Mediterranean Marine Science

Vol 20, No 2 (2019)

Visual observations of floating macro litter around Italy (Mediterranean Sea)

CLAUDIA CAMPANALE, GIUSEPPE SUARIA, GIUSEPPE BAGNUOLO, MATTEO BAINI, MATTEO GALLI, ERICA de RYSKY, MATILDE BALLINI, STEFANO ALIANI, MARIA CRISTINA FOSSI, VITO FELICE URICCHIO

doi: 10.12681/mms.19054

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.19054

Visual observations of floating macro litter around Italy (Mediterranean Sea)

Claudia CAMPANALE[1], Giuseppe SUARIA[2,3], Giuseppe BAGNUOLO[1], Matteo BAINI[4], Matteo GALLI[4], Erica DE RYSKY[4], Matilde BALLINI[4], Stefano ALIANI[2], Maria Cristina FOSSI[4] and Vito Felice URICCHIO[1]

[1] IRSA-CNR, National Research Council, Water Research Institute, Bari, Italy
[2] ISMAR-CNR, National Research Council, Institute of Marine Sciences, Pozzuolo di Lerici, Italy
[3] IEO-COB, Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Palma de Mallorca, Spain
[4] University of Siena, Department of Physical, Earth and Environmental Sciences, Italy

Corresponding author: claudia.campanale@ba.irsa.cnr.it

Handling Editor: Stelios KATSANEVAKIS

Received: 16 November 2018; Accepted: 24 March 2019; Published on line: 21 May 2019

Abstract

We report the results of a visual survey of floating natural (NML) and anthropogenic (AML) macro-litter (>2.5 cm) performed in the central part of the Mediterranean Sea during a dual-use campaign onboard the Italian Navy tall ship "Amerigo Vespucci" which circumnavigated the Italian peninsula during May-June 2016. The distribution, abundance and composition of floating marine litter was assessed using a 10 m fixed-width strip transect method. Over 88 h of transect counts were performed, for a total of 168 transects, covering an overall survey length of 1026.35 km. 4756 anthropogenic litter items were counted during the transects, 96.9 % of which were classified as plastic items. Floating litter was found throughout the entire study area with densities ranging from 0 to 9205 items/km^2 and with a mean abundance of 492 AML items/km^2 and 77 NML items/km^2 across all surveyed locations. Maximum AML densities (>3500 items/km^2) were recorded in the Adriatic Sea, while the lowest densities (<50 items/km^2) were found along the coastline of Sardinia and in the Strait of Messina. Our results document the ubiquitous presence of floating plastic litter around the Italian peninsula and underline the need to expand our knowledge about the main sources, transport, accumulation and fate of marine litter in the entire Mediterranean region.

Keywords: Plastic pollution; Floating litter; Marine litter; Mediterranean Sea; Marine pollution; Visual survey.

Introduction

The accumulation of anthropogenic litter in marine ecosystems is a growing environmental concern, the complexity and implications of which are not yet thoroughly understood. While significant actions in waste management and disposal have recently been taken (e.g. The Waste Framework Directive and the recent EU Plastics Strategy), the situation regarding plastic pollution is still concerning.

The Marine Strategy Framework Directive (MSFD, 2008/56/ EC) sets the framework for Member States to achieve Good Environmental Status (GES) for their marine waters by 2020 considering 11 descriptors. Descriptor 10 focuses on marine litter, stating that GES is achieved only when "properties and quantities of marine litter do not cause harm to the coastal and marine environment" (2010/477/EU). Recently, MSFD Commission Decision (EU) 2017/848 of 17 May 2017 laid down the criteria and methodological standards to achieve good environmental status of marine waters. This new text categorizes criteria for assessment of good environmental status into primary and secondary ones. Four criteria are associated to descriptor 10, two of them are primary: D10C1/C2 *"The composition, amount and spatial distribution of litter/micro-litter on the coastline, in the surface layer of the water column, and on the seabed, are at levels that do not cause harm to the coastal and marine environment"*, and two secondary: D10C3 *"The amount of litter and micro-litter ingested by marine animals is at a level that does not adversely affect the health of the species concerned", D10C4 "The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects" are below threshold values to be defined by member states through regional or sub-regional cooperation*. Therefore, the MSFD, together with the Barcelona Convention and its Protocols, the MLRP (Marine Litter Regional Plan), and where appropriate the recent European Plastic-Strategy (aimed at reducing or forbidding the consumption of selected single-use plastic items), are the main legal tools currently available in the

Mediterranean region for the protection of the marine environment from plastic pollution.

Marine litter is currently listed as one of the eight contaminants of the UNEP/GPA (United Nations Environment Program / Global Programme of Action) for the protection of the marine environment from land-based sources and activities and it is now considered as one of the most pervasive pollution issues, affecting all major water bodies on the planet-above and below the surface (Moore, 2008; Galgani *et al*., 2015). Besides being aesthetically detrimental, marine litter is a problem for a number of reasons and can negatively impact humans, wildlife, habitats and coastal communities (Katsanevakis, 2008; Deudero & Alomar, 2015; Newman *et al*., 2015; Rochman *et al*., 2016). Harm can happen through ingestion or entanglement by marine mammals, sea birds, turtles, fishes and other animals, with at least 690 species reported to have encountered or ingested marine litter (Laist, 1997; Derraik, 2002; Gall & Thompson, 2015). In addition, large amounts of secondary micro litter can be generated when larger macro litter undergoes mechanical, photo (oxidative) and/or biological degradation (Thompson *et al*. 2004; Barnes *et al*., 2009; Cooper & Corcoran, 2010; Andrady, 2011).

Being surrounded by a large number of industrialized countries and traversed by numerous busy shipping lanes, the Mediterranean Sea is particularly vulnerable to this form of pollution (Suaria & Aliani, 2014). Indeed, it has the highest amounts of municipal waste annually generated per person (208-760 kg/year http://www.atlas.d-waste.com) and it is now widely recognized as one of the most affected areas in the world by plastic pollution (Galgani *et al*., 2014, Deudero & Alomar, 2015; Cozar *et al*., 2015; van Sebille *et al*., 2015; Suaria *et al*., 2016). Moreover, being characterized by a net inflow of surface waters of Atlantic origin through the Strait of Gibraltar, with limited outflow possibility for items less dense than seawater (Zambianchi *et al*., 2014), the Mediterranean acts as a concentration basin collecting, retaining and accumulating floating material within its borders (Lebreton *et al*., 2012).

Despite increasing concerns about the socio-economic and environmental impacts of marine litter on the environment, (e.g. Thompson *et al*., 2009a; Gregory, 2009; Teuten *et al*., 2009) and although the Mediterranean basin is generally recognized as a particularly sensitive ecosystem (Galgani *et al*., 2010), many gaps still exist regarding temporal and spatial trends in floating litter amounts and distribution in the Mediterranean Sea as well as on its main sinks and sources.

Within this context, we present here the outcome of a shipboard sighting survey of floating natural (NML) and anthropogenic (AML) macro-litter (>2.5 cm) performed during the Spring of 2016 in the Central Mediterranean Sea, with the main objective of providing new information based on real in-situ data about the abundance and distribution of floating litter around the Italian Peninsula. Besides highlighting regional differences in the amount and composition of litter items, our large-scale dataset, provides additional information on the main drivers of litter distribution in the Central Mediterranean Sea, identifying the possible sources of litter dispersion in relation to several factors such as river discharge, coastal population density, oceanographic features, shipping and tourist activities as well as differences due to the use of different methodological approaches. As evidenced by Zambianchi *et al*. (2017), the availability of detailed data sets is fundamental to estimate the probability of litter particles reaching different subareas of the Mediterranean basin, singling out the existence of litter hot-spots and retention areas. Therefore, besides providing an updated baseline towards which, future changes in litter occurrence can be assessed, our data provide new resources for future modeling studies of litter movements and dynamics in the entire Mediterranean basin (e.g. Mansui *et al*., 2015; Liubartseva *et al*., 2018; Shchekinova & Kumkar, 2018).

Methods

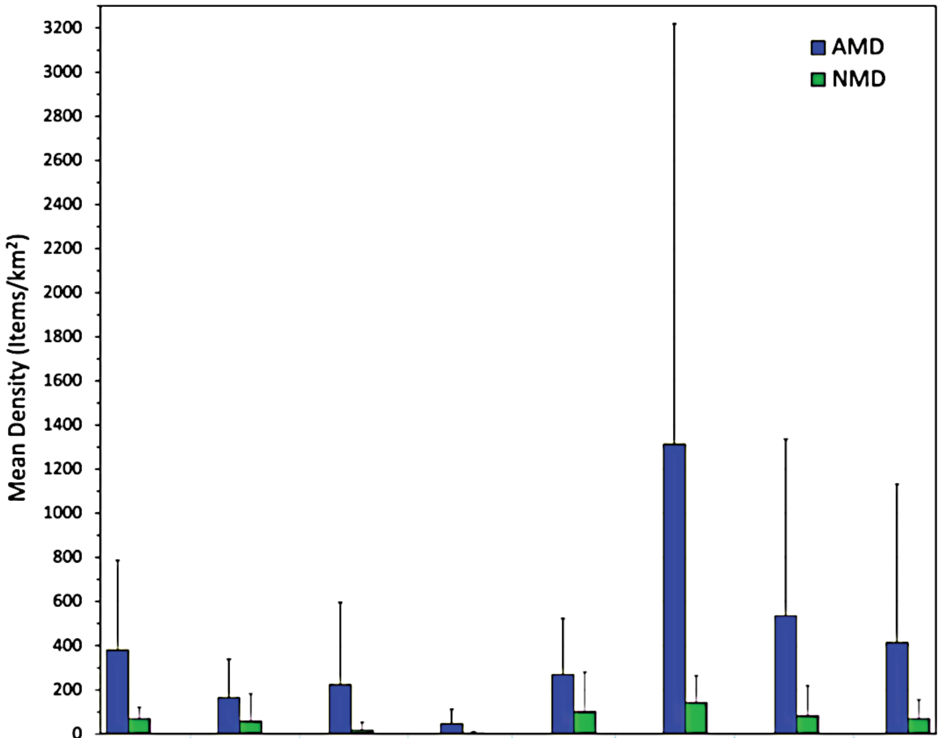
Visual observations

Data were collected between 27 April and 13 June 2016 during a dual-use campaign onboard the Italian Navy tall ship "Amerigo Vespucci" which circumnavigated the Italian peninsula according to the cooperation agreement between the Italian Navy and the Italian National Research Council (CNR) for developing research projects related to the marine environment. The monitoring of floating litter was connected to other activities of the Italian Navy exploiting the opportunity to use the ship in order to drastically reduce field operational costs (close to zero).

All the observations were performed with the naked eye from the bow area of the vessel (at 9 m above sea level). The observer recorded the GPS position of each object sighted within a strip of known width (see Section Litter density evaluation), and an operator dedicated to the transcription of results, annotated sea state and weather conditions, UTC time, ship speed, geographical coordinates, size and type of all macro-litter items (>2.5 cm). As suggested by the EU MSFD Technical Subgroup on Marine Litter (Galgani *et al*., 2013), every item was assigned to one of six size classes (A. 2.5-5 cm, B. 5-10 cm, C.10-20 cm, D. 20-30 cm, E. 30-50 cm, F. >50 cm) and to one of two major type categories: Anthropogenic Marine Litter (AML) and Natural Marine Litter (NML), following Suaria & Aliani (2014). AML was further classified into synthetic polymer materials (bags, bottles, crates and containers/baskets, cover/packaging, mussel nets/oyster nets, synthetic rope, fishing net, fish boxes-plastic, fish boxes-polystyrene, buoys, plastic sheets/industrial packaging, plastic pieces, polystyrene pieces, other plastic/polystyrene pieces), rubber (balloons and balloon sticks, balls, rubber boots, other rubber), cloth/textile (clothing, rope strings and nets, sails and canvas, other textiles), paper (cardboard, paper packaging, newspapers and magazines, other paper), processed wood (pallets, crates, wood boards, other) and metal (cans, fishing related, wire, wire mesh, barbed wire, other metal). Likewise, NML was classified as wood (mainly logs, trunks, branches), algae (*Cystoseira* spp., *Sargassum* spp., other), terrestrial vegetation (canes and bamboo, leaves, flowers) and others (e.g. cuttlefish bones, pumice, feathers, etc.).

The observations were all performed throughout daylight hours, during regular navigation of the ship at a mean speed of 7.28 knots. The survey effort was split into 30-min transects (mean length: 6.14 ± 2.63 km), changing operators after each transect in order to prevent fatigue for the observers. The exact distance covered during the transects was calculated from GPS start and stop positions using Q-GIS Software and the concentration of floating items was then related to the known transect width (Section "Litter density evaluation"). Meteorological data such as wind speed and direction were retrieved from the ship's navigational instruments, and only data taken in good visibility conditions (i.e. wind speed <21 kts and wave height <2 m) were retained and analyzed.

The study area was divided into 8 main sectors, following the biogeographical subdivision of the Italian seas



	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8
	Ligurian Sea	Coast of Sardinia and Corsica/North Tyrrenian Sea	South Tyrrenian Sea	Strait of Messina	Ionian Sea	South Adriatic Sea	Central Adriatic Sea	North Adriatic Sea
Number of transects for each sector	11	42	20	4	15	31	32	12
				Composition				
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
ARTIFICIAL POLYMER MATERIALS	269 (62.8)	434 (92.3)	186 (92.1)	24 (17.6)	210 (45.2)	2248 (94.3)	1040 (92.4)	198 (75.0)
METAL	0 (0.0)	2 (0.4)	2 (1.0)	0 (0.0)	0 (0.0)	4 (0.2)	2 (0.2)	0 (0.0)
PROCESSED WOOD	2 (0.5)	4 (0.8)	4 (2.0)	1 (0.7)	2 (0.4)	3 (0.1)	6 (0.4)	1 (0.4)
PAPER	2 (0.5)	9 (1.9)	5 (2.5)	2 (1.5)	3 (0.6)	7 (0.3)	14 (1.1)	6 (2.3)
TEXTILE	1(0.2)	3 (0.6)	3 (1.5)	0 (0.0)	10 (2.1)	14 (0.6)	14 (1.1)	5 (1.9)
RUBBER	2 (0.5)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.4)	2 (0.1)	4 (0.4)	0 (0.0)
NATURAL WOOD	64 (14,9)	0 (0.0)	1 (0.5)	47 (34.6)	153 (33.0)	92 (3.9)	31 (2.6)	25 (9.5)
ALGAE	17 (4.0)	14 (3.0)	0 (0.0)	42 (30.9)	47 (10.1)	4 (0.2)	5 (0.3)	6 (2.3)
CANES, BAMBOO	5 (1.2)	1 (0.2)	0 (0.0)	4 (2.8)	21 (4.5)	5 (0.2)	1 (0.1)	17 (6.4)
TERRESTRIAL VEGETATION	18 (4.2)	0 (0.0)	0 (0.0)	15 (11.0)	8 (1.6)	1 (0.1)	4 (0.4)	6 (2.3)
OTHER NATURAL DEBRIS	48 (11.2)	3 (0.6)	1 (0.0)	1 (0.7)	9 (1.8)	4 (0.2)	5 (0.3)	0 (0.0)

Fig. 1: Mean densities of anthropogenic (AML) and natural (NML) macro-litter (expressed as numbers of items per km^2± SD) in all surveyed sectors of the study area. The number of transects surveyed for each sector and the relative proportions of all AML and NML type categories expressed as percentage (%) and number of observed items (n) are also shown in the table.

proposed by Bianchi *et al*., (2004):

1. the Ligurian Sea, belonging to the north-western area of the Mediterranean;
2. the coastline of Sardinia (and Corsica) and the northern Tyrrhenian sea, belonging to the northern central-western area of the Mediterranean;
3. the whole coastline of Campania, the Tyrrhenian coastline of Basilicata, Calabria and Sicily, as well as most of the southern Sicilian coastline, belonging to the southern central-western area of the Mediterranean;
4. the Strait of Messina (a "micro-sector");
5. the eastern coast of Sicily (except for the Strait of Messina), the Ionian coastline of Calabria and Basilicata and the southern part of the Salento peninsula up to Otranto (in Apulia region), belonging to the central-eastern area of the Mediterranean;
6. the coastline of Murgia (south of the Gulf of Manfredonia) and Salento, north of Otranto, belonging to the southern Adriatic section;
7. the coastline from the Gulf of Manfredonia up to the Conero promontory, belonging to the mid- Adriatic sector;
8. the coastline from Conero to Istria, forming the northern Adriatic sector.

The number of surveyed transects per sector varied from 4 to 42 (Fig. 1), mainly due to different weather conditions, size of each sector, navigational schedules and operational needs during the cruises. The location of all transects and surveyed sectors is illustrated in Figure 2.

Fig. 2: Map of the study area subdivided into sectors showing the locations of all transects and the distribution of: **A)** anthropogenic macro-litter (AML) and **B)** natural macro-litter (NML) densities (circles) expressed as number of items/km^2 in all surveyed transects (n=168). Circle size reflects debris density according to the legends shown in the top right corner of each panel.

Litter density evaluation

As recommended in the monitoring guidelines developed by the EU MSFD Technical Subgroup on Marine Litter (Galgani *et al*., 2013), the distribution, abundance and composition of floating litter were assessed using a 10 m fixed-width strip transect method.The strip-transect technique involves counting the number of items detected within a fixed-width strip and the results are expressed as a simple index of abundance (Bibby *et al*., 2000; Spurr *et al*., 2012). It is important to keep in mind that the number of items identified is only indicative of the real density values, since this method is based on some simplifying assumptions. A fundamental assumption, for instance, is that the detection probability within the transect width is 100%. Moreover, the observations are restricted to predetermined boundaries, outside of which the observed objects are not recorded. This predetermined boundary should be representative of the visibility conditions encountered during the survey, and it will be mainly related to the speed of the ship and the height of the observer above sea level. Therefore, based on the characteristics of our observational set-up, a relatively narrow strip of 10 m was adopted following the recommendation of Galgani *et al.,* 2013, so that the main assumptions of strip-transect method could be met. Raw counts of AML and NML were then converted into density values by dividing the total number of sighted items by the effective area surveyed in each transect, using the following equation:

$$D_i = n_i/(L_i \times W)$$

Where n_i is the number of items seen on transect i, L_i the length of transect i and W (10 m) the fixed width of the strip transect (Andersen *et al*., 1985; Kullbicki & Sarramègna 1999). The densities of anthropogenic and natural litter were computed in all transects, expressed as numbers of items per km^2 and plotted on a density map using Q-GIS Software (Fig. 2).

Statistical analysis

Non-normal distribution of data was evaluated by the Shapiro–Wilk test for AML and NML densities in all transects. Spearman's non-parametric correlation coefficient was used to test significant relationships between the abundance of floating anthropogenic and natural macro-litter and environmental variables in all transects as well as between the density of floating natural (NML) and anthropogenic (AML) macro-litter throughout the whole survey area and for each sector separately. The environmental variables considered were wind speed (measured in knots), wind direction (measured in degree) and height of waves (measured in meters). Each environmental variable, acquired for each transect, was correlated to the density of floating natural (NML) and anthropogenic (AML) macro-litter using the Spearman rank correlation test. Spearman coefficients were calculated between each pair of the above cited variables for each different sector and for the whole basin. Spearman's coefficients were computed from the ranks of the data values rather than from the values themselves. The Kruskal-Wallis test was used to determine statistically significant differences between the medians of AML and NML within the sectors of the study area. The software used was STATGRAPHICS Centurion 18.

Results

Litter distribution and concentration

Over 88 h of transect counts were performed, for a total of 168 transects, covering an overall survey length of 1026.35 km. AML was found in 97% of all transects, with concentrations ranging from 0 to 9205 items/km^2 and a mean abundance of 492 AML items/km^2 across the whole study area (Fig. 2/A). The highest AML concentrations were recorded in single transects performed in the Northern Ionian Sea (9205 items/km^2), in the Northern Adriatic Sea (4514 items/km^2) and in two transects performed in the Southern Adriatic (4119 and 4382 items/km^2). Conversely, no AML was sighted only in a few transects performed along the coastline of Sardinia (Sector 2) and in the Strait of Messina (Sector 4). NML on the other hand, was present in 63% of the transects, with densities consistently lower than AML, ranging between 0 and 692 items/km^2 and with a mean total density of 78 NML items/km^2 across all surveyed locations (Fig.2/B). Maximum concentrations of NML were observed in transects performed in the Central Adriatic Sea, in the Northern Ionian Sea and along the coastline of Sardinia and Corsica, where values equal to 679, 693 and 612 items/km^2 were registered, respectively. No NML was sighted only in a few transects performed along the Sicilian coast, in the Strait of Messina and in the northern Tyrrhenian Sea.

When computing the mean densities of anthropogenic and natural marine litter in all sectors separately, the southern Adriatic Sea (Sector 6) proved to be the most polluted region with a mean AML concentration of 1313 items/km^2, followed by the central (Sector 7) and northern Adriatic (Sector 8) which had mean AML concentrations of 535 and 414 items/km^2, respectively (Fig. 1). The lowest AML concentrations (165 and 47 items/km^2) were found along the coastlines of Corsica and Sardinia (Sector 2) as well as in the Strait of Messina (Sector 4). The highest NML concentrations (> 100 items/km^2) on the other hand were observed in the Southern Adriatic (Sector 6) and in the Ionian Sea (Sector 5), while the lowest mean concentrations (16 and 4.8 items/km^2) were found in the waters around Sicily (Sectors 3 and 4). The Kruskal-Wallis test confirmed the statistically significant differences in the abundance of AML (Test statistic = 20.23, *P-Value* = 0.0004) and NML (Test statistic = 23.74, *P-Value* = 0.0001) between all surveyed sectors, highlighting a remarkable spatial heterogeneity in the distribution of floating material within the study area.

Composition

A total of 5493 floating items were counted during the survey, 4756 of which were AML (87%) and 737 NML (13%). Synthetic polymers (generally known as "plastic") were the most abundant and ubiquitous type of AML registered (Fig.1), representing by far the greatest proportion of all anthropogenic objects (96.9%, 4609 objects), followed by paper/cardboard (1.0%, 50 objects) and textiles (1.0%, 48 objects).

While some intact objects were seen (e.g. bags, bot-

Fig. 3: Number of litter items observed for each individual category of Synthetic Polymer Material identified in all transects of the surveyed area during the Spring of 2016.

tles, containers, etc.), irregularly shaped fragments were the dominant type of litter observed, representing 74.5% of all plastic items (n = 3432). Packaging related items (plastic sheets, cover/packaging, foam packaging/insulation/polyurethane) represented 6.3% of the total plastic items (292 items), followed by plastic bags (6.3%, n = 289 items), plastic bottles (1.8%, n = 83 items) and fishing gear (3.0%, n = 102 items), mainly consisting of mussel nets, synthetic ropes, fishing nets, buoys, and fish boxes (Fig. 3).

The overall size-class distribution of floating litter (AML + NML) revealed a marked prevalence of smaller objects ranging between 2.5 and 10 cm (68% of the total, 3733 objects). 17% (930 objects) of all objects were between 10 and 20 cm; 7% (379 objects) were in the 20-30 cm size range, just over 4% (222 objects) were comprised between 30 and 50 cm and only 4% of the objects (227 items) were bigger than 50 cm.

On average, the highest percentage of plastic materials was recorded in the Adriatic Sea (Sectors 6 and 7; Fig.2/A), where it made up more than 90% of all observed litter showing maximum densities of 1295 and 499 items/km^2 respectively. High plastic concentrations were also registered in the Ligurian Sea and in the North Adriatic Sea (Sectors 1 and 8; Fig.2/A) with mean abundances of 365 and 397 plastic items/km^2 respectively. Conversely, the lowest mean concentration of plastic items (43 items/km^2) was found in the Strait of Messina (Sector 4).

Natural Marine Litter mainly consisted of pieces of wood of various sizes (branches, log and trunks) accounting together for 56.0% of all NML, followed by Algae (18.3%) mainly *Cystoseira* spp.; other natural litter such as cuttlefish bones and pumice (11.3%); canes and bamboo (7.33%) and other terrestrial vegetation such as leaves and flowers (7.1%). Wood occurred in particularly high abundances in the Adriatic Sea, peaking respectively at a maximum of 90 and 70 pieces of wood per km^2 in sectors 6 and 7.

Over the large scale, no significant correlation was found between the abundance of floating litter and environmental variables (wind speed, wind direction and wave height). On the other hand, an overall positive correlation was found between the total abundance of AML and NML throughout the area surveyed (Spearman's R = 0.4649; $p < 0.0001$; n = 168), indicating that on a large scale, natural and anthropogenic litter tend to accumulate in the same regions, respond to the same physical processes or share the same sources (Fig. 4). Nevertheless, when sectors were individually examined at higher spatial resolutions, a significant correlation between AML and NML was only found for sector 2 (Spearman's R = 0.334; p = 0.0326) and sector 6 (Spearman's R = 0.558; p = 0.0024).

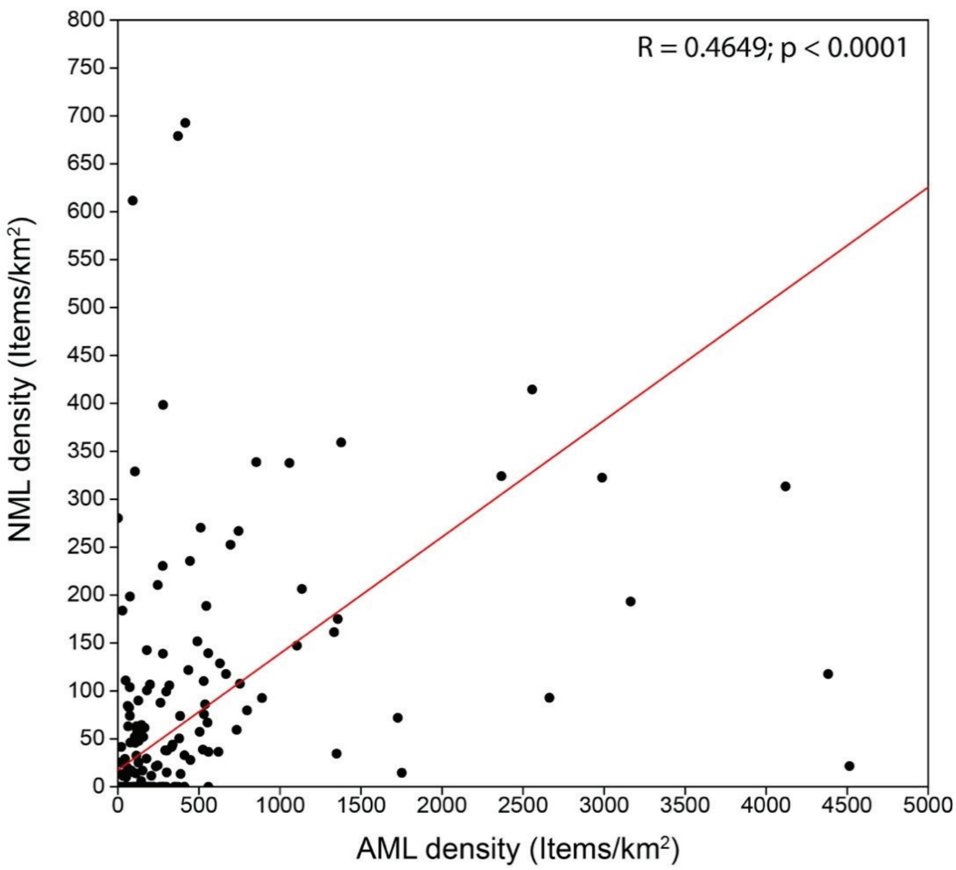


Fig. 4: Correlation between the densities (expressed in items/km^2) of floating anthropogenic (AML) and natural (NML) macro litter (> 2.5 cm) measured in all transects of the surveyed area during the Spring of 2016 (n = 168 transects). Red line shows RMA best linear fit, while Spearman's rank correlation R and *p* values are shown in the top right corner.

Discussion

AML densities found in our study (mean value 492 items/km^2; max: 9205 items/km^2) are in accordance with the abundance of floating objects observed in the Strait of Malacca (Ryan, 2013b), in Indonesian waters (Uneputty & Evans, 1997) and in the Northwest Pacific (Titmus & Hyrenbach, 2011), where very high AML concentrations, often exceeding 4000-6000 items/km^2 were found, as well as with some noticeably high values recently reported from the Adriatic Sea (Zeri *et al.*, 2018) and from the Eastern Mediterranean basin (Constantino *et al.*, 2019). Conversely – with the only notable exception of an early study by Morris (1980) – lower AML concentrations are usually reported in Mediterranean waters, with mean values ranging from 2-5 items/km^2 (e.g. McCoy, 1988; Topçu *et al.*, 2010; Arcangeli *et al.*, 2018; Campana *et al.*, 2018) to 15-175 items/km^2 (e.g. Aliani *et al.*, 2003; Suaria & Aliani, 2014; Carlson *et al.*, 2017; Di-Méglio & Campana, 2017; Ourmieres *et al.*, 2018; Palatinus *et al.,* 2019). Such discrepancies could be attributed to actual inter-annual or seasonal changes in litter input and abundance in the basin, or to other contingent factors including varying meteorological conditions, distance from land (Ryan, 2015; Pedrotti *et al.*, 2016), observation height, position and speed of the ship, which can all greatly affect the estimation of litter concentrations at sea (Dahlberg & Day, 1985; Ribic *et al.*, 1992; Titmus & Hyrenbach, 2011; Goldstein *et al.*, 2013; Ryan, 2013b; Campana *et al*. 2018). Most likely though, in our case a key role was played by substantial differences in the sampling protocols and platforms adopted by different studies (i.e. distance sampling vs strip transects; sailing boats vs larger research vessels).

As a matter of fact, a wide variety of approaches have been used in recent years to monitor and quantify the abundance of floating litter, although a careful and systematic evaluation of their performance has never been performed. When conducting surveys from ferries for instance, the speed of the ship and the height of the observer above sea level are much greater than on research vessels or sailing boats (e.g. Arcangeli *et al.*, 2018 and Campana *et al.*, 2018). As a consequence, only items bigger than 20-25 cm can be effectively recorded while most smaller fragments are generally overlooked, thus explaining the observed differences in litter concentrations (85% of all objects sighted during our survey were <20 cm). In addition, the experience of the observer, as well as the counting protocol adopted can also noticeably influence the estimation of litter density. Therefore, the lack of standardized counting techniques is currently hampering meaningful comparisons between surveys and the adoption of a harmonized approach represents an urgent requirement (Aliani *et al.*, 2003; Ryan, 2013b).

Another factor that could have influenced our results is the location of our transects and their distance from the coast. As a matter of fact, during our circumnavigation of the Italian peninsula, the route taken by the ship was mostly coastal (Fig. 2), as opposed to the off-shore location of other studies reporting lower litter concentrations (e.g.Suaria &Aliani, 2014; Arcangeli *et al*., 2018). This would suggest a decreasing gradient in litter concentrations moving from coastal to off-shore waters, which is consistent with the assumption that most litter derives from land-based sources, as already demonstrated by Ryan (2015) off the coast of South Africa, but somewhat in contrast to what was recently found for floating microplastics in Mediterranean waters (Pedrotti *et al.,* 2016).

At the same time, the very high values registered during this campaign might provide an indication of an increasing trend in Mediterranean litter concentrations over recent years. In the Adriatic Sea for instance, AML densities went from an average of 27.6 items/km^2 observed between May and October 2013 (Suaria & Aliani, 2014), to average values of 112.8 items/km^2, 175.3 items/km^2 and 251 items/km^2 observed between 2014 and 2015 (Carlson *et al.*, 2016; Palatinus *et al.*, 2019 and Zeri *et al.,* 2018 respectively), up to a mean value of 842.3 items/km^2 observed during this survey (Spring, 2016).Therefore, especially in light of a 13% increase in international tourist arrivals (UNWTO, 2018) combined with a steady 9% increase in European plastic demand (Plastics Europe, 2017), a current increase in the fluxes of marine litter into the Adriatic Sea cannot be ruled out, even though no clear increase in AML concentration was found in the Liguro-Provençal basin by Di-Méglio & Campana, (2017) over a 10 year survey of floating litter distribution performed between 2006 and 2015.

Once at sea, winds and surface currents are the primary driver of floating litter transport in the marine environment (Lebreton *et al*., 2012, Liang *et al*., 2018). The main large oceanic convergence zones (‘‘garbage patches’’) are characterized by high concentration areas of plastic fragments (Ryan, 2014; Lebreton *et al*., 2018), with the accumulation of floating materials directly related to the anticyclonic wind force and its associated Ekman transport (Eriksen *et al*., 2014, Cozar *et al*., 2014). At a finer scale, regional seas have also been under investigation, with the Mediterranean region systematically showing levels of plastic pollution comparable, if not higher, than those found in the main oceanic convergence zones (Cozar *et al*., 2015; Suaria *et al*., 2016). Existing numerical simulations however, seem to exclude the presence of permanent accumulation areas in the Mediterranean basin, suggesting instead the existence of seasonal short-term retention areas, combined with a substantial accumulation of plastics on the coastlines and on the sea bottom, with relatively short residence times of floating objects at sea in the order of 7-80 days (Liubartseva *et al*., 2016; 2018; Carlson *et al*., 2017; Politikos *et al*., 2017; Zambianchi *et al*., 2017). Within this context, the high concentrations of litter found in the Adriatic basin, would be the reflection of very high inputs into the basin, rather than accumulation and retention of floating material on the sea surface. It should be noted however, that most of these modeling exercises rely on simplified parameterization of litter behavior at sea and as of today, they are not capable of accurately resolving the fine-scale inter- and intra-seasonal pulsations in litter inputs into the basin, which are largely driven by temporal variations in anthropogenic factors such as tourism, beach usage, coastal population, river outflows, waste production and maritime traffic (Zambianchi *et al*., 2017). Within this context, the organization of regular monitoring campaigns would be highly beneficial to the validation and improvement of the prediction capabilities of existing models.

Regarding the distribution of floating material over the central Mediterranean, our findings seem to confirm the patterns previously reported by Suaria & Aliani in 2014, with maximum densities of anthropogenic litter found in the Southern Adriatic Sea and lower densities observed in the Central Tyrrhenian and Sicilian Seas. The Adriatic Sea has recently been highlighted as a hot-spot for floating (Arcangeli *et al*., 2018; Zeri *et al*., 2018; Palatinus *et al*., 2019), benthic (Pasquini *et al*., 2016; Fortibuoni *et al*., 2019; Strafella *et al*., 2019) and beach litter (Vlachogianni *et al*., 2018), and our findings provide further evidence about the severity of the problem for the entire Adriatic region. Indeed, the Po river in the Northern Adriatic, was already identified as one of the largest contributors of plastic pollution to the entire Mediterranean, being responsible for an annual influx of 1350 tons of plastic year^{-1} (Liubartseva *et al*., 2018), with this also explaining the higher concentration of natural litter observed in this region (presumably of riverine origin), as well as the correlation between the two in the entire Adriatic basin. Similarly, high concentrations of both AML and NML were found in the northern Ionian Sea, perhaps suggesting the co-existence in this area of shared sources or favorable hydrographic conditions to the local retention of floating material. On the other hand, the low concentrations of AML and NML observed along the coastlines of Corsica and Sardinia, as well as in the Strait of Messina could be related to the highly dissipative characters of these regions or alternatively, to the relative absence of large pollution sources in these areas.

On the whole, very high levels of plastic pollution were found in our study area, with plastic items accounting for 97% of all anthropogenic materials observed. This figure is consistent with information reported from other parts of the world (e.g. Derraik, 2002; Thiel *et al*., 2003; Gregory, 2009; Hinojosa & Thiel, 2009; Titmus & Hyrenbach, 2011; Ryan, 2013a.), as well as from the Mediterranean Sea (Galgani *et al*., 2010; Suaria & Aliani, 2014; Pasquini *et al*., 2016; Vlachogianni *et al*., 2018; Zeri *et al*., 2018; Constantino *et al*., 2019; Palatinus *et al*., 2019), consistently reporting the prevalence of plastic (accounting for more than 70%, sometimes up to 90-100%) in floating, benthic and beach litter. Most of the plastic items observed during our survey were categorized as irregular plastic fragments, suggesting a secondary origin of these items, probably derived from the fragmentation of larger objects. Progressive fragmentation of these items, likely to be favored by continuous beaching and resuspension along Mediterranean shores, will inevitably contribute to the pool of secondary microplastics (<5 mm), already copiously present in Mediterranean surface waters (Collignon *et al*., 2012; de Lucia *et al*., 2014, Cozar *et al*., 2015; Panti *et al*., 2015; Fossi *et al*., 2016; Ruiz-Orejón *et al*., 2016; Suaria *et al*., 2016; Baini *et al*., 2018; Ruiz-Orejón *et al*., 2018, Zeri *et al.,* 2018, Palatinus *et al.,* 2019).

In conclusion, our findings record substantial amounts of floating anthropogenic material around the Italian peninsula confirming once again the severity of the marine litter problem for the entire Mediterranean region. Very high quantities of small plastic fragments were observed and floating litter densities were generally higher than those previously reported from the Mediterranean Sea. The problem is aggravated by the basin's limited exchanges with other oceans, its densely populated coasts, highly developed tourism, heavy maritime traffic and various additional inputs of litter from rivers and urbanized areas (UNEP, 2015). Our results clearly underline the need for systematic monitoring campaigns in order to fill the knowledge gaps in our understanding of litter dynamics and behavior in the Mediterranean Sea as well as to monitor the effectiveness of recent and future regulatory actions. Research should now focus on expanding our knowledge about the main sources, transport, impacts and fate of marine litter in the marine environment as well as on defining standardized methodological approaches, a fundamental requirement for meaningful comparisons of different datasets. Furthermore, effective management strategies are urgently required to prevent and contain the release of litter into the marine environment in order to select key priorities to design a program of mitigation strategies and support the monitoring of their effectiveness over the entire Mediterranean region.

Acknowledgements

This work was financially supported by a cooperation agreement between the Italian Navy and the Italian National Research Council (CNR) for developing research projects related to the marine environment. The authors would like to thank the individuals involved in data collection: Dr. Roberto Mauro, Dr. Ida Rascio, Dr. Barbara Rotella and Dr. Marina Tumolo. Special thanks are extended to the officers and crew of the Italian Navy tall ship "Amerigo Vespucci".

References

Aliani, S., Griffa, A., Molcard, A., 2003. Floating debris in the Ligurian Sea, north-western Mediterranean. *Marine Polluion. Bulletin,* 46 (9), 1142-1149.

Andersen, D.E., Rongstad, O.J., Mytton, W.R., 1985. Line transect analysis of raptor abundance along roads, *Wildlife Society Bulletin,* 13, 533-539.

Andrady, A.L., 2011. Microplastic in the marine environment. *Marine Pollution Bulletin*, 62, 1596-1605.

Arcangeli, A., Campana, I., Angeletti, D., Atzori, F., Azzolin, M. *et al.,* 2018. Amount, composition, and spatial distribution of floating macro litter along fixed trans-border transects in the Mediterranean Basin. *Marine Pollution Bulletin*, 115 (1-2).

Baini, M., Fossi, M. C., Galli, M., Caliani, I., Campani, T.

et al., 2018. Abundance and characterization of microplastics in the coastal waters of Tuscany (Italy): The application of the MSFD monitoring protocol in the Mediterranean Sea. *Marine Pollution Bulletin*, 133, 543-552.

Barnes, D.K., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation andfragmentation of plastic debris in global environments. *PhilosophicalTransactions of the Royal SocietyB:Biological Sciences*, 364 (1526), 1985-1998.

Bianchi, C.N., 2004. Proposta di suddivisione dei mari italiani in settori biogeografici. *Notiziario SIBM*, 46: 57-59.

Bibby, C.J., Burgess, N.D., Hill, D.A., Mustoe, S.H., 2000. Bird census techniques. Academic Press 2nd edn. London, 302 pp.

Campana, I., Angeletti, D., Crosti, R., Di Miccoli, V., Arcangeli, A., 2018. Seasonal patterns of floating macro-litter across the Western Mediterranean Sea: a potential threat for cetacean species. *Rendiconti Lincei. Scienze Fisiche e Naturali*, 1-15.

Carlson, D. F., Suaria, G., Aliani, S., Fredj, E., Fortibuoni, T. *et al*. 2017. Combining Litter Observations with a Regional Ocean Model to Identify Sources and Sinks of Floating Debris in a Semi-enclosed Basin: The Adriatic Sea. *Frontiers in Marine Science*, *4*, 78.

Collignon, A., Hecq, J.H., Galgani, F., Voisin, P., Collard, F. *et al.,* 2012.Neustonicmicroplastic and zooplankton in the North Western MediterraneanSea. *Marine Pollution Bulletin* 64 (4), 861-864.

Constantino, E., Martins, I., Sierra, J.M.S., Bessa, F., 2019. Abundance and composition of floating marine macro litter on the eastern sector of the Mediterranean Sea. *Marine Pollution Bulletin*, 138, 260-265.

Cooper, D.A., Corcoran, P.L., 2010. Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii. *Marine Pollution Bulletin*, 60 (5), 650-654.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Ubeda, B. *et al.,* 2014. Plastic debris in the open ocean. *Proceedings of the National Academy of Sciences*, 111, 10239-10244.

Cózar, A., Sanz-Martin, M., Martì, E., Gonzalez-Gordillo, J.I., Ubeda, B. *et al.,* 2015. Plastic Accumulation in the Mediterranean Sea. *PloS ONE* 10 (4), e0121762.

Dahlberg, M., Day, R., 1985. Observations of man-made objects on the surface of the North Pacific Ocean.198-212. In: *Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii.*Shomura, R.S., Yoshida, H.O., Honolulu, Hawaii (July 1985).

De Lucia, G.A., Caliani, I., Marra, S., Camedda, A., Coppa, S. *et al.,* 2014. Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). *Marine Environmental Research,* 100, 10e16.

Derraik, J.G., 2002. The pollution of the marine environment by plastic debris: areview. *Marine Pollution Bulletin,* 44 (9), 842-852.

Deudero, S., Alomar, C., 2015. Mediterranean marine biodiversity under threat: Reviewing influence of marine litter on species. *Marine Pollution Bulletin,* 98, 58-68.

Di-Méglio, N., Campana, I. 2017. Floating macro-litter along the Mediterranean French coast: composition, density, distribution and overlap with cetacean range. *Marine Pollution Bulletin*, 118 (1-2), 155-166.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J.*et al.,*2014. Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. *PLOS ONE,* 9 (12), 1-15.

Fortibuoni, T., Ronchi, F., Mačić, V., Mandić, M., Mazziotti, C. *et al*. 2019. A harmonized and coordinated assessment of the abundance and composition of seafloor litter in the Adriatic-Ionian macroregion (Mediterranean Sea). *Marine Pollution Bulletin*, 139, 412-426.

Fossi, M.C., Marsili, L., Baini, M., Giannetti, M., Coppola, D. *et al.,* 2016. Fin whales and microplastics: The Mediterranean Sea and the Sea of Cortez scenarios. *Environmental Pollution,* 209, 68-78.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. *Marine Pollution Bulletin*, 92 (1-2), 170-179.

Galgani, F., Zampoukas, N., Fleet, D., Franeker, J.V., Katsanevakis, S. *et al*., 2010. Marine Strategy Framework Directive: Task Group 10 Report Marine Litter. Office for Official Publications of the European Community,JRC Scientific and Technical Reports, No31210, 57pp.

Galgani, F., Hanke, G., Werner, S., Oosterbaan, L., Nilsson, P. *et al.,* 2013. Guidance on Monitoring of Marine Litter in European Seas. MSFD Technical Subgroup on Marine Litter (TSG-ML) Publications Office of the European Union: Luxembourg. Report EUR, No 26113, 120pp.

Galgani, F., Claro, F., Depledge, M., Fossi, C., 2014. Monitoring the impact of litter in large vertebrates in the Mediterranean Sea within the European Marine Strategy Framework Directive (MSFD): constraints, specificities and recommendations. *Marine Environmental Research*, 100, 3-9.

Galgani, F., 2015. Marine Litter Within the European Marine Strategy Framework Directive. *Journal of Marine Science,* 70 (6), 1055-1064.

Galgani, F., Hanke, G., Maes, T., 2015. Global distribution, composition and abundance of marine litter p. 29-56. In: *Marine anthropogenic litter*.Bergmann, M., Gutow, L., Klages, M. (Eds). Springer, Cham. Heidelberg New York Dordrecht London.

Goldstein, M.C., Titmus, A.J., Ford, M., 2013. Scales of spatial heterogeneity of plasticmarine debris in the Northeast Pacific Ocean. *PloS ONE* 8 (11), e80020.

Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings– entanglement, ingestion, smothering, hangers-on, hitch-hiking and alieninvasions. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 364 (1526),2013-2025.

Hinojosa, I.A., Thiel, M., 2009. Floating marine debris in fjords, gulfs and channels ofsouthern Chile. *MarinePollution Bulletin,* 58 (3), 341-350.

Katsanevakis, S., 2008. Marine debris, a growing problem: Sources, distribution, composition, and impacts. p. 53-100. In: *Marine Pollution: New Research*. Hofer T.N. (Ed). Nova Science Publishers, New York .

Kullbicki, M., Sarramégna, S., 1999. Comparison of density estimates derived from strip transect and distance sampling for underwater visual censuses: a case study of Chaetodontidae and Pomacanthidae. Aquatic Living Resource, 12 (5), 315-325.

Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marinedebris including a comprehensive list of species with entanglement andingestion records. p. 99-139. In: *Marine Debris*. Coe J.M., Rogers D.B. (Eds) Springer, New York.

Lebreton, L.-M., Greer, S., Borrero, J., 2012. Numerical modelling of floating debris inthe world's oceans. *MarinePollution Bulletin,* 64 (3), 653-661.

Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J. *et al.,* 2018. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Scientific Reports* 8 (1), 4666.

Liang, J.H., Wan, X., Rose, K.A., Sullivan, P.P., McWilliams, J.C., 2018. Horizontal dispersion of buoyant materials in the ocean surface boundary layer. *Journal of Physical Oceanography*, 48, 2103-2125.

Liubartseva, S., Coppini, G., Lecci, R., Creti, S., 2016. Regional approach to modeling the transport of floating plastic debris in the Adriatic Sea. *Marine Pollution Bullettin,* 103, 115-127.

Liubartseva, S., Coppini, G., Lecci, R., Clementi, E., 2018. Tracking plastics in the Mediterranean: 2D Lagrangian model. *Marine Pollution Bulletin*, 129 (1), 151-162.

Mansui, J., Molcard, A., Ourmieres, Y. 2015. Modelling the transport and accumulation of floating marine debris in the Mediterranean basin. *Marine Pollution Bulletin*, 91(1), 249-257.

McCoy, F.W., 1988. Floating megalitter in the eastern Mediterranean. *Marine Pollution Bullettin*, 19 (1), 25-28.

Moore, C.J., 2008. Synthetic polymers in the marine environment: a rapidlyincreasing, long-term threat. *EnvironmentalResearch,* 108 (2), 131-139.

Morris, R.J., 1980. Floating plastic debris in the Mediterranean. *Marine Pollution Bulletin,* 11 (5), 125.

Newman, S., Watkins, E., Farmer, A., ten Brink, P., Schweitzer, J.P., 2015. The economics of marine litter. P. 367-394. In: *Marine anthropogenic litter*. Bergmann M., Gutow L., Klages M. (Eds), Springer, Cham.

Ourmieres, Y., Mansui, J., Molcard, A., Galgani, F., Poitou, I. 2018. The boundary current role on the transport and stranding of floating marine litter: The French Riviera case. *Continental Shelf Research*, 155, 11-20.

Palatinus, A., Viršek, M. K., Robič, U., Grego, M., Bajt, O. *et al.,* 2019. Marine litter in the Croatian part of the middle Adriatic Sea: Simultaneous assessment of floating and seabed macro and micro litter abundance and composition. *Marine Pollution Bulletin*, 139, 427-439.

Panti, C., Giannetti, M., Baini, M., Rubegni, F., Minutoli, R. *et al.,* 2015. Occurrence, relative abundance and spatial distribution of microplastics and zooplankton NW of Sardinia in the Pelagos Sanctuary Protected Area, Mediterranean Sea. *Environmental Chemistry*, 12 (5), 618-626.

Pasquini, G., Ronchi, F., Strafella, P., Scarcella, G., Fortibuoni, T., 2016. Seabed litter composition, distribution and sources in the Northern and Central Adriatic Sea (Mediterranean). *Waste management*, 58, 41-51.

Pedrotti, M.L., Petit, S., Elineau, A., Bruzauda, S., Crebassa, J.C. *et al.,* 2016. Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land. *PloS one,* 11, e0161581.

Plastics Europe. Plastics - the Facts, 2017. *An analysis of European plastics production, demand and waste data*. Association of Plastic Manufacturers, Brussels https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf (Access date: 2018-07-07), 44 pp.

Politikos, D.V., Ioakeimidis, C., Papatheodorou, G., Tsiaras, K., 2017. Modeling the Fate and Distribution of Floating Litter Particles in the Aegean Sea (E. Mediterranean). *Frontiers in Marine Science*, 4, 191.

Ribic, C.A., Dixon, T.R., Vining, I., 1992. *Marine debris survey manual*. NOAA Technical Report NMFS 108, 92pp.

Ryan, P.G., 2013a. Litter survey detects the South Atlantic garbage patch. *Marine Pollution Bulletin*, 79 (1-2), 220-224.

Ryan, P.G., 2013b. A simple technique for counting marine debris at sea revealssteep litter gradients between the Straits of Malacca and the Bay of Bengal. *Marine PollutionBulletin,* 69 (1), 128-136.

Ryan, P. G., 2014. Litter survey detects the South Atlantic 'garbage patch'. *Marine Pollution Bulletin*, 79 (1-2), 220-224.

Ryan, P.G., 2015. Does size and buoyancy affect the long-distance transport of floating debris? *Environmental Research Letters,* 10 (2015) 084019.

Rochman, C. M., Browne, M.A., Underwood, A.J., Franeker, J.A., Thompson, R.C. *et al.,* 2016. The ecological impacts of marine debris: unraveling the demonstrated evidence from what is perceived. *Ecology*, 97 (2), 302-312.

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2016. Floating plastic debris in the Central and Western Mediterranean Sea. *Marine Environmental Research*, 120, 136-144.

Ruiz-Orejón, L. F., Sardá, R., Ramis-Pujol, J., 2018. Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain). *Marine Pollution Bulletin*, 133, 636-646.

Shchekinova, E., Kumkar, Y., 2018. Modeling of small sea floaters in the central Mediterranean Sea: seasonality of at-sea distributions. *arXiv preprint arXiv:1804.07166*.

Spurr, E.B., Borkin, K.M., Drew, K.W., 2012. Line-transect distance sampling compared with fixed-width strip-transect counts for assessing tomtit (*Petroicamacrocephala*) population trends. *New Zealand Journal of Ecology,* 36 (3), 0-0.

Strafella, P., Fabi, G., Despalatovic, M., Cvitković, I., Fortibuoni, T. *et al*., 2019. Assessment of seabed litter in the Northern and Central Adriatic Sea (Mediterranean) over six years. *Marine Pollution Bulletin*, 141, 24-35.

Suaria G., Aliani S., 2014. Floating debris in the Mediterranean Sea. *Marine Pollution Bulletin,* 86 (15), 494-504.

Suaria, G., Avio, C.G., Mineo, A., Lattin, G.L., Magaldi, M.G. *et al.,* 2016. The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters. *Scientific Reports,* 6, 37551.

Teuten, E.L., Saquing, J.M., Knappe, D.R., Barlaz, M.A., Jonsson, S. *et al*., 2009. Transport andrelease of chemicals from plastics to the environment and to wildlife.

Philosophical.Transactions of the*RoyalSocietyB: Biological Sciences,* 364 (1526), 2027-2045.
Thiel, M., Hinojosa, I., Vásquez, N., Macaya, E., 2003. Floating marine debris incoastal waters of the SE-Pacific (Chile). *Marine Pollution Bulletin,* 46 (2), 224-231.
Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J.*et al.,* 2004. Lost at sea: where is all the plastic? *Science,* 304 (5672), 838.
Thompson, R.C., Moore, C.J., vomSaal, F.S., Swan, S.H., 2009. Plastics, theenvironment and human health: current consensus and future trends. *PhilosoficalTransactions of the Royal Society B: Biological Sciences,* 364 (1526), 2153-2166.
Titmus, A.J., Hyrenbach, D.K., 2011. Habitat associations of floating debris andmarine birds in the North East Pacific Ocean at coarse and meso spatial scales.*Marine Pollution Bulletin,* 62 (11), 2496-2506.
Topçu, E.N., Tonay, A.M., Öztürk, B., 2010. A preliminary study on marine litter in the Aegean Sea. *Rapports Communications international Mer Méditerranèe* 39, 804.
UNEP/MAP, 2015. *Marine litter assessment in the Mediterranean*. United Nations Environment Programme -Coordinating Unit for the Mediterranean Action Plan, Barcelona Convention, Athens 2015, 45 pp.
UNWTO, 2018.*Compendium of Tourism Statistics, Data 2012-2016*. United Nations - World Tourism Organization, pp. 598. Retrieved July 2018 from http://www.e-unwto.org/doi/book/10.18111/9789284418442
Uneputty, P., Evans, S., 1997. The impact of plastic debris on the biota of tidal flats inAmbon Bay (Eastern Indonesia). *Marine Environmental Research,* 44 (3), 233-242.
Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D. *et al.,* 2015. A global inventory of small floating plastic debris. *Environmental Research Letters*, 10 (12), 124006.
Vlachogianni, T., Fortibuoni, T., Ronchi, F., Zeri, C., Mazziotti, C. *et al.,* 2018. Marine litter on the beaches of the Adriatic and Ionian Seas: An assessment of their abundance, composition and sources. *Marine Pollution Bulletin*, 131, 745-756.
Zambianchi, E., Iermano, I., Suaria, G., Aliani, S., 2014. Marine litter in the Mediterranean Sea: an oceanographic perspective. p. 31-41. In: *CIESM Workshop Monograph 46: Marine litter in the Mediterranean and Black Seas*, Briand F. (Ed). CIESM Publisher, Monaco.
Zambianchi, E., Trani, M., Falco, P., 2017. Lagrangian Transport of Marine Litter in the Mediterranean Sea. *Frontiers inEnvironmental Science,* 5, 5.
Zeri, C., Adamopoulou, A., Varezić, D.B., Fortibuoni, T., Viršek, M.K. *et al.,* 2018. Floating plastics in Adriatic waters (Mediterranean Sea): From the macro-to the micro-scale. *Marine Pollution Bulletin*, 136, 341-350.