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Seafloor litter in two protected areas (Sopot and Dražin vrt) in the Boka Kotorska Bay (Montenegro, southeast Adriatic Sea)

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ABSTRACT

The first assesment of seafloor marine litter pollution in marine protected areas in Montenegro is presented. Surveys were performed during 2020 and 2021 year at two protected marine areas "Sopot" and "Dražin vrt". Methodology was based on visual survey by SCUBA diving during cleaning campains. The results show dominance of plastic litter (46.91%), while considering the size classes, the most numerous was size class I (46.54%). Mean density of marine litter was 3 items/100 m^2. Results indicate that both investigated MPA's are highly polluted by seafloor marine litter, what highlights the need for constant monitoring.

Keywords: MPA, seafloor litter, marine pollution, *Savalia savaglia*, Adriatic Sea

INTRODUCTION

Marine litter is defined as any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment (UNEP, 2009). The Mediterranean Sea is one of the areas most affected by marine litter worldwide (Suaria *et al*., 2016; Vlachogianni, 2019), mainly due to the combination of densely populated coast, tourism, maritime traffic and negligible tidal flow (Barnes *et al*., 2009; Liubartseva *et al*., 2019). Even in pristine environments of the Mediterranean, such as coastal and Marine Protected Areas (MPA), marine litter is impacting and threatening different habitats and species. Impacts vary from entanglement and ingestion, to bio-accumulation and bio-magnification of toxics released from litter items, facilitation of introduction of invasive species, damages of benthic habitats, etc. (Vlachogianni, 2019; Robuck, 2020). Marine litter pollution can be addressed as major threat to the biodiversity of the Mediterranean basin, as marine litter can be found everywhere:lying on the shores, floating

on the surface, laying on the seabed.

It has been estimated that up to 70% of the marine litter that enters the Sea ends up on the seabed (UNEP, 2005), and according to Pasquini *et al*. (2016), the Adriatic Sea is one of the most affected areas by seafloor litter in the Mediterranean. Adriatic Sea is identified as preferential area for plastic accumulation (Ruiz-Orejon *et al*., 2016; Carlson *et al*., 2017) especially due to transboundary effects caused by sea currents (Palatinus *et al*., 2019). Liubartseva *et al*. (2016) estimated that 40% of litter enters the Adriatic basin through the rivers, 40% through coastal urban populations, and 20% through shipping and fishing activities.

There are different survey methods for seafloor litter monitoring: ROV (Remotely Operated Vehicles), trawling, scuba diving (Consoli *et al*., 2018), where trawling is one of the most commonly and most used method. Trawling is mainly used among soft bottoms of deeper waters, and it is not allowed in shallow coastal waters. Scuba diving is one of the most convenient method for shallow, coastal waters and additionally it is appropriate for application in areas with high ecological value, e.g. protected or sensitive areas (Stagličić *et al*., 2021).

As MPA's are areas of the ocean and marine set aside for long-term conservation aims and home to vulnerable and sensitive resources, impacts from marine litter can be particularly harmful. It is impacting habitat integrity, harming marine life, e.g. crushes sensitive species such as corals and also can impact shoreline and underwater cultural and historical resources (Robuck, 2020).

Unfortunately, up until 2021 Montenegro was the only Mediterranean country, besides Bosnia & Herzegovina, that has not established any MPA. Since April 2021, Montenegro has declared MPA "Platamuni" (Službeni list Crne Gore, 063/21) and MPA "Katič" (https://www.gov.me/clanak/crna-gora-dobila-drugo-zasticeno-morsko-i-obalno-podrucje-park-prirode-katic). Additionally, two preventive marine protected areas "Sopot" and "Dražin vrt" has been declared due to the exceptional value of biodiversity, and especially the coralligenous community of the golden coral *Savalia savaglia* Bertolini, 1819 (Službeni list Crne Gore, 95/21).

As "Sopot" and "Dražin vrt" are under high anthropogenic pressure, cleaning campains were organized with aim to raise the awareness, promote protection measures as well as to assess the composition and abundance of seafloor marine litter in these two MPA's and decrease impact of marine litter to those vulnerable habitats.

MATERIAL AND METHODS

Study area

"Sopot" and "Dražin vrt" are situated in the inner part of the Boka Kotorska Bay (Fig. 1). "Sopot" is situated near to the coast, 1.5 km to the west from the settlement Risan. The central coordinate of the protected area is 42° 30′ 36.738″ N, 18° 40′ 48.227″ E. Total surface of protected area is 2.3 ha. The greatest depth is 28 m. "Dražin vrt" is also situated near to the coast, 0.5 km to the east from the settlement Perast. The central coordinate of this protected area is 42° 28′ 59.642″ N, 18° 42′ 54.202″ E. Total surface of protected area is 1.1 ha. The greatest depth is 26 m. At both localities, a huge number of *Savalia savaglia* colonies inhabit the rocky-sandy bottom, at depth range from 12 to 24 m and this is the largest known population of this protected species in the Mediterranean Sea (UNEP/MAP-PAP/RAC-SPA/RAC & MSDT, 2019). The most of colonies are at depths from 15 to 20 m, and this is additional fact that makes these localities specific, as it is known that *S. savaglia* prefer

deeper water, usually over 40 m (Giusti *et al*., 2015).

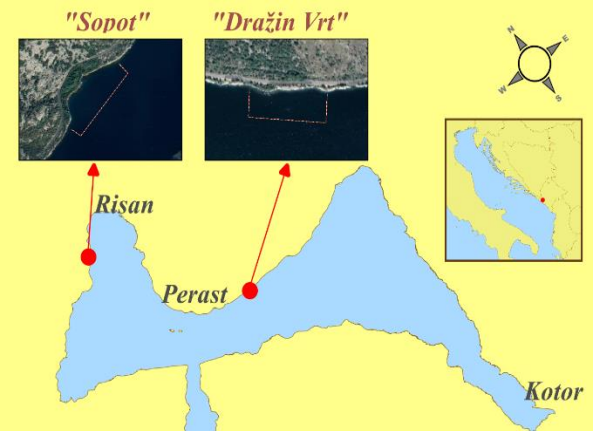

Figure 1. MPA "Sopot" and "Dražin vrt" in Boka Kotorska Bay

Survey method, data collection and processing

Seafloor marine litter was collected during two successive years (August 2020 and October 2021) by SCUBA diving (4–6 divers).

All colected litter was removed from the sea bottom and classified according to "Methodology for monitoring marine litter on the seafloor (Shallow coastal waters (0–20 m) Visual surveys with SCUBA/snorkelling)" (Vlachogianni *et al*., 2014). Marine litter was classified in seven litter categories: artificial polymer materials (APM) or plastic, rubber, cloth/textile, paper/cardboard, processed/ worked wood, metal, glass/ceramics and also in six size classes: G< 25 cm^2; H< 100 cm^2; I< 400 cm^2; J< 2500 cm^2; K< 1 m^2; L> 1 m^2. Additionally, during 2021 litter items were weighed, so the litter weight is available only for this year.

For the data analysis and visualization Microsoft Office Excel 2013 was used. Density of marine litter was calculated as number of items per 100 m^2 (no. items/100 m^2) and items weight per 100 m^2 (kg/100 m^2). As the requirement of homogeneity was met (Levene's test), t-test was used to obtain if there are differences among locations and among period of investigation.

RESULTS

At both locations, covering surface of 3.4 ha, a total of 1876 marine litter items were collected. The largest amount of litter on both locations was collected at depth range 5–15 m. Obtained data (number and weight of litter) are classified in seven categories (Table 1). Both locations, during both cleaning campaigns were paper/cardboard-free. Total weight of collected litter during 2021 was 149.891 kg and mean litter weight density was 0.503 ± 0.29 kg/100 m^2. The density of litter, in terms of number, throughout study areas ranged from 1.46 to 4.55 items/100 m^2, while the mean density was 3 ± 1.28 items/100 m^2.

Dominant litter category at "Sopot" was glass/ceramics (500 items), while at "Dražin vrt" plastic was dominant (583 items). However, t-test showed that there is no statistically significant differences in total litter amount among study locations ($t = 0.12$; $p > 0.05$), neither among study periods ($t = 0.60$; $p > 0.05$), huge difference is noticed between number of glass/ceramics items in 2020 (588 items) and 2021 (92 items).

Plastic was the most numerous litter category (46.91%), followed by glass/ceramics (36.25%) and metal (13.54%), while in terms of weight, rubber was the heaviest litter category (34.47%), followed by plastic (33.92%) and metal (20.21%) (Fig. 2). Considering the size classes, the most numerous was size class I (46.54%), followed by class H (28.20%) and class G (22.12%) (Fig. 3).

Percentage composition of top 10 the most numerous litter items is given in Figure 4. Those 10 items had percentile share of 93.82% in total litter. Bottles, plastic and glass,

Table 1. Number and weight of seafloor marine litter at investigated locations during both investigated years (* - no weight data for 2020)

		Sopot_2020	Dražin vrt_2020	Sopot_2021	Dražin vrt_2021	Total_2020	Total_2021
NUMBER	**Total No. items**	**641**	**522**	**340**	**373**	**1163**	**713**
Litter category	APM	89	318	208	265	407	473
	Rubber	5	7	11	8	12	19
	Cloth/Textile	8	10	5	6	18	11
	Paper/Cardboard	0	0	0	0	0	0
	Processed/Worked wood	0	0	1	1	0	2
	Metal	100	38	54	62	138	116
	Glass/Ceramics	439	149	61	31	588	92
WEIGHT	**Total weight (kg)**	*****	*****	**67.953**	**81.938**	*	**149.891**
Litter category	APM	*	*	30.673	20.173	*	50.846
	Rubber	*	*	26.14	25.52	*	51.66
	Cloth/Textile	*	*	0.79	1.625	*	2.415
	Paper/Cardboard	*	*	0	0	*	0
	Processed/Worked wood	*	*	0.07	0.25	*	0.32
	Metal	*	*	1.45	28.85	*	30.3
	Glass/Ceramics	*	*	8.83	5.52	*	14.35

accounted more than 2/3 of total litter. Plastic bottles (code G6) had contribution of 35.13%, while glass bottles (incl. pieces) (code G200) had contribution of 34.33%. Among metal category, beverage (code G175) were the most numerous (11.46%).

DISSCUSION

Marine litter is growing pollution problem all over the World Ocean. As Stagličić *et al*. (2021) mentioned, the bulk of investigation devoted to the issue addresses the type and distribution of beach and floating marine litter, whereas still, little information is available regarding the seafloor marine litter, especially for shallow coastal environments. In addition to this, MPAs as very sensitive and ecologically valuable areas, should be in the focus of monitoring protocols concerning the problem of marine litter. That is why this study is important contribution to the knowledge on abundance and composition of seafloor marine litter at two small protected areas in Montenegro.

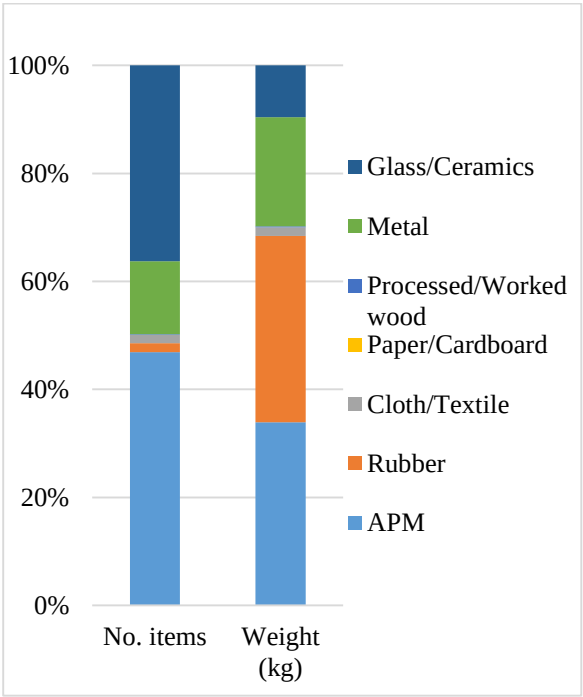

Figure 2. Percentage composition of litter categories by number and weight

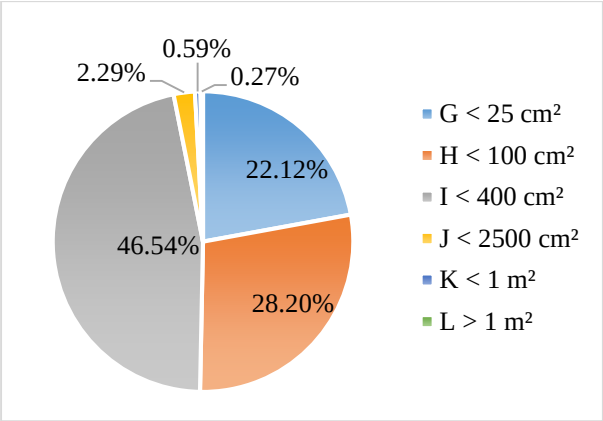

Figure 3. Percentage composition of litter size classes by number

In this study quite large amount of seafloor litter was collected at two protected marine areas "Sopot" and "Dražin vrt". Six categories of marine litter were present on both investigated localities, during both investigated periods, while both localities were paper/cardboard-free. Based on field tests and rough estimates, paper/cardboard is one of the fastest degradable material in marine environment (Booth *et al.*, 2017). Additionally, this litter category includes items which are mostly light and subject to splitting and tearing by waves and sea currents, so can very easily be transported to the deeper waters or washed ashore. A huge difference noticed between number of glass/ceramics items in 2020 (588 items) and 2021 (92 items) may be due to the fact that a lot of old waste, i.e. glass bottles, was collected during 2020.

Mean densities in terms of number (3 ± 1.28 items/100 m^2) are compared to the results given by other authors for different parts of the Mediterranean (Table 2). Mean densities in terms of weight (0.503 ± 0.29 kg/100 m^2) were almost the same as results given by Krstulović (2020) for open coast of Montenegro, but far less compare to the results which are available for Boka Kotorska Bay (Krstulović, 2020) and other Mediteranean countries e.g. Turkey and Croatia (Mutlu *et al.*, 2020; Stagličić *et al.*, 2021) (Table 2). This disagreement is probably due to the fact that mean density in terms of weight in this study is available only for 2021 year. Consoli *et al.* (2020) estimated that mean seafloor litter density in terms of number and terms of weight for whole Mediterranean are 43.55 items/100 m^2 and 31.93 kg/100 m^2, respectively. In all mentioned studies, including this one, methodology based on SCUBA diving was used, and some authors mentioned that this methodology allows more detailed study of seafloor marine litter comparing to trawling or ROV so the high values of marine litter can be also attributed to it (Melli *et al.*, 2017; Vlachogianni *et al.*, 2017; Consoli *et al.*, 2020; Stagličić *et al.*, 2021).

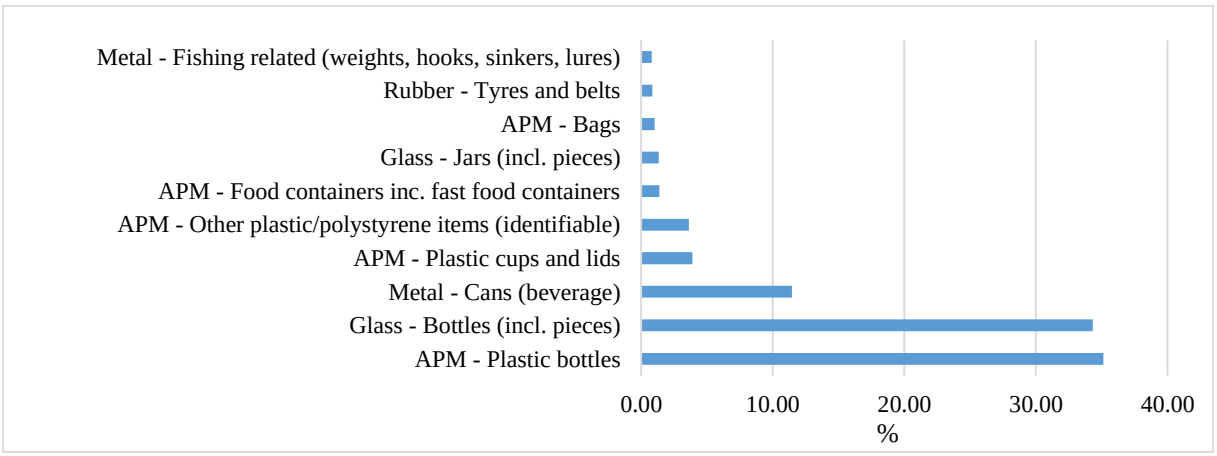

Figure 4. Percentage composition of top 10 numerous litter items

APM was the dominant litter category (46.91%). Our results are in line with similar studies dedicated to shallow coast of Montenegro (Mačić *et al*., 2017; 2018; Krstulović, 2020), as well as Adriatic Sea (Strafella *et al*., 2014; Renzi *et al*., 2019; Scotti *et al*., 2021; Stagličić *et al*., 2021) and other Mediterranean areas (Katsanevakis & Katsarou, 2004; Pasternak *et al*., 2019; Consoli *et al*., 2020; Mutlu *et al*., 2020; Scotti *et al*., 2021). Plastic marine litter is a global, growing threat. When plastic arrives at seafloor, it can persist there for decades. Accumulation in the sediments might alter the quality of seabed habitats by imposing physiological and toxicological risks (Casoli *et al*., 2017).

A large amount of marine litter was collected at both surveyed areas (1163 items during 2020 and 713 items during 2021 year) and these locations are still not completely cleaned. Boka Kotorska Bay is recognised as area where accumulation of marine litter is much higher compared to open sea (Mačić *et al*., 2017; Krstulović, 2020). This is semi-enclosed bay, with law tidal flow, intense tourism and maritime transport, heavily populated coastlines, and long fishery tradition what contributed to the Bay apparently being much more affected by marine litter pollution compare to open sea. Furthermore, as reported by Mačić *et al*. (2017) at some locations different materials were previously dumped illegaly on the coast, close to the road, and later on that material was dumped into the sea what

Table 2. Seafloor litter densities (no. items/100 m^2; kg/100 m^2) below 40 m depth from various Mediterranean areas

Area	Survey method	Depth range (m)	Mean density (no. items/ 100 m^2)	Mean density (kg/100 m^2)	Reference
Montenegro, Adriatic Sea	scuba diving	9–24	4.61	/	Vlachogianni *et al*., 2017; Fortibuoni *et al*., 2019
Slovenia, Adriatic Sea	scuba diving	3–17	0.68	/	Vlachogianni *et al*., 2017; Fortibuoni *et al*., 2019
Bosnia and Herzegovina, Adriatic Sea	scuba diving	6–18	6.13	/	Vlachogianni *et al*., 2017; Fortibuoni *et al*., 2019
Greece, Eastern Mediterranean Sea	scuba diving	0–25	1.5	/	Katsanevakis & Katsarou, 2004
Montenegro, Adriatic Sea	scuba diving	0–40	0.25	/	Mačić *et al*., 2017
Israel, Eastern Mediterranean Sea	scuba diving	0–10	2.01	/	Pasternak *et al*., 2019
Turkey, Eastern Mediterranean Sea	scuba diving	10–35	1.9	1.3	Mutlu *et al*., 2020
Italy, Central and south Mediterranean	scuba diving	/	2.75	/	Scotti *et al*., 2021
Croatia, Adriatic Sea	scuba diving	5–12	20	6	Stagličić *et al*., 2021
Montenegro, Adriatic Sea, Boka Kotorska Bay	scuba diving	/	5.41	3.85	Krstulović, 2020
Montenegro, Adriatic Sea, Boka Kotorska Bay	scuba diving	0–16	35.3	12.32	Krstulović, 2020
Montenegro, Adriatic Sea, open coast	scuba diving	0–6	23.7	0.48	Krstulović, 2020
Mediterranean Sea, whole	scuba diving	< 30	43.55	31.93	Consoli *et al*., 2020
Montenegro, Adriatic Sea, Boka Kotorska Bay	scuba diving	0–30	3	0.503	This study

is most probably the main reason for so high concentrations of marine litter at these two locations. Once again this points to the fact that only a reduction of marine litter at the sources could reduce its impact.In terms of size class, the most numerous was size class I with contribution of 46.54%, followed by class H (28.20%) and class G (22.12%). Vlachogianni *et al*. (2017) reported size class H as the most numerous, followed by class I and class G in shallow coastal waters of Slovenia, Montenegro and Bosnia and Herzegovina, while Mačić *et al*. (2018) found size classes G and H as dominant in marine litter collected in the "Papuča" cave.

Dominance of those three size classes in marine litter is in accordiance to the results regarding top three numerous items (plastic bottles, glass bottles, beverage) which we obtained in this study. Plastic bottles, glass bottles and beverage belong only to the size classes G, H and I. Plastic bottles, glass bottles and beverage had contribution of 80.92% in total marine litter. Dominance of the plastic bottles, glass botles and beverage is also reported in Natura 2000 site of the central eastern Adriatic Sea (Stagličić *et al*., 2021). Plastic bottles are found to be in the top three litter items along the Italian and east Adriatic coast (Vlachogianni *et al*., 2017; Scotti *et al*., 2021). Regarding Mačić *et al*. (2017), plastic and metal debris as bottles and cans, are the usual debris in locations where tourist facilities or settlements are located on the coast, and investigated MPA's "Sopot" and "Dražin vrt" which were in the focus of this study are just such areas.

Having in mind that marine litter is global problem and that amount of marine litter is increasing, our attention and reaction is required. Increasing awareness is necessary, as well as implementation of monitoring protocols. Although, there are many initiatives for cleaning beaches and coastal seas, only a reduction of marine litter at the sources could reduce its impact in protected areas, as dedicated analysis on the MPA's shows that the risk therein is controlled by the proximity to marine litter sources (Soto-Navarro *et al*., 2021).

CONCLUSIONS

The present study represents one of the first studies regarding abundance and composition of seafloor marine litter in shallow coastal protected areas in the Adriatic Sea. Litter density was in range from 1.46 to 4.55 items/100 m^2, with mean density 3 ± 1.28 items/100 m^2. Plastic had the main contribution in marine litter, with dominance of bottles and obtained results are in line with similar studies among different Mediterranean areas. Intensive increasing awareness is necessary regarding marine litter pollution, implementation of monitoring protocols and the main fact is prevention and a reduction of marine litter at the sources.

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Otpad na morskom dnu u dva zaštićena područja (Sopot i Dražin vrt) u Bokokotorskom zalivu (Crna Gora, jugoistočni Jadran)

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SAŽETAK

U ovom radu je data prva procjena zagađenosti morskog dna otpadom u zaštićenim morskim područjima u Crnoj Gori. Istraživanja su sprovedena tokom 2020 i 2021. godine u dva zaštićena morska područja "Sopot" i "Dražin vrt". Metodologija je bila zasnovana na vizuelnom istraživanju autonomnim ronjenjem u okviru akcija čišćenja. Rezultati su ukazali na dominantnost plastike u ukupnom otpadu (46.91%), dok je u odnosu na veličinu najbrojnija bila klasa I (46.54%). Prosječna gustina otpada je iznosila 3 komada/100 m^2. Dobijeni rezultati ukazuju da su oba istraživana morska zaštićena područja zagađena u pogledu otpada, što ističe potrebu za stalnim monitoringom.

Ključne riječi: MPA, otpad na morskom dnu, zagađenje mora, *Savalia savaglia,* Jadransko more