Article

Posidonia Spheroids Intercepting Plastic Litter: Implication for Beach Clean-Ups

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Abstract: This study evaluates for the first time the plastic litter occurrence in Posidonia spheroids of four Mediterranean sandy beaches at different anthropogenic impact. A total of 80 spheroids was analyzed and 202 plastic items were found. Spheroids entangled a high number of plastic litter (132 plastic items/kg) with significant differences between beaches. Our results highlight the importance to implement the beach cleaning plan for the removal of all spheroids in order to prevent them from flaking and releasing the marine litter trapped inside them again in the environment. Spheroids should be manually removed in order to protect the banquettes. The removal should be involved all spheroids, independently from their size. This study adds data for the implementation of the monitoring program of marine litter and contributes to the development of specific management measures as well as implement Mediterranean action plans.

Keywords: *Posidonia oceanica*; aegagropilae; plastic litter; beach management; Mediterranean Sea

1. Introduction

In 2021, global plastic production reached about 90 million metric tons, with great consequences for the marine environment [1]. Plastic pollution is a big threat to aquatic environments and their inhabitants [2,3]. Plastic litter may affect marine ecosystems by transporting toxics adsorbed on the surface [4]. Plastics can act as a vector also for alien species [5] and can cause adverse effects in marine organisms [6–10]. Moreover, plastic litter can affect the marine trophic web [11,12] since plastics are also ingested by marine biota [13,14], and once ingested, can translocate into cells and tissues [15–17]. Although studies focused on plastic litter were carried out in marine and coastal ecosystems [18,19], only recently, the analysis of litter ashore from the sea to the beach has received the attention of the scientific community [20–23].

Posidonia oceanica (L.) Delile is the main dominant and endemic seagrass plant present in the Mediterranean Sea that forms huge underwater meadows from 0.5 to 40 m of water depth [24]. It plays an important ecological role in providing water quality improvement, CO_2 absorption, sea floor and beach stabilization, coastal protection, as well as refuge and nursery areas for several marine organisms [25–28]. *P. oceanica* is a protected species under several international conventions ratified by Mediterranean countries and is a priority natural habitat type for conservation under the Habitat Directive (92/43/EEC). Moreover, *P. oceanica* has been selected as an indicator of the Good Environmental Status for marine areas within the Marine Strategy Framework Directive (MSFD, 2008/56/EC).

During the autumn season, *P. oceanica* loses its leaves which, by waves and currents, accumulate on adjacent beaches as wrack beds [21]. The leaves, when decomposed, can create huge banquettes that protect the beaches from sea erosion [29], provide feed for invertebrate communities [30], and nutrients for dune plants [31]. *P. oceanica* debris can also form fibrous assemblages, called aegagropilae (herein after EG), by hydrodynamic movements [32]. EGs, commonly known as sea balls, sea rissoles, sea potatoes, beach balls, Neptune balls, or Kedron balls, are frequently found along Mediterranean beaches [33]. Their composition is an open question as the plant organ from which the fibers arise is not known. Anyway, during the EGs formation, plastic debris occurring on the sea bottom, shoreline, and on the beach gets trapped within the balls [21,34]. For this reason, *P. oceanica* provides an ecosystem service, and in the context of beach litter management, EGs removal has been recently proposed to eliminate the associated plastic items [21].

In this context, we decide to investigate for the first time the presence of plastic litter in EGs of four sandy beaches of Sicily (Central Mediterranean Sea). The aims of this paper were: i) to quantify plastic debris within EGs, ii) to compare plastic litter in EGs along beaches with different anthropogenic impact, iii), and to evaluate the correlation between plastic abundance and EGs size. The evaluation of plastic abundance within EGs is important as they can reflect the plastic pollution level of both marine and beached sediments. The relation between EGs size and plastic abundance can have implications in the context of beach litter management. In accordance with Pietrelli et al. [34], we expect to find greater quantities of plastic items in the largest balls.

2. Materials and Methods

2.1 Study areas and samplings

EGs were collected from four Sicilian beaches: three beaches along the South-West part of Sicily close to Mazara del Vallo (Trapani, Italy), namely Capo Feto (1), Tonnarella (2), and San Vito (3), and the last one located along the East coast of Sicily in the Ionian Sea, close to Augusta (Siracusa, Italy), named Spiaggetta del Sole (Figure 1, Figure 2).

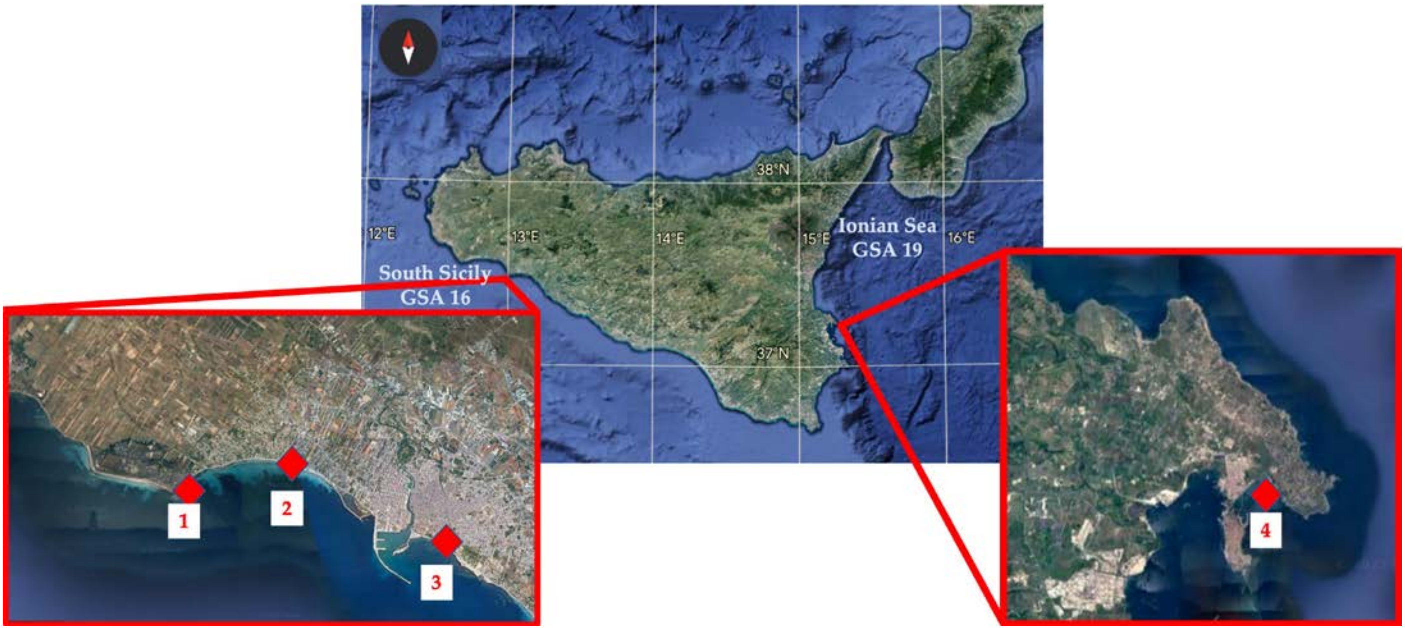

Figure 1. Study areas along the coast of the South of Sicily and the Ionian Sea. The investigated beaches: 1) Capo Feto; 2) Tonnarella; 3) S. Vito; 4) Spiaggetta del Sole. Map was created using Google Earth: https://earth.google.com/web/@37.58144601,14.57542175,322.02108172a,456382.74704598d,30.00066939y,0h,0t,0r

Figure 2. Pictures of the investigated beaches.

Capo Feto (37°39'35.3"N 12°31'40.6"E) is a Site of Community Importance (SCI), as well as an area deserving of special protection (92/43/CEE). In July 2011, according to the Convention on Wetlands of International Importance, inserted in the Ramsar wetlands' list. Tonnarella (37°39'36.5"N 12°34'03.9"E) and S. Vito (37°38'17.8"N 12°36'38.7"E) are beaches with high anthropogenic impact during the summer and represent important tourist destinations. Spiaggetta del Sole (37°14'26.0"N 15°14'11.3"E), is within the Gulf of Augusta that is an area with high anthropic impact considered one of the most polluted of the Mediterranean Sea due to the high presence of heavy metals [35,36]. The investigated areas are briefly summarized in Table 1.

Table 1. Description of four investigated beaches.

	Capo Feto	Tonnarella	S. Vito	Spiaggetta del Sole
GPS Coordinates	37°39'35.3"N 12°31'40.6"E	37°39'36.5"N 12°34'03.9"E	37°38'17.8"N 12°36'38.7"E	37°14'26.0"N 15°14'11.3"E
Area	South of Sicily GSA 16	South of Sicily GSA 16	South of Sicily GSA 16	Ionian Sea GSA 19
Beach composition	Sand	Sand	Sand	Sand

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Major usage beach	Protected area	Local and tourist people swimming. fishing and other activities	Local and tourist swimming	local people. swimming. sunbathing. fishing. surfing
Distance from the city (Km)	4.5	1.6	0	1.3
How often is the beach cleaned	Never	once a year, during spring	once a year, during spring	Once a year, before summer
Method used to clean	Manually	Manually	Meccanically	Meccanically

GSA: Geographical Sub Area

Four hundred EGs, one hundred for each site, were collected simultaneously on the beaches within a band 1 km long and 5 m wide starting from the shoreline, in summer 2022 before the beach clean-up.

2.2 Plastic isolation

Once in the laboratory, samples were dried at room temperature (25 °C) and low humidity for several days [21], then 20 EGs for each beach were selected to obtain the widest range size (Figure 3).

Figure 3. Images of selected EGs from the four beaches.

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Selected samples were weighted (g) and the length (mm) of the three principal axes was measured with a digital caliper assuming that EG is like an ellipsoid (Figure S1). After that, EGs were carefully disentangled manually into fibers under a laminal flow microbiological hood. The fibers were sieved at 8 mm, 5 mm, 1 mm, and 0.63 mm using stainless steel sieves, washed with water to remove sand and salt, and dried at room temperature [34]. Then the disentangled EGs were observed under a stereomicroscope in order to isolate plastic debris. Each suspected item was undertaken the hot needle test. The hot needle test is an accepted and cheap method to verify plastic particles on the bases of their response [14,37,38]. The tip of a thin needle was heated and each isolated particle was tested under the stereomicroscope. When particles melted after exposition to the hot needle, they were confirmed as plastic items [39]. Isolated plastic items were classified based on their size (small-microplastics: 0.1–0.9 mm; large-microplastics: 1-4.9 mm; mesoplastics: 5–25 mm; macroplastics: >25 mm), shape (pellet, fiber, tangled fiber, foam, fragment, film, and sphere).

2.3 Prevention contamination

To limit contamination, the samples were processed in a room with restricted access according to [40]. Moreover, all workspaces and tools were cleaned with ethanol and filtered deionized water, and cotton clothing was worn.

2.4 Data analysis

The roundness of EGs was calculated by the equation:

$$\boldsymbol{Roundness} = \frac{\mathbf{1}}{\mathbf{3}} \times \frac{\boldsymbol{W} \times \boldsymbol{H} \times \boldsymbol{L}}{\boldsymbol{D_{max}}}$$

where W is the width, H is the height, L is the length, and D_{max} is the maximum value measured (Figure S1). Roundness is 1 for a perfect round and less than 1 for any other object.

For each beach, plastic frequency of occurrence (FO%) and abundance (number of plastic items/spheroid) were calculated. Chi-squared test (χ^2) was performed in order to check potential significant differences between the occurrence of plastic items. Spearman correlation was performed to assess the correlation between: 1) plastic abundance vs EGs weight; 2) plastic abundance vs EGs length; 3) plastic abundance vs EGs height; 4) plastic abundance vs EGs width; 5) plastic abundance vs EGs roundness. The Kruskal–Wallis non-parametric test was used to test whether there were any significant differences in the plastic abundance between sampling sites. All graphs and statistical analyses were performed using GraphPad Prism 8.4.2.3.

3 Results

3.1 Plastic abundance

A total of 80 EGs were analyzed (length: from 17.2 to 87.4 mm; width: from 13.7 to 72.3 mm; height: from 27.2 to 114.4 mm; weight: from 1 to 74 g). In Table 2 are reported detailed information for each beach. A total of 240 suspected items was isolated, of these, 202 were positive for the needle test. Fifty-five EGs (68.7 %) included plastic items. within these, 32.7% contained one plastic item, 14.5% contained 2 items, 9.1% contained 3 items, and 43.6% contained more than 4 items. The highest number of plastic items found within a

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EG was equal to 19. Plastic abundance was 2.5 items/spheroid, corresponding to 132 items/kg. The smallest EG with plastic items weighted 1g.

Table 2. Morphometric data of EGs sampled in the four investigated beaches.

Beach	N	Length range (mm) (mean ± SD)	Width range (mm) (mean ± SD)	Height range (mm) (mean ± SD)	Roundness (mean ± SD)	Weight range (g) (mean ± SD)	N items/spheroid	N items/kg
Capo Feto	20	17.2-73.0 (50.6 ±18.2)	16.5-61.0 (45.8±17.0)	27.2-86.5 (56.6 ±18.4)	0.7-0.9 (0.9±0.1)	1-49 (20±15)	0.5	26.9
Tonnarella	20	21.8-87.4 (54.5±23.0)	15.4-72.3 (41.5±17.8)	29.1-98.3 (60.4±19.8)	0.5-0.9 (0.8±0.1)	3-73 (25±22)	1.5	58.8
S. Vito	20	20.0-85.4 (47.6±18.6)	17.5-57.6 (37.0±14.0)	30.5-106.7 (57.7±24.7)	0.5-09 (0.8±0.1)	1-71 (18±21)	3.2	175.7
Spiaggetta del Sole	20	23.7-79.2 (49.6±14.6)	13.7-30.9 (35.4±10.1)	28.2-114.4 (56.0±20.4)	0.6-0.9 (0.8±0.1)	1-34 (12±9)	4.8	408.5
TOTAL	80	17.2-87.4 (50.6±15.3)	13.7-72.3 (39.9±20.6)	27.2-114.4 (57.7±20.6)	0.5-0.9 (0.8±0.1)	1-73 (19.0±17.9)	2.5	132.5

SD: standard deviation.

No correlation between plastic abundance and weight/width/height/roundness were found (rs: from 0.15 to 0.19; $p>0.05$). There was a weak positive correlation between plastic abundance and EG length (rs: 0.24; $p<0.05$).

The length range of plastic items, with the exclusion of the tangled fibers (not measurable), ranged from 0.1 to 50 mm. Plastics items were represented by small microplastics (1%), large microplastics (26.7 %), mesoplastics (54.5 %), and macroplastics (17.8 %). The debris found were mostly fibers (48.5%), tangled filaments (41.6%), fragments (8.4%), and films (1.5%). The most frequent color was white (37.1%), followed by transparent (19.3%), green (9.9%), dark blue (8.9%), black (7.4%), red (5.9%), light blue (4.1%) and other (7.4%).

3.2 Beach comparison

The plastic items were found in the EGs of all beaches. In particular, the occurrence was highest in the EGs of Spiaggetta del Sole (100 %), followed by San Vito (80%), Tonnarella (70%), and Capo Feto (25%) (Figure 4). Significant differences in the occurrence of plastic items were only detected between Spiaggetta del Sole and Capo Feto (χ^2: 62.5, $p<0.05$).

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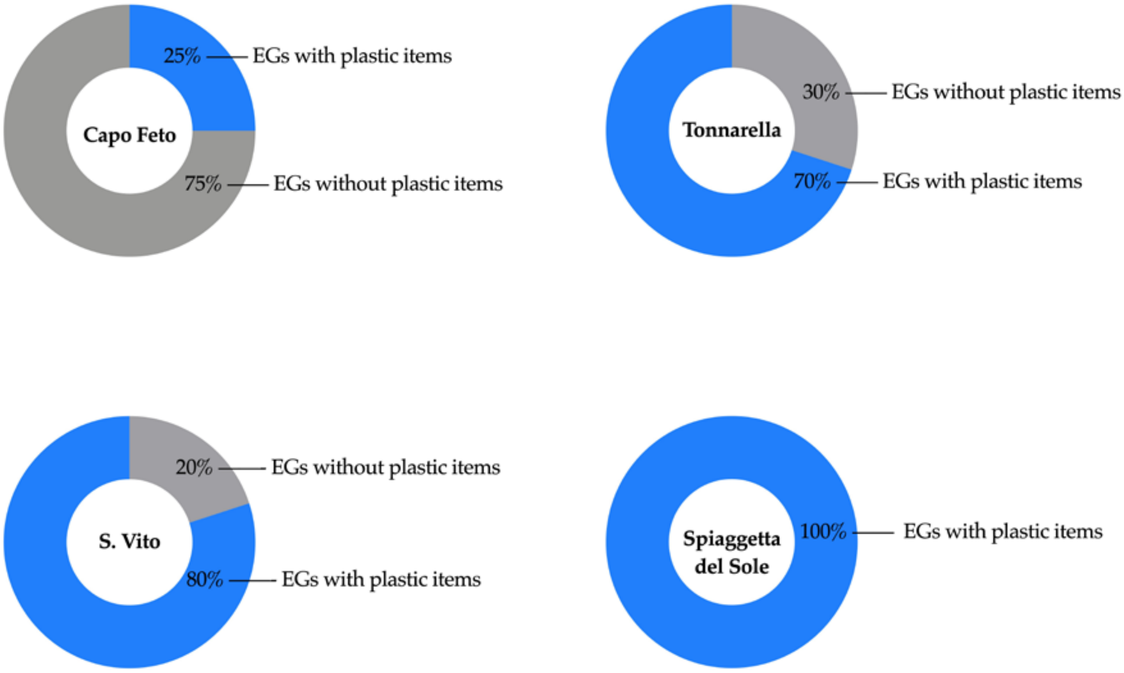

Figure 4. Percentage of Posidonia EGs with and without plastic items for each beach.

Similarly, plastic abundance (items/spheroid) was highest in the EGs of Spiaggetta del Sole (4.8 items/spheroid), followed by S. Vito (3.2 items/spheroid), Tonnarella (1.5 items/spheroid), and Capo Feto (0.5 items/spheroid) (Table 2, Figure 5, Figure S2). Kruskall-Wallis test revealed significant differences in plastic abundance values between beaches (H: 27.5, p<0.01).

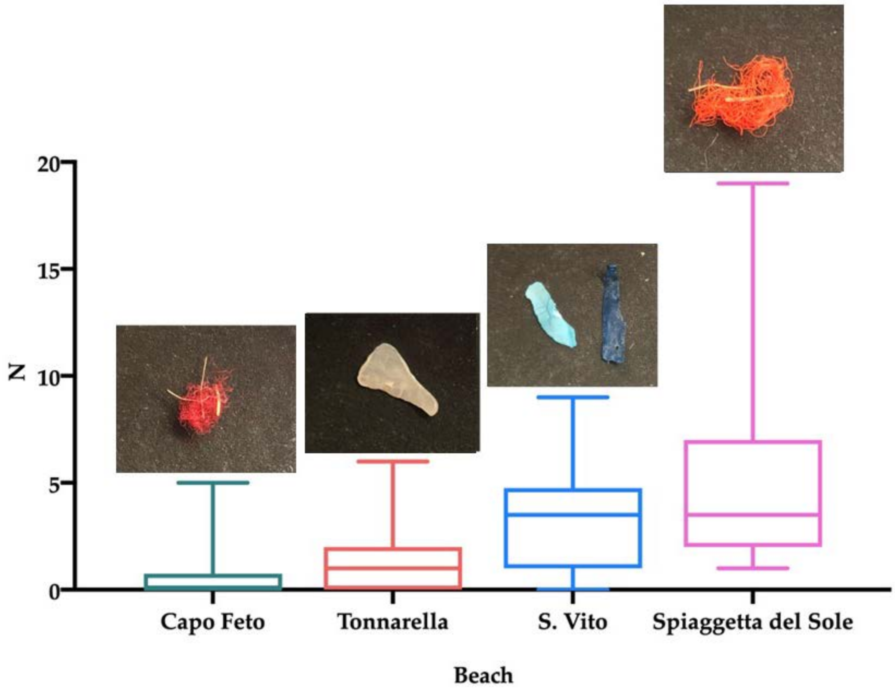

Figure 5. Box plot of plastic abundance in EGs of the four beaches. Pictures refer to plastic items found in each beach.

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As concern size, large microplastics were the most abundant in the EGs of Capo Feto beach; mesoplastics were more abundant in EGs of Tonnarella, S. Vito, and Spiaggetta del Sole beaches (Figure 6). Fibers and tangles fibers were the most frequent in all beaches investigated, except to Tonnarella, where fragments prevailed (Figure 7).

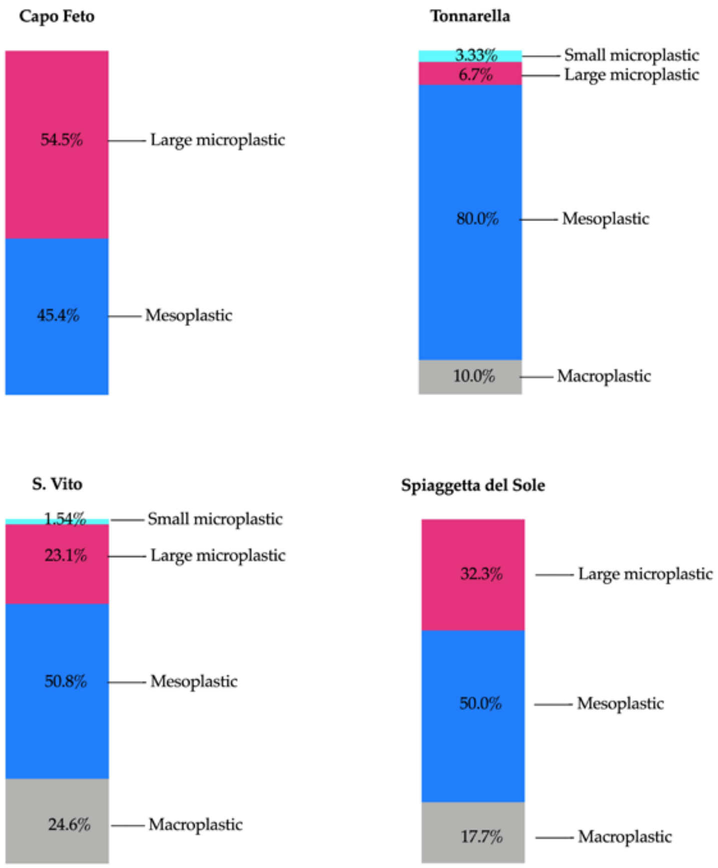

Figure 6 Size (%) of plastic items in EGs of the four beaches.

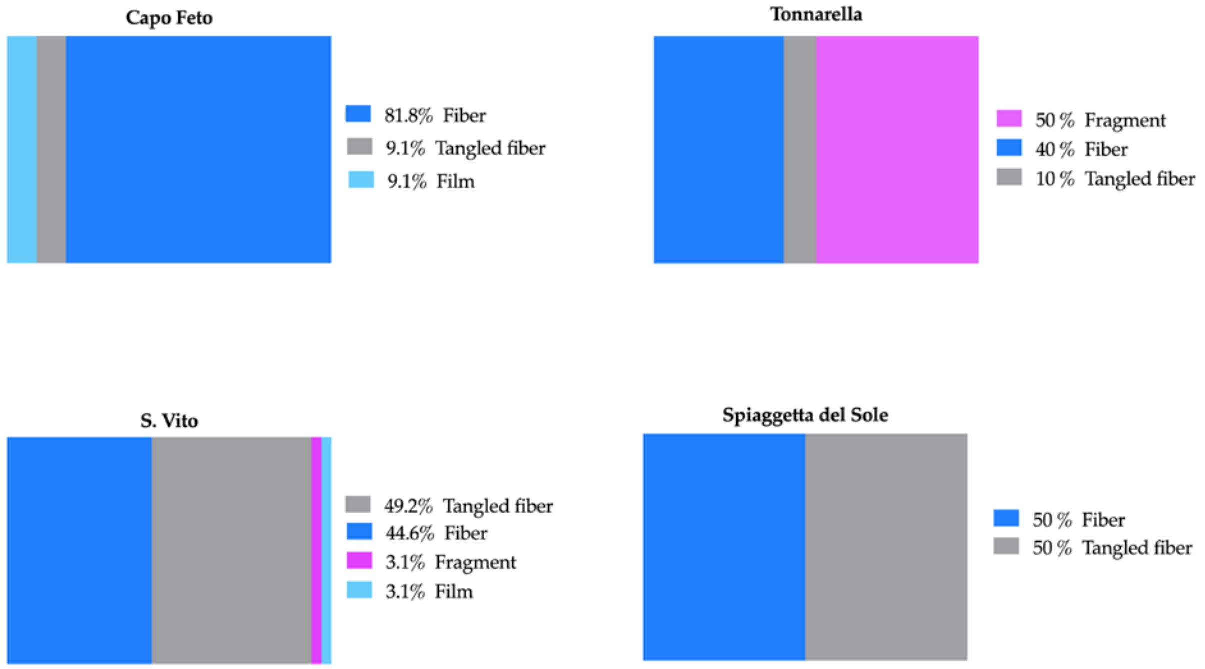

Figure 7. Shape (%) of plastic debris found in beached EG.

For what concerns the colours, in Capo Feto were founded major quantity of green and white debris, in Tonnarella the most abundant debris colour was withe, in S. Vito transparent and in Spiaggetta del Sole white (Figure 8).

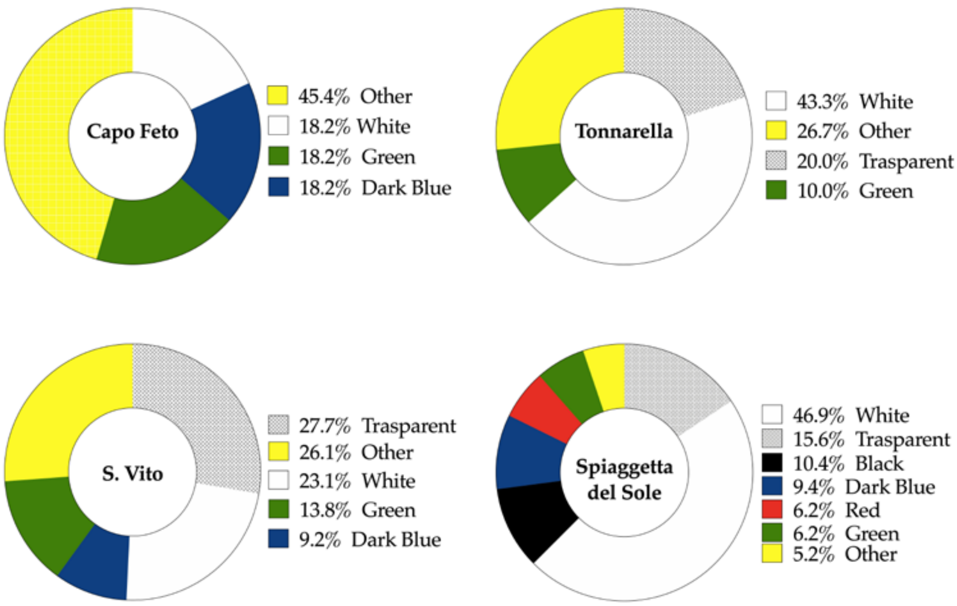

Figure 8. Colours (%) of plastic debris found in EGs.

4. Discussion

This study evaluated for the first time the presence of plastic litter entrapped in Posidonia EGs on four Sicilian sandy beaches. Although the survey is limited to a single year and a single season, it was possible to collect the first data on plastic abundance within EGs in the considered areas.

EGs, during their development, can incorporate debris occurring on the sea bottom, seawater, beach sediments, and in the air. Plastic occurrence present in EGs of this study (68.7%) is higher than those reported by Sanchez-Vidal et al. (17%) [21] and Pietrelli et al. (53%) [34]. Similarly, plastic abundance reported in this study (2.5 items/spheroid) was higher than those reported in EGs in the central Tyrrhenian Sea beaches (0.6 items/spheroid) [34]. Unlike what we expected, there was a weak correlation between the size of the EGs and the abundance of plastic litter. In fact, plastic items were found even in the smallest EGs, and sometimes even in greater quantities than in the larger balls.

In this study EGs trap plastic litter from micro (< 5mm) to macro (> 25 mm) as also reported for *P. oceanica* meadows [41]. Like other plants, such as the dune plants and the mangroves [42,43], also Posidonia EG entangle a high number of plastic litter (132 items/kg). The fact that EGs are able to trap plastic items make them plastic pollution indicators.

As regard the plastic shape, we found mostly fibers (48.5%) and tangled fibers (41.6%), followed by fragments (8.4%), and films (1.5%). Sanchez Vidal et al., also, reported in the EGs mostly filaments and fibers (65%), followed by fragments (22%) and film (8%) [21].

Tangled fibers have been reported in crustacea decapoda as *Nephrops norvegicus* [44], *Eriocheir sinensis* [45], *Aristeus antennatus* [46], *Pontastacus leptodactylus* [47], and *Parapenaeus longistroris* [48]. This is the first time that these kind of fibers were reported in the EGs. Wójcik-Fudalewska et al. [45] suggested for *E. sinensis* that the formation of tangled fibers was due to the peristaltic movements of the stomach. In the same way, the authors hypothesize that tangled fibers formation are related to the mechanical movement that generates the EGs.

4.1 Beach comparison

The monitoring carried out made it possible to highlight some differences between the beaches, attributable to the different locations and different use of the same. The EGs collected on Spiaggetta del Sole presented the greatest abundance of plastic items (4.8 items/spheroid). On the contrary, EGs from Capo Feto beach (SCI), showed the lowest plastic items abundance (0.5 items/spheroid). Tonnarella and S. Vito beaches were also impacted by plastic litter with intermediate values (1.5 and 3.2 items/spheroid, respectively). Fibers and tangled fibers were the main shapes recorded in this study. All the investigated beach, especially Spiaggetta del Sole and S. Vito beaches, showed typical pollution due to the textiles, in fact, in this area, there is a waste water treatment plant. Textiles are currently the main source of microfibers in the environment [49,50]. Manshoven et al. [51] reported that wearing and washing synthetic textiles is regarded as responsible for the discharge of between 0.2 and 0.5 million tons of MPs into the oceans each year. Conventional wastewater treatment, including tertiary treatment techniques, may remove up to 98% of microfibers [52].

4.2 Implications for cleaning up

The fact that plastics might be intercepted by EGs has useful implications for beach cleanup management. EGs removal should be carried out by being careful of vegetation, in fact, the removal of the balls should be manual at least in those stretches of coast where the EGs are on the banquettes (which play an important ecological role within the beaches and should be preserved [53]. This kind of management should be the best practice, especially in protected areas (i.e. Capo Feto). Moreover, it is necessary to implement the beach cleaning plan for the removal of all EGs, both small and large, in order to prevent them from flaking and releasing the marine litter trapped inside them again in the environment. In this study, the small EGs could include up to 8 plastic debris. In other words, EGs should be removed independently from their size as their removal can help to mitigate plastic pollution in the marine environment. Until now the degradation time of EGs is not known [21]. We can hypothesize that the dense outward shell of the EGs and the refractory character of their lignocellulosic fibers make EGs resistant to degradation. In any case, what happens to “old EGs” and relative plastic debris once ashore deserves further investigations.

The EGs removal would collect the approval of stakeholders (tourists, local administrators) that generally dislike their presence on the beach. EGs have structural, mechanical, and physical properties that make them useful in different applications. The uses of EGs might also help in the future to sustain the economic growth of all the countries of the Mediterranean Sea. The removed EGs could be used as a renewable substrate to produce bio-absorbents in environmental remediation, as insulation and reinforcing materials for building and construction, as new material to create paper and textiles and biofuel and bioplastic generation for the next generation [54–57].

This study adds data for the implementation of the monitoring program of marine litter and contributes to the development of specific management measures as well as implement Mediterranean action plans.

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References

1. Ng, C.H.; Mistoh, M.A.; Teo, S.H.; Galassi, A.; Ibrahim, A.; Sipaut, C.S.; Foo, J.; Seay, J.; Taufiq-Yap, Y.H.; Janaun, J. Plastic Waste and Microplastic Issues in Southeast Asia. *Front. Environ. Sci.* **2023**, *11*, doi:10.3389/fenvs.2023.1142071.
2. Andrady, A.L. Microplastics in the Marine Environment. *Mar. Pollut. Bull.* **2011**, *62*, 1596–1605, doi:https://doi.org/10.1016/j.marpolbul.2011.05.030.
3. Sharma, S.; Sharma, V.; Chatterjee, S. Microplastics in the Mediterranean Sea: Sources, Pollution Intensity, Sea Health, and

Regulatory Policies. *Front. Mar. Sci.* **2021**, *8*, 634934.
4. Mathalon, A.; Hill, P. Microplastic Fibers in the Intertidal Ecosystem Surrounding Halifax Harbor, Nova Scotia. *Mar. Pollut. Bull.* **2014**, *81*, 69–79, doi:https://doi.org/10.1016/j.marpolbul.2014.02.018.
5. Barnes, D.K.A. Invasions by Marine Life on Plastic Debris. *Nature* **2002**, *416*, 808–809, doi:10.1038/416808a.
6. Jepsen, E.M.; de Bruyn, P.J.N. Pinniped Entanglement in Oceanic Plastic Pollution: A Global Review. *Mar. Pollut. Bull.* **2019**, *145*, 295–305, doi:https://doi.org/10.1016/j.marpolbul.2019.05.042.
7. Markic, A.; Gaertner, J.-C.; Gaertner-Mazouni, N.; Koelmans, A.A. Plastic Ingestion by Marine Fish in the Wild. *Crit. Rev. Environ. Sci. Technol.* **2020**, *50*, 657–697, doi:10.1080/10643389.2019.1631990.
8. Ryan, P.G. Ingestion of Plastics by Marine Organisms. *Hazard. Chem. Assoc. with Plast. Mar. Environ.* **2019**, 235–266.
9. Santos, R.G.; Machovsky-Capuska, G.E.; Andrades, R. Plastic Ingestion as an Evolutionary Trap: Toward a Holistic Understanding. *Science* **2021**, *373*, 56–60, doi:10.1126/science.abh0945.
10. Porcino, N.; Bottari, T.; Mancuso, M. Is Wild Marine Biota Affected by Microplastics? *Animals* 2023, *13*.
11. Provencher, J.F.; Ammendolia, J.; Rochman, C.M.; Mallory, M.L. Assessing Plastic Debris in Aquatic Food Webs: What We Know and Don't Know about Uptake and Trophic Transfer. *Environ. Rev.* **2019**, *27*, 304–317, doi:10.1139/er-2018-0079.
12. Carbery, M.; O'Connor, W.; Palanisami, T. Trophic Transfer of Microplastics and Mixed Contaminants in the Marine Food Web and Implications for Human Health. *Environ. Int.* **2018**, *115*, 400–409, doi:10.1016/j.envint.2018.03.007.
13. Collard, F.; Ask, A. Plastic Ingestion by Arctic Fauna: A Review. *Sci. Total Environ.* **2021**, *786*, 147462, doi:https://doi.org/10.1016/j.scitotenv.2021.147462.
14. Mancuso, M.; Panarello, G.; Falco, F.; Di Paola, D.; Savoca, S.; Capillo, G.; Romeo, T.; Presti, G.; Gullotta, E.; Spanò, N.; et al. Investigating the Effects of Microplastic Ingestion in Scyliorhinus Canicula from the South of Sicily. *Sci. Total Environ.* **2022**, *850*, 157875, doi:https://doi.org/10.1016/j.scitotenv.2022.157875.
15. Brennecke, D.; Duarte, B.; Paiva, F.; Caçador, I.; Canning-Clode, J. Microplastics as Vector for Heavy Metal Contamination from the Marine Environment. *Estuar. Coast. Shelf Sci.* **2016**, *178*, 189–195, doi:https://doi.org/10.1016/j.ecss.2015.12.003.
16. Farrell, P.; Nelson, K. Trophic Level Transfer of Microplastic: Mytilus Edulis (L.) to Carcinus Maenas (L.). *Environ. Pollut.* **2013**, *177*, 1–3, doi:https://doi.org/10.1016/j.envpol.2013.01.046.
17. Collard, F.; Gilbert, B.; Compère, P.; Eppe, G.; Das, K.; Jauniaux, T.; Parmentier, E. Microplastics in Livers of European Anchovies (Engraulis Encrasicolus, L.). *Environ. Pollut.* **2017**, *229*, 1000–1005, doi:https://doi.org/10.1016/j.envpol.2017.07.089.
18. Mghili, B.; Keznine, M.; Hasni, S.; Aksissou, M. Abundance, Composition and Sources of Benthic Marine Litter Trawled-up in the Fishing Grounds on the Moroccan Mediterranean Coast. *Reg. Stud. Mar. Sci.* **2023**, *63*, 103002, doi:https://doi.org/10.1016/j.rsma.2023.103002.
19. Cau, A.; Franceschini, S.; Moccia, D.; Gorule, P.A.; Agus, B.; Bellodi, A.; Cannas, R.; Carugati, L.; Cuccu, D.; Dessì, C.; et al. WITHDRAWN: Scattered Accumulation Hotspots of Macro-Litter on the Seafloor: Insights for Mitigation Actions. *Environ. Pollut.* **2021**, 118232, doi:https://doi.org/10.1016/j.envpol.2021.118232.
20. Mghili, B.; Analla, M.; Aksissou, M.; Aissa, C. Marine Debris in Moroccan Mediterranean Beaches: An Assessment of Their Abundance, Composition and Sources. *Mar. Pollut. Bull.* **2020**, *160*, 111692, doi:https://doi.org/10.1016/j.marpolbul.2020.111692.
21. Sanchez-Vidal, A.; Canals, M.; de Haan, W.P.; Romero, J.; Veny, M. Seagrasses Provide a Novel Ecosystem Service by Trapping Marine Plastics. *Sci. Rep.* **2021**, *11*, 254, doi:10.1038/s41598-020-79370-3.
22. Gallitelli, L.; Cesarini, G.; Sodo, A.; Cera, A.; Scalici, M. Life on Bottles: Colonisation of Macroplastics by Freshwater Biota. *Sci. Total Environ.* **2023**, *873*, 162349, doi:10.1016/j.scitotenv.2023.162349.
23. Andriolo, U.; Gonçalves, G. Is Coastal Erosion a Source of Marine Litter Pollution? Evidence of Coastal Dunes Being a Reservoir of Plastics. *Mar. Pollut. Bull.* **2022**, *174*, 113307, doi:https://doi.org/10.1016/j.marpolbul.2021.113307.

24. Trache, D.; Tarchoun, A.F.; De Vita, D.; Kennedy, J.F. Posidonia Oceanica (L.) Delile: A Mediterranean Seagrass with Potential Applications but Regularly and Erroneously Referred to as an Algal Species. *Int. J. Biol. Macromol.* **2023**, *230*, 122624, doi:10.1016/j.ijbiomac.2022.11.169.
25. Bellissimo, G.; Sirchia, B.; Ruvolo, V. Monitoring of Posidonia Oceanica Meadows in the Sicilian Coasts under the Water Framework Directive (WFD). In; 2020; pp. 510–518 ISBN 978-88-5518-146-4.
26. Calvo, S.; Calvo, R.; Luzzu, F.; Raimondi, V.; Assenzo, M.; Cassetti, F.P.; Tomasello, A. Performance Assessment of Posidonia Oceanica (L.) Delile Restoration Experiment on Dead Matte Twelve Years after Planting—Structural and Functional Meadow Features. *Water* **2021**, *13*, doi:10.3390/w13050724.
27. Kalogirou, S.; Corsini-Foka, M.; Sioulas, A.; Wennhage, H.; Pihl, L. Diversity, Structure and Function of Fish Assemblages Associated with Posidonia Oceanica Beds in an Area of the Eastern Mediterranean Sea and the Role of Non-Indigenous Species. *J. Fish Biol.* **2010**, *77*, 2338–2357, doi:10.1111/j.1095-8649.2010.02817.x.
28. Mateo Ramírez, Á.; Urra, J.; Marina, P.; Rueda, J.; García Raso, J. Crustacean Decapod Assemblages Associated with Fragmented Posidonia Oceanica Meadows in the Alboran Sea (Western Mediterranean Sea): Composition, Temporal Dynamics and Influence of Meadow Structure. *Mar. Ecol.* **2015**, *37*, doi:10.1111/maec.12284.
29. Boudouresque, C.; Pergent, G.; Pergent-Martini, C.; Ruitton, S.; Thibaut, T.; Verlaque, M. The Necromass of the Posidonia Oceanica Seagrass Meadow: Fate, Role, Ecosystem Services and Vulnerability. **2016**.
30. Colombini, I.; Mateo, M.Á.; Serrano, O.; Fallaci, M.; Gagnarli, E.; Serrano, L.; Chelazzi, L. On the Role of Posidonia Oceanica Beach Wrack for Macroinvertebrates of a Tyrrhenian Sandy Shore. *Acta Oecologica* **2009**, *35*, 32–44, doi:https://doi.org/10.1016/j.actao.2008.07.005.
31. Del Vecchio, S.; Marbà, N.; Acosta, A.; Vignolo, C.; Traveset, A. Effects of Posidonia Oceanica Beach-Cast on Germination, Growth and Nutrient Uptake of Coastal Dune Plants. *PLoS One* **2013**, *8*, 1–8, doi:10.1371/journal.pone.0070607.
32. Blondel, V.D.; Guillaume, J.L.; Lambiotte, R.; Lefebvre, E. Fast Unfolding of Communities in Large Networks. *J. Stat. Mech.-Theory Exp.* **2008**, *2008*, P10008.
33. Lefebvre, L.; Compère, P.; Gobert, S. The Formation of Aegagropiles from the Mediterranean Seagrass Posidonia Oceanica (L.) Delile (1813): Plant Tissue Sources and Colonisation by Melanised Fungal Mycelium. *Mar. Biol.* **2023**, *170*, 19, doi:10.1007/s00227-022-04166-0.
34. Pietrelli, L.; Di Gennaro, A.; Menegoni, P.; Lecce, F.; Poeta, G.; Acosta, A.T.R.; Battisti, C.; Iannilli, V. Pervasive Plastisphere: First Record of Plastics in Egagropiles (Posidonia Spheroids). *Environ. Pollut.* **2017**, *229*, 1032–1036, doi:https://doi.org/10.1016/j.envpol.2017.07.098.
35. Feo, M.L.; Bagnati, R.; Passoni, A.; Riva, F.; Salvagio Manta, D.; Sprovieri, M.; Traina, A.; Zuccato, E.; Castiglioni, S. Pharmaceuticals and Other Contaminants in Waters and Sediments from Augusta Bay (Southern Italy). *Sci. Total Environ.* **2020**, *739*, 139827, doi:https://doi.org/10.1016/j.scitotenv.2020.139827.
36. Bianchi, F.; Bianca, S.; Linzalone, N.; Madeddu, A. Surveillance of Congenital Malformations in Italy: An Investigation in the Province of Siracusa; [Sorveglianza Delle Malformazioni Congenite in Italia: Un Approfondimento Nella Provincia Di Siracusa.]. *Epidemiol. Prev.* **2004**, *28*, 87 – 93.
37. Kapp, K.J.; Yeatman, E. Microplastic Hotspots in the Snake and Lower Columbia Rivers: A Journey from the Greater Yellowstone Ecosystem to the Pacific Ocean. *Environ. Pollut.* **2018**, *241*, 1082–1090, doi:https://doi.org/10.1016/j.envpol.2018.06.033.
38. Silva, A.B.; Bastos, A.S.; Justino, C.I.L.; da Costa, J.P.; Duarte, A.C.; Rocha-Santos, T.A.P. Microplastics in the Environment: Challenges in Analytical Chemistry - A Review. *Anal. Chim. Acta* **2018**, *1017*, 1–19, doi:https://doi.org/10.1016/j.aca.2018.02.043.
39. Lusher, A.L.; Welden, N.A.; Sobral, P.; Cole, M. Sampling, Isolating and Identifying Microplastics Ingested by Fish and Invertebrates. *Anal. Methods* **2017**, *9*, 1346–1360, doi:10.1039/c6ay02415g.

40. Bottari, T.; Mancuso, M.; Pedà, C.; De Domenico, F.; Laface, F.; Schirinzi, G.F.; Battaglia, P.; Consoli, P.; Spanò, N.; Greco, S.; et al. Microplastics in the Bogue, Boops Boops: A Snapshot of the Past from the Southern Tyrrhenian Sea. *J. Hazard. Mater.* **2022**, *424*, 127669, doi:https://doi.org/10.1016/j.jhazmat.2021.127669.
41. Navarrete-Fernández, T.; Bermejo, R.; Hernández, I.; Deidun, A.; Andreu-Cazenave, M.; Cózar, A. The Role of Seagrass Meadows in the Coastal Trapping of Litter. *Mar. Pollut. Bull.* **2022**, *174*, 113299, doi:https://doi.org/10.1016/j.marpolbul.2021.113299.
42. Ben-Haddad, M.; Abelouah, M.R.; Hajji, S.; Rangel-Buitrago, N.; Alla, A.A. The Halophyte Cakile Maritima Scop. 1772 as a Trap of Plastic Litter on the Moroccan Coast. *Mar. Pollut. Bull.* **2023**, *187*, 114574, doi:https://doi.org/10.1016/j.marpolbul.2023.114574.
43. De, K.; Sautya, S.; Dora, G.U.; Gaikwad, S.; Katke, D.; Salvi, A. Mangroves in the “Plasticene”: High Exposure of Coastal Mangroves to Anthropogenic Litter Pollution along the Central-West Coast of India. *Sci. Total Environ.* **2023**, *858*, 160071, doi:10.1016/j.scitotenv.2022.160071.
44. Welden, N.A.C.; Cowie, P.R. Environment and Gut Morphology Influence Microplastic Retention in Langoustine, Nephrops Norvegicus. *Environ. Pollut.* **2016**, *214*, 859–865, doi:10.1016/j.envpol.2016.03.067.
45. Wójcik-Fudalewska, D.; Normant-Saremba, M.; Anastácio, P. Occurrence of Plastic Debris in the Stomach of the Invasive Crab Eriocheir Sinensis. *Mar. Pollut. Bull.* **2016**, *113*, 306–311, doi:https://doi.org/10.1016/j.marpolbul.2016.09.059.
46. Carreras-Colom, E.; Constenla, M.; Soler-Membrives, A.; Cartes, J.E.; Baeza, M.; Padros, F.; Carrasson, M. Spatial Occurrence and Effects of Microplastic Ingestion on the Deep-Water Shrimp Aristeus Antennatus. *Mar. Pollut. Bull.* **2018**, *133*, 44–52, doi:10.1016/j.marpolbul.2018.05.012.
47. Yücel, N.; Kılıç, E. Microplastic Contamination in the Freshwater Crayfish Pontastacus Leptodactylus (Eschscholtz, 1823). *Mar. Pollut. Bull.* **2022**, *185*, 114337, doi:https://doi.org/10.1016/j.marpolbul.2022.114337.
48. Bono, G.; Falsone, F.; Francesca, F.; Di Maio, F.; Gabriele, M.; Gancitano, V.; Geraci, M.; Scannella, D.; Mancuso, M.; Okpala, C.; et al. Microplastics and Alien Black Particles as Contaminants of Deep- Water Rose Shrimp (Parapenaeus Longistroris Lucas, 1846) in the Central Mediterranean Sea. *J. Adv. Biotechnol. Bioeng.* **2020**, *8*, 23–28, doi:10.12970/2311-1755.2020.08.04.
49. Carr, S.A. Sources and Dispersive Modes of Micro-Fibers in the Environment. *Integr. Environ. Assess. Manag.* **2017**, *13*, 466–469, doi:10.1002/ieam.1916.
50. Gavigan, J.; Kefela, T.; Macadam-Somer, I.; Suh, S.; Geyer, R.; Gavigan Jenna; Kefela, T.; Macadam-Somer Ilan; Suh Sangwon; Geyer Roland Synthetic Microfiber Emissions to Land Rival Those to Waterbodies and Are Growing. *PLoS One* **2020**, *15*, 1–13, doi:10.1371/journal.pone.0237839.
51. Manshoven, S.; Smeets, A.; Malarciuc, C.; Tenhunen, A. *Microplastic Pollution from Textile Consumption in Europe*; 2022;
52. Murphy, F.; Ewins, C.; Carbonnier, F.; Quinn, B. Wastewater Treatment Works (WwTW) as a Source of Microplastics in the Aquatic Environment. *Environ. Sci. Technol.* **2016**, *50*, doi:10.1021/acs.est.5b05416.
53. Rotini, A.; Chiesa, S.; Manfra, L.; Borrello, P.; Piermarini, R.; Silvestri, C.; Cappucci, S.; Parlagreco, L.; Devoti, S.; Pisapia, M.; et al. Effectiveness of the “Ecological Beach” Model: Beneficial Management of Posidonia Beach Casts and Banquette. *Water* **2020**, *12*, doi:10.3390/w12113238.
54. Restaino, O.F.; Giosafatto, C.V.L.; Mirpoor, S.F.; Cammarota, M.; Hejazi, S.; Mariniello, L.; Schiraldi, C.; Porta, R. Sustainable Exploitation of Posidonia Oceanica Sea Balls (Egagropili): A Review. *Int. J. Mol. Sci.* **2023**, *24*, doi:10.3390/ijms24087301.
55. Verhille, G.; Moulinet, S.; Vandenberghe, N.; Adda-Bedia, M.; Gal, P. Le Structure and Mechanics of Aegagropilae Fiber Network. *Proc. Natl. Acad. Sci.* **2017**, *114*, 4607–4612, doi:10.1073/pnas.1620688114.
56. Pfeifer, L. “Neptune Balls” Polysaccharides: Disentangling the Wiry Seagrass Detritus. *Polymers (Basel).* **2021**, *13*, doi:10.3390/polym13244285.
57. Rubio-Portillo, E.; Martin-Cuadrado, A.-B.; Ramos-Esplá, A.Á.; Antón, J. Metagenomics Unveils Posidonia Oceanica

"Banquettes" as a Potential Source of Novel Bioactive Compounds and Carbohydrate Active Enzymes (CAZymes). *mSystems* **2021**, *6*, e0086621, doi:10.1128/mSystems.00866-21.