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Nearshore survey and cleanup of benthic marine debris using citizen science divers along the Mediterranean coast of Israel

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ABSTRACT

Information on marine debris along the Mediterranean coast of Israel, especially on the seafloor, is limited. Many recreational divers are enthusiasts of marine conservation and can thus contribute to data collection which does not require highly specialized training. The Society for the Protection of Nature in Israel together with The Israeli Diving Federation established the diver volunteer program “Sea Guard” (“Mishmar Hayam” in Hebrew), which supports marine conservation through citizen science. The divers were trained in marine ecology and survey methods to conduct independent surveys and lead underwater cleanups. For the first time, we have described the patterns of benthic debris density and composition in the nearshore environment of the southeastern part of the Mediterranean Sea. We found that benthic marine debris in the nearshore along the Israeli Mediterranean coast is primarily plastic, likely originating from the use of local beaches. Fishing, boating and domestic activities also play an important role as sources for marine debris. The currents' regime prevented the debris from accumulating on the seafloor in the nearshore environment, with the exception of several “debris traps”. Our findings will be useful for the development of programs to improve coastal waste management.

1. Introduction

Marine debris (MD) is defined as “solid materials of human origin that are discarded at sea or reach the sea through waterways or domestic and industrial outfall” (National Academy of Science, 1975). MD is considered a threat to marine biodiversity, ecosystems, animal well-being, fisheries, maritime transport, recreation and tourism, local societies and economies (Gregory, 2009; Teuten et al., 2009; Thompson et al., 2009; Mouat et al., 2010; Gold et al., 2013; UNEP/MAP, 2014; Galloway, 2015). The concern has grown with recent new findings, indicating high and rapidly increasing levels of micro-plastic litter (Galloway, 2015). The third session of the UN Environment Assembly (UNEA3) that took place in Nairobi, Kenya on December 2017 put the spotlight on pollution as an urgent human health crisis (UNEP, 2017).

In general, submerged (i.e. benthic) debris tends to become trapped in areas of weak current circulation where sediments accumulate, such as around rocks or wrecks, as well as in depressions or channels (Galgani et al., 1996; Schlining et al., 2013; Pham et al., 2014).

In estuaries, large rivers are responsible for substantial input of debris to the seabed (Lechner et al., 2014; Rech et al., 2014) and transport waste far offshore because of their high flow rate and strong currents (Galgani et al., 1995, 1996; 2000). Alternatively, small rivers and estuaries can also act as a sink for debris, when weak currents facilitate deposition on shores and banks (Galgani et al., 2000). The consequence is an accumulation of MD in bays and lagoons, rather than in the open sea. These are also the locations where large amounts of derelict fishing gear accumulate and cause damage to shallow-water biota and habitats (Dameron et al., 2007; Kühn et al., 2015). Debris that

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reaches the seabed may have started as floating debris, transported over considerable distances, before sinking to the seafloor as a consequence of heavy fouling or waterlogging. And thus, some accumulation zones have been identified far from coasts (Galgani and Lecornu, 2004; Bergmann and Klages, 2012; Woodall et al., 2014, 2015). Plastics are present in large amounts on the seabed of all seas and oceans (Galil et al., 1995; Galgani et al., 2000, 2015; Barnes et al., 2009) with a global average of 47.8% of the seabed covered with debris according to Litterbase (2018), and higher percentage in the eastern Mediterranean – ranging from 73% to ~ 84% in Turkey (Topcu et al., 2010; Eryaşar et al., 2014), and from ~45% to 95% in Greece (Katsanevakis and Katsarou, 2004; Koutsodendris et al., 2008; Ioakeimidis et al., 2014).

Mediterranean sites have high MD densities owing to the combination of a densely-populated coastline, shipping in coastal waters, negligible tidal flow and a limited water exchange through the Strait of Gibraltar (Galgani et al., 2015). Studies in the Mediterranean show that between 60% and 80% of all debris found on the coast originated from local recreational activities (Galgani et al., 2015; Pasternak et al., 2017). Previous studies in the Mediterranean have found that nearshore MD is concentrated in shallow coastal areas rather than in deep water (Koutsodendris et al., 2008) and in bays more than in open sea areas (UNEP, 2012; Galgani et al., 2015; Brennan and Portman, 2017).

1.1. Benthic marine debris in nearshore along the Mediterranean coast of Israel

The Mediterranean coast of Israel extends about 195 km from Zikim near the border with Gaza Strip to Rosh HaNikra near the Lebanese border (Fig. 1). This coastal section, with the exception of Haifa Bay, the Carmel headland and a few small rocky bluffs, has a straight and mostly sandy shoreline that gradually changes its orientation from northeast to almost north (Bitan and Zviely, 2018). From a sedimentological perspective, the Israeli coast and its shallow continental shelf (i.e. from the shore to max 30 m depth) are mainly sandy (Zviely et al., 2007) especially along the southern coasts. Longshore currents are generated by the radiation stresses of breaking waves and shearing stresses of local winds. Since radiation stresses are generally at least an order of magnitude greater than shear stresses, these stresses predominate in the surf zone during wave storms. Beyond this region, the shallow shelf currents are generated by local winds (Kit and Sladkevich, 2001; Kunitsa et al., 2005).

The wave-induced and wind-induced longshore currents are active in both directions. However, the long-term net longshore current runs northward along the entire coast of Israel, (Perlin and Kit, 1999; Zviely et al., 2007). Current measurements are technically impossible in the Israeli surf zone, since no current meters can be placed on a sandy and dynamic bottom and survive the local wave storms. As a result, all wave and current meters are placed offshore, in depths deeper than 15 m (Kunitsa et al., 2005; Pasternak et al., 2018). But coastal currents can reach a maximum theoretical value of up to 2.0 m/s during severe storms (Stiassnie and Shemer, 1987; Kit and Kroszynski, 2014). Approximately 98% of the winds reach the shores of Israel at a velocity no greater than 38 km/h (awaken winds) where 77% of these winds blow from the North, North-West and West. During spring and autumn, the winds come primarily from the East, and in summer the sea breeze varies: in the morning, winds are circular from the South and West, in the afternoon the winds are from the North, and in the evening the winds are from the East until early morning (Almagor, 2002; Rosentraub and Brenner, 2007). Tides along the Israeli coast are insignificant, ranging from 15 to 40 cm, which is not sufficient to create sediment transporting or beach eroding currents (Golik and Rosen, 1999).

The Israeli coast is cleaned regularly by the local municipalities (Alkalay et al., 2007), but during the spring, summer and autumn light MD can be blown into the water by East winds. Once reaching the sea, MD may be cast back ashore, sink to the seabed or drift along the coast in longshore currents (Pasternak et al., 2018). Strict oversight by the Ministry of Environmental Protection almost completely stopped untreated effluents flows to the Mediterranean Sea (unless due to accidents), resulting in a low percentage of sanitary items on Israeli beaches (Pasternak et al., 2017). Most MD originates from other land-based sources such as beach vacationers and from urban communities especially after heavy rains that flush the debris via streets' drainage systems. And with the increasing anthropogenic pressure on the Israeli coast, with more visitors finding refuge from the summer heat, or camping for longer periods, coastal MD loads are increasing (Pasternak et al., 2017). The most important criterion preferred by a typical Israeli visitor is a clean sandy beach (Barak, 2013). However, by the end of the day, especially during the holidays, beaches that are not cleaned immediately by the local authorities can look like a dumpsite (Fig. A.1). When it comes to MD, there seems to be a disconnection between the awareness of what is wrong (e.g., the coast is dirty, marine animals are dying), what needs to be done (cleaning), and the visitor's personal responsibility (not littering, collecting MD) (Alkalay and Pasternak, 2008).

1.2. Marine debris data collection relies on citizen science

The realization of the difficulty in collecting data over such large spatial and temporal scales, which requires a mass of manpower, led to the development of volunteer-based monitoring programs (mainly beach surveys) on a variety of temporal and spatial scales. The US National Marine Debris Monitoring Program (NMDMP) (Sheavly, 2010) and the Marine Litter Watch (MLW) of the European Committee (EEA, 2014) are examples of MD monitoring programs at national and international levels. The Ocean Conservancy was the first non-governmental organization (NGO) to collect data during coastal cleanups on an international scale, and currently maintains the largest international database regarding MD, gathered solely by volunteers during the International Coastal Cleanup (ICC) (Ocean Conservancy, 2018).

Public participation in scientific research, commonly named citizen science (CS), has long been used to deal with research questions that would otherwise not have been addressed due to lack of dedicated resources (Irwin, 2001; Cooper et al., 2007; Couvet et al., 2008; Silvertown, 2009; Dickinson et al., 2010; van der Velde et al., 2017). CS projects can involve volunteer participants from school-aged children to adults. Participants may be involved in a variety of roles including study design, data collection, processing and analysis and dissemination of information to the broader community (Tulloch et al., 2013; Theobald et al., 2015). The engagement of volunteers in science is becoming an established practice with a steadily increasing number of projects, in a variety of disciplines, that deliver information to support science and management (Cohn, 2008; Silvertown, 2009; Hand, 2010; Teleki, 2012). When appropriately designed, validated and communicated, CS projects may serve two main objectives: (1) providing scientifically sound data (often over large temporal and spatial scales) that would otherwise not be collected; (2) promoting public awareness especially in environmental surveys, where volunteers may discover that they are an important cause of the problem, which may generate a motivation to act (Pattengill-Semmens and Semmens, 2003; Cigliano et al., 2015; Theobald et al., 2015; Cerrano et al., 2016). Therefore, CS monitoring projects can deliver a strong educational and conservation message as well as encourage behavioral changes of the participants (Branchini et al., 2015).

Many recreational divers are enthusiasts of marine conservation and can also contribute to marine litter data collection. For example, the international Professional Association of Diving Instructors (PADI), founded “Project AWARE” in the 1990s, which has become an independent movement aiming to increase awareness of problems in the marine environment, including MD. In 2011, in the framework of their program “Dive against Debris”, “Project AWARE” established a global data collection system at the organization's website. Through this site,

Fig. 1. Study area. The surveys and cleanups sites are written in blue. The Google Earth images show the diving survey transects (white lines) along the Neve Yam coast and near the Alexander River outlet. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

divers can report debris encountered during dives and data can be obtained from the organization (https://www.projectaware.org/diveagainstdebrismap).

Unlike beach surveys, recruitment of divers for benthic marine debris (BMD) surveys is difficult. Locating, training and then obtaining participation from a large number of knowledgeable SCUBA divers is challenging, even under the best of circumstances (Loerzel et al., 2017). A second limitation is that the data collection must be validated (Hidalgo-Ruz and Thiel, 2015). Ideally, design and implementation of data validation processes would occur from project inception through allocation of time, financial resources and personnel to support this outcome. However, not all CS organizations have the consistent and secure resources to conduct the necessary work to enable reporting on data quality, especially long-term or grassroots CS projects (Schläppy et al., 2017). In practice, many funding sources suitable for CS seek innovation through "new activities" and may not support funding for existing human resource costs that are critical for long-term initiatives. This chronic limitation of resources can result in staff or volunteer burn-out, reduced partnership outcomes, non-essential reiterations and mission shift (Schläppy et al., 2017).

According to "Project AWARE"'s website, there are MD data only from Greece, Turkey, Cyprus and Israel in the eastern Mediterranean. It appears that the divers in Israel are willing to act in a group, but not individually. Also, it seems that people do not like to do the "paper work" and fill in reports, as was noted when participating in the ICCs (First Author personal observation).

As part of an integrated MD project in Israel, a CS survey program for benthic MD was initiated. The aim of the present study was, therefore, to evaluate the density and composition patterns of submerged BMD found in the Israeli nearshore area based on systematic surveys and data collected by volunteers, as well as to assess the design of the Israeli volunteer programs.

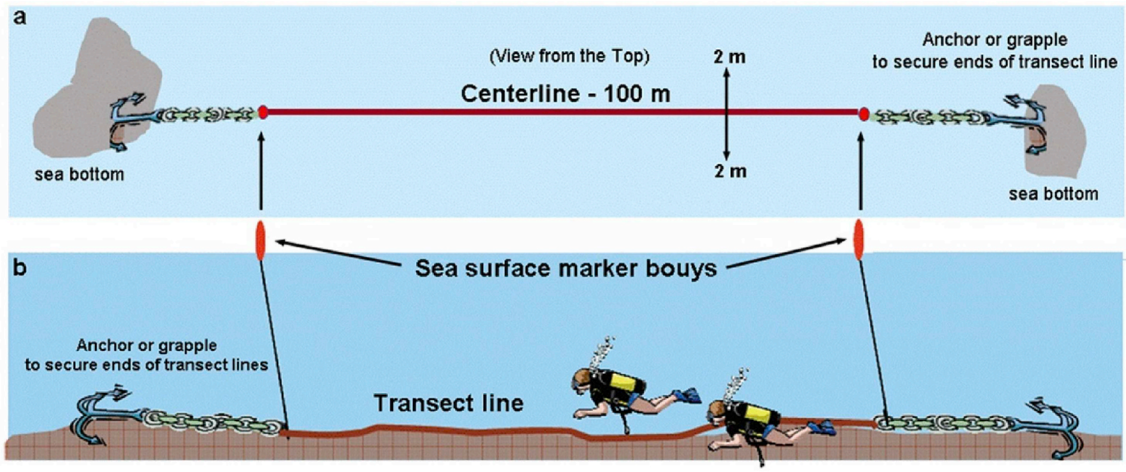

Fig. 2. Layout for benthic visual debris survey; divers swim along the transect line and collect or record all debris items found within 2 m on both sides of the line; (a) top view, (b) side view (modified after Cheshire et al., 2009).

2. Methods

There were three phases to the research – a baseline survey; Citizen Science submerged BMD cleanups; and Citizen Science "Sea Guard" program. The benthic visual debris surveys were based on 100 m by 4 m transects covering a total area of 400 m^2 per site. These transects were marked by a 100 m long centerline and debris was counted within 2 m on each side of the line (Fig. 2).

2.1. Baseline survey

There is little known about the distribution of BMD in the nearshore area along the Mediterranean coast of Israel. To start to fill this information gap, a baseline survey (BLS) was conducted between 2012 and 2015.

Seventeen coastal sites were surveyed by a research team using SCUBA diving (Fig. 1). Most of the sites are characterized by fine sandy beaches and sandy sea bottom. Ten of the 17 sites are located near marine infrastructure (i.e. ports, harbors, marinas, detached breakwaters, groins) or natural rocky features (i.e. abrasion platforms, beachrock and submerged reefs). The other seven sites are adjacent to beaches where beach MD surveys were previously conducted (Pasternak et al., 2017).

In the first year of the BLS (September 2012 to June 2013), transects perpendicular to the shore, from the waterline to about 3 m depth, were conducted. The aim of this BLS was to determine if there were specific depths where BMD might accumulate, and how it is affected by the breakwater. During the second year (October 2013 to May 2014), MD BLS were conducted in open water from EcoOcean's R/V Mediterranean Explorer (Pasternak et al., 2018). The BLS were carried out in water of 10 m depth, adjacent to the previously conducted benthic surveys sites and parallel to the shoreline. In the third year (May 2015 to July 2015), BLS were done in 10 selected sites with weak water circulation that were assumed to be "debris traps". All BLS were conducted in calm sea conditions (e.g., wave height less than 0.5 m), with good visibility in the northern sites and poorer visibility in the southern sites.

2.2. Citizen science submerged benthic debris cleanups

We initially attempted to gather information about benthic MD from diving centers during underwater cleanups (UWC), in a framework of a cooperative program with The Israeli Diving Federation (TIDF), to raise public awareness for the marine environment. However, when there was no researcher present at the time of the cleanup, the debris collected was not reported nor categorized. Subsequently, the cooperative program was restarted in May 2015 with a representative researcher of TIDF accompanying the volunteers at major cleanup events. The researcher and divers weighed all mesh bags containing MD (in order to report how much MD was removed), sorted the debris according to Cheshire et al. (2009), and transferred the data to the research team (Fig. A.2). There were 33 UWC done at 12 sites (Fig. 1) between May 2015 and November 2017. (Details on the UWC are in Table B.1).

In some cases, when the entity responsible for the beach (i.e. local municipality or the Israeli Nature and Park Authority) was involved in the cleanup, a short report of the results and recommendations was issued to the contact person.

2.3. Citizen science "Sea Guard" program

In 2015, the research team joined the Society for the Protection of Nature in Israel (SPNI) and TIDF to establish the divers' "Sea Guard" ("Mishmar Hayam" in Hebrew) volunteer program, which supports marine conservation through CS. For this program, we developed new diver specialty courses: "Reef Diver" and "Underwater Surveyor", both aimed to increase divers' knowledge and awareness of two environmental issues: MD and biodiversity.

The volunteer divers in the program were trained to conduct independent surveys and lead UWC. The four days training course was led by diving instructors who all had a Ph.D. in marine ecology or were graduate students in the field. Training included presentations about the local coastal environment, environmental issues, identification of local marine life, conservation and MD and marine biota survey methods. During the course, the divers were trained to use the survey equipment, plan the dive and survey, and conduct underwater surveys. Between May 2015 and May 2018, 16 "Sea Guard" surveys (SGS) were conducted in seven different sites, in the northern part of Israel (Fig. 1). All surveys were conducted in nearshore rocky bottom sites (0–5 m depth) that were suspected to be MD traps, selected using satellite images (Tables B.1-2, Figs. A.3-4). All the SGS were supervised by researchers who verified the dive plan and monitored the quality of the survey, usually by snorkeling above the surveyors (Note: Details on the SGS are specified in appendix B.2). The SGS were conducted mainly in the northern and central coasts of Israel, because the seafloor of the southern part of Israel is mostly sandy (i.e. fewer potential MD traps), and, with the high wave regime (Pasternak et al., 2018), there are fewer days of good visibility due to turbidity caused by the movement of fine sand and light objects. UWC organized by the SGS is conducted in all parts of Israel (Table B.2).

In March 2017 the "Sea Guard" expanded its activities and started a citizen science pilot "Adopt a Beach" as part of the Israeli IMAP

Table 1
Percentage change and seasonal net accumulation (gain and loss) rates of benthic MD at three sites along the Israeli coast 2016–2018.

% Change	items gained/day	Items lost/day	No. of items gained	No. of items lost	No. of items in Time 2	No. of items in Time 1	Days elapsed	Time period	Season	Site
167%					56	21		15 July 2016–15 July 2017	Annual	Sdot Yam
383%					174	36		24 March 2016–24 March 2017	Annual	Neve Yam
−76%	0.12	1.49	12	145	42	174	97	24 March 2017–28 June 2017	Spring	Neve Yam
−4%	0.13	0.13	16	17	25	26	126	6 March 2017–10 July 2017	Spring/Summer	Alexander River
131%	0.62	0.14	72	16	97	42	117	28 June 2017–23 Oct 2017	Summer/Autumn	Neve Yam
24%	0.18	0.13	22	16	31	25	124	10 July 2017–17 Nov 2017	Summer/Autumn	Alexander River
67%	1.33	0.50	106	40	162	97	80	23 Oct 2017–12 Jan 2018	Autumn/Winter	Neve Yam
129%	0.37	0.13	61	21	71	31	166	17 Nov 2017–2 May 2018	Autumn/Spring	Alexander River

(Integrated Monitoring and Assessment Program and related Assessment Criteria). In this pilot, the volunteers conducted four SGS in a year in Neve Yam and Alexander River (see survey sites positions in table B.3 and description in Appendix C). Results were reported to UNEP through the Israeli Ministry of Environmental Protection and Israel Oceanographic and Limnological Research (IOLR) (Pasternak and Mayzel, 2018). In addition, the "Sea Guard" volunteers are conducting ecological surveys for several coastal municipalities as part of their "Blue Flag" reports, and for the promotion of marine reserves.

2.4. Analysis

2.4.1. Collected data

For analysis, we assigned the debris items to one of four categories to determine the possible sources of BMD collected from the seafloor. The source categories were: fishing and boating (monofilament lines, fishing lures, light bulbs and processed wood) recreational (personal items, food related single-use items, beach related items), domestic (plastic pieces, packaging), and construction and industrial (metal wires, plastic pipes and Electric Company hose-cleaning sponge balls). The categories were based on the findings of the beach surveys (Pasternak et al., 2017). The use of abundance instead of weight was preferred in order to give more emphasis to the nature of debris items rather than their mass (Galgani et al., 2013; Pasquini et al., 2016).

For the BLS and SGS, we calculated MD density as number of items per 400 m^2 overall and by categories per site. When there were multiple transects per site, we averaged the outcomes of the transects to estimate site-level density. To classify the sampled sites according to their cleanliness, we used an adaptation of the Clean Coast Index (CCI) proposed by Alkalay et al. (2007) as used by Fernandino et al. (2015). Since plastic does not have the same representativeness in benthic environment but is considered to be 90% of the MD on the Israeli coast (Alkalay et al., 2007; Pasternak et al., 2017), we multiplied MD density from the data by 0.9, and divided them by 20, to get the same correction coefficient ($K = 20$) used in the CCI. Using the adjusted densities, the sampling points could be classified as: very clean (0–2); clean (2–5); moderate (5–10); dirty (10–20); and extremely dirty (> 20) (Fernandino et al., 2015).

In the UWC, the covered areas were not measured, so density could not be calculated.

For the BLS, we considered the first year as coastal surveys, the second-year surveys as open water surveys, and the third year both open water (four surveys) and coastal (six surveys). We used sites that had both coastal and open water surveys to examine if there were differences in the composition of the BMD between coastal and open water sites. We tested for a difference using the Wilcoxon test for paired samples (Conover, 1999). We also categorized the bottom substrate as either sandy or rocky. We tested whether the density of BMD differed by bottom substrate using a Mann-Whitney test (Conover, 1999). Summary statistics were calculated by type of survey and by bottom substrate. Data were displayed graphically by site to illustrate spatial patterns for density and composition. We calculated the proportions of items by category for the SGS and the benthic cleanups. We used average composition if there was more than one survey or UWC at a given site. Summary statistics were calculated for both categories and material.

We compared the composition of benthic MD from the SGS and the UWC with the composition of benthic items collected worldwide during the 2016–2018 International Coastal Cleanup (ICC) and reported to The Ocean Conservancy (Ocean Conservancy, 2016, 2017, 2018). For this comparison, we combined the SGS and UWC and re-categorized the items using the more detailed categories from Pasternak et al. (2017). This was done in order to compare composition across data sets. For this comparison we calculated the percentages as total debris in each category/total debris over all SGS and UWC. We also calculated proportion of items by material (Plastic, Cloth/fabric, Metal, Wood, Glass

Table 2
Rankings of the UWC and "Sea Guard" programs by the criteria of Cigliano et al. (2015) for successful citizen science programs. 0 -not relevant to program; 1 - hope to get there as program develops; 2 - sometimes met; 3 - fully reached.

"Sea Guard" program	Underwater cleanups	Outcomes	Toolkit
3	2	Informed advocacy	Policy change
2	0	Co-created/cooperative policy development and implementation	
1	1	Policy evaluation	
2	1	Policy change:	
2	3	● Inspiring effective advocacy	
1	1	● Increasing public awareness of the issue	
		● Increasing likelihood of policy change	
3	3	Awareness and inspiration	Educational
2	1	Individual behavior change	
2	1	Science literacy and critical thinking	
2	1	Foundations for collaboration	Community
2	1	Integration of multiple knowledge sources	
3	3	Provide long-term data to address management needs Focus	Site Management
1	2	Improve rapid response to and detection of episodic or stochastic events	
2	1	Enhanced sustainability of monitoring and management of sites	
1	0	Aiding existing species management infrastructure	Species management
1	0	Galvanizing support	
3	2	Quality and effectiveness of science	Research
2	0	Programmatic innovation	
2	2	Accessibility and participation	

Table 3
Rankings of the UWC and "Sea Guard" programs by the criteria of Hidalgo-Ruz and Thiel (2015) for data collection/quality control of citizen-science studies and volunteer engagement. 0 - not relevant to program; 1 - hope to get there as program develops; 2 - sometimes met; 3 - fully reached.

"Sea Guard" program	Underwater cleanups	Aspects	Criteria
3	3	Preparation of easy and straightforward protocols	Ensure data quality
3	2	Training of volunteers	
3	2	In situ supervision by professional participation	
2	1	Validation of data and samples	
3	2	Research questions presented in way that is easy for volunteers to understand	Ensure volunteer engagement
2	1	Encourage volunteers to describe any uncertainties to researchers	
3	1	Plan for ample time for recruitment and training of volunteers	
3	3	Explore the use of novel technological tools, such as smartphone applications and geo-referenced photos	
3	0	Professional scientist demonstrates the tasks that volunteers will be performing in the field beforehand	
2	1	Volunteers are involved in data evaluation and communication of results as a concluding activity	

and ceramic, Paper, and Rubber/sponge) to compare the ratio of plastic in the BMD to that found in the ICC benthic data.

In Neve Yam, Sdot Yam and Alexander River sites, where we conducted multiple surveys over time, we calculated percent change between surveys (Eq. (1)).

$$[(\text{total debris at time 2} - \text{total debris at time 1})/(\text{total debris at time 1})] \times 100 \tag{1}$$

This equation measures the effect of both net marine debris gain and net marine debris loss between the surveys. We determined which items made up the majority of debris' elements lost or gained, specifically items that had counts of 10 or more. We used within-year surveys of the same transects to investigate seasonal variation in BMD net loss and net accumulation rates. To calculate net loss and net accumulation rates, we used the differences between item counts on the first and second surveys. If no items of a specific category were seen on the first survey but were present on the second survey, an accumulation event was assumed to have taken place. If fewer items of a given debris category were seen on the second survey compared to the first one, a loss was assumed to have taken place. We calculated elements lost or gained/day to standardize among the surveys. We made seasonal calculations for Neve Yam and Alexander River sites. Calculation of summary statistics and statistical tests were done using the R statistics package version 3.4.3. Significance level was assessed at a P of 0.05.

2.4.2. Marine debris citizen science programs' evaluation

We evaluated our MD CS programs (UWC and "Sea Guard" volunteers) using the criteria of Cigliano et al. (2015) for successful citizen science programs, and the criteria of Hidalgo-Ruz and Thiel (2015) for ensuring data quality and engagement of volunteers. To determine if we met the criteria, we used the following ranking: 0 - not relevant to program; 1 - hope to get there as program develops; 2 - sometimes met; 3 - fully reached. We then compared rankings within the programs to identify where we were most successful and then across the two volunteer programs to assess where we were most successful in designing the programs.

3. Results

3.1. Benthic marine debris density

3.1.1. Baseline surveys

Density and composition of BMD along the Israeli coast varied spatially (Fig. 3). Overall BMD density on the coastal surveys was 11.4 items per 400 m^2 (SD = 17.4 items per 400 m^2, n = 19 sites), while BMD density in open water was 4.7 items per 400 m^2 (SD = 5.3 items per 400 m^2, n = 18 sites). According to the CCI, the Israeli benthic area was very clean (CCI = 0.4 with the exception of two sites that were found clean). There was more BMD in the coastal water than in open water ($Z = 3.07$, $P < 0.01$, n = 15 sites) but BMD densities did not differ between sandy and rocky sites ($Z = -0.97$, $P = 0.34$). The

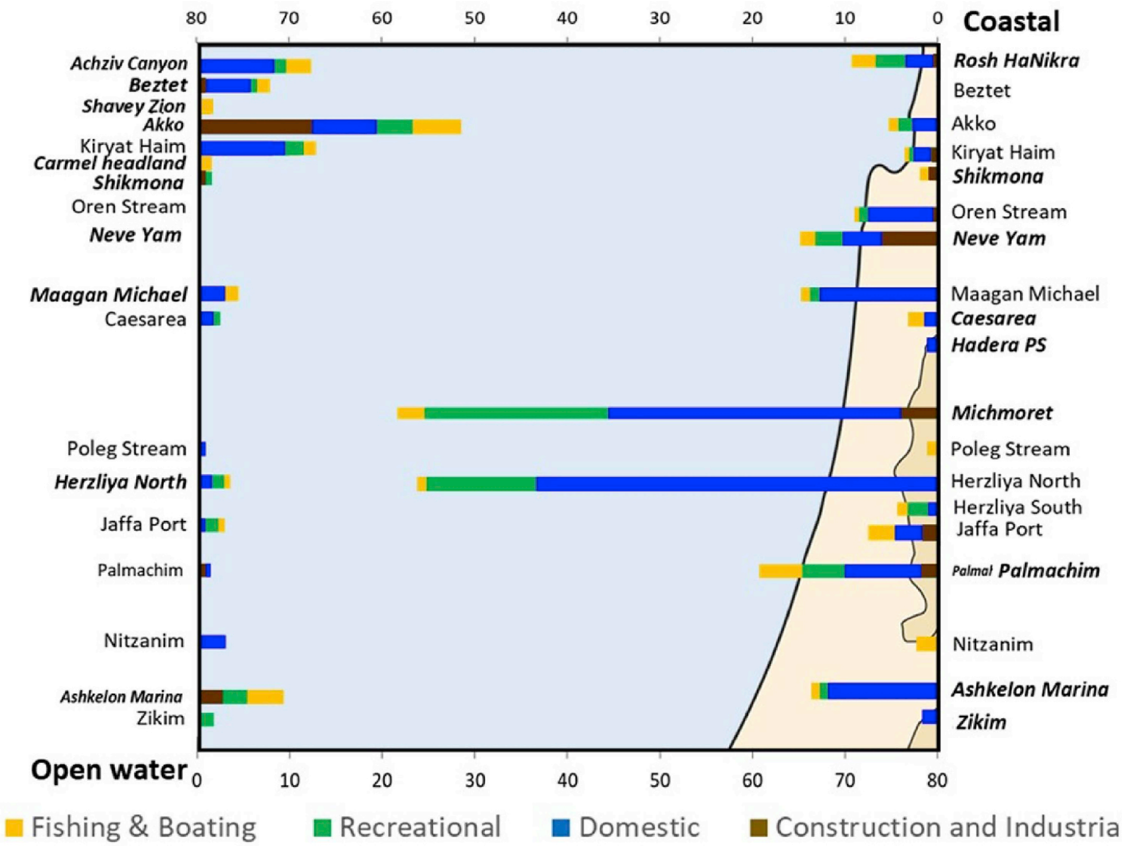

Fig. 3. Site-level baseline benthic marine debris by category in the coastal area (right) and open water (left) off Israel. The names in bold italic are sites that had a rocky bottom. Top ruler: Number of items per 400 m^2 found in the coastal surveys, Bottom ruler: Number of items per 400 m^2 found in the open sea surveys.

highest BMD densities on the coast were found on the central Israeli sites of Michmoret and Herzliya North with a density of 59 items per 400 m^2. Both of these sites were considered clean (CCI = 2.7), while the other sites were very clean (CCI < 1). The BMD at both sites was primarily domestic and recreational items (Fig. 3). The Herzliya North site is a sandy area partly enclosed by detached breakwaters and adjacent to a very popular beach. The site at Michmoret has a rocky bottom with sandy patches. In the open water surveys, the highest density of BMD (21.6 items per 400 m^2, CCI = 1.08 – very clean) was found in northern Haifa Bay (i.e. Akko Bay) and was mostly construction material (Fig. 3).

3.1.2. "Sea Guard" surveys

In the 16 surveys done by volunteers in seven sites that were chosen for having the potential as MD traps, 1254 debris items were found in a total area of 24,000 m^2 (20.9 items per 400 m^2, CCI = 0.9 - very clean). In these SGS, Michmoret was found once again with the highest BMD densities (average of 41.8 items per 400 m^2, CCI = 1.9 - very clean), followed by Achziv (30 items per 400 m^2), (Fig. 4). Neve Yam, which was a site surveyed both in the baseline surveys and by the volunteers, presented 4.7 items per 400 m^2 (Fig. 4), which was similar to that found on the BLS (3.75 items per 400 m^2) (Fig. 3). At all sites, all four debris categories were present.

3.2. Benthic marine debris composition

3.2.1. "Sea Guard" surveys compared to underwater cleanups

Submerged BMD data in Israel from both SGS and UWC (Fig. 5) were classified mainly as the Recreational and Fishing and Boating. UWC picked up more recreational items (average = 40.3% of items, SD = 10.7%, n = 11 sites) compared to the SGS (average = 25.8%, SD = 9.7%, n = 7 sites) (Z = 2.22, P = 0.027). On the other hand, Fishing and Boating composition was similar (SGS average = 30.1%, SD = 20.1%; UWC average: 25.2%, SD = 9.3%). Items from Domestic and Construction and Industrial categories were the lowest for both SGS and UWC (Domestic: SGS average = 21.3%, SD = 12.9%; UWC average: 19.5%, SD = 9.4%; Construction and Industrial: SGS average = 22.8%, SD = 13.4%; UWC average = 15.0%, SD = 16.3%) with Construction and Industrial slightly lower in the cleanups (Z = −1.67, P = 0.10).

3.2.2. BMD composition on the different sites

Fishing equipment was the most abundant category in Achziv (62%), Rosh HaNikra (53%), Palmachim (average of 46%) and Sdot Yam (average of 33%) (Fig. 6). All these sites are popular recreational fishing sites. In Apollonia and Jaffa (Givat Aliya), both sites were previously used as a dumping site for construction materials, and this is reflected in the benthic MD composition being 50% and 44% construction related items, respectively, (Fig. 6). All the bathing beaches (Nahariya, Habonim Nahsholim, Michmoret, Alexander River, Herzliya, and Tel Aviv), as well as Michmoret Marina, had a higher composition of Domestic items (Fig. 6), specifically due to the presence of plastic bags, and Domestic and Recreational items comprised more than 50% of the benthic MD.

3.2.3. Comparison between the composition of BMD and ICC

In comparison of the BMD composition in Israel (from both SGS and UWC) to that collected worldwide during the ICCs in the same period (Fig. 7), there were relatively more Fishing and Boating items and fewer Drinking bottles and cans in Israel than found on the seafloor around the world. Monofilament fishing lines and ropes were the most common Fishing and Boating items for both the ICC and Israel benthic surveys.

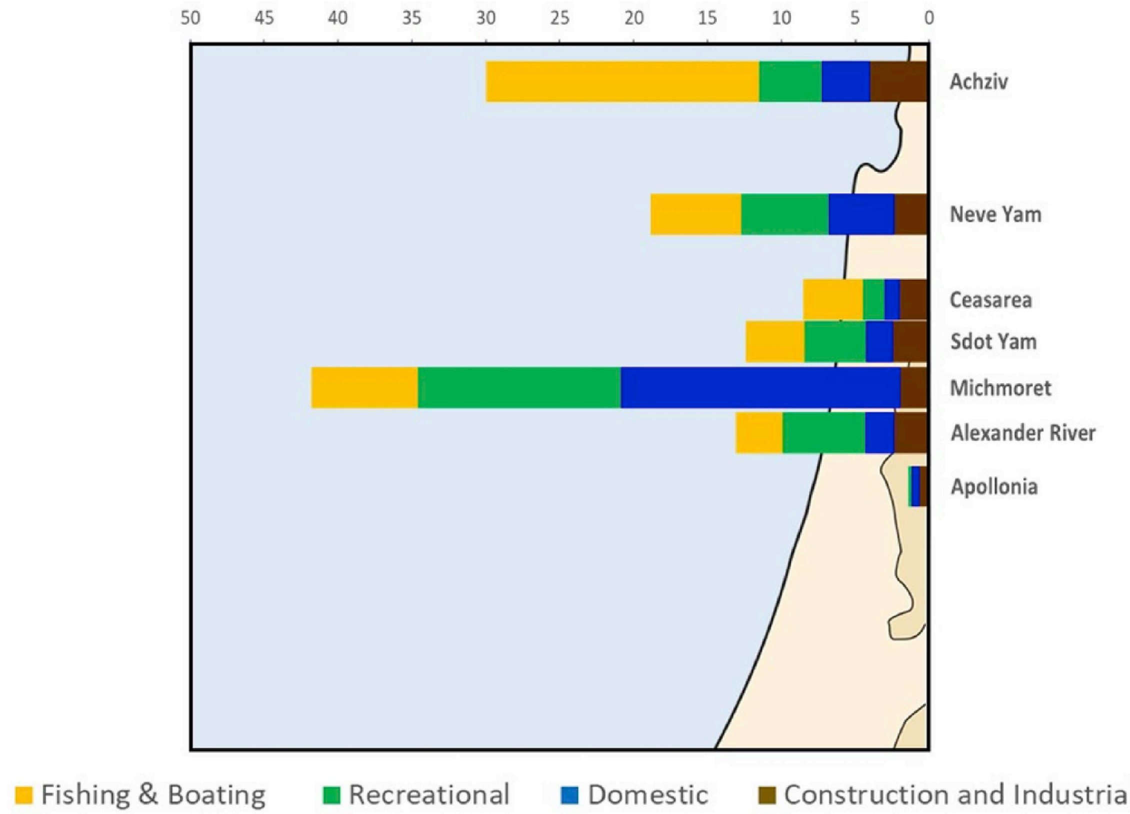

Fig. 4. Site-level submerged benthic marine debris items by category from SGS collected by trained volunteers ("Sea Guard") in northern Israel. Top ruler: Number of items per 400 m^2 found in the surveys.

Cigarette butts were negligible on the Israeli coastal sea bottom while they were present (6%) in the benthic data of the ICC (Fig. 7).

Plastic was the most common material found on the bottom of the coastal waters of Israel, making up 69.7% of all items found, while plastic items found on the ICC benthic surveys made up only 57.4%. Typical plastic items found on the seabed were bottles filled with sand and/or water and items made of durable plastic which is heavier, or items that got covered by fouling, lost buoyancy and sank to the seabed, where they got caught in the rocks.

3.3. Accumulation rates

On an annual basis, BMD increased at both Neve Yam and Sdot Yam sites (Table 1). At Neve Yam, 50.6% of the items contributing to the increase between years were fishing hooks (1 lure at survey 1; 58 fishing hooks at survey 2) and plastic bags (5 bags at survey 1; 26 bags at survey 2). In general, Sdot Yam did not have as much debris as Neve Yam (Table 1) and no specific items made up the majority of items gained between the years (i.e., did not have counts of 10 or more). On a

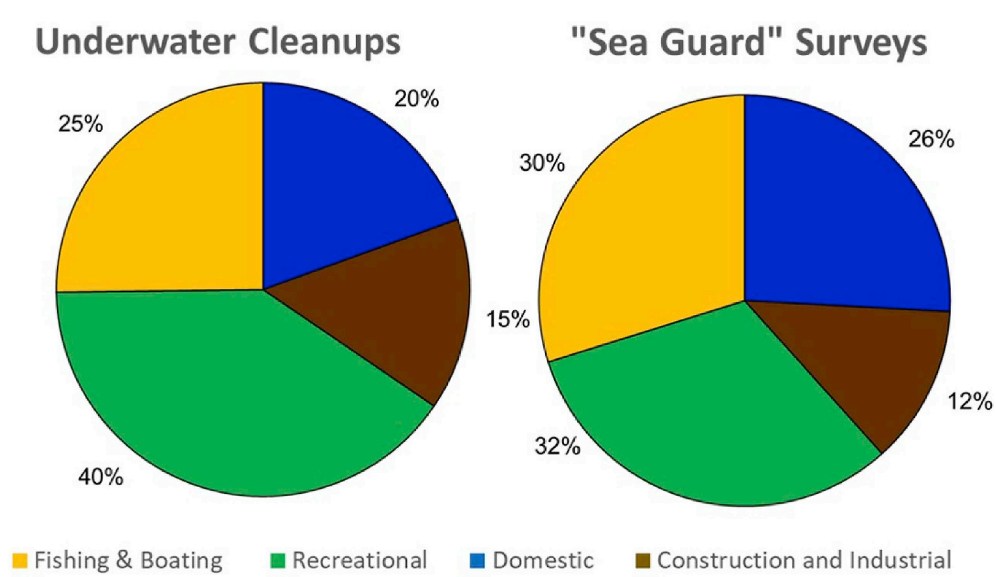

Fig. 5. Percentage of the total items found in each category in the "Sea Guard" surveys and the cleanups.

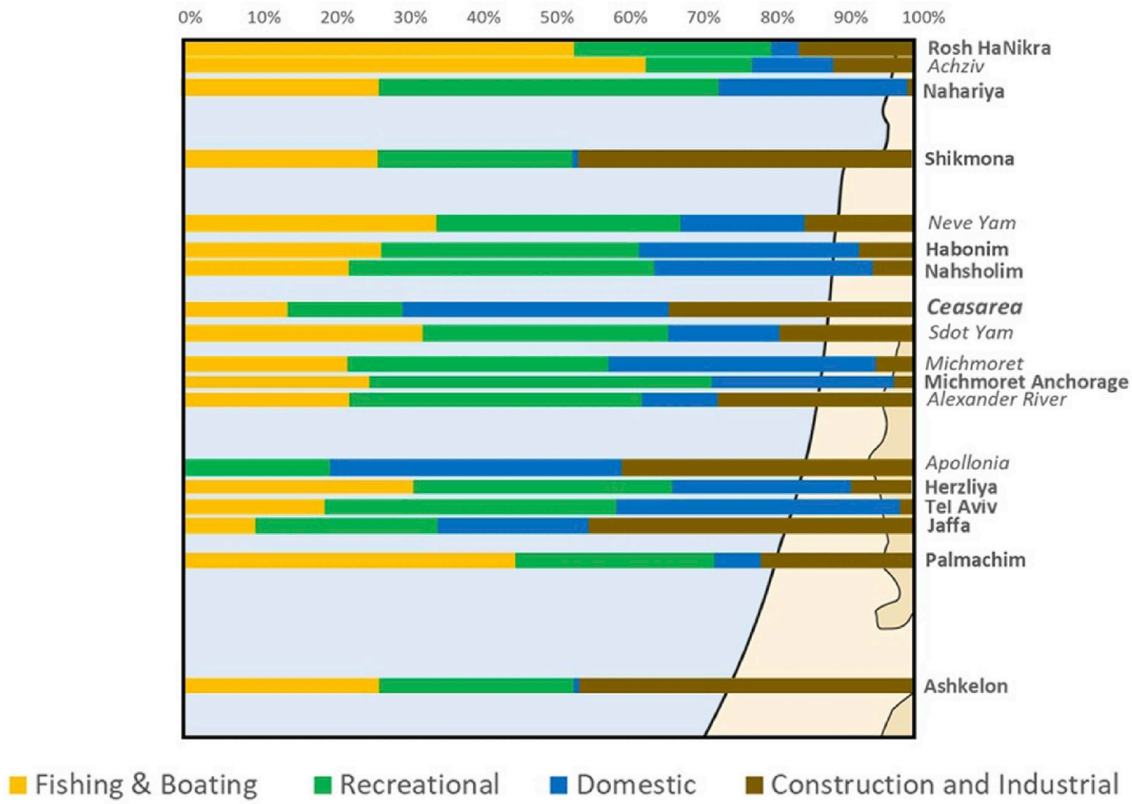

Fig. 6. Percentage of the items in categories in the SGS (in bold letters) and the UWC (in *italic*) according to the sites (Caesarea is in bigger fonts since both survey and cleanup took place).

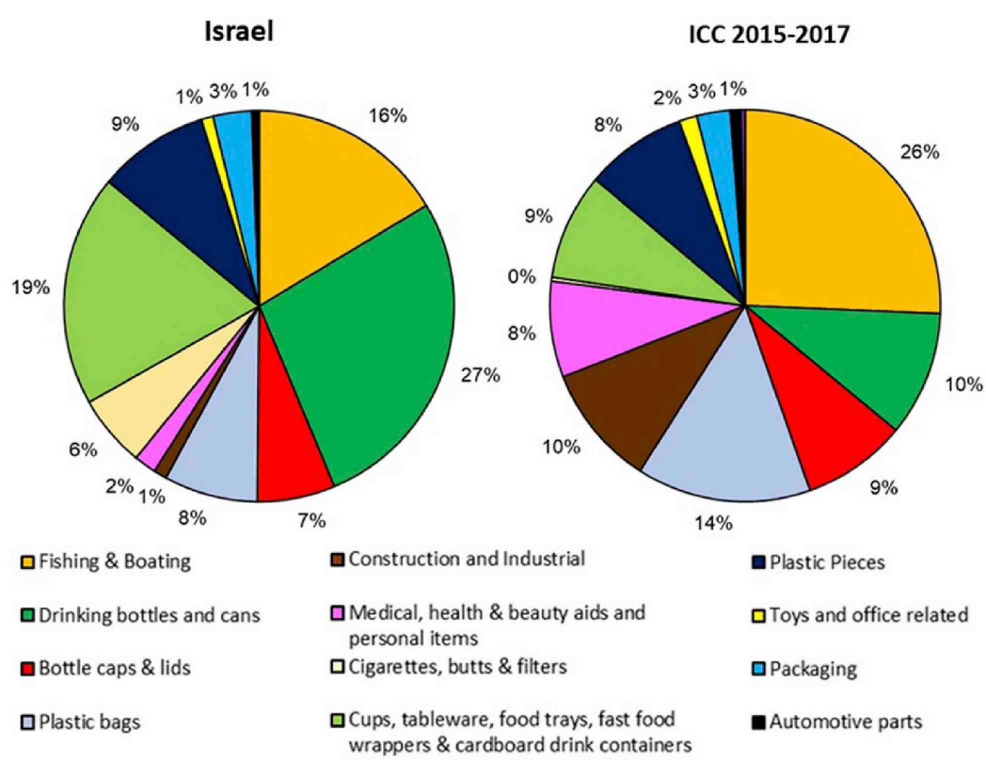

Fig. 7. Comparison among MD found on the Israeli sea floor and benthic items collected worldwide and reported to Ocean Conservancy (the items were reported as part of the total data in ICC 2016–2018 reports and sent separately to the first author).

seasonal basis, at both Neve Yam and Alexander River, net loss was higher than net accumulation during the spring, resulting in a decline in the BMD over that period (Table 1). Net loss was higher at Neve Yam compared to Alexander River (Table 1). This pattern was reversed in the other seasons, with net accumulation being higher than the net loss, resulting in an increase of BMD over the year (Table 1). Net accumulation was higher at Neve Yam compared to Alexander River over the summer/autumn (Table 1).

3.4. The success of marine debris citizen science programs in Israel

Overall, the “Sea Guard” program met most of the criteria for a successful citizen scientist program and was more likely to contribute to MD research and coastal management than the UWC (Tables 2–3). Neither of the Israeli volunteer programs was designed to focus on any particular species and, thus, the low scores in species management for both programs were not surprising (Table 2).

Our results in the “Adopt a Beach” pilot were part of the Israeli IMAP report (Pasternak and Mayzel, 2018), and the Nature and Park Authority published the results of the cleanups during “Man and Sea week”, in their magazine (Mayzel, 2018).

We used the results from surveys done at Habonim nature reserve, to point out the most abundant items (fishing related items and drinking bottles) at their site and offered possible ways of restricting the use of drinking bottles and fishing items at the reserve. The results of UWC conducted in Herzliya on November 2017, which indicated that most of the BMD were single-use items, were used by one of the city council members, and Herzliya announced they are becoming the first ‘plastic free city’ in Israel (Curiel, 2018). Additionally, the results of the underwater surveys are frequently used by the NGOs Ecoocean and The Society for the Protection of Nature in Israel to support education, awareness raising activities and advocacy for marine litter pollution reduction and management.

4. Discussion

For the first time, we have described the patterns of BMD density and composition in the nearshore environment of the southeastern part of the Mediterranean Sea. According to the CCI, the Israeli benthos was very clean. Other underwater visual surveys (using scuba/snorkeling) have shown that the nearshore areas in the northeastern Mediterranean Sea and the Adriatic and Ionic seas are also very clean (average BMD density 14.9/1000 m^2, CCI = 0.27, in Greece according to Katsanevakis and Katsarou, 2004; 2.78 items/100 m^2, CCI = 0.5 in the Adriatic and Ionic seas according to Vlachogianni et al., 2016). In comparison to the Mediterranean, Fernandino et al. (2015) reported that in Brazil, the nearshore area is moderate clean (CCI = 7.2). The difference between Brazil and the other countries may result from the fact that in Brazil the studied beaches were located in shallow semi-closed areas resulting in low mobility of benthic litter (Fernandino et al., 2015), while the Mediterranean sites were located in more open areas resulting in higher benthic litter mobility (Katsanevakis and Katsarou, 2004; Vlachogianni et al., 2016). The fact the Israeli Mediterranean coast is straight without any significant bays (except of the Bay of Haifa which sometime act as a “MD trap”) may also account for its relative cleanliness.

According to our BLS results, most of the BMD was found from the coast out to about 3 m depth (max about 100 m from shoreline). Therefore, we assume that sunken MD that reached the 10 m depth, considered the deeper part of the breaker zone, may be subjected to offshore currents generated by local winds, and drift out of the Israeli nearshore environment.

Our SGS and UWC focused mainly on the north-central part of the Israeli Mediterranean coast, because the southern part is mostly sandy bottomed, which means that there are less MD traps, as well as less days of good visibility due to sand movement. MD trawl surveys are conducted by the IOLR team in the Ashdod area twice a year starting in 2015 (Zurel, 2018).

BMD composition along the Israeli nearshore environment appeared to be influenced by the adjacent coastal use and is local in origin: Fishing equipment was the most abundant in sites near popular recreational fishing beaches, construction materials were found in former dumping sites, and domestic and recreational items were found near bathing beaches.

Plastic was the predominant material making up the BMD in the Israeli coastal waters, with higher percentages than the global average, but similar to other sites in the eastern Mediterranean, especially Turkey. Benthic plastic was found in much lower percentages than on the beaches, probably due to the neutral or even high buoyancy of plastic in seawater. Plastic items found on the seabed are usually bottles filled with sand or/and water, items made of heavier durable plastic, and items that are covered by fouling. Lead fishing weights, which are rarely found on beaches but are a commonly found as BMD, tend to get trapped on rocky bottoms and cannot be recovered by the fishermen.

Assuming linear loss and gain rates of MD, it appears that MD does not accumulate in Neve Yam and Alexander River sites, most probably due to strong wave-induced longshore currents (Kit and Sladkevich, 2001; Zviely et al., 2007) and river flumes (Galgani et al., 1995, 1996, 2000). Another possibility is that some of the items were removed by divers for reuse – especially fishing lines and hooks that were found in some of the early observations but were missing in the later surveys. Net loss during spring and accumulation during summer/autumn may be the result of currents or higher anthropogenic pressure during the summer and autumn.

There was a difference between the MD composition from using SGS and UWC. This may be due to the different dive sites and/or the methods. The results from the SGS are more accurate as they represent the amount of MD per a fixed area, while the area in UWC was not measured. Also, the quality of the data collected in the SGS is much better, since these operations were supervised by professionals. Yet, it is still possible to compare the results in the different dive sites and the results from our beach surveys when we refer to the percentages of the items found by categories and material. Percentage of recreational items were much higher in the UWC than on the SGS, probably because the cleanups were done adjacent to bathing beaches. Some of the differences in the construction and industrial items (slightly lower in the cleanups) may be because construction items like bricks and some metallic pieces may not be removed during cleanups (due to their heavy weight or because divers believed that they could be left in the marine environment as part of the rocky habitat).

Overall, the “Sea Guard” is a successful CS program, meeting the majority of the criteria for data collection and volunteer engagement, as it was designed to provide scientifically-sound data using CS, so data quality and volunteer engagement were important considerations. The “Sea Guard”' program is now based on more independent work of the volunteers, in organizing and conducting of BMD surveys and cleanups (according to a yearly schedule).

However, one topic not considered in evaluating CS programs is a stable source of funding. In 2018, the foundation which had funded the “Sea Guard” program shifted its budget to an umbrella organization for all of the NGOs, called “The Mediterranean People”, and the “Sea Guard” program is now funded only by TIDF. The funding for the “Adopt a Beach” surveys conducted for the Israeli NAP also stopped after only one year of surveys. This has resulted in a lower budget to run the “Sea Guard” program and recruit new volunteers which may cause the program to fade, as described also by Schläppy et al. (2017).

The UWC program sometimes or fully reached the data quality goals; however, aspects of volunteer engagement were achieved more successfully the “Sea Guard” program. While the UWC, which are designed for cleaning the underwater environment and raising public awareness, do not yield as high a quality of data as the “Sea Guard” program, UWC require a much lower budget and reach a greater number of people. Regardless of how the benthic data are collected, our findings are sent to local beach managers and are used for the development of programs to improve coastal waste management, as well as public awareness promotors. Because the local authorities' contractors only clean the beach, our UWC are the only way the underwater environment is being cleaned.

Overall, our results have been used by managers to educate the public that use their specific sites to reduce MD loads on their properties. In addition, the results from our study have been used by local government to address waste management in general for their community. But there are other ways our study results can help improve waste management and reduce MD. For example, our results indicate that items used for fishing contribute to BMD. Most of the sport fishermen in Israel use fishing rods to fish from sensitive natural coastal hard substrates such as abrasion platforms (e.g., Milazzo et al., 2015; Brennan and Portman, 2017). The physical pressure and the MD that the fishermen leave on these sensitive areas, such as vermatid reefs, may cause irreversible damage to this unique habitat. Managers and policy makers may want to consider ways to reduce this impact (e.g., replacing natural rocky substrate with artificial ones) and funding MD reduction activities through mechanisms such as licensing fees or fees on specific fishing items. Reducing MD loads in the coastal environment depends on understanding the extent of the issue through studies such as ours and then using the results to identify management or policy actions that could be used to address the issue.

5. Conclusions

The present study describes the density and composition patterns of submerged MD along the Mediterranean coast of the Israeli nearshore based on systematic surveys and data collected by volunteers. The nearshore environment is mostly very clean and the BMD along the Israeli coast is mostly plastic, originating from local beach recreation. However, cleaning the Israeli coast regularly may lower the MD delivered to seabed, and with the exception of a few sites, the marine debris seems to leave the littoral zone and either submerges to the continental shelf and the abyss or enters the Mediterranean circulation.

The Israeli volunteer programs yielded data as well as public awareness. In the "Sea Guard" program we created a way for dedicated people to independently organize and conduct BMD surveys and cleanups. In the absence of a guaranteed annual budget, it will be hard to continue these activities, and especially to recruit new volunteers.

Our data on BMD provide another layer of information about coastal waste and point out the main items that could be the focus of waste management. Our results clearly show that the nearshore is affected by its adjacent coast, but unlike the beaches in Israel that are regularly cleaned, there are no regular underwater cleaning programs managed by any authority. Thus, divers who clean the seabed provide a public service.

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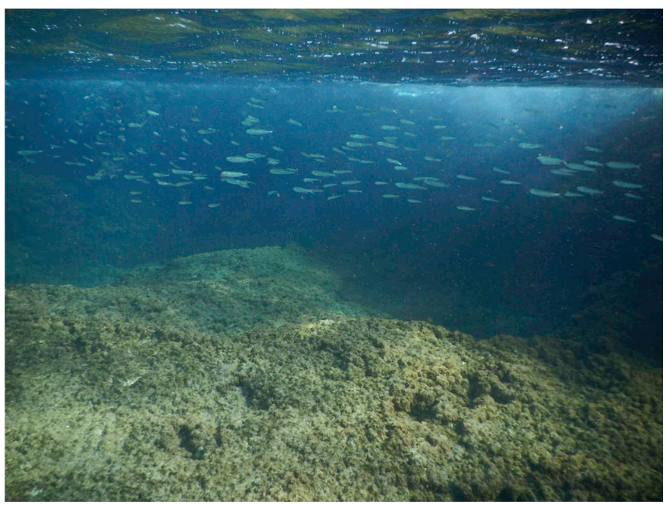
Appendix A. MD Surveys and cleanup related photos

A.1. Beaches that are not cleaned immediately by the local authorities, especially during the holidays, can look like a dumpsite (Nitzanim, 7.8.2016, from South to North).

A.2. "Sea Guard" volunteers on a UWC in Palmachim (taken on 2.4.2018), carrying signs of (from left to right): the Protection of Nature in Israel (SPNI), Sea Guard and The Israeli Diving Federation (TIDF).



A.3. Neve Yam rocky seabed (3.10.2016, 100 m West to the coast).

A.4. Michmoret rocky seabed (3.10.2015, 100 m west to the coast. Taken by: Reem Neri, "Sea Guard").

Appendix B. MD Surveys and cleanups when and where

Table B.1
UWC dates, locations and events' framework

Frame work	South Divers	Sea Guard	Sea Guard	Octopus	Reef	School of Marine Sciences	Caesarea Old Port	North Wind	North Wind	Sea Guard	Putzker	Sea Guard	Dive Center/Group
	Ashkelon	Palmachim	Jaffa	Tel Aviv	Herzliya	Michmoret	Caesarea	Nahsholim	Habonim	Shikmona	Nahariya	Rosh HaNikra	Location (N ←)
	NR	NR + BB	DS + BB	BB	BB	SM	RF	BB	BB	NR	BB	NR + RF	Type
Man and Sea Week[a]						10.6.2015	5.6.2015						Date
Man and Sea Week							12.6.2015						
Course							18.12.2015						
Course				14.5.2016									
Man and Sea Week[a]						5.6.2016	12.6.2016	4.6.2016			3.6.2016		
ICC			16.9.2016										
Course							4.11.2016						
Private												20.2.2017	
Course							5.5.2017						
Man and Sea Week[a]		9.6.2017		23.6.2017	10.6.2017	4.6.2017	2.6.2017	9.6.2017	16.6.2017		9.6.2017		
Local Community									23.6.2017				
Local Community									13.10.2017				
Abyss Treasure[b]								20.10.2017					
IDC Student Council					24.11.2017								
Sea Guard		2.4.2018											
Man and Sea Week[a]	8.6.2018	16.6.2018			8.6.2018	13.6.2018	1.6.2018			8.6.2018	1.6.2018		
–	1	3	1	2	3	4	8	3	3	1	3	1	Total (33)

NR- Nature Reserve; RF - Recreational Fishing; BB - Bathing Beach; DS - Dumping Site; SM - Small Marina.

[a] The Nature and Parks Authority, in cooperation with the Ministry of Environmental Protection and Aquaculture, started in 2013 the Man and Sea week (Shvua Adam VaYam) which includes information and cleaning activities along the Israeli coast. In 2015, we started to conduct UWC during this week.

[b] Abyss treasure, a prize-winning competition, that connects the divers to the sea and the ancient marine heritage of Israel, by searching for underwater treasure hidden on the sea floor between the ruins of ancient ports. An additional prize was given to divers who collected the greatest amount of BMD (by weight).

Table B.2
SGS dates, locations and events' framework

Frame work	Sea Guard	School of Marine Sciences	Sea Guard	Sea Guard	Sea Guard	Sea Guard	Sea Guard	Dive Center/Group
	Apollonia	Alexander River	Michmoret Beach	Sdot Yam	Neve Yam	Caesarea	Achziv Beach	Location (N ←)
	NR	BB	BB + RF	BB + RF	RF	RF	RF	Type
Sea Guard				15.7.2016	24.3.2016			Date
Sea Guard			8.12.2016					
Sea Guard	11.2.2017						3.2.2017	
NAP		6.3.2017			24.3.2017			
Sea Guard						5.5.2017		
NAP		10.7.2017			28.6.2017			
Sea Guard				15.7.2017				
NAP		17.11.2017			24.10.2017			
NAP			9.2.2018		12.1.2018			
NAP		2.5.2018						
–	1	4	2	2	5	1	1	Total (16)

Note: The marine debris underwater observations were done as part of the National Action Plan (NAP) for land-based pollution reduction, reported to UNEP. NR- Nature Reserve; RF - Recreational Fishing; BB - Bathing Beach; DS - Dumping Site; SM - Small Marina.

Table B.3
NAP surveys

Dates	Azimuth	Starting point (long/Lat)	Transect length	Transect #	Location
24.03.2017 28.06.2017 23.10.2017 12.01.2018	295°	32°40′59.67″N, 34°55′39.07″E	100	1	Neve Yam
	180°	32°41′01.17″N, 34°55′35.26″E	100	2	
	270°	32°40′49.38″N, 34°55′35.25″E	100	3	
	185°	32°40′49.38″N, 34°55′34.26″E	100	4	
	180°	32°40′43.93″N, 34°55′38.45″E	100	5	
	295°	32°40′41.53″N, 34°55′37.58″E	100	6	
06.03.2017 10.07.2017 17.11.2017 02.05.2018	010°	32°23′44.62″N, 34°51′46.81″E	100	1	Alexander River
	190°	32°23′44.62″N, 34°51′46.81″E	100	2	
09.02.2018	180°	32°24′45.45″N, 34°52′08.33″E	200	1	Michmoret
	180°	32°24′43.39″N, 34°52′07.11″E	200	2	
	180°	32°24′40.29″N, 34°52′06.69″E	200	3	

Appendix C. Description of the NAP survey sites

Neve Yam beach: Located some 20 km south of city of Haifa, under the jurisdiction of Hof HaCarmel Regional Council. The surveyed area is on the underwater reefs west of the abrasion platforms made of cemented aeolian sandstone which forms a rocky substrate locally known as “Kurkar” that surround two headlands. One of the headlands is still intact while the other has been partly deteriorated by a water park and an abandoned event garden (Fig. 1). The shallow reefs of Neve Yam attract a large number of fish and rod-fishermen using the headland tend to leave their trash on the headland (Fig. 1).

Alexander River: Located in central Israel, about 5 km north of the city of Netanya. The river length is about 45 km and it flows from the western Samarian Hills to the Mediterranean Sea. The drainage basin area of Alexander River is 553 km^2 (including several small ephemeral streams), its mean annual flow is 10.4 m^3, with maximum peak discharge of 260 m^3/s (Lichter et al., 2010). These characteristics makes Alexander River a major source of inland originated MD. The Beit Yannay National Park beach, located south of the river outflow, provides a bathing beach and camping sites to visitors (Fig. 1). This 1 km long beach is well maintained and is cleaned regularly. The northern beach of Alexander River stretches 500 m to the coastal cliff of Michmoret, boarding school and the Marine College of the Ruppin Academic Center. This beach is not heavily used for bathing, but mainly by kite-surfers and beach walkers, and is less thoroughly cleaned. The dives in this site were conducted on the submerged reefs in front of Alexander River, which stretch 300 m offshore and parallel to the coastline.

Michmoret: During the planned winter survey, it was not possible to dive in the vicinity of Alexander River, due to heavy rains resulting in currents and very poor visibility at the river mouth, therefore, the dive on 9.2.2018 was conducted in Michmoret (Kushi Quite Beach), some 1.2 km north of the river outlet. This beach is unauthorized (no lifeguard services or other beach facilities) and under the jurisdiction of Emek Hefer Regional Council. A restaurant and a diving center are located on backshore. The beach is sandy, and its sea bottom is rocky with sand patches.

Appendix D. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ocecoaman.2019.03.016.

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