Benthic Marine Litter in Three Greek Gulfs: Are Mean Density Estimates Truly Representative?

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Abstract In this study, seafloor litter loads were compared across three major gulfs in Greece—Saronikos, Thermaikos, and Patras Gulf—by analyzing and synthesizing existing datasets from published research. Particular emphasis is placed on evaluating depth related spatial patterns, methodological differences, and potential sources of bias to provide a clearer understanding of the pollution status, highlight existing data gaps, and underscore the urgency for further research on the topic. Thermaikos appears to be the most heavily polluted, followed by Saronikos, with Patras Gulf showing the lowest litter levels. Plastic materials dominate the composition of marine litter, particularly food and beverage packaging, while a variable proportion of the litter is associated with fishing activities. Litter density tends to decrease with depth, with the dramatically higher concentrations observed in nearshore shallow waters (0–5 m) by scuba divers, whereas the lowest densities are recorded through trawling surveys in deeper areas.
Keywords: benthic litter, scuba dives, ROV, trawlers, gulf

1. Introduction

Marine litter is found in all aquatic environments, originates from multiple sources, and causes a wide range of environmental, economic, safety, health, and cultural impacts. EU Member States are required to implement appropriate measures and monitoring programs to prevent the degradation of aquatic ecosystems caused by litter. Specifically, the quantity, composition, distribution and sourcing of litter must be defined and monitored. Furthermore, the establishment of pollution limits and the comparability of pollution by area pose significant difficulties. In this context, this paper aims to comment on the difficulties in the comparability of litter pollution in the three most polluted gulfs of Greece.

2. Methods

The most studied gulf in terms of litter pollution is the Saronikos Gulf, with approximately 109 sampling efforts covering a total studied area of around 6 km² (Table 1). The available data span from 2003 to 2020. A wide range of depths has been examined, from very shallow waters (minimum depth: 0 m) to deeper areas reaching up to 350 m. Additionally, a variety of methodologies have been employed, including dives, remotely operated vehicles (ROVs), towed underwater cameras, and trawlers. In Thermaikos Gulf, several dives were conducted in fishing ports at depths of 0–5 m between 2020 and 2024, with the main objectives of cleaning these areas and recording the findings. Additionally, ROV transects were carried out at depths ranging from 15 to 90 m to investigate the benthic litter load of the gulf. A total area of 0.08 km² was covered. In Patras Gulf, a total of 18 trawl transects were conducted in 2013 at depths of up to 150 m, covering an area of 2.9 km². It is noteworthy that data for shallow waters in Patras Gulf are currently unavailable. The available findings are derived exclusively from surveys conducted in fishing grounds, characterized by soft seabed and deeper waters.

3. Results and discussion

Thermaikos Gulf exhibits the highest mean density of marine litter among the gulfs studied, with 170,875 items/km². In contrast, Saronikos Gulf shows a markedly lower mean density of 12,145 items/km²—approximately one order of magnitude lower. Gulf of Patras presents the lowest recorded density, at just 641 items/km², which is roughly two orders of magnitude lower than Thermaikos and one order of magnitude lower than Saronikos. Diving surveys further highlight the burden on Thermaikos' shallow waters (0–5 m depth), which exhibit an average litter density (737,900 items/km²) about 19 times higher than that of Saronikos (39,000 items/km²). Data from ROV surveys reinforce this trend, with Thermaikos again showing the highest density (15,000 items/km²)—roughly four times greater than Saronikos (3,500 items/km²). Lastly, comparing the data from trawlers, Saronikos (1058 items/km²) shows 1.7 times higher density than Patras (641 items/km²).

Table 1. Summary of sampling effort across the three gulfs (density is given in items/km²)

		Dives	ROV	TUC	Trawls	Total
Saronikos	No.	31	7	1	70	109
	Depth	0-25	20-55 & 95-115	0-100	50-350	0-350
	Year	2003 & 2020	2014 & 2019	2018	2013-2014	2003-2020
	Area Covered	79,406 m²	28,158 m²	14,200 m²	5,869,591 m²	6 km²
	Mean Density (items/km²)	39,000	2,628	9,789	1,058	**12,145 (117-251,250)**
Thermaikos	No.	11	40	-	-	51
	Depth	0-5	15-90	-	-	0-90
	Year	2020-2024	2020-2024	-	-	2020-2024
	Area Covered	73,557 m²	9,835 m²	-	-	0.08 km²
	Mean Density (items/km²)	737,900 (1,250-4,810,000)	15,000 (0-84,000)		-	**170,875 (0-4,810,000)**
Patras	No.	-	-	-	18	18
	Depth	-	-	-	max 150 m	max 150 m
	Year	-	-	-	2013	2013
	Area Covered	-	-	-	2.9 km²	2.9 km²
	Mean Density (items/km²)	-	-	-	641± 579	**641**

In the shallow waters of Thermaikos Gulf, the most commonly encountered litter category consists of food and beverage packaging, primarily single-use plastics (46% SUP). In contrast, in deeper waters, the majority of items (65%) are fishing-related debris, such as fishing lines and nets. The shallow waters of Saronikos Gulf are also primarily polluted by food and beverage packaging, such as bottles, cans, and cups. Trawling surveys mainly reveal plastic bags, sheets, and bottles. Additionally, approximately 15% of the litter recorded at depths of 50–350 m is attributed to fishing activities. In the Patras Gulf, the majority of marine litter is attributed to land-based sources, with only 8.7% linked to fishing activities. Among all litter items collected by trawlers, 34% were plastic bags, 12.9% were glass bottles, and 12.4% were cans.

Litter densities in nearshore shallow-water environments, as assessed through scuba diving surveys, are typically substantially higher than those recorded in deeper, offshore areas. This pattern is primarily attributed to the proximity of these areas to densely populated coastal zones. Consequently, the elevated values in shallow waters can significantly influence and raise the overall mean litter density calculated for a given region.

More than half of the litter recorded on the seafloor across all three gulfs consists of plastic, a finding that aligns with the results of numerous recent studies on marine litter. In terms of litter categories, food and beverage packaging—such as cups, bottles, and cans—emerges as the most prevalent across all study areas. SUPs also constitute a significant portion of the total litter although policy changes have been made in Greece, which aim to reduce plastic pollution by banning the use of specific single-use plastic items. Fishery is also considered an important contributor to litter pollution in all cases.

Comparisons between different studies and regions should be approached with caution, as several key factors often vary.

A. Timing of surveys: For instance, much of the scuba diving data from the Saronikos Gulf were collected over two decades ago.
B. Sampling site selection: Sampling points may introduce bias; for example, the scuba diving data from Thermaikos were collected in fishing ports, which are known hotspots for marine litter accumulation. Moreover, the heavily polluted coastal stretch of the Saronikos Gulf—from Eleusis to Piraeus Harbor—has not been surveyed.
C. Methodological differences: Each method has inherent limitations. Trawlers, an opportunistic method, for example, operate primarily in fishing grounds with soft, flat seabed, and their catch efficiency can vary. In contrast, ROVs have a restricted field of view and typically cover smaller areas, with their effectiveness dependent on visibility conditions. While divers also cover relatively restricted areas, they benefit from a broader field of view and greater capacity to visually identify and classify litter items.
D. Area coverage: The estimation of seabed area surveyed by the three main means (scuba, ROV and trawling) poses significant uncertainties.

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