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Vessel-based photographic assessment of beach litter in remote coasts. A wide scale application in Saronikos Gulf, Greece

Irene Papachristopoulou [a,*], Anastasios Filippides [a], Elias Fakiris [b], George Papatheodorou [b]

[a] OZON, Non-Governmental Organization, 20100, Corinth, Greece
[b] Laboratory of Marine Geology and Physical Oceanography, Department of Geology, University of Patras, 26500, Patras, Greece

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ABSTRACT

The abundance of marine debris was quantified for a total of sixty-two inaccessible beaches in the western Saronikos Gulf, Greece. High resolution images were obtained through vessel-based photography survey, merged into seamless photomosaics, and manually processed to quantify beach litter abundance. A sample of four selected beaches were subjected to detailed photography followed by beach macro-litter (≥2.5 cm) *in-situ* sampling surveys over a period of one year, to calibrate and validate the proposed method. Regression analysis between photographic and *in-situ* data showed a significant correlation, hence providing a highly accurate regression model to assess the real number of beach litter stranded on the rest of the investigated beaches, exhibiting clear correlations to the hydrodynamic status of the area and, provide an indication of the main litter sources. The proposed method is an easily applicable and useful tool for fast and low-cost macro-litter monitoring in extended, remote coastlines, when only photographic data are available.

1. Introduction

Marine Litter pollution is an ever-increasing and complex threat for the balance of the Global Ocean (Papatheodorou, 2012; Ryan, 2015; UNEP, 2015; Maes et al., 2018). The presence of marine debris has been registered in all marine compartments, stranded on shorelines (Debrot et al., 2013; Munari et al., 2016; Williams et al., 2016; Martin et al., 2018; Asensio-Montesinos et al., 2019; Aytan et al., 2019), floating on water surface (Law et al., 2010; Ryan, 2014; Cózar et al., 2017; Topouzelis et al., 2019; Constantino et al., 2019; Palatinus et al., 2019) and submerged on the seabed (Galgani et al.,1996; Stefatos et al., 1999; Ioakeimidis et al., 2014; Strafella et al., 2015, 2019; Maes et al., 2018; Palatinus et al., 2019). Litter generated by diverse human activities on land or at sea, and due to improper management, can drift by diverse drivers (water runoffs, wind, wave, sewages) towards coastal and pelagic zones (Galgani et al., 2015; Duckett and Repaci, 2015; Critchell et al., 2015; UNEP, 2016; Prevenios et al., 2018). The introduction and accumulation of beach litter (BL) to the marine environment entails a series of adverse effects on the function and sustainability of marine ecosystems (Laist, 1987; Katsanevakis et al., 2007; Kühn et al., 2015; Deudero and Alomar, 2015; Beaumont et al., 2019; Mazarrasa et al., 2019), as well as has serious socio-economic implications (Beaumont et al., 2019). Ingestion of and entanglement by BL has been extensively recorded in marine organisms (Robards et al., 1995; Gregory, 2009; Deudero et al., 2015; Gall and Thompson, 2015; Kuhn et al., 2015; Wilcox et al., 2015; Fossi et al., 2018). Additional risks to native biodiversity have emerged due to transportation of non-native species by floating debris (Barnes, 2002; Galgani et al., 2014; Katsanevakis et al., 2014; Kiessling et al., 2015; Rech et al., 2016). Moreover, plastic bioaccumulation through the food chain is an issue of great concern since nano- and micro-size particles are increasingly found in organisms like fish and mussels, commonly consumed by humans (Setälä et al., 2014; Rochman et al., 2015; Vethaak and Leslie, 2016). Likewise, there is evidence that plastics, apart from absorbing, also release toxic chemicals in the environment (Teuten et al., 2009; Engler et al., 2012; Rochman et al., 2013; Iñiguez et al., 2016; Tourinho et al., 2019). The aesthetic degradation caused by the BL disposal (McGranahan et al., 2007; Avio et al., 2017; Leggett et al., 2018), affects tourism, recreational activities, and the well-being of coastal regions populations (Santos et al., 2005). Fishing and aquaculture sectors are directly affected by BL with reductions in the quantity and in the quality of their production. Similarly, the shipping sector suffers damage of operational machinery and equipment (UN Environment, 2017).

Evaluating the abundance of marine debris is a complex assignment since their sources are multiple and widespread (Kordella et al., 2013

* Corresponding author.
Email address: irene.papa@protonmail.com (I. Papachristopoulou)

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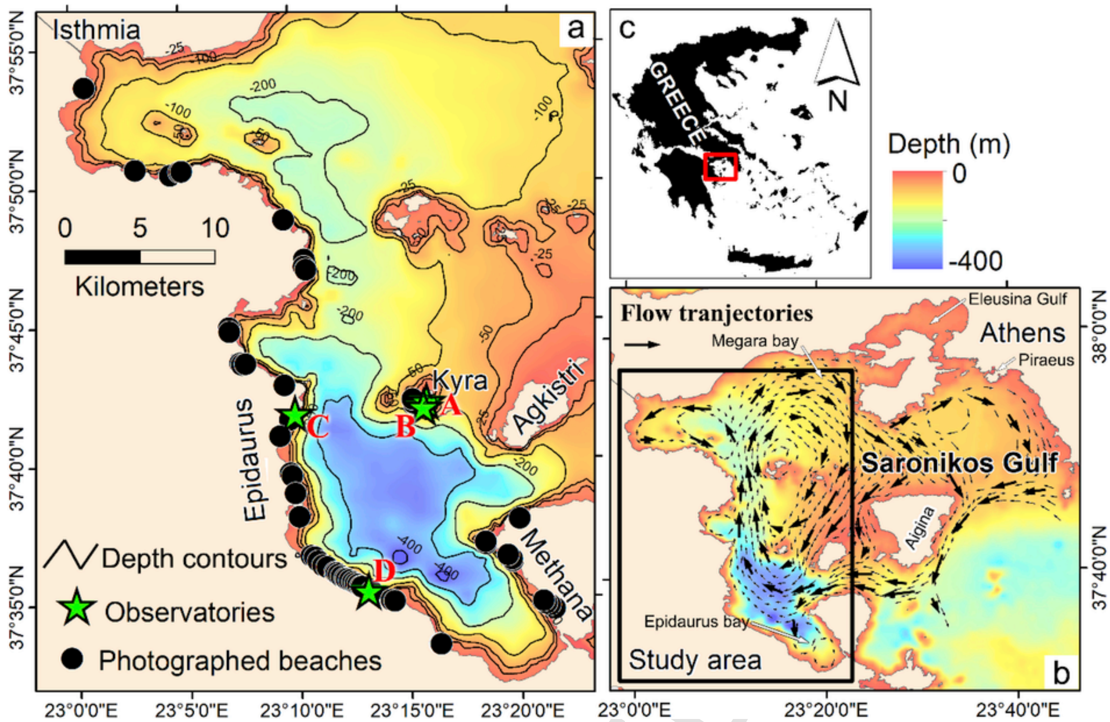


Fig. 1. (a) Bathymetric map and geographical distribution of the sixty-two inaccessible beaches of western Saronikos Gulf. Green stars (and A to D letters) indicate the four observatories (beaches A to D) of in-situ sampling and vessel-based photography surveys, while black dots indicate the fifty-eight beaches where only remote photography took place. (b) General near-surface circulation of the Gulf, as derived from Copernicus (https://www.copernicus.eu/en) and Fakiris (2004). (c) Inset map of Saronikos Gulf. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Detailed plan of BL in-situ sampling versus photographic surveys in western Saronikos Gulf.

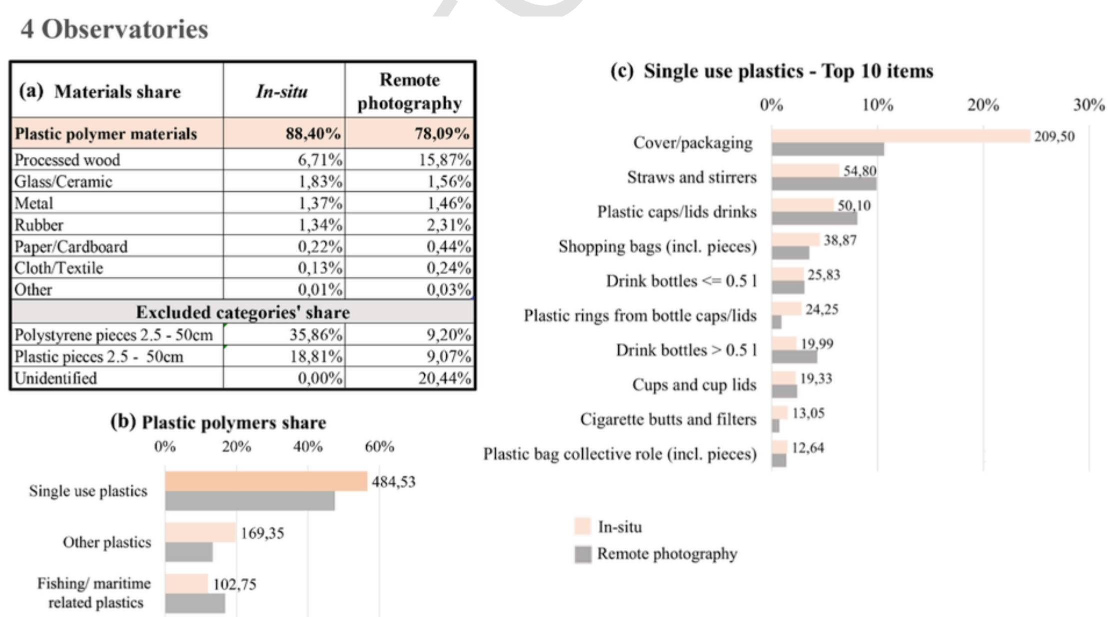
Sampling period & method Beach name		2017		2018					
		Aug–Oct		Nov–Jan		Feb–Apr		May–Jul	
		In-situ	Photography	*In-situ*	Photography	*In-situ*	Photography	*In-situ*	Photo
Beach A	Kyra 1	18/10	18/10	25/01	25/01	25/04	25/04	07/08	07/08
Beach B	Kyra 3	27/10	27/10	31/01	31/01	27/04	27/04	08/08	08/08
Beach C	New Epidaurus 1	23/10	–	28/01	28/01	02/05	02/05	08/08	08/08
Beach D	Methana Road 18	06/11	06/11	02/02	02/02	04/05	04/05	09/08	09/08
58 beaches									12-13/07

; Rech et al., 2014; UNEP, 2016; Carney Almroth and Eggert, 2019). Furthermore, regardless of their original entry point to the marine environment, BL can travel over long distances following hydrodynamical distribution patterns that are difficult to predict. Theorical approximations about BL distribution in different marine compartments accept that 70% is accumulated on the coastline and seafloor, 30% within the water column, and 1% remain at the sea surface (UNEP, 2016). Studies on the output from models suggest that after the initial release within the marine environment, the pollution normally concentrates near coastline and remain there for decades or even centuries (Derraik, 2002; Lebreton et al., 2012; Politikos et al., 2017). Nevertheless, marine debris abundance in coastal areas shows a time dependent non-linear pattern of accumulation (Kako et al., 2010), as they are occasionally washed away towards the open sea, in dependence of nearshore hydrodynamics (Bowman et al., 1998; Kataoka et al., 2013, 2015). These facts underline the double role of the beaches as receptors but also as secondary sources of BL (Kataoka et al., 2018), and highlight the necessity of the development of systematized shoreline monitoring programs, to tackle BL re-introduction to the open seas.

Concentrated efforts of macro-litter surveys and beach clean-up operations made by volunteer organizations, provide useful data for BL concentrations mainly in public bathing sites (Nelms et al., 2017). However, distant and rugged coastline segments are difficult to monitor in a conventional way. In response to the shoreline complexity restrictions, a variety of remote, aerial monitoring methods have been implemented, using fixed wing aircrafts (Kataoka et al., 2018), bush planes (Moy et al., 2018), balloons (Nakashima et al., 2011), aerial vehicles (Veenstra and Churnside, 2012; Papakonstantinou et al., 2016; Deidun et al., 2018; Martin et al., 2018) and webcams (Kako et al., 2010; Kataoka et al., 2012). Nevertheless, most of these techniques, imply considerable operational costs for equipment and technical expertise requirements, as well as additional ground validation surveys, deemed necessary to prove the accuracy of the method.

In this study we develop a novel method for fast, wide scale, and low-cost beach macro litter (≥2.5 cm) assessment through the use of photography and statistical analysis of manually detected BL counts. An accurate dataset was derived from four (4) beaches (defined as observatories) that are regularly monitored at the western Saronikos Gulf. The results indicate a significant relationship between

Fig. 2. Example of photomosaic digitizing process in QGIS environment. Black points represent the BL items registered in the A-B area. White squares indicate zoomed example areas, while 1–9 numbers show samples of different identified item categories. 1: Plastic water bottle, 2: Plastic cap/lid drink, 3: Plastic cup, 4: Rope, 5: Cigarette filter, 6: Straw, 7: Float for fishing net, 8: Plastic cup and 9: Cup lid.



(a) Materials share	*In-situ*	Remote photography
Plastic polymer materials	**88,40%**	**78,09%**
Processed wood	6,71%	15,87%
Glass/Ceramic	1,83%	1,56%
Metal	1,37%	1,46%
Rubber	1,34%	2,31%
Paper/Cardboard	0,22%	0,44%
Cloth/Textile	0,13%	0,24%
Other	0,01%	0,03%
Excluded categories' share		
Polystyrene pieces 2.5 - 50cm	35,86%	9,20%
Plastic pieces 2.5 - 50cm	18,81%	9,07%
Unidentified	0,00%	20,44%

Fig. 3. A detailed graphical representation of the composition of BL registered *in-situ* (light orange) and through remote photography (grey) on the four observatories of western Saronikos Gulf. (a) Percentage share by litter material (excluding plastic and polystyrene pieces 2.5–50 cm and unidentified items). Excluded categories' total shares are presented separately. (b) Classification of plastic polymer materials by source, expressed as percentage share (top axis) and mean density. (c) Percentage share (top axis) of the top ten categories within single use plastics. Mean BL densities expressed as items per 100 m beach length are given next to the *in-situ* (light orange) bars. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

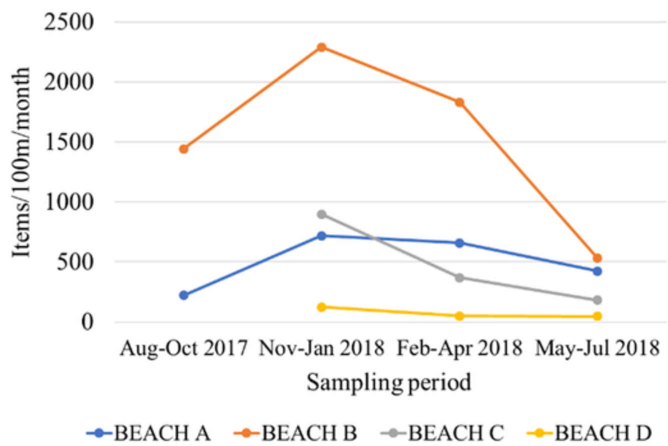


Fig. 4. Temporal variation of BL accumulation rates within the surveyed year, on the four observatories of Saronikos Gulf, expressed as number of items per 100 m beach face length per month (items/100 m/month). Note that data for Beach C and Beach D during August–October 2017 were excluded from the analysis as referred to the first clean-up (stock accummulation) data.

photographic and the collected *in-situ* data. A simple split regression model was adequate to predict the real number of stranded litter items, thus making it feasible to be applied on the rest of the fifty-eight (58) inaccessible beaches of western Saronikos, where only photographic registrations of BL were acquired. The aim of this work is to provide simple monitoring guidelines, that overcome any necessity of specialized equipment and expertise. The whole operation has been accomplished only by means of a small vessel, a digital camera and free software for the analyses, making it convenient to perform by almost any interested team at any other region. The proposed methodology is in-line with the International Directives of the Marine Strategy Framework (MSFD, 2008/56/EC) and the UNEP/MAP IG.21/9 for data collection and marine litter management. Moreover, it is aligned with the guidelines proposed by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) for the quick monitoring and mapping of sholeline litter accumulation in order to determine the areas of most concern and organize targeted clean-up operations (GESAMP, 2019).

2. Methods

2.1. Study area

2.1.1. Geographical setting

The Gulf Saronikos is located in the South West Aegean Sea (Eastern Mediterranean). It forms a partially enclosed basin (2,600 km^2), delimited by the coast of Peloponnese at the western boundary, the coast of Attica at northeast boundary, while its southern side directly connects with the Aegean Sea. The socio-anthropogenic pressures on the eastern part of the Gulf originate from Athens (Attica region: approximately 4 million inhabitants) and Piraeus city-port through which 17,525 people travelled in 2013 (www.olp.gr). This implies that the area is affected by urbanisation (treated wastes, surface runoff, sewage discharges), a wide range of industrial activity (shipyards, oil refineries, steel/metal industry, plastic cables industry etc.), intensive marine traffic, and other port related activities. On the western part, the main activities include tourism, recreational marine activities, agricultural activity, and an extensive network of aquaculture and fish farming.

With respect to its bathymetry and seabed morphology, the Gulf is divided into two parts. The eastern and relatively shallower part consists of a flat basin with a mean depth of 90 m and a maximum of 100 m. Another large and flat shallow basin (~50 m) extends around the Aigina and Agistri islands, while at the western part the depths are significantly greater, ranging between 230 m (northern region) and 450 m (southern region), which is the deepest of the entire Gulf.

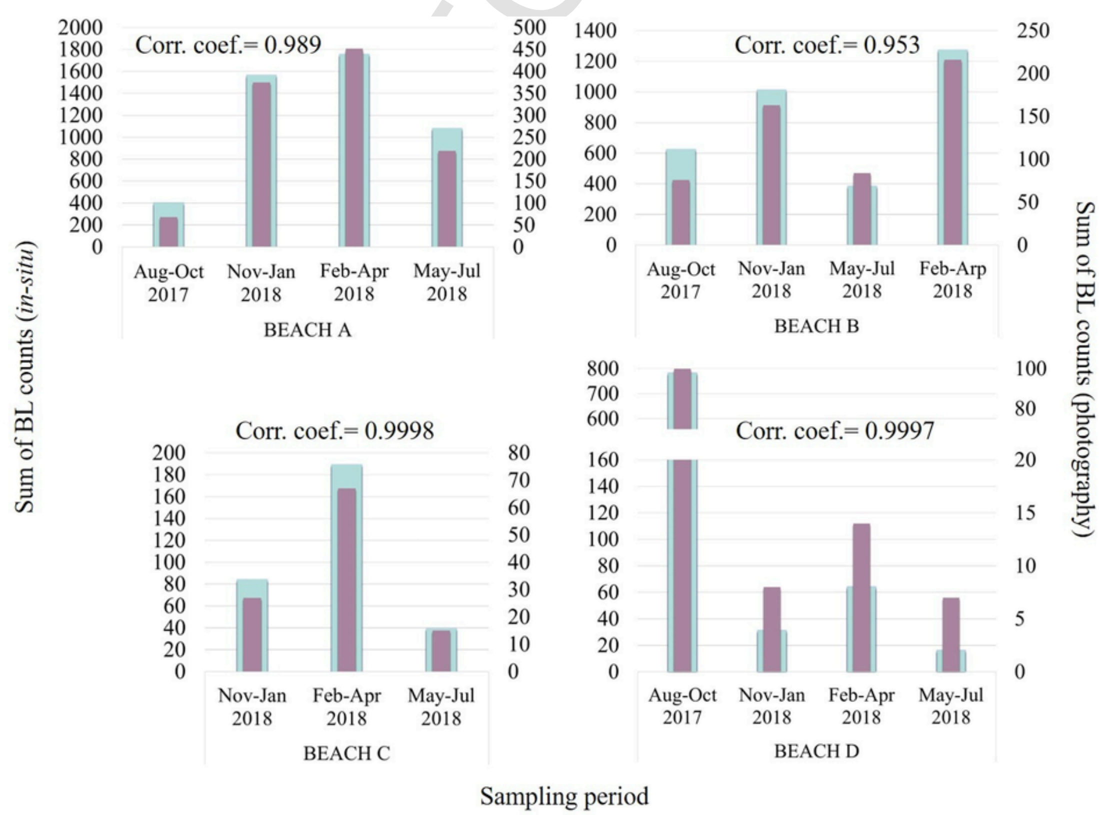


Fig. 5. Counts of BL items registered in-situ (purple) and through photography (light blue). Note that plastic and polystyrene pieces 2.5–50 cm counts excluded from the analysis. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

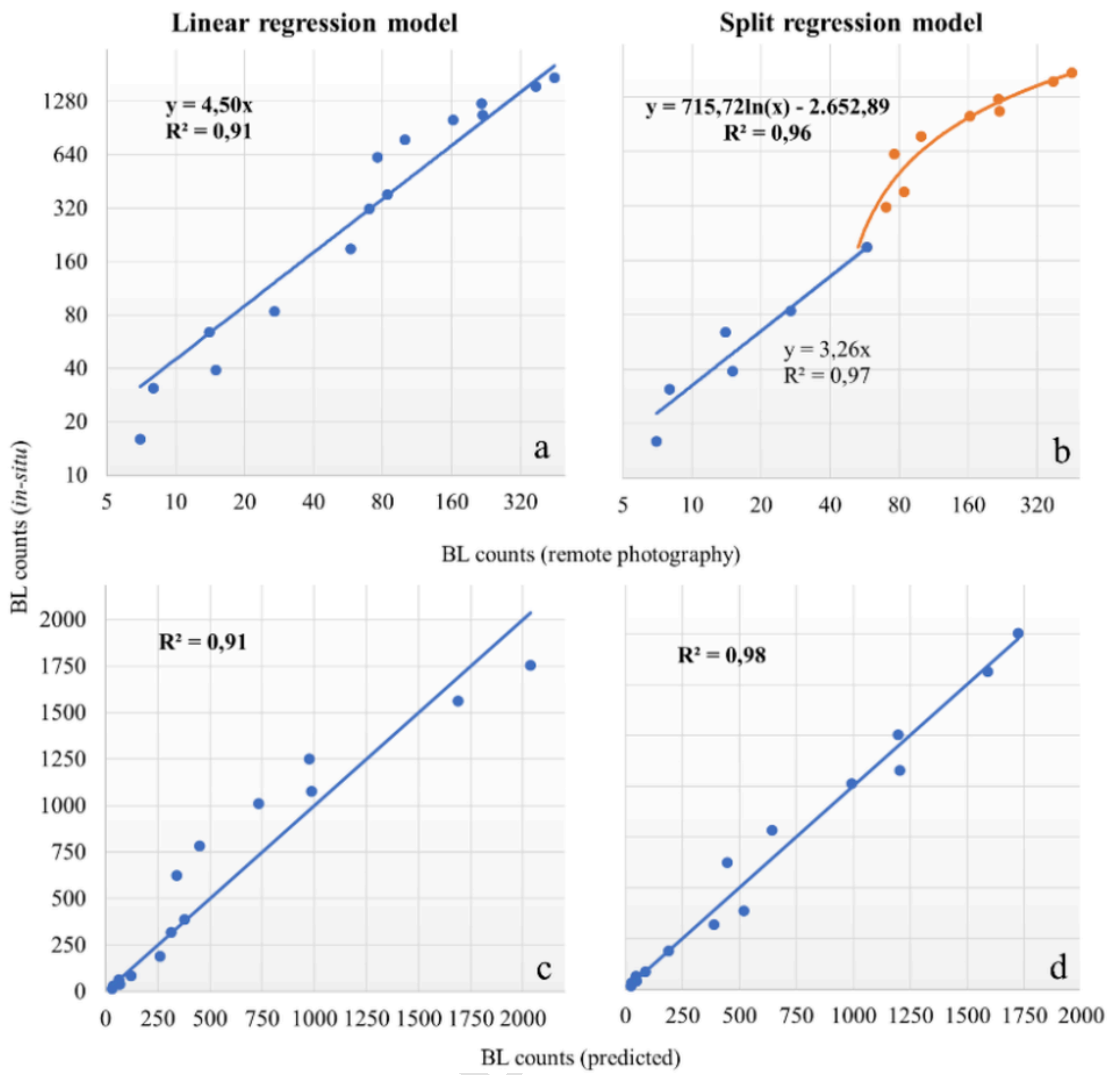


Fig. 6. Correlation between the number of BL items registered in-situ (axis y) and through photography (axis x) in all four observatories and periods through (a) linear and (b) split regression model. Correlation between the number of BL items registered in-situ (axis y) and assessed through (c) linear and (d) split regression model (axis x). Note that the top two graphs' axes are log-log (with base 2) transformed in order to better visualize low value data.

The open boundary at south-southeast includes a smooth continental slope, starting from the 100 m depth contour and reaching 300 m, as one move towards Aegean Sea (Fig. 1).

2.1.2. *Oceanographical setting*

The oceanographic circulation in the Saronikos Gulf is essentially controlled by the existence of seasonal flows, while the wind has a complementary effect, leading to a short-term variability of near-surface circulation structures (Kontoyannis, 2010). Between December and April, the Gulf is highly barotropic, due to vertical mixing processes. Conversely, a seasonal pycnocline is fully developed between August and September and at depths of 40–70 m, resulting to a two-layer flow structure. The hydronynamics of the area have been well studied through Acoustic Doppler Current Profiling and Mathematical simulation (Fakiris, 2004; Zacharias and Fakiris, 2005; Kontoyannis, 2010; Kalaroni et al., 2019).

In general, during winter, the Saronikos Gulf maintains an eastward flow (Kontoyannis, 2010; Kalaroni et al., 2019). On the other hand, during summer, the water masses at the deeper later move westwards. A closed anticyclonic loop in the northern part of the western sub-basin is established throughout the year (Fakiris, 2004; Kalaroni et al., 2019). Eastward flow enters the central part of the Gulf through Aigina and Salamina islands, giving rise to an anticyclonic meander and the synchronous formation of smaller scale, recurrent cyclonic recirculation structures (Kontoyannis, 2010). Main water mases exit southwards, forming a wide anticyclone in the south-eastern part of the eastern sub-basin (Kalaroni et al., 2019). Concerning deep layer's circulation in summer, a meander flow structure originating from the eastern Gulf then separates in two branches. The one loops northward (South-West of Salamina) and the other further splits into two near-parallel cyclonic formations, as it enters the western part of the Gulf (Kontoyannis, 2010).

The strait between Aigina and the peninsula of Methana links the water masses of western and eastern Saronikos, which in turn connect to the southern open boundary. Due to the general anticyclonic circulation, water masses move eastward, then shift to the west while reaching either the central or the north-eastern part of the Gulf, and re-enter the western sub-basin through Aigina, Methana, and Angistri straits (Copernicus; Fakiris, 2004).

During the transitional period in spring, a distinct pattern of circulation is developed at each side of the Gulf. In the western part, the eastward flow in the upper layers enters the sea-corridor between Aigina and Salamina islands and directly shifts back to the west, whereas at the eastern part the flow meanders northward. In the deeper layer, at the western part, two distinct flow structures are observed, the one directed eastward (South of Salamina) and the other heading south

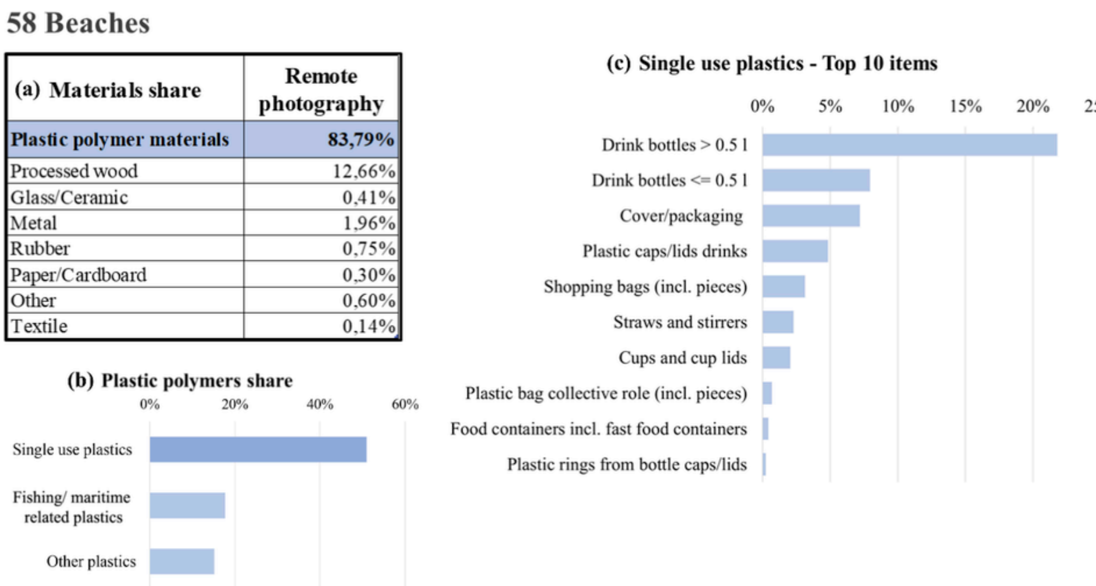


Fig. 7. A detailed graphical representation of the composition of BL registered through remote (before the application of split regression) on the fifty-eight beaches of western Saronikos Gulf. (a) Percentage share by litter material (excluding plastic and polystyrene pieces 2.5–50 cm and unidentified items). (b) Classification of plastic polymer materials by source, expressed in percentage share. (c) Percentage share of the top ten categories within single use plastics.

Table 2
Total number of BL items per 100 m of beach face length, registered at the four observatories from October 2017 to August 2018 through in-situ sampling.

Beach name		Items/100 m
Beach A	Kyra 1	8,308
Beach B	Kyra 3	8,042
Beach C	New Epidaurus 1	1,216
Beach D	Methana Road	4,264

and parallel to the western coastline. At the eastern part, an anticyclonic flow structure directs to the south (Kontoyannis, 2010).

Fig. 1b illustrates the general near surface circulation of the study area, as derived by Copernicus (https://www.marine.copernicus.eu/en, product id: MEDSEA_ANALYSIS_FORECAST_PHY_006 _013, date: 15/11/2018, Depth: –1.02) and found in Fakiris 2004, both regarding modelling the case of North winds 3-4 Bf (predominant 25% of annual winds due to the Hellenic National Meteorological Service).

2.2. Sampling strategies

2.2.1. Field sampling strategy overview

The study area consists of a cluster of sixty-two (62) inaccessible beaches along the western Saronikos Gulf stretching over 137 km of coastline, from the Corinth Canal to the peninsula of Methana. The sampled area includes six beaches located on Kyra, a small island within the western basin. The geographical distribution of the sixty-two inaccessible beaches are presented at Fig. 1a. These sites were selected as they are not subjected to human activities. Litter is neither collected nor left by beach visitors; thus, seasonal monitoring can reflect the long-term patterns of beach litter accumulation (GESAMP, 2019).

From this beach cluster, four beaches were selected to be 'observatories' of systematical BL monitoring surveys. Vessel-based photography, total beach clean-ups, and at the same time, sampling for macro-litter, were carried out over a period of thirteen months, between August 2017 and August 2018. The detailed plan of the monitoring

Table 3
Regression analyses results of in-situ data and photographic data, ranked by ascending number of items registered through remote photography. Plastic and polystyrene pieces 2.5–50 cm were excluded from analyses.

Beach	Sampling period	Items *in-situ*	Items photography	Linear regression		Split regression	
				Assessed BL items	Error %	Assessed BL items	Error %
Beach D	May–Jul 2018	16	7	31,53	97,03%	22,78	42,35%
Beach D	Nov–Jan 2018	31	8	36,03	16,22%	26,03	16,04%
Beach D	Feb–Apr 2018	64	14	63,05	1,48%	45,55	28,83%
Beach C	May–Jul 2018	39	15	67,55	73,22%	48,80	25,14%
Beach C	Nov–Jan 2018	84	27	121,60	44,76%	87,85	4,58%
Beach C	Feb–Apr 2018	189	58	261,21	38,21%	188,71	0,15%
Beach A	Aug–Oct 2017	317	70	315,25	0,55%	387,86	22,35%
Beach B	Aug–Oct 2017	623	76	342,27	45,06%	446,72	28,29%
Beach B	May–Jul 2018	386	84	378,30	1,99%	518,36	34,29%
Beach D	Aug–Oct 2018	782	100	450,36	42,41%	643,14	17,76%
Beach B	Nov–Jan 2018	1012	163	734,09	27,46%	992,83	1,89%
Beach B	Feb–Apr 2018	1252	217	977,28	21,94%	1197,63	4,34%
Beach A	May–Jul 2018	1078	219	986,29	8,51%	1204,20	11,71%
Beach A	Nov–Jan 2018	1563	375	1688,85	8,05%	1589,16	1,67%
Beach A	Feb–Apr 2018	1754	452	2035,63	16,06%	1722,82	1,78%
				ERROR: 29,53%		**ERROR: 16,08%**	

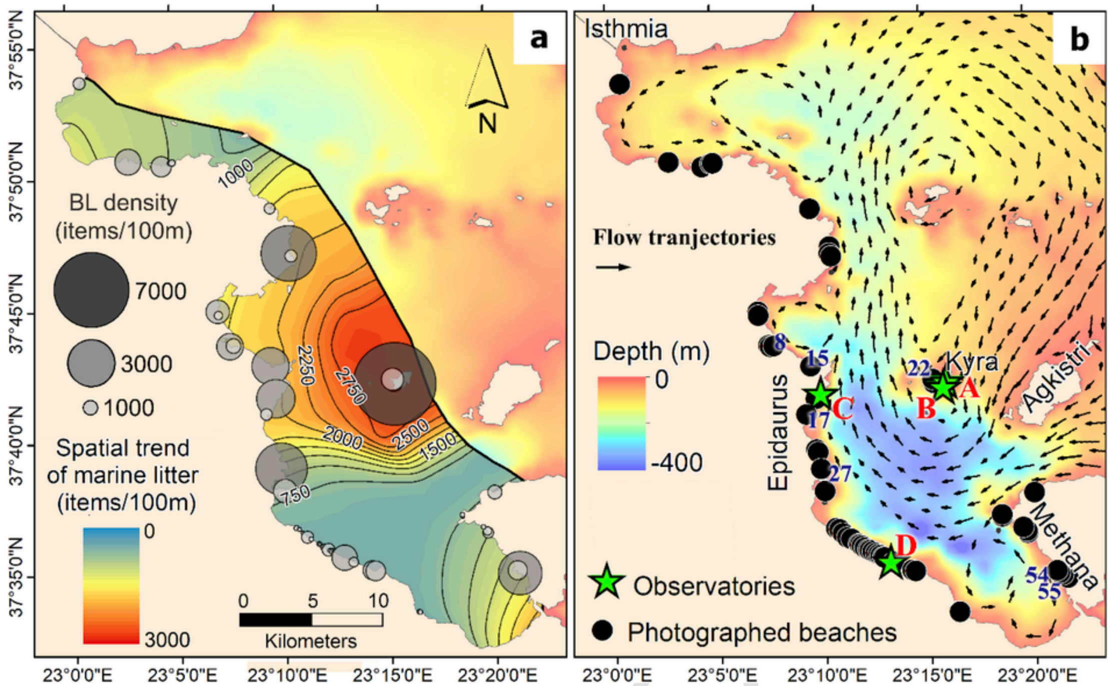


Fig. 8. (a) Map of BL spatial distribution estimated through split regression model on the fifty-eight beaches in western Saronikos Gulf (expressed as number of items per 100 m beach length). (b) Bathymetric map of the study area showing the location of the four observatories of in-situ and remote photography survey (green stars) and of the rest of the 58 beaches (black dots) of only remote photography survey. Letters A-D indicate the four selected beaches (observatories), A: Kyra 1, B: Kyra 3, C: New Epidaurus 1 and D: Methana Road 18. Black arrows indicate the near-surface circulation of the Gulf, as derived from Copernicus (https://www.copernicus.eu/en) and Fakiris (2004). The numbers (8, 15, 17, 22, 27, 54 and 55) indicate the beaches found to have the greatest BL concentrations in western Saronikos Gulf. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

surveys is presented in Table 1. Accordingly, due to the absence of human intervention at these sites, the litter flux rates (the amount of litter accumulation per unit time) can be estimated with a higher degree of accuracy, as described in paragraph 3.5.2.1. (Selection of survey sites) of the EU MSFD TGBL D.10 ‘Guidance on Monitoring of Marine Litter in European Seas’ (Galgani et al., 2013). The characteristics of the studied beaches are presented in Annex 1.

The criteria taken into consideration for the selection of the observatories, were: (i) beach morphology and sedimentological characteristics (rocky, gravelly, ground depressions, vegetation, etc.), (ii) orientation (exposure to different wind and oceanographic factors such as wave conditions and currents) and (iii) the influence by diverse sources of BL. Moreover, a sufficient geographical coverage had to be ensured in order to represent all particularities enclosed in the wider area of western Saronikos Gulf.

Beach A (Kyra 1) is located on the southeast of Kyra Island, has a South orientation and faces the Methana and Aigina natural passage towards the Aegean Sea. This beach is 137 m long and its width ranges from 3 m to 12 m, with relatively low foreshore slope. Rocks cover approximately the one-third of the total length, while the other two-thirds are free from natural obstacles (e.g. large beach rocks, vegetation). Low and scrub vegetation covers almost the entire upper limit of the beach. The main activities carried out include professional and recreational fishing throughout the year, while during summer is visited by recreational boats and vessels and is used as bathing site.

Beach B (Kyra 3) is located on the southwest of Kyra Island, has a West-SouthWest orientation and faces the western coast of the Saronikos Gulf. The beach is 44 m long and 10 m wide, with a moderate foreshore slope and a small cavity on the northern side. The beach is generally used for the same activities as for Beach A.

Beach C (New Epidaurus, 1) is located 2 km north of the New Epidaurus small marina. It has a SouthEast orientation, facing the southern basin of west Saronikos Gulf and, by extension, the Methana and Aigina natural passage towards the Aegean Sea. This beach is 28 m long, with a range from 4 m to 10 m wide, and with moderate foreshore slope. Low, scrub vegetation and rocks extent along the upper limit. There are several fish farms half a kilometre north of this beach and professional and recreational fishing are common activities in the area.

Beach D (Methana Road, 18) has a NorthEast orientation. It is located on a coast of the Old National Road Epidaurus - Methana. This beach is 104 m long, range from 6 m to 10 m wide, with a steep slope. There are no natural obstacles on beach. Both professional and recreational fishing are performed in the area.

2.2.2. Vessel-based photographic recording

Detailed photographic surveying was carried out from the operational boat Nautilus (a 9 m long plastic boat, type A. Hellas 26WA with a Honda VTEC 225 hp outboard engine) for each of the sixty-two beaches. High resolution photography was conducted for the fifty-eight beach sites (excluding the four observatories) during July 12–13, 2018 in order to make a first estimate for the BL concentrations along the investigated coastline. The same approach was used at the observatories to capture BL, for comparison purposes, prior to clean up and physical recording.

In all occasions, a sequence of successive images was captured along the entire beach length, covering the area from the waterline to the upper vegetation or slope limit. The photographic documentation was carried out, while the boat performed slow runs (speed of 1 mile per hour) parallel to the shore. The camera handler, standing up on the stem of the boat, used a Nikon D80 10.2 MP Digital SLR camera, with Nikon Zoom-NIKKOR 18–135 mm f/3.5–5.6 GED lens. The overall height of the photo shooting, from sea surface to the camera lens, was approximately 3 m (considering a 1.30 m height between the stem of the boat and the water surface, plus the observer's height of 1.80 m). Thus, the shooting angle ranges between 20 and 30°, depending on the distance from the beach. The photographic recording of the litter load at all sixty-two inaccessible beaches was conducted from a distance of 10–20 m between the vessel and the coastline attempting to maintain it as steady as possible, depending on the shore and the seabed morphology.

The missions were conducted under optimal weather conditions (< 3 Bf) to avoid adverse wind and wave effects (camera movement, minimum safe distance from the shore). Photographic documentation for the four observatories, was carried out during morning hours. For the other fifty-eight beach sites, times of photography ranged from the morning hours to early afternoon. The quality of captured photographs is affected by the time of the photography (hence the angle of the sun) and the orientation of the beach. Optimal clarity and sharpness were achieved by adjusting ISO, shatter speed and aperture exposure parameters. Under favourable weather-lighting conditions, camera was set in automatic mode, at ISO setting 125. At cloudy and/or wavy conditions camera was set at the shatter speed priority mode, and a higher ISO and shatter speed settings were manually selected.

2.2.3. Beach litter clean-up and recording

Physical BL clean-up campaigns were organised on all four beaches, designated as observatories, on three-month seasonal intervals covering a full year (October 2017–August 2018). In this case, the entire beach was subjected to thorough clean-up and *in-situ* sampling. This was done after the vessel-based photography mentioned above (section 2.2.2). The collection, identification, and categorization of litter items was always performed by the same, well-trained, professional crew, using the methodology proposed by EU MSFD TGBL D.10 'Guidance on Monitoring of Marine Litter in European Seas' (Galgani et al., 2013), thus avoiding personal observation discrepancies. According to this monitoring protocol, the BL findings were divided into eight (8) material types and two hundred thirteen (213) item categories. Each litter item was assigned the corresponding identification code (G1-G213). Field experience has shown that a minimum crew of three skilled personnel is required for the overall operation (boat operation, photography and litter sampling), while another two are enough for remote photography (boat and photography operation).

2.3. Data preparation and analysis

The different sets of photographic and corresponding *in-situ* records from the four observatories were aggregated in a common database format, according to (i) beach (Beach A, B, C and D), and (ii) sampling dates and periods. Litter items were listed by general code (TSG_BL), grouped by material types (plastic polymers, metal, processed wood, etc.) and item type categories (e.g. drink bottles, straws/stirrers, lolly sticks etc.). Further categorization that specifically deal with usage was also carried out. This included: (a) 'single use plastics' including 4/6 pack yokes, plastic bags, plastic drink bottles, plastic food containers, plastic caps/lids, cover and packaging (incl. crisps packets/sweets wrappers, cigarette box packaging/tobacco pouches), lolly/cotton bud sticks, cutlery/trays, straws, cups and cup lids and food containers and, (b) 'fishing/maritime related plastics' (related also to shipping/other maritime industries, aquaculture, recreational boating) including cleaner bottles/containers, fish feed bags, synthetic rope and string and cord ($\phi < 1$ cm), rope ($\phi > 1$ cm), nets, fish boxes, polystyrene pieces > 50 cm (constituting pieces of fish boxes or buoy filling material), fishing lines, light sticks, floats, buoys, crates, bait packaging, strapping bands and other fishing related items.

2.3.1. Panorama photo-merging and beach litter identification

The location and spatial distribution of the investigated beaches were illustrated using Google Earth satellite imagery. Selected beaches were identified as polygons, and their basic characteristics (coastline length, beach area and orientation) were determined. The resulting 'beach identity' sheets are presented in Annex 1.

Manually captured images during the vessel-based photography were stitched into panoramas (photomosaics) through HUGIN open source software, to obtain marine debris accumulation, avoiding double counting of BL items in overlapping areas (Fig. 2). The computational time for stitching the photographs on an Intel(R) i7 PC with CPU at 2.20 GHz was 15–20 min per 100 m beach length. An average of 30–35 frames per 100 m of beach length were used, with horizontal overlapping ranging from 15 to 20% on both sides of the frame.

Panoramas were imported into QGIS open source software, to digitize BL items and register them on a vector database file, along with information about litter material, category and coordinates (x, y) in a relative coordinate system linked to the sizing in pixels of the image (Fig. 2). The abovementioned characteristics of the digitized BL items were exported to a common database format for further processing. Digital identification of litter items followed the same protocol as per *in-situ* survey described in section 2.2.2, while observed items of unknown categories were designated as 'unidentified'. Results were visualized using Excel 2010 and QGIS free software.

2.3.2. Data curation - statistical analyses

In-situ data registrations for all four observatories and for the given periods were used to plot the average concentrations of BL types and categories, as well as the temporal variation of the litter counts per sampling period, in order to make a general assessment.

The Pearson's correlation coefficient between the different photographic and corresponding *in-situ* registrations, concerning the same BL categories, was used for indicating the agreement between pairs of data. Furthermore, regression analysis was performed, in order to check the feasibility of making predictions about the true BL items using the photography-registered ones.

The datasets were examined and very small items that are not visible in the photographs were excluded. Only litter items registered by both photographic and *in-situ* methods were used for building the regression/prediction models. In order to have comparable data between *in-situ* and photographic BL percentage shares and better visualize the results, 'plastic' and 'expanded polystyrene pieces 2.5–50 cm' categories were excluded from the analysis, as they mostly contain too small-sized pieces which additionally lack a well-recognizable shape (in contrast to the well-defined item categories of the same class size, like plastic caps/lids, straws/stirrers etc.), and thus cannot be adequately detected and categorized through photographs. Moreover, expanded polystyrene pieces stranded on the white pebble substrate of the study area are difficult to detect due to their whitish colour and irregular shape. 'Non-identifiable' items in photos were also removed from the analysis to avoid skewing the results (Figs. 3–7). The excluded categories (plastic and polystyrene pieces 2.5–50 cm and unidentified items) were calculated separately in the *in-situ* dataset in order to also give a picture of their contribution to the totally registered BL items (Fig. 3a).

BL item quantities were converted to densities as items per 100 m of beach face length (items/100 m), rather than as items per beach area unit (items/m^2) in order to facilitate the comparability of beach litter items at a local, global and cross-sectional level (beached, floating and/or benthic litter). Tide effects can alter seasonal comparability of BL data, not only between different geographic locations, but even for the same beach site. Also, as described by Prevenios et al., 2018: (i) if litter densities are expressed per beach area unit, a narrow beach would appear more heavily littered than a wider beach, having the same length and litter load, and vice versa; (ii) global scale comparisons could only be carried out for the global coastline, as there is no defined global coastal area; (iii) BL data expressed per beach length unit could enhance correlations between beached litter and drifting floating litter at the same beach. All elementary statistical analyses were based on the above extracted BL densities.

Finally, a Trend Surface Analysis using a quadratic local polynomial interpolation was applied to model the spatial distribution of BL densities in western Saronikos Gulf. This was used as a proxy to general floating litter pathways in the area.

3. Results

3.1. Beach litter quantities and accumulation rates through in-situ sampling

A total of 21,830 BL items were collected and categorized (Table 2) from October 2017 to August 2018 through *in-situ* sampling. The average BL density was 1,983 items per 100 m beach face length. Plastic polymers were the most abundant type, representing 88.40% of all litter collected. Processed wood, glass/ceramics, metal and rubber constituted 6.71%, 1.83%, 1.37% and 1.34% respectively, while all the other material types represent less than 1% of the total items found. Fig. 3a shows the percentage share of litter types registered through both *in-situ* and photography, while 'unidentified' items, 'plastic', and 'polymer pieces between 2.5 and 50 cm' categories are presented separately ().

Polystyrene pieces 2.5–50 cm was the most abundant category registered *in-situ*, constituting 35.86% of all items found. Classification of plastic polymer items per potential use (Fig. 3b), show that 'single use plastics' was the most significant litter source accounting for 56.55% and 47.50% of the total items registered *in-situ* and through remote photography, respectively. The top ten items within single use plastics are presented in Fig. 3c. Cover/packaging was the most abundant litter category found accounting for 24.45% of all litter registered *in-situ*, followed by straws and stirrers (6.40%) and drink bottles' plastic lids (5.85%).

Fig. 4 depicts the temporal variation of all litter types, recorded during each sampling period (at approx. three-month intervals) at each of the four observatories.

There is an increasing trend in BL accumulation rates between August–October (Beach A and B) and November–January 2018 periods, while during the latter all beaches reach their highest densities. A maximum of 2,289 items per 100 m were recorded in Beach B. During the February–April 2018 and May–July 2018 periods, the number of litter items reduced in all beaches (more apparently in Beaches B and D, reaching their lowest values of 530 and 46 items respectively in May–July 2018). The overall temporal variation of BL accumulation rates exhibits a seasonal pattern, with higher values in winter (Nov–Jan 2018, Feb–Apr, 2018) than in summer (Aug–Oct 2017, May–Jul 2018). This is most likely linked to the wind-and-wave conditions during winter, depositing greater amounts of floating litter on the beaches (Prevenios et al., 2018). Greater accumulation rates during winter have been previously reported by Walker et al., 1997.

3.2. Correlation between in-situ and vessel-based photography data

Plots of the *in-situ* and corresponding photographic data for the four observatories during each sampling period are presented in Fig. 5. Small items like 'plastic' and 'polystyrene pieces 2.5–50 cm', were excluded from the analysis, for the reasons explained in section 2.3.2. In general, there is a significant agreement in the correlation number of litter items of photographic and *in-situ* litter registrations, for all periods at beaches A, B and C. Note that data for Beach C during August–October 2017 were excluded from the analysis as there are only *in-situ* and no corresponding photography registrations (Table 1). Small scale discrepancies in correlations between the number of litter items observed, are presumably related to occasional phenomena and will be discussed later in section 4.1.

A linear regression model was used to explore the relationship between the counts of BL registered through photography and *in-situ* sampling at the four observatories (Table 3). This was carried out in order to determine the best fit function which describes the correlation between these data. The derived function enhances our ability to make high-accuracy estimations of the actual number of BL items where only photographic data are available. Linear regression (Fig. 6a) between counts from the *in-situ* and vessel-based photography method, during the four validation periods demonstrates a significant correlation ($R^2 = 0{,}91$; Fig. 6c).

Although linear regression (Fig. 6a) between the above pairs of data gave an adequate goodness of fit, there was a noticeable change when more than 60 items were detected, through photography. Hence, the use of two regression lines with a break point was decided as the preferred method to model and assess BL quantities through photographic counts, now-on referred to as a split regression model ($R^2 = 0{,}98$; Fig. 6d). The first part of the data, from 0 to 60 litter items, was best fit using a linear regression model with an intercept set to 0 items. The second part, from 61 to 500 items, was best fit using a logarithmic regression model (Fig. 6b).

By applying the split regression model, the average error decreased from 29,53% (linear regression) to 16,08% (Table 3), indicating a significant improvement of the model efficiency (Fig. 6 b and a respectively). Similarly, the R^2 increased from 91% (linear regression) to over 98% (split regression) (Fig. 6c and d respectively). The resulting values of linear and split regression analyses, between October 2017 and August 2018 are presented in Table 3.

3.3. Estimating the true abundance of beach litter in western Saronikos through vessel-based photography method

A total of 17,805 items were registered through photography, during the on-site monitoring surveys conducted for the totality of the fifty-eight inaccessible beaches of western Saronikos Gulf. The average number of BL registered, expressed as per 100 m beach length, was 318 items. The application of the split regression model resulted in 66,887 items in total and an average of 1,153 items expressed as per 100 m beach face length, that are 3.5 times as much as the correspond values registered through photography (before spit regression model application). The exact number of BL items assessed per beach is presented in Annex 2.

Plastic polymers constitute 83.79% of the BL items registered through photography (before the application of split regression), processed wood 12.66% and metal 1.96% (Fig. 7a), while any other material type represents less than 1% of the total share. Additional classification of plastic polymers per potential use is presented in Fig. 7b. 'Single use plastics' was again the most important category, representing 50.94% of the total items classified, while drink bottles >0.5l regarded 21.77%, drink bottles <0.5l (7.88%) and cover/packaging (6.97%) were the most frequent litter categories found (Fig. 7c).

4. Discussion

4.1. Suitability of vessel-based photography for BL assessment

In this study, a significant relationship ($R^2 > 98\%$) between the actual number of BL registered *in-situ* and their corresponding number assessed through vessel-based photography was exhibited, in four selected beaches defined as observatories. The derived regression functions were used as 'proxies' to best approximate the quantity and the quality of litter for the other fifty-eight inaccessible beaches of Western Saronikos Gulf, which have been previously identified through photographic records. Vessel-based photography provides a decent trade-off between quality photographic documentation, spatial coverage, processing time, and operational cost, while, unlike other remote methods, it could easily be performed by non-experts. The proposed method could be perfectly applied for the effective designing of BL monitoring programmes, in accordance with the Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean (GESAMP, 2019). Moreover, it goes one step beyond the approaches proposed through the project AMARE (Actions for marine Protected Areas), for quick identification of accumulation areas, and especially for long distance surveys at extended coastlines. Indeed, this approach enhances our ability, not only to categorize and visually assess the quantity-quality of BL, but also to calibrate of the real density of BL stranded on the coastline.

Aerial photography monitoring by light fixed-wing planes (Moy et al., 2018; Kataoka et al., 2018), balloons (Nakashima et al., 2011) imply several flight restrictions (FAA or else) and significantly higher operational costs. BL monitoring with higher performance (operating time, flight distance and control) Unmanned Aerial Vehicles (UAVs), also imply considerably higher acquisition and operational costs, in comparison with vessel-based monitoring. On the other hand, low-cost drone solutions like quadcopters (Martin et al., 2018; Gausi et al., 2018; Deudin et al., 2018; Bao et al., 2018) imply certain limitations on flight time (limited battery duration), and hence on the spatial coverage range and flexibility of the monitoring surveys. Especially when it comes to monitoring extended and remote coastlines, where the use of a boat is deemed necessary, the vessel-based photography method has an advantage over other proposed, low-cost monitoring methods. The exclusive use of 'low-cost' drones cannot satisfy long distance monitoring due to the above-mentioned limitations. On the other hand, the use of drone systems launched from a boat, would imply additional operational time and complexity, which in turn adds to the higher cost of equipment acquisition. However, an important point to mention here is that, in certain cases, the auxiliary use of drone systems could help overcome potential limitations of vessel-based monitoring surveys. Shallow coastal waters or the presence of natural, or manmade obstacles (e.g. reefs or fish-farming units) in the nearshore waters, could adversely affect the boat's distance from the shore, thus inhibiting vessel-based photographic documentation with a camera. This is also the case where safety regulations related to the minimum distance from the shore are applied, due to the presence of swimming zones or divers in the water or other reasons (coastal areas of conservation concern, regional navigational hazards etc.). As regards the use of webcams (Kako et al., 2010; Kataoka et al., 2012) for long distance surveys, one needs to consider additional set-up complexity, maintenance and operating costs (e.g. regular visits for functional check-ups, lens cleaning, data acquisition etc.).

Moreover, vessel-based photography significantly minimises the risk for equipment lost implied by the use of both UAS and webcam monitoring methods. In addition, it has a lower computational complexity than the above-mentioned methods. On the hand, vessel-based photography method has a certain limitation on image processing, regarding its ability to precisely assess the real size of litter items captured, in comparison with the aerial photography methods (Nakashima et al., 2011; Moy et al., 2018). Though, experts' judgment on visual assessment of litter size and/or comparisons of not-known size items with adjacent natural features or other objects of known size (e.g. drinking water bottles) could overcome size estimation restrictions.

Regardless the chosen method, the quantification of BL abundances by means of remote photography implies certain limitations. As size and contrast with substrate decrease, litter items are more likely to be overlooked, due to camera specification restrictions. Additional parameters related to natural lighting and illumination (sunshine, cloudiness, shadows) and weather conditions (wind-and-wave) during photography could adversely affect the quality and resolution of the derived images, and therefore our ability to detect and/or precisely identify BL items through photographs. Moreover, particularities in beach morphology such as small coastal landslides/rockfalls, cavities, large beach rocks, areas of ground depression and vegetation, together with certain patterns in the debris accumulation profile of a beach (such as debris pilling spots, high reed and algal accumulations) function as 'traps' or hiding spots of BL, adding complexity to the identification task and lead to quantificational underestimations (Image S1).

Considering these limitations in the case of the present study, the orientation and morphology of each beach, in relation to the angle of the sun during photography, could generate different shadowing effects over the beach surface. This in turn could create heterogeneities on the quality of the derived images, which adversely affect the consistency of results. Similarly, variations in the distance of the vessel from the coast (e.g. due to nearshore morphology), affect the angle and resolution of photography and subsequently the uniformity of derived panoramas. Both the above considerations could apply when examining one beach site or comparing different sites. Similarly, the presence of 'traps' or 'blind spots' on the beaches, causes inevitable underestimations during BL photo counting. In order to compensate this limitation, the four observatories were selected considering, among other factors, the morphology and sedimentological characteristics of all examined sites and the particularities involved in the study area (See selection criteria in section 2.2.1).

Despite the above-mentioned restrictions, manual camera operation on vessel-based photography has obvious advantages over the other remote photography techniques, offering significantly higher resolutions. Human operator can instantly evaluate photographic conditions and compensate for each different frame by changing the settings of the lens (focal points, light sensitivity, focal lengths, zoom, picture angle etc.), as opposed to automated, fixed lens photography, used in aerial surveys. This minimises post processing time of the photographs (to improve sharpness and clarity). As regards the angle of shooting, top-down aerial photography appears less effective while vegetation is present. On the other hand, low-angled, vessel-based photography, allow for better detection of BL entangled in and beneath vegetation. Similarly, litter items stuffed through steep coastal slopes or underneath large rocks, the part of them facing towards the shore, could also be detectable through vessel-based photography. When layered litter stock in piles are present, only their upper part could be registerable by both aerial and vessel-based monitoring methods. Finally, compared to top-down aerial photography, low-angle vessel-based photography that conforms to the overall height of shooting and the distance of the vessel from the shore, may prove less effective in capturing the whole vertical range of a beach and thus all BL items on it. This is especially true in the case of very weak beach slopes. However during the vessel based surveys conducted in the present study, the angle of shooting (approx. 20–30°) in relation with the slopes of the beaches under examination were appropriate, allowing to capture snapshots of decent quality (in terms of vertical distortion) and thus reliable for the assessment of the number of BL through photo counting.

Limitations related to the size and/or shape of the litter items and/or their long- and short-term accumulation patterns on beaches, affect the degree of correlation between *in-situ* and remote BL registrations. Items categories like cover/packaging, plastic caps/lids drinks, straws and shopping bags are high ranking in both *in-situ* and remote photography, as they pose a standardised, well-recognizable shape and/or colour (Figs. 3c and 7c, respectively). Contrarily, categories like plastic and expanded polystyrene pieces between 2.5 and 50 cm which are most frequently found during *in-situ* sampling, are considerably underestimated when counted through photography (Fig. 3a). The reason for this, lies to the fact that the latter categories refer to fragments of irregular shape (rather than well-defined items) which, moreover, have in their majority a size close to the low limit of macro-plastics (2.5 cm). At this point, it is worth mentioning that, the greater share of items that could not be identified during digital registration, also belong to the same size class. On that basis, it can be assumed that most of the items characterized as 'unidentified' through photography, are more likely to fall under the above-mentioned categories (plastic and/or polystyrene pieces 2.5–50 cm). Consequently, these categories were excluded from the proposed method, since their inclusion in the correlation analysis (*in-situ* versus photographic data) would lead to potentially misleading results.

Fishing/maritime related plastics was the second most significant litter category registered through remote photography both in the four observatories (Fig. 3c) and in fifty-eight beaches (Fig. 7c), representing 16.81% and 17.70% of the total items found, respectively. Items included in this category like synthetic rope are in the top 10 items ranking both for the four observatories (9.27%) and the fifty-eight beaches (3.69%). Others, like rope and polystyrene pieces >50 cm were lower ranked on beaches cleaned regularly (four observatories: 1.92% and 0.44%, respectively), in comparison with their rankings on sites where no clean ups have been taken place (fifty-eight beaches: 3.51% and 3.63%, respectively). (Fig. S1; Image S1). Moreover, it is worth mentioning that fishing/maritime related categories found stranded on a number of beaches such as fish farming platforms and cages (both included in 'other fishing related' category) were significantly greater in size in comparison with all the other litter categories identified (Image S2). This statement highlights that our 'number of items per 100 m beach face length' approach to the assessment of the BL contribution (used in the present study as the most convenient to our analyses needs), may although underestimates the true significance of fishing/maritime related sources to the total litter load observed in the study area.

By comparing litter categories registered remotely at the four observatories and at the rest of the fifty-eight beaches, cover/packaging was the most frequently found in the first beach cluster, while drink bottles (most of them are water bottles) during the latter cluster (Figs. 3b and 7b, respectively). Moreover, drink bottles categories are considerably lower in ranking regarding the four observatories results (Fig. 3c). Empirical evidence on the four observatories has shown that certain BL categories were likely to be found in greater concentrations during the first beach clean-ups, while their number reduced significantly on subsequent samplings. The same fact is also observed with categories like 'sacks of unknown use', 'ropes' and 'polystyrene pieces >50 cm' (Fig. S1; Image S1). Considering that the fifty-eight beaches are remote, and therefore have never been cleaned, the presence of higher concentrations of the above-mentioned categories, are probably linked to their long-term accumulation stock on the beaches. Consequently, slight data discrepancies are to be expected between assessments of BL based on the fifty-eight beaches where no clean-up operations took place, and the four observatories of systematic sampling and clean-up surveys within the framework of present work. This underlines the difference in composition observed between the BL stock resulting from years of accumulation, and that accumulated temporally over fixed time intervals.

Based on the above, photographic documentation through vessel-based photography allows to make accurate assessments about the real number of BL stranded in remote and inaccessible shorelines, having significant benefits over other remote sensing techniques available regarding image quality and trade-offs between wide spatial coverage and cost-and-time effectiveness.

4.2. Environmental drivers and litter sources favouring the accumulation of litter on beaches of western Saronikos Gulf

In general, the most common BL types and categories observed at the four observatories and at the fifty-eight beaches, bear no significant differences. Plastic polymer materials, as expected, were the most common type of litter registered in both cases (88.40% *in-situ* and 78.09% photographic, regarding the four observatories and 83.79% photographic, regarding the fifty-eight beaches). Processed wood was the second most frequent material type registered through photography both at the four observatories (15.87%) and at the rest of the fifty-eight beaches (12.66%). This fact is related to the wood's positive buoyancy, that facilitates the sea transportation in remote shores. In terms of plastic polymer materials', single use plastics was the most abundant type registered through remote photography both at the four observatories (47.50%) and at the fifty-eight beaches (50.94%).

The total BL spatial distribution in the fifty-eight inaccessible study sites (Fig. 8a and b) compares well to the near surface circulation of Saronikos Gulf as derived by Copernicus and found in Fakiris (2004), both regarding modelling the case of North winds 3–4 Bf (predominant 25% of annual winds based on the Hellenic National Meteorological Service). The general anti-cyclonic circulation in the western sub-basin in combination with the predominant Northerly winds provides a continuous supply of BL to the study area, originating from the south-western sector of Athens metropolitan area (Megara and Eleusina bays and Salamina island) (Figs. 1b and 8b). Excessive industrial and maritime activities, as well as the presence of uncontrolled landfills on the latter, were the most important sources of litter inside the study area. Moreover, westward distribution currents observed through Methana, Aigina and Agkistri straits, are also identified as important pathways of floating litter mainly for the southernmost sector of the study area (Bay of Epidaurus) originating both from the above mentioned areas but also from the south-eastern coastline of Athens metropolitan area and Piraeus city port (Figs. 1b and 8b).

The complex morphology of the coastline, with prominent seaward extensions, is another key aspect affecting BL distribution in the study area. Rocky and irregular features like small islands and rocky islets could form intermitted barriers for the sea currents pathways, occasionally diminishing their velocity, hence enhancing the deposition of their litter load to adjacent coastlines.

The highest concentration of BL in the study area (~7,828 items per 100 m beach length) is observed at Beach 22 (Annex 2; Fig. 8a and b) in Kyra island. This fact could be explained as the Kyra island forms a natural obstacle to the southward movement of general anticyclonic water circulation in the area. Likewise, concentrations greater than 3,000 items per 100 m beach length observed in Beaches 8, 15, 17 and 27 (Annex 2; Fig. 8a and b), are linked to the general westward circulation predominating at the northern and central part of the west Saronikos Gulf.

Great litter densities observed in Beaches 54 and 55 (Annex 2; Fig. 8a and b) (3,043 and 3,978 items/100 m beach length, respectively) are linked to: (i) the general anticyclonic circulation (ii) the westward circulation observed between Aigina island, Methana and Agkistri island and (iii) the local littering activities (uncontrolled landfills, fish farming). Passing through the straights of Methana and Agkistri island, westward flow forms a small-scale cyclonic structure in the southernmost part of the Study area, distributing its litter loads (Figs. 1b and 8b).

5. Conclusions

Simultaneously capturing photographic and corresponding *in-situ* data from four selected remote beaches, defined as observatories, were used as a calibration dataset to accurrately estimate the abundance of BL at the fifty-eight remote beaches of the same region, were *in-situ* data were absent. We have developed a simple method of using vessel-based remote photography interpretation as a proxy to predicting the abundance of beach litter in remote beaches, hence providing wide scale, rapid and high-quality data, with an accuracy of $R^2 > 98\%$ in predicting the true beach litter abundances. A detailed photographic data collection for the totality of remote beaches (approx. 6.5 km of remote coastline) in western Saronikos Gulf (coastline extention approx. 8.5 nautical miles) was achieved in just a couple of days (~20 working hours), while data processing (photomosaicking, litter identification and registration) was accomplished in about three weeks, including the respective learning curve.

Both data from (i) regular samplings at the four observatories (*in-situ*) and (ii) on-site remote monitoring (photography) at the fifty-eight beaches, show that plastic polymer materials are the most abundant BL type. Slight differentiation between BL categories registered during *in-situ* sampling and photography campaign depends on the performance or absence of prior beach clean-ups on these inaccessible sites. The fifty-eight beaches on which clean-ups have not been performed best reflect the accumulation stock of the beaches, while the four observatories of systematic clean-up and sampling surveys best reflect temporal accumulation rates observed in fixed time intervals. Single-use plastics (cover/packaging, straws, caps/lids, shopping bags, drink bottles etc.) registered in data from both monitoring approaches, confirming their predominant presence in the coastal environment.

Beach macro-litter monitoring is of great importance, in order to assess the problem of plastic pollution in marine environment, reveal areas of first concern and plan effective strategies of immediate intervention, aligned with European Union (EU) and United Nations (UN) directives and policies. The outcome of our surveys, are in accordance with research findings worldwide (European Commision, 2018; Ocean Conservacy, 2018; Moy et al., 2018). They further justify 2019/904 EU directive to reduce the impact of certain plastics on the environment and the EU drive to develop Plastic Strategy legislative initiatives to specificaly tackle single-use plastics and fishing/maritime related accesories.

Future investigation could combine data for BL concentrations predicted by the proposed method for the sixty-two inaccessible beaches with meteorological and sea current data in order to investigate the spatial variability and distributions of the BL in the wider area of western Saronikos Gulf. The regular repetition of the remote observations for greater time periods, could also enhance the generation of spatiotemporal models for BL concentrations regarding the same area.

Declaration of competing InterestCOI

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2019.110684.

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