habitat types (e.g., mangroves, (Martin et al., 2019); shrubs and dune plants, (Andriolo et al., 2020; Gallitelli et al., 2021); wetland, (Cresta and Battisti, 2021)). In detail, it is reported that plants with long and resistant branches, such as *Arundo* wrack, can lead to the formation of a debris skein acting as a barrier for microplastic and as a trap for marine anthropogenic litter (Battisti et al., 2020a).

4.2. Beach litter in psammophytes of two beaches with different anthropogenic impact

Psammophytes of the "Montorsoli" beach were very impacted by marine litter, represented mainly by plastic, bricks, and tile

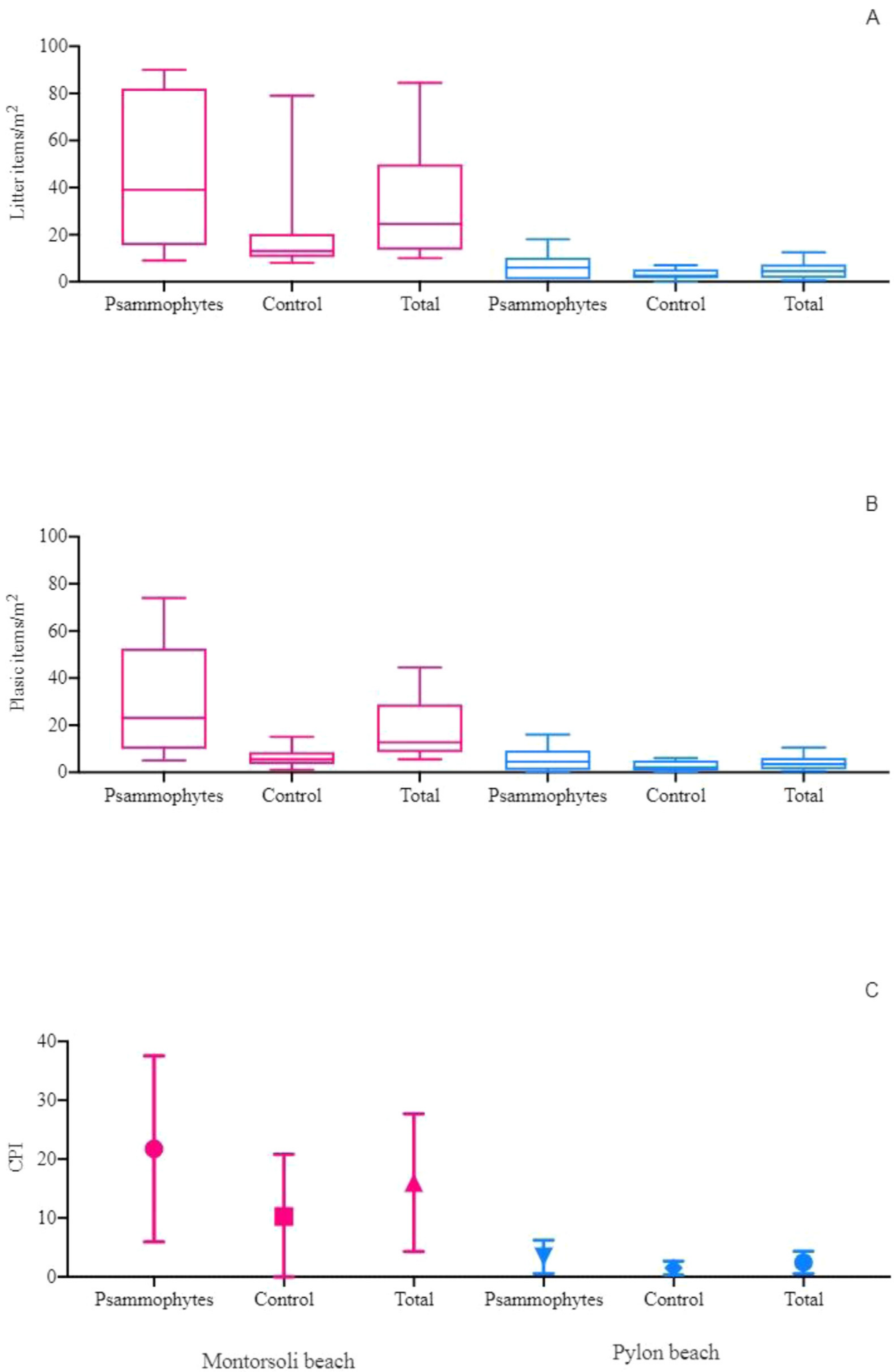

Fig. 7. Litter density (A), plastic density (B) and clean patches index (C) of the dunal plants of the Strait of Messina.

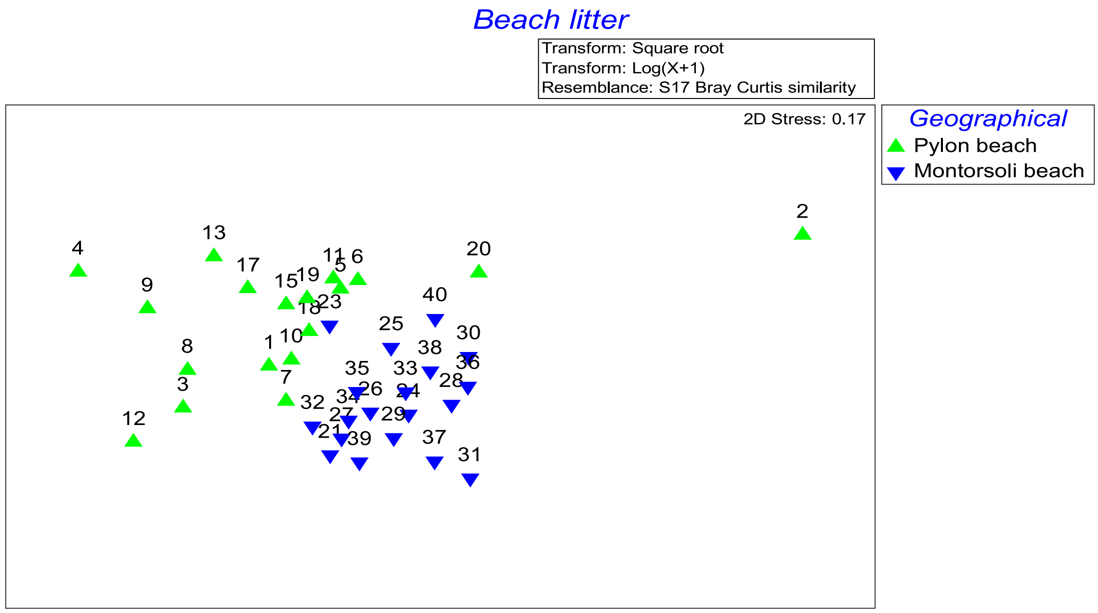

Fig. 8. Non-metric multi- dimensional scaling (MDS) ordination of the patches according to geographical site.

residues. In the "Montorsoli" beach, the psammophytes are located very close (a few meters) to the coastline and, for this, could be affected by the upwelling and rafting phenomena that characterize the Strait of Messina. The upwelling currents together with the influence of wind, create the recurrent phenomenon of the stranding of mesopelagic fish. As well as mesopelagic fish, also marine litter suffers the effects of stranding as demonstrated by Battaglia et al. (2019) which highlighted the presence of colonization of floats from stranded derelict fishing gears.

On the other hand, the density and FO of construction materials were very high and equally distributed both in psammophytes and in control patches, indicating that their distribution is not influenced by the presence of the vegetation (i.e., no trap effect). The source of this litter type, which compromises the aesthetic of the beach, dates back to the eighties when huge quantities of demolition material were dumped into several streams near the "Montorsoli" beach, and then reached the sea, as confirmed by Pierdomenico et al. (2019) that reported the presence of bricks in the Strait of Messina canyon.

Our studies showed that psammophytes of the "Pylon" beach were the least impacted by ML. Our results are particularly important because Cape Peloro, and therefore the "Pylon" beach, is included within the Special Protected Area. Despite the anthropogenic disturbance, this area still preserves the floristic-vegetational aspects of considerable landscape and naturalistic importance. Cape Peloro is also strategic for migratory flows of birds moving within the basin of the Mediterranean (Corso, 2001). In fact, the Strait of Messina (together with the Strait of Gibraltar and the Bosphorus) represents the most important areas in which Mediterranean migratory flows are concentrated, especially during the spring season.

4.3. Clean patch index

The clean patch index (CPI) applied in this study represents the degree of cleanliness of a beach in a simple and objective way. The CPI could be a new approach for dunal vegetation cleanliness assessment that could be useful as a tool to monitor the efficiency of periodic and targeted clean-ups of dunal plants.

Indeed, marine litter accumulates in coastal dunes and causes serious damage to these fragile ecosystems (Mo et al., 2021). Although dune plants play an important role because by intercepting waste, they could prevent a threat to biodiversity and ecosystems, and therefore this trapping is to be considered an ecosystem service (Cresta and Battisti, 2021). In this regard, plants intercepting plastic litter could prevent a threat to biodiversity and ecosystems. The fact that plastics might be intercepted by psammophytes has useful implications for beach clean-up management (Battisti et al., 2020b,a; Battisti and Gippoliti, 2019). However, litter removal should be carried out being careful of vegetation and birds of conservation concern (Battisti et al., 2022). Commonly, the cleaning of beaches is carried out using mechanical equipment (Pinardo-Barco et al., 2023). Differently, in this regard, only specialized workers should operate, and innovative technologies such as drones and satellites may be used to map anthropogenic litter in areas with low accessibility (Andriolo et al., 2021, 2020). In all this framework, citizen science and management should be encouraged (Gallitelli et al., 2023).

The presence of the beach litter indirectly produces the alteration of biotic communities because the mechanical technique does allow no distinction between beach litter and biological resources such as plants and animals. In the recent past, these techniques caused the leveling of the dune system of the "Pylon" beach. Even in the absence of very proper dune systems, the psammophytes may act as significant reservoirs of historical plastics, playing a critical role in their recycling and retention in the coastal zone as reported by Turner et al. (2021) for the dunal systems.

As concern, the management implications, the EU's Birds and Habitats Directives oblige member states to apply all necessary measures to avoid disturbing and damaging protected bird species. Moreover, the MSFD Descriptor D10 ("Properties and quantities of marine litter do not cause harm to the coastal and marine environment") calls for Member States to cooperate and establish regional and sub-regional specific threshold values, implement monitoring mechanisms, identify sources of and harm caused by ML, as well as to identify technical solutions for ML management.

5. Conclusion

In this study the authors show for the first time the role of dunal plants as a trap for macro litter in two sandy beaches located along the Strait of Messina. The study highlights the importance of Psammophytes that act as a barrier to marine litter. Moreover, their occurrence could also contribute to beach litter management. Further studies, maybe through the seasonal monitoring of these and other beaches located along the Strait of Messina, will be able to give us a picture of the dynamics that are linked to the stranding of the ML. Finally, this study adds important data for the implementation of the monitoring program within the Marine Strategy Framework Directive. Our results may also contribute to the development of specific management measures as well as implement National and Regional action plans.

CRediT authorship contribution statement

M. Mancuso: Investigation, Writing – original draft, Review. **G. Genovese:** Investigation, Writing – original draft, Review. **N. Porcino:** Formal analysis, Investigation, Data and writing curation. **S. Natale:** Investigation, Data curation. **A. Crisafulli:** Investigation, Data curation and writing. **D. Spagnuolo:** Investigation, Review. **M. Catalfamo:** Data curation. **M. Morabito:** Investigation, Writing – original draft, Supervision. **T. Bottari:** Project administration, Conceptualization, Formal analysis, Investigation, Writing – original draft, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2023.103057.

References

Acta Plantarum, from 2007 on - "Indice Schede botaniche". Available on line (access date: 07 February 2023): https://www.actaplantarum.org/schede/schede_new.php.

Alkalay, R., Pasternak, G., Zask, A., 2007. Clean-coast index—a new approach for beach cleanliness assessment. Ocean Coast. Manag. 50, 352–362.

Andriolo, U., Gonçalves, G., 2022. Is coastal erosion a source of marine litter pollution? Evidence of coastal dunes being a reservoir of plastics. Mar. Pollut. Bull. 174, 113307. http://dx.doi.org/10.1016/j.marpolbul.2021.113307.

Andriolo, U., Gonçalves, G., Bessa, F., Sobral, P., 2020. Mapping marine litter on coastal dunes with unmanned aerial systems: A showcase on the Atlantic Coast. Sci. Total Environ. 736, 139632. http://dx.doi.org/10.1016/j.scitotenv.2020.139632.

Andriolo, U., Gonçalves, G., Sobral, P., Bessa, F., 2021. Spatial and size distribution of macro-litter on coastal dunes from drone images: A case study on the Atlantic Coast. Mar. Pollut. Bull. 169, 112490. http://dx.doi.org/10.1016/j.marpolbul.2021.112490.

Asensio-Montesinos, F., Anfuso, G., Corbí, H., 2019. Coastal scenery and litter impacts at alicante (SE Spain): management issues. J. Coast. Conserv. 23, 185–201. http://dx.doi.org/10.1007/s11852-018-0651-8.

Azzaro, F., Decembrini, F., Raffa, F., Crisafi, E., 2007. Seasonal variability of phytoplankton fluorescence in relation to the Straits of Messina (Sicily) tidal upwelling. Ocean Sci. 3, 451–460. http://dx.doi.org/10.5194/os-3-451-2007.

Barnes, D.K.A., 2002. Invasions by marine life on plastic debris. Nature 416, 808–809.

Battaglia, P., Consoli, P., Ammendolia, G., D'Alessandro, M., Bo, M., Vicchio, T.M., Pedà, C., Cavallaro, M., Andaloro, F., Romeo, T., 2019. Colonization of floats from submerged derelict fishing gears by four protected species of deep-sea corals and barnacles in the Strait of Messina (central Mediterranean Sea). Mar. Pollut. Bull. 148, 61–65. http://dx.doi.org/10.1016/j.marpolbul.2019.07.073.

Battisti, C., Fanelli, G., Filpa, A., Cerfolli, F., 2020a. Giant Reed *(Arundo donax)* wrack as sink for plastic beach litter: First evidence and implication. Mar. Pollut. Bull. 155, 111179. http://dx.doi.org/10.1016/j.marpolbul.2020.111179.

Battisti, C., Gallitelli, L., Vanadia, S., Scalici, M., 2023. General macro-litter as a proxy for fishing lines, hooks and nets entrapping beach-nesting birds: Implications for clean-ups. Mar. Pollut. Bull. 186, 114502. http://dx.doi.org/10.1016/j.marpolbul.2022.114502.

Battisti, C., Gippoliti, S., 2019. Not just trash! Anthropogenic marine litter as a 'charismatic threat driving citizen-based conservation management actions'. Animat. Conserv. 22, 311–313. http://dx.doi.org/10.1111/acv.12473.

Battisti, C., Perchinelli, M., Luiselli, L., Dendi, D., Vanadia, S., 2022. Cages mitigate predation on eggs of threatened shorebirds: A manipulative-control study. Conservation 2, 450–456. http://dx.doi.org/10.3390/conservation2030030.

Battisti, C., Poeta, G., Romiti, F., Picciolo, L., 2020b. Small environmental actions need of problem-solving approach: Applying project management tools to beach litter clean-ups. Environments 7, http://dx.doi.org/10.3390/environments7100087.

Ben-Haddad, M., Abelouah, M.R., Hajji, S., Rangel-Buitrago, N., Alla, A.A., 2023. The halophyte Cakile maritima Scop. 1772 as a trap of plastic litter on the Moroccan coast. Mar. Pollut. Bull. 187, 114574. http://dx.doi.org/10.1016/j.marpolbul.2023.114574.

Benaissa, N., Haddad, F., Bendiab, A.T., Bensahla-Talet, L., Hamou, A., Dimache, A., 2021. A preliminary study on macro-litter pollution on beaches along Aïn El Turk Bay. Geoecomarina 27, 83–89. http://dx.doi.org/10.5281/5779786.

Biondi, E., Blasi, C., 2013. Prodromo Della Vegetazione d'Italia. In: Check-List Sintassonomica Aggiornata di Classi. Ordini e Alleanze Presenti in Italia.

Bottari, T., Mancuso, M., Pedà, C., De Domenico, F., Laface, F., Schirinzi, G.F., Battaglia, P., Consoli, P., Spanò, N., Greco, S., Romeo, T., 2022. Microplastics in the bogue, Boops boops: A snapshot of the past from the southern Tyrrhenian Sea. J. Hazard Mater. 424, 127669. http://dx.doi.org/10.1016/j.jhazmat.2021.127669.

Bottari, T., Micale, V., Liguori, M., Rinelli, P., Busalacchi, B., Bonfiglio, R., Ragonese, S., 2014. The reproductive biology of *Boops boops* (Linnaeus, 1758) (Teleostei: Sparidae) in the southern Tyrrhenian Sea (Central Mediterranean). Cah. Biol. Mar. 55, 281–292.

Bray, J.R., Curtis, J.T., 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27, 326–349.

Busalacchi, B., Bottari, T., Giordano, D., Profeta, A., Rinelli, P., 2014. Distribution and biological features of the common pandora, *Pagellus erythrinus* (Linnaeus, 1758), in the southern Tyrrhenian Sea (Central Mediterranean). Helgol. Mar. Res. 68, 491–501. http://dx.doi.org/10.1007/s10152-014-0404-5.

Calderisi, G., Cogoni, D., Loni, A., Fenu, G., 2023. Difference between invasive alien and native vegetation in trapping beach litter: A focus on a typical sandy beach of W-Mediterranean Basin. Mar. Pollut. Bull. 192, 115065. http://dx.doi.org/10.1016/j.marpolbul.2023.115065.

Camedda, A., Coppa, S., Palazzo, L., Marra, S., Massaro, G., Serrentino, F., Vencato, S., Brundu, R., de Lucia, G.A., 2021. Characterization and assessment of micro and macroscopic litter in Sardinian Beaches (Western Mediterranean Sea). Water Air Soil Pollut. 232, 41. http://dx.doi.org/10.1007/s11270-021-04993-9.

Carbery, M., O'Connor, W., Palanisami, T., 2018. Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health. Environ. Int. 115, 400–409.

CBD Technical Series No. 67, 2012. Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions. United Nations Environment Programme Secretariat of the Convention on Biological Diversity.

Cesarini, G., Cera, A., Battisti, C., Taurozzi, D., Scalici, M., 2021. Is the weight of plastic litter correlated with vegetal wrack? A case study from a Central Italian beach. Mar. Pollut. Bull. 171, 112794. http://dx.doi.org/10.1016/j.marpolbul.2021.112794.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. http://dx.doi.org/10.1111/j.1442-9993.1993.tb00438.x.

Clarke, K.R., Gorley, R.N., 2006. Primer. PRIMER-e, Plymouth, p. 866.

Corso, A., 2001. Raptor migration across the Strait of Messina, southern Italy. Br. Bird. 94, 196–202.

Cresta, E., Battisti, C., 2021. Anthropogenic litter along a coastal-wetland gradient: Reed-bed vegetation in the backdunes may act as a sink for expanded polystyrene. Mar. Pollut. Bull. 172, 112829. http://dx.doi.org/10.1016/j.marpolbul.2021.112829.

de Araújo, M.C.B., Costa, M.F., 2006. Municipal services on tourist beaches: costs and benefits of solid waste collection. J. Coast. Res. 22, 1070–1075.

de Araújo, M.C.B., da Costa, M.F., 2007. Visual diagnosis of solid waste contamination of a tourist beach: Pernambuco, Brazil. Waste Manag. 27, 833–839.

Debrot, A.O., Meesters, H.W.G., Bron, P.S., de León, R., 2013. Marine debris in mangroves and on the seabed: largely-neglected litter problems. Mar. Pollut. Bull. http://dx.doi.org/10.1016/j.marpolbul.2013.03.023.

di Blasi, C., 2008. Modeling chemical and physical processes of wood and biomass pyrolysis. Prog. Energy Combust. Sci. 34, 47–90.

Di Natale, A., Mangano, A., Ciavaglia, E., Celona, A., 2014. Bluefin tuna (*Thunnus thynnus* L.) line fisheries in the Italian seas. Old and recent data.

Fortibuoni, T., Amadesi, B., Vlachogianni, T., 2021. Composition and abundance of macrolitter along the Italian coastline: The first baseline assessment within the European Marine Strategy Framework Directive. Environ. Pollut. 268, 115886. http://dx.doi.org/10.1016/j.envpol.2020.115886.

Fossi, F., Vlachogianni, T., Anastasopoulou, A., Alomar, C., Zeri, C., 2019. Toolkit for monitoring marine litter and its impacts on biodiversity.

Gallitelli, L., Battisti, C., Olivieri, Z., Marandola, C., Acosta, A.T.R., Scalici, M., 2021. Carpobrotus spp. patches as trap for litter: Evidence from a Mediterranean beach. Mar. Pollut. Bull. 173, 113029. http://dx.doi.org/10.1016/j.marpolbul.2021.113029.

Gallitelli, L., Battisti, C., Scalici, M., 2023. Dunal plants intercepting macrolitter: Implications for beach clean-ups. Mar. Pollut. Bull. 187, 114585. http://dx.doi.org/10.1016/j.marpolbul.2023.114585.

Gündoğdu, S., Çevik, C., 2019. Mediterranean dirty edge: High level of meso and macroplastics pollution on the Turkish coast. Environ. Pollut. 255, 113351. http://dx.doi.org/10.1016/j.envpol.2019.113351.

Laglbauer, B.J.L., Franco-Santos, R.M., Andreu-Cazenave, M., Brunelli, L., Papadatou, M., Palatinus, A., Grego, M., Deprez, T., 2014. Macrodebris and microplastics from beaches in Slovenia. Mar. Pollut. Bull. 89, 356–366. http://dx.doi.org/10.1016/j.marpolbul.2014.09.036.

Mancuso, M., Panarello, G., Falco, F., Di Paola, D., Savoca, S., Capillo, G., Romeo, T., Presti, G., Gullotta, E., Spanò, N., Bono, G., Giuliano, S., Bottari, T., 2022. Investigating the effects of microplastic ingestion in *Scyliorhinus canicula* from the South of Sicily. Sci. Total Environ. 850, 157875. http://dx.doi.org/10.1016/j.scitotenv.2022.157875.

Mandić, M., Gvozdenović, S., De Vito, D., Alfonso, G., Daja, S., Ago, B., Cela, E., Ivanović, A., Zoto, A., Malovrazić, N., Beli, E., Ingrosso, G., De Leo, F., Pestorić, B., Lule, A., Vata, F., De Rinaldis, A., Carpentieri, C., Bode, A., Nazaj, S., Hoxhaj, M., Durmishi, C., Paladini, G., Peraš, I., Raičević, M., Fraissinet, S., Boero, F., Piraino, S., 2022. Setting thresholds is not enough: Beach litter as indicator of poor environmental status in the southern Adriatic Sea. Mar. Pollut. Bull. 177, 113551. http://dx.doi.org/10.1016/j.marpolbul.2022.113551.

Markic, A., Gaertner, J.-C., Gaertner-Mazouni, N., Koelmans, A.A., 2020. Plastic ingestion by marine fish in the wild. Crit. Rev. Environ. Sci. Technol. 50, 657–697. http://dx.doi.org/10.1080/10643389.2019.1631990.

Martin, C., Almahasheer, H., Duarte, C.M., 2019. Mangrove forests as traps for marine litter. Environ. Pollut. 247, 499–508. http://dx.doi.org/10.1016/j.envpol.2019.01.067.

Mathalon, A., Hill, P., 2014. Microplastic fibers in the intertidal ecosystem surrounding Halifax Harbor, Nova Scotia. Mar. Pollut. Bull. 81, 69–79.

Menicagli, V., Balestri, E., Biale, G., Corti, A., La Nasa, J., Modugno, F., Castelvetro, V., Lardicci, C., 2022. Leached degradation products from beached microplastics: A potential threat to coastal dune plants. Chemosphere 303, 135287. http://dx.doi.org/10.1016/j.chemosphere.2022.135287.

Menicagli, V., Balestri, E., Lardicci, C., 2019. Exposure of coastal dune vegetation to plastic bag leachates: A neglected impact of plastic litter. Sci. Total Environ. 683, http://dx.doi.org/10.1016/j.scitotenv.2019.05.245.

Menicagli, V., Balestri, E., Vallerini, F., Castelli, A., Lardicci, C., 2020. Combined effect of plastic litter and increased atmospheric nitrogen deposition on vegetative propagules of dune plants: A further threat to coastal ecosystems. Environ. Pollut. 266, 115281. http://dx.doi.org/10.1016/j.envpol.2020.115281.

Mghili, B., Analla, M., Aksissou, M., Aissa, C., 2020. Marine debris in Moroccan Mediterranean beaches: An assessment of their abundance, composition and sources. Mar. Pollut. Bull. 160, 111692. http://dx.doi.org/10.1016/j.marpolbul.2020.111692.

Mo, A., D'Antraccoli, M., Bedini, G., Ciccarelli, D., 2021. The role of plants in the face of marine litter invasion: A case study in an Italian protected area. Mar. Pollut. Bull. 169, 112544. http://dx.doi.org/10.1016/j.marpolbul.2021.112544.

Munari, C., Corbau, C., Simeoni, U., Mistri, M., 2016. Marine litter on Mediterranean shores: Analysis of composition, spatial distribution and sources in north-western Adriatic beaches. Waste Manag. 49, 483–490. http://dx.doi.org/10.1016/j.wasman.2015.12.010.

Nelms, S.E., Galloway, T.S., Godley, B.J., Jarvis, D.S., Lindeque, P.K., 2018. Investigating microplastic trophic transfer in marine top predators. Environ. Pollut. 238, 999–1007.

Orthodoxou, D.L., Loizidou, X.I., Baldwin, C., Kocareis, C., Karonias, A., Ateş, M.A., 2022. Seasonal and geographic variations of marine litter: A comprehensive study from the island of Cyprus. Mar. Pollut. Bull. 177, 113495. http://dx.doi.org/10.1016/j.marpolbul.2022.113495.

Pierdomenico, M., Casalbore, D., Chiocci, F.L., 2019. Massive benthic litter funnelled to deep sea by flash-flood generated hyperpycnal flows. Sci. Rep. 9, 1–10.

Pignatti, S., Casa, R., Harfouche, A., Huang, W., Palombo, A., Pascucci, S., 2019. Maize crop and weeds species detection by using uav vnir hyperpectral data. In: IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium. IEEE, pp. 7235–7238.

Pignatti, S., Guarino, R., La Rosa, M., 2017. Flora d'Italia, 2a Edizione Edagricole, Bologna.

Pinardo-Barco, S., Sanromualdo-Collado, A., García-Romero, L., 2023. Can the long-term effects of beach cleaning heavy duty machinery on aeolian sedimentary dynamics be detected by monitoring of vehicle tracks? An applied and methodological approach. J. Environ. Manag. 325, 116645. http://dx.doi.org/10.1016/j.jenvman.2022.116645.

Poeta, G., Fanelli, G., Pietrelli, L., Acosta, A.T.R., Battisti, C., 2017. Plastisphere in action: evidence for an interaction between expanded polystyrene and dunal plants. Environ. Sci. Pollut. Res. 24, 11856–11859. http://dx.doi.org/10.1007/s11356-017-8887-7.

Porcino, N., Bottari, T., Falco, F., Natale, S., Mancuso, M., 2023b. Posidonia spheroids intercepting plastic litter: Implication for beach clean-ups. http://dx.doi.org/10.20944/preprints202306.1286.v1.

Porcino, N., Bottari, T., Mancuso, M., 2023a. Is wild marine Biota affected by microplastics? Animals 13, http://dx.doi.org/10.3390/ani13010147.

Ryan, P.G., 2015. A brief history of marine litter research. Mar. Anthropog. Litter 1–25.

Ryan, P.G., 2019. Ingestion of plastics by marine organisms. In: Hazardous Chemicals Associated with Plastics in the Marine Environment. pp. 235–266.

Santos, R.G., Machovsky-Capuska, G.E., Andrades, R., 2021. Plastic ingestion as an evolutionary trap: Toward a holistic understanding. Science 373, 56–60. http://dx.doi.org/10.1126/science.abh0945.

Soto-Navarro, J., Jordá, G., Compa, M., Alomar, C., Fossi, M.C., Deudero, S., 2021. Impact of the marine litter pollution on the Mediterranean biodiversity: A risk assessment study with focus on the marine protected areas. Mar. Pollut. Bull. 165, 112169.

Spanò, N., Domenico, E.D., 2017. Biodiversity in Central Mediterranean Sea. In: Mediterranean Identities - Environment. Society, Culture. InTech, http://dx.doi.org/10.5772/intechopen.68942.

Suaria, G., Avio, C.G., Mineo, A., Lattin, G.L., Magaldi, M.G., Belmonte, G., Moore, C.J., Regoli, F., Aliani, S., 2016. The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. Sci. Rep. 6 (37551).

Thiel, M., Hinojosa, I.A., Miranda, L., Pantoja, J.F., Rivadeneira, M.M., Vásquez, N., 2013. Anthropogenic marine debris in the coastal environment: a multi-year comparison between coastal waters and local shores. Mar. Pollut. Bull. 71, 307–316.

Turner, A., Amos, S.L., Williams, T., 2021. Coastal dunes as a sink and secondary source of marine plastics: a study at Perran Beach, southwest England. Mar. Pollut. Bull. 173, 113133.

Vlachogianni, T., Fortibuoni, T., Ronchi, F., Zeri, C., Mazziotti, C., Tutman, P., Varezić, D.B., Palatinus, A., Trdan, Š., Peterlin, M., Mandić, M., Markovic, O., Prvan, M., Kaberi, H., Prevenios, M., Kolitari, J., Kroqi, G., Fusco, M., Kalampokis, E., Scoullos, M., 2018. Marine litter on the beaches of the Adriatic and Ionian Seas: An assessment of their abundance, composition and sources. Mar. Pollut. Bull. 131, 745–756. http://dx.doi.org/10.1016/j.marpolbul.2018.05.006.

Zaccone, R., Caruso, G., Azzaro, M., Azzaro, F., Crisafi, F., Domenico, E. De, Domenico, M. De, Ferla, R. La, Leonardi, M., Giudice, A. Lo, Maimone, G., Mancuso, M., Michaud, L., Monticelli, L.S., Raffa, F., Ruggeri, G., Bruni, V., 2010. Prokaryotic activities and abundance in pelagic areas of the Ionian Sea. Chem. Ecol. 26, 169–197. http://dx.doi.org/10.1080/02757541003772914.