

MARINE LITTER IN THE BLACK SEA

Editors
Ülgen Aytan, Maria Pogojeva,
Anna Simeonova

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FOREWORD

Pollution is one of the major threats for the Black Sea and plastic litter is relatively a new issue in this enclosed sea, which is very vulnerable to environmental degradation. It is already known that the Black Sea suffers from several threats, such as overfishing, IUU fishing, habitat loss, climate change and various types of pollution.

In terms of marine litter, either damped from the vessels or from the rivers or even on the shores, is a visible pollution problem. Micro plastics, however, are often less visible and can be more dangerous because the collection and removal of them is almost impossible. Regional cooperation is essential for strategic planning, data sharing, exchange of information and public awareness issues. We know that high percentage of marine litter in the Black Sea is non-biodegradable and the problem is not only aesthetic but also severely damaging marine biodiversity, such as sea birds and cetaceans.

We hope that this publication will be useful for decision makers, scientists, naturalists, fishermen, NGO's and anyone who is interested in the protection of the Black Sea. I thank all the authors who contributed to this book with their efforts, namely, their time and knowledge, as well as their continuous passion for the protection of the Black Sea environment. Dr. Ülgen AYTAN has played a crucial role for this publication and TUDAV is very thankful for her diligence and motivated endeavours.

Finally, we believe that this work is unique in many ways due to its contents based on the wide range of new information and original outputs of many surveys in the Black Sea. Let's hope that this enclosed sea will be free from plastic litter one day…

Bayram ÖZTÜRK
Director
Turkish Marine Research Foundation
Beykoz, İstanbul - October, 2020

PREFACE

Marine litter is one of the fastest growing threats to the marine environment. In a single year, millions tons of litter, mainly plastic, end up in the oceans and seas due to human activities. The problem is complex as one plastic item may fragment into millions of microscopic particles with very slow rates of biodegradation, making their removal an extremely difficult task. The continued accumulation of these persistent materials poses a significant risk to marine life, human health and the economy, and calls for urgent actions.

The Black Sea is especially at risk from marine litter and plastic pollution because of the high river discharge from several countries into this semi-enclosed basin. The problem in the region needs to be tackled on several fronts including regional initiatives, legally binding directives, international cooperation, education programmes and evidence-based scientific knowledge. In recent years, an increasing number of studies have addressed the concern in relation to marine litter and its potential effects on Black Sea ecosystem. However, there is still a need to fully understand the environmental, public health and socio-economic impacts of plastics in the region.

This book was prepared during the Covid-19 outbreak which was an unprecedented situation around the world, giving us time to slow down and learn from our mistakes, especially our drastic effects on nature. During this period, researchers from many countries came together for this book to provide valuable data on the current status of marine litter, particularly plastic pollution, in the Black Sea environment. The book compiles information from sources to distributions of macro- and microlitter in different matrices of the ecosystem. Interactions of plastics with biota are also presented. The book also highlights gaps in knowledge and different aspects of policy and management.

We believe that this book will be of interest for scientists, naturalists, fishermen, NGO’s, decision makers, politicians and anyone interested in a sustainable healthy Black Sea. We also believe that this book provides needed information for governments and other stakeholders to take urgent actions to reduce and remove marine litter in the Black Sea.

I would like to express my very great appreciation to the authors and editors, who made this book possible during lockdown. I am sincerely thankful to Dr. Arda M. TONAY for his technical edit and Ms. Zeynep GÜLENÇ for her technical assistance. I would like to offer my special thanks to Dr. Bayram ÖZTÜRK, founder and president of TUDAV, for his trust and support for this book.

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Plastic pollution along the Bulgarian Black Sea coast: Current status and trends

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Abstract

Quantitative assessment of marine litter pollution along the Bulgarian Black Sea coastline was presented, based on surveys conducted on 10 beaches during the summer - autumn period 2017 - 2019. A total amount of 167679 items were recorded, removed and classified into 8 major groups of material types on aggregated basis. The highest abundance was in 2017 (77196 nos.), followed by 2019 (49789 nos.) and 2018 (40694 nos.). The vast majority of ML was from the category "Artificial polymer materials", varying negligibly through the years - from 64.9% in (2017) to 60.2% (2018). The annual average ML density within the whole country coastline was ranging from 0.59 items/m^2 in 2017 to 0.23 items/m^2 in 2019. One of the beaches was classified as "Very dirty" through the whole period - the urban beach "Channel 2 - Varna"- (3.45 items/m^2 in 2017), subject to intense littering mainly from land-based sources- coastal tourism, recreational fishing, general public, fly- tipping, etc. The most abundant plastic items (top 10) were identified. Smoking related items were the most frequent type and Cigarette butts and filters were the highest on most of the sites. A descending trend of plastic abundance was outlined during the last two years, which might be considered as a successful start in reaching "Good environmental status" according to the requirements of MSFD.

Keywords: Marine litter, plastic, pollution, Black Sea coast, Bulgaria

Introduction

Plastic pollution of marine areas has become an alarming issues worldwide, causing environmental, socio - economic and health consequences (Derraik 2002; Worm *et al*. 2006; Jang *et al*. 2014; Gall and Thompson 2015; Geyer *et al*. 2017; Karbalaei *et al*. 2018; Beaumont *et al*. 2019; Galgani *et al.* 2019). Abandoned, disposed of, lost or transported plastics by a variety of sources, can enter marine environment and drift around the water areas, inflicting trans boundary pollution or reach very remote distances where they do not normally occur (Browne *et al.* 2015; Turrell 2019; Stanev and Ricker 2019). Growing amounts of plastics are registered in all marine compartments - sea surface, water column, sea floor and shoreline. In the open sea or on the sea floor they can lead to habitat loss and biodiversity degradation, entanglement, ingestion and even mortality of marine species (Rochman *et al.* 2013; Worm *et al*. 2017; Erni-Cassola *et al*. 2019; Carreras-Colom *et al.* 2018). A significant fraction of plastic could be found on coastline discarded or unintentionally lost by recreational users, washed ashore from the sea by strong winds or scattered by waves superficial circulation and high tides, may degrade on the beaches and be washed back into the oceans (Corcoran *et al*. 2009; Jambeck *et al*. 2015; Stanev and Ricker 2019; Miladinova *et al.* 2020).

Black Sea is a typical semi-enclosed sea, very sensitive to contamination. It's extremely slow replenishment of water, limited vertical intermixing and dynamic surface circulation in combination with high anthropogenic pressure from river and canal discharges, navigation, fishery, waste dumps near the coast, tourism and recreation activities, etc., favour marine litter (ML) pollution both in the entire basin and its particular areas. To quantify the problem and take measures to reduce ML loading within the Black Sea basin, several surveys have been conducted during the last years to assess coastal littering along the Turkish, Romanian and Bulgarian Black Sea shoreline (Topçu *et al*. 2013; Terzi and Seyhan 2017; Paiu *et al*. 2017; Simeonova *et al.* 2017; Esensoy *et al*. 2018; Muresan *et al.* 2018; Simeonova and Churutkova 2019; Toneva *et al* 2019; Aytan *et al*. 2020), as well as floating ML and sediments in the Romanian Black Sea (Ioakeimidis *et al.* 2014; Suaria *et al.* 2015), SE Black Sea (Aytan *et al.* 2016; Oztekin *et al.* 2019), Bulgaria, Romania and Western Black Sea (Moncheva *et al.* 2016; Berov and Klayn 2020) and Ukraine, Russia and Georgia Black Sea (Slobodnik *et al*. 2017). The data showed that plastic is the most abundant ML in all marine compartments of the Black Sea basin, thus considering plastic pollution as one of the main problems that needs urgent actions.

Bulgaria is one of the six countries sharing all benefits and problems of the Black Sea basin. ML pollution in the Bulgarian Black Sea environment is of growing concern and a priority issue on national level. Making efforts to combat littering in the Black Sea, the country is strictly following the requirements of different conventions, directives and agreements, which are relevant to the management, and mitigation of ML problem. The Marine Strategy Framework Directive (MSFD), one of the most ambitious legislative instrument, focused on measures to ensure that "quantities and composition of marine litter do not cause harm to marine or coastal environment" (Galgani *et al.* 2011) has been transposed in the Bulgarian legislation and monitoring programs for ongoing assessment were established by the Bulgarian Ministry of Environment and Waters (MOEW) in 2014 and updated in 2017 (MOEW 2017). The first national monitoring targeted to quantify ML pollution along the Bulgarian Black Sea coast was conducted in 2015 - 2016 and initial assessment of litter composition, distribution and seasonal dynamics was made (Simeonova *et al*. 2017; Simeonova and Chuturkova 2019). Starting in 2015, national monitoring campaigns have been conducted every year in order to understand the scale of the anthropogenic ML problem and take measures to reduce ML pollution in the Bulgarian Black Sea environment.

The present paper is based on data, collected for three years period 2017 - 2019 within the updated national ML monitoring program and aims to evaluate the status and trends of coastal ML pollution, especially plastic in order to outline the issues and knowledge gaps, as well as to improve ML management on country beaches.

Materials and Methods

Beach litter sampling and analyses

Beach litter surveys were conducted on 10 beaches during the summer - autumn period 2017 - 2019 in line with MOEW monitoring program (MOEW 2017). Reference beaches were selected according to EU MSFD TG10 "Guidance on Monitoring of Marine Litter in European Seas" (Galgani *et al*. 2013) and OSPAR guidelines (OSPAR 2010), taking into consideration the following criteria: over 1 km in length (if possible); exposed to the open sea; composed of sand or gravel; accessible to surveyors and free of 'buildings' all year round; not subject to any other litter collection activities. Two sections of 100-metre stretch on each reference beach (1 km in length) were monitored, covering the whole area between the water edge to the back of the beach. During the surveys all stranded ML were collected by volunteers (Figure 1), classified, and recorded according to TSG_ML General-Code (Galgani *et al*. 2013). The items were classified in 8 categories according to the type of material: Artificial polymer materials; Rubber; Cloth/Textile; Paper/Cardboard; Processed wood; Metal; Glass/ceramics and Unidentified - a total of 167 sub-categories.

Figure 1. Marine litter surveys along the Bulgarian Black Sea coast

The average litter density per beach per year was calculated and beach cleanliness was assessed according to Alkalay's Clean Coast Index (CCI) scale: values from 0-2 indicate very clean beaches, 2-5 clean, 5-10 moderately clean, 10-20 dirty and > 20 extremely dirty (Alkalay *et al*. 2007).

Study area

The Bulgarian Black Sea coast is located at the western part of the Black Sea and stretches from Cape Sivriburun in the north at the Romanian border to Cape Rezovo on the south at the border with Turkey. The total length of the coastline is 378 km, characterized with a variety of coastal types: rocky cliffs, sandy beaches and dunes, low-lying parts of bays and lagoons (Stanchev *et al.* 2013). The beaches occupy about 200 km of the coastline and the number of sandy beaches is over 70, comprising 34.5% of the entire coastline. There are two large bays of Varna and Burgas along the coast, which are jutting out deeply into the land (Stancheva 2009). The rivers of the coastal area are with small catchment, short length and minor amount of river runoff, except river Kamchiya, which is the longest. Seventeen small rivers flow directly into the Bulgarian Black Sea and nine are the significant lakes, located along the coast (important wetlands and Ramsar sites). The Bulgarian Black Sea coastal zone is 5.21% of the country territory and hosts 8.85% of the national population, concentrated in fourteen state municipalities (BSBD 2016).

Figure 2. Map with the surveyed beaches along the Bulgarian Black Sea coast

Ten monitoring sites were surveyed, from the northern to the southern part of the Bulgarian sea coast: Northern Black Sea coast - "Durankulak" beach, "Krapets" beach, "Channel 2 - Varna"; Central Black Sea coast - "Shkorpilovtsi" beach, "Byala - Karadere" beach, "Obzor" beach, "Irakli" beach and Southern Black Sea coast - "Black Sea saltpans - Burgas" beach, "Alepu" beach and "River Veleka Mouth" beach (Figure 2).

The beaches were selected, taking into consideration the basic drivers of ML accumulation on country coastal zones: navigation and ports; urbanization; tourism and recreation; commercial and recreational fishing; rivers inflow, including wastes discharges by rivers; transboundary transfer of waste between water basins, etc. All of the sites were unguarded, out of concession, typical sandy. Only "Channel 2 - Varna" coastline is composed of gravel and pebble - not considered as a beach. Two of the sites - "Channel 2 - Varna" and "Black Sea saltpans - Burgas" beaches are within big towns Varna and Burgas respectively, with large population more than 100000 population equivalent (p.e.), big ports and developed maritime industry. "Channel 2 - Varna" is used for navigation, connecting Varna Lake and Black Sea. The rest of the beaches are near less populated areas (2000 - 10000 p.e.), used for recreation mainly during the summer period. The beaches "Shkorpilovtsi", "Obzor", "Irakli" and "River Veleka Mouth" are in close proximity to rivers, flowing into the sea. "Durankulak" beach is the northernmost beach, close to Romania and "River Veleka Mouth" beach - the southernmost, close to European Turkey.

Results and Discussion

Composition and spatial distribution of marine litter

In the last three years 2017 - 2019, during the national ML monitoring, 11 surveys were conducted in summer - autumn period on 10 sampling sites, covering 78932 m^2. A total amount of 167679 items were recorded, removed and classified into 8 major groups of material types on aggregated basis. The highest was the abundance in 2017 - 77196 nos., lower in 2019 - 49789 nos. and lowest in 2018 - 40694 nos. The vast majority of ML was from the category "Artificial polymer materials", varying negligibly through the years - from 60.2% (2018) to 64.9% in (2017) (Figure 3-5). The second most abundant category of litter was “Paper/cardboard” - from 12.5% (2018) to 14.1% (2017) and third - the category “Processed wood”, showing highest accumulation in 2019 (11.8%) and considerably lower in 2017 (5.7%).

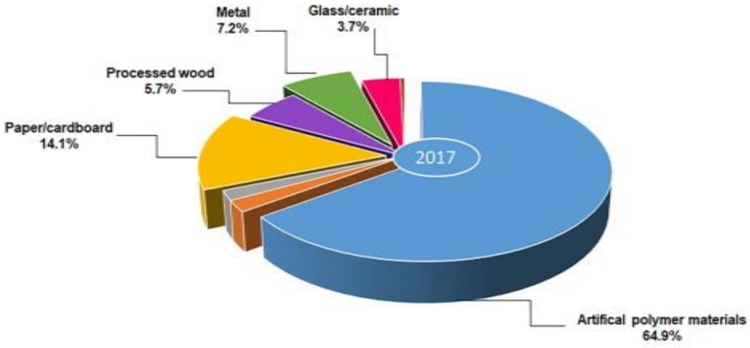

Figure 3. Total litter items per category type in percentage, 2017

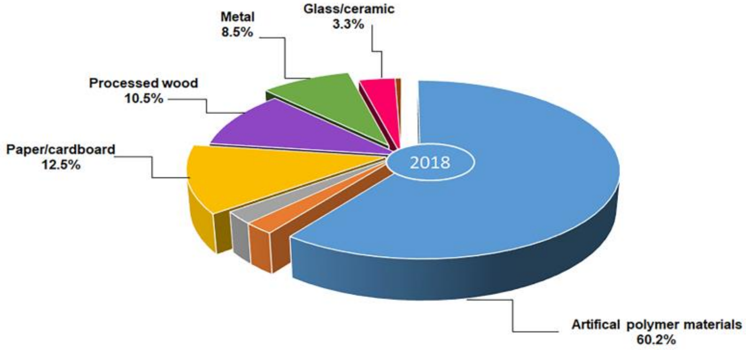

Figure 4. Total litter items per category type in percentage, 2018

The contribution of the category "Artificial polymer materials" (Plastic) to coastal ML pollution was dominant and relevant to our previous studies regarding Bulgarian Black Sea coast (Simeonova *et al.* 2017; Simeonova and Chuturkova 2019; Simeonova and Chuturkova 2020), as well as in accordance with many other observation worldwide, widely documenting that approximately more than 80% of all ML, found on beaches was plastic (Derraik 2002; Barnes *et al*. 2009; Addamo *et al.* 2017; OSPAR 2017). It was estimated that the global production of plastic will exceed 34 billion metric tons by 2050 and there will be around 12 billion tons of plastic litter in landfills and the environment (Geyer *et al*. 2017). According to the statistics, Bulgaria generated 120 million tons of plastic packaging waste in 2017, of which 65% recycled - well above the EU average rate (Eurostat 2017).

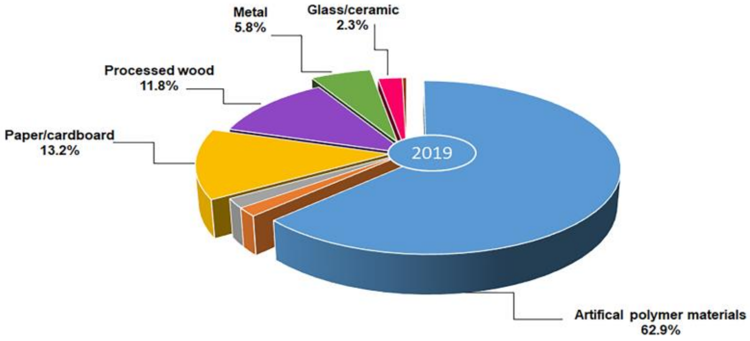

Figure 5. Total litter items per category type in percentage, 2019

It should be noted that ML abundance by category was different on each monitoring site and year, but predominance of plastic items was recorded on all stations within the whole period, varying from 54.3% to 70.4% of the total ML. In 2017 and 2019 - the highest was the accumulation on "Durankulak" beach - 70.4% and 66.2% respectively and in 2018 - on "Shkorpilovtsi" beach - 65.5 %. The lowest amounts of plastic items were found on "River Veleka Mouth" in 2017 accounting 54.3% of all litter collected.

The annual average ML density within the whole monitored country coastline was ranging from 0.23 items/m^2 in 2019 to 0.59 items/m^2 in 2017. As shown in Table 1, among the 10 examined sites, the highest was the average density on "Channel 2 - Varna", varying from 1.30 items/m^2 (2019) to 3.45 items/m^2 (2017). Therefore, "Channel 2 - Varna" was classified as "Very dirty" through the whole period according to Alkalay's CCI grades, varying from - CCI=26 (2019) to CCI = 69 (2017). In 2017, relatively high litter average densities were recorded also on "Shkorpilovtsi" beach (0.32 items/m^2), "Byala - Karadere" beach (0.32 items/m^2), "Durankulak" beach (0.47 items/m^2) and "Obzor" beach (0.50 items/m^2), being classified as "Moderately clean". In 2018 and 2019, most of the sites were classified as "Clean" or "Very clean".

Bearing in mind the results of this study and our previous findings (Simeonova *et al.* 2017; Simeonova and Chuturkova 2019; Simeonova and Chuturkova 2020), "Channel 2 - Varna" was assesses as very sensitive to ML contamination coastal area and might be considered as one of the hot spots along the Bulgarian Black Sea coast. The main reason is the variety of ML drivers, concentrated in considerable small area. Situated within one of the biggest towns in Bulgaria - Varna town, "Channel 2 - Varna" is subject to intense littering from coastal tourism and recreational fishing all year round, as well as from public and fly tipping, which are land-based sources. The navigation channel along the coastline of "Channel 2 - Varna" and the close proximity of Port Varna - East suggest that some items may originate from shipping, related to sea- based sources.

Table 1. The average ML density, CCI and cleanliness of the surveyed beaches, 2017 – 2019

Beach name	**2017**			**2018**			**2019**		
	item/ m^2	**CCI**	**Cleanliness**	**item/ m^2**	**CCI**	**Cleanliness**	**item/ m^2**	**CCI**	**Cleanliness**
Duran-kulak	0.47	9.4	Moderate	0.06	1.2	Very clean	0.08	1.6	Very clean
Krapets	0.16	3.2	Clean	0.09	1.8	Very clean	0.09	1.8	Very clean
Channel 2 -Varna	3.45	69.0	Very dirty	1.68	33.6	Very dirty	1.30	26	Very dirty
Shkorpi-lovtsi	0.32	6.4	Moderate	0.14	2.8	Clean	0.09	1.8	Very clean
Byala - Karadere	0.32	6.4	Moderate	0.12	2.4	Clean	0.13	2.6	Clean
Obzor	0.50	10	Moderate	0.24	4.8	Clean	0.18	3.6	Clean
Irakli	0.23	4.6	Clean	0.17	3.4	Clean	0.08	1.6	Very clean
Saltpans - Burgas	0.18	3.6	Clean	0.20	4.0	Clean	0.14	2.8	Clean
Alepu	0.13	2.6	Clean	0.06	1.2	Very clean	0.10	2.0	Very clean
River Veleka	0.15	3.0	Clean	0.17	3.4	Clean	0.09	1.8	Very clean

The potential drivers of ML are relevant to the economic activities and key sectors typical for the Bulgarian Black Sea: Shipping and Ports, Fishery and aquaculture and Tourism. In Bulgaria, coastal tourism constitutes a significant economic sector in terms of number of visitors and has significant contribution into regional GDP, compared to other maritime activities (MARPLAS - BS, 2017).

Undoubtedly, the amount of litter items found on all monitoring sites is in close relation with ML sources, so identifying the causes of ML is crucial to understand the origin and pathways of littering to the marine environment. Further detailed analyses to define sources and their contribution to coastal pollution will be carried out, taking into consideration - beach topography, currents specifics, river runoff, trans boundary transport, etc. and applying different scientific approaches (Veiga *et al*. 2016; Moora and Piirsalu 2016). Very often the river runoff and landfill/dumping sites, are recognized to be the most important sources, by which ML can be transported into the sea by waves, winds and rains (Suaria *et al*. 2015; Berkun *et al*. 2005; Topçu *et al*. 2013).

Top ten plastic litter

The most abundant Plastic items (top 10) along the Bulgarian Black Sea coast were identified, assessed and classified.

Top 1 - According to the results, plastic litter was primarily consisted of Cigarette butts and filters on most of the monitoring sites, exhibiting highest public usage. Predominant were the amounts on "Channel 2 - Varna" coastline - 932 nos. in 2017, gradually decreasing to 454 nos. in 2019 (Figure 6), followed by "Shkorpilovtsi - north" beach - 821 nos. (2017) and decreasing to - 325 nos. in 2019, showing the same tendency.

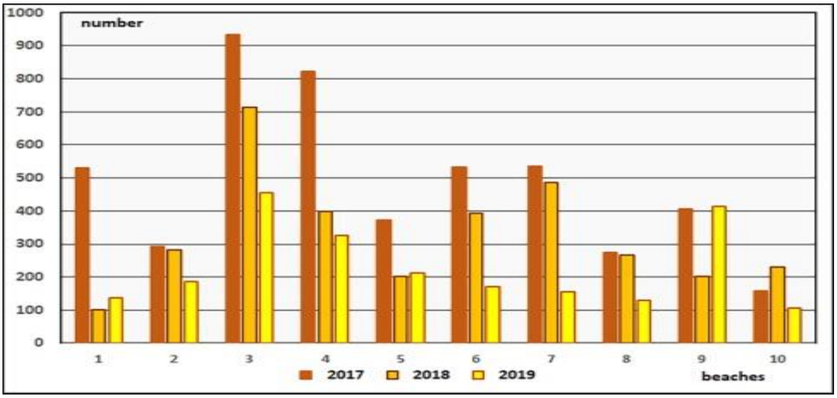

Figure 6. Cigarette butts and filters abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

On three of the beaches, comparable levels of pollution were observed in 2017 - "Durankulak North" beach - 531 nos., "Obzor" beach - 532 nos. and "Irakli" beach - 534 nos., gradually decreasing in 2018. The beaches "Obzor" and "Irakli" were reaching the lowest levels in 2019 - within 138 to 170 items. On "Durankulak North" beach and "Alepu" beach an increase was observed in 2019 compared to 2018. In general, there is a pronounced descending trend in ML-Cigarette butts and filters pollution on most of the beaches on the Bulgarian Black Sea coast.

Top 2 - Plastic /polystyrene pieces 0-2.5 cm were the second most abundant items with greatest majority again on "Channel 2 - Varna" coastline - 664 nos. (2017), 407 nos. (2018) and lowest in 2019 - 333 nos. (Figure 7).

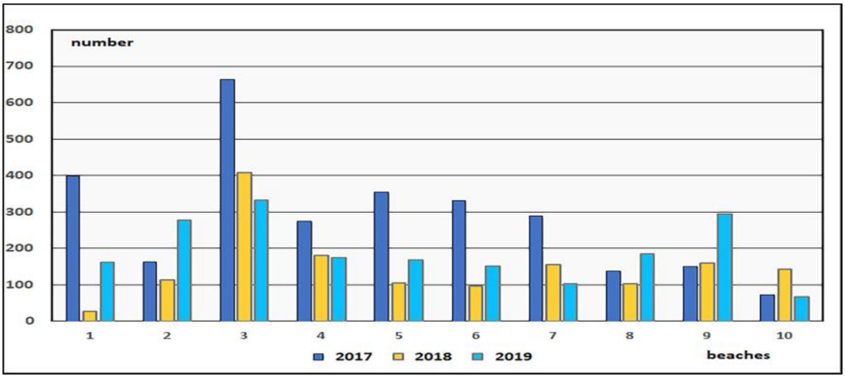

Figure 7. Plastic /polystyrene pieces 0-2.5 cm abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Beach "Durankulak North" was following "Channel 2 - Varna" with 399 nos. in 2017, but showing quite different tendency - decreasing in 2018 up to 28 items only and rising in 2019 to 161 items. Similar variances were recorded on several other beaches - "Krapets", "Byala - Karadere", "Obzor", "Black Sea saltpans - Burgas" and "Alepu".

Top 3 - The third most abundant items were Plastic caps/lids drinks highest on "Channel 2 - Varna" - 1016 nos. in 2017 and considerably lower in 2018 and 2019 - 239 nos. and 237 nos. respectively (Figure 8).

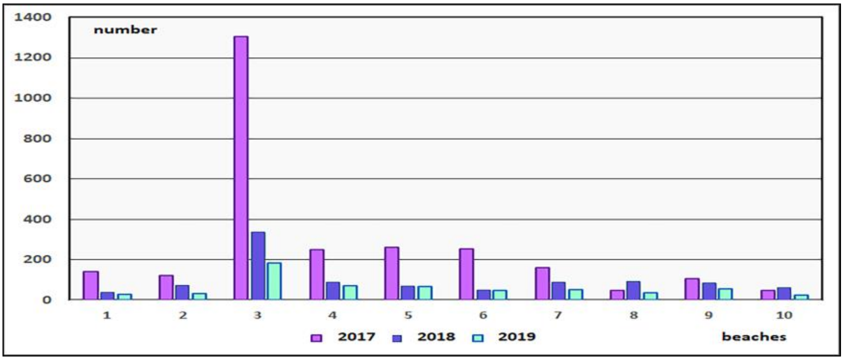

Figure 8. Plastic caps/lids drinks abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Beach "Durankulak North" was the second most polluted monitoring site with highest majority - 419 nos. in 2017, decreasing to 104 nos. in 2018 and increasing again to 142 nos. in 2019. Two other beaches were showing similar variances "Obzor" and "Alepu" beach. In general, descending trend in ML-Plastic caps/lids drinks pollution was outlined on most of the beaches during 2019.

Top 4 - Tobacco pouches/plastic cigarette box packaging is related to smoking littering, showing considerably high occurrence on most of the sites, compared with the other subcategories. The highest was the amount of these items on "Channel 2 - Varna" - 1304 nos. in 2017, slowly decreasing to 336 nos. (2018) and 182 nos. (2019) (Figure 9).

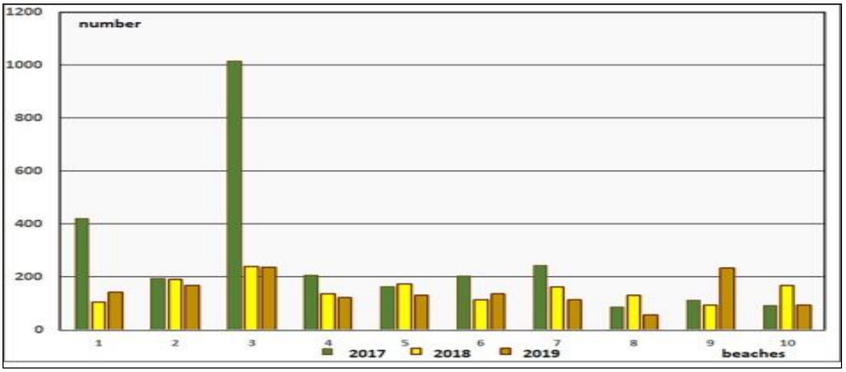

Figure 9. Tobacco pouches/plastic cigarette box packaging abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

A pronounced descending trend was observed through the whole monitoring period.

Top 5 - Plastic caps/lids unidentified were fifth in ranking the plastics abundance. The most polluted was "Durankulak North" beach - the northernmost beach, near to the Romanian border - 497 nos. in 2017 and considerable lower during the next years - 46 nos. (2018) and 59 nos. (2019) (Figure 10). "Channel 2 - Varna" was second in pollution - 430 nos. in 2017 and only 196 nos. in 2019. For most of the beaches the littering was decreasing during the last year.

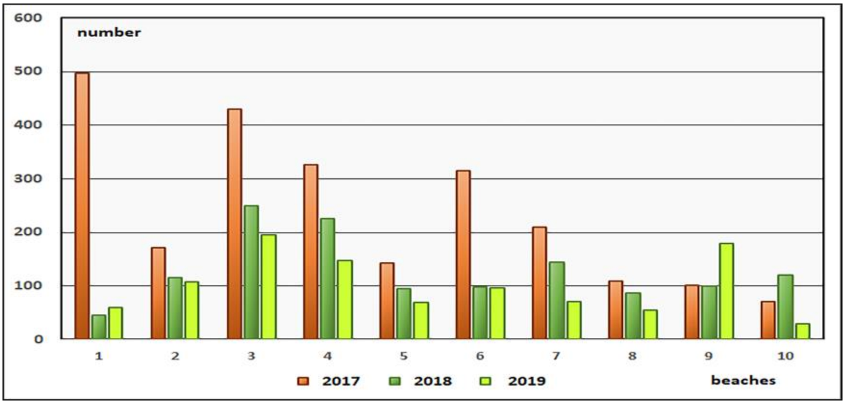

Figure 10. Plastic caps/lids unidentified abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Top 6 - Plastic cups and cup lids were dominant on two of the sites - "Channel 2 - Varna" coastline - 372 nos. and "Obzor" beach - 370 nos. in 2017, and decreasing gradually till 2019 (Figure 11). On several beaches the tendency was variable - much lower quantities in 2018 and higher in 2019: "Durankulak North", "Krapets", "Byala - Karadere" and "Alepu". The rest of the beaches showed decreasing pollution tendency.

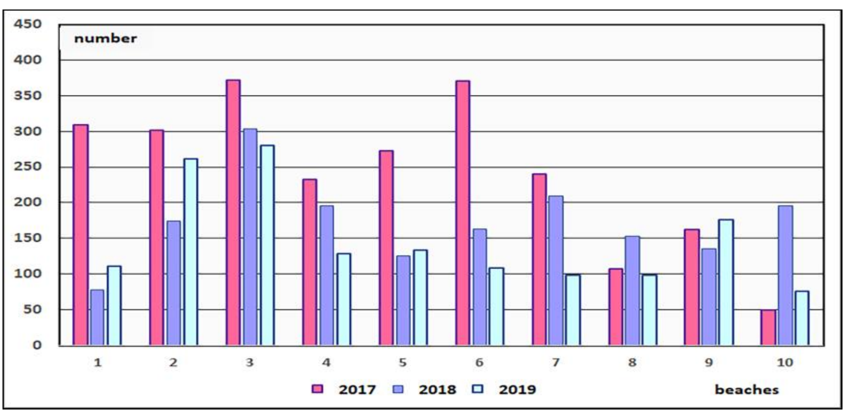

Figure 11. Plastic cups and cup lids abundance along Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Top 7 - Crisps packets/sweets wrappers were counting highest majority on "Channel 2 - Varna" - 706 nos. in 2017 and lower during the next years - 314 nos. (2018) and 185 nos. (2019) (Figure 12). On the rest of the monitoring sites the amounts were considerably lower in 2017, namely "Shkorpilovtsi -north" - 244 nos., "Durankulak North" - 215 nos., "Obzor" - 206 nos. In general, the littering was decreasing in 2019.

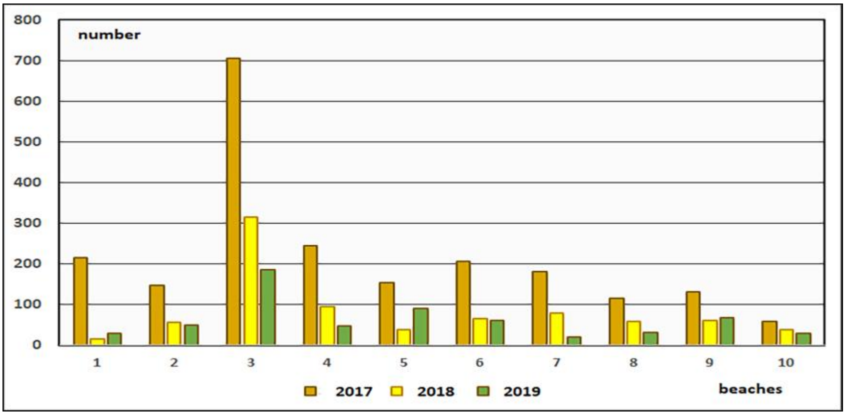

Figure 12. Crisps packets/sweets wrappers abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Top 8 - Plastic/polystyrene pieces 2.5-50 cm were highest on "Channel 2 - Varna" - 771 nos. in 2017 and lowest - 242 nos. in 2019 (Figure 13). The loadings on most of the beaches were varying - decreasing in 2018 and increasing in 2019.

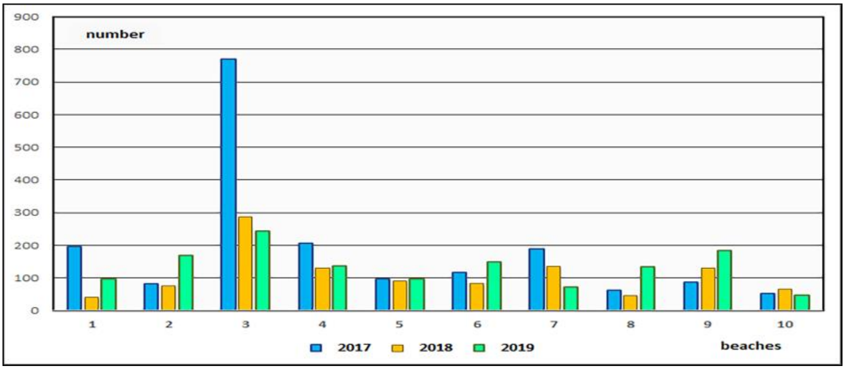

Figure 13. Plastic/polystyrene pieces 2.5 -50 cm abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Top 9 - Plastic rings from bottle caps/lids were predominant on "Durankulak North" beach - 539 nos. in 2017, rapidly decreasing the next years - 19 nos. in 2018 and 42 nos. in 2019 (Figure 14). Second, regarding pollution was "Channel 2 - Varna" - 285 nos. (2017) and decreasing to 169 nos. in 2019. A descending trend was observed for most of the beaches.

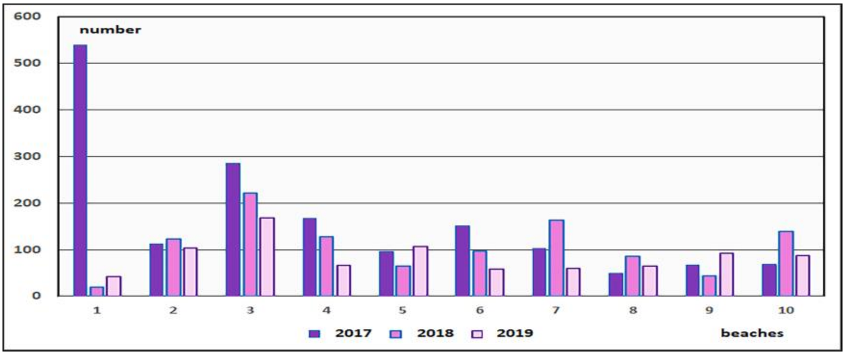

Figure 14. Plastic rings from bottle caps/lids abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

Top 10 - Straws and stirrers were dominant on "Shkorpilovtsi -north" - 291 nos. in 2017, but lower in quantities - 83 nos. in 2019 (Figure 15). Considerable loadings were recorded also on "Durankulak North" beach - 232 nos. (2017), sharply decreasing to 40 nos. (2018) and 41nos. (2019).

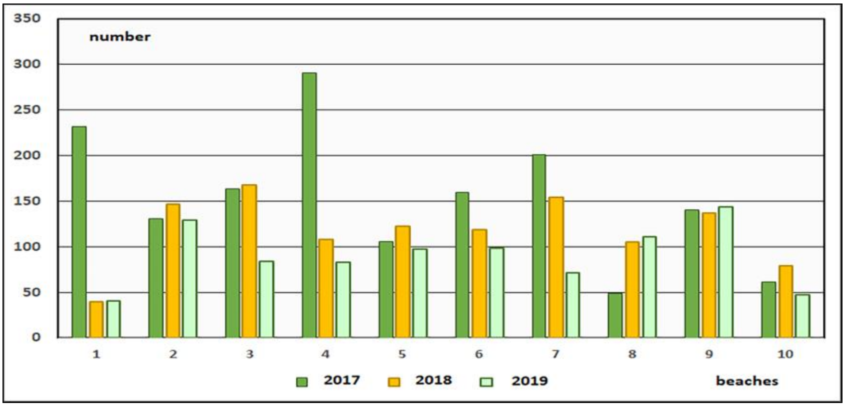

Figure 15. Straws and stirrers abundance along the Bulgarian Black Sea coast, 2017-2019: 1. Durankulak; 2. Krapets; 3. Channel 2-Varna; 4. Shkolpilovtsi; 5. Byala - Karadere; 6. Obzor; 7. Irakli; 8. Black Sea saltpans - Burgas; 9. Alepu; 10. River Veleka Mouth

For several beaches were recorded lower amounts in 2017, increasing in 2018 and decreasing again in 2019: "Krapets", "Channel 2 - Varna", "Byala - Karadere", "Black Sea saltpans - Burgas" and "River Veleka mouth".

Among plastic, Cigarette butts and filters were the most frequent type of litter on the majority of Bulgarian beaches, very much in line with the global tendencies (Ocean Conservancy 2016) and with the results regarding many European beaches, including Romanian and Bulgarian Black Sea beaches (Addamo *et al.* 2017; Muresan *et al*. 2017; Paiu *et al*. 2017; Simeonova and Chuturkova 2019). Another items related to smoking and found in very high quantities on the monitored beaches were Tobacco pouches/plastic cigarette box packaging (top 4). Items that fell in the top 10 were also plastic /polystyrene pieces with size 0-2.5 cm and 2.5-50 cm, which mostly come from disintegration of larger plastic items due to weathering and other meteorological conditions. These small items together with Crisps packets/sweets wrappers (top 7) are very easily transported by wind, waves and heavy rains from distant areas, might enter the sea or be washed back to the shore, and could be found far from the primary source. Some other plastic items with high occurrence - Plastic caps/lids, Straws and stirrers, Plastic cups and cup lids, Plastic rings from bottle caps/lids *etc.* were associated with beach/coastal tourism, fishing, etc. and they are good indicator of pollution from beach users. Due to their considerably small sizes, they might be captured in the beach vegetation or buried deep in the sand and found long after their release in the environment.

The most polluted coastline with plastic items, related to leisure activities (coastal tourism and fishing) was "Channel 2 - Varna" - urban area, impacted by very high anthropogenic load most of the year. "Durankulak North" beach, situated close to the Romanian border was showing highest predominance of Plastic /polystyrene pieces with size 0-2.5 cm, which might be due to the influence of the Black Sea rim current, encirculating the entire basin in a counter-clockwise direction and disseminating plastic pieces over the Rumanian basin. Fishing gear-containing plastic was not in the top 10 items, showing that fishing activities were not so popular and intensive along the country shoreline.
The top 10 plastic items from the northern to the southern part of the Bulgarian Black Sea coast, calculated on aggregate bases per year are presented in Figure 16.

As shown in the figure, a pronounced descending trend of pollution was outlined for most of the top 10 items until 2019: Cigarette butts and filters - 4852 nos. in 2017 and 2290 nos. in 2019; Plastic caps/lids drinks - 2733 nos. (2017) and 1430 nos. (2019); Tobacco pouches/plastic cigarette box packaging - 2694 nos. (2017) and sharply decreasing to 601 nos. (2019); Plastic caps/lids unidentified - 2374 nos. (2017) and 1010 nos. (2019); Plastic cups and cup lids - 2318 nos. (2017) and 1473 nos. (2019); Crisps packets/sweets wrappers - 2157 nos. (2017) and sharply decreasing to 612 nos. (2019); Plastic rings from bottle caps/lids - 1639 nos. (2017) and 851 nos. (2019); Straws and stirrers - 1535 nos. (2017) and 905 nos. (2019). Regarding both - Plastic /polystyrene pieces 0-2.5 cm and Plastic/polystyrene pieces 2.5-50 cm, variable pollution tendency was outlined - decreasing in 2018 and increasing in 2019.

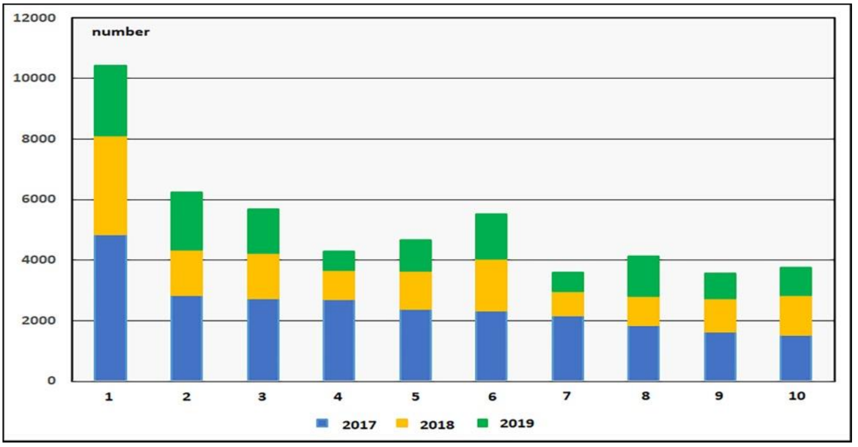

Figure 16. The top 10 plastic items along the Bulgarian Black Sea on aggregate bases per year, 2017 - 2019: 1. Cigarette butts and filters; 2. Plastic /polystyrene pieces 0-2.5 cm; 3. Plastic caps/lids drinks; 4. Tobacco pouches/plastic cigarette box packaging; 5. Plastic caps/lids unidentified; 6. Plastic cups and cup lids; 7. Crisps packets/sweets wrappers; 8. Plastic/polystyrene pieces 2.5-50 cm; 9. Plastic rings from bottle caps/lids; 10. Straws and stirrers

The decreasing trend of pollution from 2017 to 2019 might be explained with the rising public awareness regarding ML pollution, in line with some objectives of the new MOEW monitoring program. Many informal campaigns for cleaning up different beaches, especially after 2017 were organized under different initiatives - World Black Sea Day, World Water Day, Earth Day, World Environment Day, etc. Moreover, the wild camping becomes very popular during the last years on some beaches, thus shifting the relative share of plastic items to items related to other categories (processed wood, paper and glass) due to the specifics of this activity. The impact of sea wave's circulation and drift direction, as well as the influence of rivers runoff are very important factors for either the plastics distribution and variability in time. Very often, floating litter are spreading and stranding in one marine areas and after a considerable period of time may be drifted to another area or deposited on a shore far from the primary source (Stanev and Ricker 2019).

Conclusions

The present study provides quantitative assessment of coastal ML pollution on 10 beaches along the Bulgarian Black Sea coast in summer - autumn period

2017 - 2019. A total of 167679 items were collected from 78932 m^2 area during 11 surveys. The contribution of plastic items to coastal ML pollution was dominant through the whole period, varying from 54.3% to 70.4% of the total ML at the different beaches. Among plastic, smoking related items were the most frequent type of litter found on the monitored beaches, very much in line with the global tendencies. The most polluted beach was the urban coastline - "Channel 2 - Varna", subject to intense littering mainly from land-based sources - coastal tourism, recreational fishing, public, fly- tipping, etc. The average ML density on "Channel 2 - Varna" was highest, reaching 3.45 items/m^2 in 2017, thus classified as "Very dirty". A descending trend of plastic abundance was outlined, reaching the lowest levels - 60.2% (2018), compared with all monitoring campaigns conducted on the country beaches (starting in 2015). These results might be considered as a successful start in reaching "Good environmental status" according to the requirements of MSFD.

Our findings may support the application of possible mitigation measures to combat plastic pollution along the Bulgarian Black Sea coast and substantially help to address marine litter problem, such as: (i) identification of ML sources, trying to distinguish between land-based and offshore activities; (ii) reduction and prevention of waste generation that may end up in the marine environment; (iii) raising awareness of the business sector (traders, beach concessionaires, users of beach services, fishermen, etc.) and the public (tourists, students, children, etc.); (iv) stimulating nature-friendly tourism and developing regulations for "wild camping"; (v) better coordination between institutions and other organizations, related to ML monitoring and management; (vi) promoting clean up campaigns and maintenance of the beaches, as well as increasing the capacity of coastal municipalities in terms of waste and water management; (vii) integration of all current documents, related to waste minimization and waste water treatment and application in the existing Bulgarian legislation.

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Marine litter monitoring on the Black Sea beaches in 2019: The ANEMONE Project experience

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Abstract

Plastic debris is a complex cultural and multi-sectoral problem that imposes tremendous ecological, economic, and social costs around the world. One of the substantial barriers to addressing plastic pollution is the absence of adequate scientific research, assessment, and monitoring. There is a gap in information needed to evaluate impacts of marine litter on coastal and marine species, habitats, economic health, human health and safety, and social values. The Black Sea does not represent an exception and the assessments made in 2019, within "Assessing the vulnerability of the Black Sea marine ecosystem to human pressures" (ANEMONE) project represent step forward in filling this knowledge gap. 28 surveys were performed in Romania, Turkey, Bulgaria and Ukraine in spring (April) and autumn (October – November) of 2019 and artificial polymer material accounted for 78%.

Keywords: Marine litter, Black Sea, ANEMONE, plastics, pollution

Introduction

Plastics trends around the world

Marine environments are vital important to human well-being, but they are also extensively threatened by anthropogenic activities. Marine litter, or debris, is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment" (Cheshire *et al.* 2009; Schulz *et al*. 2017). This problem was first mentioned in 1870, when Jules Verne provided a graphic description of how floating debris accumulates in ocean gyres in the chapter on the Sargasso Sea in his famous novel "Twenty Thousand Leagues under the Sea".

The marine environment can be considered as a sink in which anthropogenic litter accumulates (Van Acoleyen *et al.* 2013) coming from land-based and offshore sources (Veiga *et al.* 2016). Thus, marine litter is found in all marine compartments such as beaches, shallow and deep seafloor, at the sea surface and in the water column. Marine litter is recognized as a worldwide concern by EU and global initiatives such as the United Nations Environment Programme (UNEP; see Sustainable Development Goal 14), as well as the G7 and G20. It causes harm to the environment and generates adverse economic, health and aesthetic impacts.

There have been growing awareness of the problem in recent years by scientists, industry, policy makers and environmental NGOs. Considerable media attention and associated interest from the public has been focused on this issue. Wind and sea currents make it a transboundary problem. For instance, during a field study with checking the barcodes, performed by Mare Nostrum NGO, on the Romanian beaches were found items that have the origins in such countries as Ukraine, Turkey, Italy, Bulgaria, Hungary or Cyprus, Germany, Spain, Denmark, Finland, Portugal, China, *etc*.

Due to the persistence and buoyancy of marine litter in general, and plastics in particular, impacts may be separated considerably in both time and space from the original source. Over 267 animal species are known to suffer from entanglement and ingestion of marine debris, including 86% of sea turtles, 44% of seabirds, and 43% of marine mammals. Plastic waste also constitutes an aesthetic problem in touristic areas such as natural parks and beaches. Marine litter is a problem in all EU marine waters. On reaching the ocean, it is estimated that 15% of marine debris floats on the sea surface, 15% remains in the water column and 70% rests on the seabed, both in shallow coastal areas and in much deeper parts of the oceans (UNEP 2005). Common litter items are made of plastic, paper, wood, textiles, metal, glass, ceramics and rubber discarded by humans (UNEP 2005).

The first plastics hit the market around 1950. At that time there were 2.5 billion people on Earth and the global production of plastic was 1.5 million tonnes. Today there are more than 7 billion people and plastic production exceeds 300 million tonnes annually (Plastics Europe 2015; Velis 2014). Some people have described this dramatic increase in the use of plastics as the “Age of Plastics” (Stevens 2002) or “Our Plastic Age” (Thompson *et al.* 2009). If the trend continues, another 33 billion tonnes of plastic will have accumulated around the planet by 2050 (Rochman *et al.* 2013) (Figure 1).

The quantities of plastics leaking to the oceans on a global scale are largely unknown. Reliable quantitative estimations of input loads, sources and originating sectors represent a significant knowledge gap, but it is suggested that, every year, almost 8 million tonnes of plastic leak to the ocean. It is estimated that the ocean may already contain over 150 million tonnes of plastic, of which around 250,000 tonnes, fragmented into 5 trillion plastic pieces, may be floating at the oceans' surface.

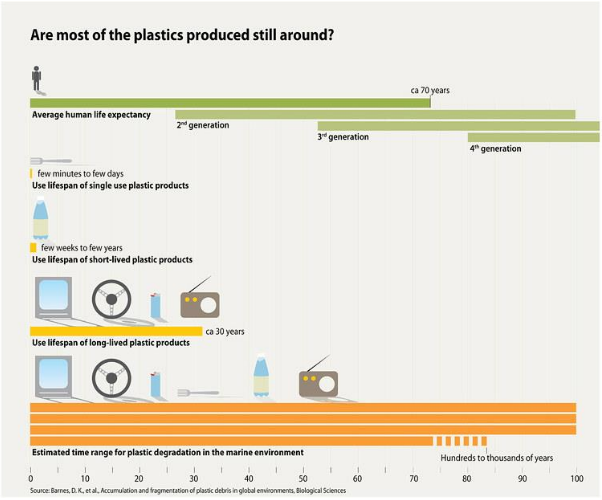

Figure 1. Accumulation and fragmentation of plastic debris in global environments (Barnes *et al.* 2009)

Between 60 and 90 % – sometimes as much as 100 % – of the litter that accumulates on shorelines, the sea surface and the sea floor is made up of one or a combination of different plastic polymers. The most common items, constituting over 80 % of the litter stranded on beaches (Andrady 2015) are cigarette butts, bags, remains of fishing gear, and food and beverage containers. Likewise, 90 % of the litter collected from sea floor trawls is made up of plastic (Derraik 2002; Galgani *et al.* 2015).

Despite the fact that rivers are major sources of marine litter, there are no global estimates on man-made debris reaching the ocean with river flows. Therefore, of the estimated 4.8 to 12.7 million tonnes of litter which enter the marine environment in 2010 from land-based sources within a 50 km-wide coastal zone (Jambeck *et al.* 2015), the proportion delivered by rivers is unknown. Debris originating farther than 50 km inland from the coast could also be added to these estimations.

Due to the slow rates of plastic degradation in the marine environment (from months to hundreds of years), it can be assumed that a major part of the debris that leaked into the ocean after the onset of mass production in the 1950s is still there. Rough estimates of the global stock of plastic marine debris range between 86 and 150 million tonnes, assuming leakage ratios between 1.4 and 2.8 % (McKinsey Center for Business and Environment 2015).

At a global level, UNEP has estimated the economic impact of marine plastics (excluding microplastics), including losses incurred by fisheries and tourism due to plastic littering, as well as beach clean-up costs, at around $13 billion per year. Only in the European Union fishing fleet is estimated to lose $81.7 million (61.7 million Euros) per year.

Materials and Methods

Monitoring of litter on the coastline should quantify and characterize litter pollution and provide comparable datasets to support national and regional assessments of marine litter pollution. Consequently, it should provide the basis for the development of solid waste management, appropriate infrastructure, control and support the mitigation measures. It should also help to understand the impact of marine litter on marine ecosystems and biota (Cheshire *et al.* 2009).

The European Commission decision of September 1st, 2010 on criteria and methodological standards on good environmental status of marine waters has established that marine litter should be evaluated. This should allow the assessment of trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source.

Sampling units can be identified on the selected beach sectors. A sampling unit is a fixed section of a beach covering the entire area from the water's edge (where possible and safe) and the area where the sandy part ends and the asphalted / built-up part begins (Galgani *et al.* 2013).

The monitoring was done on a section of 100 m length, according to the sector's delineation. The section length was the same for each monitoring session. The GPS position is obligatory in order to ensure using the same monitoring site for each monitoring session. All litter items (size more than 2.5 cm) found on the beach have a unique identification number and should be included in the monitoring protocol. Data could be entered immediately while the waste is picked up or it is also possible to collect all litter in closed bags and to make the registration afterwards. Human errors such as unclear handwriting, forgetting to enter some data in the form, not seeing all litter items (leaving litter behind), mismatching categories, etc. should be taken in account.

Any unknown items that are not listed in the monitoring protocol will be marked separately at the end of the form in the special box with brief description and photographs.

After the registration of all the items they were sorted according to the material types (plastic, metal, paper/cardboard, glass, rubber, wood, textile, other), placed in different bags and weighted separately. The weight per category was recorded in each observation sheet. The monitoring sessions were conducted in spring (April) and autumn (mid September – mid October) 2019.

Results and Discussion

Plastic litter in the Black Sea coast

Marine litter is recognized as a worldwide rising pollution problem affecting all the oceans and coastal areas of the world (Galgani *et al.* 2015; Ryan 2015; Thompson 2015) and the Black Sea is not an exception. However, there is a lack of comparable and reliable data and very limited information regarding the quantities and composition of marine litter in the Black Sea. It is admitted that the prevailing material of marine litter is plastic. In the recent years, more and more organizations are willing to combat marine litter and a variety of projects and activities are implemented nowadays in order to minimize the extent of this issue. "Assessing the vulnerability of the Black Sea marine ecosystem to human pressures" (ANEMONE) is aiming to enhance knowledges, skills, to exchange the experience and good practices, innovation, harmonized methodologies and joint research. Within the ANEMONE Project the marine litter case studies were conducted with the involvement of citizens.

ANEMONE also had made a step forward in filling the scientific research gap regarding the beach litter pollution in the Black Sea by organizing two synchronous monitoring sessions in spring (April) and autumn (October – November) of 2019 in the participating riparian countries: Romania (Mare Nostrum NGO), Bulgaria (Institute of oceanology – BAS**)**, Ukraine (Ukrainian Scientific Center of Ecology of the Sea) and Turkey (Turkish Marine Research Foundation). There were 16 surveys performed in Romania, 2 in Bulgaria, 2 in Turkey, and 6 in Ukraine - 26 surveys in total, covering a surface of 78308 m^2 of beaches.

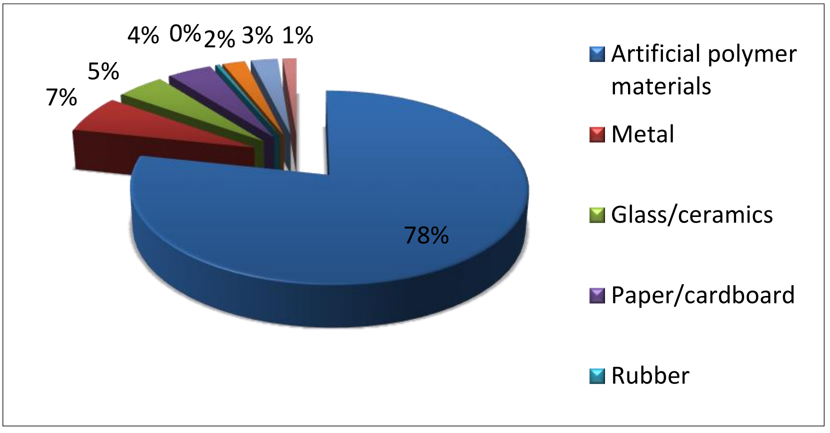

Figure 2. The most abundant materials of marine litter at Black Sea beaches (2019)

The total amount of items was 64703 (spring 27,080; autumn 37,623), the most common material was plastic, constituting 78% of the total amount (50,681 plastic items) (Figure 2). This finding is quite in line with the global statistics that emphasize the fact that plastic waste makes up to 80% of all marine debris from surface waters to deep-sea sediments.

Table 1 presents the densities per each beach sector from Bulgaria, Romania, Turkey and Ukraine, from 2009 to 2019. Within ANEMONE study, the locations with highest densities included Turkey with 2.81 items/m^2 and Romania with 0.95 items/m^2. Sites with intermediate litter density were in Bulgaria (0.57 items/m^2 and the lowest diversity was recorded in Ukraine, 0.22 items/m^2. The average density for the surveyed beaches was 0.82 items/m^2. In Romania, the densities varied between 0.18 items/m^2 (Corbu) and 2.33 items/m^2.

Table 1. Results of beach surveys for marine litter in the Black Sea

Location	Methods	Litter density (items/m^2)	Period	Authors/Organization
Romania	100 m length (MSFD)	0.95	2019	Mare Nostrum NGO
Bulgaria	100 m length (MSFD)	0.57	2019	IO-BAS
Turkey	100 m length (MSFD)	2.81	2019	TUDAV
Ukraine	100 m length (MSFD)	0.22	2019	UkrSCES
Turkey	5 – 100 m length (OSPAR)	0.09 – 3.24	2009 - 2018	Terzi *et al.* 2020
Turkey	100 length (MSFD)	1.512±0.578	2015 - 2016	Oztekin *et al*. 2020
Bulgaria	100 length (MSFD)	0.64	2017	Simeonova and Chuturkova 2020
Turkey	OSPAR	1.22 – 4.17	2016 - 2017	Aytan *et al.* 2020

In Turkey, the litter density reached up to 4.17 items/m^2 (Aytan *et al.* 2020), one of the highest value ever recorded. In Bulgaria, the litter density ranged between 0.64 items/m^2 to 0.57 items/m^2, between 2017 and 2019 (Simeonova 2020). The surveys were performed during different seasons, in different regions with specific characteristics, with more or less anthropogenic activities that influence the presence of litter. The methods used, MSFD and OSPAR Convention, are quite the same. To have a clear view of the litter density around the Black Sea basin, however, it is highly important to define a common database where to make data available and common protocols to be used in monitoring in line with the requirements of MSFD and the Convention on the Protection of the Black Sea Against Pollution.

The artificial polymer material prevailed in all participating countries, as can be easily observed in Figure 3. The highest quantity was registered in Romania (33468), followed by Turkey (9337), Bulgaria (4395) and Ukraine (3481).

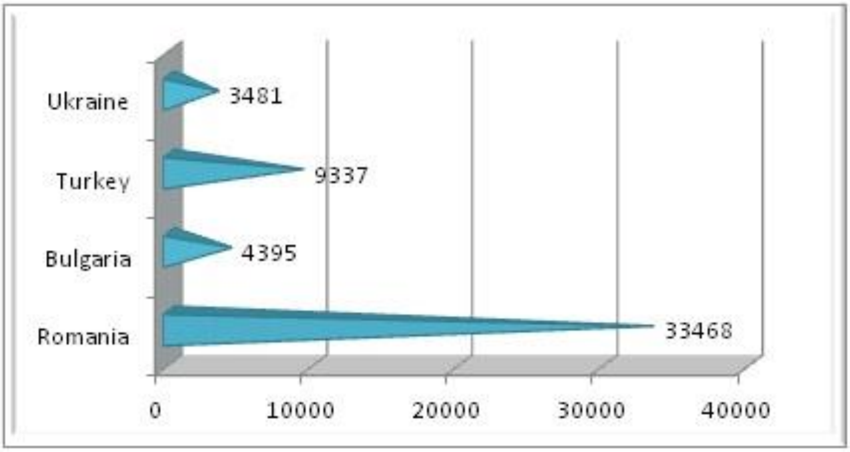

Figure 3. Artificial polymer materials on the Black Sea beaches

Plastic litter is not only an environmental, but also a health problem. Medical and sanitary wastes constitute a health hazard and could potentially seriously injure people. A large number of cotton bud sticks (475 items), diapers (32 items), syringes and their needles (25 items), medical/pharmaceuticals containers/tubes (48 items), as well as sanitary towels (103 items) were identified on the Black Sea beaches.

The top 10 common plastic items were: cigarette butts and filters (G27) (21000 items), crisps packets/sweets wrappers (4730 items), plastic pieces 2.5 cm > < 50cm (3778 items), polystyrene pieces 2.5 cm > < 50 cm (2764 items), plastic caps/lids drinks (1990 items), small plastic bags, e.g. freezer bags incl. pieces (1958 items), polystyrene pieces 0 - 2.5 cm (1729 items), straws and stirrers (1406 items), plastic pieces 0 - 2.5 cm (1193 items) and string and cord (diameter less than 1 cm) (858 items).

Plastic litter at the Romanian Black Sea coast

Regular surveys and monitoring events are being organized in Romania, by Mare Nostrum NGO, starting from 2014 for the aim of providing information on temporal and spatial distribution of marine litter. The strategy adopted is based on the measurement of quantities and inventory for collection purposes. The small fragments measuring less than 2.5 cm, micro-litter, is not being targeted by the monitoring surveys. Recording the rate at which litter accumulates on beaches through regular surveys is currently the most commonly-used approach for assessing long-term accumulation patterns and cycles. The studies performed to date have demonstrated abundance of 0.95 items/m^2. The monitoring is taking place twice per year (April and October), on 8 beach sectors established along Romanian seaside, from South to North (Vama Veche, Saturn, Tuzla, Eforie, Constanta, Mamaia Nord, Navodari and Corbu). A total of 45814 items were recorded, removed and classified. Plastic accounts for a large proportion of the litter found on beaches in all 8 areas (Table 2).

Table 2. Percentage of plastic in litter collected in Romania, 2019

Sector	April 2019		September 2019	
	Artificial polymer material (number)	**Percentage %**	**Artificial polymer material (number)**	**Percentage %**
Vama Veche	503	**55**	1.938	**88**
Saturn	513	**58**	3.271	**75**
Tuzla	183	**51**	1.669	**73**
Eforie	1.328	**34**	4.226	**79**
Constanta	1.488	**79**	7.986	**85**
Mamaia Nord	1.320	**58**	3.920	**75**
Navodari	1.464	**70**	2.967	**71**
Corbu	210	**78**	482	**89**

The average percentage for artificial polymer materials was estimated as 73% of all litter found on the Romanian beaches in 2019 (Figure 4). Metal was on the second place and reaches only 8%, followed by glass/ceramics (6%) and paper/cardboard (5%). The less abundant categories were cloth/textile and processed wood (3%), other (2%) and rubber (0%).

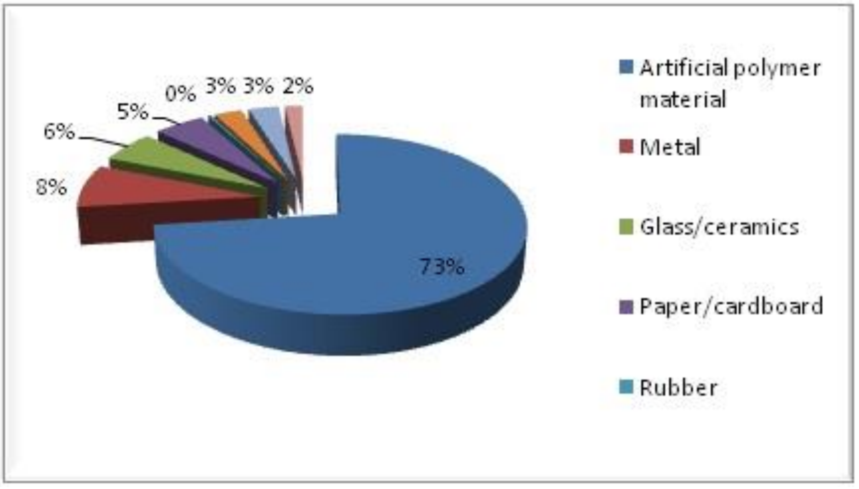

Figure 4. The most abundant materials of beach litter in Romania (categorized), 2019

Among the polymer artificial material category, the cigarette butts and filters (G27) were the most common (19779 items), followed by crisps packets/sweet wrappers (G30) (3749 items) and small plastic bags, e.g. freezer bags incl. pieces (G4) (1724 items) (Figure 5).

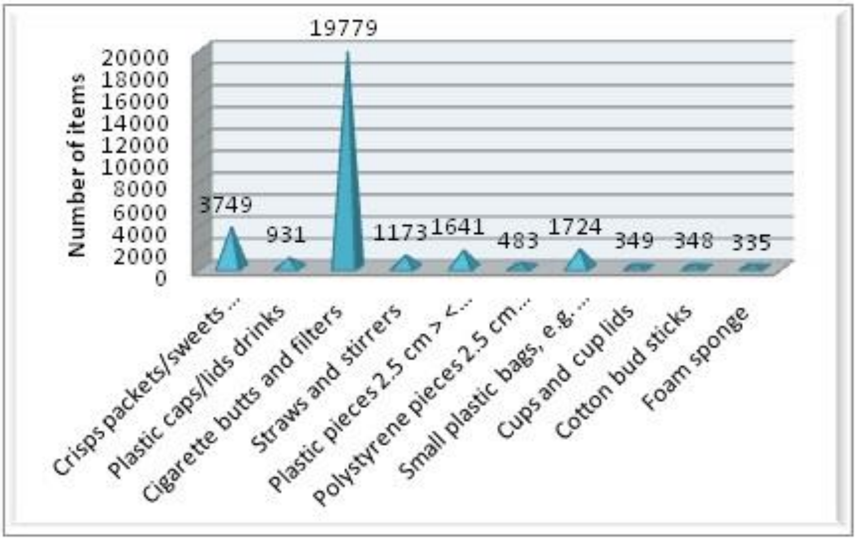

Figure 5. Top 10 items found on the 8 Romanian beach sectors, 2019

The artificial polymer material reached the highest value in 2019 (Figure 6), when there were registered 33468 plastic items. The cigarette butts averaged 59% of total number.

Figure 6. Trends of artificial polymer material in Romania, 2016 – 2019

The monitoring sessions were performed in spring, before the summer season started and in September, after it. The amount of litter was found to be very variable: April – 7009 items and September– 26459 items. For instance, Figure 7 shows the differences for the top most common items and we can see that crisps packets/sweet wrappers (G30), straws and stirrers (G35) were more abundant in the autumn session. However, this is not a rule, because there were items that showed higher number in April, such as plastic pieces 2.5 cm > < 50 cm (G79) (966 in April and 675 in September), small plastic bags, e.g. freezer bags incl. pieces (G4) (929 items in April and 795items in September) or foam sponge (G73) (182 in April and 153 in September).

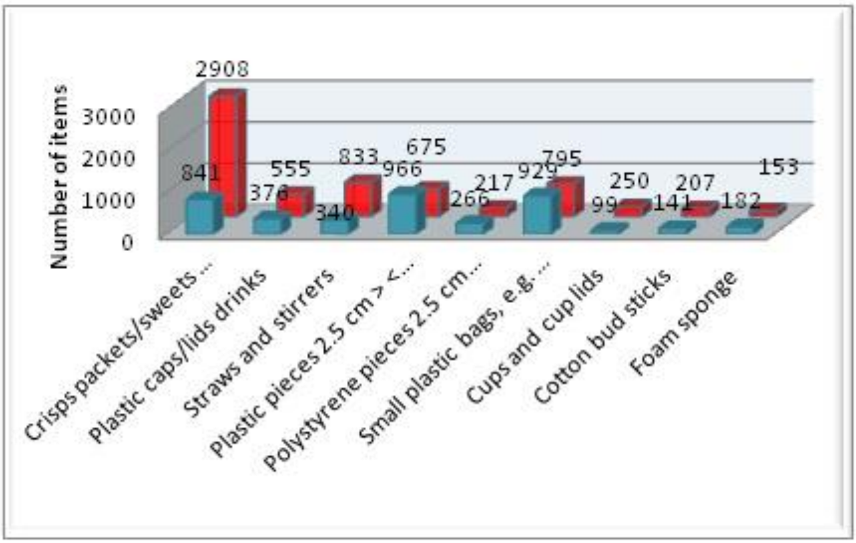

Figure 7. Differences between monitoring sessions, 2019
(Front row: spring, back row: autumn)

Plastic litter at the Bulgaria, Turkey and Ukraine coast

Institute of Oceanology – BAS, Varna, Bulgaria, within ANEMONE project organized 2 monitoring campaigns, in April and in September 2019. But, here the trend was different; meaning that in spring, the number of plastic litter was about 2.5 times higher than in autumn (Figure 8).

The most common items were cigarette butts (G27) with 659 items, followed by plastic pieces 2.5 cm > < 50 cm (G79) with 650 and crisps packets/sweets wrappers (G30) with 430 items.

In Turkey, the situation was the same as in Bulgaria. According to the monitoring reports of Turkish Marine Research Foundation (TUDAV), in spring the number of litter made of artificial polymer material was 8629 while in autumn it was 12 times less – 708 (Figure 8). However, the items counted in the autumn survey presented less as not all the litter pieces were counted due to a logistical problem. Unlike Romania and Bulgaria, in Turkey, the most abundant were polystyrene pieces 2.5 cm > < 50cm (G82) with 2251 items, plastic pieces 2.5 > <50 cm (G79) with 1438 items and plastic caps/lids drinks (G21) with 652 items.

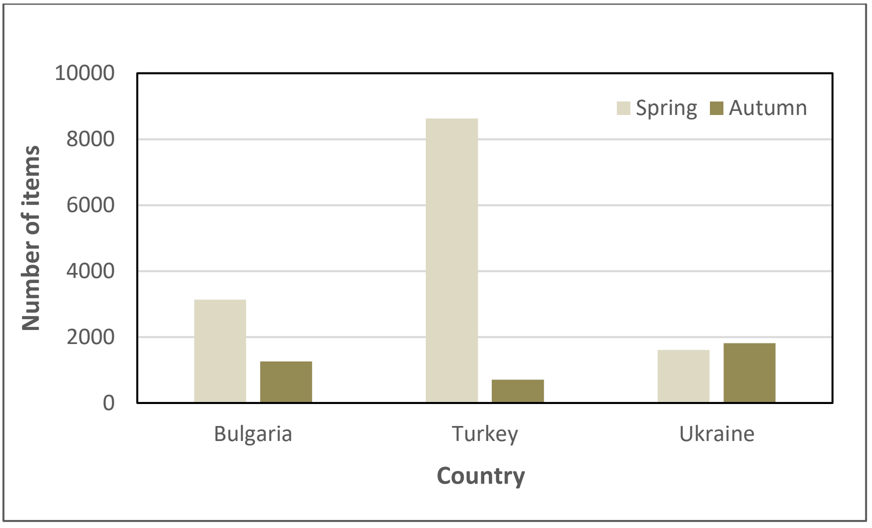

Figure 8. Plastic litter collected by the surveys in spring and autumn 2019 in Bulgaria, Turkey and Ukraine

Ukraine had a total of 3481 plastic items during two surveys made by the Ukrainian Scientific Center of Ecology of the Sea (UkrSces). The litter values were not so variable: in spring the number of plastic debris was 1669 and in autumn – 1812 (Figure 8).

The polystyrene pieces 0 – 2.5 cm (G81) prevailed in Ukraine (1006 items), being followed by cigarette butts and filters (G27) (480 items) and small plastic bags, e.g. freezer bags incl. pieces (G4) (228 items).

Conclusion

Plastic pollution is a global problem caused mainly by excessive consumption and lack of effective waste management. Nowadays, systematic efforts to collect data on the amount, distribution, composition and sources of plastic litter along the coastline of the Black Sea are rather limited. ANEMONE Project sets the baseline for joint scientific assessment and monitoring in 2019 and it should be continued in the coming years, ensuring the creation of long-term data and information series that cover the whole Black Sea coastline.

Artificial polymer material accounted up to 78% of all the litter collected. The most frequently found items included cigarette butts and filters (G27), crisps packets/sweets wrappers (G30) and plastic pieces 2.5 cm > < 50cm (G79). The highest quantity was registered in Romania, followed by Turkey, Bulgaria and Ukraine.

It is essential to support further research to fill the knowledge gaps on plastic debris fluxes, its impacts on maritime socio-economic sectors, biota and on human health, on the occurrence of abandoned, lost or otherwise discarded fishing gear (ALDFG) and on its degradation mechanisms in the environment. In this respect, in order to strengthen the efforts of the ANEMONE community it is recommended to reinforce and consolidate participatory science initiatives, encouraging the collaboration between scientific communities.

The development and implementation of common protocols and standardized methods for plastic litter assessment in the Black Sea, especially in relation with different size categories, sampling procedures and reference values are needed to be harmonized and adopted at regional and national levels of all the Black Sea countries.

Acknowledgement

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Analysis of the monitoring of the beach litter in the Georgia

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Abstract

Marine litter is included in the Marine Strategy Framework Directive as one of the Descriptors – Descriptor 10, for determination of marine environmental status (Directive 2008/56/EC_MSFD). Marine litter is considered as a crucial and complicated environmental problem in the Black Sea basin (BSC 2007). The scientific group of Iv. Javakhishvili Tbilisi State University and Scientific/ Research Firm "GAMMA" gave a start to the investigations of beach litter in the Georgian coastal area in 2015 within the EC-UNDP funded projects "EMBLAS I and II" and "EMLAS Plus". With the purpose of conducting investigations, the European monitoring methodology and protocols were harmonized and adopted for our region. Five sites in terms of macro litter monitoring in the Georgian Black Sea coastal area was selected. The survey program included identification and categorisation of macro-litter (items of 2.5 cm and over). The abundance of litter ranges within 0.07 - 1.12 items/m^2. The surveyed beaches differ by the number of visitors per season and infrastructure. Based on the results, it is deduced the plastics is the largest category of household waste accumulated on the beaches, whereas the remaining categories of paper, metal, glass and rubber do not exceeding 5% in total. An analysis of the data obtained, revealed, that the locations near the mouths of the rivers had significantly larger amounts of litter, likely receiving litter from marine and riverine sources. The continuous data monitoring is required to create more consistent picture of the marine litter dynamics in the coastal zone.

Keywords: Georgia, beach, macro litter, plastic, monitoring

Introduction

Marine litter is included in the Marine Strategy Framework Directive as one of the Descriptors – Descriptor 10, for determination of marine environmental status (EC 2008). To develop effective strategies for the establishment of survey programs that aim to reduce plastic litter and its possible impacts, it is necessary to identify and quantify the litter found and their pathways to the marine environment. The composition of litter is one of the important point of coastal assessments. A detailed study of litter composition on the beaches provides information on potential sources of the litter found and helps to assess the harm to the environment

Marine litter is considered as a crucial and complicated environmental problem in the Black Sea basin (BSC 2007). Available data are predominantly gathered on sandy beaches, while data for floating litter in the sea is exceptionally limited (Jeftic *et al.* 2009; Joint Black Sea Surveys 2017).

An assessment of beach litter shows that a large amount of debris has been observed in different areas of the southern Black Sea coast (Topçu *et al.* 2013; Terzi and Seyhan 2017; Aytan *et al.* 2020; Oztekin *et al.* 2020). The plastic is the most prevalent type of litter in the Black Sea. The southeastern side of the Black Sea was found to be more polluted than its western side (Terzi and Seyhan 2017). Conversely, compared to the eastern side, the western side of the Turkish Black Sea is ~ 3.8 times more populated and hence its marine litter was expected to be denser. An extremely high litter density (1.51 ± 0.58 items m^{-2}) is detected in Sarıkum Lagoon, which is located at about 42°N and 35°E (Oztekin *et al.* 2020). An even higher litter density with higher variance was estimated for Sarayköy Beach (2.10 ± 1.38 items m^{-2}), which is located at about 41.02°N and 40.38°E (Aytan *et al.* 2020). Monitoring of marine litter along the Bulgarian Black Sea coast (Simeonova *et al.* 2017) shows that the beaches were highly polluted due to local sources, where cigarette butts and filters were dominant. Since the highest marine litter accumulation was observed in summer, one can conclude that the accumulation is probably a result of recreational activities, increased tourist flow and wild camping. Therefore, the marine litter on the west coast of the Black Sea seems to be almost entirely of local origin. In summary, on the base of existing evidence the litter density on the west coast is less than on the south and east coasts.

Our scientific group was first that started the investigations of beach litter on Georgian coastal area in 2015 within the EC-UNDP funded projects “EMBLAS I and II” and “EMLAS Plus”. With the purpose of conducting investigations, the monitoring method and protocols were harmonized and adopted for our region. Obtained results were issued with project internal reports and some publications (Ozturk and Pogojeva 2019; Machitadze *et al.* 2016, 2018). This paper demonstrates the results of a survey conducted between 2015 and 2019 in frames of above-mentioned international projects.

Materials and Methods

Survey area

The surveyed area stretches across the central and southern part of the Black sea Georgian coastal area, from Sarpi (by the national borders of Turkey and Georgia) to river Rioni. This represents 90 km in length. Submarine slop and beaches are formed by the rivers' solid materials and alongshore transfer processes of bottom sediment. Southern part beaches – from Sarpi up to the mouth of river Natanebi – are presented with the pebble and gravel, turning to the sandy beaches on the north. Due to various anthropogenic factors within this zone, such as transit and economic corridor from east to west, intensive human activity, residential, tourist and recreational infrastructure within the coastline, the coastal and marine environments are affected with the pollution.

Sampling

Methodology for Monitoring Marine Litter on the beaches (JRC 2013) involves the assessment of the density and categories of litter items on a 100-metre survey section of the selected beach. Observations are conducted on the same section, thus the coordinates of the endpoints of the sections are marked. All items of litter on the selected sites were collected in compliance with the safety and precaution rules. Then they were counted and categorized/sub-categorised and documented within the field records. After completion of the works, the survey sites were cleaned and the collected litter is placed in the household bunkers (Machitadze *et al.* 2016, 2018).

The below considerations were taken into account for selecting 5 sites in terms of macro litter monitoring (Figure 1, Table 1);

The first selected survey sit located in 2 km to the north from the northern edge of Kobuleti. Unlike central part of Kobuleti, this zone has relatively low level of human activity: there are no private houses, touristic or recreational infrastructure, trade counters or domestic wastewater. There is no visible source of litter and the river mouth is quite far away from the beach. The area adjacent to the beach is not populated. Thus, there has not been detected any visible source of litter pollution. Taking all these facts into consideration, this part of costal line can be used for the detection of the background level of the pollution.

The second site - Ureki is a famous sea resort, becoming densely populated during the summer season. Children make up the majority of visitors due to its healing and recreational features. During the last couple of years, intensity of construction works and infrastructure development increased in Ureki, namely in Shekvetili zone. Riv. Tskaltsminda and Riv. Supsa mouths make up the northern border of Ureki. Thus, the main pollution sources of the resort's beach represent the rivers runoff and impact coming from the town.

The third survey site is located in Sarpi, along with the international East-West highway E60, which is located 200 m away from the gate of Georgian-Turkey state land border. The highway goes over the concrete wall, which is located on the backside of the beach. On the opposite side of the highway, there are private houses, hotels, cafes and guesthouses are operating. Sarpi beach gets very busy during the summer season. The effluent discharge point has been registered. The highway is permanently overcharged with cars and transit vehicles. Due to the high traffic on Georgian and Turkish crossing border, these vehicle are stuck for a couple of days. There are a lot of cafés, fast food facilities and counters for souvenirs around the place. Thus, this place is under the high pressure of human activity.

The fourth site is located close to the Riv. Tskaltsminda mouth. This section represents the northern end of Ureki beach, characterized with low customer demand and no cleaning activities are made.

The fifth monitoring site is located on southern periphery of Poti, near the Riv. Maltakva mouth. Maltakva beach spreads over 3 km. The width of the beach reaches to 170 m in some places. The beach is seasonally visited, thus the maintenance works are carried out regularly.

Table 1. Survey sites, coordinates and dates

#	Name of Beach	Coordinates	Survey date
1	Kobuleti	41.895863°N; 41.770758°E	29.10.2019
		41.895400°N; 41.770827°E	03.09.2019
		41.895854°N; 41.771141°E	17.09.2018, 20.04.2017
		41.895404°N; 41.771262°E	19.10.2016, 22.10.2015
2	Ureki	41.995491°N; 41.759237°E	26.10.2019
		41.995528°N; 41.758816°E	18.09.2019
		41.995077°N; 41.758869°E	21.10.2015
		41.995049°N; 41.759291°E	
3	Sarpi	41.522318°N ; 41.548278°E	28.10.2019
		41.522764°N; 41.548371°E	31.08.2019
		41.522902°N; 41.547649°E	20.09.2018
		41.522451°N; 41.547503°E	22.04.2017, 18.10.2016
4	Tskaltsminda	42.001920°N; 41.756811°E	26.10.2019
		42.001857°N; 41.757130°E	31.08.2019
		42.001507°N; 41.757124°E	
		42.001491°N; 41.756865°E	
5	Maltakva	42.106660°N; 41.683996°E	26.10.2019, 31.08.2019
		42.106796°N; 41.684486°E	
		42.106245°N; 41.684324°E	
		42.106419°N; 41.684780°E	

The survey program included investigation of macro-litter - 2.5 cm larger items. All items in this size category were collected, identified according to the "Master List" (JRC 2013) and recorded within the specific forms.

Figure 1. Selected sites for monitoring on beach litter along the Georgian Black Sea coast

Results and Discussion

The surveyed beaches differed with the seasonally visitor number and infrastructure. Also, with the collection, disposal and management of the litter on the beaches by the relevant municipal parties. Cleaning activities on our survey sites of Ureki and Sarpi are regularly carried out by local municipal organizations, especially during the summer holiday season (May-September). No cleaning works are carried out in the northern periphery of Kobuleti, Tskaltsminda and Maltakva as these sites are not visited by tourists.

The results revealed that the total load of macro litter on Kobuleti section (Figure 2) ranged from 1000 to 3000 items/100m. There is a clear trend towards reducing the amount of the litter from 2016 to 2019 (Figure 3).

Figure 2. Northern periphery of Kobuleti N.P. beach sampling section

There is also a visible trend of a sharp decline in the total amount of the litter in Ureki and Sarpi surveyed sites. The relatively low density of litters in these areas since 2016 as a result of daily cleaning activities. Thus, the obtained data represents the loading of a litter within a single day. The total amount of litter on these sites varied from 200 to 800 items/100m in 2017 - 2019.

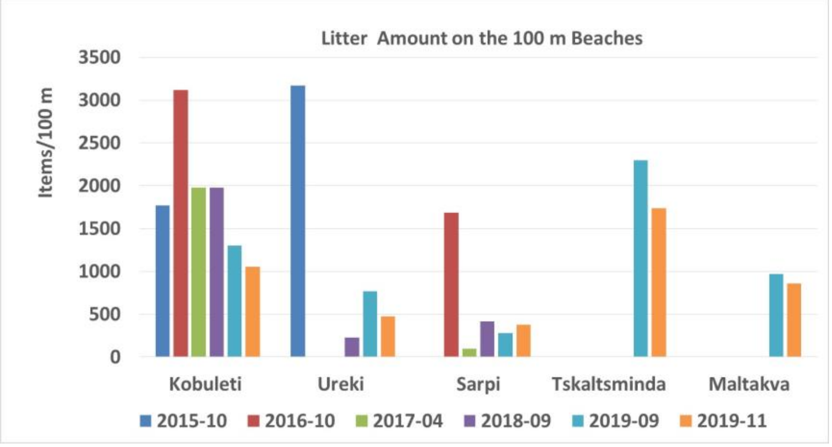

Figure 3. Total litter amount on the study beaches

According to the data of the two sessions in 2019, the density of litter on the Maltakva beach it reached to 1000 items/100m. This section can be considered as background level (like Kobuleti north periphery section). On Tskaltsminda beach, total load of litter ranged between 1700 and 2300 items/100m. Consequently, on Tskaltsminda beach there should be additional source of litter, such as river runoff. Therefore, this section should reflect their impact on the litter accumulation process.

Assessment of the studied beaches by CCI (Alkalay *et al.* 2007) shows that Kobuleti N.P. beach can be considered as moderately dirty. Although this section is not cleaned up regularly, there was a decrease in the amount of litter in 2017-2019 (Figure 2). The surveyed site in Ureki beach situated in central part of resort, whereas regular clean-ups were carried out seasonally, thus the area found as clean. Sarpi and Maltakva beaches were found to be clean. Tskaltsminda section was classified as extremely dirty due to the above-mentioned conditions (Table 2).

Table 2. Clean- coast indexes of the beaches

Name of Beach	Items/m²	CCI
Kobuleti N.P.	0.32-0.95	6–20:from moderate to dirty
Ureki	0.07-0.9	0.14–20: From clean to dirty
Sarpi	0.02-0.07	< 2: very clean
Tskaltsminda	0.84-1.12	20 +: extremely dirty
Maltakva	0.20-0.23	4–5: clean

Density of litters on studied beaches remain within the average amount of litter detected on the Black Sea coasts - 0.05-5.05 items/m^2 (Aytan *et al.* 2020) and is similar to the litter density range of other regions of the Black sea (Terzi and Seyhan 2017; Simeonova *et al.* 2017; Terzi *et al.* 2020).

In order to assess the nature of litter distribution and their sources, categorization was conducted according to the research methodology (JRC 2013). Tables 3 and 4 provides the percentage of essential categories of litter items.

Based on the results, it is deduced the plastics is the largest category of litter accumulated on the beaches, whereas the remaining categories of paper, metal, glass and rubber do not exceeding 5% in total (Alkalay *et al.* 2007).

Different ratio was identified within Sarpi beach section, whereas the content of plastic litter represents less than 70% and the share of metal litter was 10-18%. The share of rubber litter was quite high (5-9%). This might be due to the different sources of anthropogenic impact on this beach. In particular, the litter on Sarpi beach comes mainly from the highway. The road runs by the edge of the beach, whereas truck trailers have to stop for a long time while queuing to cross the state border. Thus, the drivers leave the following categories of litter: food waste, cans and bottles, as well as dismantled transport equipment.

Table 3. The percentage of litter items by the essential categories (%) on the beaches of Georgia between 2015 and 2018

Litter categories	Kobuleti N. P.	Ureki	Kobuleti N.P	Sarpi	Kobuleti N. P.	Sarpi	Kobuleti N.P	Sarpi	Ureki
Years	**2015**		**2016**		**2017**		**2018**		
Plastic	96.3	94.4	91.2	61.1	91.5	86	95.1	79.7	100
Rubber	0.1	0.3	1.9	5.1	1.9	2	1.8	5.8	-
Textile	0.9	1.7	3.3	3.3	2.8	-	-	-	-
Processed/ worked wood	0.1	0.8	0.5	1.4	-	-	-	-	-
paper/ Cardboard	0.3	0.7	-	1.6	-	-	-	-	-
Metal	1.1	1.3	1.2	18.1	1.4	10	2.6	14.5	-
Glass/ ceramics	0.8	0.7	0.4	5.8	2.4	2	0.5	-	-
Other	0.4	0.1	1.5	3.6	-	-	-	-	-

Table 4. The percentage of litter items by the essential categories (%) on the beaches of Georgia in 2019

Litter category	Tskaltsminda	Sarpi	Maltakva	Kobuleti N.P.	Ureku	Tskaltsminda	Sarpi	Maltakva	Kobuleti N.P.	Ureku
	09.2019					**10.2019**				
Plastic	95.6	68.8	93.0	90.8	89.6	98.2	68.7	96.8	95.5	97.9
Rubber	0.1	6.4	1.0	0.6	0.3	0.2	9	-	1.1	-
Textile	-	-	0.4	0.5	1.6	-	0	1.4	1	0
Paper	-	5.7	1.7	5.1	3.6	-	4.3	-	-	0.4
Processed/ workedwood	0.7	1.4	0.4	0.00	1.0	0.2	0.5	0.9	-	-
Metal	1.9	13.5	1.8	1.5	0.3	0.7	13.8	0.2	1.5	-
Glass	1.6	4.3	1.7	1.5	3.6	0.7	3.7	0.7	0.9	1.7

Regardless of cleaning activities carried out regularly, the percentage of litter categories within the surveyed sections are almost the same. In all occasions, plastic items represent the largest category of the litter. Due to this reason we have further sub-divided this category into sub-categories. The results show that the highest part of plastic litter composes the plastic bottles and caps, as well as containers of different product categories (food, cosmetics etc), packaging materials, etc. Some of these are washed out from the sea. This is deduced from the large number of unidentified plastic fragments of various sizes. These fragmentations of plastics are caused by the sea waves, UV, bacteriolocigal degredation etc. However, some part of the litter is also left by visitors on these beaches.

According to the surveys, the litter is dumped into the sea from land based sources. It is recognized that the presence of medical and pharmaceutical litter on the beaches belong to hazardous litter (Figure 4). Their ratio represents around 10% of plastic litter.

a  b 

Figure 4. Medical/pharmaceutical litter on the beaches Kobuleti (a) and Ureki (b)

A detailed visual observation of the coastal zone of the surveyed area was conducted to identify the sources of litter in the marine environment. Observations revealed several hotspots in the coastal zone.

There are certain subjective or objective factors in the coastal zone of Georgia, which cause the accumulation of large masses of litter washing upon the beaches. Daily cleanups on the resort beaches is less common after the end of the tourist season. As the result, the litter dumped on the beaches (during non seasonal time, in stormy periods) goes back in the sea and resides in the neighboring areas of the coast, depending on the direction and intencity of the streams. This can be considered as secondary loads.

One of the sources of litter in the marine environment are landfills, both municipal (organized) and spontaneous (illegal). Spontaneous landfills are one of the most serious problems and significant challenges in our country. There are illegal landfills in the coastal areas, in many large and small settlements. This problem is complex and is related to managerial and technical shortcomings, as well as low levels of public awareness. These landfills are mainly the source of the above medical and pharmaceutical litter. This type of litter is should be managed by the authorized services that serve the medical institutions.

Nowadays, there is a new legislative base on litter management in Georgia - the Waste Management Code and other normative acts, strengthening regulations and imposing new requirements on both legal entities and individuals. As the result, the following activities have been improved in the country: cleaning, collection of waste, disposal and recycling. Illegal landfills in the country were recorded, transportation of litter and polygons were arranged according to the requirements of international and national legislations. The infrastructure required for the waste management was upgraded. Thus, the declining trend in the amount of litter suggests that we are facing positive shifts. We believe that this trend is due to the activities taken place at the legislative level.

During the visual study of the shores, large areas of litter accumulation were observed on the several sections of the coastal zone. They were quite far from the nearest populated areas, which excludes the population factor in the process of accumulation. It is clear that the litter washed out from the sea have been accumulating on these sections for years, and their disposal by the municipal services is practically never done. During storms, debris still enters the sea and then moves to the other beaches of the coastal zone. So these areas of accumulation can be considered as a hotspot for constant loading (Figure 5).

Figure 5. One of the hotspot sections along the Natanebi River mouth

Conclusion

The research has been undertaken on the Black Sea coast of Georgia related to beach macro litter, the ratio between the essential categories and sub-categories and their sources. The situation of the state of the beaches was assessed by the clean-coast index (CCI). The surveyed beaches differ by the number of visitors per season and infrastructure, as well as with the collection, disposal and management of litter on the beaches by the relevant municipal parties. Based on the results, it is deduced the plastics is the largest category of household waste accumulated on the beaches, whereas the remaining categories of paper, metal, glass and rubber do not exceeding 5% in total.

An analysis of the data obtained, revealed, that the locations near the mouths of the rivers had significantly larger amounts of debris, likely receiving litter from marine and riverine sources. At this stage of investigations, no clear overall pattern in litter abundance or composition is fixed, as well as significant quantitative similarities between debris types were inconsistent, though some peculiarities in the composition of the solid waste were revealed in correlation with sources of the pollution. The continuous data monitoring is required to create more consistent picture of the marine litter dynamics in the coastal zone.

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Marine litter occurrence in the river-influenced Black Sea coast

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Abstract

Composition and abundance of anthropogenic litter were investigated on adjacent coastal beaches of three rivers flowing into the North-Western and Southern Black Sea. A single sampling survey was conducted during the period August – September 2019 within 4 sectors of sandy beaches with different level of urbanization situated at the Romanian and Turkish littoral of the Black Sea. The results of study evinced total of 3916 items with the maximum litter accumulations found on the Turkish coast. The most-represented items of anthropogenic litter in the evaluated samples were plastics, paper/cardboard, wood and glass/ceramic. Plastics made up the main share of litter on Black Sea coastal beaches near the river mouths (65–95%). The types of plastic items ranged from 15 to 54 among the sites, of which cigarette butts, plastic pieces (2.5 cm > < 50 cm), polystyrene and plastic caps/lids drinks constituted the highest number of artificial polymeric material. The characteristic of plastic litter composition of each selected Black Sea beach is attributable to river and human influences. Fragments and small plastic items were predominant for most of the beaches, including wild beaches and those that had lower levels of urbanization, confirming that riverine outflows have an important impact on plastic litter pollution on Black Sea coastal beaches.

Keywords: Beach litter, plastic pollution, river-influenced areas, Black Sea

Introduction

At present, it is widely recognized that the marine litter (ML) has affected all parts of the world's seas and oceans, being present in all marine habitats, from densely populated regions to remote points far from human activities, from beaches and shallow waters to the deepest areas of ocean (ARCADIS 2012; Galgani *et al*. 2013; van der Wal *et al.* 2013). Anthropogenic litter enters to marine environment from both sea-based and land-based sources, where may causes negative effects on the environment, economy, security, and health (Addamo *et al.* 2017; González-Fernández *et al.* 2016).

The Black Sea does not constitute an exception from marine litter global tendency; the marine litter pollution has been identified as a major issue affecting the environmental state of the Black Sea too. The occurrence of anthropogenic litter in the Black Sea has been reported in the recent years by various researchers, and is highlighted as a growing threat (Topcu and Ozturk 2010; Moncheva *et al*. 2016; Suaria *et al*. 2015; Simeonova *et al*. 2017; Öztekin *et al*. 2020; Terzi *et al*. 2020; Aytan *et al*. 2020).

Anthropogenic litter deposited on marine beaches has generally several sources, of which riverine input is estimated to be a major contributor (Castro-Jiménez *et al*. 2019; González-Fernández *et al*. 2016; Schmidt *et al*. 2017). The Black Sea is exposed to a substantial anthropogenic impact due to the big drainage basin and the large rivers runoff of the Black Sea including Danube, Dnieper, Bug, Dniester, etc. (BSC 2007; 2019). However, to date no comprehensive information is available about the amount of litter being transported through rivers to the Black Sea, as well as on the riverine litter ending-up on its coastal beaches. For this reason, our study aimed to evaluate the abundance and composition of the anthropogenic litter found on river-influenced beaches with different levels of development and use along three Black Sea regions, to reveal the transportation of land-based litter items through rivers and the pressure of river-borne litter in this particular marine basin.

Materials and Methods

Study Area

Anthropogenic marine litter was studied on four different beaches of the Black Sea located at various distances from the mouths of the most important rivers flowing into the Romanian and the Turkish Black Sea coast (Figure 1). The Romanian sites (RO01, RO02) were located 6.5 km, respectively 19.5 km in the south of the Sulina branch mouth. Sulina is the central, the shortest (70 km), and the straightest branch of the Danube River, with water depth ranging from 7 to 18 meters, and carries about 20% of the total Danube's water (Panin and Jipa 2002). Sulina beach (site RO01, 45.1438°N and 29.6845°E) is located at 2.5 kilometers from Sulina town and is an isolated beach that can be reached only by water to Sulina. It is a touristic beach with fine sand and shallow water being the widest growing beach in Romania. In 2019, the average number of tourists per year is 7396 and the town population was 3911 people (INSSE 2019). The site RO02 is located in the more Southern, narrower wild beach called Casla Vadanei (44.9945°N and 29.6369°E). Both Romanian selected beaches are also part of the Danube Delta Biosphere Reserve with local flora represented by salt and dune vegetation and include internationally protected species (Ciortescu 2015).

The Turkish sampling sites were selected in the southwestern (TR01) and southeastern (TR02) Black Sea coast near two the most important Turkish rivers (Sakarya and Yeşilırmak) flowing into the Black Sea (Figure. 1). The site TR001 (41.1261°N and 30.6470°E) is a typical sandy beach situated 0.2 km west of Sakarya River and in the proximity (6 km) of Karasu city. The site TR02 (41.3802°N and 36.6547°E) was selected on the sandy beach located in the proximity of the Yeşilırmak River (0.4 Km west) and 23 km north of Çarşamba city.

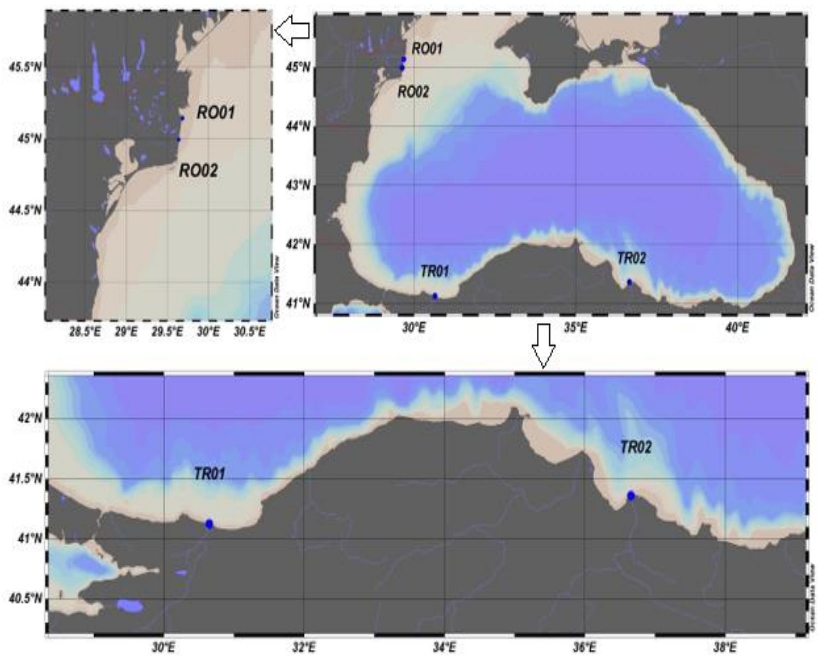

Figure 1. Map of the Black Sea study area showing the sampling sites at Romanian (RO01, RO02) and Turkish (TR01, TR02) beaches

Beach macro-litter monitoring

Data on litter deposited on the selected beaches were collected during August (in Romania) and September 2019 (in Turkey) following the work protocol described in the EU MSFD TG10 "Guidance on Monitoring of Marine Litter in European Seas-2013-JRC Scientific and Policy Reports" (Galgani *et al.* 2013). The methodology implies the visual identification of 100 m long fixed section of beach covering the whole area between the water edges (where possible and safe) or from the strandline to the back of the beach. All litter items greater than 2.5 cm were collected, counted, and categorized according to TSG – ML code given in the Annex 8.1 of the Guidance.

Results and Discussion

Litter abundance

A total of 3916 items were found on the four beaches within the three river-influenced regions of the Black Sea, with densities (items/m^2) of 0.113, 0.105, 2.039, and 0.329 for sites RO01, RO02, TR01, and TR02, respectively (Table 1). Litter abundances on surveyed beaches varied strongly between sampling sites, which can be attributed to the river type (Sulina branch of Danube River, Sakarya and Yeşilırmak River) as well as to the direct anthropogenic influence (e.g. recreational activities or illegal dumping) on sampling sites. In terms of litter abundance, the Turkish Black Sea sector recorded the highest abundance. Although the Romanian sites were located in Danube River mouth area, they were classified according to the Clean Coast Index (Alkalay *et al.* 2007) as being cleaner compared to the Turkish sites which ranged from moderate to the extremely dirty beaches (Table 1). Among all surveyed sites, the minimum abundance was registered on the wild Casla Vadanei beach (RO02), while the maximum abundance of litter was found on the urbanized Sakarya beach (TR01). Different hydrographic regimes specific for each Black Sea region selected in this study may be responsible for differences of litter abundances found in this study on all four beaches. The mean annual discharge varies strongly between the three rivers (from 1248 $m^3 s^{-1}$ in the Sulina branch to 193 $m^3 s^{-1}$ in Sakarya and 121 $m^3 s^{-1}$ in Yeşilırmak River, Driga 2004; Lekesiz *et al.* 2007) and is very likely to influence the total number of litters presented on the neighboring beaches. The litter abundances can be assigned also to the general direction and seasonal variability of major water current (the Rim Current) for the Black Sea, which could facilitate the downstream transport of Danube River-derived litter from the NWS waters southward along the South-Western and Southern Turkish coastline.

Table 1. Classification of the surveyed beaches according to the to Clean Coast Index (CCI)

Survey Site	Corresponding river	Items m^{-2}	Beach cleanliness*
RO01 (Sulina beach)	Danube (Sulina branch)	0.113	Clean
RO02 (Casla Vadanei beach)	Danube (Sulina branch)	0.105	Clean
TR01 (Sakarya beach)	Karasu- Sakarya	2.039	Extremely dirty
TR02 (Yeşilırmak beach)	Çarşamba-Yeşilırmak	0.329	Moderate

* CCI beach scale: very clean (0-2), clean (2-5), moderate (5-10), dirty (10-20) and extremely dirty (>20) (Alkalay *et al*. 2007)

Litter composition

The composition of the litter did not differ significantly between the coastal beaches of each river, especially not between the southern Black Sea Rivers (Sakarya and Yeşilırmak). The main proportions of litter types found at all four coastal beaches are shown in Figure 2. Concerning the coastal beaches of Sulina branch (Danube River), the artificial polymer materials (plastics) was the most dominant category of litter collected from both RO01(65%) and RO02 (86%) sites in August 2019. This category was followed at a great distance by paper/cardboard (~25%), as well as metal (~8%), processed/ worked wood (~5%) and cloth/textile (~3.5%). The fewest (< 1%) belonged to rubber and glass. In TR01 the most common litter type was found as artificial polymer materials 92.28% and followed by 4.18% glass/ceramic, 1.65% metal, 0.77% processed/worked wood, 0.74% paper/cardboard, 0.35% cloth/textile, 0.04% rubber. The most common litter type in TR02 was found as artificial polymer materials 94.36% and followed by 2.75% glass/ceramic, 1.59% metal, 0.58% cloth/textile, 0.43% processed/worked wood, 0.29% paper/cardboard.

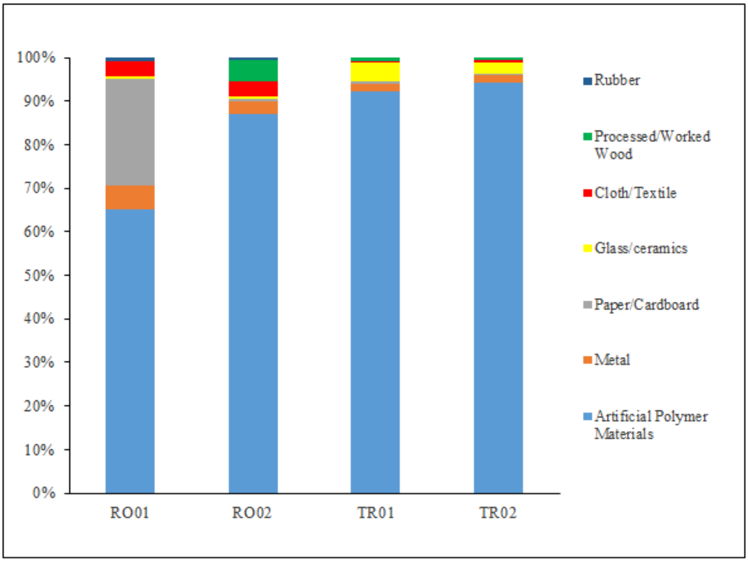

Figure 2. Proportion of the major categories of marine litters found on each evaluated beach. Note the prevalence of plastic items as major category of debris recorded in the Black Sea coastal regions impacted by diferrent rivers.

The most common litter items in the Romanian and Turkish survey sites are shown in Table 2 and Table 3, respectively. Top ten items comprised ~85% of all litter items in RO01 and RO02, and ~70% of total litter items in TR01 and TR02. All survey sites encountered top ten marine litter items occurred from artificial polymer materials (plastics), particularly Turkish sites. Beside plastics, top ten litter items for the Danube-River influenced coastal beaches also included paper/cardboard (RO01), cloth/ textile (RO01, RO02) and processed/ worked wood (RO02) (Table 2). For Turkish river-influenced sites, plastics made up almost the top ten items. The only one exception was found at TR001 where glass/ceramics bottles occupied the last place of the top ten items (Table 3).

Plastics were the most-represented items of anthropogenic litter in all the evaluated Black Sea river-influenced beaches. Figure 2 shows the distribution of marine litter per each survey area and categories where it can be seen the very large difference between artificial polymer material and other categories. The types of plastic items ranged from 15 to 54 among sites (Figure 3). With respect to items composed of plastic, for the touristic beach Sulina (RO01), the majority were cigarette butts (n=72), a marker of anthropogenic litter pollution level in highly urbanized and/or heavily used beaches (Araújo *et al.* 2018), while for the wild beach Casla Vadanei (RO02) the plastic pieces 2.5 > < 50 cm constituted the highest number of artificial polymeric material (n=41) (Figure 4). In addition to cigarette butts, in the category artificial polymeric materials were also found other plastic items such as shopping bags incl. pieces (n=2), plastic caps/lids drinks (n=6), tobacco pouches/plastic cigarette box packaging (n=6), crisps packets/sweets wrappers (n=21), straws and stirrers (n=8), plastic / polystyrene pieces 0-2.5 cm, drink bottles > 0.5l (n=21), food containers including fast food containers (n=5), plastic caps/lids drinks (n=25), medical / pharmaceuticals containers/tubes (n=3). In contrast to the Danube River beaches, none of the selected Turkish sites seemed not to be subjected to the cigarette butt's pollution. The abundance of this plastic item (G27) in both TR01 (n=4) and TR02 (n=3) beaches was lower than the 10 most common litter (Figure 3) or plastic items (Figure 4) found on the surveyed Black Sea beaches. This finding is not surprising, considering the level of urbanization of each analysed Black Sea beach. The top plastic litter items in Turkish survey sites TR01 and TR02 commonly occurred included beverage related items (drink bottles, plastic caps/lids drinks), polystyrene and plastic pieces 2.5 > < 50 cm (Figure 3 and Figure 4). These small items are generally refraction products formed as a result of degradation of large plastics and it can also be thought of as the main source of microplastics which accumulate and persist in the Black Sea environment for unlimited periods. The plastic litter items we found on the selected river-influenced beaches are similar to those formerly reported by other studies in the Black Sea coast (Topçu *et al.* 2013; Muresan *et al*. 2017; Golumbeanu *et al.* 2017; Öztekin *et al.* 2017; Terzi and Seyhan 2017; Aytan *et al.* 2020). The high presence of plastic we found on all evaluated Black Sea beaches is a common pattern that occurs in numerous other countries in coastal area (UNEP 2005). Nowadays, plastics present in anthropogenic litter are one of the biggest concerns for the ocean regarding the marine pollution because of their inherent properties, such as enduringness and widespread ascending use (Thompson *et al.* 2009; Lechner *et al.* 2014; Lebreton *et al.* 2017).

Table 2. Ten most common items of marine litter collected in the Romanian Black Sea coast during August 2019 (APM: Artificial Polymer Materials).

Survey Site	TSG_ML Code	Litter item	Material class	Percentage of total ML
RO01	G27	Cigarette butts and filters	APM	31.72
	G158	Other paper items	Paper/ Cardboard	21.59
	G30	Crisps packets/sweets wrappers	APM	9.25
	G3	Shopping Bags incl. pieces	APM	5.29
	G35	Straws and stirrers	APM	3.52
	G145	Other textiles (incl. rags)	Cloth/ Textile	3.52
	G178	Bottle caps, lids and pull tabs	Metal	3.52
	G21	Plastic caps/lids drinks	APM	2.64
	G25	Tobacco pouches / plastic cigarette box packaging	APM	2.64
	G78	Plastic/polystyrene pieces 0-2.5 cm	APM	2.20
RO02	G79	Plastic pieces 2.5 > < 50 cm	APM	27.70
	G21	Plastic caps/lids drinks	APM	16.89
	G8	Drink bottles >0.5l	APM	14.19
	G82	Polystyrene pieces 2.5 cm > < 50 cm	APM	4.73
	G22	Plastic caps/lids chemicals, detergents (non-food)	APM	4.05
	G30	Crisps packets/sweets wrappers	APM	4.05
	G7	Drink bottles <=0.5l	APM	3.38
	G10	Food containers incl. fast food containers	APM	3.38
	G138	Shoes and sandals (e.g. Leather, cloth)	Cloth/ Textile	3.38
	G171	Other wood < 50cm	Processed/ Worked Wood	3.38

Table 3. Ten most common items of marine litter collected in the Turkish Black Sea coast during September 2019 (APM: Artificial Polymer Materials)

Survey Site	TSG_ML Code	Litter item	Material class	Percentage of total ML
TR01	G21	Plastic caps/lids drinks	APM	10.69
	G82	Polystyrene pieces 2.5 cm > < 50cm	APM	10.54
	G79	Plastic pieces 2.5 cm > < 50cm	APM	9.77
	G74	Foam (packaging)	APM	7.91
	G30	Crisps packets/ sweets wrappers	APM	6.36
	G24	Plastic rings from bottle caps/lids	APM	6.15
	G74	Foam (Polyurethane)	APM	5.59
	G7	Drink bottles <=0.5 l	APM	4.96
	G23	Plastic caps/lids unidentified	APM	4.18
	G200	Bottles, including pieces	Glass/Ceramics	3.23
TR02	G79	Plastic pieces 2.5 cm > < 50cm	APM	18.06
	G82	Polystyrene pieces 2.5 cm > < 50cm	APM	11.71
	G21	Plastic caps/lids drinks	APM	6.65
	G23	Plastic caps/lids unidentified	APM	6.21
	G10	Food containers incl. fast food containers	APM	5.92
	G74	Foam (Polyurethane)	APM	5.06
	G7	Drink bottles <=0.5 l	APM	4.05
	G89	Plastic construction waste	APM	4.05
	G30	Crisps packets/ sweets wrappers	APM	4.05
	G24	Plastic rings from bottle caps/lids	APM	3.76

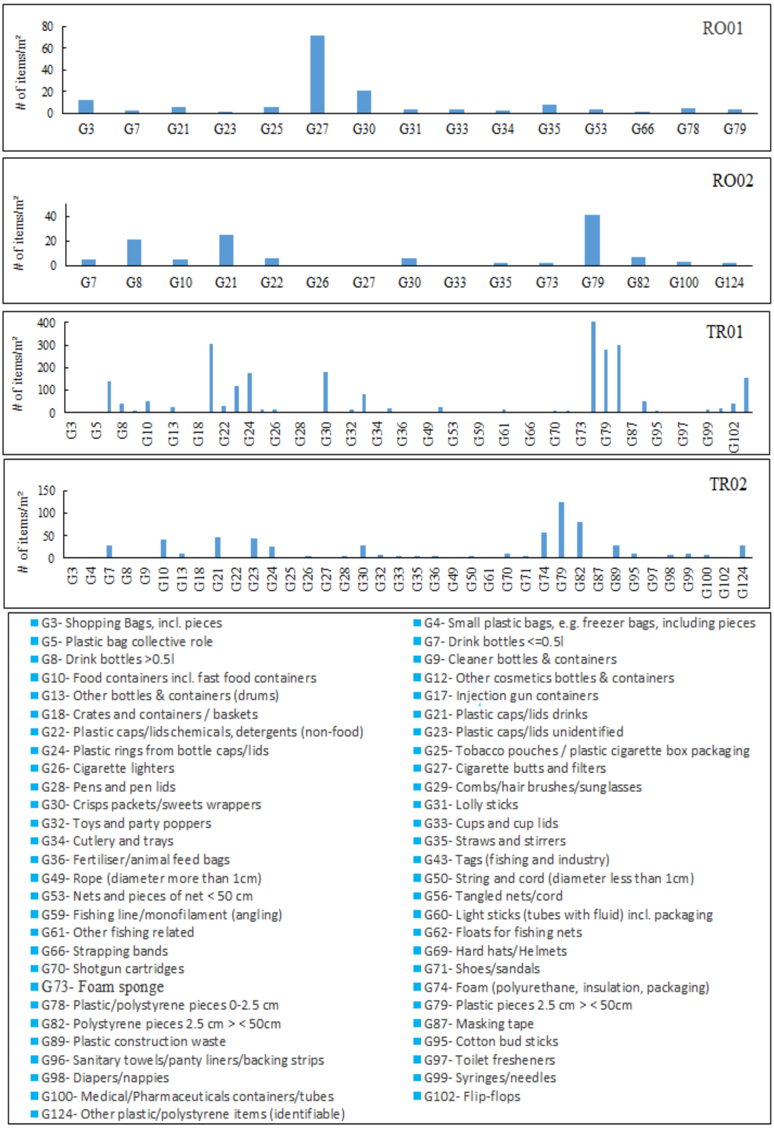

Figure 3. Plastics items (ranged from 15 to 54 among sites) counted on 4 different beaches at 2 geographical locations of the river-influenced Black Sea coast: Romania (RO01, RO02) and Turkey (TR01, TR02).

Figure 4. Distribution of the top three plastic items on Black Sea coastal beaches corresponding to the rivers Danube (RO01, RO02), Sakarya (TR01) and Yeşilırmak (TR02)

Conclusion

The results of the present study showed litter accumulation on the Black Sea coastal beaches at three important rivers mouths (Sulina-Danube River branch, Sakarya and Yeşilırmak) with the abundances increasing from the Northwestern (Romania) towards Southern (Turkish) coastline. The composition of the macrolitter recorded on each surveyed beach reflected its ability to reach the estuarine shoreline of the selected rivers and the influence of the beach users. The visual monitoring data on the beach macro-litter showed a clear predominance of plastic (up to 94% of the total items), thus confirming the previous findings regarding the major input of plastic into the sea via the rivers. However, the results presented here are based on a single sampling in late summer (August) and earlier autumn (September) 2019.

Knowledge of how the composition of marine litter varies over the space and time seems to be of a major importance for understanding of river influence in the litter pollution of the coastal Black Sea. Therefore, we suggest that further detailed studies based on sampling beaches all year round would be worthwhile in understanding of litter accumulation on Black Sea coastal beaches that are influenced by riverine input.

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Preliminary analysis of Marine Litter Watch data of the European Environment Agency with particular reference to the Black Sea

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Abstract

In this study the Marine Litter Watch (MLW) database comprising data from European beaches, including seas, rivers and lakes has been analysed mainly for the sea beaches from 2014-2019. Among the four EU regional seas, the Black Sea appeared as the most littered beach (with a median value of 652 items/100m) with the Baltic Sea the least polluted (with a median value of 78 items/100m). The percentage share of plastics on beaches was very high for most EU regional seas (79-88%). In the top 10 litter items, cigarette butt & filters abundances were much higher for the Black Sea (36.4%) and the Mediterranean Sea (22.6%), compared to those for the north-east Atlantic and the Baltic Sea (both 13.2%). With a share of 66.1%, the Black Sea had the highest rate of Single-Use Plastics (SUP). Considering combined data, sea-beach litter appeared to increase steadily after 2014 with median values from 125 to 436 items/100m. The high values for the Black Sea caused an overall increase trend in beach litter at the European scale.

Keywords: Marine litter, beach, Europe, Black Sea, Marine Litter Watch

Introduction

Litter in general, but plastics in particular, is piling up in all aquatic systems (Schwarz *et al.* 2019). Although predominantly plastics, marine litter comprises a wide range of materials including metal, rubber, glass, paper, textiles etc. The most visible environmental effect of beach litter is entanglement, which can cause fatal consequences for marine species, compromising the ability to capture and ingest food, sense hunger, escape from predators, and reproduce, as well as decreasing body condition and impairing locomotion (GEF 2012). Macro litter items (>2.5mm) can also be mistaken for food and ingested by fish, mammals, birds or turtles, which may cause severe health issues (Kühn and van Franeker 2020). Macro litter on beaches degrades to meso- (5-25mm) and/or microplastics (< 5mm) due to UV light and other environmental factors. They can be ingested by marine species and thus transferred through the food chain. Ingestion of litter may cause loss of biodiversity and a reduction in overall ecosystem functions (GEF 2012).

Beach and sea floor litter cause injuries: A study in Australia reflects that 21.6% of beach users received injuries from beach litter at designated ‘clean’ beaches (Alkalay *et al.* 2007), illustrating that even ‘clean’ beaches pose a threat (Campbell *et al.* 2016).

In addition to its environmental and health impacts, marine litter also incurs socio-economic costs, mostly affecting coastal communities (Beaumont *et al.* 2019). In order to improve touristic appeal, communities and businesses must clean up the beaches before the start of the summer season (EEA 2016). The theoretical estimated cost of keeping all 34 million km of global coastlines clean is 69 billion USD (50 billion EUR) per year (UNEP 2017), and this figure will continue to increase if littering does not stop.

Several EU policies exist, associated with the management of marine litter. The Marine Strategy Framework Directive (MSFD 2008/56/EC; EC 2008) required EU member states to ensure that, by 2020, "properties and quantities of marine litter do not cause harm to the coastal and marine environment". The Single-Use Plastics Directive (SUPD 2019/904/EC; EC 2019) introduced a set of ambitious measures such as a ban on selected single-use products made of plastic (including cutlery, plates, straws, cups), measures to reduce consumption of food containers and beverage cups made of plastic, and specific marking and labelling of certain products as well as measures to deal with waste fishing gear containing plastic (EC 2019).

Information and data on marine litter is essential for tackling this crucial environmental problem. The European Environment Agency (EEA) has developed a Marine Litter Watch (MLW) mobile app and has been collecting beach litter data (mainly for seas but also for rivers and lakes) since 2013 with the participation of communities from Europe and beyond. MLW aims to strengthen Europe’s knowledge base on marine litter and thus provide support to European policymaking.

This study presents an assessment of the data collected by the EEA-MLW initiative activities held on the beaches of Europe’s regional seas between 2013 – 2019. As a result, the analyses were performed to answer the following questions with particular reference to the Black Sea:

a) Are there differences in composition of beach litter among EU regional seas?
b) Does MLW data provide indications on trends of beach litter from European seas?

MLW dataset

The up to date information on litter collection efforts within MLW can be found at: http://www.eea.europa.eu/themes/coast_sea/marine-litterwatch. The MLW includes data from beaches of four regional seas (the Baltic Sea, the Black Sea, the Mediterranean Sea and the North-East Atlantic Ocean) as well as from rivers and lakes.

The EEA-MLW database analysed in this report covers the period of 12th March 2013-31st December 2019. After excluding duplicates, offshore areas, ports/canals, outside wider European areas, non-aquatic areas (forest, land, town, etc.), the MLW database presented 1894070 litter items from 3012 surveys belonging to lake, river and sea beaches from the wider-European area (Figure 1) Wider-European area includes several surveys from the northern Africa coasts and eastern Mediterranean coasts.

Figure 1. EEA-Marine Litter Watch data locations between 12 March 2013 and 31 December 2019.

It is worth mentioning that rivers play an important role in transporting litter to sea and lake beaches. However, this study does not include analyses from river and lake beaches (total 1138 surveys). The main analyses focused on data obtained from the sea beaches (total 1884 surveys) (Table 1).

There are two types of data collection events in the MLW: clean-up (since 12th March 2013) and "monitoring" (since 7th April 2014). With the exception of some cases where countries provide their official monitoring results to the MLW database, MLW "monitoring" data in general cannot be regarded as official monitoring data. Within the scope of MLW initiative, "monitoring" survey or "monitoring" data is used to describe the survey/data collected with timely, organised and standardised efforts of the MLW communities, using European beach litter guidelines and the “joint list” of EU Technical Group on Marine Litter (Galgani *et al.* 2013), whereas clean-up surveys represents relatively lesser standardised efforts. Although the preferred stretch of beach for survey using the MLW apps is 100 m, these ranged between 33 and 3443 m for the “monitoring” events and between 1 and 33932 m for the clean-up in the database.

In this study, for quantitative analyses were undertaken, median values (rather than means) were used as suggested by Hanke *et al*. (2019) to eliminate error caused by extreme values in the data set, which are common with the marine litter data.

Table 1. Number of surveys and litter items reported to the EEA-Marine Litter Watch for different types of events between 12 March 2013 and 31 December 2019 (only wider-European data from sea beaches).

Database	Number of surveys	Sum of litter items
Cleanup events	**1189**	**1026503**
Baltic Sea	47	16634
Black Sea	146	108458
Mediterranean Sea	435	456520
North-east Atlantic Ocean	561	444891
“Monitoring” events	**640**	**496048**
Baltic Sea	36	13941
Black Sea	75	106192
Mediterranean Sea	402	303746
North-east Atlantic Ocean	127	72169
Event type not indicated	**55**	**98394**
Mediterranean Sea	34	51602
North-east Atlantic Ocean	21	46792
Total EU Sea-Beaches	**1884**	**1620945**

Results and Discussion

Beach litter among regional seas

The total number of “monitoring” surveys (640) was less than half the number of clean-up surveys (1189 surveys; Table 1). Among the four EU seas, Mediterranean beaches underwent the highest number of “monitoring” surveys (402), followed by the north-east Atlantic (127 surveys), Black Sea (75 surveys) and the Baltic Sea (36 surveys) (Table 1).

Based on the monitoring surveys, Black Sea beaches appeared as the most littered (median value of 652 litter items per 100 m) and the Baltic Sea the least polluted (median value of 78 litter items per 100 m) (Figure 2). Litter transport from large as well as numerous small rivers coupled with improper municipal waste dumping and lower levels of environmental awareness with respect to littering in the Black Sea could be the major reasons for this result.

Comparison of median values with the past data which use mean is difficult. The overall mean values found for the southern Black Sea were 275 litter items/100 m for 2009 (Topçu *et al.* 2013) and 3798 litter items/100 m for 2016/2017 (Aytan *et al.* 2020).

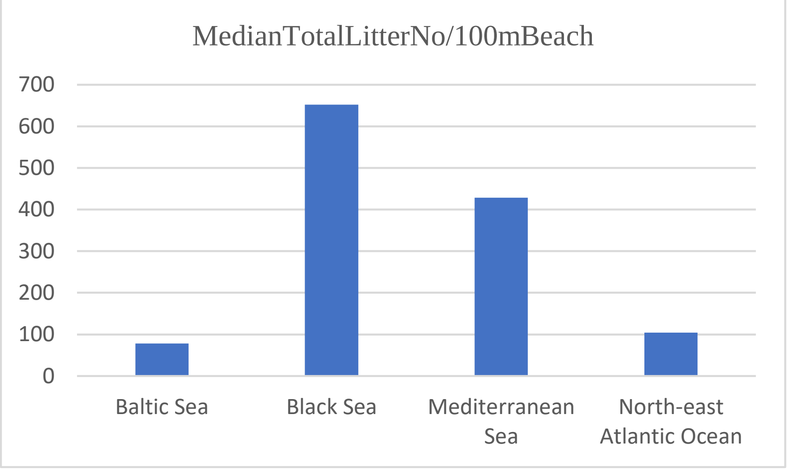

Figure 2. Comparison of litter numbers for beaches of different EU regional seas from 2014 –2019 (only European “monitoring” data for sea beaches)

The share of plastics was lowest for Baltic Sea beaches (about 61%) compared to other seas (79.8-88.5%) (Table 2). The share of plastics was also high in the southeastern Black Sea (84-91%) in 2016/2017 (Aytan *et al.* 2020) and western Black Sea (80.6%) in 2014-2017 (Paiu *et al.* 2017). Among all EU regional seas, the highest share of metals (5.3%) was recorded for the Black Sea beach litter.

Striking differences in the relative shares of different litter items were evident among the regional seas for the period 2013-2019 (Figure 3) obtained from “monitoring” events. For example, shares of cigarette butts/filters were much higher for the Black Sea (36.4%) and the Mediterranean Sea (22.6%), compared to those for the north-east Atlantic and the Baltic Sea (both 13.2%). Except for the northeast Atlantic, cigarette butts/filters were the most common litter item from beaches of all European seas. Araujo and Costa (2019) reported that the percentage share of cigarette butts/filters could be as high as 58% from beaches globally. Cigarette butts/filters, considered one of the commonest litter items on beaches, are ubiquitously disposed of, amassing as beach litter due to its light specific weight. Proper disposal of cigarette butts/filters thereby requires stringent measures. Apart from plastics fragments, drinking caps/lids, cotton bud sticks, straws and stirrers and crisp packets/sweet wrappers were notably present in all the regional seas. The list of the top ten items list is very similar to that reported for the European scale (Addamo *et al.* 2017).

Table 2. Percentage shares of different litter groups (based on total litter per beach values) among European regional seas from 2014-2019 (“monitoring” data only, paraffin excluded)

Litter category	Baltic Sea (%)	Black Sea (%)	Mediterranean Sea (%)	NE Atlantic Ocean (%)
Plastics	61.2	79.8	88.1	88.5
Glass/ceramics	18.7	4.9	3.2	3.3
Metal	3.7	5.3	2.6	1.3
Paper/Cardboard	2.4	4.3	2.7	1.3
Processed/worked wood	4.6	2.6	1.2	2.7
Cloth/textile	6.5	2.4	1.1	1.2
Rubber	2.4	0.5	1.1	1.6
Unidentified	0.5	0.1	0.1	0.1
Total	**100.0**	**100.0**	**100.0**	**100.0**

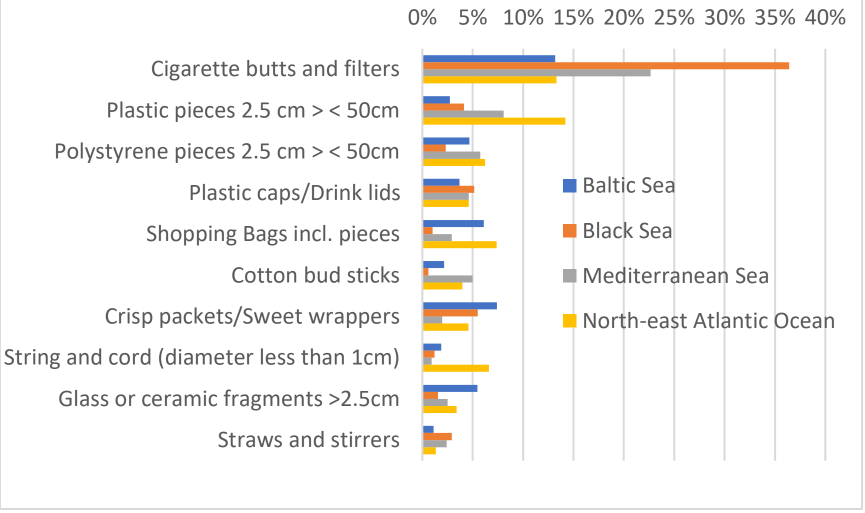

Figure 3. Comparison of Top Ten Item of litter collected by the regional sea beaches from 2014 – 2019 (“monitoring” data only, paraffin excluded)

With a percentage share of 66.1%, the Black Sea demonstrated the highest rate of Single Used Plastics (SUP) among the regional seas followed by the Mediterranean Sea (40%) (Figure 4). With a share of 12.2%, fishery related litter was highest in the north-east Atlantic and lowest for the Black Sea (1.6%) among the regional seas. Despite being among the major fishing areas of Europe, the fishery related litter also demonstrated a very low share (0.5%) in 2009 from the southern Black Sea (Topçu *et al.* 2013).

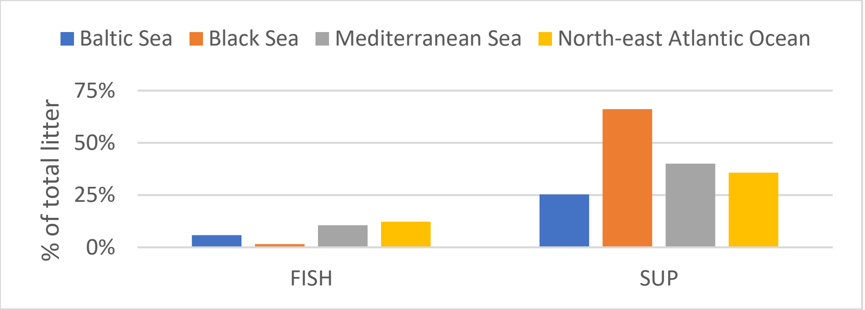

Figure 4. Comparison of regional seas for SUP and fishing-related items collected from European sea beaches between 2014 – 2019 ("monitoring" data only, paraffin excluded)

Beach litter trends for European seas

Annual median values per 100 m sea beach are shown in Figure 5 (for all seas combined) and Figure 6 (for each regional sea separately). For the combined data, sea-beach litter appeared as increasing steadily through the years; with median values rising from 125 to 436 items per 100 m beach (Figure 5). When data were displayed separately for each regional sea for the entire study period (Figure 6), the litter pollution was also at its highest for the north-east Atlantic and the Black Sea beaches in 2019. In contrary, lowest values were obtained for the Baltic and Mediterranean Seas in 2019. The high values observed in 2019 as well as in previous years were mainly due to Black Sea values, which caused an increasing trend in beach litter for the combined data at the European scale. When data from the Black Sea is excluded, litter pollution initially appears to be increasing until 2017 and later decreasing steadily (Figure 7).

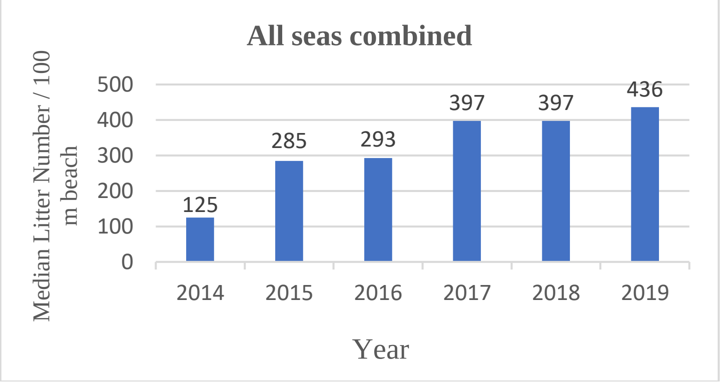

Figure 5. Changes in median beach litter numbers from 2014 – 2019 ("monitoring" data only, paraffin excluded, all regional seas combined).

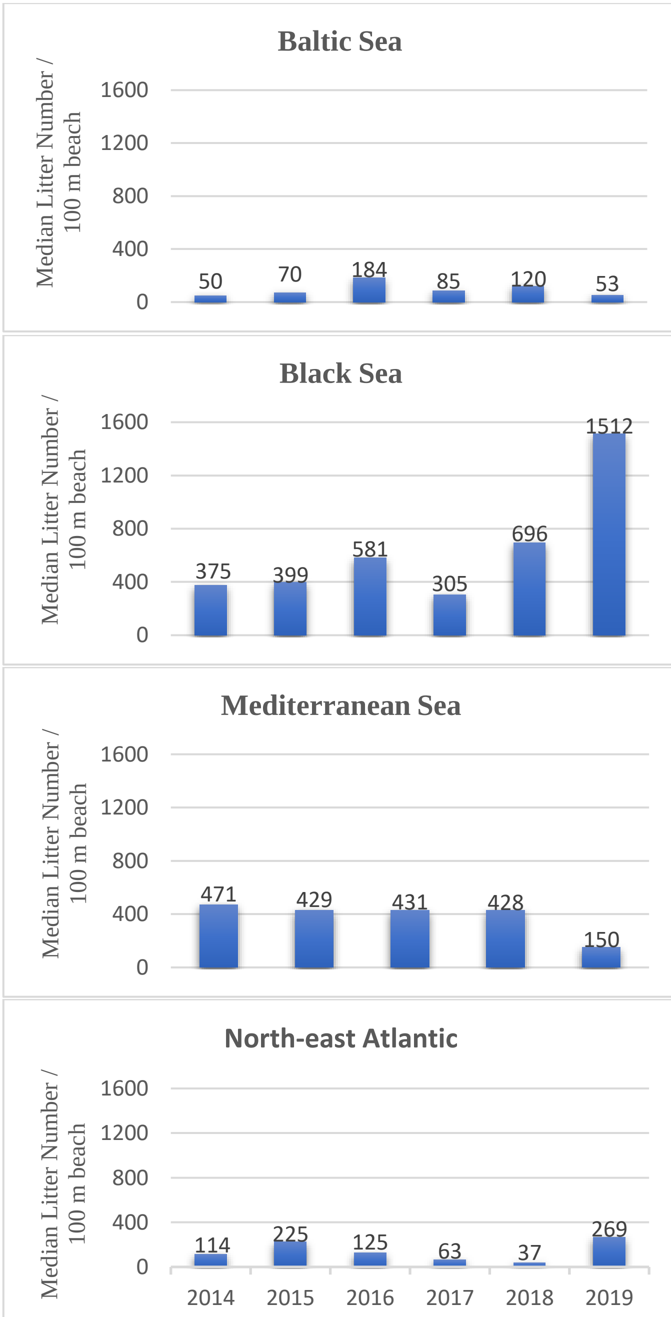

Figure 6. Changes in median beach litter numbers for each regional sea, from 2014 – 2019 ("monitoring" data only)

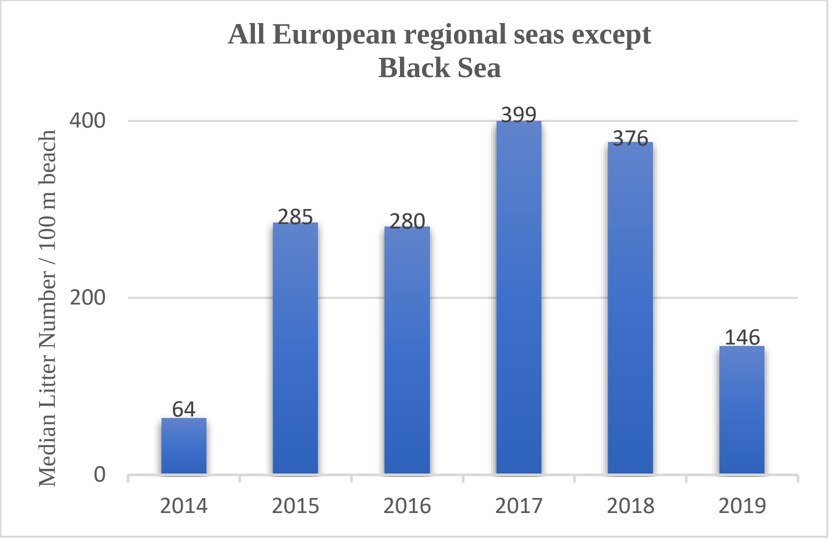

Figure 7. Changes in median beach litter numbers (combined only from the three regional seas (the Baltic, north-east Atlantic and the Mediterranean), from 2014 – 2019 ("monitoring" data only)

Over the years, an increase in beach litter pollution from 275 litter items/100m in 2009 (Topçu *et al.* 2013) to 3798 litter items/100m in 2016/2017 (Aytan *et al.* 2020) for the beach litter is also apparent for the southern Black Sea.

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Raising awareness about marine litter through beach cleanup activities along the Turkish coasts of the Black Sea

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Abstract

Beach cleanup activities were organized by Turkish Marine Research Foundation (TUDAV) and cooperating organizations on four beaches along the Turkish coast of the Black Sea. A total of 1161 kg of litter was collected with the majority consisting of plastics (425 kg). Three beaches near the Istanbul Strait had mostly plastic waste, likely from major urban sources as well as sea-based sources deposited by wave action. Beach cleanups are highly effective in raising awareness among local people, but clean coasts and clean seas, free from plastic waste, are only possible via international cooperation.

Keywords: Beach cleanup, plastic pollution, Black Sea, raising awareness

Introduction

Marine pollution and plastic waste are inextricably interconnected problems that require well thought-out, multi-step solutions on a global scale. There are various sources for marine pollution such as land-based pollution from wastewater discharge that includes domestic and industrial waste, and sea-based pollution from marine vessels including those of shipping and fisheries sectors. Marine litter can be classified as beach litter, seafloor litter, floating litter, litter in biota and microplastics (< 5 mm) (Bat *et al.* 2017).

Analyses of multiple cleanups over a number of years show that 80 to 90% of all collected materials are either plastic or include plastic components (Walther *et al.* 2018; Konecny *et al.* 2018). Urban areas, with the accompanying problems of lack of proper recycling systems and bad waste management, are the main originators of beach litter (Poeta *et al.* 2016). Plastic waste originating from beachgoers has been identified as a major component of beach litter in multiple studies (Corraini *et al.* 2018 Asensio-Montesinos *et al.* 2019; Williams *et al.* 2016), with more visits leading to a significant increase in the amount of plastic litter (Lee and Sanders 2015). Nearshore benthic habitats were also found to contain plastic waste from local beaches (Pasternak *et al.* 2019).

Marine animals are not spared the effects of plastic pollution. Seabirds, marine mammals and other marine organisms are most often subject to entanglement in, and ingestion of plastic litter (Kühn and van Franeker 2020) Microplastics end up in the stomach of many species, from the lowest ranks of the evolutionary ladder to the highest, including filter-feeding animals, economically important species and, eventually, humans (Barboza *et al*. 2018; Abreo *et al.* 2019). Microplastics have also been found in sensitive, remote ecosystems free from most anthropological pressures such as Antarctica and the deep sea (Horton and Barnes 2020). In the Black Sea, the surface and water column contain microplastics from ships such as ship paint, as well as fibres, hard plastic pieces and nylons (Aytan *et al*. 2016; Öztekin and Bat 2017).

Turkish coasts of the Black Sea are under significant anthropological pressure from marine transportation and shipping, as well as recreational activities. Currents and wave action are also responsible for marine litter being transported from foreign locations. Land-based litter from neighbouring countries and sea-based litter from shipping activities are important factors. Like the rest of the world, plastics encompass the majority of beach litter with fragmented pieces, hard plastics and food-related items taking the lead (Topçu *et al.* 2011, 2013).

Recent studies from the southern Black Sea find that 80% to 95% of beach litter consists of plastic materials, with significant amounts of land-based litter, and litter from neighbouring countries (Öztekin *et al.* 2019; Terzi *et al.* 2020). Abundance of smoking paraphernalia and food-related items, as well as the significant increase in litter density during summer seasons point to noticeable pressure from recreational activities in the region (Aytan *et al.* 2020; Simeonova and Chuturkova 2020). Bottom-trawl studies show that litter concentration, mostly plastics and fragmented pieces of multinational origins, is higher at the bottom of the Black Sea compared to the Mediterranean, as well as higher in density near the coastal shelf (Topçu and Öztürk 2010, Moncheva *et al.* 2016).

Beach cleanup efforts are also a great way to incorporate citizen science to the fight against plastic pollution. Citizen science can be an effective tool in terms of policy, education, community capacity building, site management, species management and research. This underutilized approach can be immensely effective for gathering data and raising awareness if done right (Cigliano *et al.* 2015). For example, it’s possible to achieve repeated sampling over a number of years (a time series) by taking advantage of volunteer-lead activities but standardized methods and quality control are obligatory for the success of this method (Zettler *et al.* 2017).

Materials and Methods

This work is a compilation of 4 beach cleanups on the coasts of the Black Sea. The cleanups were coordinated by TUDAV in 2019 (Figure 1).

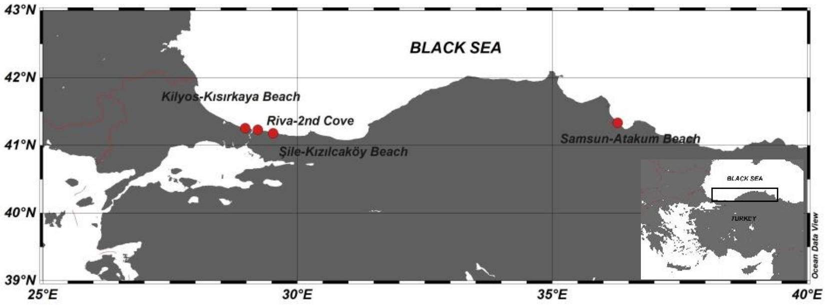

Figure 1. Location of the beaches where cleanups were carried out

Our beach cleanups were realized with the cooperation of major companies. Participants at these events were often accompanied by influencers or celebrities invited by the cooperating organizations, leading to greater participation by the general public, hence, more volunteers (Figure 2).

Figure 2. Collecting marine litter along the Samsun Beach

We collected and labelled the waste in four categories; plastic, glass, metal and others. Further categorization (i.e. textile, chemicals, rubber) to provide more insight may have been possible but it could have caused confusion amongst participants and lead to incorrect labelling of materials. Proper separation of litter was important as we needed accurate data on the abundance of various litter categories. We had prepared the collection bags with clear, legible labels before we arrived at the beach. A brief explanation on litter categories and materials found at the beach as well as a short speech on the importance of this work was given to the participants before the cleanup began.

We set three important rules for the participants;

- Everyone must wear gloves,
- Swimming is forbidden during the cleanup,
- Team leaders must be informed of injuries as a first aid kit is always available on site.

Each cleanup took approximately two hours. At the end of the litter collection, all garbage bags were weighted individually and recorded. Municipal authorities, previously informed of the cleanup, arrived to collect the litter after having been contacted towards the end of the activity.

Results and Discussion

All beaches included in this work are touristic ones. Some are more popular than others, but all are under pressure from the tourism sector. Four beaches cleaned in 2019 contained a total of 1161 kg of litter, of which 36.6% consisted of plastic - a large quantity, especially considering the fact that glass and metal are much heavier than plastic (Table 1).

Table 1. Weight and percentage of litter collected by the beach clean-ups

Name of the Beach	Date	Company	Plastic (kg)	Glass (kg)	Metal (kg)	Others (kg)	Total (kg)
Şile-Kızılcaköy Beach	24.07.2019	a	73	2	1	11	87
Kilyos-Kısırkaya Beach	20.09.2019	b	99	47	22	80	248
Samsun-Atakum Beach	20.09.2019	b	116	292	108	58	574
Riva-2nd Cove	02.11.2019	c	137	33	6	76	252
TOTAL			425 (36.6%)	374 (32.2%)	137 (11.8%)	225 (19.4%)	1161

All three beaches near the Istanbul Strait contained more plastic waste than glass, metal or other types of litter (Figure 3). Only Atakum Beach in Samsun showed significant difference, as glass litter consisted half of all litter collected. Plastic and metal litter, each less than half of glass litter collected during the cleanup, were similar in abundance. It is important to note, however, that Atakum Beach is located approximately 700 km east of other cleanup areas and likely to be under different environmental and anthropological pressures. Three beaches on the western coast of the Black Sea are affected by down currents from the northern Black Sea. Fragmented pieces of plastics from neighbouring countries and the shipping industry end up on the shoreline, carried off and deposited onto beaches by the currents and wave action (Topçu *et al.* 2011). They are also located within the city of Istanbul, a major urban area with more than 15 million people, compared to Atakum Beach in Samsun, a city with 1.3 million people (Turkish Statistical Institute 2019). This leaves Atakum Beach under less pressure from urban beachgoers, another major source of plastic waste. A third factor that may have played an important role in the different composition of beach litter is the presence of Kürtün Creek right next to Atakum Beach as rivers and creeks are carriers for industrial, commercial and fisheries-sourced litter (Williams *et al.* 2016; Aytan *et al.* 2020; Simeonova and Chuturkova 2020). Recent illegal dumping of industrial waste shortly before the cleanup began is another possibility. Further investigation is necessary to determine the cause of this extraordinary situation.

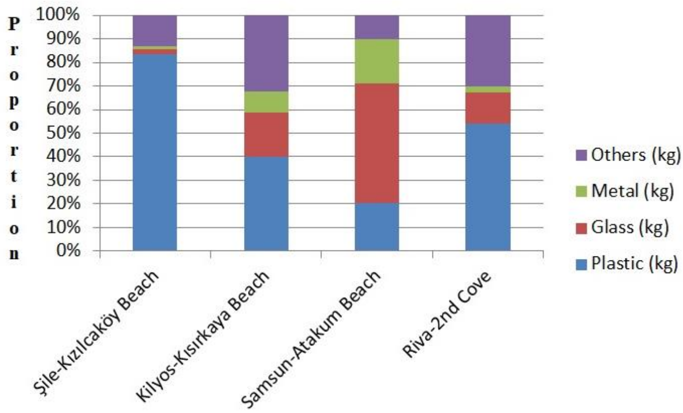

Figure 3. Percentage of all materials collected during the cleanup

The greatest benefit of beach cleanups by volunteers are not their immediate effect – a clean beach – but their success in raising awareness. Volunteers for cleanups focus on wayward litter and look at their environment with a heightened awareness and growing bewilderment at their findings. This leads them to notice small pieces of litter that they otherwise would have missed and the greater impact, as well as the novel awareness of humans' significant littering potential, makes a lasting impression.

Strong policies, better waste management practices, intergovernmental cooperation, regional and national monitoring and assessment, raising public awareness, and reducing the use of plastics in our daily lives are all necessary to stop the invasion of plastics (Black Sea Commission 2007). An important example of intergovernmental cooperation is the Marine Strategy Framework Directive (MSFD) in the EU countries. MSFD establishes a framework with 11 descriptors to achieve Good Environmental Status (GES) for the protection and sustainable use of marine ecosystems. Descriptor 10 aims to prevent damages caused by marine litter. MSFD has been important in establishing a common methodology for the assessment and monitoring of marine environments in the EU member states (Bat *et al*. 2017).

It is important to prevent litter from reaching the shorelines and aquatic environments. International cooperation is the solution to this all-encompassing problem, as interconnectedness of seas and oceans prevents the success of any lone actor in ensuring a pollution-free world.

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Marine litter problem in the southern Black Sea coastal area: An overview of the big pressure in Sinop

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Abstract

Marine litter is one of the most important pollution problems of today. It has been observed in all marine ecosystems and has a big pressure on marine coastal environment. The Black Sea is one of the most important European seas and gets its share from this pollution. Sinop, located right at the middle of the southern Black Sea coast, is a settlement with prominent fishing and tourism and no industrial pollution. The most important components of marine pollution in the city are domestic solid wastes, urban sewage systems and fishing and shipping activities. In addition to these components, physical factors such as currents, waves and winds cause pollution pressure in the region. In this research, pollution pressure from marine litter has been focused on Sinop, which is a small city with a relatively low population and pollutant load.

Keywords: Marine litter, plastic, pollution, Sinop, Black Sea

Introduction

General overview of marine litter pollution

Marine litter is defined as "any persistent, manufactured or processed solid material disposed of or abandoned in the marine and coastal environment" (UNEP 2005), and this pollutant is one of the most important pollution problems of today.

Plastics dominate marine litter that is one of the most widely used substances over the world. Excessive amount of polymeric materials go into the marine environment where it reaches micron size with degradation process that is induced by a combination of factors, including thermal oxidation, photo-oxidative degradation, biodegradation and hydrolysis and finally it is defined as microplastic (Arthur *et al.* 2009; Hammer *et al.* 2012).

Marine litter has been observed in all marine ecosystems, from densely populated regions to remote areas (UNEP 2001; UNEP and GRID-Arendal 2016). Its increasing abundance has been reported in recent years on beaches, sea surface and seafloor (Galgani *et al.* 2015).

The Black Sea makes significant contributions to the regional economy with fisheries, tourism, oil production and transport (Bat *et al.* 2018). It is a semi-enclosed sea, which has suffered important changes caused by human activities in the last four decades. Total population of the Black Sea's catchment area exceeds 160-170 million, which makes extraordinary demands on its resources and daily activities affecting the Black Sea environment (BSC 2007; Bat *et al.* 2018). Pollutants from towns and cities, farms and factories contaminate the Black Sea; some sources come directly from the coast, but most flow with rivers. Many rivers run off the Black Sea (Danube, Dnieper, Bug, Dniester, Don, Kuban, Rioni, Kızılırmak, Yeşilırmak etc.) transport noticeable loads of pollutants (Topcu *et al.* 2013) and recently it was estimated that 4.2 tonnes of plastic come to the Black Sea with the Danube river per day (1533 tonnes every year) (Lechner *et al.* 2014; Aytan *et al.* 2016). They cause serious problems in the Black sea and could cause significant damage to marine wildlife (Bat *et al.* 2018).

In recent years with consciousness of the problem marine litter pollution investigations have also increased in the Black Sea. Macro and micro litter pollution has been reported from sea floor, beaches, seawater and marine biota (Topçu *et al.* 2013; Ioakeimidis *et al.* 2014; Suaria *et al.* 2015; Aytan *et al.* 2016; Terzi and Seyhan 2017; Aytan *et al.* 2018; Şener *et al.* 2019; Mukhanov *et al.* 2019; Aytan *et al.* 2020; Gedik and Eryaşar 2020) in the Black Sea. The results of the investigations showed that all areas are seriously contaminated with marine litter.

A small city in the Black Sea: Sinop

Sinop is located right at the middle of the Turkish Black Sea coast and on the northernmost point of Turkey (Bat and Gökkurt-Baki 2014). Sinop was established on the Boztepe peninsula, which stretches out to the north of the Black Sea coastline. Provincial territory is located between 41˚12´ and 42˚06´ north latitudes and 34˚14´ and 35˚26´ east longitudes. Sinop coasts are indented shores and are not steep with comparison to the Eastern Black Sea shores. İnceburun is also the northernmost point of Anatolia. There are no harbours protected by bays and gulfs as far as Sinop in the Black Sea Turkish coasts that start from Hopa and end in the Istanbul Strait (Anonymous 2020; CDR 2018).

Sinop is a settlement with prominent fishing and tourism and no industrial pollution. The population of Sinop province is 218,243 in 2019. In 2018, average waste amount was 1.39 kg/person day and the amount of municipal waste was 65 thousand tons/year (TUİK 2020). There is a domestic pollution, which is raised especially in summer months due to increased population (Bat and Gökkurt-Baki 2014). Factors that cause marine pollution in the city are; household waste waters, solid wastes and pollution by shipping and fishing activities (CDR 2015).

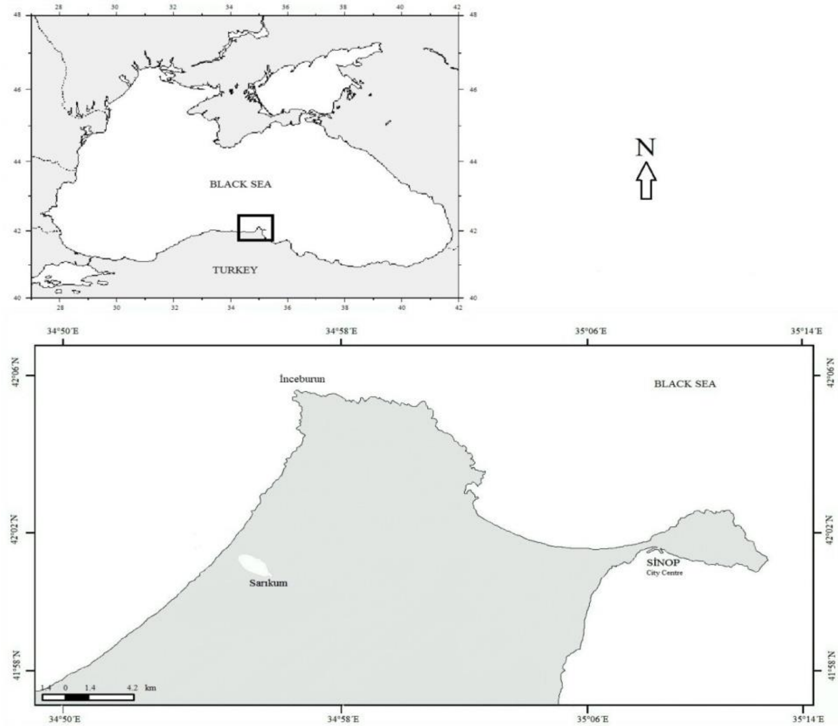

Figure 1. Sinop region map (adapted from Öztekin and Bat 2017a)

Sources of litter in Sinop

Human activities are the general sources of marine litter, which originate from both land- and sea-based sources (UNEP 2009). The primary sources of land-based litter are coastal or inland areas (beaches, piers, harbours etc.), urban disposal sites settled on the coast, water bodies (rivers, lakes and ponds) used as illegal dump areas, riverine transport of waste from landfills and other inland sources, discharges of untreated sewage systems, industrial plants, medical waste, and tourism (UNEP 2009).

One of the most important component of marine pollution in the city is domestic solid wastes. Domestic, industrial and medical wastes occurring within the Sinop city have been accumulated for approximately 10 years since 2002 in the Solid Waste Irregular Storage Area with an area of approximately 13 decares located in the Kurtkuyusu area of Abalı Village. Recently, "Solid Waste Regular Storage and Disposal Facility" has been established in Sinop to ensure that the wastes resulting from Irregular Storage do not harm the environment and human health. Domestic solid wastes in Sinop are stored in the Regular Storage and Disposal

Facility of the Union of Seaside Municipalities, which operate in Hacıoğlu Village Meşedağı District (CDR 2018).

Another shortcoming in the region is that there is no company in the province that has a license for Collection Waste Separation Facility and Recycling Facility. In order to collect the packaging wastes, a company from Samsun is purchased. There is also no Medical Waste Storage area in Sinop, the medical wastes generated in Sinop City Center within the scope of the "Medical Waste Control Regulation" are collected by the relevant company (CDR 2018).

Large rivers are responsible for a significant amount of pollutant input into the sea. Due to the high flow rate and the strength of the subcurrents, they can transfer the wastes to the sea (Acha *et al.* 2003; Barnes *et al.* 2009). Çatalzeytin, Ayancık, Karasu, Kanlıçay (Güzelceçay) and Kabalı streams located in the city of Sinop are poured into the Black Sea. These relatively small rivers bring pollutants from their way and eventually into the sea.

Urban sewage systems could also be a source of microplastic pollution. In a study on wastewater samples taken from the washing machine used at home, it has been reported that more than 1900 micro-plastic fibers (microfibers) can pass into the sewer per wash, even from a single synthetic cloth (Browne *et al.* 2011). Another factor causing pollution in Sinop is domestic wastewaters. There is no Wastewater Treatment Plant operating in Sinop. The North and South Deep Sea Discharge and Akliman WWTP are still under construction. There is only one Wastewater Treatment Plant belonging to the Municipality in Ayancık District (Pretreatment + Deep Sea Discharge) (CDR 2018).

Sea-based sources of marine litter originate from trading shipping, cruise liners and ferries; fishing activities; military navy and research vessels; pleasure boats; offshore oil and gas platforms and drilling rigs; and aquaculture installations (UNEP 2009).

Main sea-based sources of pollution in the Sinop are fishing and shipping activities. Boztepe peninsula is the most north extended point of Turkish Black Sea coastline. The three sides of the peninsula are surrounded by the sea so fisheries have an important means of income and has a significant share in the economy of Sinop (Bat *et al.* 2013). As Sinop is naturally a port city, the region stands out as a mooring point for ships during adverse weather conditions. Moreover, there is an important official aquaculture site. Due to all these activities, pollutants originating from the sea are significant for the region. Plastic litter, which is the main component in the fishing industry, is common in fishing areas (Galgani *et al.* 2000; Barnes *et al.* 2009). Fishing activities in coastal areas and the shipping traffic in the Black Sea are also among the polluting sources of the Black Sea. It has been reported that litter originating from fisheries occur quite frequently especially during the peak season of fishing (Terzi and Seyhan 2017; Öztekin *et al.* 2020).

Ocean currents, regional-scale topography and wind strongly affect marine litter dispersion and deposition (UNEP 2009). The current system in the Black Sea influences the distribution of litter. Oğuz *et al.* (1995) indicated that the upper layer waters of the Black Sea are characterized by a dominant cyclonic and mightily time-dependent basin widespread cycle. The main Black Sea current, flows over the continental slope, and two large-scale cyclonic gyres are in the eastern and western parts of the sea; half-constant anticyclonic eddies streams in the nearshore, like Sinop, Sakarya, Caucasian, Sevastopol, Batumi etc. (Ivanov and Belokopytov 2013). Once or twice a year in Sinop, for about a season a Sinop eddy could form repeatedly (Figure 2). This eddy usually depends upon propagation characteristics of the meanders superimposed on the Rim Current system (Korotaev *et al.* 2003). Therefore, Sinop is also under the influence of regional winds (N, NW, NE and W) which makes this place one of the important solid waste accumulation point in the Black Sea (Öztekin and Bat 2017a).

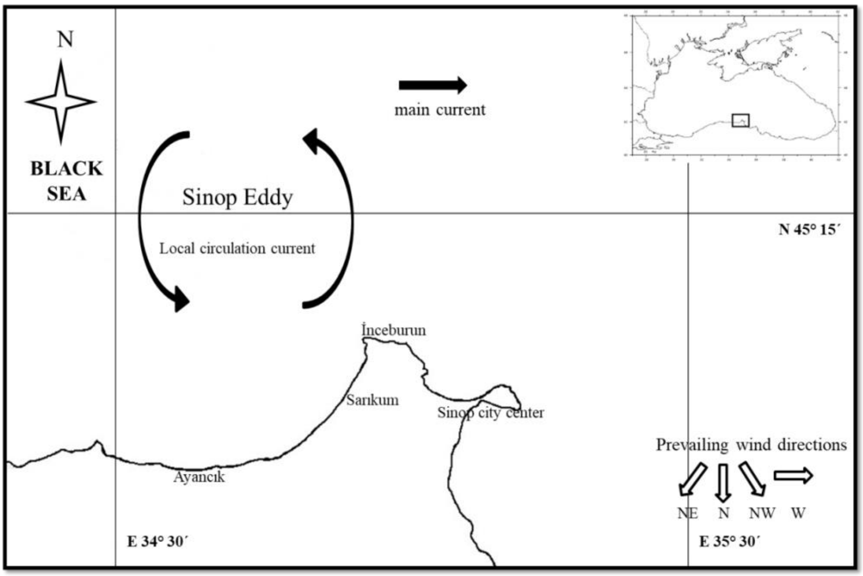

Figure 2. Current and wind directions of Sinop (taken from Öztekin *et al.* 2020)

Current Pollution Status of Sinop

The first interesting situation appeared with the suspicious barrels that turned up along the Turkish coast at Sinop in 1987-1988. The officials set to investigate the contents of these barrels but have never provided a sufficient explanation of this phenomenon, which was an issue of public attention throughout 1988 (Bat *et al.* 2018). These barrels were buried in those years in the Sinop.

Various cleaning organizations have been working over the years in the region for seabed macro litter in cooperation with the Sinop Municipality, Provincial Directorate of Security and Sinop University. In this context, cleaning activities were carried out in different areas of the city and the collected litter items were exhibited.

Scientific researches in Sinop showed that the presence of macro and micro litter was detected on the beaches, on the sea floor and in the seawater, it was observed that the marine species were affected by this pollution and the region in general is under serious pollution pressure.

Sarıkum Lagoon and its surroundings is one of the important wetlands of the Black Sea and it have been announced as Natural Protected Area. Lagoon coast is one of the research sites for marine litter pollution in the region. This area is exposed to a substantial amount of solid waste accumulation due to its geographical position through the prevailing winds, waves and currents (Öztekin and Bat 2017a). Macro and micro litter amount and composition were determined by a series of research activities conducted seasonal in the region between 2015 and 2016.

Macro litter surveys were conducted seasonally on beach and seafloor in Sarıkum Lagoon coast. Beach litter density was found that the average number was 1.512±0.578 pieces/m² and the average weight was 31.875±10.684 g/m² in Sarıkum Lagoon coast (Öztekin *et al.* 2020). Material types percentages of litter items were reported as follows: plastic - 95.61%, glass/ ceramics - 1.46%, cloth/textile - 1.31%, and the others - 1.62% in the region. Foreign origin litter was found with ratio 2.29% of all litter items and was originated Mainly from neighbouring countries. Litter items were commonly consisted of mixed packaging items (41.12%) and unidentifiable items (33.84%) in the Sarıkum (Öztekin *et al.* 2020).

At the same time seafloor macro litter amount, distribution and types were determined with beam trawl in Sarıkum Lagoon coast at four different depths (5 m, 10 m, 20 m and 30 m). The average litter amount was reported as 30.97 pieces km^{-2}. The litter density was highest in spring and 5 m was the most polluted depth. The only material was plastic with mainly rope pieces and plastic bags (Öztekin and Bat 2016).

Seafloor macro litter abundance and composition were determined also in the northmost point of Turkey, İnceburun coast in 2014. Litter amount was reported as mean 808.74±215.02 pieces km^{-2}. The maximum litter density was found in 34 m depth. The results were evaluated according to material types, plastic was found at the highest ratio (95.35%) and litter items were commonly consist of plastic bags (Öztekin and Bat 2017b).

Micro-litter investigations were performed in seawater, beach and seafloor sediment in Sarıkum Lagoon coast. Beach sediment results showed that the plastic density of 1-5 mm size class was found as 0.012±0.006 pieces g^{-1} and 659.22±552.99 pieces m^{-2}. Categorization results demonstrated that microplastic items are mainly composed of polystyrene pieces (58.72%) and hard plastic pieces (33.99%) followed by resin pellets (4.21%) and unidentifiable pieces (2.09%). The <1 mm size class plastic density varied from 0.029±0.009 pieces g^{-1}. The most common colour was white (Öztekin and Bat 2017c).

Microplastic abundance in seafloor sediments in the Sarıkum was investigated at four different depths (0.5 m, 5 m, 15 m, 30 m). Microplastic density was found as 0.037±0.011 pieces ml^{-1} and 0.021±0.006 pieces g^{-1} in sediment samples. Litter amount was found as maximum in spring and at 5 m depth. Categorization results showed that microplastic items are mainly composed of plastic fibres (60.24%), unidentified pieces (19.88%) and hard plastic pieces (16.27%) followed by nylons (2.41%) and polyurethane and polystyrene pieces (1.2%). The most common colours were found as blue (38.79%), transparent (19.39%), grey (18.79%) and white (10.91%) (Öztekin and Bat 2017d).

Microlitter pollution in seawater was investigated both at sea surface and in water column from at 4 different depths (0.5 m, 5 m, 15 m, and 30 m) in Sarıkum. Microlitter density was found as 2.667±2.325 pieces.m^{-3} and 24.475±26.153 pieces m^{-3} for sea surface and water column, respectively. Litter categorization results showed that most common litter types are other groups for both sample region (Sea surface: 55.45%; Water column: 54.21%) followed by fibres, hard plastic pieces and nylons. The other groups were mainly consisted of ship paint particles. Litter amount was found as maximum in spring in both sample regions. It was observed that the microlitter density increased on the sea surface as it moves away from the shore, whereas it increased in the water column as it approaches the shore. This situation may have caused physical factors such as current, wind and wave (Öztekin and Bat 2017a).

Recently, a dedicated project was conducted in Sinop coast with the aim to determine the amount, composition and distribution of macro litter on the beaches. The surveys were carried out for four seasons on nine different beaches with different locations and sources of pollution. The result of the project shows that all the beaches in the region are contaminated with marine litter and the most common material type is plastic. It is clear that marine litter is originated mainly from land-based sources. Fisheries related litter items are also frequently encountered when fishing activities are intense. Foreign originated litter was also detected on the beaches (Unpublished data from authors).

The effects of marine litter were investigated on various demersal fish species on the Sarıkum coast with no findings. However, the entanglement situations were registered on two fish species in the Sinop. The one of them was a *Dicentrarchus labrax* (Linnaeus 1758) which was the subject of local news (Anonymous 2013) and the other was the *Belone belone* (Linnaeus 1760) that was reported from Ministry of Agriculture and Forestry of Sinop, Gerze (Figure 3).

Figure 3. The entanglements of marine fish in Sinop

Conclusion

The results of the investigation show that Sinop coasts are significantly affected by marine litter pollution and this is a constantly growing problem. The fact of this pollution is an important issue and requires further examination on transportation, origins, types and effects on biota.

The investigations conducted in the region showed that macro litter originates mainly from land-based sources. In addition, foreign originated litter found in the region gives information about the Black Sea's unique current system and the transportation of litter items. Encountered foreign originated litter items confirm that marine litter is a cross-border problem.

Classifications according to the type of material show that plastics were the most abundant litter in the Sinop. Degradation time of plastics in nature and products of decomposition are very important for further consumption by food webs

(Aytan *et al.* 2018), the digestion of these particles also poses the danger of toxicity.

It is the human activities that constitute the source of marine litter; therefore, awareness raising activities for the people is one of the measures to be taken to reduce the production of litter.

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Integrated Marine Pollution Monitoring Program: Marine litter studies in the Black Sea coasts of Turkey

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Abstract

Marine litter is one of the crucial problems for the ecosystem health, and most of its sources are anthropogenic. The EU Marine Strategy Framework Directive is focused on Marine Litter under the descriptor 10 in order to achieve levels of marine litter that do not cause harm to the coastal and marine environment. However, there is insufficient data to evaluate marine litter. To fill in this lack of data, macro and micro litter surveys were performed as a part of the Integrated Marine Pollution Monitoring Programme. In this programme, two microplastic stations and one beach litter surveys were conducted in Black Sea. Two microplastic stations show that the fluctuation of data is heavily influenced by the inputs from the rivers. However, microplastic concentrations in the water column were found to be similar at both stations. Beach litter survey showed that amongst the percentage distributions of the total number of garbage counted in the area, plastic had the highest percentile of 91. Integrated Marine Pollution Monitoring Program 2020-2022, aims to increase the microplastic and beach litter sampling stations, as well as to reveal short, medium and long-term plans for monitoring and reducing the marine litter.

Keywords: Macroplastic, microplastic, beach litter, trawl, National Monitoring Programme, Black Sea

Introduction

Marine litter has become the most pervasive type of human-induced pollution (Green *et al.* 2018). Litter items are classified into different size classes (macro, micro) and groups (plastic, glass, etc.). In this classification, microplastics and their effects have just been understood, and the studies on this subject is very limited on the global scale (MoEU and TUBITAK-MRC 2017).

Solid wastes that are comprised of persistent, manufactured or processed materials, build up on the coastline and the sea floor as a result of long-term transportation within the water mass through direct discharge, carriage through rivers, currents, waves and the effects of wind causing significant loss of habitats, various adverse effects on living organisms and pollution. Besides, solid wastes are also responsible for causing social and economic loss. Wastes may remain in the marine environment for tens, even hundreds of years; therefore conducting only source evaluations should not be deemed sufficient and observations should be done in the field.

Marine Strategy Framework Directive (MSFD) defines marine litter as, “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment”. Descriptor 10 of the MSFD titled “Marine Litter” is focused mainly on the properties and quantities of waste discharged into marine waters and aims to achieve levels of marine litter that do not cause harm to the coastal and marine environment (TUBITAK-MRC and MoEU-GDEM 2014).

In this study, marine litter is studied at pilot scales through the “Integrated Marine Pollution Monitoring Programmes”. Table 1 shows the comparison with the indicators of MSFD under Descriptor 10, only D10C4 indicator is not covered in the monitoring programme (MoEU and TUBITAK-MRC 2017, 2019). “Integrated Marine Pollution Monitoring Programme” has been coordinated and implemented by the Ministry of Environment and Urbanization/General Directorate of EIA, Permit and Inspection/ Department of Laboratory, Measurement and by TUBITAK Marmara Research Center Environment and Cleaner Production Institute since 2014.

Table 1. Integrated Marine Pollution Monitoring Program (2014-2022) Marine Litter Criteria and indicators for GES in The Black Sea Coasts of Turkey (Commission Decision (EU) 2017/848 of 17 May 2017)

MSFD Descriptor 10
Characteristics and quantities of marine litter do not cause harm to the coastal and marine environment.

Criteria elements	Criteria	Scope / method	Description (Monitoring, 2014-2020)
Litter (excluding micro-litter), classified in the following categories: artificial polymer materials, rubber, cloth/textile, paper/cardboard, processed/worked wood, metal, glass/ceramics, chemicals, undefined, and food waste.	D10C1 — Primary The composition, amount and spatial distribution of 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.	D10C1: amount of litter per category in number of items: - per 100 metres (m) on the coastline, - per square kilometre (km^2) for surface layer of the water column and for seabed,	**Case study:** Sarısu Beach/ TR Black Sea 08 November 2018 In the 2020-2022 monitoring program, it is planned to increase the number of beach litter stations In 2021, macro litter will be monitored on sea surface along certain sections. Trawl / beam trawl seabed study was performed between 2016 and 2019. (2016: 26 trawl+21 beam trawl stations; 2019: 44 trawl stations; planned at the same stations in 2021)
Micro-litter (particles <5mm), classified in the categories ‘artificial polymer materials’ and ‘other’.	D10C2 — Primary: The composition, amount and spatial distribution of micro-litter on the coastline, in the surface layer of the water column, and in seabed sediment, are at levels that do not cause harm to the coastal and marine environment.	D10C2: amount of micro-litter per category in number of items and weight in grams (g): - per square metre (m^2) for surface layer of the water column, - per kilogram (dry weight) (kg) of sediment for the coastline and for seabed,	Microplastic level determination studies in the Black Sea were carried out in 2 stations (Giresun (TRK46) and Trabzon (TRK53)) at pilot scales in summer seasons between 2015-2016. Levels in sea sediment, surface water and water column in 2016 were provided as 3 replications. In the 2020-2022 monitoring program, it is planned to increase the number of stations.

Table 1. Continued

Criteria elements	Criteria	Scope / method	Description (Monitoring, 2014-2020)
Litter and micro-litter classified in the categories 'artificial polymer materials' and 'other', assessed in any species from the following groups: birds, mammals, reptiles, fish or invertebrates.	D10C3 — Secondary: 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.	D10C3: amount of litter/micro-litter in grams (g) and number of items per individual for each species in relation to size (weight or length, as appropriate) of the individual sampled,	Gasters and intestines of 263 fish individuals belonging to 3 fish species (*Trachurus trachurus*, *Merlangius merlangus*, *Mullus barbatus*) were examined within the scope of sampling carried out in 9 different regions for detection of impacts of microplastic pollution on biota at the Black Sea coasts.
Species of birds, mammals, reptiles, fish or invertebrates, which are at risk from litter.	D10C4 — Secondary: 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.	D10C4: number of individuals affected (lethal; sub-lethal) per species.	-

Microplastics

Determination of abundance and classification of microplastics were performed at 2 stations (Figure 1) with different matrices (surface layer, water column and sediment) during 2015-2016. A manta net with a regular opening 50 cm wide x 20 cm deep lined with a 3 m long 333 µm net fitted with a 25 x 12 cm^2 screw-fit collecting bag was used to sample the surface layer of the sea. The manta was trawled alongside the vessel (R/V TÜBİTAK MARMARA) for 30 min at 2 knots. The water column was sampled with a zooplankton net and a standard Van Veen Grab of 0.1 m^2 was used for sediment samplings.

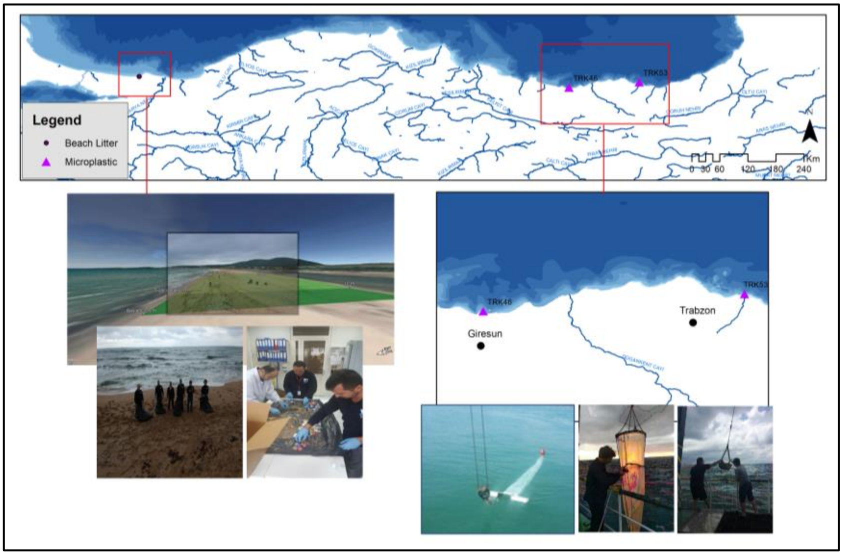


Figure 1. Microplastic and Beach litter stations

Estimating and monitoring microplastic concentration is crucial to understand human effects on the sea. Microplastic monitoring in the two stations shows that the flotation of data is heavily influenced by the inputs from the rivers. For example, surface water concentrations of microplastic in TRK53 station, which is under the influence of Değirmendere Creek, were found much higher than the TRK46 station in 2015. However, the situation was reversed in 2016 (Table 2). Microplastics concentration in the water column was found similar at both stations. Levels of sediment contamination were also similar to each other in 2015, although a prominent increase was observed in terms of microplastic amount in TRK53 compared to TRK46 in 2016 (Table 2).

Table 2. Microplastic levels detected in 2015-2016

Station	Replicate	Surface layer				Water column		Sediment	
		2016 (n/km^2)	2015 (n/km^2)	2016 (n/m^3)	2015 (n/m^3)	2016 (n/m^3)	2015 (n/m^3)	2016 (n/L)	2015 (n/L)
TRK46	R1	4008065	942857	20.04	4.71	19.86	91.88	920	2000
	R2	844262	-	4.22	-	10.69	-	1580	-
	R3	998390	-	4.99	-	7.81	-	1300	-
TRK53	R1	1378357	2306000	6.89	12.23	9.631	-	2780	1780
	R2	482.315	-	2.41	-	9.723	-	3940	-
	R3	599042	-	3.00	-	4.722	-	1240	-

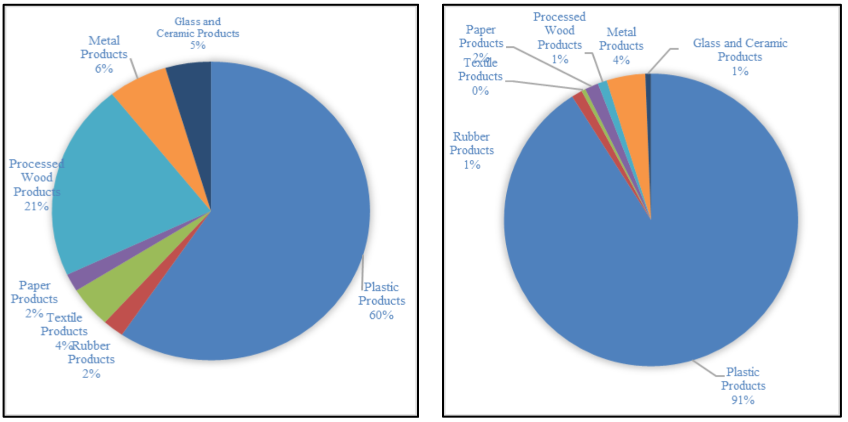
Beach Litter

Anthropogenic sources are responsible for ~80% of the plastic debris. The vast majority of this waste comes from fishing and aquaculture activities. The rest of debris arises from beach litter (Andrady 2011). The sampling study of the beach littler was conducted according to the JRC guidelines (JRC 2013).

Beach litter survey was conducted in a selected beach in the South Eastern Black Sea (40° 08' 22.11" N, 30° 08' 54.07" E) in 2018. The beach is located in Kandıra province (Figure 1) with a high population in summer (400.000 citizens) at 58 km north of Kocaeli city (~ 1.780.000 people in 2020 census). Total length of the beach is 797 m with a 5 m width. The swimming period on the beach is between June and August.

Beach litter was collected in 100 m transect according to the waste classification system established by the "MSDF marine waste assessment working group" (JRC 2013 and DISSP 2017). After being classified, the collected garbage, was weighed and photographed in the laboratory. 1728 pieces of garbage (0.292 pieces / m^2) collected from the sampling area (approximately 5.921m^2), were divided into 7 categories: plastic, rubber, textile, paper, wood, metal and glass / ceramic (Figure 2a). Cigarette butts were scanned and 13 cigarette butts (5.5 grams) were detected in the 10-meter shoreline (approximately 536 m^2). The weight of the garbage in the whole area was determined as 25.403 kg (0.043 kg / m^2). The garbage collected in an area of approximately 5921 m^2 was mostly in the plastic (approximately 60%) category, followed by 21% wood material and 6% metal material. According to the percentage distributions calculated over the total number of garbage counted in the area (5921m^2), plastic was found again at the highest level of 91% (Figure 2b). This is followed by metal waste with 4%

and paper waste with 2%. It was determined that 6 litter items found in the study area belonged to the foreign originated products.



(a) (b)

Figure 2. Distribution of weight (a) and number (b) of litter in Sarısu Beach

Conclusion

The increasing trend of human-induced pollution will result in an increase of plastic debris in the marine environment. Therefore, determining the composition, amount and spatial distribution of marine litter on the coastline, on sea surface and at the seabed is essential to achieve good environmental status and sustainable use of marine resources. It is also crucial to determine the hot spot areas to develop strategies and plans for preventing marine litter pollution. In this context, during the Integrated Marine Pollution Monitoring Program 2020-2022, it is aimed to increase the microplastic and beach litter sampling stations, as well as to reveal short, medium and long-term plans for monitoring and reducing the marine litter. It is planned also to work on floating litter in certain transects on the Black Sea in 2021.

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Studies regarding the seafloor litter on the Romanian Black Sea coast

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Abstract

The marine litter from various sources is a persistent problem of pollution along the Black Sea coast, both in the water and on the seabed. It is also a transboundary problem in this enclosed sea basin which displays a very dynamic current system, enabling transportation of any matter from a given location in the basin to almost any coastal area. Regarding the quantitative composition of the marine litter, a considerable amount is brought from the Danube River, especially in seasons with heavy rains. As respects of the qualitative information, plastic dominated in samples. Even if the trend in marine litter is decreasing, the small amounts of litter might threaten the biodiversity of the basin.

Keywords: Seafloor litter, Romanian Black Sea coast, quantitative and qualitative data

Introduction

Marine litter have been considered since the early 1960s as an acute problem for marine life, but since then the volume of these wastes, associated with environmental, social and economic growth, has been globally increasing. Marine litter, originating either from the vessels or from the shores or rivers, is a persistent pollution problem along the coasts of the Black Sea, in the deep sea and on the bottom of the sea. Marine litter is also a transboundary problem in this enclosed sea basin which displays a very dynamic current system, enabling transportation to almost any coast. Most of the marine litter items in this region is of a non-biodegradable nature, which is not only an aesthetic problem, but might threaten the biodiversity of the basin.

Recently, several national and regional actions have been taken in Romania to initiate and implement marine litter monitoring. Currently, there is still no national action plan for marine litter monitoring in the Romanian Black Sea area. At EU level, the Marine Strategy Framework Directive (MSFD) is the mandatory legal instrument dedicated to the assessment, monitoring, targeting and achieving of Good Environmental Status (GHG) for marine litter. A group of technical experts appointed by Member States to assist them in achieving good environmental status for marine litter is co-chaired by the Joint Research Center (JRC), which has developed, “Guidance for monitoring of marine litter in European seas” and, more recently, thematic reports on waste sources, monitoring of river / river waste and damage caused by marine litter; this guide was used at the begining of Romanian Black Sea ML assessment.

In our country, the monitoring of the existing waste on the seabed (waste originated from discards or loss) started in 2011 with voluntary monitoring by the National Institute for Marine Research and Development “Grigore Antipa”, facilitated by the surveys that targeted bottom trawl fishery to obtain data and information needed to assess demersal fish stocks. Starting with 2013, along with becoming partners in the project “Towards a Clean, Litter-Free European Marine Environment through Scientific Evidence, Innovative Tools and Good Governance”, there was the opportunity to address a new research direction to ease obtaining data and information on marine litter in the Romanian Black Sea area. These investigations helped to determine the biological, social and economic impact of marine wastes and to set out new monitoring, collection and recycling techniques and technologies and to draw-up measurement proposals to support policies aimed at mitigating the impact thereof, respectively.

Materials and Methods

NIMRD conducted research surveys between 2011 and 2014 (NIMRD, in Galgani *et al.* 2015) with sampling trawl (bottom trawl) for demersal fish stock assessment, enabling the collection of litter for assessing litter density, composition, and sources. A 21/22-34 m bottom trawl was employed in southern, central and northern part of Romania, at depths ranging between 15 - 90 m.

Results and Discussion

During the monitoring period 2011-2014, a total number of 168659 items of various types have been identified and inventoried. In 2012, most of hardly biodegradable materials (plastic) were found in the close vicinity of the Constanta and Mangalia harbours approx. 96.61%, (259.39 kg) of the total amount of such wastes collected from the seabed (268.48 kg), where vessel traffic is also the busiest. In 2014, 27 hauls (1625 km^2) were operated, collecting 329.18 kg (420 items) of waste, with plastic representing 27% of weight (48 % by number). The largest amounts of metal and plastic were located in the areas around the ports of Constanta, Cape Midia and Mangalia with an intense naval traffic. Nearly in the majority of hauls were identified plastic items (bags, bottles, bags, buckets, cans, linoleum, etc.) Figure 1.

A considerable contribution of plastic waste makes it through the three discharge mouths (Chilia, Sulina, Sf. Gheorghe) of the Danube River. Many fragments were from lost or abandoned fishing gear (seines, trawl, purse, *etc*.), also from other countries because of illegal fishing, and wood were brought from the three arms of the Danube carried by the currents along the shoreline in both offshore and shallow waters.

Figure 1. Marine litter types identified in the research survey (NIMRD original photos, 2012)

Figure 2. Different types of marine litter identified on the seabed
(NIMRD original photos, 2019)

Abundance, spatial distribution and qualitative composition of seafloor marine litter have been also investigated in a study area of Constanta Bay (Ioakemidis *et al.* 2014) after 16 trawling tows (9 m width, 20 mm mesh) and 76 km of sampling trawl. Plastic accounted for 45.2 ± 4.8 % of total litter (14.3 and 12.9 for bottles and bags) and 22% of debris were made of metal. In Constanta Bay the highest density (1068 items/km^2) was recorded in front of the Danube mouth, whereas no consistent distribution pattern in relation to depth was observed on the shelf (<60 m), except for metals that seems to accumulate in the deeper parts of the surveyed areas. The overall results highlight the importance of the Danube River and fishing activities as a source of marine litter in the area. Significant amount of small sized items showed the trend of marine litter to fragmentation.

The activities were repeated in 2019 at the Romanian Black Sea coast. The collection of litter from the seabed was carried out at depths between 14 and 64 m during the assessment activities for demersal fish populations (Figure 2). Two expeditions each for 10 days were carried out with the bottom trawling. From 81 trawls, only in 48 marine litter was identified.

Figure 3. Metal objects identified on the seabed (NIMRD original photos, 2019)

The 48 trawls covered an area of 2133135 m^2. All the collected waste weighted 883 kg (of which 74% were metal objects and pieces) and amounted 549 items (of which 26% represented metal objects, Figure 3); with an average density 0.41 g/m^2 and 0.0003 litter items/m^2.

Classifying by material, the waste was represented by metal objects, plastics, lost or abandoned fishing nets, bottles, and textile fabrics. The percentage in kg and number of items is presented on the figures below (Figure 4 and Figure 5).

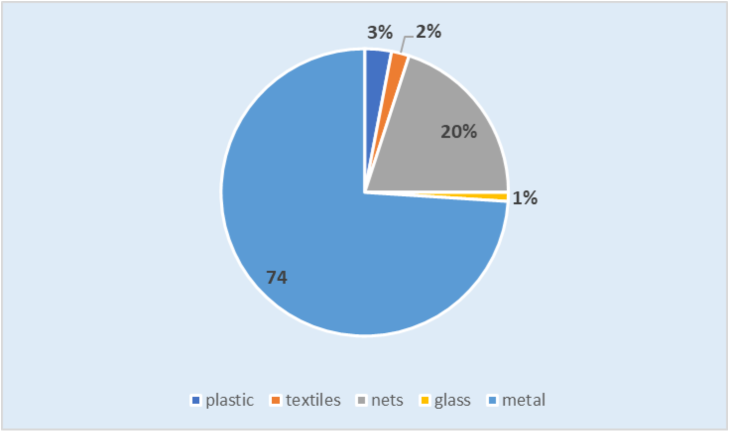

Figure 4. Typology (in percentages %) of sea floor litter along

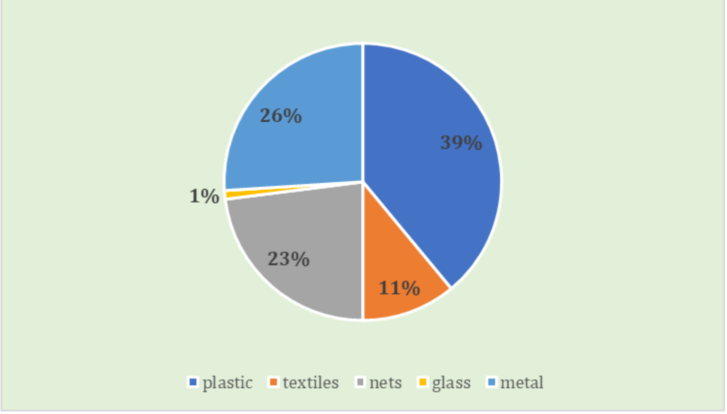

Figure 5. Number of items (in percentages %) of sea floor litter along Romanian Coast in 2019 (NIMRD data)

Compared to previous years, except for metal, the other categories showed lower values (g / m^2) with low oscillations from one year to another.

Regarding the seafloor litter, from all the methods assessed, bottom trawling (otter trawl) has been shown to be the most suitable for large-scale evaluation and monitoring (Goldberg 1995; Galgani *et al*. 1995, 1996, 2000). Nevertheless, there are some restrictions in rocky areas and in soft sediments for this method and it could underestimate the quantities presented.

The international bottom trawling surveys such as IBTS (Atlantic), BITS (Baltic) and MEDITS (Mediterranean/Black Sea) provide useful and valuable means for seafloor litter monitoring. For the Mediterranean Region, the protocol is derived from the MEDITS protocol (see the protocol manual, Bertrand *et al*. 2007). It is also a reference protocol for associated countries, including Romania and Bulgaria in the Black Sea. The hauls are positioned following a depth stratified sampling scheme with random drawing of the positions within each stratum. The number of positions in each stratum is proportional to the surface of these strata and the hauls are made in the same position from year to year. The determined depths intervals (10 – 50; 50 – 100; 100 – 200; 200 – 500; 500 - 800 m) are fixed in all areas as strata limits. The total number of hauls for the Mediterranean Sea is 1385; covering the shelves and slopes from 11 countries. The haul duration is fixed at 30 minutes on depths less than 200 m and at 60 minutes at depths over 200 m (defined as the moment when the vertical net opening and door spread are stable), using the same GOC 73 trawl with 20 mm mesh nets (Bertrand *et al*. 2007) and sampling between May and July, at 3 knots between 20 and 800 m depth.

On board of the vessel, the litter collected is weighted as total and divided into the categories and sub-categories as reported in the list below. It is mandatory to record or estimate total weight and number of items for each main category. It is facultative to register weight by categories and number of items by sub-category. In case of large amount of litter in the catch, all big sized objects of litter must be recorded while a subsample could be analysed for small sized litter (e.g. lids). Litter should be coded as total, by category and sub-category. Detailed data on total weight and litter composition must be reported in the corresponding protocol.

Qualitative and quantitative data, necessary metadata and characteristics of the haul (Date, code of haul, the GPS positions of the haul (start and end), trawled distance, average speed, characteristics of the haul (horizontal opening), depth of haul etc.), should be contained in the dedicated TA file. Information related to the fishing set and gear performance allows calculating the sampled surfaces for each haul and estimating a standardized index of litter abundance per square kilometre.

Conclusion

Reduction of marine litter is globally acknowledged as a major community challenge of our times due to its significant environmental, economic, social, political and cultural implications (Cheshire *et al.* 2009). Marine litter is one of the most harmful kinds of pollution and it is dominated by plastics (Coe and Rogers 1997). The Marine Strategy Framework Directive (MSFD), adopted in June 2008, commits Member States to apply an ecosystem approach managing the marine environment. By this directive, member states aim to achieve good environmental status (GES) of its marine waters by 2020 described by 11 descriptors.

The overall results highlight the importance of the Danube River and fishing activities as a source of marine litter in the Romanian Black Sea area. Monitoring the environmental status and managing the coastal area through the implementation of knowledge on ecosystem's biodiversity, functions and services are crucial actions to ensure the long-term sustainability and to establish the Good Environmental Status (GES) thresholds. MSFD aims to achieve a statistically measurable and significant overall reduction of sea floor litter by 2020. Despite natural fluctuations (annual variability, storm effects, etc.) that may affect the quantities dumped on shore and local applicability and technical feasibility, trend-based thresholds may be appropriate in the absence of other applicable methodologies.

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Distribution and composition of marine litter on seafloor in the western Black Sea, Turkey

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Abstract

The present study aims to determine the composition, abundance, density and accumulation areas of marine litter on the seafloor of the Turkish coastal part of the western Black Sea. The marine litter was collected with the trawl net, designed in accordance with the MEDITS trawl net plan. The survey was carried out in autumn 2019 with 14 trawl hauls in total. The duration time of the hauls was 30 minutes at a constant speed of 3 knots and depths 10-80 m in the coastal area. Litter items were identified according to the methodology and protocols of MEDITS (2017). The average abundance of marine litter on the western Black Sea seafloor was calculated as 111±37.40 items km^{-2} (between 30 and 390 items km^{-2}) and average weight 86.31±59.17 kg km^{-2} (between 0.30 and 831 kg km^{-2}). The ratio of marine litter in the study area was 71.43%. Plastic was the most common material with average abundance 79.28 ± 26.42 items km^{-2}. The abundance and weight of seafloor litter increased from western to eastern part of the studied area. The obtained data could be useful as a baseline for the future studies of seafloor marine litter in the Black Sea.

Keywords: Marine litter, Black Sea, trawling, pollution, seafloor

Introduction

The result of human activities causes more waste with an increasing population (Hoornweg *et al.* 2013). Solid waste could reach the aquatic habitats by different reasons. When it reach to the sea, marine litter can float over long distances or sink to the seafloor and accumulate in areas of low hydrodynamics (Engler 2012; Ioakeimidis *et al.* 2014; Pham *et al.* 2014; Romeo *et al*. 2015). Marine litter is defined as any permanent, processed, produced solid material that are deliberately discarded, disposed of or abandoned into river or marine or coastal environment; indirectly, brought to the marine environments by rivers, drainage systems, sewage, winds (OSPAR 2007). It is divided into two main categories of litter sources as land-based and sea-based. Litter from the land such as urban areas, industry or tourism fields can be transported into the marine habitat, through rain, rivers, wind, storm water, and sewage pipes, or can be directly disposed at the beaches and the sea (Ioakeimidis *et al.* 2014; UNEP 2009). Sea-based sources are shipping, fishing vessels, ferries, recreational activities and aquaculture farms

(Galgani *et al.* 2013; CIESM 2014; Strafella *et al.* 2015; Pasquini *et al.* 2016; Melli *et al*. 2017).

Marine litter is a major threat for marine habitats and has negative effects on economic sectors such as transportation, tourism, fisheries and aquaculture (Mouat *et al.* 2010). Recently it has become an important global environmental issue and one of the priorities at international, regional and local managements (Derraik 2002; UNEP 2009; Galgani *et al.* 2010; Elliott 2014; Sardà *et al.* 2014; UNEP 2016a; 2016b).

It was estimated that 15% of marine litter is floating on the sea surface, 15% stays in the water column and 70% is on the sea floor (UNEP 2005). It comprises of such products as packages, bags, facial cleansers and other household items. Every year in the world, 8 million tons of plastic debris ends up in the marine ecosystem (Jambeck *et al.* 2015; UNEP/MAP 2015; Villarrubia-Gómez *et al.* 2018). It can be found in all sea areas around the world and poses ecologic, economic and social impacts (Cheshire *et al.* 2009; Thompson *et al.* 2009). It could cause the fish mortality by ingestion and also reduce the catch amount indirectly. Hence, studies about the amounts and weight of marine litter are important also for stock assessments (UNEP and GRID-Arendal 2016).

There are many international and regional sea conventions and other initiatives regarding marine litter issue such as the Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Convention 1972); the Barcelona Convention for Protection of the Mediterranean Sea against Pollution, 1976; the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78); UN Convention of the Laws of the Sea, targeting the prevention, reduction and control of pollutants in the oceans from land and marine sources (UNCLOS 1982); the Convention on the Transboundary Movements of Hazardous Wastes and Their Disposal (The Basel Convention 1989); the Convention on the Protection of the Black Sea Against Pollution (the Bucharest Convention 1992); Helsinki convention on the Protection of the Marine Environment of the Baltic Sea Area 1992; Convention for the Protection of the Marine Environment of the North - East Atlantic (OSPAR 1992); UNEP global program of action for the protection of marine environment from land based activities 1995; EU Directive 2000/59/EC on port reception facilities for ship - generated waste and cargo residues, 2000; UNEP global initiative on marine litter 2009, etc. (Allsopp *et al.* 2006; Carroll 2014; UNEP 2016a).

The Black Sea is a semi-closed sea, which is characterized by high river discharge. It is vulnerable to pollution due to the enormous drainage area created by more than 170 million people from 21 countries, concentration of settlements in the coastal zone, intensive fishing activities and ship traffic (BSC 2007). In the report of the Commission on the Protection of the Black Sea Against Pollution, marine litter is reported to be the most difficult and urgent pollution problem in the Black Sea (BSC 2007). The human activities like shipping, fishing, tourism, mining, and military exercises affect the ecological situation of the Black Sea. Moreover, marine litter generates problems regarding international, regional and national regulations (BSC 2007). It could be transported on long distances through the sea, e.g. on the beaches of the Turkish part of western Black Sea items from other Black Sea countries were found (Topçu *et al.* 2013). Recently, with increasing number of marine litter studies in the Black Sea, the data was reported on beaches (Güneroğlu 2010; Topçu *et al.* 2013; Terzi and Seyhan 2017; Simeonova and Chuturkova 2019; Aytan *et al.* 2020; Terzi *et al.* 2020; Öztekin *et al.* 2020), seafloor (Topçu and Öztürk 2010; Terzi and Seyhan 2013; Ioakeimidis *et al.* 2014; Öztekin and Bat 2017) and in water column (Aytan *et al.* 2016; Öztekin and Bat 2017). Determining the current situation, possible sources and ways of transportation are of great importance in reducing and taking necessary measures at local, regional, national and international level to this cross-border problem that grows day by day (Karacan 2017).

Studies on marine litter in the Black Sea were mainly done on beach litter. Studies on floating marine litter and sea floor litter have been very limited. There was a study carried out by divers in Istanbul, where litter items were categorized (BSC 2007). In all other studies, marine litter at certain depths was examined by using bottom trawls (Topçu and Öztürk 2010; Anton *et al.* 2013; Terzi and Seyhan 2013; Ioakeimidis *et al.* 2014).

This study aims to determine the composition, abundance, weight, density and location of marine litter in the coastal zone of the Turkish part of western Black Sea to provide valuable information relying on standardized methodology and protocols of MEDITS 2017.

Materials and Methods

Study area

The Black Sea is one of the largest areas of the Mediterranean General Fisheries Commission (GFCM) and one of the most complex ecosystems in the region (GFCM 2012). The Black Sea is connected with the Mediterranean and ocean system by the Bosphorus (Istanbul Strait), the Marmara Sea and the Dardanelles (Çanakkale Strait). Its maximum depth is 2212 m (Degens and Ross 1974). The surface waters of the southwestern Black Sea enter the Bosphorus as a homogeneous layer of 40-45 m and flow towards the Marmara Sea. At the bottom of the Bosphorus partially diluted salty waters of the Mediterranean flow from Marmara to the Black Sea (Özsoy *et al.* 1988, 1994; Beşiktepe *et al.* 1994). There is a large shelf area in the northern and western part of the Black Sea (Erinç 1984). Currents in the Black Sea are circular in character and counterclockwise (Zaitsev 2008). Due to the two large cyclonic discharge systems, the Black Sea basin is characterized by dividing it into two parts as east and west (Oğuz *et al.* 1991;

Oğuz and Beşiktepe 1999; Sur *et al.* 1994). The Black Sea is roughly oval-shaped, the maximum width of the Black Sea in east-west direction is 1175 km, while the shortest distance in north-south direction is 260 km from the coast of the Crimea to Kerempe Cape in Turkey (BSC 2008).

The Black Sea is the largest meromictic basin, characterized by a permanent halocline (Sorokin 1983). Permanent pycnocline separates water from substrate, where density is approximately 17 kg/m^3, from shallow upper layer waters, where density is approximately 11 kg/m^3. The vertical mixture in the water column is limited to the top layer, so more dense waters are isolated from the oxygen source and become stable and anoxic. The pycnocline centered on about 100 m is the primary physical barrier for the vertical mixture and is the root of the stability of the anoxic interface (Murray 1989).

Annual fresh water inflow to the Black Sea via rivers is 400 km^3. The most important part of this is the Danube River (200 km^3). The maximum water discharge into the Black Sea coast in Turkey is coming from Sakarya, Kızılımak, and Yeşilırmak rivers and the amount of water each carry each year is about 6 km^3 (Çelikkale *et al.* 1999). Western Black Sea surface waters are constantly polluted, especially with the nutrient salts and organic matter carried by the Danube River (Oğuz and Rozman 1991; Mee 1992; Cociasu *et al.* 1996, 1997).

Southwestern bottom sediments of the Turkish Black Sea coasts are under the influence of substances coming from the Sakarya River, the Bosphorus, and streams. Terrestrial originated substances transported with these waters settle in the sea according to their grain size. The sedimentation, currents, waves, topographic features of the land, submarine morphological structure, bathymetry, coastal shapes and wind play an important role marine litter distribution. The main dominant unit of the surface sediment in the study area is sand, silt, clay and mud (Eryılmaz *et al.* 2002).

In Turkey's western Black Sea coasts agriculture and fishing, coal mining, shipping and touristic activities during the summer months are carried out. There are ten large cities in the region (According to the statistics of 2019; Kırklareli 360.860 population, Tekirdağ 1.030.000 pop., İstanbul 15.520.000 pop., Kocaeli 1.906.000 pop., Sakarya 1.029.650 pop., Düzce 387.844 pop., Bartın 198.999 pop., Zonguldak 213.544 pop., Kastamonu 383.373 pop., and Sinop 219.733 pop.).

Data collection and analysis

In autumn 2019 a trawl survey was carried out within the scope of the "Integrated Pollution Monitoring Program in the Sea" conducted by the Ministry of Environment and Urbanization and coordinated by TÜBİTAK-MAM ÇTÜE. Bottom trawl hauls were taken with R/V Yunus S 32 m long. The horizontal opening width of the upper collar of the trawl net was 24 m, and the mesh size of the cod-end was 14 mm (stretched mesh size). This trawl net, designed in accordance with the MEDITS trawl net plan, was hauled for 30 minutes at a constant speed of 3 knots for a total of 14 trawl hauls (Figure 1, in the coastal area between 10-80 m). The litter items from the trawl cod-end were counted, weighted and divided into nine categories: plastic, rubber, metal, glass/ceramics, cloth/textiles, processed/worked wood, paper/cardboard, other debris and undefined (Galgani *et al.* 2013). Plastics were divided into six subgroups: plastic bags, drink bottles, food wraps, hard plastic, ropes and fishing gear pieces. After that litter items have been categorized according to the methodology and protocols of MEDITS (2017). The abundance and weight of litter were calculated according to the investigated area (Sparre and Venema 1992).

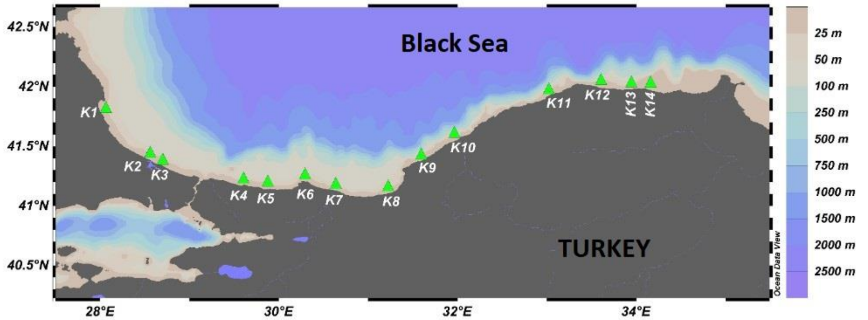

Figure 1. Study area and trawl stations

The trawl hauling area was divided into three parts according to the depths: 0-20 m (1), 20-50 m (2) and 50-100 m (3). The significance of differences between the compositions of marine litter at different depths has been tested in the PRIMER V6 software program using non-parametric analysis of similarity (ANOSIM) (Clarke and Gorley 2006). The abundance (items km^{-2}) of each group of marine litter was used for this analysis. Data were transformed using the log (x + 1) transform before calculating the Bray-Curtis similarity (Bray and Curtis 1957). Similarity percentage analysis (SIMPER) test was applied to determine the percentage of difference between depths.

Results

The average abundance of marine litter on the western Black Sea seafloor was calculated as 111 ± 37.40 items km^{-2} (between 30 and 390 items km^{-2}) and average weight 86.31 ± 59.17 kg km^{-2} (between 0.30 and 831 kg km^{-2}). The highest total seafloor litter concentration was found to be 832 kg km^{-2} at a depth of 32 m and lowest was as 0.30 kg km^{-2} at 49 m. There was no litter at four stations. The ratio of seafloor litter in the study area was 71.43%. The abundance and weight of seafloor litter calculated according to the stations are given in Figure 2. The abundance and weight of seafloor litter were increasing in the study area from west to east.

During the survey, high values of coal and wood log items were found in many stations which is due to the presence of coal deposits in the region and the drift of tree items into the marine environment through the river. These materials were not included in the evaluation since they are of nature origin.

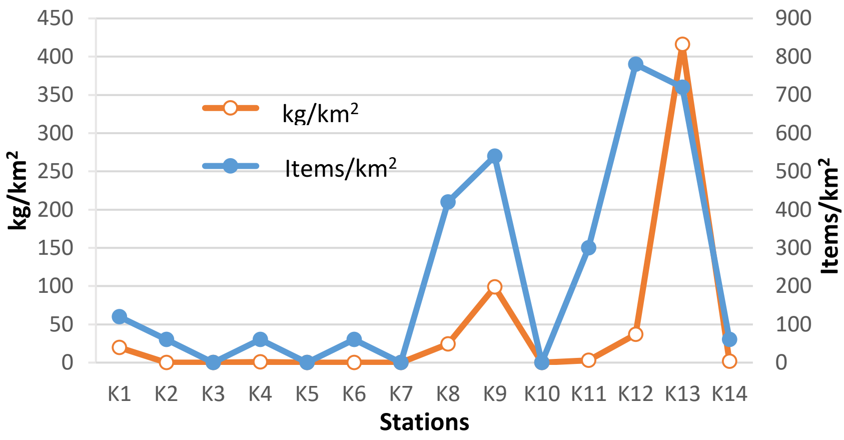

Figure 2. The abundance and weight of seafloor litter in the western Black Sea

Plastic and rubber materials were the most common materials, where plastics were the dominant group by amount (71.2%) and rubber by weight (73.5%) (Figure 3). Plastic bags, bottles, wrapping papers, hard plastics, lost fishing nets and ropes were found in the plastics group. In the Rubber group, car tires were found at the station K13 (Figure 4), while personal clothing products such as shoes and boots were also identified. No glass/ceramic, processed wood and paper/cardboard were found in the study area.

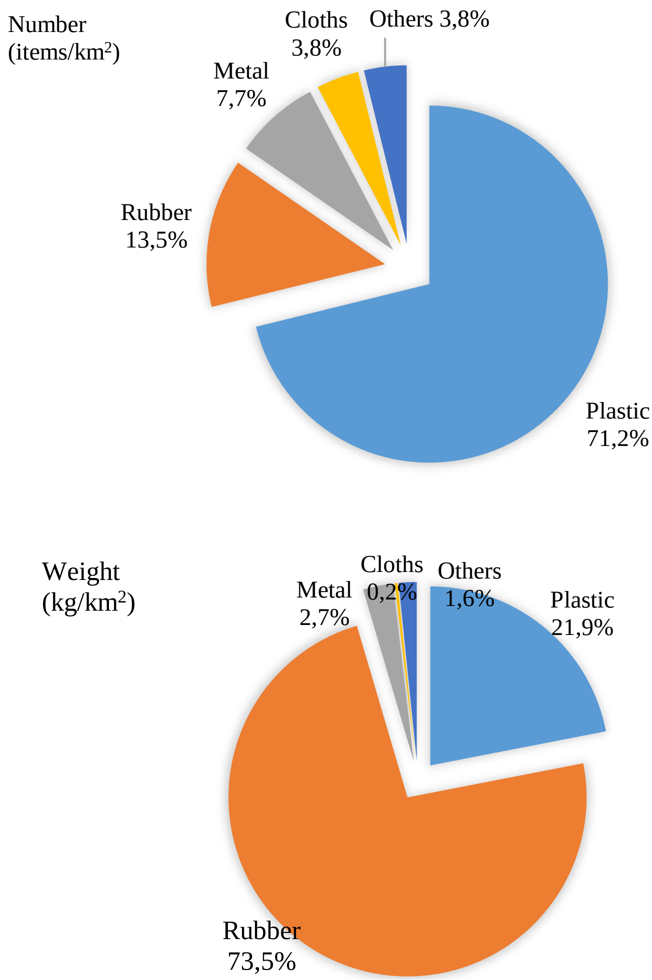

Figure 3. Distribution of seafloor litter by number and weight percentage

The composition of seafloor litter in the sampling stations is given in Figure 4. Plastic was the most common material in the study area. The average abundance of plastics was 79.28±26.42 items km^{-2} (Figure 5), followed by rubber (15.00±10.78 items km^{-2}), metal (8.57 ±3.76 items km^{-2}), cloths (4.29±4.29 items km^{-2}) and others (4.29±2.91 items km^{-2}). The presence of plastic bags within the plastic group was 35.71%, followed by plastic bottles 28.57%, food wraps 21.43%, ropes 14.29%, hard plastics 7.14% and fishing nets 7.14% (Table 1).

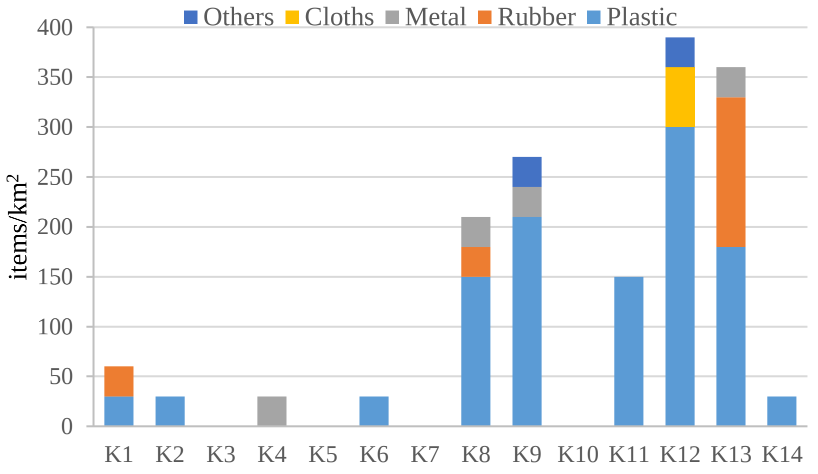

Figure 4. The abundance and composition of seafloor litter in the western Black Sea

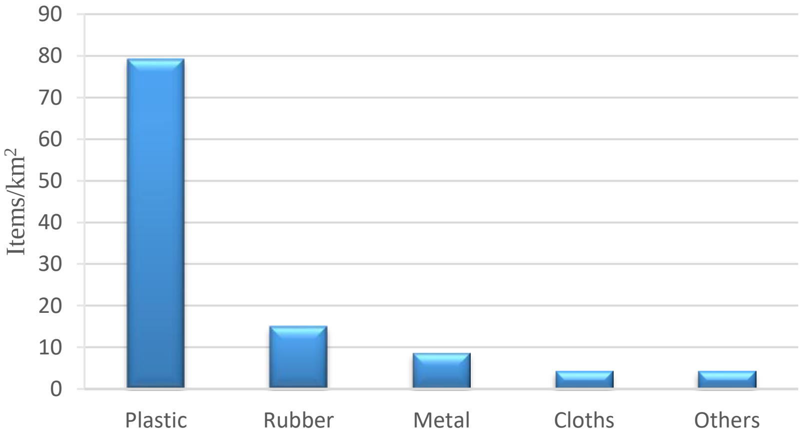

Figure 5. Average number of seafloor litter in the western Black Sea according to the material type (mean number of items km^{-2})

Table 1. The ratio, abundance and weight of seafloor litter in the western Black Sea by material type

Object Type	Occurrence %	Items km^{-2}	kg km^{-2}
Plastic	64.29	79.28±26.42	18.94±12.57
Plastic bags	35.71	32.14±16.18	2.87±2.05
Drink bottles	28.57	19.28±9.23	4.24±30.3
Ropes	14.29	12.86±10.76	0.66±0.64
Food wraps	21.43	8.57±4.90	0.12±0.09
Hard plastic	7.14	4.29±4.29	0.33±0.33
Fishing nets	7.14	2.14±2.14	10.71±10.71
Rubber	21.43	15.00±10.78	63.42±57.55
Metal	28.57	8.57±3.76	2.34±1.47
Cloths	7.14	4.29±4.29	0.21±0.21
Others	14.29	4.29±2.91	1.39±1.09

Trawling operations in the study area were made in three depth contours. No marine litter was found at depths of 0-20 m. The most common marine litter was plastics at 20-50 m and 50-100 m. Rubber was seen only at depths of 20-50 m and was the most dominant litter type in this depth by weight (Figures 6 and 7). There were some other litter items collected with the trawl operations within this study as illustrated on Figure 8.

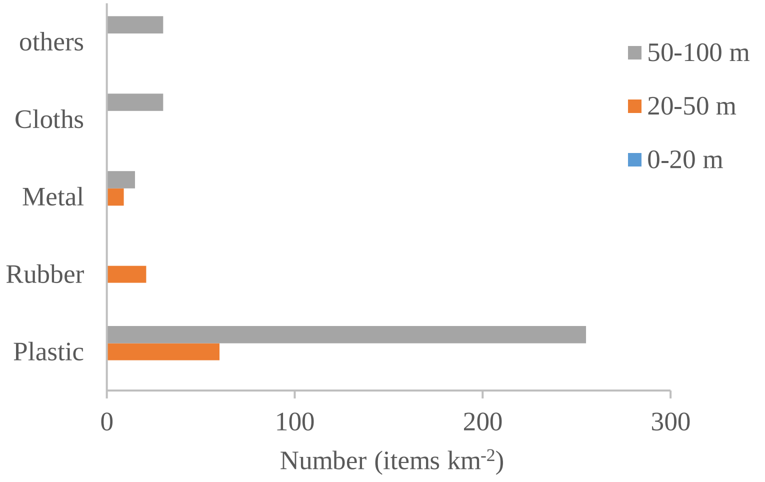

Figure 6. Average abundance of seafloor litter in the western Black Sea according to depth contours

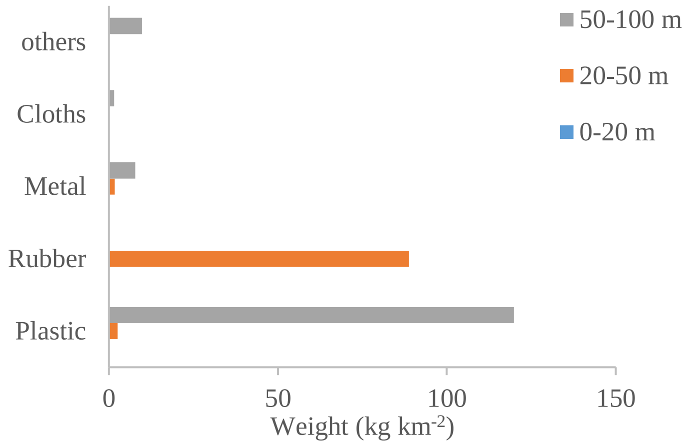

Figure 7. Average weight of seafloor litter in the western Black Sea according to depth contours

Figure 8. Some examples of marine litter collected from seafloor. (a) Log pieces; (b) Plastic bottles; (c) Metal teapot; (d) Nylon bag pieces; (e) Polymer sponge piece; (f) Log pieces, plastic boot and can; (g) Car tires; (h) Fishing nets for turbot (ghost fishing nets)

According to the one-way ANOSIM results, there are significant differences in the composition of marine litter between depth contours (global $R=0.331$; $p<0.001$). According to SIMPER analysis, plastic was the most abundant material. Contribution rate at 20-50 m depth was 85.96% and 60.91% at 50-100 m depth (Table 2). The highest average dissimilarity was found between 0-20 m and 20-50 m and 0-20 m and 50-100 m depth groups (Table 3).

Table 2. SIMPER results for the similarity of seafloor litter composition in the western Black Sea

Depth	Average group similarity	Litter category	Average similarity	similarity/ Std. deviation	Contribution %
20-50 m	33.82	Plastic	29.07	0.85	85.96
		Rubber	2.54	0.26	7.52
50-100 m	68.98	Plastic	42.02	-	60.91
		Others	26.96	-	39.09

Table 3. SIMPER results for the dissimilarity of seafloor litter composition in the western Black Sea

Comparison	Average dissimilarity	Litter category	Average dissimilarity	Dissimilarity/ Std. deviation	Contribution %
20-50&0-20m	100	Plastic	66.29	1.76	66.29
		Metal	19.26	0.57	19.26
		Rubber	14.46	0.72	14.46
		Others	20.29	4.42	31.16
20-50&50-100m	65.12	Plastic	17.67	1.1	27.14
		Cloths	11.76	0.93	18.06
		Metal	10.35	0.93	15.89
0-20&50-100m	100	Plastic	43.43	102.99	43.43
		Others	27.01	21.37	27.01
		Cloths	15.51	0.87	15.51
		Metal	14.05	0.87	14.05

Discussion

This study was carried out to determine the distribution and quantity of seafloor litter in the coastal area in the western Black Sea. The average density was 111 ± 37.4 items km^{-2} and 86.3 ± 59.2 kg km^{-2}. Due to the fact that the Mediterranean and Black Sea are a semi-closed seas, it is considered as the areas most affected by marine litter (Galil *et al.* 1995; 2014; Ioakeimidis *et al.* 2014; Stanev and Ricker 2019). In the studies conducted in the Mediterranean Sea and the Black Sea regions, the density of seafloor litter was found to be high compare to the North Sea (Table 4). Topçu and Öztürk (2010) reported that the density of sea floor litter in the western Black Sea was higher than that in the Mediterranean. The results of this study show lower densities in comparison with previous studies in the western Black Sea. For efficient management of resources and prevention of environmental pollution caused by plastic bags the Ministry of Environment and Urbanization launched an application for charging plastic bags in 2019. It mighthelp in reducing of the amount of plastig bag enters to the Black Sea. However, the most abundant material of marine litter was still plastic.

Table 4. Comparison of seafloor litter densities in the North Sea, Mediterranean Sea and Black Sea

Location	Items km^{-2}	kg km^{-2}	Depth range (m)	References
North Sea				
Celtic Sea	24.3	-	inshore	Maes *et al.* 2018
	21.6	-	offshore	
Greater North Sea	49.1	-	inshore	
	40.5	-	offshore	
Mediterranean Sea				
Adriatic Sea	-	85±26	0-100	Strafella *et al.*. 2015
North and Central Adriatic Sea	913	82	35-260	Pasquini *et al.* 2016
North and Central Adriatic Sea	-	103±42	8-100	Strafella *et al.* 2019
Gulf of Alicante (Spain)	-	0-11.6	50-700	García-Rivera *et al.* 2017
Balearic Island	-	1.39±0.13	38-800	Alomar *et al.* 2020
Greece	72-437	6.7-47.4	15-320	Koutsodendris *et al.* 2008
Island of Sardinia	58.6±5.7	17.1±3.4	0-800	Alvito *et al.* 2018
Saronikos Gulf	1211±594	-	50	Ioakeimidis *et al.* 2014
Gulf of Patras	641±579	-	50	
Echinades Gulf	416±379	-	50	
Limassol Gulf	24±28	-	50	
Antalya Bay	13.3-651	0.02-559	10-300	Olguner *et al.* 2018
Black Sea				
Romania	-	554.53	15-90	Anton *et al.* 2013
Constanta Bay	291±237	-	50	Ioakeimidis *et al.* 2014
Southern Black Sea (Samsun)	121-366	-	45-50	Terzi and Seyhan 2013
Western Black Sea	541	-	49-77	Topçu and Öztürk 2010
Western Black Sea	808±215	-	20-39	Öztekin and Bat 2017
Western Black Sea	111 ± 37.4	86.3±59.2	10-80	This study

The distribution, type and amount of marine litter reaching the seafloor varies depending on different factors such as hydrography, geomorphology, vicinity to urban areas, coastal activities, shipping, fishing and aquaculture (Bauer *et al.* 2008; Schlining *et al.* 2013; Pham *et al.* 2014; Bergmann *et al.* 2015; Consoli *et al.* 2018). The light items such as plastics could float large distances before sinking, while heavy items sink to the seafloor (Carlson *et al.* 2017). UNEP (2015) reported that marine litter from land-based sources, makes up about 80% of the total loads found in the world's oceans. Therefore, more anthropogenic litter inlet is expected in shallow sea areas near densely populated cities (Galimany *et al.* 2019). In this study, the density of seafloor litter was found to be quite low in Istanbul coastal area with the highest population compared to other regions. The currents circulation model could explain it where a cyclonic cycle takes water bodies from north to south in the eastern Black Sea and the Istanbul Strait flow system.

The marine litter collected from the seafloor during this research, was consisted mostly of plastic materials (71.2% plastic, 13.5% rubber, 7.7% metal, 3.8% cloths and 3.8% others), which are more likely to float and are easier for transportation. Similarly, in many studies conducted in different parts of the world, plastic was reported as the most common material on the seafloor (Table 5). The domination of plastic could be explained by its cheapness and widely application. Floating leads to its fast distribution and accumulation on both coastal shelf and deep sea areas.

Inadequate management of plastic waste has caused to increased contamination of freshwater and marine environments. It is estimated that between 4.8 million and 12.7 million tons of plastic waste entered to the oceans in 2010 (Lusher *et al.* 2017). The main problem is the accumulation of plastic garbage in the marine environment, since most of these materials do not decompose or do it very slowly. Plastics tend to degrade over time into small particles called microplastics. Litter at sea could be transported to large distances with ocean currents and is persistent in all marine environments (Werner *et al.* 2016). Ingestion of microplastics and associated toxic contaminants by aquatic organisms leads to the formation of a microplastic hazard in the marine environment (Lusher *et al.* 2017). Microplastic has been observed in the digestive systems of many fish and invertebrate species (Karakulak *et al.* 2009; Lusher 2015; Fossi *et al.* 2018). This situation poses a danger to food safety and human health.

Fisheries industry and artisanal/small scale fishing is of major importance for the economy of Turkey. The artisanal fleet in the western Black Sea is using a variety of gear types and targeting a large range of species. In the western Black Sea, a great amount of fishing nets were found lost (Yıldız and Karakulak 2016). Ghost fishing is an invisible and undesirable fishing caused by lost, discarded or abandoned fishing gears largely confined to passive gears such as gillnet (Breen 1990). Many of the abandoned fishing nets belong to Turkish, Bulgarian and Romanian fishermen which is shown in another study investigating sea bottom litter on the Romanian shelf (Anton *et al.* 2013). In this study, a bottom turbot gillnet was found as lost or abandoned during the bottom trawl operation. Inherently, it is well known that turbot is a highly prized species and can be illegally targeted using bottom (turbot) gillnets (Radu *et al.* 2011), and some illegal fishermen leave abandoned their turbot nets (Yildiz 2010). The fishing gear losses have many impacts continuing capture of wildlife, interaction with endangered species, and physical impact on the seafloor, introduction of synthetic material into the marine food web (Macfadyen *et al.* 2009). For the protection of marine organisms, restriction measures should be implemented to solve the derelict fishing gear problems.

Table 5. The percentage of plastic in seafloor litter collected by trawl operations in different regions.

Area	Plastic (%)	Depth range (m)	References
North Sea			
Celtic Sea	77	inshore	Maes *et al.* 2018
	94	offshore	
Greater North Sea	65	inshore	
	79	offshore	
Baltic Sea	35	6-128	Zablotski and Kraak 2019
Mediterranean Sea			
Gulf of Alicante (Spain)	68.1	50-700	García-Rivera *et al.* 2017
Balearic Island (Spain)	66	38-800	Alomar *et al.* 2020
Mediterranean (France)	71	10-800	Gerigny *et al.* 2019
Mediterranean (France)	68	<200	Galgani *et al.* 1996
Island of Sardinia (Italy)	59.4	0-800	Alvito *et al.* 2018
North and Central Adriatic Sea	80	0-100	Pasquini *et al.* 2016
North and Central Adriatic Sea	43	0-100	Strafella *et al.* 2019
Adriatic Sea, Slovenia	89	20-25	Vlachogianni *et al.* 2017
Saronikos Gulf (Greece)	95	50	Ioakeimidis *et al.* 2014
Gulf of Patras (Greece)	59.9	50	
Echinades Gulf (Greece)	67.4	50	
Limassol Gulf (Cyprus)	67.4	50	
North Lakonikos Gulf (Greece)	80	15-320	Koutsodendris *et al.* 2008
Antalya Bay (Turkey)	72.1	10-300	Olguner *et al.* 2018
Mersin Bay (Turkey)	73	19-178	Eryaşar *et al.* 2014
Black Sea			
Constanta Bay (Romania)	45.2	50	Ioakeimidis *et al.* 2014
Southern Black Sea (Turkey)	95.35	20-39	Öztekin and Bat 2017
Western Black Sea (Turkey)	73.6	21-58	Topçu and Öztürk 2010
Western Black Sea (Turkey)	71.2	10-80	This study

The problem of marine litter was admitted by the UN General Assembly in 2005, and the General Assembly called for national, regional and global actions to address the problem of marine litter. This proposal of the General Assembly expresses a lack of information and data on marine deposits, encouraging states to cooperate with industry and civil society, urge States to incorporate marine deposits into their national environmental strategies, and to develop and implement common prevention and recovery programs on marine deposits and to join efforts in a regional and sub- regional context. In response to this call, UNEP (PEP and Regional Seas Program) has taken leadership through the Global Marine Litter Initiative to address this issue, among other issues, and in this context, offered help for 11 Regional Seas worldwide (Baltic Sea, Black Sea, Caspian Sea, East Asian Seas, East Africa, Mediterranean, Northwest Pacific, Red Sea and Gulf of Aden, South Asian Seas, South East Pacific and Wider Caribbean).

As a developing region, the population on the coastline of the Black Sea Basin is dense and there are many activities in the region, such as high-energy consumption, transportation, tourism and fishing. The main issue of the marine litter problem is solid waste materials, which originate from land and sea-based sources. This problem causes negative effects on population, wildlife, abiotic nature and some economic sectors such as tourism, fishing and sea traffic. The main ways for land-based marine litter are rivers and discharge waters. Another problem is sunken litter in the sea basin apart from on the coastline or litter floating on the sea surface. Since the Black Sea is an enclosed sea with a very dynamic currents system, the marine litter problem in this region emerges as a transboundary problem (MARINTURK 2018).

The present study reports the data on marine litter collected from the seafloor in the western Black Sea and provides the information to overview the plastics management system as plastics confirmed to be the most common material of marine litter in the region where trawl surveys were performed. It is well known that plastic materials are dangerous for marine life and human health as well because of being toxic chemicals. The data also could be useful for the future comparisons regarding the marine litter to fill in the existing gaps in knowledge. Furthermore, a corresponding legislation to reduce the plastic production and consumption in the Black Sea is strongly recommended.

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Distribution and composition of seafloor marine litter in the southeastern Black Sea

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Abstract

This study was conducted to investigate seafloor marine litter abundance between Samsun (Yakakent) and Hopa within the scope of Integrated Marine Pollution Monitoring Project (ÇŞB/ÇEDİDGM-TÜBİTAK/MAM) in summer 2019. Totally, the trawl hauling operations were successfully performed in 30 stations. The works were done according to the MEDITS protocol: sampling was done at 3 different depths (0-20 m, 20-50 m and 50-100 m), marine litter was classified in 9 categories. At all sampling stations marine litter was assessed by weight and amount. The most common marine litter group was L2 tire/rubber by weight (53%) and amount (67%) when L1 plastic group - 25% by weight and L5 fabric and natural fibres - 12% by amount. Especially in the L2 group, the car and truck tires were dominated in weight of CB5 (Trabzon- Sürmene) and CB3 (Trabzon) stations.

Keywords: Marine litter, plastic, pollution, southeastern Black Sea

Introduction

The sea is very important for the human life in terms of natural resources such as food, energy and tourism. Overfishing, pollution, eutrophication, ocean acidification and global warming accompanied by sea-level rise as a result of rapid glacier melting and thermal expansion of sea water are apparent effects of man-made pressures (IPCC 2014). Public awareness and research is required to manage these problems caused mostly by human effects. In recent years, the pollution of the sea/oceans by anthropogenic litter has been validated as a serious global environmental apprehension. Marine litter is described as any lasting, machined, manufactured solid wastes that are lost, dropped, discharged via drainage systems, erosion, storm water or rivers from the land such as urban areas, industry or tourism fields to the coastal and marine environment by humans (OSPAR 2007; UNEP 2009). It is a major threat for marine environment and has negative effects for all economic sectors such as shipping, tourism, fisheries and aquaculture (Mouat *et al.* 2010). 8 million tons of plastic are dumped in to the ocean every year (UNEP/MAP 2015). There are many international and regional conventions and directives related to the Marine Litter such as the London

Convention (1972); the Barcelona Convention (1976); the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78); UN Convention of the Laws of the Sea, targeting the prevention, reduction and control of pollutants in the oceans from land and marine sources (UNCLOS 1982); the Basel Convention (1989); the Bucharest Convention (1992); the Helsinki Convention (1992); the Convention for the Protection of the Marine Environment of the North - East Atlantic (OSPAR 1992); UNEP global program of action for the protection of marine environment from land based activities (1995); EU Directive 2000/59/EC on port reception facilities for ships - generated waste and cargo residues, 2000; UNEP global initiative on marine litter (2009) (Allsopp *et al.* 2006; Carroll 2014; UNEP 2016a) and European Commission Marine Strategy Framework Directive for Good Environmental Status Technical Subgroup on Marine Litter (MSFD 2008).

The Black Sea ecosystem has experienced serious changes since the 1960s which has occurred as large-scale marine ecosystems disruptions and were mentioned in the scientific literature. The main factors aforementioned disruptions are increasing eutrophication due to river inputs and significant amount of phytoplankton biomass increase, development of opportunistic dominant species changes in the fish stocks, overgrowth of gelatinous species, changes in biochemical cycles, climatic changes occurred in the overcooling in the 1980s and overheating in the 1990s (Oguz *et al.* 2008). In addition, constantly increasing overfishing also caused fluctuations in amount of catch and fish biodiversity. Due to insufficient research, the level and negative consequences of these changes could not be predicted, and then it could occur as a sudden decrease like in anchovy stocks in 1989, which causes ecological and socio-economic losses.

The aim of the present study was to conduct a quantitative assessment of seafloor marine litter in the South-Eastern Black Sea coastal areas applying the methodology recommended by International bottom trawl surveys in the Mediterranean (MEDITS) Protocol (2017) in line with the Marine Strategy Directive Framework (Directive 2008/56/EC).

Materials and Methods

Bottom trawl surveys were realized with R/V Sürat Araştırma-1 (Table 1) of the Central Fisheries Research Institute on the South-eastern coast of the Black Sea on 20th of August and 14th of September 2019. The surveys were conducted at 30 stations in three different depth contours (0-20 m, 20-50 m and 50-100 m) considering 30 minutes bottom trawl hauling on each station (Figure 1) in accordance with MEDITS protocol adapted to the Black Sea conditions in the littoral region between Sinop and Artvin (Table 2).

Table 1. Properties of R/V Sürat Araştırma-1

Renovation year	2011
Length	28.5 m
Width	9.6 m
Draft	2.2 m
Number of staff	18
Engine power	720 HP+360 HP
Generator power	55 kW +30 kW
Fishing nets	Mid-water and bottom trawl
Cranes	3 cranes (Hydraulic, electrical and A frame)
Fuel capacity	18 tons
Water capacity	20 tons
Research Tools	Scientific eco-sounder, radar, Fishing net sensor, CTD, rosette sampler

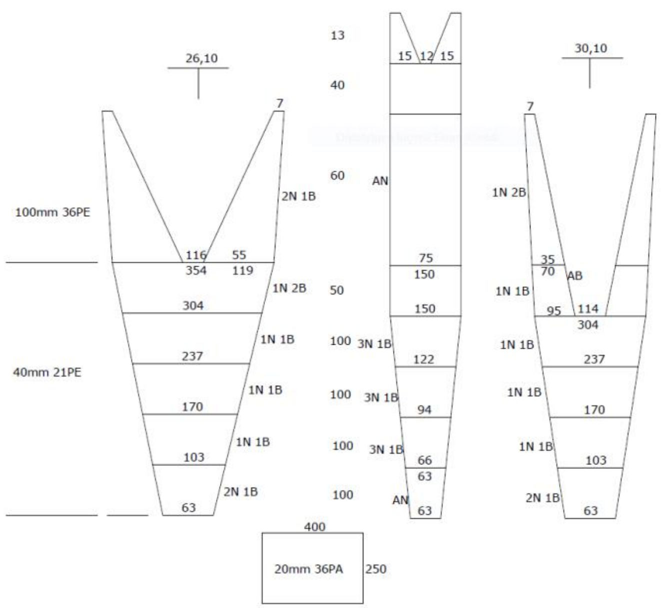

Figure 1. The technical features of the bottom trawl net

Table 2. Sampling stations

Stations No	Locations	Coordinates				Haul time (Minute)	Haul speed (Nautical Mile)	Depth (m)
		Starting		Ending				
CB1	Trabzon-Havaalanı	41°0'25"N	39°47'39"N	40°59'66"N	39°45'90"E	30	2.8	15
CB2	Trabzon-Havaalanı	40°59'87"N	39°48'58"N	40°0'44"N	39°47'18"E	30	2.8	28
CB3	Trabzon-Havaalanı	41°0'64"N	39°47'23"N	41°0'90"N	39°48'62"E	30	2.8	55
CB4	Sürmene	40°55'61"N	40°7'75"N	40°58'73"N	40°9'10"E	30	2.8	68.5
CB5	Sürmene	40°55'68"N	40°10'79"N	40°55'97"N	40°12'10"E	30	2.8	43
CB6	Çayeli	41°9'77"N	40°47'20"N	41°8'86"N	40°46'7"E	27	2.8	35
CB7	Çayeli	41°08'02"N	40°44'77"N	41°9'18"N	40°46'13"E	30	2.8	52
CB8	Fındıklı	41°15'81"N	41°6'64"N	41°14'86"N	41°5'33"E	30	2.8	30
CB9	Fındıklı	41°14'64"N	41°4'66"N	41°15'50"N	41°6'2"E	27	2.9	50
CB10	Hopa	41°22'97"N	41°20'67"N	41°25'54"N	41°22'63"E	30	2.9	27
SB1	Yakakent	41°39'6"N	35°34'19"N	41°38'75"N	35°35'70"E	25	2.9	30
SC1	Yakakent	41°42'24"N	35°28'72"N	41°42'35"N	35°30'52"E	30	2.9	59
SA1	Yakakent	41°41'18"N	35°26'9"N	41°40'83"N	35°26'74"E	25	2.9	18
SA6	Azot	41°15'76"N	36°27'7"N	41°16'13"N	36°29'16"E	30	2.9	23
SB6	Azot	41°18'7"N	36°28'84"N	41°18'46"N	36°30'63"E	30	2.9	32
SC4	Kızılırmak East	41°28'662"N	36°16'68"N	41°27'45"N	36°16'96"E	30	3	56
SB4	Kızılırmak East	41°27'67"N	36°14'78"N	41°26'14"N	36°15'85"E	30	2.9	36
SA4	Kızılırmak East	41°26'26"N	36°13'56"N	41°24'63"N	36°14'31"E	30	2.9	16
SC6	Azot	41°20'74"N	36°30'14"N	41°20'7"N	36°31'42"E	28	2.9	52
SA10	Ünye	41°10'7"N	37°8'66"N	41°9'37"N	37°10'19"E	30	2.9	16

Table 2. Continued

CB11	Melet	41°0'65''N	37°57'46''N	41°0'44''N	37°57'33''E	31	2.9	62
CB12	Melet	40°59'72''N	37°59'21''N	41°0'21''N	37°56'51''E	30	2.9	29
CB13	Melet	40°59'78''N	37°57'24''N	40°59'40''N	37°58'82''E	30	2.9	15
SC8	Yeşilırmak East	41°24'39''N	36°49'98''N	41°23'80''N	36°51'33''E	20	2.9	55
SB8	Yeşilırmak East	41°23'46''N	36°49'65''N	41°22'85''N	36°51'97''E	26	2.9	29
SA8	Yeşilırmak East	41°22'27''N	36°49'98''N	41°21'70''N	36°52'17''E	30	2.9	16
SB10	Ünye	41°10'46''N	37°12'28''N	41°10'58''N	37°10'5''E	30	2.9	33
SC10	Ünye	41°13'4''N	37°9'39''N	41°11'74''N	37°11'28''E	30	2.9	52
CB14	Çarşıbaşı	41°4'45''N	39°19'38''N	41°3'91''N	37°17'53''E	30	2.9	50
CB15	Çarşıbaşı	41°3'87''N	39°18'6''N	41°4'52''N	39°20'12''E	30	2.9	30

In each trawl sampling, after the trawl net was taken into the deck, the whole catch was measured afterwards it was separated according to group categories in the MEDITS Protocol (Table 3), count and recorded by the researchers. The biomass was calculated using the "Swept Area" method for 1 km^2 (Sparre and Venema 1992);

$$\sum_{i=1}^{n} \hat{B}_i = \frac{A.\overline{C_i}}{a_i.q}$$

$\hat{B}$: Estimate of Average Biomass
C_i: Average amount of catch in i-eth sampling
A: The total survey area (1 km^2)
a_i: Swept area in i-eth sampling
q: Catchability coefficient of the trawl net (The q was evaluated according to "0,75 and 1").

Table 3. Marine litters MEDITS Protocol category list

		Number	Weight
L1 Plastic	a. Bags		
	b. Bottles		
	c. Food wrappers		
	d. Sheets (table-cover, etc.)		
	e. Hard plastic objects (crates, containers, tubes, ash-trays, lids, etc.)		
	f. Fishing nets		
	g. Fishing lines		
	h. Other fishing related (pots, floats, etc.)		
	i. Synthetic ropes/strapping bands		
L2 Rubber	a. Tyres		
	b. Other (gloves, floats, boots/shoes, sanitaries)		
L3 Metal	a. Beverage cans		
	b. Other food cans/wrappers		
	c. Middle size containers (of paint, oil, chemicals)		
	d. Large metallic objects (barrels, pieces of machinery, electric appliances)		
	e. Cables		
	f. Fishing related (hooks, spears, etc.)		
L4 Glass/Ceramic/Concrete	a. Bottles		
	b. Pieces of glass		
	c. Ceramic jars		
	d. Large objects (ceramic basins, etc.)		
L5 Cloth (textile)/Natural fibres	a. Clothing (clothes, shoes, etc.)		
	b. Large pieces (carpets, mattresses, etc.)		
	c. Natural ropes		
	d. Sanitaries (diapers, cotton buds, etc.)		
L6 Wood processed (palettes, crates, etc.)			
L7 Paper and cardboard			
L8 Other			
L9 Unspecified			

Results

Seafloor marine litter obtained from bottom trawl sampling at 30 stations between Hopa-Samsun was classified in nine categories in accordance with the protocol. As a result, litter items were not found at stations CB6, SC6, SB4, SA8, SB8, SC8, SB10, CB12 and CB15. The most common and heavily weighted marine litters group is L1 plastic and L2 rubber materials, respectively. The distribution of the marine litter groups is shown in Figure 2 according to the q=0.75 and q=1. The average density of marine litter was calculated as 195.16±107.76 kg/km^2 in weight, 261.61±89.42 units/km^2 for q=1, 261.43±144.03 kg/km^2 in weight, 351.63±118.19 units/ km^2 for q=0.75 (Table 4).

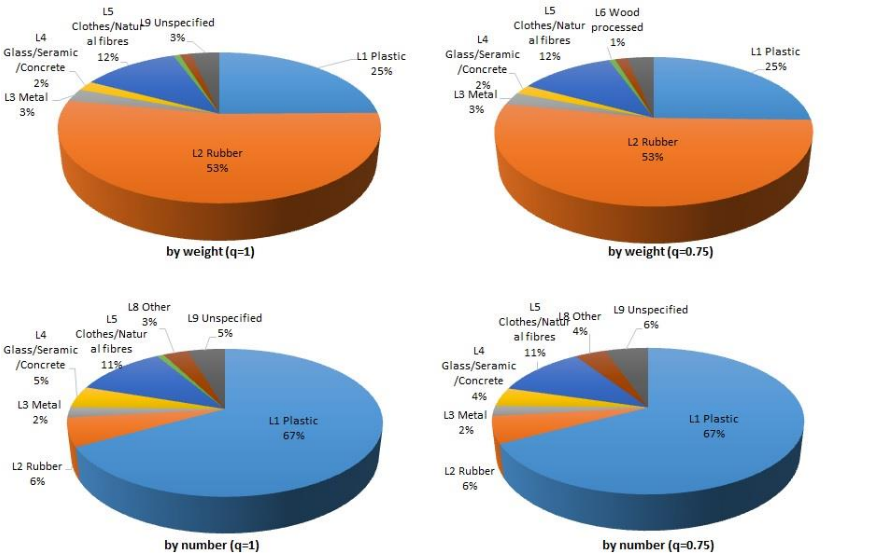

Figure 2. Overall distribution of seafloor marine litter during bottom trawl sampling at 30 stations between Hopa-Samsun

In the L2 group, especially car and truck tires create dominance in terms of weight at CB5 and CB3 stations. After these two groups, L5 includes clothing-carpet-natural fibres and hygiene materials, which have remarkable high values.

The evaluation by weight showed that the amount of L2 tire/rubber is more than 50% of the total amount of marine litter. In addition, the amount of L1 plastics was determined as 67%. The reason of the high amount of L2 is that car tires were included in sampling (Figure 3).

Table 4. Distribution of seafloor litter by stations

Station Code	**Weight (kg/km^2) q=1**	**Weight (kg/km^2) q=0.75**	**N ($unit/km^2$) q=1**	**N ($unit/km^2$) q=0.75**
CB1	45.17	60.23	600.78	801.37
CB2	69.53	92.72	734.28	979.05
CB3	1054.81	1443.48	1067.29	1335.08
CB4	1406.37	1873.15	1980.34	2640.46
CB5	2843.68	3791.56	1602.06	2136.10
CB6	0	0	0	0
CB7	225.31	301.71	467.26	623.03
CB8	2.67	3.56	44.5	59.34
CB9	3.34	4.46	47.74	63.66
CB10	4.72	6.3	64.45	85.94
SA1	14.31	19.08	103.12	137.49
SB1	0.43	0.57	42	57.29
SC1	9.88	13.18	21	28.65
SA6	41.99	56.05	85.93	114.59
SB6	0.22	0.29	21.48	28.65
SC6	0	0	0	0
SA4	9.67	12.89	21.48	28.65
SB4	0	0	0	0
SC4	0.21	0.28	20.77	27.69
SA8	0	0	0	0
SB8	0	0	0	0
SC8	0	0	0	0
SA10	6.45	8.59	214.84	286.45
SB10	0	0	0	0
SC10	1.44	1.92	33.92	45.23
CB11	93.87	125.16	374.23	499.02
CB12	0	0	0	0
CB13	8.91	11.89	171.87	229.16
CB14	11.82	15.76	128.9	341.87
CB15	0	0	0	0
Total	5854.8	7842.83	7848.24	10548.77
Mean	195.16	261.43	261.61	351.63
Variance	348389.91	622111.2	239869.77	419071.96

As a result of the sampling surveys, marine litter was not found in Çayeli, Kızılırmak, Yeşilırmak, Ünye, Melet river and Azot station named in Samsun Tekkeköy offshore (Figure 4).

Figure 3. Seafloor litter samples

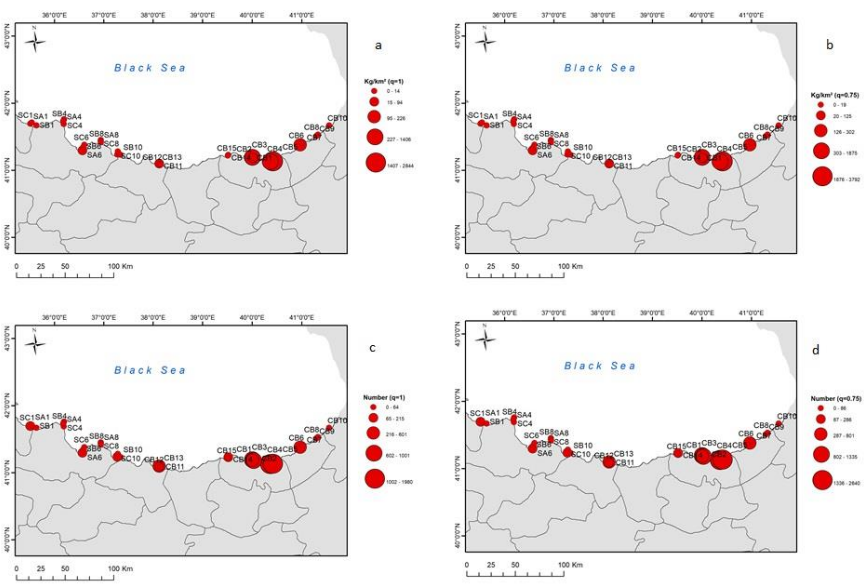

Figure 4. Distribution of marine litter by kg/km^2 (a: q=1 in weight; b: q=0.75 in weight; c: q=1 in number; d: q=0.75 in number)

The amount of marine litter could vary due to many factors such as surface structure, distance to urban areas and different flow systems. In some stations, wood blocks with excessive weight were observed. These objects were not included in the evaluation due to the organic origin. It is hard to say how distribution of marine litter is related to the depths. Seems there is no direct correlation between sampling depths and amount and weight of marine litter detected (Table 5 and 6).

Table 5. Distribution of marine litter in number according to the depth

Station Code	Depth (m)	N (km^2) q=1								
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
CB1	0-20	445.0	0	22.2	0	0	0	0	44.5	89
CB2	20-50	600.7	0	22.2	0	22.25	0	0	66.7	22.2
CB3	50-100	578.5	44.5	44.5	44.5	244.7	66	0	0	44.5
CB4	50-100	1490.8	44.5	0	44.5	356.0	0	0	22.2	22.2
CB5	20-50	890.0	311.5	44.5	44.5	200.2	0	0	22.2	89
CB6	20-50	0	0	0	0	0	0	0	0	0
CB7	50-100	111.2	66.75	22.2	200.2	44.5	0	0	22.2	0
CB8	20-50	44.5	0	0	0	0	0	0	0	0
CB9	50-100	47.7	0	0	0	0	0	0	0	0
CB10	20-50	42.9	0	21.4	0	0	0	0	0	0
SA1	0-20	77.3	0	0	0	0	0	0	0	25.7
SB1	20-50	0	0	0	42	0	0	0	0	0
SC1	50-100	0	21	0	0	0	0	0	0	0
SA6	0-20	64.4	0	0	0	0	0	0	0	21.4
SB6	20-50	21.4	0	0	0	0	0	0	0	0
SC6	50-100	0	0	0	0	0	0	0	0	0
SA4	0-20	0	0	0	0	0	0	0	21.4	0
SB4	20-50	0	0	0	0	0	0	0	0	0
SC4	50-100	20.7	0	0	0	0	0	0	0	0
SA8	0-20	0	0	0	0	0	0	0	0	0
SB8	20-50	0	0	0	0	0	0	0	0	0
SC8	50-100	0	0	0	0	0	0	0	0	0
SA10	0-20	171.8	0	0	0	0	0	0	42.9	0
SB10	20-50	0	0	0	0	0	0	0	0	0
SC10	50-100	33.9	0	0	0	0	0	0	0	0
CB11	50-100	353.4	0	0	0	20.7	0	0	0	0
CB12	20-50	0	0	0	0	0	0	0	0	0
CB13	0-20	128.9	0	0	0	0	0	0	0	42.9
CB14	50-100	128.9	0	0	0	0	0	0	0	0
CB15	20-50	0	0	0	0	0	0	0	0	0
		N (km^2) q=0.75								
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
CB1	0-20	593.3	0	30	0	0	0	0	59.3	118.6
CB2	20-50	801.0	0	29.6	0	29.6	0	0	89	29.6
CB3	50-100	771.3	59.3	59.3	59.3	326.3	0	0	0	59.3
CB4	50-100	1987.7	59.3	0	59.3	474.6	0	0	29.6	29.6
CB5	20-50	1186.7	415.3	59.3	59.3	267.0	0	0	29.6	118.6

Table 5. Continued

CB6	20-50	0	0	0	0	0	0	0	0	0
CB7	50-100	148.3	89	29.6	267.0	59.3	0	0	29.6	0
CB8	20-50	59.3	0	0	0	0	0	0	0	0
CB9	50-100	63.6	0	0	0	0	0	0	0	0
CB10	20-50	57.2	0	28.6	0	0	0	0	0	0
SA1	0-20	103.1	0	0	0	0	0	0	0	34.3
SB1	20-50	57.2	0	0	0	0	0	0	0	0
SC1	50-100	28.6	0	0	0	0	0	0	0	0
SA6	0-20	85.9	0	0	0	0	0	0	0	28.6
SB6	20-50	28.6	0	0	0	0	0	0	0	0
SC6	50-100	0	0	0	0	0	0	0	0	0
SA4	0-20	0	0	0	0	0	0	0	28.6	0
SB4	20-50	0	0	0	0	0	0	0	0	0
SC4	50-100	27.6	0	0	0	0	0	0	0	0
SA8	0-20	0	0	0	0	0	0	0	0	0
SB8	20-50	0	0	0	0	0	0	0	0	0
SC8	50-100	0	0	0	0	0	0	0	0	0
SA10	0-20	229.1	0	0	0	0	0	0	57.2	0
SB10	20-50	0	0	0	0	0	0	0	0	0
SC10	50-100	45.2	0	0	0	0	0	0	0	0
CB11	50-100	471.2	0	0	0	27.7	0	0	0	0
CB12	20-50	0	0	0	0	0	0	0	0	0
CB13	0-20	171.8	0	0	0	0	0	0	0	57.2
CB14	50-100	171.8	0	0	0	0	0	0	85	85
CB15	20-50	0	0	0	0	0	0	0	0	0

Table 6. Distribution of marine litter in weight according to the depth

Station Code	**Depth (m)**	**Weight (kg/km^2) q=1**								
		L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
CB1	0-20	12.2	0	0.3	0	0	0	0	5.2	27.4
CB2	20-50	48.0	0	0.7	0	8.2	0	0	1.5	11.0
CB3	50-100	138.4	498,4	10.7	9.7	314.7	45.6	0	0.00	37.2
CB4	50-100	663.7	378,8	0	17.1	222.2	0	0	51.7	72.7
CB5	20-50	414.1	2207.9	148.1	6.1	57.2	0	0	3.1	7.1
CB6	20-50	0	0	0	0	0	0	0	0	0
CB7	50-100	20.3	32,3	0.7	88.7	76.7	0	0	6.7	0
CB8	20-50	2.6	0	0	0	0	0	0	0	0
CB9	50-100	3.3	0	0	0	0	0	0	0	0
CB10	20-50	3.3	0	1.4	0	0	0	0	0	0
SA1	0-20	12.1	0	0	0	0	0	0	0	2.2
SB1	20-50	0.4	0	0	0	0	0	0	0	0
SC1	50-100	9.8	0	0	0	0	0	0	0	0
SA6	20-50	1.4	0	0	0	0	0	0	0	40.2
SB6	20-50	0.2	0	0	0	0	0	0	0	0
SC6	50-100	0	0	0	0	0	0	0	0	0
SA4	0-20	0	0	0	0	0	0	0	9.6	0
SB4	20-50	0	0	0	0	0	0	0	0	0

Table 6. Continued

SC4	50-100	0.2	0	0	0	0	0	0	0	0
SA8	0-20	0	0	0	0	0	0	0	0	0
SB8	20-50	0	0	0	0	0	0	0	0	0
SC8	50-100	0	0	0	0	0	0	0	0	0
SA10	0-20	4.7	0	0	0	0	0	0	1.7	0
SB10	20-50	0	0	0	0	0	0	0	0	0
SC10	50-100	1.4	0	0	0	0	0	0	0	0
CB11	50-100	92.3	0	0	0	1.5	0	0	0	0
CB12	20-50	0	0	0	0	0	0	0	0	0
CB13	0-20	8.6	0	0	0	0	0	0	0	0.3
CB14	50-100	11.8	0	0	0	0	0	0	0	0
CB15	20-50	0	0	0	0	0	0	0	0	0
Weight (kg/km^2) q=0.75										
CB1	0-20	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
CB2	20-50	16.3	0	0.5	0	0	0	0	6.9	36.4
CB3	50-100	64.1	0	0.9	0	10.9	0	0	14.7	2,1
CB4	50-100	244.6	644.5	14.2	13.1	416.,6	60.8	0	0	49.6
CB5	20-50	884.9	505.1	0	22.8	296.2	0	0	66.9	97.0
CB6	20-50	552.1	2943.9	197.4	8.2	76.3	0	0	4.2	9.5
CB7	50-100	0	0	0	0	0	0	0	0	0
CB8	20-50	26.9	44.4	0.9	118.2	102.4	0	0	8.9	0
CB9	50-100	3.5	0	0	0	0	0	0	0	0
CB10	20-50	4.5	0	0	0	0	0	0	0	0
SA1	0-20	4.4	0	1.8	0	0	0	0	0	0
SB1	20-50	16.16	0	0	0	0	0	0	0	2.9
SC1	50-100	0.57	0	0	0	0	0	0	0	0
SA6	20-50	13.18	0	0	0	0	0	0	0	0
SB6	20-50	1.86	0	0	0	0	0	0	0	54.2
SC6	50-100	0.29	0	0	0	0	0	0	0	0
SA4	0-20	0	0	0	0	0	0	0	0	0
SB4	20-50	0	0	0	0	0	0	0	12.9	0
SC4	50-100	0	0	0	0	0	0	0	0	0
SA8	0-20	0.3	0	0	0	0	0	0	0	0
SB8	20-50	0	0	0	0	0	0	0	0	0
SC8	50-100	0	0	0	0	0	0	0	0	0
SA10	0-20	0	0	0	0	0	0	0	0	0
SB10	20-50	6.3	0	0	0	0	0	0	2.3	0
SC10	50-100	0	0	0	0	0	0	0	0	0
CB11	50-100	1.9	0	0	0	0	0	0	0	0
CB12	20-50	123.1	0	0	0	2.1	0	0	0	0
CB13	0-20	0	0	0	0	0	0	0	0	0
CB14	50-100	11.5	0	0	0	0	0	0	0	0.4
CB15	20-50	15.7	0	0	0	0	0	0	0	0
CB1	0-20	0	0	0	0	0	0	0	0	0

Discussion

In this study, the bottom trawl sampling was carried out to determine the distribution of marine litter at 30 stations located between Hopa and Sinop (3820000m² of total swept area). The majority of marine litter consists of rubber group in weight (53%) and in amount (67%), followed by plastic group in weight (25%), cloth, and natural fibre group in amount (12%). In 2016, plastic (62%) and cloth/natural fibres (31%) have constituted the majority for the Eastern Black Sea during the Environment and Urbanization, TUBITAK-MRC survey (2017). It could be a sign that plastic origin products consumption has increased during the last three years. The total amount of marine litter was estimated as 5854.8 kg (q=1) in weight and 7848.24 kg/km^2 in amount (q=1). These numbers were higher than Terzi *et al.* (2020), Terzi and Seyhan (2017), Anton *et al.* (2013), Moncheva *et al.* (2016) and Ioakeimidis *et al.* (2014). It could be explained by extensive survey areas in comparison with mentioned studies. At the same time marine litter density (litter item per km^2) was lower than Topçu and Öztürk (2010)'s research for the western part of the Black Sea. It is well known, that the western part of the Black Sea is under higher pressure of urbanization, industrialization, shipping, tourism besides it has an intensive river flows from the all countries coasts. Therefore, density of marine litter is higher there than in the other part of the Black Sea. The density of plastics (especially plastic bags) was found quite high in comparison with rubber. Plastic as light, flexible and long lasting material is a highly distributed material. At the same time, it can be easily carried by the wind and currents. The EU has defined plastic bag as a most important threat for the marine environment in the world (Ioakeimidis *et al.* 2014). In early 2019 Turkish Government has limited of the usage of plastic bag e and promoted the natural fibres bags usage to decrease the plastic pollution. The effects of these measures could be seen in the upcoming years. There were also found fishing gears especially gillnets among the marine litter samples. These types of fishing gears continue ghost fishing in the Black Sea seabed. Topçu and Öztürk (2010) have found a lot of fishing gears in their sampling area in the Western Black Sea. Considering the distribution of marine litter samples depending on depths, the density was mostly 50-100 m depth in Trabzon and its surrounding stations, whereas in Ordu and Samsun stations density were mostly 0-20 m. Moncheva *et al.* (2016) explained this situation with vicinity of land-based resources, human activities and weak currents. It could be also connected with sea bottom structure, which it is shallow in Samsun shelf area in comparison with deeper areas at Trabzon stations.

Conclusion

This research presents distribution and composition of marine litter in the South-eastern Black Sea. The Black Sea has an enclosed area and dynamic current system, intensive river flows and high anthropogenic pressure, which are considered to be the main pathways of marine litter pollution in the Black Sea.

There are some studies on this topic for the last years but not enough data to predict the status of pollution. All riparian countries should increase cooperation in monitoring, control measures, standardization of methodologies for studying and combating marine litter. The plastic materials should be limited for everyday use by regional legislation and public awareness should be increased.

Acknowledgement

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Marine plastics in the fishing grounds in the Black Sea

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Abstract

Marine plastics are considered as a major threat to the marine ecosystem and coastal economies. The plastics in the marine environment have direct and indirect negative effects on the economic income derived from the marine environment. Marine plastics also affect fisheries, one of the most important sectors providing food and income at local and international levels. Possible impacts of the marine plastics on the Black Sea fisheries were discussed along with a case study of a seafloor litter. A total of five trawl surveys were carried out the southern Black Sea trawling areas of the Samsun province. 67 litter items weighing 10 kg were collected during the surveys. The most abundant litter items were nylon (61.26%), plastic (21.52%) and, metal (5.38%) in total. Nylon has a considerably high surface-area-to-volume ratio, which results in blocking the codend in the trawl fishery and increases by-catch. The metal and plastic items in the catch can damage both the fishing gear and the catch, which may reduce the income and increase the repair costs. The field data on the direct and indirect effect of the marine plastics on the fisheries are limited. More comprehensive studies are needed to determine the levels of the impacts on fisheries. Unless reduction and prevention measures are implemented, the accumulation of the plastics in the marine ecosystem may cause even more economic loss and risk to human health.

Keywords: Fisheries, marine plastics, economic impacts, Black Sea, bottom trawl

Introduction

Marine litter has been an object of research in the last decade due to the uncertainties of its state and effects in the marine environment. It is increasingly recognized as a serious, worldwide concern (Galgani *et al*. 2019). In the beginning, researchers mainly focused on the spatiotemporal distribution and the composition in the marine environment. These studies revealed that from busy coasts to most remote ones, including polar were contaminated with marine litter and they were found to be accumulated on the surface, coasts, and benthic zones of the marine ecosystem (Galgani *et al*. 2015). In addition, it is well documented that the composition of the litter items is mostly dominated by plastic, which is from anthropogenic origin. Unless preventive measures taken and applied strictly, due to a wide range of usage, growing production, and durability, continuous accumulation of plastic items in the marine environment is inevitable.

Marine plastics pose an impact on marine wildlife, habitats, coastal economies, and even human health. A wide range of marine and terrestrial organisms were affected including vertebrates, invertebrates, and microbiota (Galloway *et al*. 2017; Law 2017). Vertebrates are the most reported organisms, interacted with marine plastics (Ozturk and Altinok 2020) since they are relatively more detectible and recognizable. This can involve bias and under estimation of the interaction of small marine invertebrates and microorganisms. Entanglement and ingestion are the most reported interaction type especially by marine mammals, turtles, seabirds, and fishes (Thiel *et al*. 2018). Beyond direct effects on living organisms, marine plastics have potential economic impacts on fishing, shipping, tourism activities (Galgani *et al*. 2019).

Recently, a considerable literature has grown up around the theme of marine litter in the Black Sea (Paiu *et al.* 2017; Terzi and Seyhan 2017; Simeonova and Chuturkova 2019; Aytan *et al*. 2020; Miladinova *et al*. 2020; Oztekin *et al*. 2020; Terzi *et al*. 2020). Similar to the global trend, the litter items in the Black Sea environment mostly consist of plastic. Circulation of the currents results in the build up of floating waste in certain marine areas and along some coastal zones. A recent study using mathematical models confirmed by field observations, show the effects of currents in the Black Sea on the distribution and concentrations of this type of waste (Miladinova *et al*. 2020).

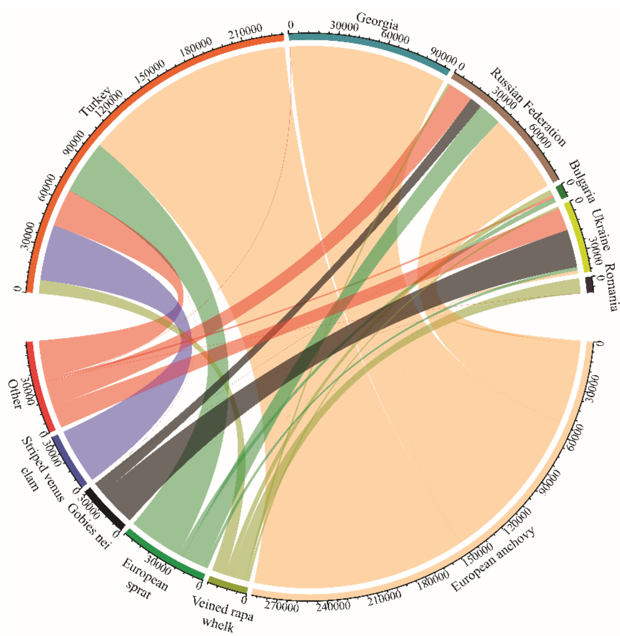

Figure 1. Most exploited stocks in the Black Sea and share of the stakeholder countries (Data from 2017 was used for visualization. Sources: FAO (2020) and TUIK (2020)

The Black Sea is a young and enclosed sea with a unique ecosystem. It is surrounded by six countries with different socio-economic structures. Each country has their exclusive economic zones (EEZ) and regulations on fisheries management (Düzgüneş and Erdoğan 2014). The stocks, especially small pelagic fishes are being exploited by the surrounding countries at different levels (Figure 1). In addition to the fishing, the stocks in the Black Sea are under the pressure of different types of pollution as well (Bat *et al*. 2018). In this study, potential effects of the marine plastics on the Black Sea fisheries are discussed along with a case study of a seafloor litter.

Impacts of marine plastics on fisheries

Fisheries highly rely on the well-being of marine flora and fauna. While the fisheries sector is considered as a source of marine plastics (Lively and Good 2019), it is also subject to economic costs itself. Fishing vessels and aquaculture facilities can be shown as the main sources of nets, ropes, pots, feedbags, and polystyrene boxes.

There are numerous ways that marine plastics bring impact to fisheries including, but not limited to: damage to fishing gear and vessel, interruption of the fishing operation, restricted catch, and contamination of fish and shellfish with plastics.

Damage to Fishing Gear and Vessel

Marine plastics can damage the fishing vessel and gear when encountered. This creates a direct economic impact resulting in repair or replacement of the damaged or lost gear. Wallace (1990) reported that over 45% of the fishing vessels had their propellers entangled, over 30% had their gear fouled, and almost 40% had their engine cooling system blocked by plastic debris at some point in time in the Eastern US. The direct effect of marine litter (repair costs and direct losses in revenue etc.) to Scottish fishing vessels was reported between €17,000 and €19,000 per vessel annually (Mouat *et al*. 2010). An estimation by Acoleyen *et al*. (2013) showed that the annual cost of the marine litter on the European fishing fleet is 61.67 million euros which is nearly 1% of the revenue generated by the EU fishing fleet (Table 1).

Table 1. The estimated cost of marine litter on the EU fishing fleet (Acoleyen *et al*. 2013)

	Annual cost per vessel (€)	**Number of vessels in the EU**	**Total annual cost EU (m€)**
Cost of reduced catch revenue (trawlers)	2.340	12 238	28.64
Cost of removing litter from fishing gear (trawlers)	959	12 238	11.74
Cost of broken gear & fouled propellers	191	87 667	16.79
Cost of rescue services	52	87 667	4.54
Total			**61.67**

Interruption of Fishing Operation

Entangled propellers restrict and/or slowdown the movement of the fishing vessel and obstructed cooling systems cause engines to overheat which interrupt the fishing operation. Marine plastics can entangle and damage fishing gear. The cleaning of entangled plastic items on the fishing gear creates a downtime and workforce loss.

Restricted Catch

The accumulation of marine litter in the trawl can block the grid and cause commercial losses (Eryaşar *et al*. 2014). The static nets contaminated with the litter items, become more visible to fish and causes a reduction in yield. Benthic and suspended plastic items can make it difficult to detect marine organisms for divers which reduces the amount of catch.

Contamination of fish and shellfish with plastics

An increasing amount of marine plastics are found among the fisherman's catch which consumes time to remove and damage the freshly caught fish. The ingestion of microplastics by the molluscs leads to economic losses as a result of perceived risk by consumers.

Human Casualties

Marine plastics especially the derelict fishing gear, and ropes are a major threat to divers who harvest marine organisms from the seafloor. It can be difficult to spot these items since they are designed to be less visible under water conditions. Once entangled the divers face difficulties escaping and/or call for help. Incidents resulting in the death of divers because of lost nets have been reported in Korea (NOWPAP MERRAC 2013).

Materials and Methods

The survey was conducted with a commercial fishing vessel on the southern Black Sea trawling areas of the Samsun province in December 2012 (Figure 2). The area is located between two large rivers namely Kızılırmak, and Yeşilırmak and is very busy during the fishing season. A total of five bottom trawl hauls were performed on randomly selected routes by the captain to assess the benthic litter items.

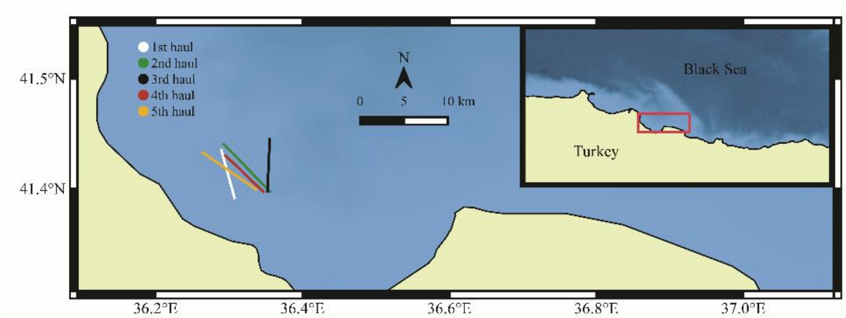

Figure 2. Map of the sampling area and location of trawl shots.

A bottom trawl net with 25 m mouth opening and 22 mm mesh size was used to collect the litter items. The hauls were performed at the speeds between 2.8–3.2 knots, for 1–1.5 hours (Table 2).

Table 2. Details of the trawl hauls

Haul number	Swept area (km^2)	V (knot)	Duration (hours)	Depth (m)
1	0.05	2.8	1	45.00
2	0.08	2.8	1.5	47.30
3	0.07	2.9	1.3	50.00
4	0.06	3.2	1	45.50
5	0.08	2.8	1.5	47.30

Collected litter items were distinguished by material (nylon, plastic, textile, paper, rubber, metal, and glass) and subcategories (nylon pieces, general packaging, beverage, fishing gear, clothing, food packaging, newspaper, medical, mechanical parts, tires, and undefined). The categorization of materials were done according to OSPAR (2010), however no standard procedure was followed while defining the subcategories. Although nylon is a type of plastic and commonly used for general packaging, due to high abundance it was assessed separately. Also, a tire collected during the survey was excluded from calculations, because of its highweight. The litter items were counted and weighed to estimate number and weight of the items per km^2. Analyses and data visualizations were done by using R 4.0.0 (R Core Team 2020).

Results and Discussion

A total of 67 litter items weighing 10 kg were collected from five trawl surveys. The density of litter items ranged between 121–366 items/km^2 in terms of number and 2.30–24.58 kg/km^2 in terms of weight (Table 3). Abundance was relatively lower compared to other studies conducted on the Turkish coast of the Black Sea (Topçu and Öztürk 2010; Öztekin and Bat 2017).

Table 3. Density of litter items (Terzi and Seyhan 2013).

Number of haul	Density	
	items/km^2	kg/km^2
1	366	17.41
2	296	24.58
3	121	2.30
4	185	19.76
5	142	10.45
Mean	222	14.90

Nylon (61.26%) was the most abundant material followed by plastic (21.52%) and, metal (5.38%) in total (Figure 3a). Regarding subcategories nylon pieces (40.17%) were the most abundant followed by general packaging (25.12%) and, beverage containers (13.08%) (Figure 3b). Although the litter density is different, the composition of dominant litter categories was in accordance with Topçu and Öztürk (2010).

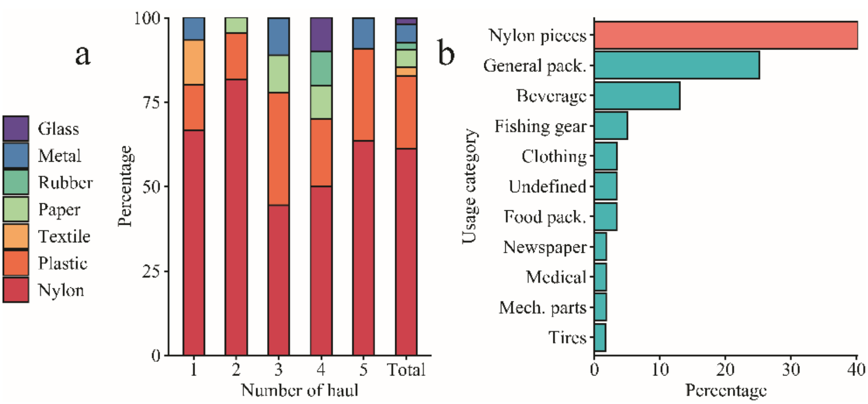

Figure 3. Composition of the collected litter items by material (a) and subcategories (b) (Terzi and Seyhan 2013).

Our findings revealed that the composition of litter items was dominated by nylon pieces from carrier packs and another packaging. These items are light-weighted so that they can be easily transported by the winds. The surface-area-to-volume ratio of nylon is very high compared to other collected litter items. Because of this feature nylon is more prone to sink which may be the reason for the dominance in the composition on benthic zone. Thanks to their wide surface area they can cover the codend and effect the selectivity (Eryaşar *et al*. 2014).

Conclusion and Recommendations

Mismanagement of a high amount of plastic waste has brought a sprawling international problem. This problem has been recognized as a major global environmental issue by international organizations such as the United Nations and European Commission. Actions were planned in national and international scale to reduce and minimize the plastics in the marine environment (European Commission 2010; OECD 2019).

The field data on the direct and indirect effect of the marine plastics on the fisheries is very limited not only in the Black Sea but also in other seas of the world. However, it is clear from the limited data that the marine plastics have negative impacts on the fisheries. Unless reduction and prevention measures implemented, the accumulation of the plastics in the marine ecosystem may cause more economic loss and even risk to human health.

There are several ways to reduce the entrance of plastic items to the marine environment. The most cost-efficient way is reduction at source. The use of biodegradable materials instead of single-use plastics can reduce production and entrance. Deposit refund system is also a good practice of reduction at source for single-use plastics. A successful example is the Norsk Resirk refund system which was started in 1999. An environmental fee is added to the basic fee for single-use beverage packing for sale in Norway. When the packaging was returned by the customers, they are refunded the environmental fee. According to the 2018 annual report, 88.6% of participating plastic bottles and 87.3% of participating cans were returned and recycled (Infinitum AS 2018).

Strict waste management, high waste collection, and recycling are more costly, compared to reduction of source, which allows plastics to be collected before it reaches the marine environment. Clean-up operations such as beach cleanups can be conducted to remove the plastics that are already marine environment. Not only beaches but also fishing grounds can be cleaned with fishing vessels with the implementation of a buyback.

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Composition of floating macro litter across the Black Sea

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Abstract

This work represents the results of the first multinational integrated assessment of floating marine macro litter (FMML) pollution of the Black Sea. In the frame of the EMBLAS project ('Improving environmental monitoring in the Black Sea') basin-crossing exploration surveys (Joint Open Sea Surveys, JOSS), specific national surveys (National Monitoring Studies, NMS) and surveys from ships-of-opportunity, all including opportunistic monitoring of floating litter, were performed during 2016-2019 in the Black Sea. The surveys involved scientists from Georgia, Russia and Ukraine, while scientists from Romania, Bulgaria and Turkey participated to accompanying workshops and trainings. These pilot studies demonstrated the importance of harmonization of reported data for comparison of results between different surveys and areas. Litter was monitored by trained observers, acquiring georeferenced data through a tablet computer application, developed by Joint Research Centre, Ispra (JRC) using for the first time a harmonized MSFD approach. The observations confirmed that marine litter was present in all Black Sea areas and consists mostly from plastic. The aim of this study is to provide a Top FMML items list and to compare the abundance, composition, material and size categories of found items in the Black Sea surveys.

Keywords: Marine litter, pollution monitoring, floating macro litter, marine litter categories, Black Sea

Introduction

Marine litter has been recognised as threat for marine wildlife by the European Marine Strategy Framework Directive, the Regional Sea Conventions and by international provisions, such as the UN Sustainable Development Goal 14. Monitoring data are needed in order to assess the spatial distribution of litter in the different environmental compartments and to identify the sources of litter in order to plan appropriate and efficient measures.

Floating debris constitutes the fraction of debris in the marine environment, which is transported by wind and currents at the sea surface and is thus directly related to the pathways of litter at sea. Floating litter items can be transported by the currents until they sink to the seafloor, be deposited on the shore or degrade over time (Andrady 2015). Floating marine macro litter (FMML) represents a direct threat to marine wildlife and is the precursor of marine micro litter.

In the frame of the EMBLAS project (Improving environmental monitoring in the Black Sea) basin-crossing multinational exploration surveys (Joint Open Sea Surveys, JOSS), specific national surveys (National Monitoring Studies, NMS) and surveys from ships-of-opportunity, all including opportunistic monitoring of floating litter, were performed during 2016-2019 in the Black Sea. The surveys involved scientists from Georgia, Russia and Ukraine, while scientists from Romania, Bulgaria and Turkey participated to accompanying workshops and training.

As methodologies for monitoring of floating macro litter are still under development, the EMBLAS surveys provided opportunities for discussion, testing approaches and contributing to the further development of the monitoring tools. The harmonization of monitoring and the providing of guidance is essential, as operationally defined parameters are being quantified. The aim of this study is to provide a top items list composition and to compare the abundance, composition, material and size categories of the found items in the Black Sea surveys.

Materials and Methods

The monitoring of FMML is based on visual observations. Observation position and observed transect width are chosen in order to ensure the monitoring of target size ranges. Harmonization of reported item classes and size information is important for comparison of results between different surveys and areas. The Joint Research Centre (JRC) “Floating Litter Monitoring” Tablet App provides a tool for a harmonized monitoring and facilitates the recording of metadata such as position, transect information, ship speed, and etc. The main objective of the EMBLAS project was to obtain comparable results from all participating countries (Georgia, Russia and Ukraine), and the JRC Tablet App provides a common approach to this (González-Fernández and Hanke 2017).

FMML monitoring was performed in EMBLAS projects surveys in the period 2016-2019 by trained observers, acquiring georeferenced data along the vessels route with the “Floating Litter Monitoring” Tablet App and according to the

‘Guidance on Monitoring of Marine Litter in European Seas’ (Galgani *et al.* 2013).

During the EMBLAS monitoring activities in 2016-2019, the observers performed 555 transects (observation sessions) in total. These transects corresponded to observations over a length of 5410 km and covered an area of 127 km². (Table 1, Figure 1).

Table 1. FMML monitoring EMBLAS activities main characteristics in 2016-2019.

Indicators	2016	2017	2019	Sum
Number of transects	193	192	170	555
Distance covered (km)	238	3140	2032	5410
Area observed (km^2)	9	88	30	127

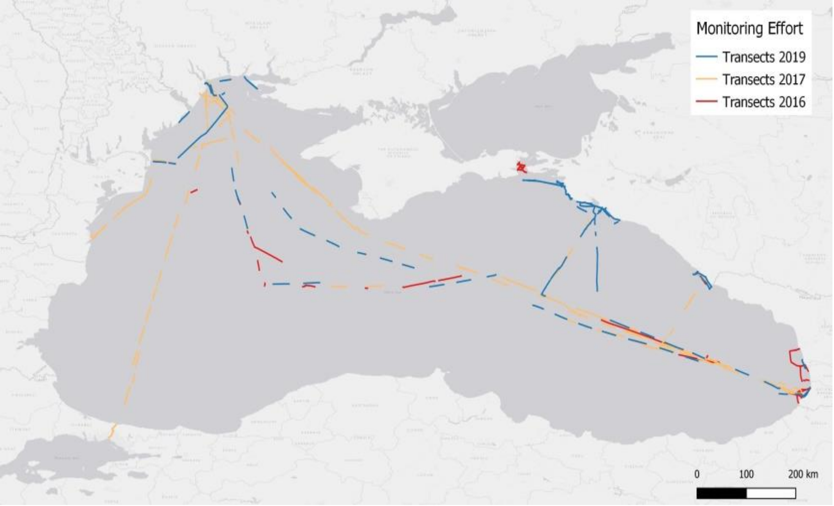

Figure 1. EMBLAS floating macro litter monitoring effort: transects 2016, 2017 and 2019

Results and Discussion

Top items

In total, during the EMBLAS monitoring surveys of 2016-2019, the observers had identified 10217 litter items. The most common litter items were plastic pieces (39.7%) and polystyrene pieces (11%), meaning fragments represented 50 % of the floating litter. Unidentified items, classified as other plastic/polystyrene items, scored second in the ranking (15.8%). Other relevant categories included cover/packaging (9.9%), plastic bags (7.0%), foam (37%), plastic bottles (2.8%), plastic sheets (1.8%), plastic containers (1.3%), synthetic rope (1.2%) and other paper items (1.2%). The rest of litter categories showed limited individual contributions <1% (Table 2).

Table 2. FMML top items identified during the EMBLAS monitoring activities in 2016-2019.

Rank	ML Items	Number	% of total	% Cumulative
1	Plastic pieces	4056	39.70	39.70
2	Other plastic/polystyrene items	1609	15.75	55.45
3	Polystyrene pieces	1120	10.96	66.41
4	Cover / packaging	1007	9.86	76.27
5	Bag	719	7.04	83.30
6	Foam	382	3.74	87.04
7	Plastic bottle	291	2.85	89.89
8	Sheets	185	1.81	91.70
9	Plastic container	137	1.34	93.04
10	Synthetic rope	125	1.22	94.26
11	Other paper	124	1.21	95.48
12	Paper packaging	86	0.84	96.32
13	Other metal	63	0.62	96.94
14	Other rubber	59	0.58	97.51
15	Wood boards	49	0.48	97.99
16	Beams / Dunnage	44	0.43	98.42
17	Fish boxes - polystyrene	28	0.27	98.70
18	Cans	21	0.21	98.90
19	Other textiles	17	0.17	99.07
20	Balloons	16	0.16	99.23
21	Rubber boots	15	0.15	99.37
22	Buoys	10	0.10	99.47
23	Not identified litter items	9	0.09	99.56
24	Table cloth	8	0.08	99.64
25	Fishing net	8	0.08	99.72
26	Fish boxes - plastic	5	0.05	99.77
27	Newspapers and magazines	5	0.05	99.81
28	Balls	3	0.03	99.84
29	Wire	3	0.03	99.87
30	Clothing	3	0.03	99.90
31	Rope / string and nets	3	0.03	99.93
32	Pallets	2	0.02	99.95
33	Tyres and belts	2	0.02	99.97
34	Gloves	2	0.02	99.99
35	Barrels	1	0.01	100.00
	Grand Total	**10217**		

The ranking list of the 10 top marine litter items in beaches at European level has been derived using the total abundance method (i.e. total sum of items collected in each survey, and normalized with transect lengths of 100 m), based on a compiled 2016 pan-European data set (Table 3) (Addamo *et al.* 2017). There are clear correlations when comparing the top floating and beach litter items. In both lists, the first positions include plastic and polystyrene pieces. Many other plastic litter categories are commonly found in both lists (e.g. packaging of different origin like cover/packaging and crisps packets/sweet wrappers, plastic bags, and other plastic/polystyrene items). On the contrary, there are widely spread litter items on the beaches that would sink at sea (e.g. string/cord, cigarette butts/ filters, plastic caps and lids, cotton bud-sticks, paraffin/wax), which are not present floating at sea.

Table 3. Top ten marine beach litter items at European scale and the total amount per each item, listed by total abundance. Detailed information indicate the TG ML-General Code (ID), Material and Name of each item, following the MSFD Master List of Litter Item Categories (Addamo *et al.* 2017)

TOP	ID	Material	Name	Amount
1	G76+G79+G82	Plastic	Plastic/polystyrene pieces 2.5cm > < 50 cm	52999
2	G75+G78+G81	Plastic	Plastic/polystyrene pieces 0-2.5 cm	49198
3	G50	Plastic	String and cord (diameter less than 1 cm)	48919
4	G27	Plastic	Cigarette butts and filters	21854
5	G20+G21+G22+G23+ G24	Plastic	Plastic caps and lids (drinks, chemicals, detergents (non-food), unidentified)/plastic rings from bottle caps/lids	18732
6	G95	Plastic	Cotton-bud-sticks	13579
7	G213	Chemicals	Paraffin/wax	10305
8	G30	Plastic	Crisp packets/sweet wrappers	10267
9	G124	Plastic	Other plastic/polystyrene items (identifiable)	10142
10	G2+G3+G4+G5	Plastic	Plastic bag (Shopping bags, small plastic bags, e.g. freezer bags, plastic bag collective role; what remains from rip-off plastic bags)	6197

The prevailing material during all the EMBLAS surveys were artificial polymer materials (commonly known as plastics) – 94.9% in total. Paper/Cardboard reached 2.1% of total amount, and processed/worked wood, rubber, metal, cloth/textile constituted less than 1% (Table 4, Figure 2).

The materials distribution at sea corresponds well with European beach litter observations, where the percentage of plastic litter was 84% (Figure 3). The prevalence of plastics in FMML investigations in comparison with beach litter could be explained by higher buoyancy and durability characteristics of plastics materials. The later could facilitate the accumulation of floating plastic litter at sea.

Table 4. FMML the most abundant materials during the EMBLAS monitoring activities in 2016-2019.

Material	Proportion (%)
Artificial polymer materials	94.86
Paper/Cardboard	2.10
Processed/worked wood	0.93
Rubber	0.93
Metal	0.86
Cloth/textile	0.23
Not identified	0.09

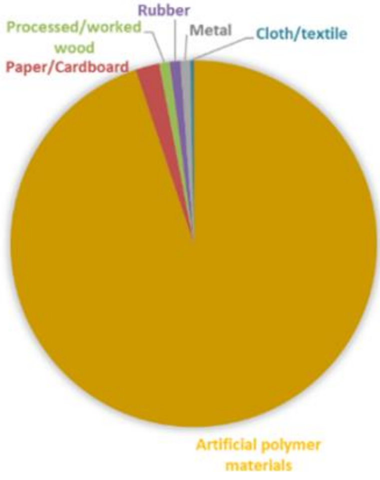

Figure 2. FMML the most abundant materials during the EMBLAS monitoring activities in 2016-2019

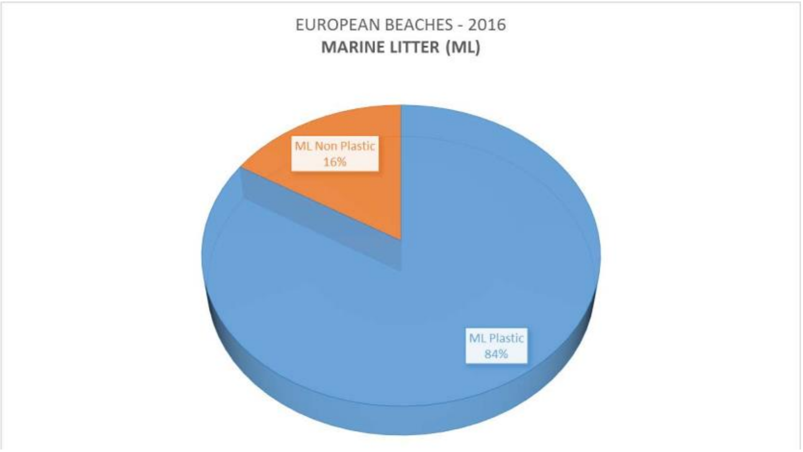

Figure 3. Beach litter material at the European scale. The abundance is expressed as the percentage of total litter amounts (Addamo *et al.* 2017).

Size distribution of Top 10 items

Overall results show that smaller items were the most abundant. On figure 4, the clear dependence is demonstrated, being larger items much less frequent.

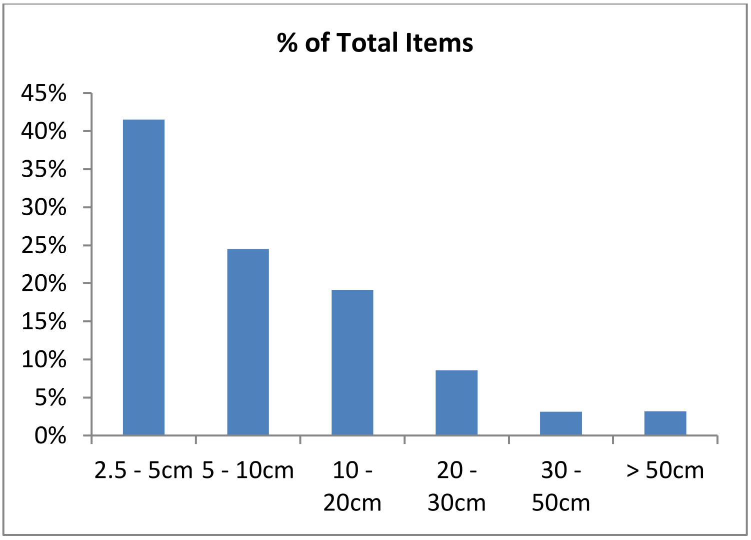

Figure 4. Total items size distribution

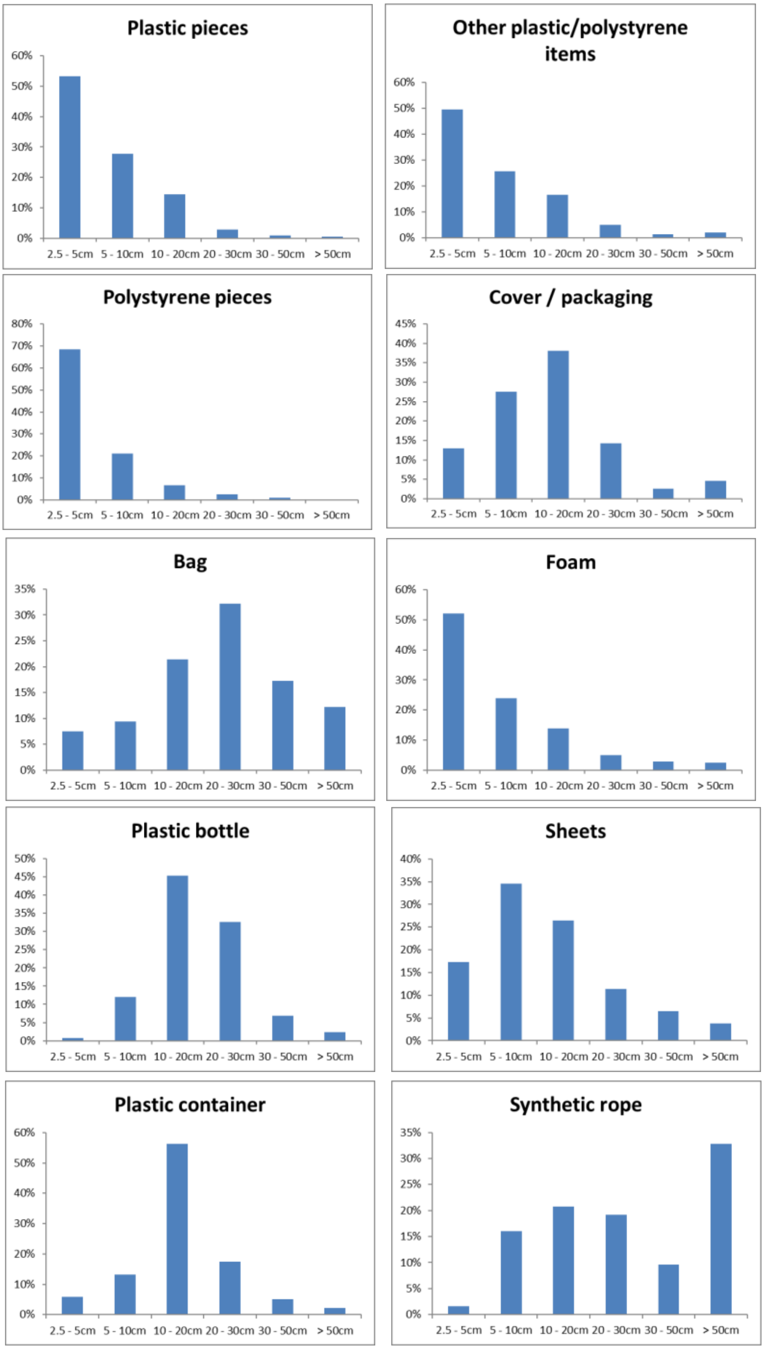

Figure 5. Top 10 litter items size distribution

The size distribution of the most common litter items is more diverse. Plastic pieces, polystyrene pieces, other plastic/polystyrene items and foam repeat the overall picture showing the frequency decrease with the size increase. The most abundant sizes are 2.5-10 cm. Other top litter items have different abundance in size categories. Cover/packaging, plastic bags and sheets vary in all size classes, the most frequent range for cover/packaging was from 2.5 cm to 30 cm, for plastic bags 10-50 cm, for plastic sheets 2.5-20 cm. Plastic bottles were mostly presented by size 10-30 cm and plastic containers 10-20 cm. Synthetic rope was estimated as more than 50 cm in most cases (Figure 5).

These are the results of the first multinational integrated assessment of floating marine macro litter composition in the Black Sea, based on large-scale exploration surveys performed during 2016-2019 in the frame of the EMBLAS project, where the abundance, composition and size classes of more than 10 thousand litter items were analysed.

Conclusions

The prevailing floating litter material is artificial polymers, i.e. plastics, reaching up to 94.9% of all found litter items. The most common litter items were plastic pieces, other plastic/polystyrene items and polystyrene pieces (representing all three together 66.4%), cover/packaging (9.9%), plastic bags (7.0%), foam (3.7%), plastic bottles (2.8%), plastic sheets (1.8%), plastic containers (1.3%), synthetic rope (1.2%). The abundance of litter items decreases with the size. The most frequent litter size ranges cover from 2.5 to 20 cm. In comparison with beach litter top items, higher percentage of plastics were determined in FMML, which could be explained by buoyancy and durability characteristics of plastic material, facilitating accumulation areas at sea.

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Results of the monitoring of the marine and riverine floating macro litter in the Black Sea, Georgia

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Abstract

The paper reviews the floating macro litter surveys conducted in 2016-2019 within the Georgian sector of the Black Sea to identify and assess the density and sources of marine litter. The survey was conducted as a part of “EMBLAS II” and “EMBLAS Plus” projects. Observation of floating litter was determined by the 10-th descriptor of the Marine Strategy Framework Directive and was used to assess environmental status of marine environment. Four essential rivers: Chorokhi, Supsa, Natanebi and Rioni were monitored. The data were collected by visual observation sessions from bridges during 1 hour. On the sea surface, the floating macro litter was observed from the board of the vessels. According to the observations of rivers, litter flux was varied from 300 to 700 items.h^{-1} for non-litter and 50 to 130 items.h^{-1} for plastic litter with the majority of packaging materials, bottles and containers. According the data of sea floating macro litter survey along the Georgian seashore in 2016, the mean density of litter was 76.3 items.km^{-2}. The main source of litter was land-based sources. Meanwhile, the possible sea based sources were container ships queued on the outer raid (north of the port of Poti).

Keywords: Floating macro litter, plastic, pollution, Georgia, Black Sea

Introduction

Marine litter is considered as a crucial and complicated environmental problem in the Black Sea basin (BSC 2007). The majority of the litter originates on land and river flow is the main source of litter into the basin. The amount of marine debris in the marine environment has shown a steady increase in time (Ryan 2015; Galgani *et al.* 2015). Plastic typically constitutes the main part of marine litter with a proportion varying between 60% and 80% of the total marine debris. Thus, globally, there is a rising concern about the risks and possible adverse effects of marine debris accumulation. It is obvious that litter enters the ocean from either marine or land based sources. The method of visual counting is focusing on macro plastics (> 2.5 cm), field measurements count from macro plastics to larger 2.5 cm plastic items (Lechner *et al.* 2014; van der Wal *et al*. 2015), while statistics often disregard the litter size. Floating litter items can be transported by the currents until they sink to the seafloor, be deposited on the shore or degrade over time (Andrady 2015). It is expected that the quantities of litter will increase in the environment as a consequence of further direct introductions, however the likely paths and potential sinks or hot spots of accumulation are not clear.

The paper reviews the surveys conducted in 2016-2019 at the Georgian sector of the Black Sea, aimed to identify the categories of litter floating on the surface of rivers and seas as well as assess the nature and sources of distribution. The survey was conducted as part of EMBLAS II and EMBLAS Plus projects (2016-2019). Observation of floating litter is determined by the 10-th descriptor of the Marine Strategy Framework Directive and is used to assess environmental status of marine environment.

Materials and Methods

The assessment of floating litter and its impact need to be performed with harmonised methodologies to obtain comparable data that allows a prioritization of efforts when designing litter-reducing activities. Methodology for floating litter monitoring on the sea and rivers surface (Galgani *et al.*2013) envisage the counting and classification of litter items by categories and size range. Count and classification of different litter items at the rivers and sea surface was based on the Riverine Litter Observation Network (RiLON) activities. Data was collected by visual observations and documented using the JRC "Floating Litter Monitoring Android Application Version 2.0" for mobile devices that allows a harmonized reporting and is compatible with the MSFD Master List of Categories of Litter Items (EU 2016; González-Fernández and Hanke 2017). Consequently, the use of a common list allowed a harmonized data processing and analysis, facilitating the ranking of the most frequent observed litter items. Method was agreed via international collaboration.

Six specific surveys were carried out within EMBLAS II and EMBLAS Plus projects at Georgian rivers and sea area (Machitadze *et al.* 2018; Pogojeva *et al.* 2018; Ozturk and Pogojeva 2019). The surveys of riverine floating macro litter were conducted from the bridges, existing close to the rivers' mouths (Figure 1).

Figure 1. Riverine floating macro litter survey sites

There were four essential rivers: Chorokhi, Supsa, Natanebi and Rioni. The data were collected by visual observation sessions during 1 hour, from bridges, with at least two trained observers (Figure 2). The height of the bridges from the river surface permitted to identify litter items in sizes > 2.5 cm size, across the width of the river. Observers recorded only floated litter or suspended in the river surface layer using the mentioned Litter Monitoring Apps. Data obtained with the JRC Table App was sent to the Black Sea Commission and to the JRC RIMMEL Database for the analysis. Riverine floating data of Georgian rivers are regularly published in the RiLON reports (González-Fernández and Hanke 2016).

Figure 2. Riverine floating macro litter observations from the bridges

Sea surface floating macro litter monitoring was conducted from the board of vessels. Floating litter at sea surface was monitored during NPMS/JOSS surveys in 28 - 31 May 2016, by observations from Research Vessel "Mare Nigrum", using the same JRC Tablet Computer Application "Floating Litter" (Figure 3). Observations took place along of the transects between the sampling stations, in conditions of 5 knots speed of vessel. The sea surface floating litter survey sessions of 2019 were carry out on the board of the boat "Gagra", State Hydrographic service of Georgia, and Training Vessel of Batumi State Maritime Academy.

Figure 3. Floating macro litter observations on board of Mare Nigrum

Results and Discussion

Floating Riverine Macro Litter

Two categories of the litter were presented on the surface of rivers: natural organic (leaves, peelings, bird feathers), and artificial materials (plastics, rubber, textiles, etc.). The mobile app was used to categorize both types of litter. From the summary data of 6 monitoring sessions on mentioned rivers, it is deduced that the estimated loading values (whole rivers cross-section), ranging from 50 to 130 (in average 81) items·h^{-1} of plastic litter, and from 300 to 700 (in average 403) items·h^{-1} of Non-Litter (Table 1).

Table 1. Rivers surface floating macro litter summary (total number of items.h^{-1})

Type of Litter	Observation date	River Chorokhi	River Natanebi	River Supsa	River Rioni
Litter	10.2016	9	43	67	12
Litter	04.2017	22	38	12	8
Litter	07.2017	41	2	14	52
Litter	11.2017	6	14	7	20
Litter	08.2019	1	14	38	7
Litter	11.2019	18	25	5	9
Average	**-**	**16.2**	**22.7**	**23.8**	**18.0**
Average of single observation			**20.2**		
Non-Litter	10.2016	126	334	94	97
Non-Litter	04.2017	83	106	52	51
Non-Litter	07.2017	95	153	54	125
Non-Litter	11.2017	30	167	38	27
Non-Litter	08.2019	16	168	246	58
Non-Litter	11.2019	114	63	24	102
Average	**-**	**77.3**	**165.2**	**83.8**	**76.7**
Average of single observation			**100.8**		

Analysis of the results shows that largest amount of the natural material was brought by the Natanebi River to the Black Sea (Figure 4). During our observations, their number ranged from 63 to 334 items.h^{-1} (Table 1), in average 166 items.h^{-1}. The minimum amount of this type of litter was detected in the Rioni River varied between 27 items.h^{-1} and 126 items.h^{-1}, with an average 77 items.h^{-1}. Comparing the average plastic flux data, the lowest average load was observed in the river Chorokhi (16 items.h^{-1}), and the highest on the Supsa River (24 items.h^{-1})(Figure 5).

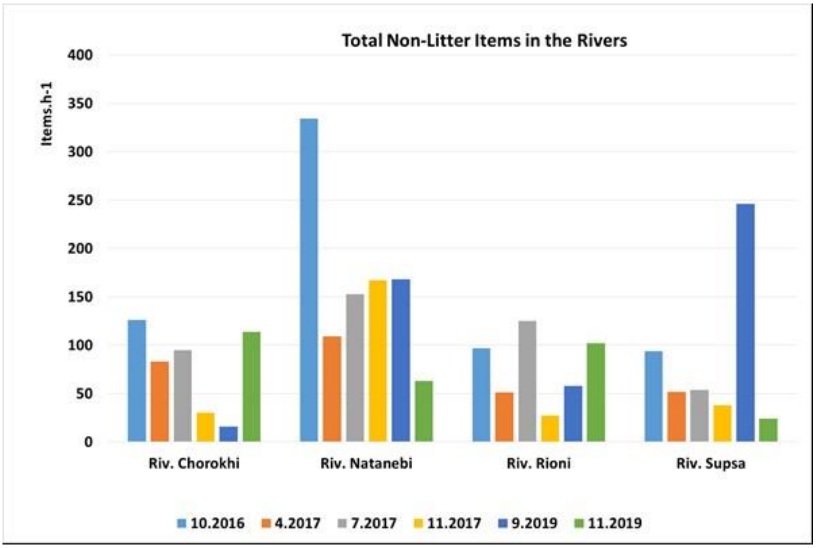

Figure 4. Number of floating non-litter items in rivers

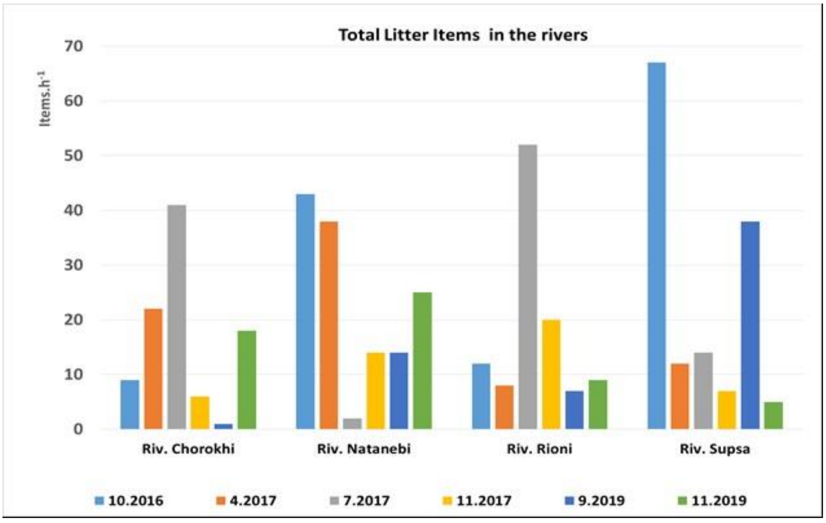

Figure 5. Number of floating macro litter items in rivers

Average loading of litter for the single observation was 20.2 items$\cdot h^{-1}$ (Table 1). This level of loading from our observed rivers is close to flux from European rivers (18 items$\cdot h^{-1}$) (González-Fernández and Hanke 2018).

The results of plastic litter categories (Figure 6) show that the packaging material (21.5%), plastic bottles (16.1%) and containers (15.3%) were the most common items observed, followed by plastic bags (12.4%).

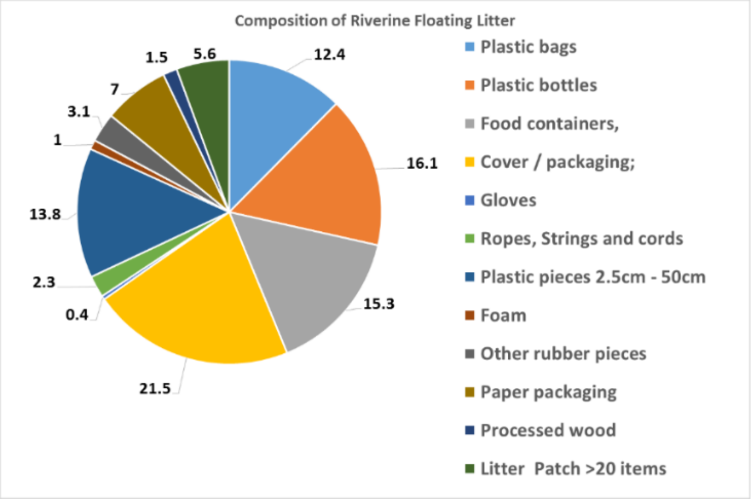

Figure 6. Composition of riverine floating macro litter

Floating Marine Macro Litter

Chemical and biological studies were conducted at 15 hydrographic stations in the territorial waters of Georgia during the National Pilot Monitoring Studies in 2016. Observation of floating macro litter was carried out between the stations on 19 transects. The total length of the studied sections was 114 km and the width of the observations was 10 m, covering 1.14 km^2 surface area.

A total of 478 items of litter were recorded across the surveyed area, with 87 items of them was natural organic material. Figure 7 represent the litter composition and distribution in the surveyed area. The density of litter equals to 76.3 items.km^{-2} (up to 91.7% of total litter was plastics). According to the results of the observations, the artificial material was dominated by packaging material (more than 25% of the total quantity) and plastic pieces (>2.5 cm -50< cm)(16% of the total quantity).

Floating marine macro litter surveys were conducted twice: in early September and at the end of October in 2019, as part of the "EMBLAS Plus" project. Early in September, during the 90-minute observations on Batumi-Chakvi transect, 28 items of litter and 50 items of non-litter were identified (Figure 8). On the observed area of this transect (0.33 km^{-2}), the density of litter was founded 85 items per sq km (up to 92.8% plastics).

Plastic Bags	79
Cover / packaging	121
Plastic bottle	28
Plastic container	18
Plastic pieces 2.5cm - 50cm	78
Synthetic rope	14
Foam	6
Paper packaging	20
Other rubber	7
Other textiles	3
Metal	1
Other wood	75
Feathers	12
Total Litter	**375**
Total Non-Litter	**87**
Litter patch >20 items	**16**

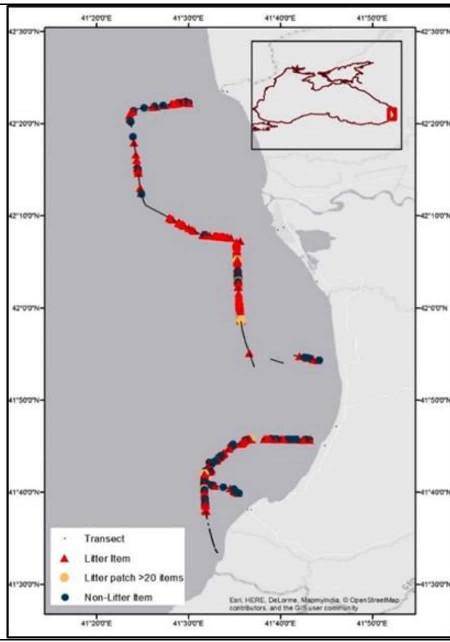

Figure 7. Composition and concentration of floating macro litter along the Georgian coastal zone

No floating macro litter were observed during the 2-hour observations on Kobulteti-Tsikhisdziri transect. The specific composition of litter was noticeable during the observations of Poti transect (Figure 9). In particular, there was an increased number of plastic bottles and polystyrene fragments (Figure 10), moving by the sea flow in the direction of the shore. Presumably, the source of their origin could have been container ships queueing on the outer raid (north of the port of Poti). This argument is based on the number of facts: the uniform compositions of the litter - polystyrene fragments that are used for industrial packages and plastic bottles, present on the shipping vessels; In addition, this litter is not degraded, indicating to the fact that they were not present in the sea for a long time. Therefore, the litter in this area most likely originates from the sea based sources such as shipping vessels, from where it possibly gets in the sea and subsequently on the beaches. The highest density of litter (448 items.km^{-2}) was observed on the Poti transect (11-km long).

Floating marine macro litter observations conducted on Batumi-Kobuleti transect at the end of October 2019 and the transect layout is demonstrated in Figure 11. On Batumi-Kobuleti coastal water (0.3 km^{-2}), mean floating macro litter density was 47 items.km^{-2} (up to 92.8% of total litter was plastics).

Litter Categories	Item Number
Plastic Bags	9
Plastic bottles	1
Food containers	6
Cover / packaging	4
Polystyrene pieces 2.5 cm - 50cm	4
Synthetic rope	2
Paper packaging	2
Total Litter	**28**
Total Non-Litter	**50**

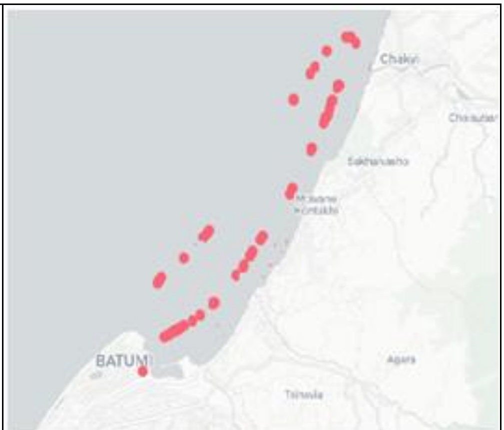

Figure 8. Composition and concentration of floating macro litter in the Batumi-Chakvi

Litter Categories	Item Number
Plastic bottle	34
Food containers	7
Cover / packaging	3
Gloves	1
Polystyrene pieces 2.5 cm - 50cm	21
Plastic pieces 2.5cm - 50cm	3
Foam	1
Other paper	2
Rubber (balls)	1
Proceeded wood	2
Total Litter	**75**
Total Non-Litter	**7**

Figure 9. Composition and concentration of floating macro litter in the Poti transect

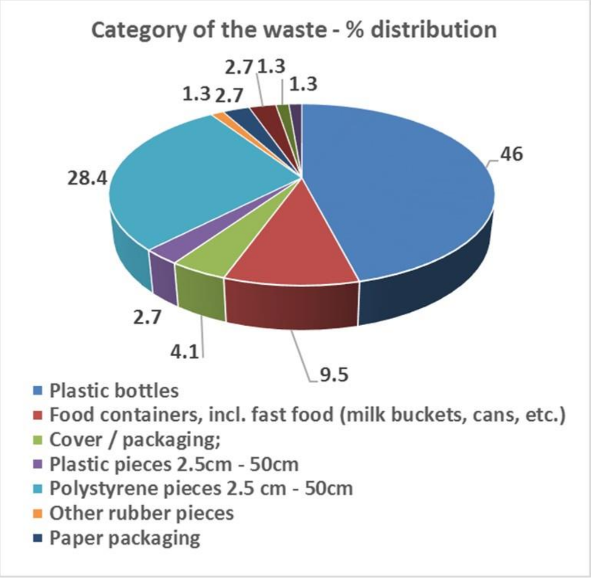

Figure 10. Litter items observed in the Poti transect

Litter Categories	Item Number
Plastic bottle	1
Cover / packaging	6
Polystyrene pieces 2.5 cm - 50cm	5
Metal Cans	1
Paper	
Paper packaging	1
Total Litter	**14**
Total Non-Litter	**56**

Figure 11. Composition and concentration of floating macro litter in the Batumi –Kobuleti transect

Conclusion

The study of the floating macro litter was conducted in the Black Sea waters of Georgia in accordance with the methodology recommended by the European Union Directive. Natural and artificial litter reclamation was carried out and distribution channels were detected. According to the observations of rivers Chorokhi, Natanebi, Supsa and Rioni in 2016-2019, it was detected the density of litter from 300 to 700 items.h^{-1} of Non-Litter and 50 to 130 items.h^{-1} of plastic litter with the majority were packaging materials, bottles and containers. According the data of survey along the Georgian seashore in 2016, sea floating macro litter mean density was 76.3 items.km^{-2}. The large number of plastic bags and packaging materials were detected on the sea surface during the observations along the Georgian coastal waters in 2016 and 2019. The density of litter varried from 47.2 to 448 items.km^{-2}. Land based sources were likely to be the main sources of litter. The possible sea based sources were container ships queued on the outer raid (north of the port of Poti).

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Anthropogenic litter input through rivers in the Black Sea

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Abstract

The sources and quantities of marine litter and plastic pollution in the Black Sea are yet unknown. It is important to identify the main pathways in order to enable mitigation strategies to reduce the input of plastic waste to the marine environment. In this sense, rivers in this region are expected to play an important role in transporting mismanaged waste to the sea, but data on this matter is still very limited. This study presents a first compilation of riverine floating macro litter data collected in rivers flowing into the Black Sea. Visual observations provided indicative information on the most frequent litter items and rates of riverine litter fluxes in ten rivers from Ukraine, Russia, Georgia and Turkey. Top items presented an 83.7% of plastics, including cover / packaging, bottles, pieces and bags as main contributors. Riverine litter fluxes were variable, showing median values between 4 and 75 items/hour in the different rivers, and maximum values up to 700 items/hour in the individual monitoring sessions. The establishment of future monitoring programmes require the implementation of harmonized approaches and consistent frequency in the data collection to improve the representativeness of results, enabling appropriate comparable assessments of riverine litter inputs in the Black Sea.

Keywords: Riverine litter, plastic pollution, monitoring, floating litter, macro litter

Introduction

The fact that most of the anthropogenic litter is produced inland suggests that rivers can act as an important pathway in transporting mismanaged wasted from land-based sources to the marine environment (Lebreton *et al.* 2017). Litter, and therefore plastics, that are present in the river basins are exposed to transport mechanisms (e.g. winds, rain, and runoff) that allow them to reach the freshwater waterways to continue their journey downstream towards the seas. This is of especial interest in the Black Sea, a semi-enclosed water body with great potential for litter accumulation because of its very limited interchange with other seas. In this sense, the Black Sea is subject to a high anthropogenic pressures because it receives freshwater inputs from several large rivers (Danube, Dnieper, Dniester, Don, Kuban, Sakarya, Southern Bug, *etc*.) draining an extensive land surface, and numerous small-medium rivers along its densely populated coast (Jaoshvili 2002; Stanev and Ricker 2019).

It is only in the recent years that researchers have started measuring the quantities of plastics in rivers and their inputs to the ocean, offering very limited data in terms of temporal and geographical coverage (Emmerik and Schwarz 2020). Further, monitoring approaches were not in place and data collection was biased to microplastic measurements, resulting in a general lack of information on macro litter fluxes in rivers for most regions in the world (González *et al.* 2016). In order to start covering these data gaps, a methodological approach for riverine floating macro litter monitoring was developed under the project RIMMEL led by the Joint Research Centre (JRC) of the European Commission (González-Fernández and Hanke 2017), which further facilitated a collaboration within the EMBLAS project for the implementation of the first floating litter monitoring collecting data in rivers draining freshwater into the Black Sea (EMBLAS 2020).

The value of the information gathered from riverine litter data collection is linked to the global issue of Marine Litter and, in the case of the European Regional Seas, it can provide input to the implementation of the Descriptor 10 (Marine Litter) under the Marine Strategy Framework Directive (European Commission 2008) and the Regional Sea Convention for the Black Sea: Black Sea Commission (http://www.blacksea-commission.org/).

This study analyse the first compilation of riverine floating macro litter data collected in rivers flowing into the Black Sea, considering monitoring efforts under the EMBLAS project in Ukraine, Russian Federation and Georgia, and additional data from two rivers in Turkey. Results provide a top items ranking list for floating litter in the region and an overview on the estimated litter flux values per river, derived from visual observations.

Materials and Methods

The EMBLAS project collected data in the following rivers: Danube, Dniester in Ukraine; Aderba and Don in Russia, and Chorokhi, Natanebi, Rioni and Supsa in Georgia. Further, the same approach was implemented by Turkish colleagues in the rivers Firtina and Taslidere. Figure 1 shows the rivers and their corresponding monitoring sites.

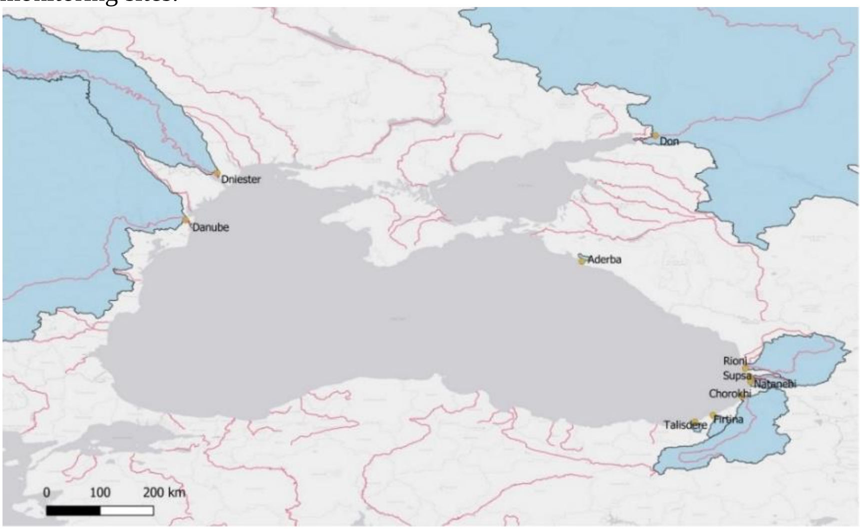

Figure 1. Riverine floating macro litter monitoring: Rivers and monitoring Stations in Ukraine (Danube and Dniester, Russia (Don and Aderba), Georgia (Rioni, Supsa, Natanebi and Chorokhi) and Turkey (Firtina and Taslidere) (Blue areas showing the drainage area of the surveyed rivers).

The monitoring setup followed a harmonized approach as described in González-Fernández and Hanke (2017). In brief, data collection consisted of visual counting from vantage points (*e.g.* bridges) made by trained observers to register the number and identity of floating macro litter items (>2.5 cm) passing by in the river water surface layer. Data was registered during short monitoring sessions (30-60 minutes) using a Floating Litter Monitoring application developed by the JRC. Monitoring sites were selected in the last reach of the rivers to account for litter input to the sea. The application sets a common list of litter items for the harmonization of data reporting that is based on the litter categories described in 'Guidance on Monitoring of Marine Litter in European Seas' (Galgani *et al.* 2013). The observers scanned for floating litter on a predefine observation track width that allows extrapolating the results to the total river width, assuming equal distribution across the river.

The data compilation gathered 91 monitoring sessions, corresponding to almost 73 hours of observations, which were performed during different periods in the timeframe from 2016 to 2020. The river basin area and monitoring effort details are included in Table 1.

Table 1. River basins and monitoring effort distribution

	River basin area (km²)	Distribution of monitoring sessions*	Number of monitoring sessions	Hours of monitoring
Aderba	194	2017 (1)	1	0.5
Chorokhi	22,065	2016 (1), 2017 (3), 2019 (2)	6	6.1
Danube (Kiliya branch)	802,032	2017 (11)	11	8.3
Dniester	72,531	2017 (13), 2019 (12)	25	24.1
Don	429,400	2016 (7), 2017 (14)	21	11.0
Natanebi	687	2016 (1), 2017 (3), 2019 (2)	6	6.1
Rioni	14,667	2016 (1), 2017 (3), 2019 (2)	6	6.1
Supsa	1,112	2016 (1), 2017 (3), 2019 (2)	6	6.0
Taslidere	326	2020 (6)	6	3.0
Firtina	1,155	2020 (3)	3	1.5
Total		**2016 (11), 2017 (51), 2019 (20), 2020 (9)**	**91**	**72.6**

* Number of monitoring sessions per year in parentheses.

Results and Discussion

Top items

The top items list considered 904 litter items identified by the observers during their monitoring sessions (Table 2). The list of items comprised 26 litter categories, with the top 10 items representing 93% of the total number. The top 10 items showed seven plastics, two paper and one processed wood categories. The most frequent plastic items were cover/packaging (17,2%) related food packaging and wraps, bottles (16.4%), plastic pieces (14.1%), bags (11.1%) and other non-classified plastic/polystyrene items (9.4%) in the top five. Most of these categories correspond to identifiable single use plastics. The sum of plastic pieces and polystyrene pieces made up to 18.8 %, being an indicative value for fragments. The rivers in the Black Sea region showed lower proportions of these fragments than rivers in the Mediterranean Sea (31.6%) and the North East Atlantic region (61.2%), but higher than in a river monitored in the Baltic sea (4.2%) (González-Fernández *et al.* 2018). Also, although the addition of new data can modify the composition of the litter categories ranking, the proportion of fragments observed herein was similar to the 18.2% reported previously for the Black Sea, where only data from EMBLAS 2016-2017 was available (González-Fernández *et al.* 2018).

Table 2. Floating Macro Litter top items list in the Black Sea Rivers.

Ranking	Litter Items	Number	% of total	% Cumulative
1	Cover / packaging	156	17.18	17.18
2	Plastic bottle	149	16.41	33.59
3	Plastic pieces	128	14.10	47.69
4	Bag	101	11.12	58.81
5	Other plastic/polystyrene items	85	9.36	68.17
6	Plastic container	70	7.71	75.88
7	Paper packaging	49	5.40	81.28
8	Other paper	48	5.29	86.56
9	Polystyrene pieces	42	4.63	91.19
10	Pallets	17	1.87	93.06
11	Other rubber	11	1.21	94.27
12	Foam	10	1.10	95.37
13	Fish boxes - plastic	9	0.99	96.37
14	Rubber boots	7	0.77	97.14
15	Synthetic rope	6	0.66	97.80
16	Cans	6	0.66	98.46
17	Wood boards	3	0.33	98.79
18	Sheets	2	0.22	99.01
19	Gloves	2	0.22	99.23
20	Other metal	1	0.11	99.34
21	Tyres and belts	1	0.11	99.45
22	Beams /Dunnage	1	0.11	99.56
23	Other textiles	1	0.11	99.67
24	Newspapers & magazines	1	0.11	99.78
25	Clothing	1	0.11	99.89
26	Rope / string and nets	1	0.11	100.00
Total		**904**	100	

Overall, plastic was the most abundant litter material comprising 83.7% of the total items, followed by paper (10.8%) and processed wood (2.3%) (Figure 2). The predominance of plastic items is a common result when studying marine litter in different environmental compartments such as beach, floating and seabed (Galgani *et al.* 2015). Beach litter can contain 84% of plastic litter at European level (Addamo *et al.* 2017) , and specifically 83% in the Black Sea (EMBLAS

2018), matching the results obtained for floating litter in the rivers. Further, floating litter in the Black Sea shows usually a higher percentage of plastic items (94.9%), and predominance of fragments (50%) (Pogojeva *et al.* 2020) compared to the rivers. The latter may respond to a sorting process subject to beaching, and deterioration and fragmentation of litter items (like paper material), limiting their presence in open waters.

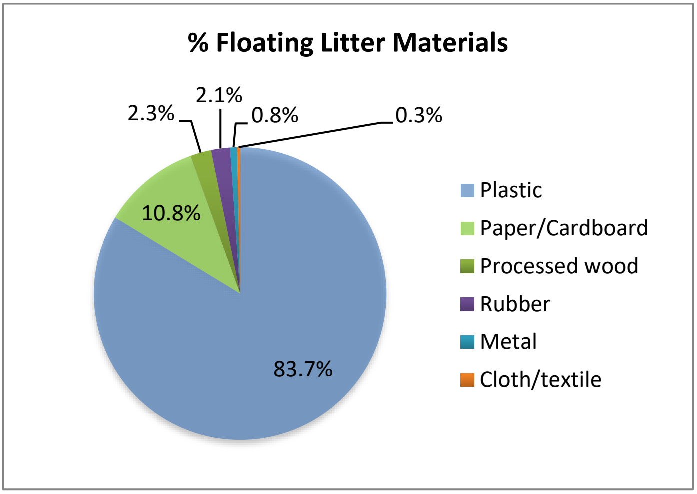

Figure 2. Floating litter materials as percentage of total items

Litter flux

The analysis of litter flux, calculated as items per hour, showed a high variability in the results, both within and among the studied rivers. Figure 3 presents the data distribution in boxplots for each river. Due to the influence that extreme values can have on the mean values, in this case, it is preferable to compare the median values. The observation on the Ukrainian side of the River Danube (Kiliya branch), presented the highest median (~72 items/hour), and litter flux values up to ~350 items/hour. In contrast, the River Don, second largest river in this study, showed the lowest median (~4 items/hour) and maximum values of ~32 items/hour. The River Don observations were performed from a very high bridge (30 metres), which may have resulted in an important bias towards large items, missing numerous smaller items on the water surface, providing therefore underestimated litter fluxes. The rest of the rivers provide median litter fluxes in the range 10-50 items/hour, and maximum values ~150 items/hour. The only exception was observed in the River Firtina, where an outlier of 700 items/hour was calculated. River Firtina had only three observation sessions, which limits its statistical analysis, otherwise the rest of the litter fluxes calculated in this river fit in the range observed for similar rivers in Georgia.

Differences in litter flux are affected by multitude of factors such as the range of river basin size scales, river flow regime, land cover and other climatological conditions, and the number of monitoring sessions performed in each river. Socio-economic factors are also relevant, i.e. the population density in the river basin, the land use, waste management level and life styles can have a great effect on the amount of litter available to be transported by rivers to the sea. All of these factors hinder comparing pollution levels among rivers.

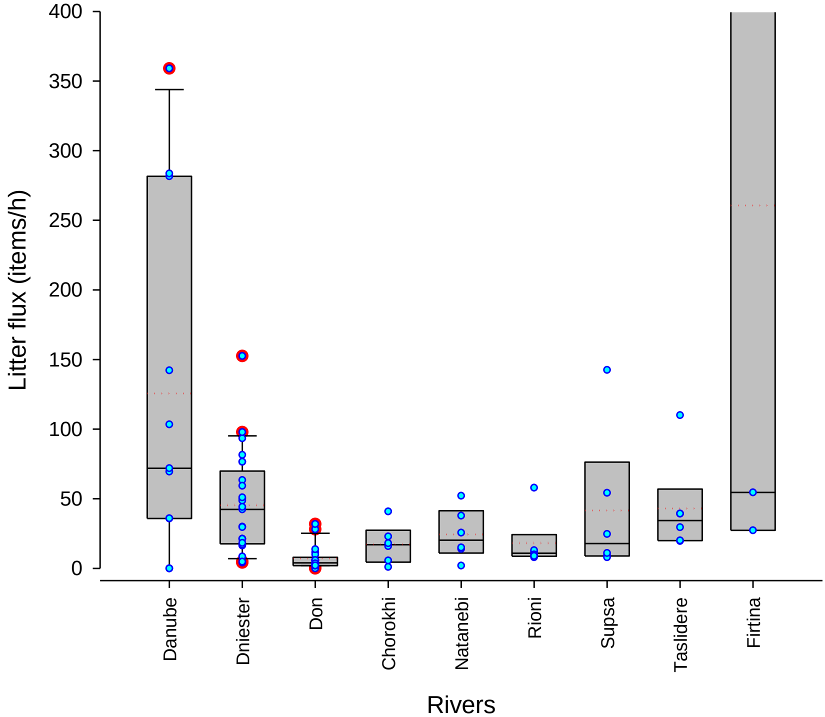

Figure 3. Litter flux (items/hour) per river. Boxplots include litter flux values (light blue dots), quartiles (box), percentiles 10 and 90 (whiskers), outliers (red dots), mean (solid black line) and median (dotted red line) for each river. River Firtina river presented an outlier (700 items/hour) that is not visualized in the current Litter flux axis scale (0-400 items/hour).

Overall, although the low number of observations in certain rivers from the Black Sea is a limiting factor to extract conclusions, the range of litter fluxes observed in the region matches in order of magnitude with that observed in other European regions, e.g. River Rhone in France (0-293 items/hour), River Rhine in The Netherlands (10-75 items/hour), Rivers Llobregat and Besòs in Spain (0-429 items/hour) and River Tiber in Italy (~10-130 item/hour, at Fiumicino canal) (Crosti *et al.* 2018; Castro-Jiménez *et al.* 2019; Vriend *et al.* 2020; Schirinzi *et al.* 2020).

Conclusions

The harmonization of a visual observation methodology can provide simple and fast an initial assessment of riverine floating macro litter input to the sea at regional scale. Riverine floating macro litter in rivers draining into the Black sea contains 84% of plastic items. The most frequent items included a majority of identifiable single use plastic. Litter flux presented a high variability in a range comparable to other European regions.

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Microplastic pollution along the southeastern Black Sea

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Abstract

Within the scope of TUBITAK 118Y125 project, microplastic pollution was investigated at the coastal areas of the mouth of several rivers in the southeastern Black Sea, namely the rivers Karasu, Kızılırmak, Yesilırmak, Melet, Aksu, Değirmendere and Fırtına. Here we present results of the first cruise that occurred during July 2019. At each station, samples were collected from surface waters with manta trawl, from several depths with Niskin bottles and from sediments with box core. Microplastics were characterized using optical microscopy, FT-IR and SEM/EDS in terms of size, morphology and chemistry. Surface microplastic concentration ranged between 1.783 and 40.03 par.m^{-3} (0.178x10^{6}-4x10^{6} par. km^{-2}). The primary shapes were fragments (49%), followed by films (31.3%), fibres (17.7%), foams (1.9%) and beads (0.1%). Twelve different colours of microplastics were detected in surface waters with the most common colour being white (34.3%), followed by transparent (28.9%) and blue (11.8%). The average size was calculated as 1.540 ± 1.065 mm, 1.984 ± 1.022 mm, 2.076 ± 1.205 mm, 2.302 ± 1.225 mm and 0.670 ± 0.245 mm for fragments, films, fibres, foams and beads, respectively. Microplastic concentrations at subsurface depths, reached up to 20 par.l^{-1}. An increasing MP concentration with depth was observed. Microplastic concentrations in sediment varied from 74.1 to 1778.8 par.m^{-2} (0.004-0.192 par.ml^{-1}). The primary shapes in the sediment were fibres (66.4%), followed by fragments (19.9%), films (13.3%) and beads (0.4%), no foam was found. Ten different colours of microplastics were found in the sediment with blue being the most common colour (40.7%) followed by red (23.5%) and transparent (15.9%). The average size was calculated as 1.253 ± 0.954 mm, 1.035 ± 0.429 mm, 1.358 ± 0.892 mm, and 0.079 mm for fibres, fragments, films, and beads, respectively. The FT-IR analysis confirmed the presence of eight polymers in surface waters and tree polymers in the sediment samples. Polyethylene and polypropylene were the most common polymers both in sea surface and in sediment. Our results confirm that microplastics were present in all matrices (surface, water column and sediment) of the Black Sea. Project results will provide data on distribution, sources and effects of microplastics required to implement the “Marine Strategy Framework Directive”.

Keywords: Microplastic, marine litter, pollution, MSFD, Black Sea

Introduction

Microplastics (MPs) are defined as plastic particles smaller than 5 mm (Arthur *et al.* 2009). Primary MPs are the ones originally manufactured in these sizes for a wide range of products, including personal care products, clothing and pellets from plastic industry. Secondary MPs are the ones resulting from mechanical and biological degradation processes that breakdown larger plastic into smaller particles (Andrady 2011). The accumulation of MPs in marine systems is presently a major environmental problem, with potential hazards to marine ecosystems and public health. They can enter the marine food webs via ingestion by marine organisms, transport pathogens and release toxic chemical properties, which can harm marine biota and contaminate seafood consumed by humans (Wright *et al.* 2013).

The European Union (EU) Marine Strategy Framework Directive (MSFD, 2008/56/EC) aims to establish a good environmental status of the European seas by 2020 (EC 2008). The MSFD requires that all EU Member States take measures to maintain or achieve good environmental status that is defined by means of 11 qualitative descriptors. Under descriptor 10, which is related to Marine Litter, to achieve a good environmental status of MPs (D10C3) it is required that "*The composition, amount, and spatial distribution of micro-litter in the surface layer of the water column, in sea-floor sediment, and possibly on coastlines, is at a level that does not cause harm to the coastal and marine environment*".

The Black Sea is one of the marine regions of the EU with the highest risk for marine litter pollution because it is a nearly enclosed sea with high river discharge from several industrialized countries. Marine litter surveys in the sea surface (Suaria *et al.* 2015; Berov and Klayn 2020), sea floor (Topçu and Öztürk 2010; Moncheva *et al.* 2016) and beaches (Topçu *et al.* 2013; Terzi and Seyhan 2017; Simeonova *et al.* 2017, 2020; Terzi *et al.* 2020; Oztekin *et al.* 2020; Aytan *et al.* 2020) have shown that nearly 80 % of marine litter consist of plastic items, and more than half of these plastics are from single-use (or short-term) items and unidentified plastics fragments (BSC 2007; Oztekin *et al.* 2020; Aytan *et al.* 2020; Simeonova *et al.* 2020). Although composition and distribution of macroplastic has been reported, there is still limited data on composition and concentration of MPs in the Black Sea (Aytan *et al*. 2016; Oztekin and Bat 2017; Berov and Klayn 2020).

In this chapter, we present preliminary results of the TUBITAK 118Y125 project "Distribution, composition, sources and ecological interactions of micro- and nanoplastics in the southeastern Black Sea". The project aims to assess seasonal distribution, composition, concentration of microplastics in sea surface, water column and sediment with their possible sources in the southeastern Black Sea. It also aims to investigate possible pathways of micro- and nanoplastics to enter food web and their effects on function of lower trophic levels of pelagic food web.

Effects of physical environment on distribution of microplastics are also to be evaluated. Sampling was undertaken at the mouth of seven big rivers along the SE coast of Black Sea, during four cruises. Here in this chapter, we focus on the MP abundance and composition measured during the first cruise.

Materials and Methods

Sampling

MP in surface waters, subsurface depths and sediment in the SE Black Sea were measured during the first research cruise of the TUBITAK project 118Y125 in July 2019. Samples were collected at the mouth of seven important rivers in the SE Black Sea between 05.07.2019-08.07.2019 (Table 1, Figure 1). For each river, one station was immediately at the river mouth and a second station was more offshore waters (here after called coastal), resulting in a total of 14 stations.

Table 1. Locations, coordinates and depths of sampling stations in the southeastern Black Sea

Location	Station	Depth	Coordinate
River Karasu	SN1	103 m	42°06'57.6"N 35°07'11.7"E
(SİNOP)	SN2	7 m	42°02'19.5"N 35°04'09.0"E
River Kızılırmak	SK1	94 m	41°46'03.4"N 35°56'01.1"E
(SAMSUN)	SK2	6 m	41°44'23.0"N 35°57'27.6"E
River Yeşilırmak	SY1	98 m	41°45'00.9"N 36°38'58.8"E
(SAMSUN)	SY2	7 m	41°23'25.6"N 36°39'26.9"E
River Melet	OR1	94 m	41°05'38.6"N 37°56'40.9"E
(ORDU)	OR2	6 m	40°59'34.1"N 37°56'06.9"E
River Aksu	GR1	110 m	40°55'31.7"N 38°26'19.3"E
(GİRESUN)	GR2	6 m	40°55'07.5"N 38°26'18.0"E
River Değirmendere	TR1	110 m	41°01'04.8"N 39°45'40.8"E
(TRABZON)	TR2	12 m	41°00'22.6"N 39°45'26.5"E
River Fırtına	RZ1	110 m	41°12'12.7"N 40°57'59.5"E
(RİZE)	RZ2	10 m	41°11'25.5"N 40°57'43.4"E

The microplastics from surface waters were collected using manta trawls (333 µm mesh). Nets were towed horizontally for 10 min at ship speed of approximately 2 knots, in the upper 20 cm of the water column (Figure 2). To collect all MPs samples stocked, net was washed with seawater. Samples were immediately transferred into the glass bottles and preserved in 4% borax-buffered formaldehyde.

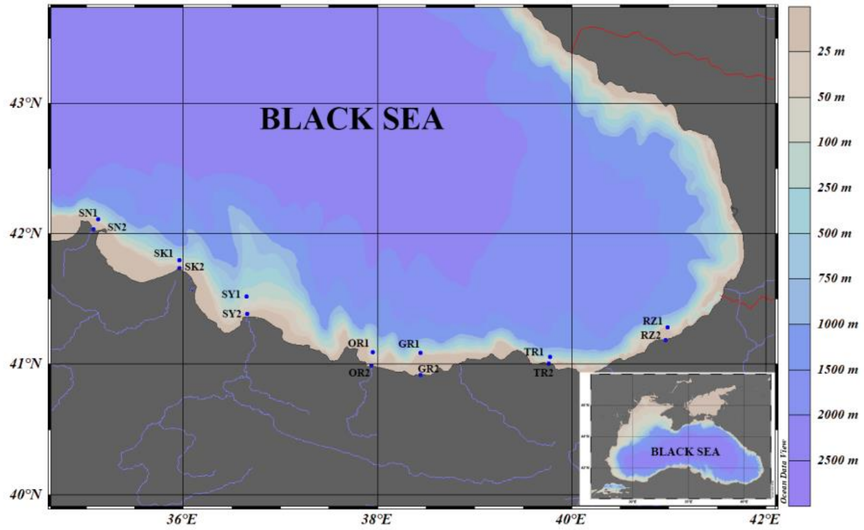

Figure 1. Sampling stations

Figure 2. Microplastic sampling from surface waters

To investigate distribution of MPs in the water column and possible subsurface accumulations, we also collected water samples at various depths with Niskin bottles, but this was only performed at the coastal station of each river. Seawater samples were taken from 3 m, euphotic depth (1 % PAR depth), above and below halocline. 30 L seawater were collected from each depth using 5 l Niskin bottles mounted on a SBE32 Carousel water sampler. Water samples were filter through a 5 mm, 1mm and 200 µm stainless steel sieves. The material collected on the sieves was transferred to glass vials and 1 ml of hydrochloric acid (HCl) was added and stored until analysis.

Regarding sediment samples they were collected by box corer (total area = ~ 0.1 m^2) from approximately 5 m depth from the river mouth stations and 100 m depth contour from the coastal stations (Figure 3). Surface sediments to 5 cm depth were taken using metal spoons and samples were stored in glass jars at -20°C until further analysis.

Figure 3. Microplastic sampling from sediment

Laboratory analysis

To assess the presence of MPs in the Manta trawl (surface) and Niskin bottles (subsurface) samples, wet peroxide oxidation was used (Masura *et al.* 2015). Samples were sieved through a 5 mm mesh, rinsed with ultrapure water to remove salt and transferred to a 200 ml conical flask. To catalyses the reaction 10 mL of aqueous 0.05 M Fe (II) solution was added to sample. Then, Hydrogen peroxide (30 % H_2O_2) solution was filtered through a 0.2 µm filter and added (app. 20 ml) to conical flask to remove the biological material. The mixture was placed in a temperature-controlled oven at 40ºC until all biological material was digested (up to 72 h). If the biological material was not completely removed, more H_2O_2 solution was added. After this, 100 ml of saturated NaCl solution (d: 1.2 g cm^{-3}) was poured into the sample to minimise filtration time. The mixture was filtered onto a 10 µm filters and left to dry in a petri dish in the oven. Samples then were visually examined under a Leica SAPO stereo microscope. Microplastics were identified according to morphological characteristics and physical response features (Desforges *et al.* 2014). Microplastics were visually classified according to type (film, fibre, fragments, foam, pellet, microbead), colour and size-class (<0.2 mm, 0.2-0.5 mm, 0.5-1mm, 1-2 mm, 2-5 mm).

Sediment samples were homogenized and their volume (ml) and weight (g) were recorded. Density flotation method was used to extract MPs from sediment samples (Frias *et al.* 2018). For this process, saturated NaCl solution (d:1.2 g cm^{-3}) were prepared with ultra-pure water and the solution was filtered through a 0.2 μm filter to reduce potential contamination from salt. Sediment samples (425-700 ml) were put into glass beakers and hypersaline solution were added. Sediment samples were stirred with a stainless-steel spoon for a few minutes and allowed to settle for 1 hour. Three settlements were done to ensure all plastics were recovered. Floating plastics and supernatant were filtered through a 10 μm sieve. Debris retained on the sieve were rinsed into clean glass beakers and H_2O_2 (30%) solution was added. Beakers were covered with aluminium foil and kept in the room temperature for 168 h. At the end of this period, the solution including MPs was filtered onto 10 μm filters and left to dry in a petri dish in the oven. Samples then were visually inspected using a ZEISS Stemi 508 stereo microscope and classified according to type (film, fibre, fragments, foam, pellet, microbead), colour and size-class (<0.2 mm, 0.2-0.5 mm, 0.5-1mm, 1-2 mm, 2-5 mm).

Fourier transform infrared spectroscopy (FT-IR) was used to confirm the synthetic polymer origin of the most common types of MPs found in sea surface and sediment. FT-IR analysis was carried out on a Perkin Elmer Spectrum 100 FT-IR spectrophotometer. The spectrum range was 4000-650 cm−1 and a resolution of 1.0 cm-1 with 32 scans for each measurement. The polymer type identification was done by comparing absorbance spectra to a reference the library by using Perkin Elmer SEARCH Plus® software. Spectra for each sample was compared with reference FT-IR data and samples showing more than 70% spectral similarity were accepted.

Contamination control

Cotton lab coats and nitrile gloves were worn at all times. All laboratory analysis was done in laminar flow cabin and microscopic identification in work cabin. To account for a potential air borne contamination, dampened PCTE filters in a petri dish were placed for every stage of the sampling and laboratory work. Several procedural blanks (H_2O_2 in an empty well) were also run alongside with sample processing. In case contamination was noted, particles were excluded from the data.

Results

In July 2019, averaged MP concentration in the surface waters for all stations ranged between 1.80 and 47.97 $par.m^{-3}$ ($0.18x10^6$ and $4.70x10^6$ $par.km^{-2}$) with the highest in the River Kızılırmak (Samsun) (Figure 4). The primary shapes were fragments (49%), followed by films (31.3%), fibres (17.7%), foams (1.9%) and microbeads (0.1%) (Figure 4, Figure 5).

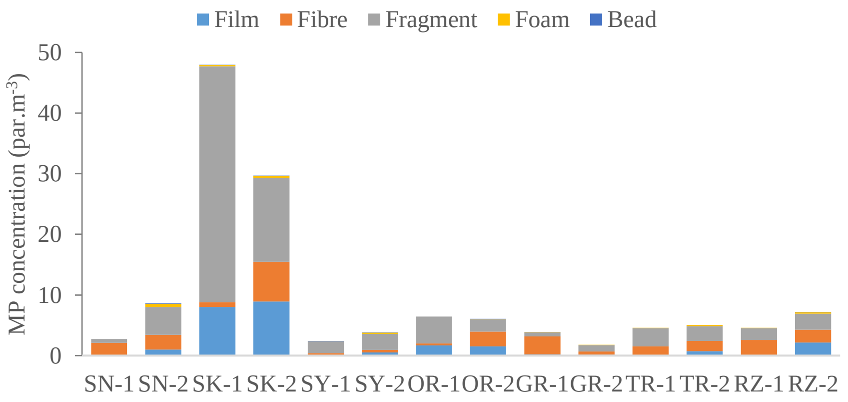

Figure 4. Concentration of microplastics in surface waters in the sampling stations

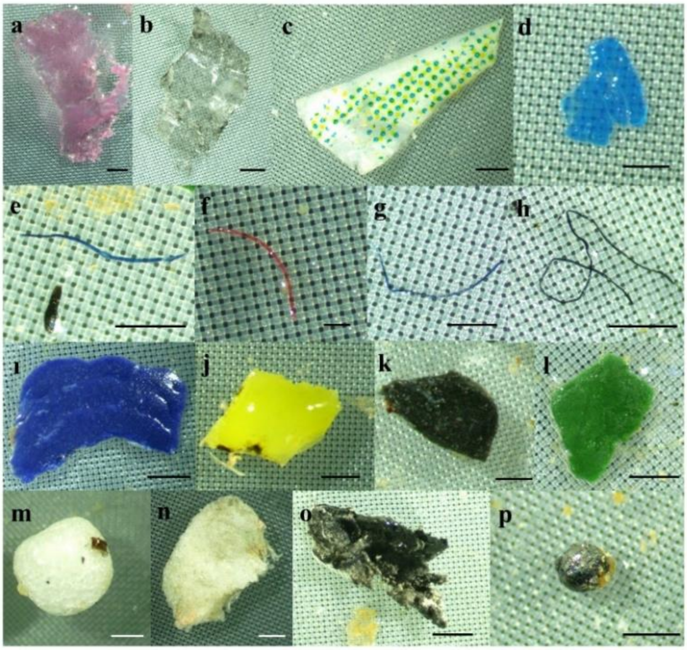

Figure 5. Examples of films (a-d), fibres (e-h), fragments (ı-l), foams (m-o), microbead (p) collected from surface waters (scale bar=500 µm)

A total of 12 different colours of MPs were detected in surface waters with the most common colour being white (34.3%), followed by transparent (28.9%) and blue (11.8%) (Figure 6). The MP size varied from 0.107 to 4.998 mm and 0.085 to 4.995 mm in river mouth and coastal stations, respectively (Table 2).

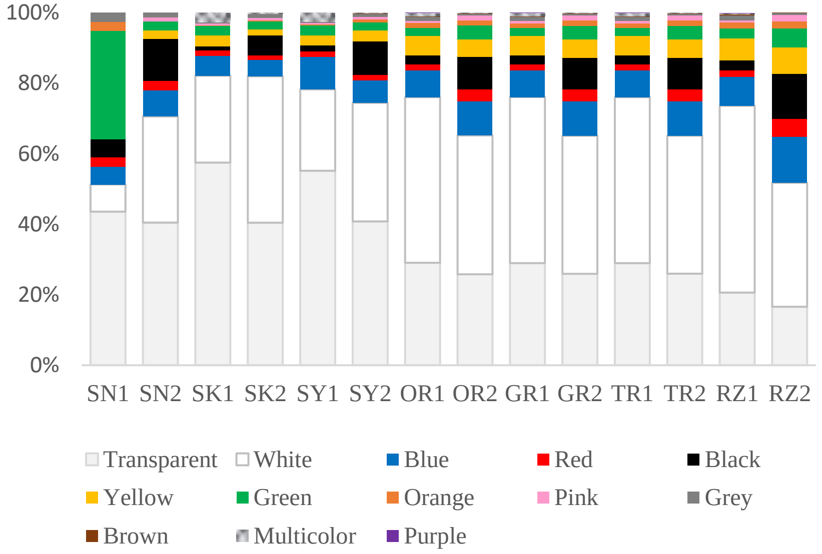

Figure 6. Colour of microplastics in surface waters in the sampling stations

Table 2. Minimum, maximum and average size (mm) ± standard deviation (SD) of microplastics in the surface waters of the river mouth and coastal stations

Station	MP types	Minimum	Maximum	Average±SD
River mouth	Film	0.156	4.998	1.967±0.998
	Fibre	0.163	4.942	2.076±1.205
	Fragment	0.107	4.972	1.540±1.065
	Foam	0.280	4.839	2.302±1.225
	Bead	0.496	0.843	0.670±0.245
Coastal	Film	0.457	4.985	2.309±1.054
	Fibre	0.246	4.995	2.565±1.248
	Fragment	0.163	4.979	1.714±0.983
	Foam	1.073	2.780	1.732±0.532
	Bead	0.085	0.160	0.120±0.031

Subsurface concentration and composition of MPs varied between sampling depths and stations (Figure 7). MP concentration ranged between 0 to 20 par. l^{-1} and, in general, an increasing trend from east to west was observed. Over each sampled depth, the highest average MP concentration was in the euphotic depth (9.3 par. l^{-1}), followed by below halocline (5.9 par. l^{-1}), above halocline (5.9 par. l^{-1}) and 3 m depth (4.3 par. l^{-1}). Regarding all samples, fibres (42.8 %) were the prevalent shape followed by fragments (35.5 %), films (21.5 %), foams (0.2 %) and microbeads (0.05 %).

9).

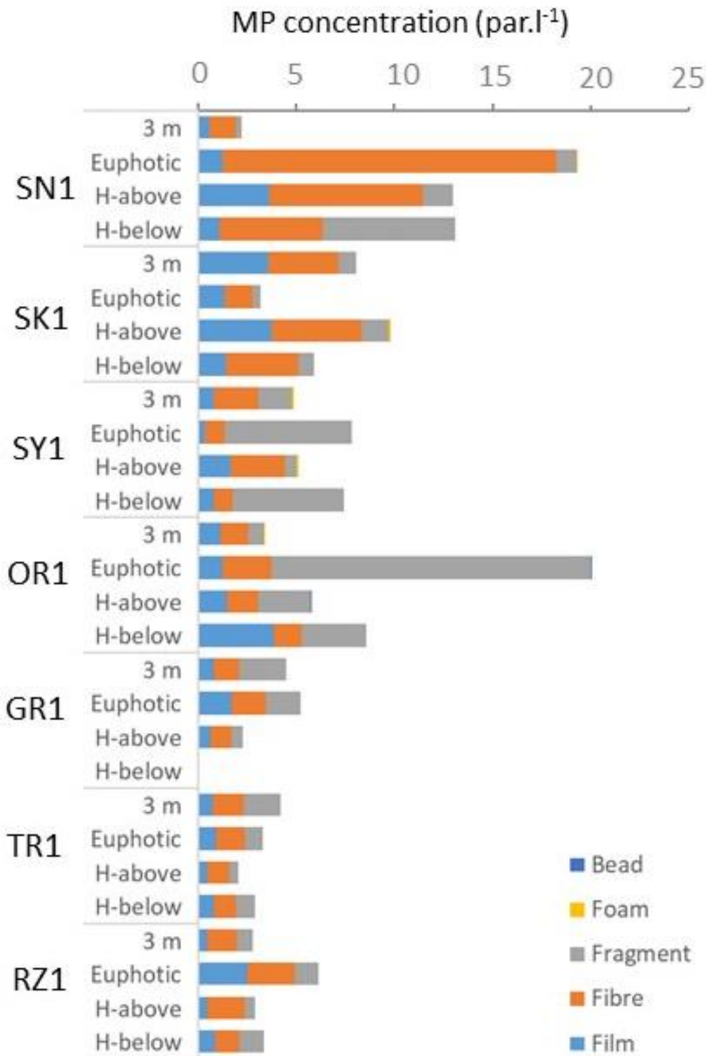

Figure 7. Concentration of microplastics in subsurface waters, including 3 m, euphotic depth, above and below halocline

Microplastic concentrations in sediment varied from 74.1 to 1778.8 par.m^{-2} (0.004-0.192 par.ml^{-1}) with the highest in the River Değirmendere (Trabzon). The primary shapes were fibres (66.4%) in the sediment, followed by fragments (19.9%), films (13.3%) and beads (0.4%), no foam was found (Figure 8, Figure 9).

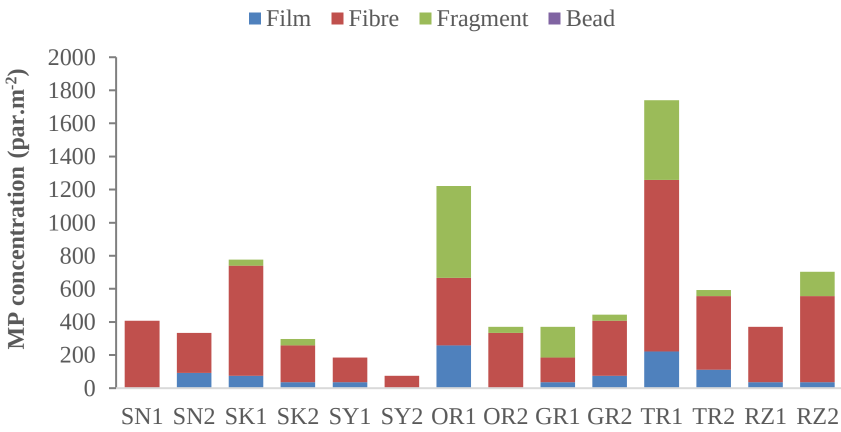

Figure 8. Microplastic concentration in the sediment of the sampling stations

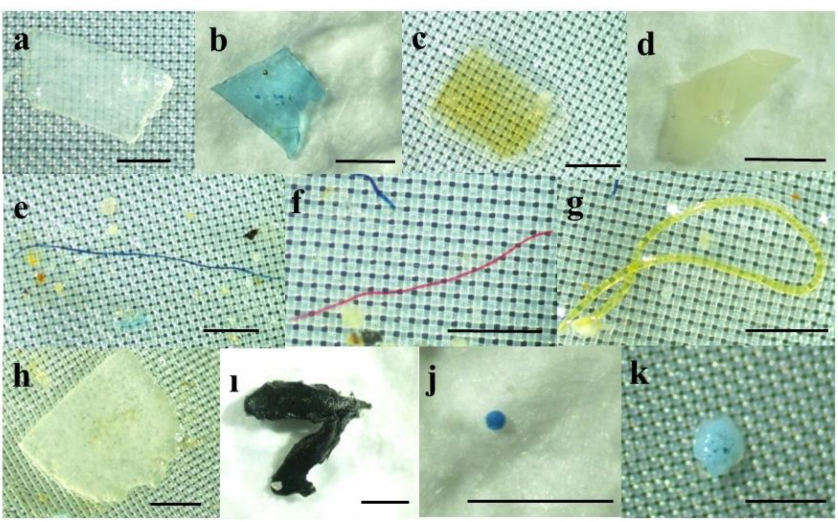

Figure 9. Examples of films (a-d), fibres (e-g), fragments (h-ı), and microbeads (j-k) collected from surface waters (scale bar=500 µm)

Total of 10 different colours of MPs were found in the sediment with blue (40.7%) being the most common colour followed by red (23.5%) and transparent (15.9%) (Figure 10). The average size was calculated as 1.253 ± 0.954 mm, 1.035 ± 0.429 mm, 1.358 ± 0.892 mm, and 0.079 mm for fibres, fragments, films, and microbeads, respectively (Table 3).

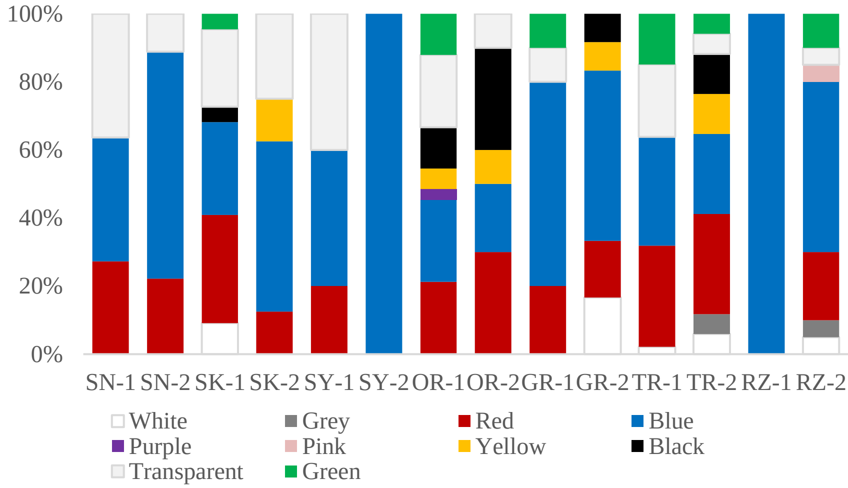

Figure 10. Colour of microplastics in the sediment of the sampling stations

After analyses of randomly chosen 90 MPs, a total of eight different polymer found in the surface waters; polyethylene (PE), polypropylene (PP), polyacrylic (PAC), polyethylene terephthalate (PET), polystyrene (PS), polystyrene/ polyacrylic copolymer (PS/PAC), styrene-butadiene rubber (SBR) and polyamide/nylon (PA) (Figure 11). Polymer composition were less diverse in sediment samples compare to surface waters, represented with PE, PP and PA (Figure 12). PE and PP were the most common polymers found in both surface waters and sediment samples.

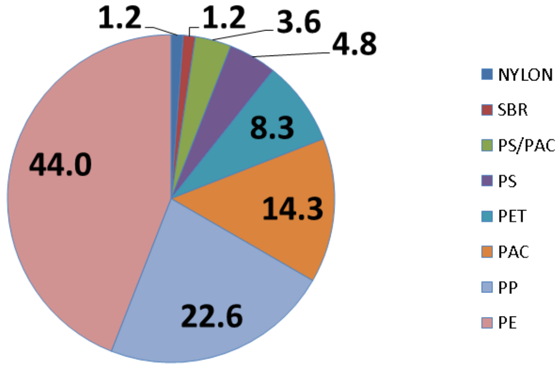

Figure 11. Polymer composition of surface microplastic samples

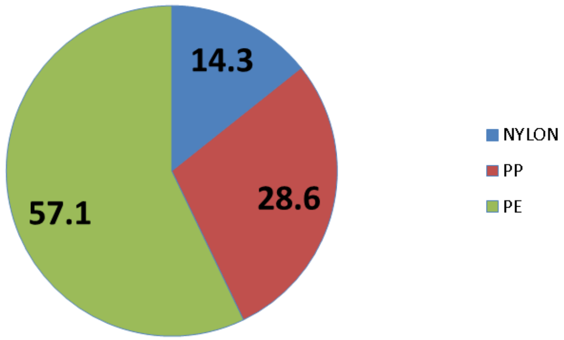

Figure 12. Polymer composition of sediment microplastic samples

Table 3. Minimum, maximum and average size (mm) ± standard deviation (SD) of microplastics in the sediment of the sampling stations

Station	Film	Fibre	Fragment	Microbead
SN1	-	0.32-3.32 1.53±0.85	-	-
SN2	1.02-2.31 1.63±0.66	0.64-3.91 1.51±0.96	-	-
SK1	1.05-1.24 1.15±0.13	0.22-3.73 1.22±0.92	1.83-1.95 1.89±0.08	-
SK2	0.87	0.42-3.51 2.11±1.08	0.09	-
SY1	1.51	0.61-2.36 1.26±0.81	-	-
SY2	-	0.96-1.41 1.18±0.31	-	-
OR1	0.13-2.62 0.94±0.89	0.35-2.71 1.27±0.90	0.10-0.90 0.43±0.25	-
OR2	-	0.69-2.71 1.28±0.72	0.12	-
GR1	0.98	0.14-1.56 0.59±0.65	0.09-0.32 0.22±0.09	-
GR2	0.67-4.46 2.56±2.67	0.22-2.22 0.90±0.73	0.94	-
TR1	0.63-2.82 1.59±0.72	0.18-3.59 1.07±0.88	0.18-1.36 0.47±0.35	0.07
TR2	0.90-1.12 1.01±0.15	0.27-4.55 1.16±1.18	0.55-1.05 0.80±0.35	-
RZ1	1.19	0.46-1.74 0.84±0.48	-	-
RZ2	1.27	0.29-4.23 1.54±1.31	0.33-1.20 0.73±0.37	-
Average	**1.035± 0.429**	**1.253± 0.954**	**1.358± 0.892**	**0.079**

SEM analysis provide images of surface textures of MPs collected in the SE Black Sea (Figure 13). The cracks, pits and groves of these MPs provide evidence that these small plastics will continue to break down into nanoplastics.

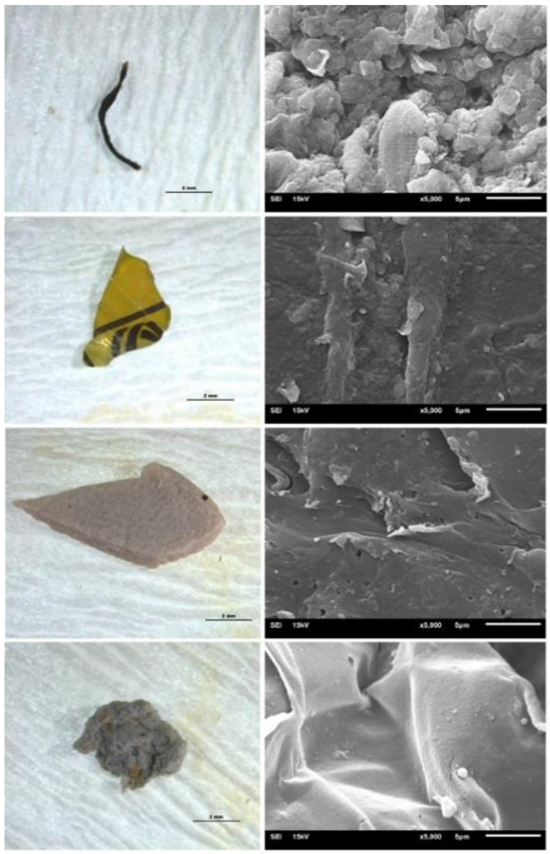

Figure 12. Scanning electron microscope (SEM) images of microplastics collected from SE Black Sea

Conclusion

In this study, we assessed the concentration and composition of MPs at three ecological matrices (sea surface, water column and sediment) of seven river-influenced coastal regions of the SE Black Sea. We found MPs in all matrices demonstrating the ubiquity of MPs pollution in the Black Sea. The number of MPs at the surface ranged between 1.78 and 40.03 par. m^{-3}, but at the subsurface depths, these numbers were nearly two order of magnitude higher. Methodological differences (Manta trawl versus Niskin bottles) could explain some differences; but an increasing MP concentration with depth was indeed observed in most stations for the subsurface sampling. In future studies, there is a need to consider also the < 333 um fraction of MPs (which is not measured by

Manta trawl) and investigate vertical distributions of MPs in order to have a more complete characterization of MP pollution in the Black Sea. MPs were made of eight different polymers, with a majority of PE and PP both in surface waters and in sediment. Dominance of PE and PP in our samples is a good reflection of European production of these plastics. Since plastic generation is expected to increase, more research is needed to better understand the sources, transport, fate and effects of MPs in Black Sea.

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Distribution of micro- and mesolitter in the southwestern part of the Black Sea

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Abstract

The micro- and mesolitter topic is of great interest nowadays, but the lack of data leads to uncertainty on the impact generated over the marine environment. The aim of the paper is to analyse the micro- (< 5 mm) and mesolitter (5 mm-25 mm) distribution from the southwestern part of the Black Sea, from 18 samples collected in October 2019 from Romanian, Bulgarian and Turkish marine waters. Micro- and mesolitter were present in the surface waters of all three countries, showing variations of size and density.

Keywords: Microlitter, mesolitter, density, Black Sea

Introduction

The first studies regarding the presence of microplastics appeared in the 1970s (Carpenter *et al.* 1972). The middle of the 20th century is characterized by an increase in global production of plastics, being accompanied by an accumulation of plastic litter in the marine environment (Barnes *et al.* 2009). Being dispersed by currents and winds, persistent plastics are rarely degraded but become fragmented over time (Thompson 2015).

The massive accumulation of microplastics in water bodies has been recognized by scientists and authorities worldwide, previous studies proving the ubiquitous presence of microplastics in the marine environment (Browne *et al*. 2010). Thus, with the Marine Strategy Framework Directive (MSFD-criteria D10C1) the EU prescribes a mandatory monitoring of microplastics and the EU Technical Subgroup on Marine Litter (TSG-ML) proposed a standardized monitoring strategy for microplastics in the EU (Hanke *et al.* 2013).

At the moment, the sampling methodology and the classics of microplastics is not well defined, so it is very important to establish a standard working method for obtaining an overview of microplastics, their sorting, distribution and the effects of microplastics on the marine ecosystem (Cole *et al.* 2011).

Synthetic polymers have a lower density than marine water, which is why most of them float on the surface of water, yet they also appear to a lesser extent in the water column (Hidalgo-Ruz *et al.* 2012).

Ingestion of microplastics may lead to “potentially fatal injuries such as blockages throughout the digestive system or abrasions from sharp objects” (Wright *et al.* 2013), which, in contrast to microplastics, mainly affect microorganisms, smaller invertebrates or larvae. What is more, microplastics can release toxic additives upon degradation and accumulate persistent organic pollutants (POPs) (Rochman *et al.* 2013; Bakir *et al.* 2012; Engler 2012; Teuten *et al.* 2009). Because of their small size, microplastics harbour the risk of entering marine food webs at low trophic levels and propagating toxic substances up the food chain (Besseling *et al*. 2013).

Because microlitter are on the same size scale as that of planktonic organisms, they are potentially available to several plankton predators (Hidalgo-Ruz *et al.* 2012; Wright *et al.* 2013), which possibly mistake them for food (Desforges *et al.* 2015). Microlitter ingestion may affect predator-prey relationships and the carbon cycle (Galloway *et al.* 2017) and cause physical and chemical hazards to the organism (Wright *et al.* 2013).

The Black Sea poor ecological conditions are a result of its limited water exchange with the open basins, weak vertical and enhanced pollutants including macro and microplastics by river discharges, domestic and touristic wastes, fisheries activities and other shipping discharges. Because most of the pollutants come from the shore and near-shore regions of the marine environment, the processes of horizontal mixing and shelf seawater exchange are of the great importance (Oztekin *et al*. 2017).

The microlitter presence in the water column is an important issue and requires further examination about transportation, origins, types and effects on biota, the paper aiming to investigate the density and distribution of this type of pollution.

Materials and Methods

Between 30. 09. 2019 - 08. 10. 2019, an international expedition within ANEMONE Project took place on the continental shelf of the Black Sea (Romania, Bulgaria, Turkey) in which 18 micro- and mesolitter samples were collected (Figure 1).

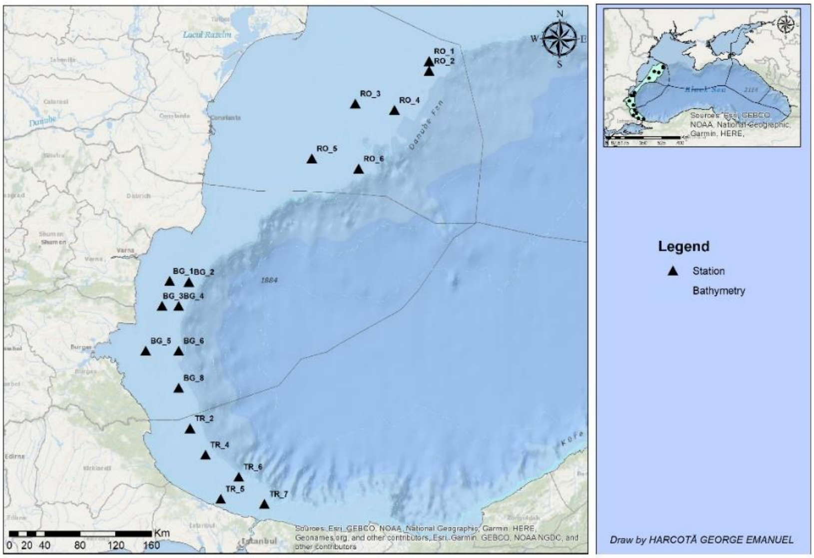

Figure 1. Map of station locations

Sampling

A net for microplastic sampling was used to collect micro- and mesolitter samples. The used equipment was manufactured by Hydro-Bios, with a frame size of 70x40 cm, the length of the net bag: 260 cm; mesh size: 200 µm, and a float mounted on the sides of the frame in order to support the net on the water surface. These characteristics of the net allow the accumulation of organisms and particles that flows on the sea surface layer. After assembling the net, it was attached to the winch cable and rinsed with fresh water before use to prevent sample contamination.

Figure 2. Sampling of micro- and mesolitter

After the net was launched the following information were noted:

- ✓ sampling start time.
- ✓ the starting value of the flowmeter.
- ✓ Start GPS position.
- ✓ average speed of the RV.

While towing the net, the ship had a semi-circular motion to prevent the net from entering the ship's operating area.

The sampling time was 10 minutes, after the time expired, the net was slowly towed on board the ship.

After the net was lifted out of the water the following information were noted:

- ✓ the end time of the sampling.
- ✓ flowmeters stop value.
- ✓ End GPS position.

The net is recommended to be washed with filtered seawater on the outside of the sieve to avoid possible contamination. After the sampling was performed, the collecting recipient was detached, and the sample was stored in 1L container, preserved with 8 mL of 37% formaldehyde per 100 mL sample and stored in a sun-protected place. After each sampling, the net and the flowmeter must be rinsed thoroughly with fresh water (Alexandrov *et al.* 2014) (Figure 3).

Figure 3. Sampling of micro- and mesolitter

For microscopic processing, the sample was passed through a 60 µm sieve, retaining both micro- and mesolitter and organic matter. The sample was washed with filtered seawater to minimize contamination and reduce the amount of formaldehyde (37%) and it was brought to a lower volume, depending on the sample density.

The analysis of microlitter was performed for 1-5 mm size group. Mesoplastics were also classified according to two size classes 5 – 10 mm, and 10 - 25 mm. These were counted and measured under the Olympus SZX 10 stereomicroscope. Quantitative analysis consisted in assessing the number of microlitter and their size on a known volume unit (microlitter/m^3 and mesolitter/m^3) (Figure 4).

The paper uses the term micro- and mesolitter (ML) because the identification was made as marine litter, the types of micro- and mesoplastics found in the samples being not assessed.

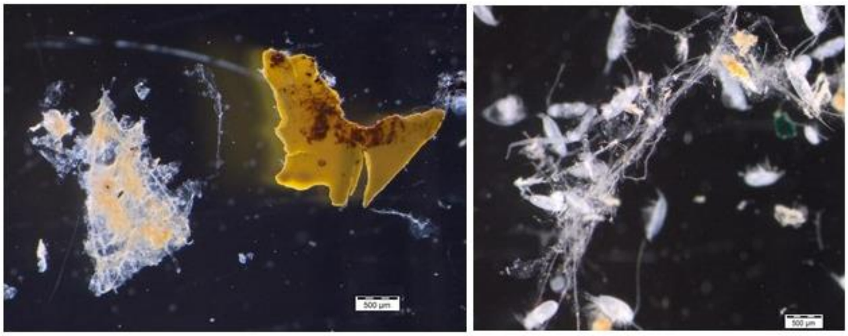

Figure 4. Micro- and mesolitter identified in the collected samples

Results and Discussion

From the samples analysis we observed the presence of microlitter with dimensions between 1 - 5 mm in the stations shown in figure 5, as follows:

- In the Romanian marine water, the maximum density value was recorded in station RO_4 with 78.9 ML/m^3 and the minimum value of 6.35 ML/m^3 being recorded in station RO_2.
- In the Bulgarian marine water, the maximum density value was recorded in station BG_3 with 99.45 ML/m^3 and the minimum value of 2.75 ML/m^3 in being recorded in station BG_8.
- In the Turkish marine water, the maximum density value was recorded in station TR_4 with 45.58 ML/m^3, and the minimum value of 2.85 ML/m^3 being recorded in station in TR_5.

Mesolitter between 5 - 10 mm was identified in nine out of 18 stations. In the Romanian marine area, this category was present in four stations out of six, station RO_3 recording the maximum density value - 8.95 ML/m^3 while in RO_1 was recorded the minimum density of mesolitter - 1.43 ML/m^3 (Figure 6). In the Bulgaria marine area, the 5 - 10 mm mesolitter was present in three stations, the recorded density being 2 times lower than in the Romanian marine area. In Turkish marine area 5 - 10 mm mesolitter appeared in only one station, the density being five times lower than the one recorded for the Romanian Black Sea samples.

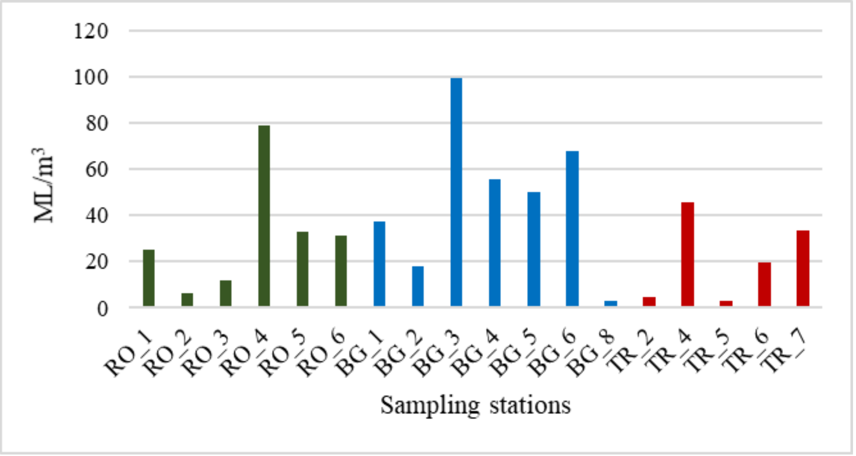

Figure 5. Density of microlitter in SW Black Sea

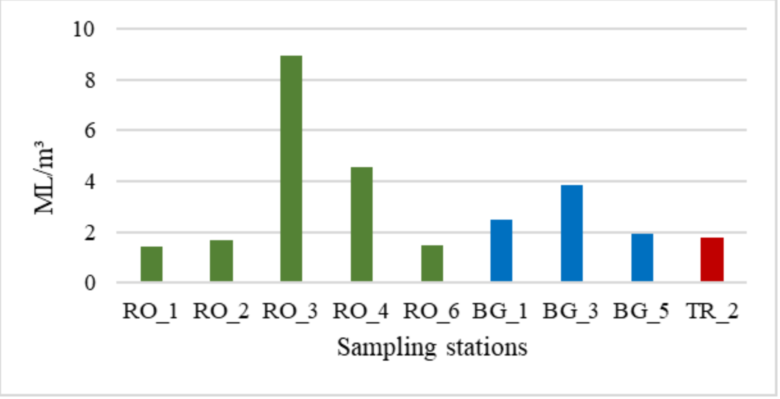

Figure 6. Density of mesolitter with dimensions between 5-10 mm in SW Black Sea

Mesolitter higher than 10 mm was recorded only in two stations from the Romanian marine area, with densities of 0.85 ML/m^3 in RO_2 and 1.83 in RO_4 (Figure 7).

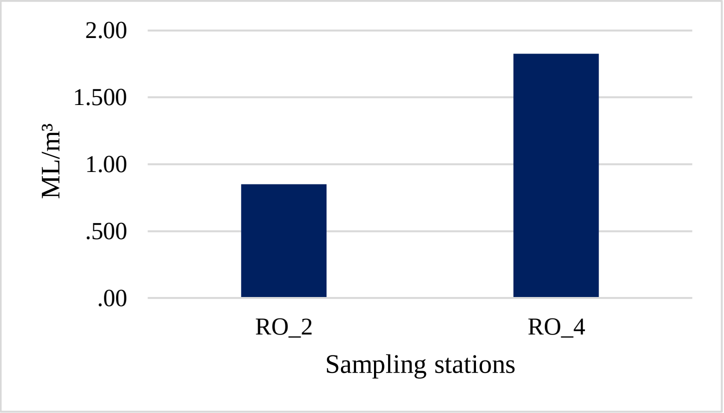

Figure 7. Density of mesolitter with dimensions between 10 - 25 mm in Romania Black Sea area

The microlitter average density presented variations. 1-5 mm microlitter recorded the highest density value in samples collected from the Bulgarian marine area, in Romania and Turkey being present in lower densities. 5-10 mm mesolitter was present in very low densities in all three countries, while the 10-25 mm mesolitter category was found only in the Romanian marine area (Figure 8).

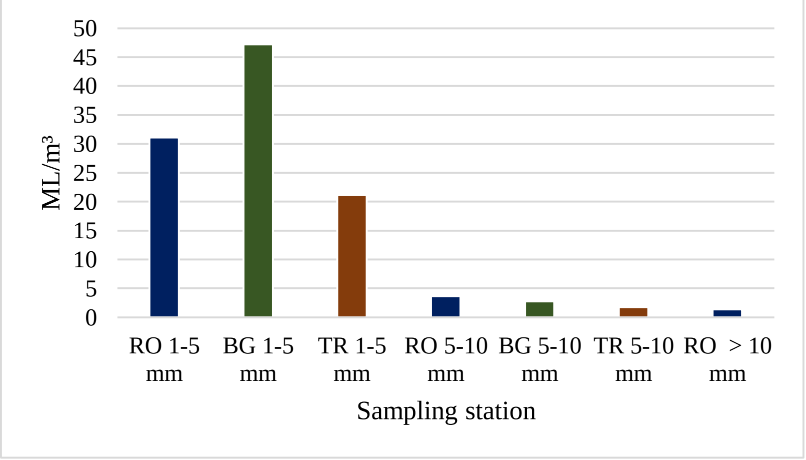

Figure 8. Average density of micro- and mesolitter in SW Black Sea

Microlitter and mesolitter distribution recorded high quantities in the Bulgarian marine area (BG_6), being present in lower quantities in the Romanian and Turkish marine areas (Figure 9).

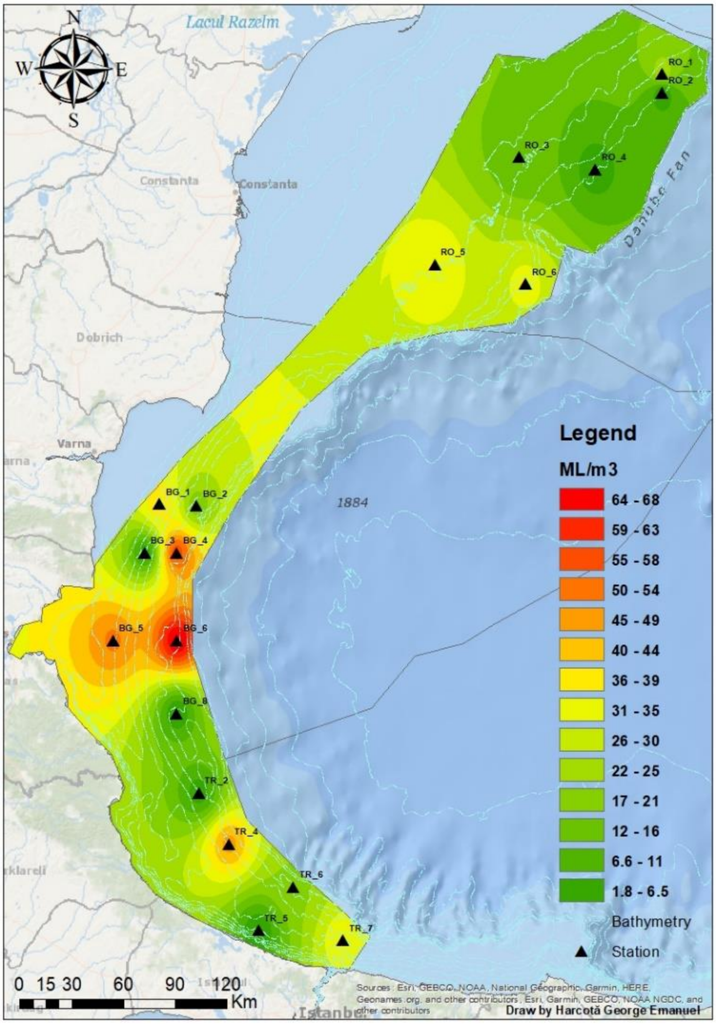

Figure 9. Microlitter and mesolitter distribution in the SW Black Sea

Conclusions

The 1-5 mm microlitter size was reported in all countries, with densities that varied from one station to another. Following the analyses performed, a higher density of the 1-5 mm microlitter was observed in the Bulgarian marine area (99.45 ML/m^3 in station BG_3). All three analysed microlitter and mesolitter dimensions were present in the samples collected from the Romanian marine area. In the Turkish marine area, the microlitter was present in smaller quantities than in all the other studied areas. The average density presented variations, the 5-10 mm category being the one with the lowest values in all countries.

Acknowledgements

The study has been supported by the ANEMONE project "Assessing the vulnerability of the Black Sea marine ecosystem to human pressures", funded by the European Union under ENI CBC Black Sea Basin Programme 2014-2020, grant contract 83530/20.07.2018.

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Microplastics accumulation on the Black Sea coast: Scenario analysis

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Abstract

The quantification of microplastics in the coastal marine waters is a problem of increasing importance. This study is an attempt to quantify the microplastic accumulation along the Black Sea coasts and to identify areas potentially in risk of high microplastic density. Here we use an ocean circulation model paired with a Lagrangian particle tracking model to describe the microplastics distribution and coastal accumulation. Assuming several microplastic release zones, the relative quantity of particles accumulating in each Black Sea's littoral country is estimated. On the base of recent knowledge for the input of microplastics to the Black Sea, the average annual accumulation in the coastal waters is evaluated (e.g., it is greater than $5x10^3$ items m^{-3} or 0.5 g m^{-3} in several locations).

Keywords: Microplastic distribution, particle tracking, stokes drift, litter sources, coastal pollution

Introduction

Marine plastic litter is an emerging environmental challenge since the production of plastic is steadily increasing. About 1.5 to 4.5% of the world's plastic production is disposed of directly from the land into the sea (Jambeck *et al*. 2015). Microplastics (MP) are generally defined as plastic particles smaller than a few millimetres down to the micrometre range. The smaller the size of the plastics, the wider the range of marine organisms that can absorb or interact with them. Besseling *et al*. (2019) provided a review of current occurrence, in-situ measurements, modelling approaches, processes, effects and effect thresholds with regards to microplastics in the aquatic environment. The level of public interest on the subject of microplastic pollution is expected to peak around 2022, as has been forecast based on the history of attention focused on other contaminants of emerging concern (Halden 2015). High concentrations of MP have been detected in rivers and lakes in Europe (Lechner *et al*. 2014; Faure *et al*. 2015; Klein *et al*. 2015). Management and regulation of increasingly abundant plastics have been recognised recently as priorities of the European Commission (EC 2018, Plastics Strategy), as general awareness of the detrimental effects on the environment and health due to the widespread use of plastics has risen, both in the general population and at policy maker level.

The Black Sea appears to be particularly susceptible to the accumulation of floating litter (BSC 2007; Lebreton *et al.* 2012; Aytan *et al.* 2016; Miladinova *et al.* 2020b). Many surveys are focused on collecting and analysing marine litter from the Black Sea beaches (Simeonova *et al.* 2017; Aytan *et al.* 2020; Oztekin *et al.* 2020), while data for floating MP in the sea is exceptionally limited. MP quantification requires weighing or counting, which is a difficult task especially for small particles, which are barely visible to the naked eye (Molly *et al.* 2019). This type of pollution crosses state boarders, passing from rivers and lakes into the ocean and from one organism to another, accumulating along the food chain (e.g., Carbery *et al.*2018). Despite the large number of qualitative studies of MP in the marine environment, the accuracy of MP estimates is currently hindered by lack of input data. Specifically, data on MP concentration in river runoffs and streams are missing.

Detailed knowledge of the concentration of MP in marine and in coastal waters, is crucial for assessing the risk to the environment and for managing MP derived risk. In general, it is unknown what part of MP collected on the beach and coastal waters has a local origin as, in many cases, MP pollution has a cross border/supranational origin. Thus, tracing microplastics back to their sources is an important challenge in the evaluating MP abundance and risk management. This study describes a model assessment of (small and micro) plastic transport in the Black Sea and focuses on coastal plastic accumulation. The cross-border transport of plastics is, thus, evaluated. The present study aims to estimate the density of MP in the coastal waters of the Black Sea using available MP input data from observations and statistical approaches.

Materials and Methods

To simulate MP transport and accumulation, the output of a Black Sea circulation model (Miladinova *et al*. 2017) is paired with a particle tracking model, Ichthyop v3.3 (Lett *et al.* 2008) that computes trajectories of virtual particles released from selected geographical areas. The Black Sea's hydrodynamic circulation model describes the main sea circulation dynamics, such as fronts, filaments and mesoscale eddies, which are relevant to MP transport. The meteorological forcing from the European Centre for Medium Range Weather Forecast (ECMWF) available from http://www.ecmwf.int, based on 6-hourly records was applied. It is part of the ERA-Interim project (2009-2018). Freshwater input has been estimated using the values from the Global Runoff Data Centre (GRDC, http://www.bafg.de/GRDC) runoff. The model is initialized by means of temperature and salinity 3D fields coming from the MEDAR/MEDATLAS II project (http://www.ifremer.fr/medar). The model has a horizontal grid spacing of 2 x 2 min latitude–longitude (approx. 3–4 km). We hypothesize that when a particle reaches the shore it stops moving. From that moment onwards, the particle is removed from the simulation and remains trapped on the beach. The model keeps track of the accumulation of beached particles during the simulation period. The most common form of MP in the surface open ocean consists of fragments of consumer plastic with a medium material density of 0.9-0.965 g cm^3 (e.g., low- and high-density polyethylene, polypropylene, and foam polystyrene) that allows particles to float in the water (Barnes and Milner 2005). The direct effect of the wind drag on the individual particles is not considered, since small floating plastic fragments are assumed to move under the sea surface in agreement with previous modelling approaches. Our model does not consider neither particle biofouling nor settling.

The same numerical approach has been previously applied to study the circulation and accumulation of floating litter in the Mediterranean Sea (Macias *et al.* 2019) and in the Black Sea (Miladinova *et al.* 2020b). In order to study particle accumulation, which is independent of the number of released particles, a relative particle density index (RPD) is introduced as RPD (%) = (number of particles in a grid box/total amount of released particles) x 100. In order to decrease the effect of interannual regional climate variation on the particle distribution, the 10-year (2009-2018) mean number of particles in each grid box is used for RPD evaluation. The RPD values are then grouped into a small number of bins for increased clarity of the RPD visualization.

Scenario setup

Seven different scenarios are considered in the study (Table 1). In the beginning of January (H1) or July (H2), 12000 particles are released homogeneously over the basin surface. Prior to their release, the initial particle density in the basin is set to zero. RPD is saved three months after the release. These scenarios are intended to evaluate the impact of Stokes drift. Particles are released in winter (H1) and summer (H2) in order to study the seasonal importance of the Stokes drift on particles accumulation along the coast.

Furthermore, five scenarios are simulated with a release from a selected zone (i.e., Danube mouth, shelf area next to Istanbul, Kerch Straight, Dniepr mouth and Rioni mouth). Release zones are located in the front of the river mouth for the Danube, Dniepr and Rioni scenarios and in the front of the Kerch Strait for Azov (Figure 1a). The Istanbul particle release zone is placed on the shelf nearest to the city. Due to the lack of regular monitoring data for the inputs of MP to the Black Sea, we use a scaled approach to define the particle release locations and concentrations. Our scenarios are based on the model predictions made in Siegfried *et al*. (2017). Their model calculated an export rate of 1503 tonnes of MP per year from the Danube to the Black Sea, while the total MP influx from land-based sources reached 4100 tonnes per year. This means that the Danube accounts for 37% of the total MP input to the Black Sea. According to Siegfried *et al.* (2017), in the year 2000, excluding the Danube, a high influx of MP is found along the south-western coast of Turkey (Istanbul), Azov Sea, Dniepr and Rioni rivers.

Individual simulations are performed by releasing particles from each one of the zones and the results are summed to estimate the accumulation of particles due to several sources. When the combined effect of several sources is calculated, the output of each scenario is scaled according to the proportion given in Figure 1b. The onset of particle release occurs in the beginning of every year and 1000 particles are released from a given zone daily throughout 365 days. Doubling the number of released particles does not change the relative output of the model. All scenarios are carried out separately for each year between 2009 and 2018.

Table 1. Scenario names, release locations, dates, and schedules.

Scenario name	Release location	Number of particles	Start date	End date	Schedule of release
H1	Homogeneous	12000	January, 1	March, 31	All particles are released on the same starting date
H2	Homogeneous	12000	July, 1	September, 30	All particles are released on the same starting date
Danube	Danube mouth	365000	January, 1	December, 31	1000 particles are released daily
Istanbul	Shelf area next to Istanbul				
Azov	Kerch Straight				
Dniepr	Dniepr mouth				
Rioni	Rioni mouth				

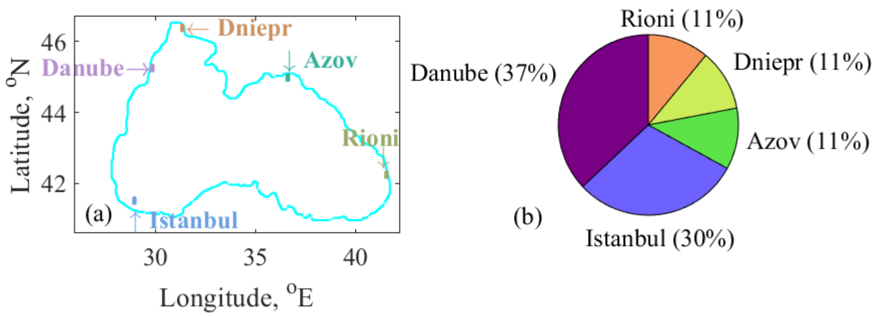

Figure 1. (a)The Black Sea's microplastic release zones and (b) the relative contribution of each release zone.

Stokes drift

A modification of the model presented in Miladinova *et al.* (2020b) is made to account for the effect of Stokes drift velocity (U_{st}) on the particle distribution. The Stokes drift velocity represents the difference between the average Lagrangian flow velocity of a fluid portion and the average Eulerian flow velocity of the fluid. Here, it is evaluated on the base of a simple parameterisation by wind speed (Wu 1983): $\boldsymbol{U}_{st} = 0.0186(gLU_w^{-2})\boldsymbol{U}_w$, where $\boldsymbol{U}_w$ is the wind velocity at 10 m height, g – gravity and L - wind fetch. The Stokes drift current varies from about 2.3 to 2.6% of the wind speed, when wind fetch increases from 0.1 to 1000 km. Given the relative low impact of this parameter, wind fetch is fixed to 100 km in this study.

To evaluate the impact of including Stokes drift in our simulations, tracking of 12000 particles is performed with and without Stokes drift velocity. Figure 2 illustrates the variation of the beached particle density over time. For scenario H1, (i) and (ii) show the relative density of beached particles (%) in the case with and without Stokes drift, respectively. For the H2 scenario, curves (iii) and (iv) illustrate the case with and without Stokes drift. In winter (i and ii), the inclusion of the Stokes drift velocity decreases considerably particle beaching times. This is an expected result, as winds are considerably stronger in the winter. Counterintuitively, the addition of Stokes drift increases the beaching time in summer slightly (iii and iv).

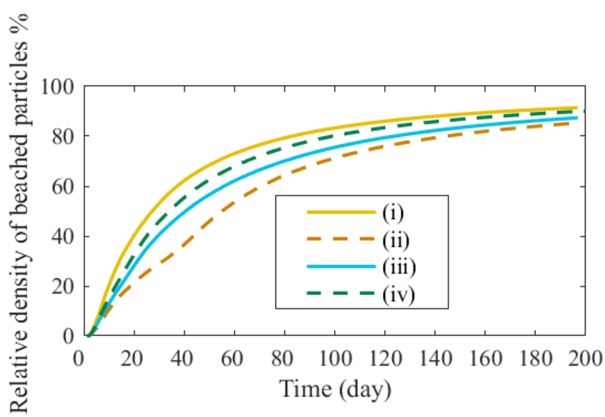

Figure 2. Relative density of beached particles (%) over time: (i) and (ii) denote scenario H1 with and without Stokes drift, respectively; (iii) and (iv) illustrate results for scenario H2.

Figure 3a shows the RPD three months after the release in January (H1), while Figure 3b includes the RPD three months after the release in July (H2). Both plots illustrate the RPD without Stokes drift effects. RPD values are grouped within six intervals [0.1; 0.2), [0.2; 0.5), [0.5; 1), [1; 1.5), [1.5; 2) and ≥ 2 %. Areas with

RPD less than 0.1 are left blank. The preferred areas for coastal beaching in both winter and summer include the southwest coast of Turkey (the area around the Istanbul and the Sakarya River), several locations along the south-eastern Anatolian coast and spreading across the entire eastern coast. Fewer particles are accumulated along the northern coast in summer (H2) whilst a higher concentration is found along the southern coast in summer months.

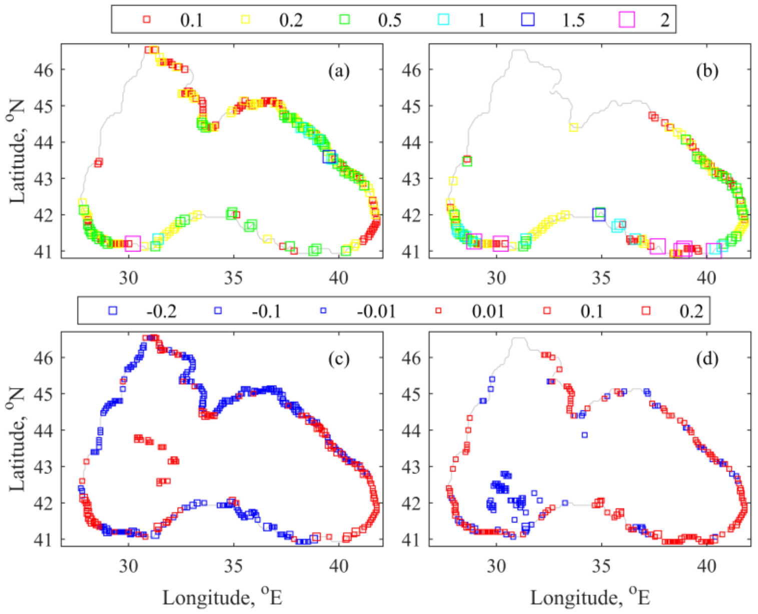

Figure 3. (a) RPD (%) three months after the release in January (H1) and (b) RPD three months after the release in July (H2); (c) difference between RPD (%) of the model without Stokes drift and RPD (%) of model with Stokes drift three months after the release in January (H1); and (d) the same as in (c) but three months after the July particle release (H2).

Differences between the RPD simulated by the model that ignores the Stokes drift and the RPD of the model that takes into account the Stokes drift are shown in Figure 3c and d. Six bins within the intervals ≤ -0.2, (-0.2; -0.1], (-0.1; -0.01], [0.01; 0.1), [0.1; 0.2) and ≥ 0.2 % are defined. Differences in plastic concentration of the order less than 10^{-2} % are not plotted. Blue squares denote RPD decrease due to the addition of the Stokes drift term, while the red squares indicate RPD increase. When the particles are released in January, more particles accumulate along the coast and fewer are left in the inner basin in the case when considering the Stokes velocity contribution (Figure 3c). More particles are beached along the northern and southern coast in scenario H1 with Stokes drift. The effect of the Stokes drift in summer is substantially reduced due to low wind velocities (Figure 3d). Note that most of the differences in summer are in the range (-0.1; -0.01] and [0.01; 0.1) %, and more particles accumulate in the western inner basin.

Model results suggest that the addition of Stokes drift velocity, as parameterized in Wu (1983), leads to considerable changes in particle accumulation along the south-western and eastern Black Sea coast in winter months. The inclusion of the Stokes drift leads to fewer particles accumulating along the eastern and south-western (41.4 - 42.13° N) coast. On the contrary, along the northern and western coasts and in several locations along the southern coast particles tend to accumulate in larger numbers when Stokes Drift is considered. Due to the lack of consistent data to evaluate the model, we cannot assess whether the addition of Stokes drift velocity improves the performance of the model.

Measured data

The available monitoring data on the distribution and density of MP in the Danube is summarised in Table 2. Only three studies (Lechner *et al.* 2014; SFRA0025 2015; Liedermann *et al.* 2018) presented data from surveys in the Danube, while for other hot spots of marine litter generation (e.g., Istanbul, Azov Sea, Dniepr and Rioni) data is not reported. Data from Danube has been collected from several river transects (with different population densities and hydrological conditions), in different time periods and with different methodologies. The mass density of MP collected with nets of ≥ 0.5 mm mesh size is higher than with finer nets, while the abundance is lower. The analysis of filtration efficiency and side-by-side measurements with different mesh sizes showed that nets ≥ 0.5 mm led to better results (Liedermann *et al.* 2018). According to SFRA0025 (2015), the usage of larger mesh size nets is most appropriate for determining the river MP load in terms of g m^{-3}. However, for determining the potential harm of the river input of MP in terms of item m^{-3}, SFRA0025 (2015) propose to use finer mesh size nets. Note that two different estimates are given in Table 2 in the study considering the Galati region: (MP) corresponding to the small mesh size and (SP) corresponding to the bigger mesh size. Comparing the mass density in closely located areas near Vienna and Heimberg (nets = 0.5 mm), it is obvious that microplastic mass density in Lechner *et al.* (2014) is 100-fold higher than in Hohenblum *et al.* (2015). Mass density according SFRA0025 (2015) (nets = 0.33 mm) better agree with the data in Hohenblum *et al.* (2015). It appears that the number of collected particles measured in number of items captured per m^{-3} varies broadly depending on the nets and collecting methodologies.

Total load of MP dispersed into the Black Sea depend on the river discharge. Forecasts for loads (Table 2), expressed in ton $year^{-1}$, show the expected trend for MP concentration with increasing distance from the river source (Hohenblum *et al.* 2015 and SFRA0025 2015). While the estimated MP river-based loading in Vienna in terms of number of item $year^{-1}$, is close to the case (SP) of bigger particles by SFRA0025 (2015). In summary, the available studies about river inputs of MP to the Black Sea basin are not sufficient for a precise evaluation of the actual inputs. However, they can be used as a proxy to estimate the approximate concentrations (in item m^{-3} and g m^{-3}) of plastic particles accumulated on the Black Sea coast.

Table 2. Observed concentrations of microplastics in different sections of the Danube. Estimated annual influx of microplastics into the Black Sea from Danube, calculated for these sections

Danube study area		Particle number (item m^{-3})	Particle mass (g m^{-3} x10^{-3})	Net mesh size (mm)	Danube flow rate (m^3 s^{-1})	Load item $year^{-1}$ x 10^{10}	Load ton $year^{-1}$	Survey period	Reference
Aschach		-	0.063-0.22 0.105-0.33	0.25 0.5	1100-2100	-	2.19 – 14.6	Spring 2014	Hohenblum *et al.* 2015
Vienna		0-14 x10^4 mean 0.317	0.2-615 mean 4.8	0.5	1930	1.928	292.187	Apr-Jul 2010 and 2012	Lechner *et al.* 2014
Hainburg		-	0.046-2.5 0.054-6.1	0.25 0.5	1500-3000	-	2.19 – 24.1	Spring 2014	Hohenblum *et al.* 2015
Galati	(MP)	10.6	1.2	0.33	6500	217.31	237.97	May-Sep 2014	SFRA0025 2015
	(SP)	0.113	2.6	3.2		2.315	532.395		

Results and Discussion

MP sources into the Black Sea

Firstly, we evaluate the contribution of plastic influx zones, described in Figure 1a to the pollution of the Black Sea littoral coast. Five scenarios are carried out separately and the number of particles in the grid boxes is calculated considering final position of MP particles at the end of the simulation year. The particles in the grid boxes spanning the coastline of each state are then summed to count the overall number of accumulated particles per country. Furthermore, the numbers of particles per country are averaged across the time period 2009-2018 and the mean RPD (%) per country is calculated and presented in Figure 4.

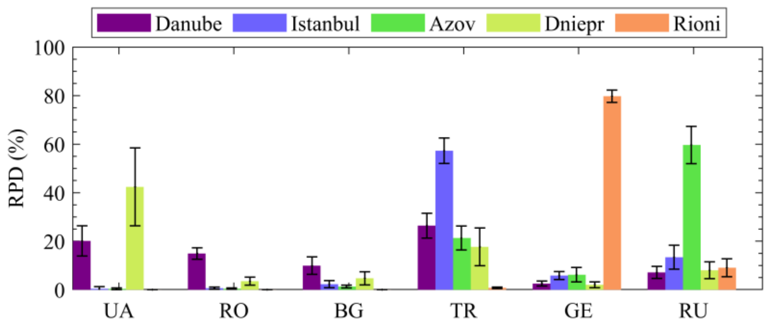

Figure 4. Simulated annual RPD accumulation (%) along the coastlines of the Black Sea littoral countries. Error bars indicate one standard deviation. The same number of particles (1000 per day) is released from each zone (see legend). UA -Ukraine, RO - Romania, BG – Bulgaria, TR – Turkey, GE – Georgia, and RU – Russia.

The Danube scenario is a clear example of high transnational pollution. All coastal states receive particles coming from the Danube. The largest number of released particles reach Turkey (26.45%) and Ukraine (20%). In the other four scenarios, the country that releases the particles gets back the largest number of particles. The release from Rioni leads to a high number of beached particles (91.3%), where the majority are trapped on the Georgian coast (79.63%) and a smaller part reach the Russian coast (10%). Another scenario showing a high percentage of beached particles is Azov (89%), while for the other three scenarios (e.g., Danube, Dniepr and Istanbul) the percentage is about 80%.

Microplastic pathways

The location of the release zones differs oceanographically, which is the main reason for the different final location of the micro-particles. For example, two of the plastic emitters (Danube and Dniepr) are placed on the North Western Shelf (NWS), where particle propagation is initially controlled by the Danube plume movement. Miladinova *et al.* (2020a) suggested three major Danube pathways – (1) southward pathway along the western coast; (2) initially directed to the north and east, then turning to the south and being shifted eastward; and (3) trapped for a month or more on the NWS, then turns to the south being shifted eastward. Following (1), the particles are expected to beach mostly along the western coast (e.g., Romania, Bulgaria and Turkey). If the particles follow pathways (2) and (3), they are expected to accumulate along the coastline of the NWS countries (Romania, Ukraine and Russia). The Danube plume flow affects the distribution of particles released from Dniepr zone. Particles coming from this zone are locked in the NWS for a certain time. Then, the system current captures and transports them to the south-west in a cyclonic direction. For this reason, both Ukraine and Turkey accumulate the majority of particles released from the Dniepr (Figure 4). Variability in the NWS river plume pathway leads to variability in the quantity of particle beaching along the Ukraine/Russian coastline.

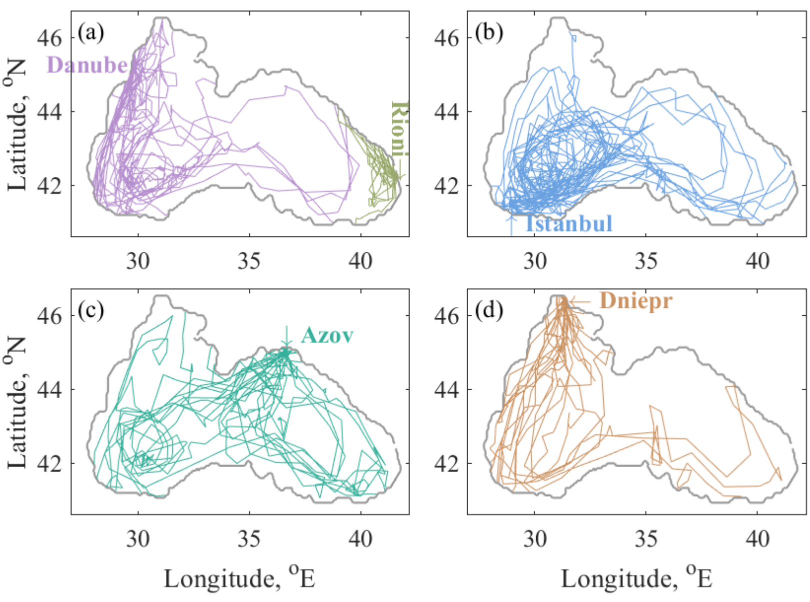

Figure 5. Particle trajectories in 2009 starting from different release zones. (a) Danube and Rioni; (b) Istanbul; (c) Azov and (d) Dniepr. One per month trajectory is represented in colour particular for the zone.

Figure 5 shows an example of simulated MP trajectories corresponding to specific release zones. One per month trajectory is presented in a region-specific colour. As expected, MP transport from the Danube zone is strongly dependent on Danube volumetric flow and particle trajectories follow the southward direction along the west shelf (Figure 5a). Usually this transport does not follow the western coastline, yet is shifted to the east (pathways (2) and (3)). Particles released in the western basin flow preferably in the west gyre (Figure5a, b and d). Particles released from Azov Sea and which are not trapped near the Kerch Straight are transported by the main cyclonic current. The particles are thus transported to the southwest or southeast coast depending on the integrity of the main current. If the current splits into two main gyres (summer-autumn), Azov particles circulate in the eastern gyre. Whereas, if the current is integrated (in winter-spring), the particles are forced to move along the western gyre (Figure 5c). The eastern gyre is weaker than the western and usually resides in the eastern basin, along with several vigorous cyclonic and anticyclonic eddies in the easternmost part (Miladinova *et al.* 2020b). These eddies capture most of the particles released by the Rioni, thus limiting the trajectories of the particles to the easternmost part (Figure 5a).

Microplastics accumulation on the Black Sea coastal waters

In the next set of experiments, we intend to estimate the approximate density of MP in the coastal waters of the Black Sea in terms of items per m^{-3} and grams per m^{-3}. Since RPD (%) represents the relative density of the particles (relative to the particle input), if the MP input is known, we can easily estimate the MP concentration in the basin by multiplying the RPD by the input values. We calculate the volumetric density, namely the number of particles in each grid box divided by the box volume. In order to find volumetric densities we need to evaluate the approximate microplastics input. The variability of the input is significant in the samples from the Danube regions (Table 2). We are aware that the measured concentrations (loads) are only order of magnitude estimates, not precise data. The accumulation of MP when considering different release zones is shown in Figure 6. The input is calculated by using the Danube input (MP) from SFRA0025 (2015). We analysed the respective microplastic concentrations with caution, as the authors suggest an overestimation due to the very high Danube discharge during the sampling period. In addition, MP concentrations in the Black Sea, calculated using the Danube input (SP) by SFRA0025 (2015), can be easily estimated by multiplying the results presented in Figure 6 by a factor of 0.01 (see in Table 2, particle number (item m^{-3}) for (MP) and (SP), respectively). The remaining sources are estimated on the basis of the relative contribution of each source given in Figure 1b. For better visibility, the microplastic concentration are grouped in 6 bins (see legend in Figure 6) and the size of the symbols increases with the concentration.

The location and particle density of the input zone are important for modelled MP concentrations. Substantial MP densities are found locally near the input zone. In Figure 6a are shown MP densities resulting from a release from the Danube zone. The Danube zone is in close proximity to the Danube river mouth (Figure 1a) and releases $6.3x10^9$ items per day (calculated from (MP) in Galati). MP density in coastal regions is greater than 10^4 (item m^{-3}). Far away from the Danube, MP density decreases slightly to ~10^3 (item m^{-3}) until Cape Kaliakra (28.47°E, 43.37°N) where it becomes ~10^2 (item m^{-3}) or less. There, MP accumulation on the coast is suppressed by the Kaliakra anticyclonic eddy (Miladinova *et al.* 2020a), which shifts MP flow to the east. Further along the south-western coast between 27.8 and 29°E, MP density begins to increase (.5-2 x 10^3 items m^{-3}). The Istanbul release zone is in this area. Notwithstanding the release from Istanbul, this area receives MP released from Danube, Dniepr and Azov (Figure 6a, c and d). In several locations along the Anatolian coast, MP densities of about 10^3 (items m^{-3}) are calculated and MP tend to accumulate north and northeast of the Danube. The rest of the Black Sea coast is less polluted by the input from the Danube. The lower particle accumulation along the eastern coast is a new finding of the study, which incorporates Stokes drift and differs from results presented in Miladinova *et al.* (2020b).

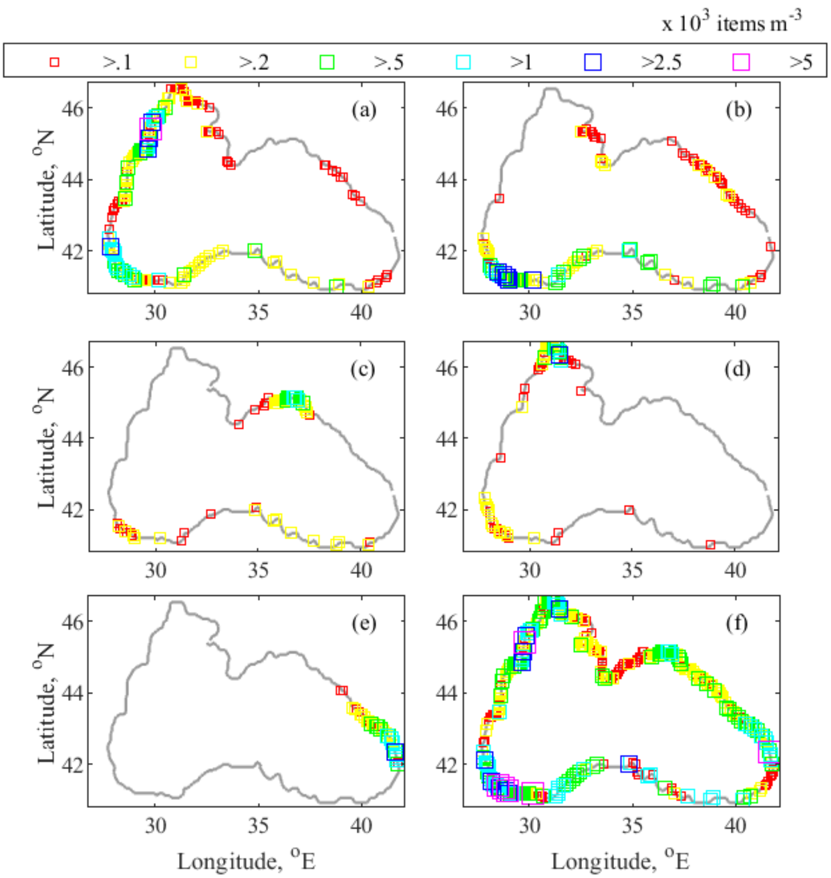

Figure 6. Mean density of microplastics x 10^3 (item m^{-3}) over 1999 – 2018 in the case of different sources (a) Danube; (b) Istanbul; (c) Azov; (d) Dniepr; (e) Rioni and (f) all five sources together.

MP released from Istanbul are accumulated predominately along the Anatolian coast, eastern coast and western Crimea. Looking at Figure 6, it is evident that several zones along the Anatolian coast always accumulate MP (e.g. Kefken (30.2°E, 41.17°N), Ereğli (31.3°E, 41.2°N), Zonguldak (31.5°E, 41.3° N), Sarikum (34.9°E, 42° N) and Tirebolu (38.87 °E, 41.07°N)). While the influence of the release location for the nearby beaching particles is obvious, these hot spot beaching sites at the Anatolian coast are independent of the release location. Figure 6f represents the total effect of MP release from all five sources. The most polluted coastal areas are in the vicinity of Istanbul, Kefken, Rioni and Danube (MP concentration >50 item m^{-3}). Our recent results confirm previous findings that the southwest coast of Turkey (the area around the Bosphorus Straight and the Sakarya River) is a hotspot of MP accumulation, regardless of the location of MP release.

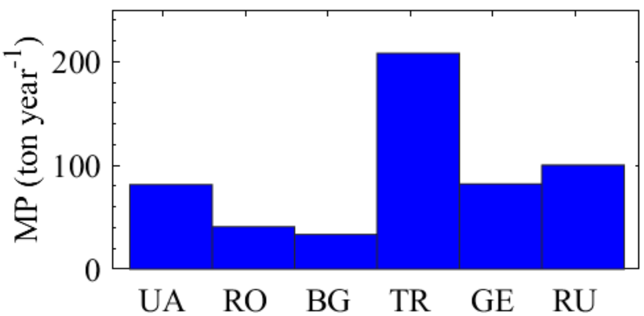

Figure 7. Annual microplastic accumulation (ton $year^{-1}$) along the coastlines of the Black Sea littoral countries.

Model results may be used to explore and quantify the risk of MP accumulation on the Black Sea coast. For example, Figure 7 shows the approximate MP accumulation (tonnes per year) of Black Sea countries. It is derived from the annual RPD accumulation (%), presented in Figure 4, and then is scaled with estimated inputs to the Black Sea. Assuming that the annual Danube load is 238 tonnes $year^{-1}$ (SFRA0025 2015) and that it accounts for 37% of the total input (Siegfried *et al.* 2017), the total input of MP can be estimated at 643 tonnes per year. Assuming the relative contribution of each release like that presented in Figure 1b, we can estimate inputs to the Black Sea expressed in ton $year^{-1}$ and thus also estimate MP accumulation per country (Figure 7). The annual accumulation of input (SP) can be easily calculated, as its input is twice as large (Table 2). Turkey collects the largest amount of MP, which is not surprising, as it has the largest coastline (1700 km), and MP tends to accumulate in large concentrations in many geographical locations along the Turkish coast (Figure. 6f). Figure 7 may obviously change, when different inputs are assumed.

Nevertheless, the simulations show the potential of the Black Sea coastal countries to retain and accumulate MP.

Comparison with measured data

No monitoring is yet in place for MP in the Black Sea. Because of this, no direct assessment of model prediction is currently possible. The results of our model can, however, be compared with published observations of MP concentrations at several specific sites (Table 3).

In Sevastopol Bay (33.5°E, 44.6°N) our model forecasts 0.16 x 10^3 (item m^{-3}) mean MP density (Figure 6f). This value is two orders of magnitude higher than the measured density by Mukhanov *et al.* (2019). However, if (Galati-SP) input is assumed, then model results are in agreement with the observed values. Berov & Klayn (2020) recorded the highest densities of floating MP west of Cape Kaliakra and outer Burgas Bay-Pomorie (27.63°E, 42.57°N). Additionally, there is a notable increase of concentrations of MP in the vicinity of Cape Kaliakra and Burgas Bay-Pomorie in comparison with the measured MP along the transect connecting these two sampling points. Our results also show elevated MP concentrations at these specific sites and drastically low concentrations along the coastline that connects them. (Figure 6f). Our model estimates for MP concentrations, expressed in item m^{-3}, are also two orders of magnitude higher than the observations (of the same order for (Galati-SP) input), probably due to the overestimation of the input sources (SFRA0025 2015).

Table 3. Observed concentrations of microplastics in the Black Sea.

Black Sea region	Particle number (item m^{-3})	Particle mass (g m^{-3}) x10^{-3}	Net mesh size (mm)	Survey period	Reference
South-eastern part	600-1200	-	0.2	Nov 2014 Feb 2015	Aytan *et al.* (2016)
Bulgarian coast	0.15-2.54 (mean 0.62)	0.0044-6.54 (mean 0.917)	0.3	8-10 Aug 2017	Berov and Klayn (2020)
Sevastopol Bay	0.6-7	0.006-0.75	0.3	Jan-May 2019	Mukhanov *et al.* (2019)

If the smallest sized particles are not counted in the samples, the number of particles in the model and the data might be very different. Indeed, MP concentrations in g m^{-3} agree much better with simulation results. The measured MP density near Cape Kaliakra is 6.5 x10^{-3} (g m^{-3}), while the model forecast is 18 x10^{-3} (g m^{-3}). Comparing our results with the observational data provided by Aytan *et al.* (2016), we can conclude that they agree quite well (our model forecasts 200-1000 item m^{-3}). Interestingly, the results of the model show a maximum accumulation in the study area exactly where the survey data reaches a maximum. The maximum MP density of 1.7×10^3 (item m^{-3}) is simulated at (40.3°E, 41°N). Therefore, there exists reasonable agreement with the few measurements available.

Conclusions

This model predicts MP accumulation sites in coastal areas, when emitted by land-based sources and entering the sea through river runoffs. It also estimates the relative contribution of several land-based sources to the Black Sea coastal pollution. All of the Black Sea coastal states receive MP coming from the Danube, whereas the largest number of MP accumulate along the Turkish and Ukrainian coasts. The south-western Black Sea coast (near Istanbul) and southern Black Sea lagoons are plausible hotspots for MP accumulation. Data from recent surveys on MP distribution along the Black Sea coast appear to support model simulations. So far, there is lack of adequate empirical data on the volumes, types and time evolution of MP in fresh waters surrounding the Black Sea. Yet, the model estimates can be considered as trends for the MP marine water pollution dynamics of the Black Sea. Despite the model limitations, an evaluation of the MP density of the Black Sea waters is important because it provides the likely regional hotspots for MP concentration. This work can also support the identification of priority regions, for monitoring of MP accumulation and planning of future coastal water cleaning facilities.

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Cetaceans and marine litter in the Black Sea

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Abstract

Marine litter, especially plastics, is an essential source of danger for cetaceans. Since the Black Sea is a semi-enclosed sea with numerous rivers flowing in, marine litter accumulated here pose a serious threat to the three cetacean species inhabiting the basin vulnerable. This paper reviews the studies in the Black Sea since 1956 on the relationship between marine litter and cetaceans. Impacts of marine litter on cetaceans, especially entanglement and ingestion, have been compared with similar cases elsewhere in the world. Since there are very few studies on the relationship of marine litter and cetaceans in the Black Sea, we cannot elucidate the effect of the increase in marine litter on cetaceans in recent years, thus further and continuous studies are needed.

Keywords: Marine mammals, cetacean, marine litter, plastics

Introduction

The Black Sea is a semi-enclosed basin connected to the Mediterranean Sea via the Turkish Straits System (TSS-Marmara Sea, Istanbul and Çanakkale Straits) and one of the largest anoxic basins in the world (Tezcan *et al*. 2017). More than 40 rivers flow into the Black Sea, three of which are major ones, carrying wastes of industrialized countries of the basin (Jaoshvili 2002; Oğuz 2017). These factors with very dynamic current system make the Black Sea very vulnerable to marine litter (Topçu *et al*. 2013). The insufficiency of the importance given to the Black Sea coastal pollution, as well as the presence of ship traffic, active tourism areas, and intensive fishing activities, are harmful for all marine organisms, including cetaceans (BSC 2007). In the Black Sea, there are three cetacean subspecies; *Phocoena phocoena relicta* (harbour porpoise), *Tursiops truncatus ponticus* (bottlenose dolphin) and *Delphinus delphis ponticus* (short-beaked common dolphin) (Öztürk 1999). The populations of cetacean in the Black Sea defined as subspecies are listed in the IUCN Red List of Threatened Species (IUCN 2020); harbour porpoise and bottlenose dolphin are EN (Endangered), common dolphin is VU (Vulnerable).

Nowadays, plastic, the most abundant man-made substance in the world, is one of the most typical marine and freshwater pollutants, also takes the lead in marine litter (Zaitsev 2008; GEF 2012; Gall and Thompson 2015). Since plastic is a lightweight, flexible and durable material, it has become one of the most useful materials today (Thompson *et al*. 2009). There is a significant amount of plastic litter throughout the world's oceans and seas (Jambeck *et al*. 2015). It is estimated that only plastic litter could reach 250 million metric tons in oceans and seas until 2025 (Jambeck *et al*. 2015).

Marine litter can directly affect marine species such as by entanglement or ingestion, or indirectly, such as changes in habitat (NOAA 2014a, b). For marine mammals, macro plastics (> 2.5 cm) in various sizes can cause poor swimming ability, hunger, malnutrition, life-threatening injuries and death due to entanglement or ingestion (Laist 1997; Derraik 2002; Gregory 2009; GEF 2012; NOAA 2014a). Ingestion of plastic or other marine debris has been documented for 48 cetacean species (9 mysticetes, 39 odontocetes) which means 56% of all cetacean species (Baulch and Perry 2014) and entanglement for 53 species (CBD 2016). The reporting of entanglement and ingestion by marine mammals began in the 1960s (Laist 1997; GEF 2012). However, the seriousness of the problem was not noticed until the early 1980s (Reeves 2009). Enormous amount of plastic currently used in our daily life has caused damage on marine mammals due to the entanglement and ingestion of marine debris. The number of marine animal species (663 species) affected by these two particular types of interaction with marine debris has increased by 40 % since 1997 (GEF 2012). After this report, the number of species has risen to 817 with additional impact factors considered, such as ingestion, entanglement, ghost fishing, and dispersal by rafting and provision of new habitat (CBD 2016).

The ingestion of plastics can cause blockage and wounds in the digestive system, the latter leading to satiation, starvation and general debilitation often fatal in marine organism (Gregory 2009). In addition to being fatal for marine mammals, ingestion and entanglement may have different consequences, indirectly. Taking plastic in the stomach and not being able to digest affects the sense of hunger (appetite), which leads to deterioration in body condition (GEF 2012). Some entanglement may occur when a marine animal is attracted to debris caused by a normal array of behaviour such as feeding and playing (Laist 1997). It is also a concern for marine mammals, as it can provide a way to transfer harmful chemicals from plastics (Bradney *et al*. 2019; Chen *et al.* 2019), directly ingesting microplastics (< 5 mm) or introducing them into the body through a food chain (Simmonds 2012; Lusher *et al*. 2015). Dolphins are known to be playful with many living or inanimate objects around them. Some species of dolphins can carry a piece of algae, plastic, or another pliable object in a manner to keep it balanced on their jaws, flippers, dorsal fin, or tail, for gameplay (Silva 2005; Würsig 2009). In addition, the squid diet of many species makes them prone to swallowing plastics (Hooker 2009).

Although studies on marine litter pollution, including macroplastics and/or microplastics, in the Turkish Black Sea have increased in recent years (Topçu and Öztürk 2010; Topçu *et al*. 2013; Aytan *et al*. 2016, 2020), there are very few studies on their affect or relationship with cetaceans.

Studies on marine litter and cetaceans in the Black Sea

One of the first and most comprehensive studies on the relation of cetaceans and marine litter in the Black Sea was made during the winter-spring period between 1933 and 1934 by Kleinenberg (1956), who reported many foreign bodies from the stomachs of common dolphins (*Delphinus delphis*), such as, coal slag, wood and paper pieces, bird feathers, cherry stones and even a bunch of roses.

Tonay *et al*. (2007a) examined the stomachs of 42 harbour porpoises bycaught in turbot nets and/or stranded on the Turkish western coasts of the Black Sea between 2002 and 2003. They found various plastic pieces in five stomachs (12%). However, 40.9 g plastic bags (Figure 1) and sheeting were found in the stomach content of one individual (Table 1). This was the fourth reported case of plastic ingestion by a harbour porpoise in 2007 after those reported in Baird and Hooker (2000).

Table 1. List of harbour porpoises with plastics in the stomach contents on the Turkish western Black Sea coast (Tonay *et al*. 2007a).

No	Total length (cm)	Sex	Date	Items ingested	Stranding/ Bycatch
1	135	female	10.04.2003	Plastic pieces	Stranding
2	98	male	10.05.2003	Plastic pieces	Bycatch
3	140	female	28.05.2003	Plastic pieces	Bycatch
4	135	female	28.05.2003	Plastic pieces	Bycatch
5	130	female	21.06.2003	Plastic bags and sheeting	Bycatch

Figure 1. The stomach of the harbour porpoise (no. 5 in Table 1) with full of plastics and the plastic pieces found in the stomach (Background grid 15x15cm).

On the northwestern coast of the Crimea Peninsula from January to November 2008, a total of 120 cetacean individuals were caught as bycatch (118 harbour porpoises and 2 bottlenose dolphins). Fresh and relatively fresh carcasses of 12 harbour porpoises were necropsied and stomach contents were examined. There was no marine litter in their stomachs (Birkun and Krivokhizhin 2008).

The stomach contents of stranded bottlenose dolphins on the Crimean coast were analysed in 2013. Organic parts (fish, bivalve shell fragments, and isopods), plastic and other debris (small pebbles, wood) were found in the stomachs of these dolphins (Gladilina and Gol'din 2014).

Bilgin *et al*. (2018) carried out a study between March 2010 and September 2011, in Rize, the eastern Turkish Black Sea coast. Stomachs of 52 harbour porpoises, and 6 common dolphins were examined and no plastic was detected in any of them. However, they found a dead stranded common dolphin with the plastic handle of a tin can attached to the upper jaw. Similar cases had been reported previously elsewhere in the world and plastic parts of various shapes, such as twin-like, ring, affecting the feeding of cetaceans (minke whale *Balaenoptera acutorostrata*, short-beaked common dolphin, Franciscana dolphin *Pontoporia blainvillei*) by wrapping around their rostrum or beak (Gill *et al*. 2000; Independent.ie 2014; GZH 2018; Daily Mail 2019).

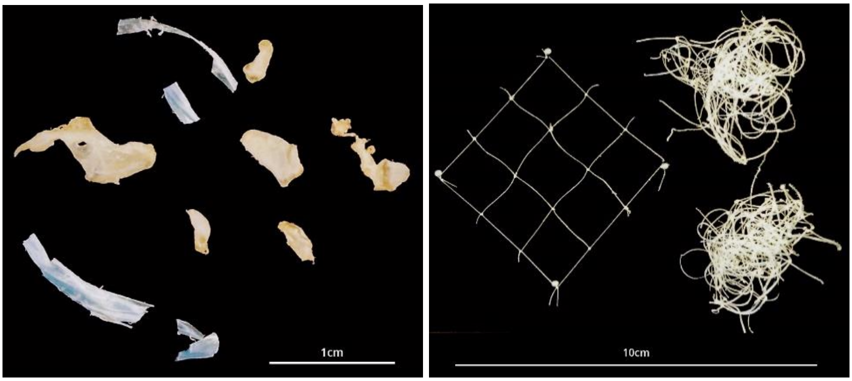

Figure 2. Plastic nylon parts and nylon net found in a stomach of a stranded bottlenose dolphin in the TSS (Dede 1999)

Cetacean depredation on fishing gear sometimes results in the ingestion of fishing gear (Gomerčić *et al*. 2009). Gladilina *et al.* (2015) reported near Crimea in 2014 that a piece of polyamide fishing net was found in the mouth of a bottlenose dolphin. As the cause of death, it was speculated that the dolphin swallowed a piece of net incidentally; the net entangled the throat and broke the larynx, which caused the choking with blood. There is a study indicating that the cetacean interaction with plastic debris and fishing net is observed in the TSS, connecting the Black Sea and Marmara Sea. It has been reported that nylon parts and nylon nets used for catching demersal fish were detected in a stomach of a stranded bottlenose dolphin (body length 228cm, female) in the Istanbul Strait (Dede 1999) (Figure 2). In another two studies on cetacean stomach contents, no plastic residue was found in the stomachs of 4 harbour porpoises (Tonay *et al*. 2007b) and 13 individuals (7 common dolphins, 3 bottlenose dolphins, 2 harbour porpoises, 1 striped dolphin) (Bayar 2014).

Ghost nets

Fishing devices also consist significant part of marine litter and ghost nets in particular have been considered as a serious threat for marine ecosystem. Ghost fishing had been defined as the loss of fishing nets resulting in continuous hunting without control by fishermen (Smolowitz 1978; Breen 1990). However, it is usually hard to distinguish entanglement in active fishing gear from that in abandoned gear for cetaceans (Simmonds 2012). Turbot nets in particular, which are installed at the sea but not hauled later, become ghost nets in the Black Sea and the number of such nets is unknown. These nets cause decrease habitats of harbour porpoises and bottlenose dolphins by creating a risk of bycatch (Birkun 2002; Birkun *et al*. 2007). In a study conducted in the southwestern part of Crimea in 2008, three old ghost nets were found and only mussels and some invertebrate species were identified in these nets (Birkun and Krivokhizhin 2008). Öztürk (2013) revealed that, however, given the turbot nets retrieved in the Exclusive Economic Zone (EEZ) by the cooperation of the Turkish-Romanian governments, Illegal, Unreported and Unregulated (IUU) fishing is a major source for the ghost fishing in the Black Sea. Ghost fishing damages the benthic ecosystem as well (Öztürk 2013). According to the survey conducted with local fishermen, in the 2008 and 2009 fishing seasons, a total amount of 1279 turbot nets were lost in Istanbul (Yıldız and Karakulak 2016), 1254 of which were in the Romanian and Ukrainian EEZ (Yıldız 2010).

Figure 3. A stranded bottlenose dolphin with a piece of old fishing net.

During the stranded cetacean monitoring studies, a bottlenose dolphin carcass was found in June 2012 on the western Turkish Black Sea coast with a piece of net which looked like the one used in the 1970-80's in Turkey (Figure 3). However, since the net was very clean, if this type of net is used in the other Black Sea riparian countries, it may also come with currents. For example; this type of net had been used at least until 2009 or 2010 in Ukraine (pers. comm. Pavel Gol'din*). In any case, it was obvious that a bottlenose dolphin was entangled by an old net.

Conclusion

There are not enough studies carried out periodically about the effects of increasing pollution and plastic wastes in the Black Sea on protected marine mammals. For the cetacean species in the Black Sea, there is a lack of scientific knowledge, such as critical habitats, anthropogenic and natural threats, and life history *etc*. (Birkun 2008).

The risk of bycatch in turbot nets for cetaceans was determined as almost doubled if the net also entangles plastic litter. Birkun (2009) reported one km of turbot net contaminated by plastics caught 2.3 cetaceans whereas one km of the same net free from plastics caught 1.2 cetaceans.

Marine plastic litter has a fatal effect on cetaceans, especially on their longevity for entanglement and ingestion. GEF (2012) reported that if the marine litter is not controlled, some cetacean species may face the risk of extinction (GEF 2012). In the marine ecosystem, it is particularly important to prevent and remove ghost nets. One of good examples was the removal of about 449,000 m^2 abandoned nets between 2014-2018 in 600 locations in Turkish marine and freshwaters (BSGM 2019).

Considering that the cetacean species in the Black Sea are endangered, we should make every effort to decrease the amount of marine litter in the Black Sea. More studies are required to reveal the consequences of the relationship between marine litter and cetaceans. Besides, it is of great importance for the Black Sea that public awareness is increased and that governments and NGO's carry out marine litter removal or preventive activities.

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Colonizing of bottom marine litter by benthic organisms in the northwestern Black Sea (Gulf of Odessa)

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Abstract

In the Black Sea, plastic pollution is in the top of marine litter flowing from the rivers and may change the bottom landscapes providing the new type of substrate for benthic assemblages. The great efforts have been made by monitoring organizations to understand the composition and concentration of marine litter in the region. However, a few studies have been conducted to analyze the processes of biofouling formation on the surface of plastic substrate. The aim of present research was to initiate the study of community structure on the surface of plastic substrates in the northwestern Black Sea. The plastic litter was sampled on three transects in the Gulf of Odessa at depths of 1-2, 3-4 and 5-6 m on July and October in 2018. Video transects revealed 32 items of litter per 1 km2, whereas video observations by diver showed maximum concentration of litter on the depth of 2-3 m between the coastal hydrotechnical constructions. The most common litter was plastic bags (up to 80%). On the surface of collected marine plastic litter, the diverse and complex assemblage of benthic organisms was registered. For the first time 49 species of microalgae (Bacillariophyta (38 species), Chlorophyta (1), Dinophyta (2) and Cyanoprokaryota (8)), 5 species of macrophytes, 14 groups of meiobenthos (Harpacticoida (19 species), Ostracoda (13 species)) and 4 species of macrozoobenthos were found on plastic surface in NWBS region. Benthic communities were represented by typical widespread species that dwell on other artificial and natural surfaces in this water area. The lower abundance of benthic organisms was revealed on plastics in comparison with natural substrates. The dense material (white plastic bags) has less biofouling than transparent plastic bags and bottles. Intensification of general biofouling was observed on the bottles in summer and on plastic bags in autumn. The further studies should be focused on patterns of biofouling formation, comparison with the other substrates and processes of plastic biodegradation that will form understanding of the "good environmental status" of the Black Sea in line with the Marine Strategy Framework Directive.

Keywords: Meiobenthos, diatoms, biofouling, colonizers, sea-floor plastic

Introduction

Plastic pollution forms up to 80 % of the marine litter that floats on the surface or submerges in deeper layers of the world ocean. In the Black Sea the level of plastic contamination is being studied in recent years and reported by the Black Sea Commission and various projects (Birkun *et al.* 2007; EMBLAS 2017; Moncheva *et al.* 2016; Aytan *et al.* 2016, 2020; Sapozhnikov *et al.* 2018; Snigirova and Kurakin 2019; Stanev and Ricker 2019). However, there is still lack of knowledge on this problem. According to the data that were obtained during EU-UNDP Project "EMBLAS-Plus" the Black Sea is considered to be the most polluted sea within European seas. In order to identify the main sources of marine litter, main efforts are now focused on monitoring the pollution and quantification of different types of marine litter, such as beach (beach litter), floating (floated litter), bottom (sea-floor litter) (Galgani *et al*. 2013) and on biota. The plastics are in the top of 5 types of marine litter that are flowing in the Black Sea from the rivers. Within them plastic bottles and bags represent 10–20% from the general amount of litter. Great efforts are made by monitoring structures and institutes to reveal the composition and concentration of marine litter in marine environment – especially for floating and beach litter (Şahin *et al.* 2018; Aytan *et al.* 2020). The studies on microplastics in the water column and surface and its concentration in the crustaceans are very challenging in the Black Sea and fulfilled by colleagues from Turkey (Aytan *et al.* 2016, 2018; Oztekin and Bat 2017). There are a few works that describe the seafloor marine litter in the Black Sea using underwater shooting or analyses of fisherman catches (Eruz 2014; Moncheva *et al.* 2016). The main factors that favor deposition of the marine litter on the sea-floor are direction of currents and bottom topography (Eryaşar *et al.* 2014). However, less studies have been made to analyze the processes of biofouling formation on the surface of plastic substrate and signs of its degradation (Harms 1990; Eich *et al*. 2015; Kiessling *et al*. 2015; Pauli *et al*. 2017; Snigirova and Portyanko 2018; Snigirova and Kurakin 2019, Uzun 2019). While floating on the surface of sea the litter began to degrade under the influence of insolation, high temperatures, wave activities, and macroorganisms that settle on it. The litter items are separated on smaller fragments turning to microplastics with time. However, some big particles of plastics may sink and become a part of benthic assemblages (benthoplastics) providing the new type of substrate and changing the bottom landscapes. The aim of present research was to initiate the study of community structure on the surface of plastic substrates in the northwestern Black Sea (NWBS). The special attention was payed to microalgae and meiobenthic organisms.

Materials and Methods

The plastic litter (films and bottles) was sampled on three transects in the Gulf of Odessa (NWBS) at depths of 1-2, 3-4 and 5-6 m (Figure 1). The samples were collected on July (28 samples) and October (23 samples) in 2018. To make an inventory of types of bottom marine litter on each site the diver with the help of underwater shooting made a video-transect (50 m length). The samples of plastics were put into big polyethylene bags. Then, to collect mobile meiobenthic organisms, the samples of plastics were washed on the sieves (1 mm and 70 µm mesh size). All the samples were fixed in 70 % ethanol in seawater and stained by Bengal Rose. Plastic with periphyton was cut into smaller fragments and fixed together with the substrate. Further processing of the samples was carried out in the laboratory of Institute of Marine Biology of the NAS of Ukraine.

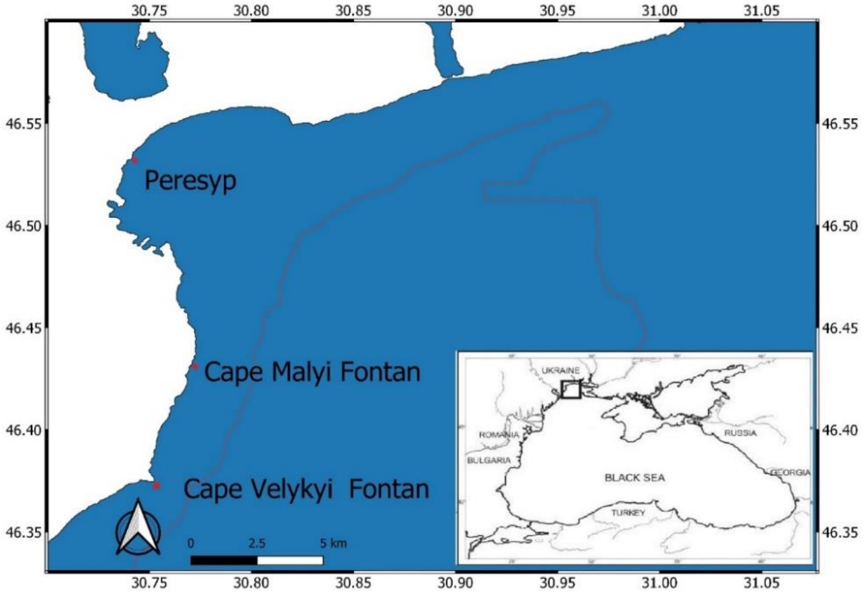

Figure 1. Map of the sampling sites in the Gulf of Odessa (northwestern Black Sea)

Plastic samples with phytoperiphyton were studied under light microscope Konus Biorex (×160, ×640 magnification). For the observation of the general location of the algae and cyanobacterial colonies developing on a plastic surface we prepared temporal alcohol-glycerin slides. For identification of diatom algae, the permanent slides were prepared, using hydrogen peroxide (30%) and ultrasound (10 minutes on 35 kHz) for separation from plastic (Nevrova *et al.* 2015). To calculate the abundance, we used counting chambers (0.01 ml) (Olenina *et al.* 2006).

The meiobenthic organisms were counted in Bogorov chamber under a stereomicroscope (×32), then ostracods and harpacticoids were identified under the light microscope (×200, ×400 magnification). The quantitative parameters were abundance, biomass and frequency. The last one was calculated as the percentage ration of number of samples, in which the species was presented, to the total number of samples. For the species identification the copepods, samples were dehydrated in glycerol-alcohol solution (Hulings and Gray 1971). Ecological features (life forms) of the harpacticoids were given according to the following papers (Hicks and Coull 1983; Chertoprud *et al.* 2006). For species identification and nomenclature of algae, we used the AlgaeBase (Guiry and Guiry 2020) and the following sources (Witkowski *et al.* 2000; Komárek and Anagnostidis 1998, 2005), for harpacticoids (Griga 1969; Wells 1976; Apostolov and Marinov 1988), for ostracods (Shornikov 1969; Dycan 2006).

Results and Discussion

Distribution of seafloor plastic litter

During the study, we found out that marine litter unequally spreads at the studied sites. Its largest amount was found in the area of Peresyp and Cape Velykyi Fontan, the lowest amount was observed in the area of Cape Malyi Fontan. The data on all units of marine litter, which were registered during the analysis of the video transect on three horizons at each station are presented in Table 1. A total of 900 m^2 of seafloor was analyzed in the summer and autumn periods. We recorded 29 units of marine litter (or 32 items of litter per 1 km^2).

Table 1. The number items of marine litter in studied area in the Gulf of Odessa

Area	1-2 m		3-4 m		5-6 m		Total
	summer	autumn	summer	autumn	summer	autumn	
Peresyp	-	7	1	2	1	2	13
Cape Malyi Fontan	1	-	1	1	-	1	4
Cape Velykyi Fontan	3	-	-	1	-	8	12

The most common litter was transparent and dense polyethylene films (21 units). PET bottles in the analysis of video transects were found only twice at the station of Cape Velykyi Fountan. Among other types of litter there are ropes, glass bottles, cloth, etc. (6 units). Some of them are shown on the Figure 2. During the analysis of the videos, we tried to estimate the surface of marine litter. The surface of the film in the studied water area varied from 6 to 400 cm^2; bottles –150-230 cm^2. We fixed also single fragments of larger litter – up to 2 m^2 (textile, rope).

The amount of litter in the coastal zone is affected by the season: 7 items of litter was registered in video transects in summer and 22 – in autumn It is likely that after an active tourist period, various types of litter accumulate in the waters of the Gulf of Odessa. In the summer, we have not recorded the litter on almost half of the transects. In this period, its higher concentration was observed at a depth of 1-3 m. In the autumn it was possible to register litter three times more than in the summer. Moreover, at Peresyp site the amount of litter decreases with depth, and in the area of Cape Velykyi Fontan on the contrary, the maximum amount of garbage was found at a depth of 6 m. Up to 79.31 % of seafloor litter was presented by PET (72.41%) and PETF (6.90%) (plastic bottles and bags). The other litter was made of ropes, glass bottles, fabric, etc.

Figure 2. Types of marine litter from the seafloor of the Gulf of Odessa:
1-3 – fragments of plastic bottles with biofouling, 4-6 – fragments of plastic bags,
7-9 – pieces of dense plastic

The predominance of different types of plastic in marine litter could have been assessed from the collected samples to analyze the biofouling. At the same time, unfortunately, it is difficult to assess on what area they were gathered. The distribution of plastic by type was as follows: 24 samples of bags, 7 samples of bottles, 3 samples of thick dense plastic, 1 plastic cup and 1 mesh. The presence of bottles increases with a depth. In general, such a distribution was observed during the analysis of video transects. Based on visual observation of divers big amounts of marine litter were accumulated on the depth of 2 m between hydro-technical constructions or under the influence of high hydrodynamics in coastal zone. They were not considered in this study due to the absence of biofouling on them.

Microalgae on the plastic substrates

On the surface of seafloor plastic litter, we have found 49 species of microalgae belonging to 4 groups: Bacillariophyta, Chlorophyta, Dinophyta and Cyanoprokaryota. The diatoms (38 species) and cyanobacteria (8 species) formed the basis of the diversity, other groups were less represented (Table 2).

Table 2. Species diversity of microalgae on plastics

	Species name	Type of plastic		
		Plastic bag	Bottle	Others*
	Bacillariophyta			
1.	*Achnanthes brevipes* C.Agardh	+	+	-
2.	*Achnanthes brockmanii* Simonsen	+	-	-
3.	*Acanthodiscus* sp.	+	-	-
4.	*Planothidium delicatulum* (Kütz.) Round & Bukht.	+	-	-
5.	*Amphora* cf. *hyalina*	+	-	-
6.	*Halamphora coffeiformis* (C.Agardh) Levkov	+	-	-
7.	*Amphora ovalis* (Kütz.) Kütz.	+	+	+
8.	*Amphora* sp.	+	+	+
9.	*Brebissonia lanceolata* (C.Agardh) R.K.Mahoney & Reimer	+	-	-
10.	*Cocconeis scutellum* Ehrenb.	+	+	+
11.	*Cocconeis* cf. *costata*	+	-	-
12.	*C. placentula*	+	-	-
13.	*C. neothumensis*	-	+	+
14.	*Coscinodiscus* aff. *radiatus* Ehrenb.	+	+	-
15.	*Diatoma elongata* (Lyngbye) C.Agardh	+	-	+
16.	*Diatoma vulgaris* Bory	+	+	+
17.	*Dimeregramma minus* (W.Greg.) Ralfs	+	+	-
18.	*Diploneis chersonensis* (Grunow) Cleve	-	+	-
19.	*Diploneis fusca* (W.Greg.) Cleve	+	-	-
20.	*Lyrella* sp.	+	-	-
21.	*Melosira moniliformis* (O.F.Müller) C.Agardh	+	-	-
22.	*Navicula palpebralis* Brébisson & W.Sm.	-	+	-
23.	*Navicula pontica* (Mereschkowsky) A.Witkowski, M.Kulikovskiy, E.Nevrova & Lange-Bert	+	+	-
24.	*Navicula ramosissima* (C.Agardh) Cleve	+	-	-
25.	*Navicula salinarum* Grunow	+	+	+
26.	*Navicula* sp.	+	+	+
27.	*Tryblionella acuminata* W.Smith 1853	+		
28.	*Nitzschia microcephala*	+	+	-
29.	*Nitzschia* aff. *sigma* (Kütz.) W.Sm.	-	+	-
30.	*Nitzschia hybrida* Grunow	-	-	+
31.	*Opephora* sp.	+	+	
32.	*Plagiotropis lepidoptera* (W.Greg.) Kuntze	+	-	-
33.	*Pleurosigma elongatum* W.Sm.	+	-	-
34.	*Rhoicosphenia abbreviata* (C.Agardh) Lange-Bert.	+	+	-
35.	*Staurophora salina* (W.Sm.) Mereschkowsky	+	-	-
36.	*Synedra* sp.	+	-	-
37.	*Tabularia fasciculata* (C.Agardh) D.M.Williams & Round	+	-	-
38.	*Tabularia tabulata* (C.Agardh) Snoeijs	+	-	-

Table 2. Continued

	Cyanoprokaryota			
39.	*Calothrix* sp.	+	-	-
40.	*Merismopedia punctate* Meyen	+	+	-
41.	*Microcrocis* sp.	+	+	-
42.	*Oscillatoria curviceps* C.Agardh ex Gomont	+	-	-
43.	*Oscillatoria* sp.	-	-	+
44.	*Phormidium nigro-viridae* (Thwaites ex Gomont) Anagnostidis & Komárek	-	+	-
45.	*Spirulina* aff. *adriatica* Hansgirg	-	+	-
46.	*Xenococcus* sp.	-	+	-
	Chlorophyta			
47.	*Monoraphidium arcuatum* (Korshikov) Hindák	-	+	+
	Dinophyta			
48.	*Dinophyta* sp. gen.	-	-	+
49.	*Prorocentrum micans* Ehrenberg	+	-	-

The most common representatives of microalgae were species from the genera *Cocconeis* and *Amphora*, which formed a dense layer on the plastic surface (Figure 3). *Cocconeis scutellum* Ehrenberg, *Cocconeis* cf. *costata*, *Amphora ovalis* (Kützing) Kützing, *Amphora* sp. were the most common species on the plastics. It should be noted that only a few species of diatoms, cyanoprokaryotes and green algae-macrophytes are attached directly to the plastic. Other species form epiphytic groups that attach to the surface of macrophytes or on the layer of *Cocconeis* and *Amphora* species. Some species (*Achnanthes brevipes*, *Diatoma elongate*, *Diatoma vulgaris*, *Melosira moniliformis*, *Navicula* sp., *Rhoicosphenia abbreviata*) form colonies to which microalgae can also attach.

The abundance of microalgae on plastics varied in a wide range from 10 $x10^6$ cells cm^{-2} to 1.6 $x10^6$ cells cm^{-2}, averaging 124.3 $x10^3 \pm$ 38.3 $x10^3$ cells cm^{-2}. On the transparent plastic film, the abundance averaged 134.2 $x10^3$, on the dense it was twice less – 58.5 $x10^3$ cells cm^{-2}. On the surface of the bottles the abundance of microalgae reached 146.2 $x10^3$ cells cm^{-2} on average. The diatoms were the most numerous (Figure 4).

The abundance of cyanoprokaryotes varied in the range from 75 cells cm^{-2} to 24 $x10^3$cells cm^{-2}. The abundance of green algae was 5-154 cells cm^{-2}. Diatoms presented in fouling up to 92% of the total, followed by cyanoprokaryotes – 9%, and green algae – 0.2%. Diatoms were found on almost all studied plastic samples. Cyanoprokaryotes were less common, we found them on 50% of the bottles and 30% of plastic bags. The dense material has less biofouling than transparent (Figure 4). The diatoms formed 3.5 times less fouling on dense samples of litter (white plastic bags) than on transparent plastic bags and bottles. Thus, cyanoprokaryota were presented to a greater extent on the dense substrate.

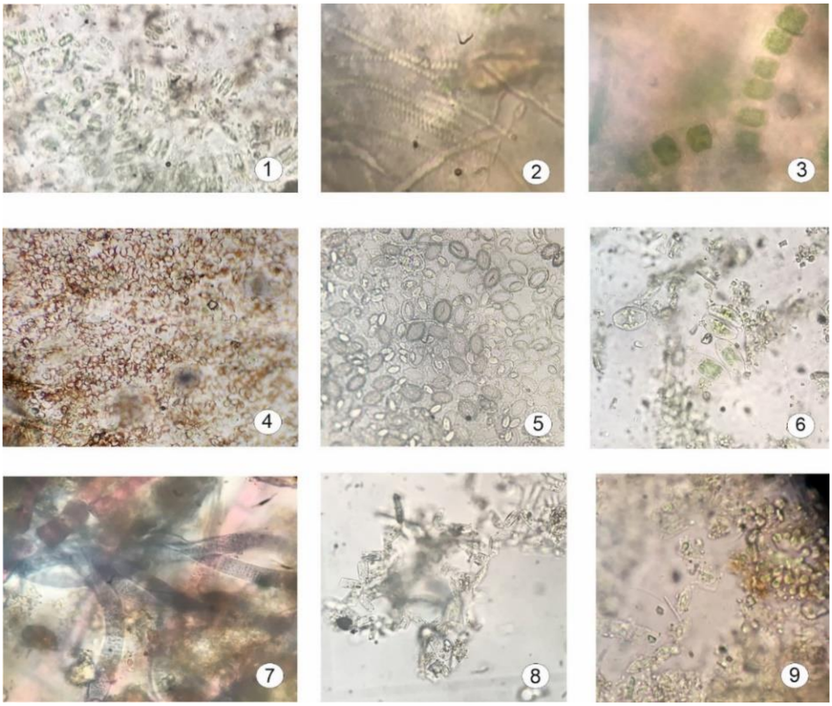

Figure 3. Microphytoperiphyton on the surface of seafloor marine litter from the Gulf of Odessa: 1 – *Amphora* sp., 2 – *Spirulina adriatica*, 3 – *Melosira moniliformis*, 4, 5 – *Cocconeis scutellum, Cocconeis* cf. *costata*, 6 – *Amphora ovalis*, – *Oscillatoria curviceps*, 8, 9 – colonies of diatoms.

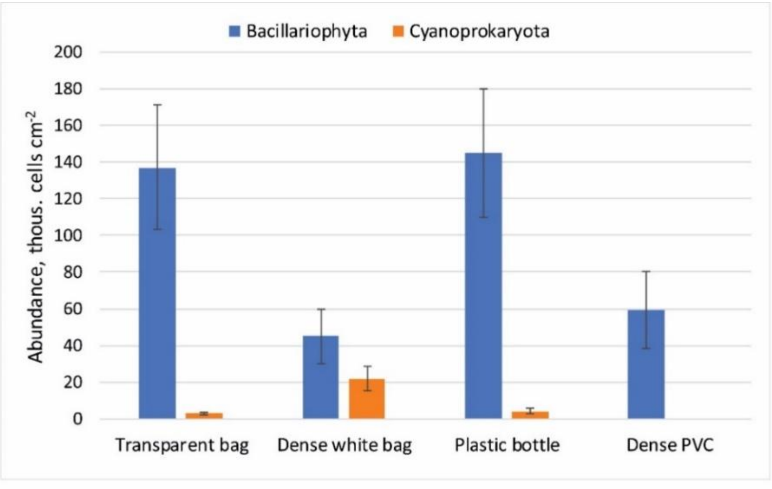

Figure 4. Microphytoperiphyton on different types of sampled plastic from the Gulf of Odessa

We have not revealed high correlations (R^2=0.6) between abundance of microalgae and the depth of the sites (Figure 5). We may say that there was a decreasing trend of the microfouling on the depth of 2-4 m and higher values of microalgae abundance on 1 and 6 m. Probably it is explained with the fact that pieces of litter that are in deeper layers spend more time underwater. Some samples from 1 m were buried with a sand that favored biofouling. The other reason of unclear correlation with the depth is that we do not know how long the plastic is on the sea floor. Some of the collected material had macrozoofouling (mollusks), which may indicate that the plastic was underwater for at least four to six months. In this case, there was a complex biofouling with components of macrozoobenthos, macrophytes and meiobenthic organisms. Therefore, on such samples, we observed a significant variety of microalgae. However, some of the plastic samples had no macrozoofouling, which indicates that the pieces were a relatively short time in the marine environment. The distribution of such samples by depth varies due to the high wave activity in the coastal zone. In this regard, further research should be directed to experimental studies for formation of biofouling in the marine environment and in the laboratory.

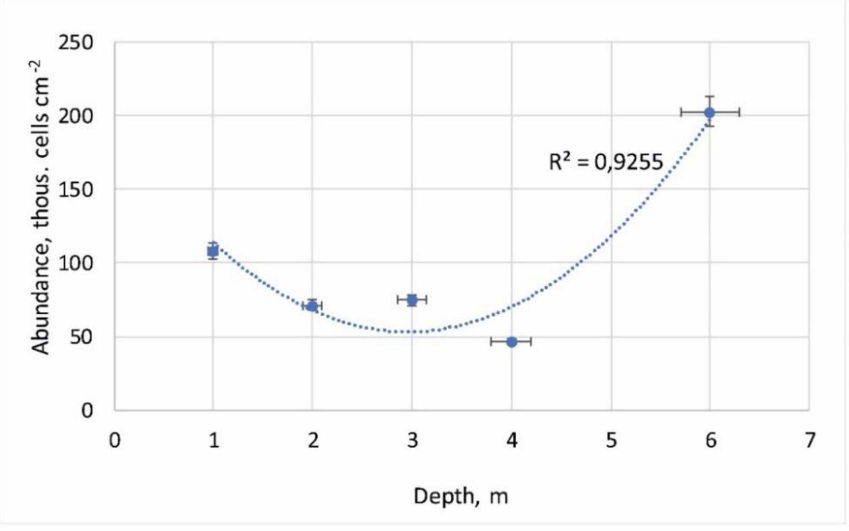

Figure 5. Relation with the phytoperiphyton abundance on the plastic substrates and sampling depth

All the species found on the samples were inherent to the Gulf of Odessa. The quantitative structure of microalgae on plastic substrates also corresponds to the values known from the literature (Table 3). Table 3 shows the data on phytoperiphyton that was exposed no more than 3-4 weeks. For comparison, we used our data on plastic fragments without macrozoofouling, which assumes the existence of these artificial substrates in the marine environment for no longer than 1-2 months. Thus, it is demonstrated that the quantitative indicators of microalgae on plastic materials coincide with the level of fouling in the NWBS.

Table 3. Comparison of the phytoperiphyton of plastic materials with other substrates from the studied area

Type of the substrate	Abundance 10^3 cells cm^{-2}	Reference
Glass (field experimental)	110-280	Ryabushko *et al.* 2013
Glass (laboratory experiment)	45	Snigirova and Aleksandrov 2015
Silicon (laboratory experiment)	23	Snigirova and Aleksandrov 2015
Experiment. plates with sand (0,25 мм)	88	Snigirova and Aleksandrov 2015
Macrophytes	2-15	Garkusha 2016
sand	35-99	Snigirova 2015
Polyethylene (field experimental.)	43-80	Garkusha 2016
Plastic (without zoofouling)	40-300	present study

Macroalgae on the plastic substrates

On the studied plastic substrates, we revealed the macroalgae with the most of them were in the beginning of their growth. Appearance of the macrophytes of the surface of any substrate creates favorable conditions for the development of meiobenthic organisms. Among the macroalgae, the most common were the green algae *Ulvella scutata* (Reinke) R. Nielsen, C. J. O'Kelly & B. Wysor and *U. lenz* P. Crouan & H. Crouan, whose colonies often covered the plastic with a solid carpet (Figure 6). *Enteromorpha* sp. (= *Ulva*) (mainly seedlings), *Ceramium rubrum* C.Agardh, *Callitamnion corymbosum* (Smith) Lyngbye were also observed. The colonies of *U. sulcata* are very small in size (25-125 µm in diameter), so we recorded its abundance when calculating the number of microphytes (152 ind.$\cdot$$cm^{-2}$). It is worth noting that it was possible to calculate it on transparent plastic directly, because when it is separated from the substrate, its identification and counting is complicated. Based on the observations, the degree of autotrophic macrofouling depended on the season and the type of substrate. The coverage of macroalgae on plastic items collected in summer were almost half compare to autumn. Obviously, this is due to the duration of the litter staying on the bottom in marine environment.

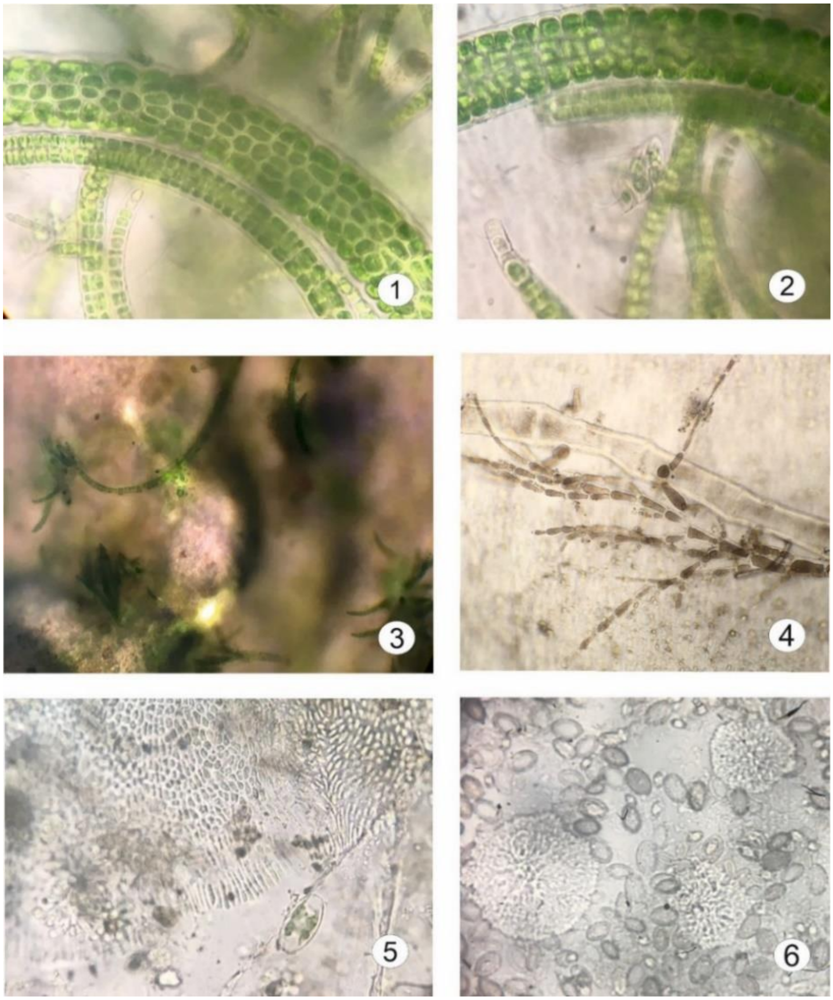

Figure 6. Fouling of the plastic substrate by macroalgae on the sample sites in Gulf of Odessa: 1, 2, 3 – *Ulva* sp., 4 – *Callitamnion corymbosum*, 5 – *Ulvella lenz*, 6 – *U. scutata* and the layer of *Cocconeis scutellu*

Macrozoobenthos on the plastic substrates

In our study, we revealed several taxa of macrozoobenthos on the surface of sea-floor litter (Figure 7). These were representatives of the Bryozoa, Bivalvia, Crustacea, Annelida, Gastropoda. The most common were *Mytilus galloprovincialis* Lamarck, 1819, *Mytilaster lineatus* (Gmelin, 1791), *Amphibalanus* sp., and *Membranipora* cf. *membranaceae* (Linnaeus, 1767). Representatives of these groups of animals are common and widespread in the NWBS. On several samples, we also noted worms and eggs laying of Gastropoda.

Figure 7. Representatives of macrozoofouling on plastic litter in the Gulf of Odessa: 1, 2 – *Mytilus galloprovincialis*; 3, 4, 8 – *Mytilaster lineatus*; 5 – clutches of gastropods, 6 – *Amphibalanus* sp., 7, 8 – *Membranipora* cf. *membranaceae* (Linnaeus, 1767)

The mollusk *M. galloprovincialis* dominated on the surface of plastic bags. On the bottles, the number of *Amphibalanus* sp. and the percentage of surface coverage by Bryozoa significantly increases. The fouling by *Membranipora* cf. *membranaceae* of the plastic bags did not exceed 25% of the total area, whereas this value on the bottles averaged 50%. The abundance of *Amphibalanus* sp. on plastic bags averaged 75 ± 38 ex. m^{-2}, *M. galloprovincialis* 838 ± 497 ind.·m^{-2} and *M. lineatus* 50 ± 27 ind.·m^{-2}. The abundance on the surface of bottles was 451 ± 92 ind m^{-2}, 329 ± 152 ind m^{-2}, 94 ± 89 ind m^{-2} respectively.

Meiobenthos on the plastic substrates

Meiobenthos associated with the macrofouling on plastic substrates studied for the first time. To the best of our knowledge there is no information on contribution of this group of zoobenthos on litter surface neither in the Black Sea, nor in any European sea. 14 groups of organisms represented this assemblage on plastic substrates: Foraminifera, Nematoda, Harpacticoida, Ostracoda, Halacaridae, Turbellaria, Oligochaeta, Polychaeta, Bivalvia, Gastropoda, Cirripedia, Isopoda, Amphipoda, Chironomidae.

Table 4. Species composition of Harpacticoida (Crustacea, Copepoda) and their frequency (F, %) on plastic bags and bottles

No	Species	F (%) bag	F (%) bottles
1.	*Ameira parvula parvula* (Claus, 1866)	100	85
2.	*Dactylopusia tisboides* (Claus, 1863)	100	90
3.	*Ectinosoma melaniceps* (Boeck, 1845)	60	70
4.	*Paradactylopodia brevicornis* (Claus, 1866)	50	65
5.	*Canuella perplexa* (Scott T. et A., 1893)	40	35
6.	*Harpacticus littoralis* (Sars G. O., 1910)	40	45
7.	*Tisbe bulbisetosa* (Volkmann-Rocco, 1972)	40	-
8.	*Paradactylopodia latipes* (Boeck, 1865)	35	25
9.	*Enchydrosoma sordidum* (Monard, 1926)	30	35
10.	*Heterolaophonte stroemii stroemii* (Baird, 1837)	30	15
11.	*Normanella serrata* (Por, 1959)	30	45
12.	*Tisbe marmorata* (Volkmann-Rocco, 1973)	30	20
13.	*Harpacticus obscurus* (Scott T., 1895)	20	30
14.	*Laophonte elongata elongata* (Boeck, 1873)	20	40
15.	*Laophonte thoracica* (Boeck, 1865)	20	5
16.	*Heterolaophonte uncinata* (Czerniavski, 1868)	15	10
17.	*Amphiascus cinctus* (Claus, 1866)	10	-
18.	*Bulbamphiascus imus* (Brady, 1872)	10	-
19.	*Harpacticus flexus* (Brady et Robertson D., 1873)	-	10

The taxonomy of harpacticoids and ostracods were studied more precisely because of low information on these groups from the NWBS in general and their important role as indicators of the quality of the environment. On the surface of plastic bags and bottles we found 19 species of harpacticoids (Table 4) that belong to the following families: Ameiridae (1 species), Canuellidae (1), Cletodidae (1), Dactylopusiidae (3), Ectinosomatidae (1), Harpacticidae (3), Laophontidae (4), Miraciidae (2), Normanellidae (1), Tisbidae (2). The detailed analysis showed that the species composition on plastic bags and bottles did not differ significantly: from 19 species the 15 were common for both substrates. Most species belong to epibenthic form (10 species), but they have a relatively low frequency (from 5% to 45%), which indicates their accidental presence on the types of plastic. It should be noted that only four species have the frequency higher than 50%: *A. parvula parvula*, *D. tisboides*, *E. melaniceps*, *P. brevicornis*.

We found 13 species of ostracods on the plastic substrate belonging to 7 genera (Table 5). Six species of these representatives of crustaceans are common to all types of plastic: *Hemicytherura bulgarica* (Klie, 1937), *Leptocythere multipunctata* (Seguenza, 1983), *Paradoxostoma intermedium* Mueller, 1894, *Paradoxostoma variabile* (Baird, 1835), *Xestoleberis cornelii* Caraion, 1963, *Xestoleberis decipiens* Mueller, 1894.

Table 5. Species composition of ostracods (Crustacea, Ostracoda) and their frequency (F, %) on plastic bag and bottle

No	Species	F (%) bag	F (%) bottle
1.	*Hemicytherura bulgarica* (Klie, 1937)	80	40
2.	*Paradoxostoma intermedium* Mueller, 1894	30	75
3.	*Xestoleberis cornelii* Caraion, 1963	45	60
4.	*Xestoleberis decipiens* Mueller, 1894	10	100
5.	*Leptocythere devexa* Schornikov, 1966	25	-
6.	*Semicytherura euxinica* (Caraion, 1967)	20	-
7.	*Leptocythere multipunctata* (Seguenza, 1983)	15	10
8.	*Paradoxostoma variabile* (Baird, 1835)	10	15
9.	*Xestoleberis aurantia* (Baird, 1838)	10	-
10.	*Loxoconcha bulgarica* Caraion, 1960	-	15
11.	*Loxoconcha elliptica* Brady, 1868	-	10
12.	*Loxoconcha pontica* Klie, 1937	-	10
13.	*Cytherois cepa* Klie, 1937	-	2

Hemicytherura bulgarica (34.62%) and *Xestoleberis cornelii* (19.23%) were the dominant species on plastic bag, whereas *Xestoleberis decipiens* (36.75%), as well as *Xestoleberis cornelii* and *Paradoxostoma intermedium* (26.5% each) dominated on the plastic bottles.

Meiobenthos is divided into two groups; eumeiobenthos (organism that dwell here during the whole period of life) and pseudomeiobenthos (organisms that are presented in this community only during larval period or juvenile stage). Among eumeiobenthic organisms the dominant group was Harpacticoid copepods, their abundance were 12285 ± 3639 ind.$\cdot$m^{-2} (34.4%) on plastic bag and 13390 ± 4140 ind.$\cdot$m^{-2} (26.9 %) on the bottle (Figure 8). Nematoda presented the subdominant group. The average abundance of ostracods on plastic bags (3583±1447 ind.$\cdot$m^{-2}) was two times higher than on the bottle surface (1204 ± 320 ind.$\cdot$m^{-2}), which was 6.0% and 3.4% of the total meiobenthos, respectively. Other representatives of eumeiobenthos (Foraminifera, Halacaridae, Turbellaria,) did not exceed 1000 ind.$\cdot$m^{-2} and 3% of the total abundance. Turbelaria had the lowest abundance, 11 ind.$\cdot$m^{-2} (0.03%) on plastic bag and 100 ind.$\cdot$m^{-2} (0.3%) on bottle.

Within the pseudomeiobenthic groups, the proportion of Gastropoda on plastic bag was higher than other groups (5365±4486 ind. m^{-2}, that made 15% of total meiobenthos abundance); contrarily, on the plastic bottles, Polychaeta, Bivalvia and Amphipoda were more abundant (each more 4000 ind.$\cdot$m^{-2}, made up 12.3-13.5 % of total meiobenthos). Larvae of insects Chironomidae had the lowest abundance with 21±10 ind.·m^{-2} (0.06%) on plastic bag and 140 ind.·m^{-2} (0.3%) on bottle. Oligochaeta were observed only on the bottles.

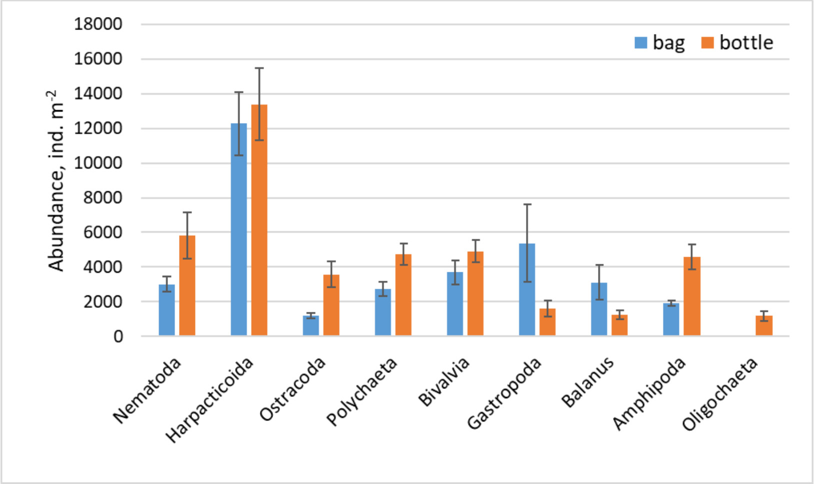

Figure 8. Average abundance of some meiobenthic taxa on the plastic substrates

In general, the contribution of eu- and pseudomeiobenthic organisms to the total abundance of meiobenthos differed slightly. The contribution of pseudomeiobenthic organisms are much higher (nearly two times) than eumeiobenthic organisms (Table 6).

Table 6. Abundance (ind.m^{-2}) and biomass (mg.m^{-2}) of eu- and pseudomeiobenthos

Value	Plastic bag		Plastic bottle	
	eu-	**pseudo-**	**eu-**	**pseudo-**
Abundance	17992	17714	24158	18637
Biomass	210.49	881.02	246.72	1138.91

Biomass of gastropods dominated (321.95 mg·m^{-2}) on the plastic bag, whereas amphipods were the most dominant group on the bottles` surface (550.0 mg·m^{-2}) (Figure 9). Thus, 93% of the biomass was formed by one eumeiobenthos group (Harpacticoida) and five pseudomeiobenthic groups (Oligochaeta, Polychaeta, Bivalvia, Gastropoda, Amphipoda). Such groups as Foraminifera, Nematoda, Ostracoda, Halacaridae, Turbellaria, Cirripedia, and Isopoda made no more than 3% of the total biomass value on both types of plastic. The percentage of ostracods in the total biomass of meiobenthos on a plastic substrate is very insignificant, and made 1.3% on plastic bag (23.19 mg·m^{-2}) and 0.86% on the bottle (7.83 mg·m^{-2}).

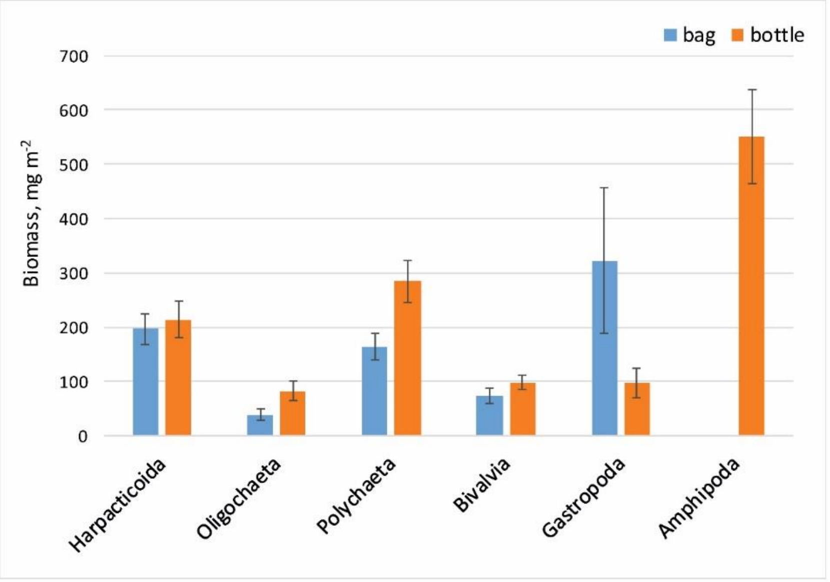

Figure 9. Biomass of meiobenthic taxa on different types of plastic substrate

To assess the processes of fouling on plastic materials, we compared it with the natural substrates. We have chosen sand and stones to compare their fouling with bottles, and two species of macroalgae to compare with plastic bags. The average quantity of meiobenthos on natural substrates was 4 (biomass) and 6.5 (abundance) times higher than on the plastic. The fouling of meiobenthos is distinguished in separate cluster (Figure 10). However, higher diversity of taxa was observed on the plastic (14 taxa) than on stone (11), sand (9), *Ulva* sp. (12) and *Ceramium* sp. (11).

Most of the meiobenthic groups (Nematoda, Harpacticoida, Polychaeta, Bivalvia) were much more abundant on natural substrates (from 3 to 12 times higher), except Foraminifera, Ostracoda, Halacaridae, which their abundance was higher or approximately the same on the bottles than on sand. *Balanus* was observed on plastic more often than on stone (5.6 time higher). Chironomidae were found only on plastic. Isopoda, Amphipoda were observed on both, bottles and bags but were not on sand and stones. Foraminifera were presented on plastic but was not observed on the macrophytes. The abundance of Gastropoda on the plastic bag prevailed than on both species of macrophytes. Ostracods prevailed 32 times on macrophytes than on plastic bags and made 25 % of total meiobenthos abundance. The most abundant group in meiobenthos – Harpacticoida was 3.5-4.0 times less on plastic bags than on macroalgae and 2.3-3.5 times less on bottles than on stone and sand.

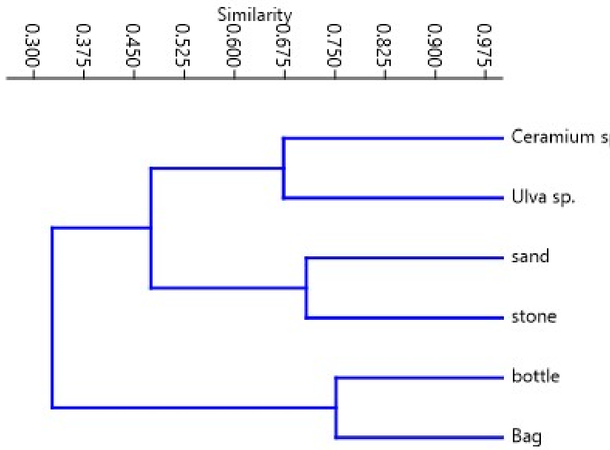

Figure 10. Distribution of meiobentos (Bray-Curtis index) on natural and plastic substrates in the northwestern Black Sea (Gulf of Odessa)

Our findings agree with the previous studies of fouling on artificial substrates, such as hydrotechnical traverses and piers in the Gulf of Odessa (Vorobyova *et al.* 2016). The taxonomical composition of organisms on plastic substrate was more diverse than on traverses (Foraminifera, Gastropoda, Balanus, Isopoda, Amphipoda were not presented on the last ones), but the total density of organisms was significantly less. The reason of these differences is difficult to explain with current knowledge.

The future researches should be focused on the processes of fouling formation and interactions between meio- and macrozoobethic assemblages on the plastic substrate in the field and laboratory experiments.

Conclusion

In the Gulf of Odessa (NWBS), comparably low amount of marine litter on the sea floor was found. The preliminary assessment of its quantity based on underwater video-transect method showed the presence of 32 items of litter per km^2. Underwater observations of diver provide evidence that litter concentrates usually on the depth of 2-3 m between the coastal hydrotechnical constructions. The most common litter was plastic bags. In autumn, the litter abundance was three times more than in summer.

On the surface of marine plastic litter that was collected on the depth 1-6 m we revealed the diverse and complex assemblage of fouling microphytes and meio- and macrozoobenthic organisms. It was represented by typical widespread species that dwell on other artificial and natural surfaces in this water area. For the first time 49 species of microalgae (Bacillariophyta (38 species), Chlorophyta (1), Dinophyta (2) and Cyanoprokaryota (8)), 5 species of macrophytes, 14 groups of meiobenthos and 4 species of macrozoobenthos were found on plastic surface in NWBS region. Intensification of general biofouling was observed on the bottles in summer and on plastic bags in autumn. Thus, the plastic marine litter becomes a widespread substrate in the sea-bottom representing a new habitat for biofouling communities.

The further studies of benthic communities should consider the integration of the marine litter as a new habitat for benthic organisms in the marine environment. This research should be developed in two directions. The first one is the study of patterns of biofouling formation on seafloor marine litter surface and its comparison with the natural and other artificial substrates in the NWBS. The second one is the experimental field and laboratory studies of the processes of biofouling on plastic substrates. The assessment of the marine litter impact on the benthic environment should become one of the elements of the routine monitoring and will form understanding of the "good environmental status" of the Black Sea in line with the Marine Strategy Framework Directive.

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Microbial biofilm on plastics in the southeastern Black Sea

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Abstract

In this study we used scanning electron microscopy to characterize microbial biofilm communities on the surface of plastics commonly used in daily life and fisheries, namely polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyamide (PA, nylon) and polyvinylchloride (PVC). For this purpose, we submerged the plastic items in a coastal station in the southeastern Black Sea during five months (February-June 2019) and recorded the evolution of microbial biofilm formation. Diverse microbial communities formed on plastics surface within a month. Diatoms were the most diverse and abundant group of the plastic colonizers represented by 18 genera. Bacteria were also abundant and a diverse group on plastic surface. Dinoflagellates, ciliates, choanoflagellates, auxospores and unidentified organism were also observed. After microbial formation we also observed invertebrate assemblages on plastic. Our experimental results confirm the current concern that plastic is a new pelagic substrate for microorganisms and invertebrates in the Black Sea and that these communities may play an important role in plastic degradation and represent a novel compartment of the ecosystem.

Keywords: Plastic, biofilm, plastisphere, microbial communities, biodegradation, Black Sea

Introduction

Plastics are widespread pollutant in the marine ecosystems from coastal waters to ocean gyres (Derraik 2002; Law *et al.* 2010), negatively affecting marine life by ingestion (Jacobsen *et al.* 2010; Provencher *et al.* 2010), entanglement (Derraik 2002), alterations of habitats, transporting pathogens and invasive species and releasing toxic chemicals, such as polychlorinated biphenyls (e.g. Zarfla and Matthies 2010).

Most of the plastics are positively buoyant, dispersed by wind and ocean currents. Significant amounts of plastics become neutrally buoyant and finally sink into the water column (Moore *et al.* 2001; Ye and Andrady 1991) and eventually accumulate in the benthic environment (Besseling *et al.* 2017; Eerkes-Medrano *et al.* 2015). During their long-distance transport, plastic litter can serve as a substrate for microorganism colonization and invertebrate assemblage formation (De Tender *et al.* 2015; Harrison *et al.* 2014; Rummel *et al.* 2017). This microbial biofilm formation plays a significant role in the fate of marine plastic pollution by affecting the buoyancy (Ye and Andrady 1991; Moore *et al*. 2001; Lobelle and Cunliffe 2011), degradation rate (Andrady 2011; Zettler *et al.* 2013), and toxicity level of plastics (Harrison *et al.* 2011).

Rapid formation of microbial biofilms was observed on plastic surfaces within few weeks in marine environments, and the taxonomic composition of biofilms on plastic particles was distinct from the microbial assemblages of the surrounding water (De Tender *et al*. 2017; McCormick *et al.* 2014; McCormick *et al*. 2016). Therefore, plastics have now been referred as a specific niche for microbial life, known as the “Plastisphere” (Zettler *et al.* 2013).

Plastic is mistaken as food by a variety of organism from plankton to mammals (Wright *et al.* 2013). Thus, rich microbial biofilm might increase the attractiveness of plastics for many marine organisms. In addition, marine plastics may also supply energy for microorganisms capable of biodegrading polymers and/or associated compounds (Zettler *et al.* 2013). Although microfouling can play a role and increase the degradation of plastics (Webb *et al.* 2009, Harshvardhan and Jha 2013), microfouling can also protect plastics against UV radiation, which delays fragmentation of plastics (O’Brine and Thompson 2010).

The Black Sea is a semi-enclosed sea with high river discharge as a result of the drainage area of several industrialized countries (Aytan *et al.* 2016). This makes plastic pollution a complex and urgent problem in this semi-enclosed basin. High concentration of macroplastic litter has been reported from the sea surface (Suaria *et al.* 2015), sediment (Topçu and Öztürk 2010; Moncheva *et al.* 2016; Öztekin and Bat 2017a) and beaches (Topçu *et al*. 2013; Vişne and Bat 2016; Simeonova *et al.* 2017; Terzi and Seyhan 2017; Simeonova and Chuturkova 2020; Terzi *et al*. 2020; Öztekin *et al.* 2020; Aytan *et al.* 2020). Recent studies have also reported high concentration of microplastics in the surface waters of the Black Sea (Aytan *et al*. 2016; Öztekin and Bat 2017b; Berov and Klayn 2020).

Due to the important role of biofilm formation on the fate and impacts of plastic, studies on plastisphere have increased in recent years in various geographic regions (Zettler *et al.* 2013; Oberbeckmann *et al.* 2014; Zettler *et al.* 2015; Ivar do Sul *et al.* 2018). Characterization of microfouling communities on marine floating plastics were reported from the North Atlantic (Zettler *et al.* 2013), water around Australia (Reisser *et al.* 2014), the North Pacific Gyre (Carson *et al.* 2013) and the Mediterranean (Masó *et al.* 2016). Regarding Black Sea, there is limited knowledge on microbial biofilm communities in the Black Sea (Snigirova and Portyanko 2018; Snigirova *et al*. 2019a, 2019b).

Scanning electron microscopy (SEM) is one of the best tools for studying microfouling communities (Delgado and Fortuño 1991; Cros and Fortuño 2002). The objective of this study was to characterise microbial biofilm formation on commonly-used plastic items with the aim of contributing to an understanding the fate of plastics in the Black Sea. Here we report preliminary results on: i) what are the biofilm communities; ii) how fast biofilm formation occurs and iii) differences on biofilm communities between polymers.

Materials and Methods

In order to characterize microbial biofilm formation, we have performed an experimental study where new plastic items were hanged in a rope at two meters depth in a harbour for several months. Throughout this period, we have investigated the plastic biofilm formation. Conventional plastic items that are frequently used in daily life and fisheries were chosen to determine the microbial biofilm communities. The polymer types of the plastic items (Table 1) were determined with Perkin Elmer Spectrum 100 Fourier Transform Infrared Spectrometer (FT-IR). The spectrum range was 4000-650 cm^{-1} and a resolution of 1.0 cm^{-1} with four scans for each measurement. The polymer type identification was done by comparing absorbance spectra to a reference the library by using Perkin Elmer SEARCH Plus® software.

Table 1. Submerged plastic items used in this study

Usage	Sample	Polymer
Single used items	Shopping bag	PE
	Stretch film	PE
	Bubble wrap packing	PE
	Bottle <0.5 L	PET
	Food package	PET
	Food package	PP
	Plate	PS
	Fork	PS
Fishing related items	Net	PA
	Net	PE
	Rope diameter <1 cm	PE
	Twisted Rope diameter <1 cm	PP
	Fishing line	PA
	Fishing hoop	PP
	Float	PE
	Float	PVC

The plastic samples were hanged in a rope at two meters below the sea surface in a harbour (41° 03' 7'' N, 40° 36' 31'' E) in the SE Black Sea (Figure 1). Water depth was approximately 12 m. Sampling was carried out monthly between February to June of 2019. In each sampling, approximately 3 cm^2 pieces of each item were cut out and put into cryovials (Figure 2). Samples were fixed immediately with 4% formaldehyde for 2-23 h. Then, they were transferred to 50% ethanol in Phosphate Buffered Saline (PBS) (Zettler *et al.* 2013) and kept at −20 °C. All materials were sterilized prior to the study.

Figure 1. Location of study area

Samples for SEM were exposed to the ethanol series on ice for 10 minutes at 50%, 70%, 85% and 95% followed by 3 x 15 minutes in 100% ethanol (Zettler *et al.* 2013). The samples were then immediately dried using the Quarum K850 critical spot and overlaid with silver (Figure 3). Plastics surface were visualized with Jeol JSM-6610 Scanning Electron Microscope (SEM).

Figure 2. Sampling from submerged plastic items

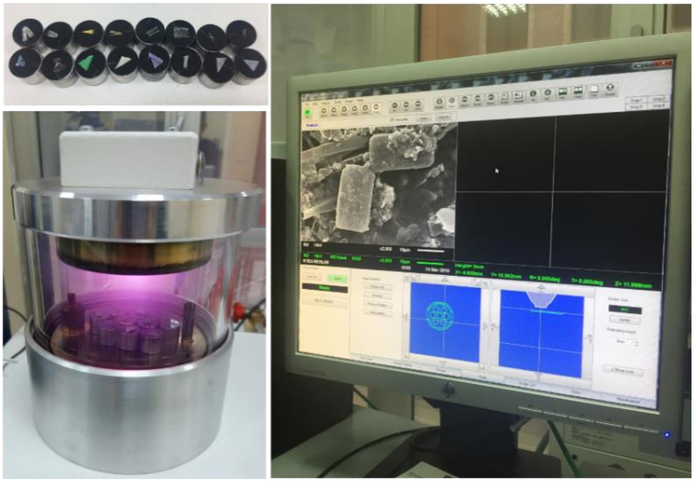

Figure 3. SEM analysis of microbial biofilm on plastics

SEM images were used for species identification. 5-10 fields of SEM view were enumerated, and species grouped into major taxa (diatoms, dinoflagellates, ciliates and choanoflagellates). Species identification were done to lowest taxonomic level possible. Previously described taxa was used to identify diatoms (Stefano *et al.* 2000; Sarno *et al.* 2005; Corlett and Jones 2007; Totti *et al*. 2009; Garcia and Odebrecht 2009; Hoppenrath *et al.* 2007; Zettler *et al.* 2013; Belando *et al.* 2012; Reisser *et al.* 2014; Romagnoli *et al.* 2014; Wang *et al*. 2014; Sugie and Suzuki 2015; Lee *et al*. 2019), auxospores (Kaczmarskaa *et al.* 2018; Samanta *et al*. 2020; Diatoms 2020) dinoflagellates (Masó *et al.* 2016), ciliates (Henjes and Assmy 2008), choanozoans (Thomsen and Østergaard 2017), and bacteria (Reisser *et al.* 2014).

Results and Discussion

Our study significantly adds to existing knowledge that a diverse microbial community, particularly diatoms and bacteria, colonizes plastics in the Black Sea (Figure 4). We observed that a microbial biofilm formed on unused plastics within a month. Such rapid microbial biofilm formation on marine plastics has also been reported in previous studies (Lobelle and Cunliffe 2011; Briand *et al*. 2012; Oberbeckmann *et al*. 2014; Dang *et al*. 2018; Zettler *et al.* 2013).

In this study, we examined the microbial biofilm formation on different types of plastic polymers, namely polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), polyamide (PA, nylon) and polyvinylchloride (PVC). We observed differences in microbial biofilm formation among these polymers PET was the polymer with more abundant and diverse communities, followed by PE, PP, PA, PVC and PS. Differences in microbial biofilm formation between different polymer types have also been found in other studies (Carson *et al.* 2013; Zettler *et al.* 2013).

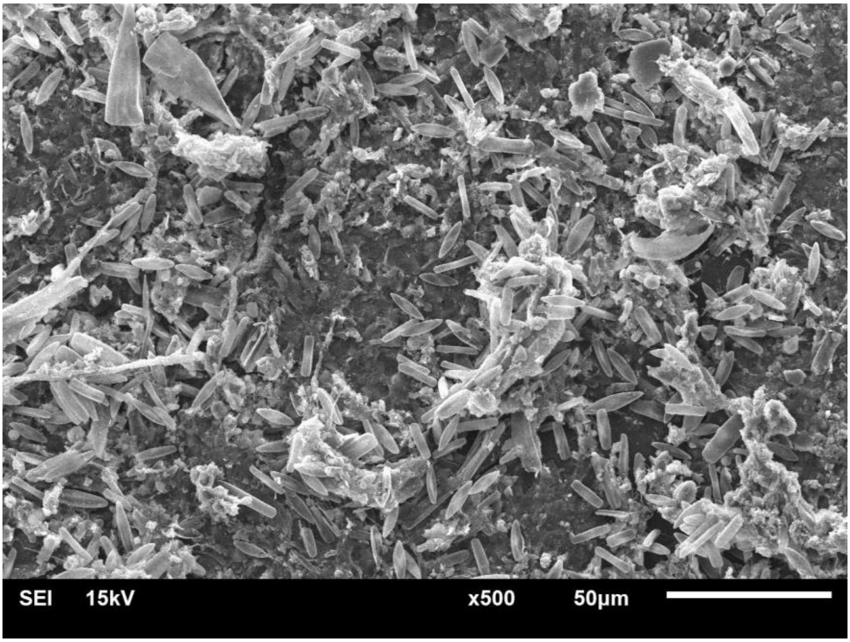

Figure 4. Example of diverse microbial biofilm on plastics

Regarding microbial biofilm communities they were comprised of diatoms, dinoflagellates, ciliates, choanoflagellates, bacteria, auxospores and unidentified species (Figure 5).

Diatoms and bacteria were the first colonizers and the most abundant and diverse group of biofilm communities which is in line with previous findings (Carson *et al.* 2013; Zettler *et al.* 2013; Reisser *et al.* 2014). A total of 18 taxa of diatoms were identified; *Achnanthes, Amphora, Cocconeis, Cylinrotheca, Delphinies, Grammatophora, Halamphora, Licmophora, Navicula, Nitzcshia, Pleurosigma, Pseudonitzschia, Thalassionema, Coscinodiscus, Melosira, Pseudostriatella, Skeletonema* and *Thallasiosira (*Reisser *et al.* 2014; Masó *et al*. 2016; Thompson *et al*. 2017; Gomez-Ramirez *et al*. 2019; Di Pippo *et al.* 2020; Rogers *et al.* 2020) (Figure 6).

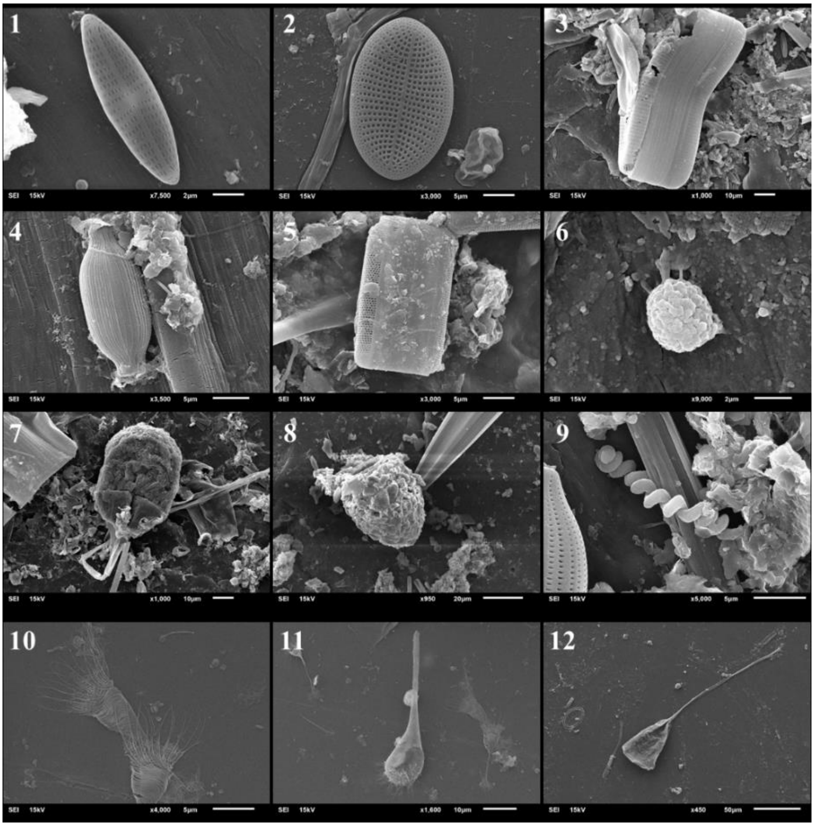

Figure 5. SEM images showing examples of the microbial communities on plastic items: diatoms (1-5), auxospore (6), dinoflagellate (7), ciliate (8), bacteria (Spirillum) (9), choanoflagellates (10), unidentified organisms (11-12).

Diatoms have been reported to be the first colonisers of surfaces of plastics in the sea and recognised to have an important role in biofilm formation (Cooksey and Wigglesworth-Cooksey 1995; Patil *et al*. 2005; Zettler *et al*. 2015). Pennate diatoms belonging to the genera *Amphora* and *Navicula* are well known cosmopolitan fouling species (Molino and Wetherbee 2008; Molino *et al.* 2009; Pelletier *et al.* 2009) and these species have been also reported on plastic surfaces (Reisser *et al.* 2014; Oberbeckmann *et al*. 2014).

Abundant of rounded, elongated, and spiral forms of bacteria were also observed within a month in PP, PA, PS items. Bacterial populations growing on plastics interacted with the plastic surface by forming pits and grooves (Figure 7). Previous studies have reported on hydrocarbon-degrading bacteria (Zettler *et al.* 2013) and experiments demonstrated that marine bacteria can indeed biodegrade polymers (Sudhakar *et al.* 2007; Artham *et al.* 2009; Balasubramanian *et al.* 2010; Harrison *et al.* 2011; Zettler *et al.* 2013; Harshvardhan and Jha 2013). Further studies are needed to understand the role of the bacteria found in present study in degrading plastic.

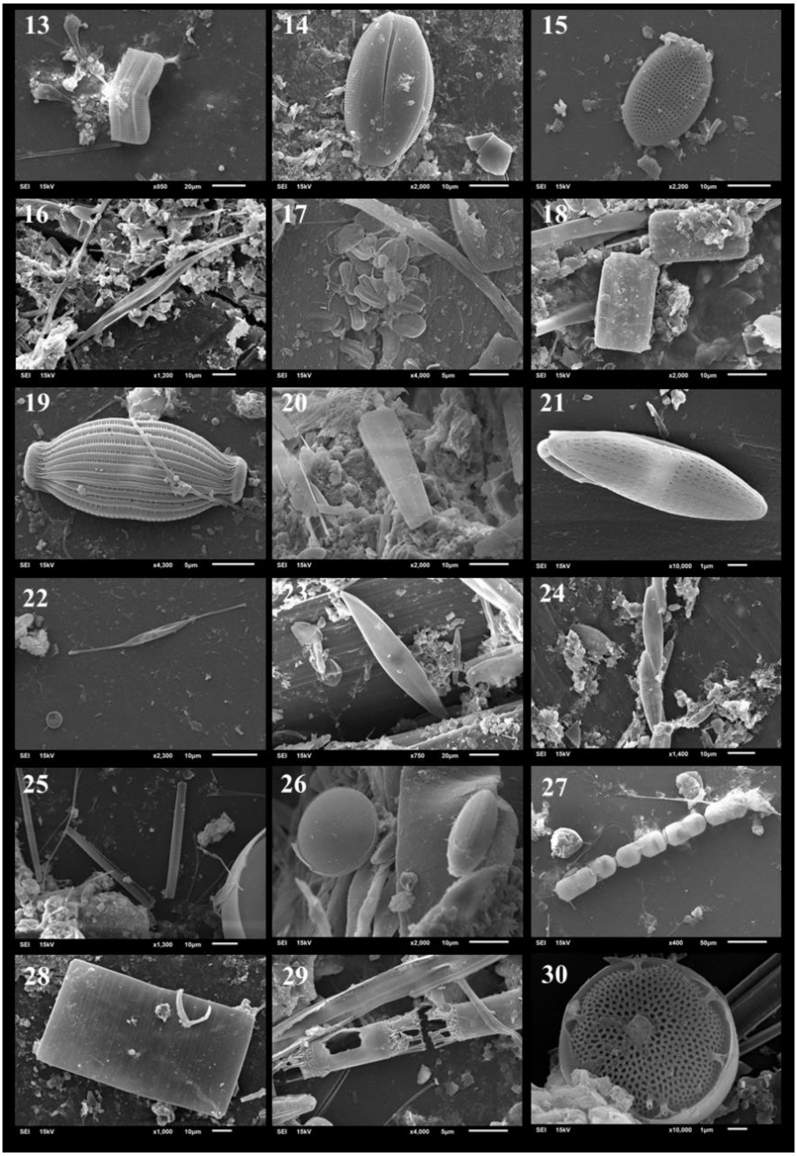

Figure 6. SEM images showing examples of the diatom species **(**13-30) *Achnanthes* sp. (13), *Amphora* sp. (14), *Cocconeis* sp. (15), *Cylinrotheca* sp. (16), *Delphinies* sp. (17), *Grammatophora* sp. (18), *Halamphora* sp. (19), *Licmophora* sp. (20), *Navicula* sp. (21), *Nitzcshia* sp. (22), *Pleurosigma* sp. (23), *Pseudonitzschia* sp. (24), *Thalassionema* sp. (25), *Coscinodiscus* sp. (26), *Melosira* sp. (27), *Pseudostriatella* sp. (28), *Skeletonema* sp. (29), *Thallasiosira* sp. (30).

Surface texture and structure are important factors that determine biofilm adhesion rates and community succession (Fazey and Ryan, 2016). Positive relation between diatom density and qualitative surface ‘‘roughness’’ of particles was reported (Bravo *et al.* 2011). Often a result of plastic degradation, more fouling microorganisms occur in the rough surfaces and the degradation process may accelerate colonization leading to eventual sinking, or make the item more likely to be ingested, passing adsorbed persistent organic pollutants up the food chain (e.g. Tanaka *et al.* 2013).

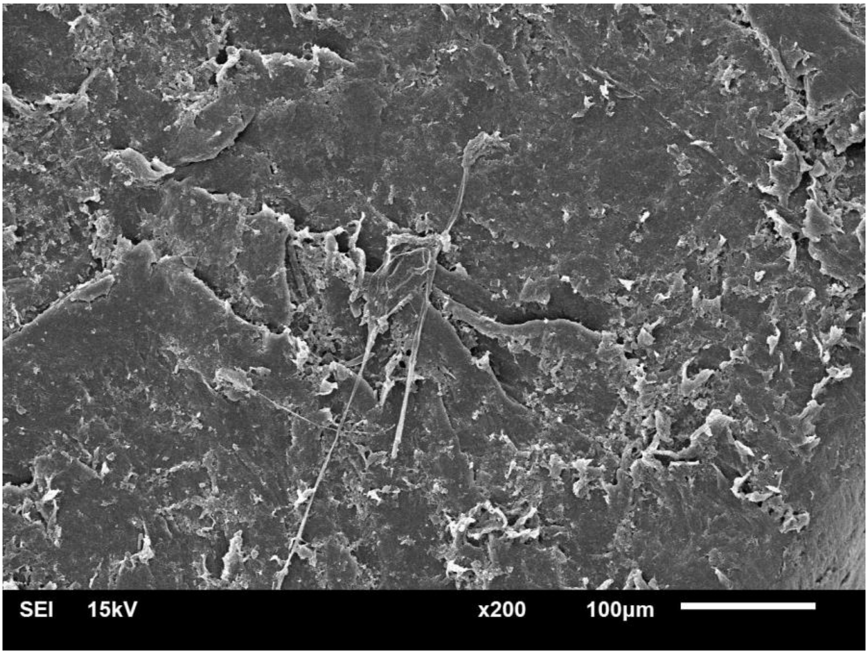

Figure 7. Example of micro textures (pits and groves) on the plastic surface

The choanoflagellates, which is a ubiquitous group of aquatic bacterivorous filter feeders (Arndt *et al.* 2000), were also found on biofilm in present study. Dinoflagellates were not abundant and only found in first sampling in the PET bottle surface. Dinoflagellates are atypical organisms to be found on plastic surface. However, recent studies have also reported plastics fouled by individuals, and cysts of the potentially harmful dinoflagellate species (Maso *et al.* 2003; Zettler *et al.* 2013; Reisser *et al.* 2014). Ciliates were only observed in the PE. We also found many unidentified organisms of various morphology and sizes (Figure 5).

An increase in abundance of microbial biofilm communities was observed in last two months of sampling (May and June 2019), which could have been related to increasing temperatures. In June 2019, invertebrate assemblages (bryozoans, barnacles, gastropods, bivalves) were observed on plastic (Figure 8).

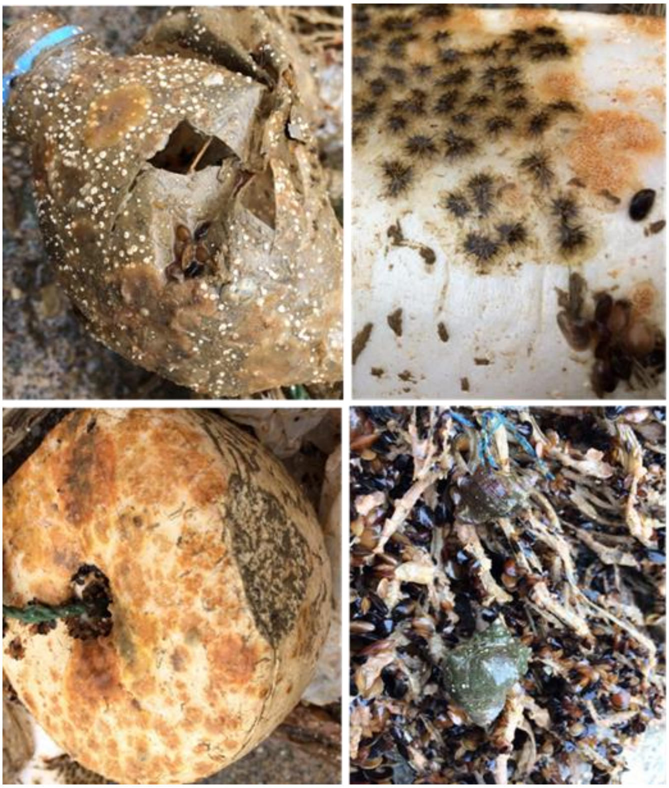

Figure 8. Diverse fouling invertebrate assemblages on plastics surface

Conclusion

Plastics with various forms (particle, film or fibre; smooth or rough surface, etc.) and chemical compositions (high and low densities, additives, adsorbed chemicals, etc.) can serve as a substratum for microfouling communities in marine ecosystems (Oberbeckmann *et al.* 2015). PE, PES, PP and PA account for 74% of global plastic production and are often used in single-used products (Geyer *et al.* 2017; Plastics Europe 2017). They are also the most common polymers exist in the marine environment (Browne *et al.* 2011). Our results confirm that these plastics represents a new anthropogenic substrate in the Black Sea. We observed that unused plastics became rapidly (within a month) colonized by biofilm forming microorganisms. Such biofilm formation is likely to affect buoyancy, degradation and toxicity of plastics in Black Sea. Although it is not possible to scan all surface area of the plastics by SEM, the random areas that were chosen to be scanned, still provided an important information of the biofilm communities.

These preliminary results provide information on temporal evolution of biofilm formation on plastics, the colonizing communities and their differences among various types of polymers. Simultaneously, as part of the TUBITAK project "Distribution, composition, sources and ecological interactions of micro- and nanoplastics in southeastern Black Sea" (Project Number ÇAYDAG 118Y125), we also collected floating plastics from the SE Black Sea coastal waters between July 2019 and June 2020. Those data will be compared with the results of the present work, for a better understanding of biofilm communities. The fast colonization found in this study (around a month) can be used as an indicator for the time that a plastic has entered the Black Sea environment.

Future studies need to increase knowledge on the microbial biofilm communities and processes involved in the formation of a biofilm. Further observational and experimental studies on the microbial biofilm on plastics might also support the development of biotechnological solutions (e.g. hydrocarbon-degrading bacteria) for better disposal practices for plastic litter in the Black Sea.

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Microphytes assemblages on the neustoplastics from the northern Black Sea

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Abstract

Drifted plastics (or so-called neustoplastics) is considered to be colonized by marine organisms that could use the polymers as a substrate, participate in their decomposition, and form unusual biological communities that adapt to severe conditions of the environment in the near-surface layer of water. In this study, we initiated the research of microphytes that may dwell on the plastics on the water surface in the northern part of the Black Sea coastal waters. Two types of neustoplastics were analyzed: polyethylene film (PE-film) with microphytes fouling that was occasionally sampled and polyethylene terephthalate bottle (PET-bottle) that has been exposed to fouling for about six weeks. The microphytes forming fouling on PE-film was represented with 14 taxa of cyanobacteria and 8 species of Bacillariophyta. The most numerous genera were *Calothrix* and *Mastogloia*. Strict hierarchy of the assemblage was noticed, the first layer of microalgae that was located directly on the surface of the PE-film was presented mostly by *Mastogloia* species that formed capsules (the most abundant *M. lanceolata*) and three species of *Calothrix* with short trichomes. *C. scopulorum* and *C. parietina* formed upper layer of the assemblage protecting the microphytes from the aggressive environment. On the surface of PET-bottle assemblage was formed by mosaic scattered spots with different spatial organization. The upper layer was again formed by cyanobacteria *Leptolyngbya foveolarum* and colonies of the diatom *Neosynedra provincialis*. Other 10 species of diatoms, 1 dinoflagellate and 7 cyanobacteria were presented in the assemblage. The architecture of both studied assemblages represented the existence of specific adaptations of microphytes that dwell on polymer substrates near the water surface. The assemblage on the PET-bottle was more diverse and with more complicated hierarchical structure.

Keywords: Neuston, plastic, microalgae, drifters, synthetic polymers

Introduction

The period of intense plastic pollution of water bodies will certainly go down in the geological history of the planet as an independent layer that has no analogues in the past. Plastic that occurs into the seas, oceans and fresh waters degrades quite slowly. It can take centuries to complete decomposition of the plastics such as low-pressure polyethylene (HDPE), polypropylene (PP) and polyethylene terephthalate (PET) (Barnes *et al.* 2009). Up to now, it is known that plastics has a negative impact on marine biota (Hammer *et al.* 2012). On the one hand mechanical and physiological harm is mentioned – entanglement and physical damage (Laist 1997), as well as digesting of the litter (Auman *et al.* 1997). On the other hand, the plastic particles can also have a toxic effect on the processes of humoral regulation and, thus, the life cycles of organisms (Colton *et al.*, 1974; Fossi *et al.* 2001, 2012, 2016, 2017; UNEP 2005; Ng and Obbard 2006; Rios *et al.* 2007; Murray and Cowie 2011; Rochman *et al.* 2013; Avio *et al.* 2015, 2017), which leads to a decrease in their vitality and a decrease in diversity. Nevertheless, being on the surface of waterbodies the objects made of these materials come into interaction with hydrobionts. Since the density of most of the plastics are not very different from water (0.96 g/cm^3 for HDPE, 0.9-0.92 g/cm^3 for PP and 1.38 g/cm^3 for PET), they float at a surface waters for a long time. PET is heavier than sea water, but most of the soft bottles made from it sink to the bottom. Bottles with a lid closed contains air and can stay in the sea surface, which gives them the properties of drifters for a long time.

Among the entire set of dwellers of a particular habitat, there is a certain number of species (usually not too large) that can use plastic as a substrate for living. Primary colonization on plastics occurs in the near-surface layer of the water column under conditions of high insolation, intense hydrodynamics, and frequent temperature changes. Being exposed to aggressive environmental influences, plastic objects or their fragments gradually become a substrate for some species of marine organisms (Lobelle and Cunliffe 2011) and this new part of the planet`s is called plastisphere (Zettler *et al.* 2013).

More than 380 taxa have been mentioned to drift on the floated marine litter (Kiessling *et al.* 2015), or as it is called “neustonic plastics” (Day *et al.* 1990; Moore *et al.* 2002; Collignon *et al*. 2012; Aytan *et al*. 2016) or “neustoplastic” (Snigirova *et al.* 2019). Accordingly, the communities of organisms that colonize plastic surface could be named “neustoplaston”. The study of these communities, primarily those formed mainly by microorganisms (for example, microphytes) is extremely important because of the following reasons.

Firstly, they can take an active part in the biodegradation of synthetic polymers: they penetrate in the cracks, scratches and other deformations on their surface, and then actively reproduce there, pushing the edges of these “wounds” and forming new ones (Pekhtasheva *et al.* 2012; Eich *et al.* 2015). This leads to gradual processes of fragmentation of large plastic into smaller parts which called microplastics (< 5 mm). In this way, with the participation of microorganisms, microneustoplastics can be formed from macroneustoplastics. The destructive properties of microorganisms are important in this context for understanding new natural processes.

Secondly, such communities are formed by microorganisms that capable to inhabit a substrate that is new for nature and live on it in rather aggressive environmental conditions. Their properties and abilities – both individual and at the level of simply organized assemblages – can be further used for the purposes of mariculture and biotechnology.

Thirdly, the drifted plastics may be considered as additional way of biological invasions due to ability of plastic particles overcome big distances passing seas and oceans with the water currents (Pinochet *et al.* 2020). There are also the precedents of a new taxa found on the surface of artificial polymers and the new ones are likely to be found in future (West *et al.* 2016). However, this type of anthropogenic pathways for the bioinvasions is discussable and least understandable question (Lewis *et al.* 2005; NOAA 2017). The species that adapted to live on the plastic surface wider in their ecological niches and might overcome big distances through the seas and oceans and occur in new water areas.

Microbial colonization on plastics might enhances microplastic ingestion by marine organisms from zoopankton to mammals. Colonization of plastics also changes the buoyancy and sinking rates of plastics, thus it effects the time of plastics occur in the surface/water column and bioavailability of plastics. Finally, under the weight of growing communities, neustoplastics gradually sink into the water column, becoming for some time a planktoplastic, and then getting to the bottom. To understand the effects of microphytes fouling on the fate of neustoplastics, it is necessary to take into account the features of the formation and the structure microphytes fouling in various environmental conditions.

Our studies were conducted in the northern part of the Black Sea coastal waters, in areas with intense anthropogenic stress and a fairly high level of pollution, including plastic. The aim of this study was to describe the species composition and spatial organization of microphytes assemblages of two types of neustoplastics in the North Black Sea, to understand their features and to compare microphytes fouling in different neustoplastics

Materials and Methods

In this study, we analyzed two types of neustoplastics that were sampled in coastal area of Crimean Peninsula. In October 2016 the big peace of polyethylene film with microphytes fouling was occasionally sampled near Gurzuf (44.5454 N, 34.2955 E). Another item for present study was polyethylene terephthalate bottle that was exposed from August, 4 till September, 19 in 2018 near a mussel farm in the Gulf of Sevastopol (44.6168 N, 33.5019 E) on the surface of the sea. To analyse the species and horologic structure of microphytes` assemblage the several fragments of polyethylene material were taken (each about 15 cm^2) with different extent of microphytes fouling. The samples were fixed with 96-% of ethanol and were preserved in dark cold place. The further processing of the samples was made in the laboratory of Institute of Oceanology RAS under light microscopes Leica DMLS и Leica DM-2500. Firstly, the assemblage on the polyethylene was observed without preliminary treatment on water temporary slides. For identification of diatoms the permanent slides were prepared. Organic compound was burned with the help of concentrated sulphuric acid. The frustules were separated from the substrate with a help of ultrasound (Nevrova *et al.* 2015). To identify the microalgae and cyanobacteria the following atlases and revisions were used (Sadogurska 2013; Krammer and Lange-Bertalot 1986; Sims *et al.* 1996; Witkowski *et al.* 2000; Komarek 2013; Diatoms of North America 2020). Nomenclature of the taxa was specified based on algaebase.org (Guiry and Guiry 2020).

Results and Discussion

Microphytes assemblages on the neustonic polyethylene film

The microphytes fouling covered the both sides of transparent and very cracked (damaged) polyethylene film. The density and transparency of the film let to study the structure of the microphytes assemblage on its both surfaces without turning it over. Thus, the microphytes fouling in the process of growth was well illuminated from all sides. There should not be no shading effect from the substrate folds. From both sides of the film the golden-brown fouling of different density was clearly visible. At the edges, the fragment was severely torn, but the stretching effect was not noted.

Figure 1. Cyanobacterial fouling on polyethylene film in neustoplastics of the North Black Sea: 1 – *Calothrix scopulorum* C.Agardh ex Bornet et Flahault; 2 – *C. fusca* f. *parva* (Ercegovic) Poljansky; 3 – *Dichothrix gypsophila* Bornet et Flahault; 4 – *C. fusca* Bornet et Flahault; 5 – *C. parietina* Thuret ex Bornet et Flahault; 6 – *C. brevissima* G.S.West.

The microphytes fouling was represented with 14 taxa (Sapozhnikov *et al.* 2018) (6 taxa of cyanobacteria from the genera *Calothrix* и *Dichothrix* (Figure 1) and 8 species of Bacillariophyta from the genera *Mastogloia, Halamphora, Cocconeis, Navicula* and *Nitzschia*) (Figure 2). Here we observed a scarcely diverse community. However, it was developed under significantly more aggressive conditions than, for example, assemblages of the rocky supralittoral.

To compare with, on the same part of the littoral coast we noted the read algae+cyanobacteria+diatoms assemblage that consisted of more than 30 species of micro- and macroalgae. Among them there were *Ceramium* sp. and *Lophosiphonia* sp., 8 species of cyanobacteria that were morphologically closed to *Calothrix* (*Scytonematopsis crustacean, Calothrix fusca, C. fusca* f. *parva, C. contarenii, C.* aff. *vivipara, C. parietina, C. scopulorum* and *Calothrix* sp. 1), 2 species of *Leptolyngbya*, *Schizothrix cresswellii, S. telephoroides* and 5 species of crust forms of cyanobacteria (*Entophysalis granulosa, E. major, Pleurocapsa minuta* and *Placoma vesiculosa*), which form the lowest layer of the assemblage. Within the diatoms we found species of *Halamphora, Mastogloia, Cocconeis, Navicula, Nitzschia, Licmophora, Achnanthes* and *Rhopalodia*.

In spite of comparatively low number of species the assemblages of microphytes on the film was clearly tiered with strictly ordered elements of architecture. All 5 species of *Calothrix* and *Dichothrix gypsophila* had trichome covered with multilayered transparent sheaths that hide the lower part of their trichomes.

This morphological feature is a beneficial adaptation, which allowed them to develop in relatively “greenhouse” conditions, reducing the aggressive effects of light, temperature drops and the mechanical effects of waves – in a hydrodynamically active and light-saturated environment in the subsurface of the sea. The larger species with raised trichomes formed upper layer of the assemblage: *C. scopulorum* and *C. parietina.* Their patches with 0.7-1.2 mm thickness covered up to 60-70% of the film surface, when the exfoliated sheaths protected the microphytes assemblage from the aggressive environment. The second more lower layer of trichomes was formed by spreading patches of *D. gypsophila*, 0.3–0.4 mm height. And finally, small patches of three more species C*alothrix fusca, C. fusca* f. *parva. C. brevissima* grown on both sides of the film rising above the surface on 70–100 μm. *C. brevissima* was represented by very small groups with several trichomes in the thinnest sheaths.

The layer of cyanobacterial trichomes grown on the polyethylene film was not continuous, but they were grouped along the shallow deformations and cracks, and especially densely in the places of branching of cracks.

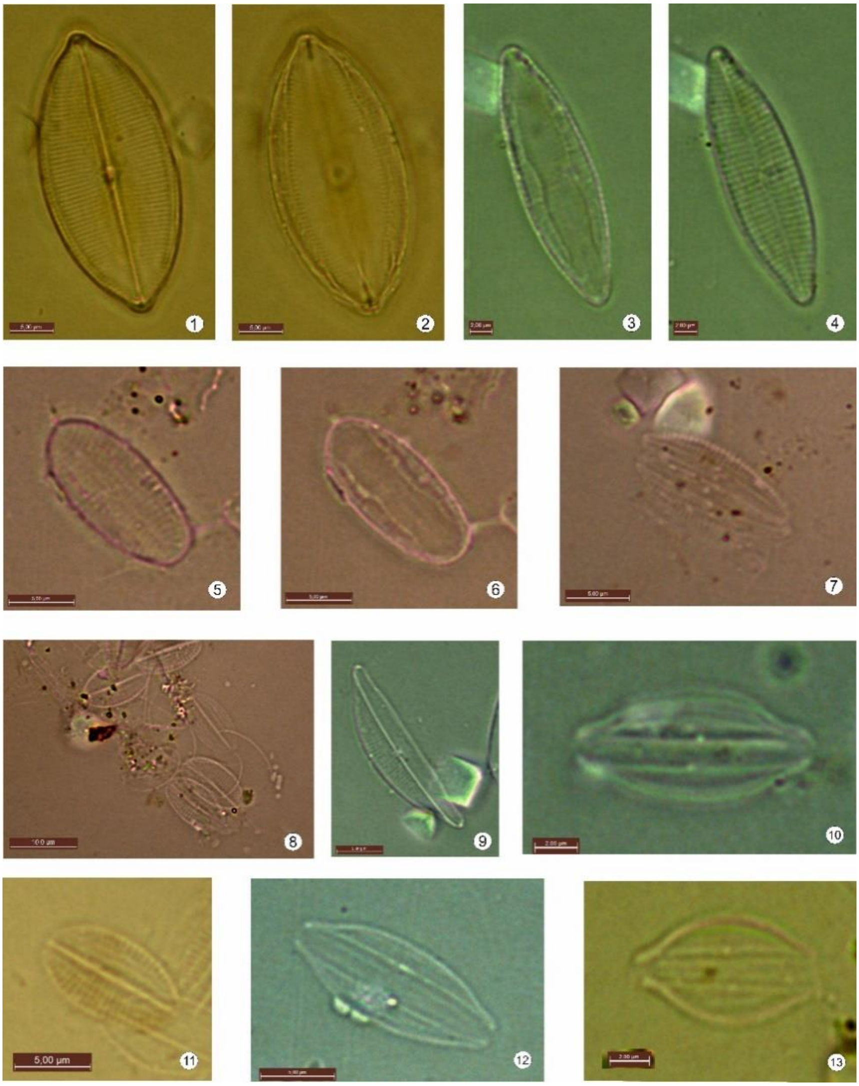

Figure 2. Bacillariophyta on the polyethylene film in neustoplastics of the North Black Sea: 1, 2 – *Mastogloia lanceolata* Thwaites ex W.Smith, 3, 4 – *M. pusilla* Grunow; 5, 6 – *M.* aff. *urveae* Witkowski; 7 – *Halamphora* aff. *luciae* (Cholnoky) Levkov; 8, 11 – *Cocconeis* aff. *neothumensis* Krammer; 9, 10, 12 – *H.* aff. *coffeaeformis* (C.Agardh) Levkov; 13 – *H.* aff. *tenerrima* (Aleem et Hustedt) Levkov.

Three species of *Mastogloia* genus that form polysaccharide capsules, were located in various tiers of the assemblage. *M. lanceolata* was the most abundant and presented in three size modifications. The shortest one but wide with the following parameters: 27.9–34.3 μm length (on average 31.2 μm) and 13.2–16.1

μm width (on average 14.8 μm) – was registered in thick-walled capsules only on the sheaths` surface of *C. scopulorum* and *C. parietina*. Moderate in size form with parameters: 34.3–41.8 μm length (on average 39.3 μm) and 14.1–17.3 μm width (on average 15.9 μm) in thinner capsules dwelled the sheaths` surface of *D. gypsophila* as well as directly on the film under the cyanobacteria and on opened surfaces of the polyethylene. At least the biggest form of *Mastogloia* with parameters 45.5–47.6 μm length (on average 46.4 μm) and 16.9–18.5 μm width (on average 17.3 μm) – placed in thick capsules was met predominantly wider open places on the film surface, that were not fouled with cyanobacteria.

Mastogloia pusilla and *M*. aff. *urveae* with capsules occurred much less frequent, the percentage ratio of density was the following: *M. lanceolata : M. pusilla : M.* aff. *urveae* ≈ 80.39:15.69:3.92. The last two species had the cells sizes 21.3– 25.5 × 6.5–7.4 μm (on average 24 × 7 μm) and 14.2–23.9 × 6.6–11.2 μm (on average 19 × 8.9 μm), respectively. Both species dwell on the surface of sheaths of *C. scopulorum, C. parietina* и *D. gypsophila* in the lower part of their patches. They were not registered directly on the film.

Besides the encapsulated forms of diatoms that were protected from the aggressive impact of environment with the help of secreted polymers (polysaccharides), the 4 species of attached diatoms were massively registered. These were *Halamphora* aff. *coffeaeformis, H.* aff. *tenerrima, H.* aff. *luciae* and *Cocconeis* aff. *neothumensis,* which used the sheaths in the bases of patches of bigger species *Calothrix* and *D. gypsophila* as a substrate (or a hideout).

Table 1. Cells sizes of attached species of Bacillariophyta in the basis of the sheaths in patches of *Calothrix* spp. *Dichothrix gypsophila* from polyethylene film of neustoplastic in the North Black Sea

Species	**Length (μm)**			**Width (μm)**		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
Halamphora aff. *tenerrima*	6.2	13	9.8	3.9	7	5.4
Halamphora aff. *coffeaeformis*	11.3	21	14.5	3.7	6.7	5.7
Halamphora aff. *luciae*	8.5	14.5	11.6	4.3	6.6	5.4
Cocconeis aff. *neothumensis*	8.6	11.1	10.1	4.5	6.7	5.7

The average data on the valves lengths of nonencapsulated attached forms of diatoms did not exceed 15 μm (with maximum 21 μm) (Table 1). These were relatively small species that were compactly placed under the cover of polymer sheaths of cyanobacteria. Small cells of *Cocconeis* aff. *neothumensis* formed colonial settlements, which were especially dense and widely spread over the substrate. In its settlement other species were rarely met. Accumulation of small species such as *H.* aff. *tenerrima u H.* aff. *luciae* was registered rising on the sheaths of *Calothrix* spp. The mid-size *H.* aff. *coffeaeformis* did not form the colonies. They were met basically in peripheral part of the fouling of other species. The percentage ratio of species density is the following: *C.* aff. *neothumensis : H. tenerrima : H. coffeaeformis : H.* aff. *luciae* ≈ 32.71 : 44.86 : 17.29 : 5.14. It is worth mentioning that directly on the PE-film these species were not register. Besides in the neustoplastic assemblage single cells of highly mobile species such as *Navicula pontica* and *Nitzschia dissipata* were met.

Microphytes assemblages on the neustonic polyethylene terephthalate bottle

In September 2018, we studied the microphytes fouling on the surface of PET-bottle that floated on the surface of the sea in conditions of periodical eutrophication – on this location of water area once a day was a discharge of waste waters from the city.

The thickness of the microphytes fouling made about 1.3-1.5 mm. We also observed the layering of the community. However, it was hard to strictly interpret the peculiarities of the horological structure. The assemblage was formed by mosaic scattered spots with different spatial organization. It is quite possible that growth of the fouling under conditions of intensive hydrodynamics and excessive lighting (as aggressive factors) was flavored with a constant influx of nutrients (nitrogen and phosphorus compounds). Such a regular stuffing of “fertilizers” contributed to a decrease in competition for nutrient resources among the microphytes that inhabited the substrate.

For example, as a part of the upper layer, we met an extensive, almost monospecific patches of filamentous cyanobacteria *Leptolyngbya foveolarum*, as well as very large colonies of the diatom *Neosynedra provincialis*, formed by branching chains of long cells, in some places braided by trichomes of *Symploca elegans* (Figure 3, 4). Among the colonies of *N. provincialis*, tubular colonies of diatoms such as *Berkeleya* aff. *sparsa* and *Parlibellus delognei*. Here, the formation of small loose colonies of coccoid cyanobacteria *Asterocapsa salina* and *Chroococcus* cf. *montanus*, as well as compact aggregates of the diatoms *Halamphora eunotia* and *H. obscura* took place. Single cells of *Halamphora tenerrima* were met. Note that these *Halamphora* species also formed the lowest level of the community, where they lived in colonial settlements, together with *Amphora helenensis* and *Seminavis strigosa*.

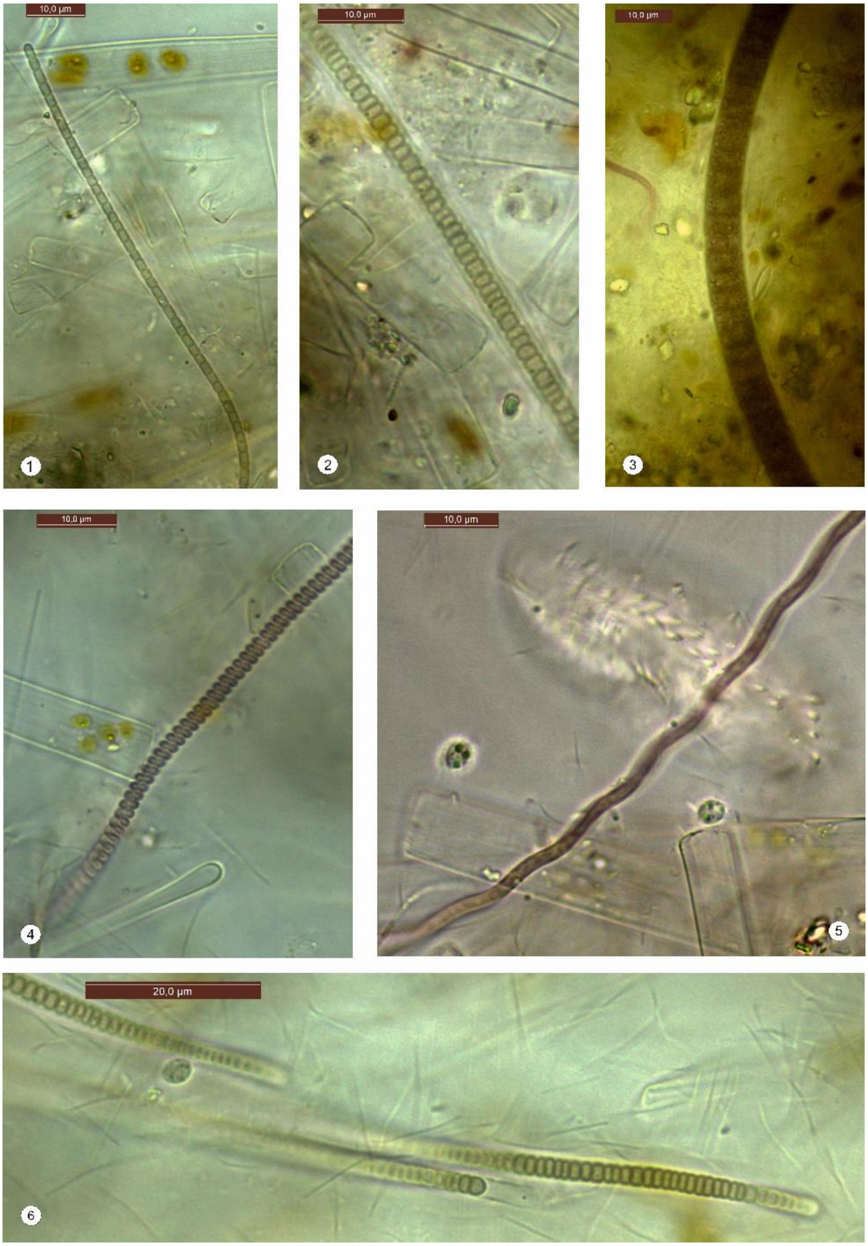

Figure 3. Cyanobacterial fouling on polyethylene terephthalate in neustoplastics of the North Black Sea: 1 – *Symploca elegans*, 2, 6 – *Leptolyngbia foveolarum*; 3 – *Phormidium* sp.; 4 – *Spirulina subsalsa*; 5 – *Limnothrix* aff. *pseudovacuolata*.

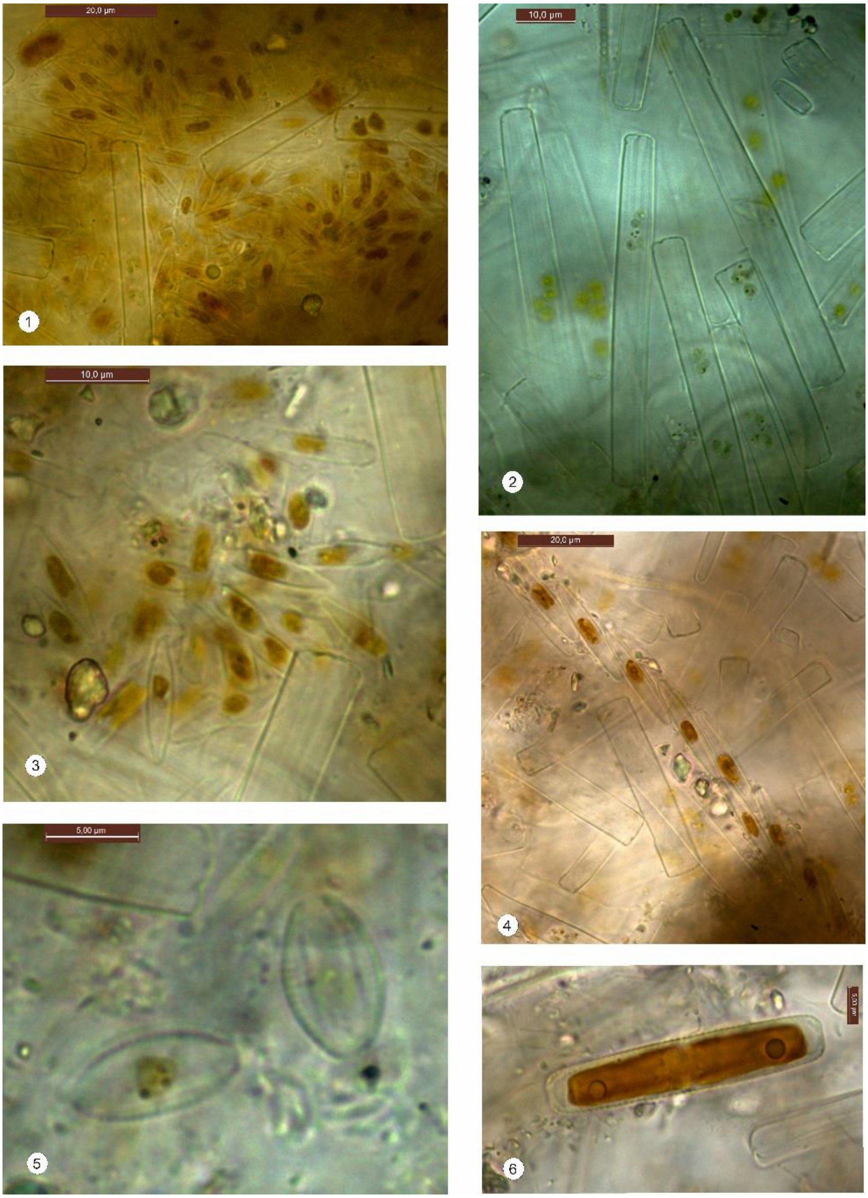

Figure 4. Bacillariophyta on polyethylene terephthalate in neustoplastics of the North Black Sea: 1 – *Neosynedra provincialis* and colonies of *Proshkinia bulnheimii*; 2 – *Neosynedra provincialis; 3* - colonies of *Proshkinia bulnheimii*; 4 – colonies of *Berkeleya* aff. *sparsa*; 5 – *Amphora helenensis*; 6 – *Navicula pontica*.

In addition, quite independent spots on the surface of the bottle were formed by mucilage colonies of the diatom *Proschkinia bulnheimii* – their branches in some places penetrated into the colonies of other species. Among the patches of colonial forms an individual trichomes of *Phormidium* sp., *Geitlerinema* sp., *L. foveolarum, Limnothrix* aff. *pseudovacuolata* and *Spirulina subsalsa*, motile diatoms *Navicula pontica* and *Entomoneis punctulata*, as well as dinoflagellates *Prorocentrum lima* were often met. Among the colonies of microphytes, small colonies of heterotrophic bacteria developed in mass.

We see that under the described conditions a multispecific and structurally diverse periphyton rather quickly developed on PET-bottle. However, at this stage of fouling development, no damage corresponding to the destructive activity of microphytes was observed on the surface of the PET.

This assemblage was absolutely different from what we observed on the PE film. Moreover, it was much more diverse than the microphytes fouling formed on the piers and traverses located in the bay. There, in the zone of intense impact of the waves, assemblage of cyanobacteria composed of *Asterocapsa salina, Placoma vesiculosa, Gloeocapsopsis* sp. 1, *Gloeocapsopsis* sp. 2 and *Calothrix* sp. 1. For the most part, they built compact colonies from very densely located cells immersed in a common polymer matrix.

So, the rolling waves had a much stronger effect on the diversity of assemblage in this biotope – their kinetic energy during impacts on the traverses could be much higher than those that passed under a PET bottle dangling on the surface 200 m from the coast. This factor can be regarded as significantly more extreme than rocking on the waves.

Conclusion

The assemblage on the surface of PE-film that was studied in the period of maximum biodiversity (in the beginning of October) the formation of microphytes fouling in the supralittoral of the Black Sea was poorer than assemblage of coastal rocks. However, we should note that the studied extremotolerant assemblage differed in significant order of its components: presence of layering, microhabitat localization of certain species and size modification of others. Such an architecture of the community testifies the forming of specific adaptations of microphytes to the living on poorly studied on PE-substrate that is widely spread in the Black Sea

We suppose that compact groups of trichomes that grow along the deformed sectors of PE-film surface, including cracks, might mechanically influence the substrate that led to its destruction. Their tight attachment and growing wide may assist mechanical widening of deformations and taking into account the loss of elasticity of the film, this should have led to the deepening and growth of cracks. The diatom fouling, which massively developed on the sheaths in base of patches, could have additional abrasive effect on the substrate.

In turn, microphytes fouling on a PET bottle was characterized by a significantly higher diversity compare to the epilithic community of microphytes on coastal rocky substrates. It is worth taking into account that the factor of a less aggressive effect of surface waves on a bottle swinging on waves far from the shore than on shore protection structures. In the result of the study of the microphytes fouling formation of the plastics` surface in a strongly eutrophic zone we conclude the following. Firstly, taking into account the growth rate of the layer of living microphytes on PET, it can be assumed that after 3-4 months the fouling can reach such a power and weight that it will easily pull the bottle under water if the air can escape from the bottle. The second important moment is that the rapid formation of a multi-species microphytes fouling on PET in case of available tiering (not even too obvious) gives reason to expect a further increase in the diversity of this structure and the complexity of its architecture, in accordance with the ecological features of the new species.

In the presence of similar environmental conditions in these regions of the Black Sea, the assemblage that was formed on PET had wider plastic ecological capabilities than on PE. As prerequisites for this, it makes sense to consider the higher strength and lower elasticity of PET in comparison with PE, as well as the fact that the assemblage here was formed under initially more severe conditions – on the very surface of the water. The second reason significantly narrows the range of adaptive capabilities of the early colonizers: they must grow rapidly, forming powerful colonies that protect their cells well from direct sunlight and preserve moisture with non-periodic drying of the substrate.

Together with the assessment of the microphytes fouling formation in nature, our group conducts the various experiments either in the laboratory, or in natural conditions. The results of these experiments let us find out the adaptive strategies of microalgae during colonization of the artificial polymers, as well as to understand the principles of organization of multispecies mosaic structures and their role in biodestruction of marine plastics. This is especially relevant when in the result of Covid-19 Pandemia the great amount of individual protection equipment that are made mainly from plastics, occurred in the seas and oceans.

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Microplastics in bivalves in the southern Black Sea

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Abstract

Presence of microplastics in five bivalve species in the southern Black Sea was investigated for the first time. Bivalve species *Donax trunculus* (Linnaeus 1758), *Chamelea gallina* (Linnaeus 1758), *Abra alba* (W. Wood 1802), *Anadara inaequivalvis* (Bruguière 1789) and *Pitar rudis* (Poli 1795) were collected from River Yeşilırmak and River Melet mouths in June 2020. Microplastics were found in all bivalve species, except for *Abra alba*. A total of 92 microplastics were found in 89 individuals analysed. The average number of microplastics ranged from 1.69 to 4 mp.ind^{-1}. Fibres were the most common type of microplastic type in each bivalve species, followed by fragments and films. No microbead was found. The most common size class was 1-2 mm (34 %). A total of 9 different colours of microplastics were found with black and blue being the prevalent colours. Our results suggest that microplastic pollution in bivalves collected from southern Black Sea is relatively high, suggesting trophic transfer in the food web and risk for human by contaminated diets.

Keywords: Bivalve, Mollusca, microplastic, ingestion, southern Black Sea

Introduction

World plastic production is increasing exponentially and reached to 360 million tons in 2018 (Plastics Europe 2019). Substantial amounts of this production reach the marine ecosystem from multiple sources. It has been estimated that between 15 and 51 trillion plastic particles, weighing up to 236,000 tons have accumulated globally in marine ecosystems (Van Sebille *et al.* 2015). Because of the widespread use and persistent nature of them, plastics are now becoming ubiquitous in marine waters, sediments and organisms (Yang *et al.* 2015; Andrady 2011; Bosker *et al.* 2017).

Seafood represents an important pathway for microplastics (< 5 mm) (MPs) and associated toxic contaminants for humans (Teng *et al.* 2019). Filter feeders such as bivalves directly take MPs within their prey or take them accidentally (Li *et al.* 2015). Bivalves are probably one of the largest sources MPs for humans, as they are consumed as a whole in seafood (Lusher *et al.* 2017). High intake of MPs by bivalves have been reported by many studies (Van Cauwenberghe and Janssen 2014; Van Cauwenberghe *et al*. 2015; Li *et al.* 2016; Digka *et al.* 2018; Capolupo *et al.* 2018; Abidli *et al.* 2019; Naudi 2019). The concentration of MPs in bivalves was reported as significantly higher in the regions where human activities are intense (Li *et al*. 2016). Thus, they are an important bio-indicator species for monitoring MP pollution (Van Cauwenberghe *et al.* 2015; Wesch *et al.* 2016; Li *et al.* 2016; Lusher *et al.* 2017; Qu *et al.* 2018; Li *et al.* 2019).

Black Sea is the drainage area of multiple industrialized countries (BSC 2007; Aytan *et al.* 2016). Rivers transport substantial amounts of plastic litter to the basin (BSC 2007). Plastic constitutes > 80 % of marine litter in the sea floor, sea surface and on beaches (e.g. Topcu and Oztürk 2010; Guneroglu 2010; Topcu *et al.* 2013; Aytan *et al.* 2016). Recent estimations showed that Black Sea has almost two times more plastics compare to neighbouring Mediterranean Sea (EMBLAS Plus 2019). Microplastics are an emerging contaminant of concern in the Black Sea (Bosker *et al.* 2017). Recent studies reported high concentrations of MPs from the surface waters of the SE Black Sea and highlighted the importance of land-based sources (Aytan *et al.* 2016; Oztekin and Bat 2017).

Although studies on occurrence and sources of MPs in the seawater and sediment have increased in the last years (e.g. Aytan *et al.* 2016; Oztekin and Bat 2017; Berov and Klayn 2020), there is still limited knowledge on occurrence, ingestion and their effects on biota in the Black Sea. The structure and functioning of the macro benthic community in the Black Sea is one of the important indicators in assessing ecological health (BSC 2007). The aim of this study was to determine the presence of MPs in bivalves. For the first time, MPs in five common species of bivalves, collected from the mouth of two important rivers in the southern Black Sea, were assessed.

Materials and Methods

Study area and sampling

Sediment samples were collected in the southern Black Sea on board of R/V KARADENIZ ARAŞTIRMA during June 2020 as a part of TUBITAK project 118Y125. Sediment samples were taken from the mouth (app. 5 m depth) of River Yeşilırmak and River Melet by box corer. Sediment samples were sieved from 5 mm stainless steel sieve to collect the bivalve samples. Bivalve species were taken and stored in glass bottles containing 96% ethyl alcohol until the laboratory analysis.

Figure 1. Sampling areas in the southern Black Sea (ST1: River Yeşilırmak (Samsun), ST2: River Melet (Ordu)

Laboratory Analysis

A total of 89 individuals belonging to 5 bivalve species *Donax trunculus* (Linnaeus 1758), *Chamelea gallina* (Linnaeus 1758), *Abra alba* (W. Wood 1802), *Anadara inaequivalvis* (Bruguière 1789) and *Pitar rudis* (Poli 1795) were chosen (Figure 2). Total length (mm) (TL), total height (mm) (TH), total weight (gr) (TW) and soft tissue weight (mm) (STW) were recorded for each individual (Table 1).

Figure 2. Bivalve species. **a.** *Chamelea gallina* (Linnaeus 1758), **b.** *Donax trunculus* (Linnaeus 1758), **c.** *Abra alba* (W. Wood 1802), **d.** *Anadara inaequivalvis* (Bruguière 1789), **e.** *Pitar rudis* (Poli 1795)

Soft tissues of bivalves were rinsed with Milli-Q water and were placed in glass bottles. 10% KOH solution were added to glass bottles and covered with aluminium foil. 10% KOH solution, which is considered to provide the most efficient removal of soft tissue, while protecting microplastics, was used (Thiele *et al.* 2019). Samples were kept at 40° C for 48 hours. When the biological material was completely removed, samples were filtered on 10 µm filters. Filters were transferred into the glass petri dishes and left to dry in the oven.

Presence of MPs was visualised under a ZEISS Stemi 508 stereo microscope and their images were taken with an integrated digital camera. Microplastics were classified by types (fibres, fragments, films and microbeads) and colour. The largest cross sections of MPs were measured and classified into 4 size categories: 0.1mm - 0.5mm, 0.5mm - 1mm, 1mm – 2mm, 2mm-5mm. Suspected items were checked whether they were plastics or not using the hot needle test (Hermsen et *al.* 2018).

Table 1. The number of individual (n), total length (TL), total height (TH), total width (TW), soft tissue weight (STW) of bivalve species analysed

Species	n	TL (mm)	TH (mm)	TW (gr)	STW (gr)
D. trunculus	51	14.53±2.03	8.72±1.25	0.37±0.23	0.13±0.09
C. gallina	31	17.08±3.76	15.18±3.22	1.55±1.00	0.37±0.24
A. alba	4	17.02±1.35	12.27±0.91	0.48±0.12	0.19±0.02
A. inaequivalvis	2	38.89±9.85	31.62±8.32	15.22±7.53	5.38±3.22
P. rudis	1	34.64	28.81	4.20	1.84

All laboratory analysis was conducted under strict clean-air conditions. To prevent contamination, Cotton laboratory coats were worn and working surfaces were cleaned. All the equipment was cleaned by ultra-pure water before used. During all step of the analyses, procedural blanks were performed simultaneously with samples to control air-born contamination and filters were checked under microscope prior to use. Petri dishes with dampened filters were kept next to the sample during microscopic examinations and checked for presence of MPs. In case similar particles were found in the control samples they were excluded from the analysis (Foekema *et al.* 2013).

The number of MPs in each individual was counted and the mean MP ingestion was calculated for all species (mp.ind^{-1}). The mean frequency of occurrence (FO %) of MPs calculated for each species. To compare the number of MPs among bivalve species a one-way analysis of variance (ANOVA) was performed. Significance level was considered for $P < 0.05$ in all statistical analyses.

Results and Discussion

For the first time five bivalve species *Donax trunculus* (Linnaeus 1758), *Chamelea gallina* (Linnaeus 1758), *Abra alba* (W. Wood 1802), *Anadara inaequivalvis* (Bruguière 1789) and *Pitar rudis* (Poli 1795), which are common in Black Sea coastal waters, were examined for the presence of microplastic.

Microplastics were found in all species analysed except for *A. alba,* most likely due to the low number of individuals analysed for this species. The total of 92 MPs were found in 47 (53 %) of the 89 individuals examined. Three types of MPs were found. Fibres (66 %) were the most common type, followed by films (25 %) and fragments (9 %) (Figure 3). No microbeads or foam was found. Fibres and films were found in the individuals of *D. turunculus*, *C. gallina*, *A. inqequvalvis* and *P. rudis,* however fragments were only found in *D. turunculus* and *C. gallina*.

Our results support previous studies that fibres are the most common type of MPs reported from bivalves (Devriese *et al.* 2015; Li *et al.* 2016). Fibres were also reported as common type of MPs from surface waters of the SE Black Sea (Aytan *et al.* 2016). Composition and concentration of MPs ingested by bivalves indicates the status of pollution in their area (Li *et al.* 2019) and prevalence of fibres suggests land-based pollution sources such as sewage and run-offs.

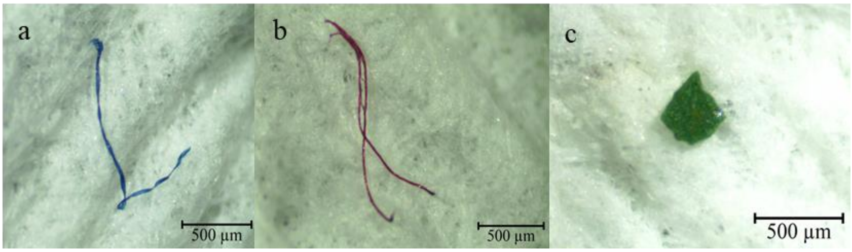

Figure 3. Examples of microplastic types found in bivalve species (a: film, b: fibre, c: fragment)

The average concentration of MPs ranged from 1.69 and 4 mp.ind^{-1} (Table 2). A maximum of seven MPs were found in an individual. Reported concentrations of MPs in bivalve species varies between studies from all around the world (Table 3). Our results are consistent with reports from the Mediterranean Sea (Avio *et al.* 2017; Digka *et al.* 2018) and coastal waters of China (Li *et al.* 2016; 2018; Teng *et al.* 2019) but higher than the study on the French Atlantic coast (Phuong *et al.* 2018). Differences between studies are most likely a result of different concentrations and compositions of MPs in the water column and in sediment and of methodological differences.

In this study, frequency of occurrence of MPs was 57 % in *D. trunculus* and 48% in *C. gallina*. Our values are very close to the study conducted in the Mediterranean Sea (45-47 %) (Digka *et al.* 2018) and higher than the study reported from the Italian coast (10-36 %) (Avio *et al.* 2017). Frequency of occurrence was 100 % for *A. inaequivalvis* and *P. rudis,* most likely due to the low number of species analysed. Significant differences in the number of MPs among bivalve species was found ($p < 0.05$, one-way ANOVA).

Size of MPs found in bivalves varied between 0.15 and 4.56 mm in size, the most dominant size group was 1-2 mm. Average size for MPs were 1.44 ± 0.88, 1.42 ± 0.93, 0.40 ± 0.21 mm for films, fibres and fragments, respectively. The most dominant size group was 1mm – 2mm in films and fibres, and 0.1-0.5mm for fragments. During the study, two mesoplastics (> 5 mm) in the form of fibres were found (5.74-10.40 mm) (Figure 4). The size of MPs in bivalves found in this study is the same range and order of previous studies (Table 3).

Table 2. Total number of bivalve species analysed, total number of individuals with microplastic, feeding occurrence (FO %), total number of microplastics found in bivalve species and average concentration of microplastics in in each bivalve species

Species	No of ind. analysed	Ind. with MP	FO %	No of MP	Conc. of MP
Donax trunculus	51	29	57	49	1.69
Chamelia gallina	31	15	48	31	2.07
Anadara inaequivalvis	2	2	100	8	4
Pitar rudis	1	1	100	4	4
Abra alba	4	0	0	0	0
	89	**47**	**53**	**92**	**1.95**

Table 3. Comparison with previous studies

Location	mp.ind^{-1}	Type	Colour	Size (mm)	Reference
China	1.5-1.7	Fibre	-	0.03-4.7	Li *et al.* 2016
Mediterranean	1.7 ± 0.2	Fragment	Blue	0.1-5	Digka *et al.* 2018
China	1.4 -7.0	Fibre	Light colours	<0.1	Li *et al.* 2018
Italia	-	Fibre	Black, Blue	0.75–6	Renzi *et al.* 2018
France	0.6 ± 0.6	Fragment	Grey	0.03-2	Phuong *et al.* 2018
China	2.93	Fibre	-	<1.5	Teng *et al.* 2019
Italia	1-2	Fragment	-	0.1-5	Avio *et al.* 2017
Black Sea	1.69-4	Fibre	Black, Blue	0.15-4.56	This study

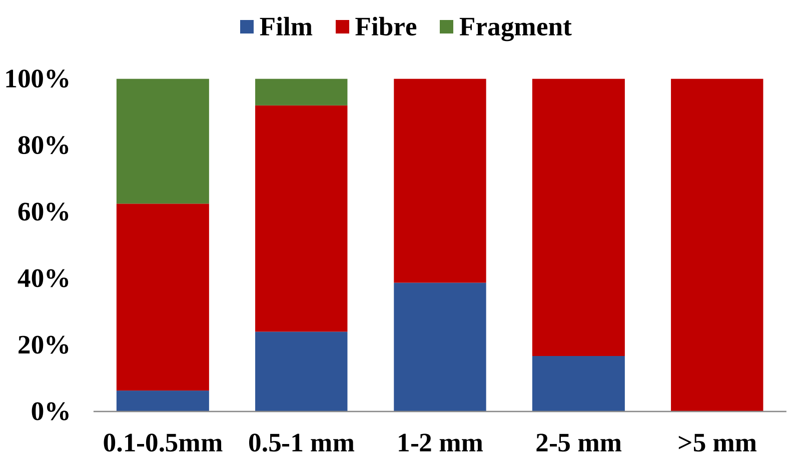

Figure 4. Percentage of size distribution of microplastics in bivalve species

A total of nine different colours MPs found in bivalves (Figure 5). Blue (43 %) was the most dominant colour, followed by black (32 %), green (7 %), orange (7 %), red (4 %), transparent (4 %), white (1 %), yellow (1 %) and pink (1 %). The most diverse colours were observed in the fibres followed by the fragments. While blue was dominant colour of films and fibres, green colour was dominant colours of fragments (Figure 5). The prevalence colours of black and blue found in present study agrees with reports from Mediterranean Sea (Table 3).

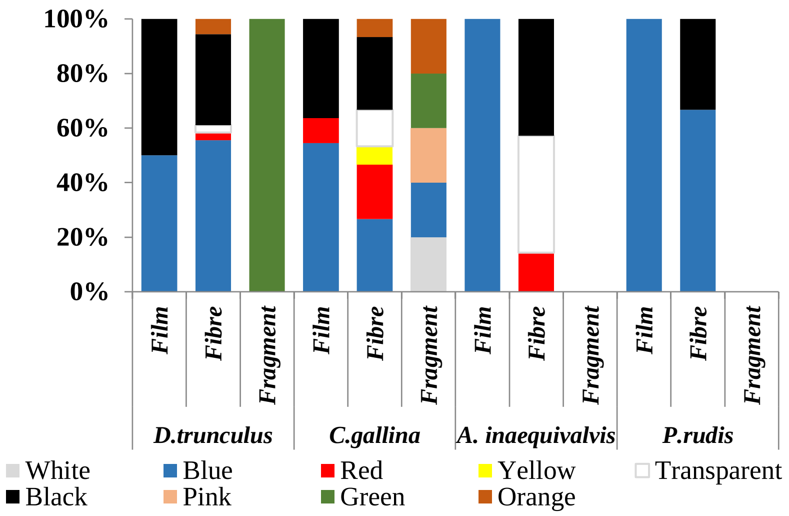

Figure 5. Percentage of colours of microplastics in each bivalve species

Conclusion

There is an increasing awareness that MPs are a ubiquitous contaminant in marine environment including biota. This calls for suitable indicators to monitor trends of MP pollution. Bivalves have been widely used as bioindicator species for monitoring coastal pollution and are now being reported to contain significantly amounts of MPs. In this study, we evaluated MP ingestion in five common bivalve species in the southern Black Sea. The results revealed that around half of the bivalve analysed contained MP. This shows that bivalve species are vulnerable to MP contamination, representing a potential risk to human health. The most common forms of MP was fibres, which is an evidence of land-based pollution sources in the study area. Our results suggest that bivalves can be used as a potential bioindicator of MP pollution of coastal waters in the Black Sea. There is an urgent need to investigate uptake, accumulation and toxicity of MPs in both field and experimental studies.

Acknowledgements

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Presence of microplastics in zooplankton and planktivorous fish in the southeastern Black Sea

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Abstract

Present work provides preliminary results that microplastics are present in critical components of the Black Sea pelagic food web, namely in copepods and planktivorous fish European anchovy. A total of 6 and 8 microplastics were detected after the examination of 2136 *Acartia* (*Acartiura*) *clausi* and 2123 *Calanus euxinus*, resulting in microplastics ingestion of 0.002 par/*Acartia* (one MP for every 356 *Acartia*) and 0.004 par/*Calanus* (one MP for every 265 *Calanus*), respectively. The microplastic size was in the same range of natural preys of these copepods. Fragments were the most common type of ingested microplastics, followed by film. Colour of ingested particles were black, blue and red. Regarding MP presence in planktivorous fish, we examined the digestive tract content of 230 individuals of European anchovy. A total of 57 microplastics were found in 47 fishes, representing a presence of MP in 20 % of fish analysed. Fibres were the most common microplastics, followed by films and fragments. The findings show presence of microplastic in both copepods and European anchovy, calling for urgent investigations on effects of microplastics on biota and human health.

Keywords: Microplastic, zooplankton, European anchovy, ingestion, Black Sea

Introduction

Plastic is one of the major waste disposal problems in the world. Global annual production continues to increased (360 million tons in 2018, Plastics Europe 2019) and ~ 5% of this production has been estimated to end in the ocean (Jambeck *et al*. 2015), making up the majority of marine litter (Derraik 2002). Once plastic enters the marine environment, it breakdowns into smaller particles called as microplastic (< 5 mm) which further fragment into nanoplastics (<100 nm) (Arthur *et al.* 2009). Microplastics (MPs) also include primary particles produced in microscopic sizes including granulates used in cosmetics, washing powders, cleaning agents or pellets (Fendall and Sewell 2009). Because of their durability, MPs then become widely abundant and may require centuries to decompose (Moore 2008; Barnes *et al.* 2009).

The MP sizes are in the same range of plankton, therefore they are bioavailable for many marine organisms (Wright *et al.* 2013). Once MPs are ingested, they can enter the food web (e.g. Setala *et al.* 2014) with potential ecotoxicological effects due to adsorption of persistent, bioaccumulative and toxic pollutants (e.g. Martins and Sobral 2011). Recent studies have shown that filter feeders and zooplankton ingest MPs (Cole *et al.* 2013; Steer *et al.* 2017; Botterell *et al.* 2019) and that MP-associated contaminants may transfer through food chain into human diets (Zarfl and Matthies 2010). The effects of MP ingestion on vital functions of zooplankton such as growth, reproduction, survival rates, nutritional behaviour, and life cycle has been reported in experimental studies (Botterell *et al.* 2019).

Zooplankton plays an important role in the marine food web, linking between primary producers and higher trophic levels (Steinberg and Landry 2017), and by producing faecal pellets important for benthic organisms (Turner 2002). The zooplankton in the Black Sea is less diverse, but more abundant, when compared to neighbouring Mediterranean Sea (BSC 2007). Any changes in the function of zooplankton due to the MPs might negatively affect the whole ecosystem, particularly the fish stocks.

Ingestion of MPs by fishes has also been reported from many other regions in the world (e.g. Davison and Asch 2011; Boerger *et al.* 2010; Lusher *et al.* 2013; Compa *et al.* 2018) but this has not yet been quantified for Black Sea. Relatively high concentration of microplastics in the surface waters of the Black Sea was reported in recent studies (Aytan *et al.* 2016; Öztekin and Bat 2017; Berov and Klayn 2020). The SE Black Sea is an important area for feeding, spawning and nursery grounds for commercially important fishes (FAO 2015), thus bioavailability of MPs has to be understand as much as possible.

European anchovy (*Engraulis encrasicolus*) is small pelagic fish that distributes throughout the Black Sea. European anchovy is among the species most consumed, and commercially, it is the most important fish landed in Turkish Black Sea national ports (TUIK 2019). European anchovy feed on plankton over a broad size-spectrum, from small phytoplankton cells up to large crustaceans and fish eggs. European anchovy can directly feed on MPs or indirectly by trophic transfer (through zooplankton), however, there is no yet published study on the presence of MPs in fish in the Black Sea.

This study provides preliminary results on the most likely pathways of MPs in the pelagic food web of the SE Black Sea and risks affecting commercial fish stocks and consumers. In the present study, we assessed the presence of MPs in copepods, which are the dominant zooplankton group in the Black Sea, and in planktivorous fish European anchovy.

Materials and Methods

Assessment of Presence of MPs in Zooplankton

Presence of MPs in zooplankton were assessed in the SE Black Sea as a part of TUBITAK 117Y207 project. Sampling were carried out at 12 stations located in the SE Black Sea (Figure 1) during August 2015, November 2015, February 2016, May 2016 and August 2016. (Table 1). Zooplankton samples were collected from upper boundary of anoxic waters (sigma theta 16.2) to surface by WP2 net (0.38 m^{-2} opening, 200-µm mesh). To collect all MPs samples stocked, net was washed with seawater. Samples were immediately transferred into the glass bottle and preserved in 4% borax-buffered formaldehyde.

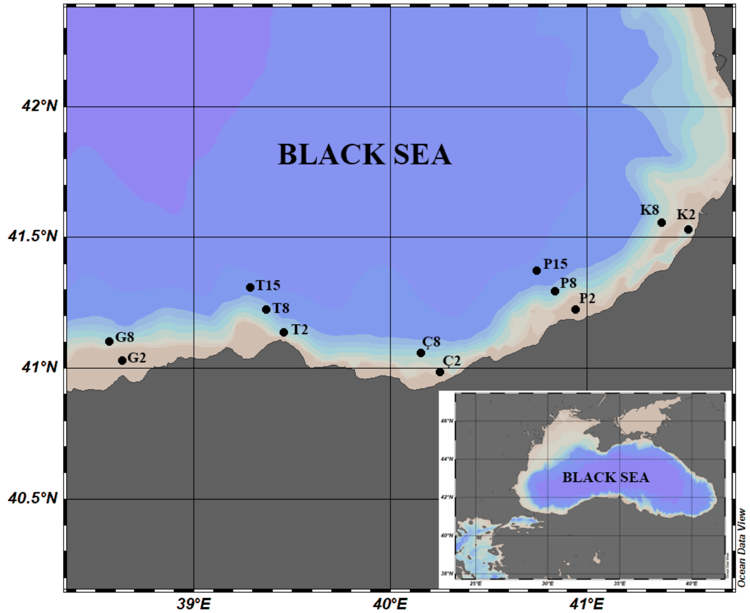

Figure 1. Sampling stations

In the laboratory, the dominant zooplankton species *Acartia* (*Acartiura*) *clausi* Giesbrecht, 1889 and *Calanus euxinus* Hulsemann, 1991 were chosen for assessment of MP ingestion. Individuals of copepods were picked out by using a forceps and Pasteur pipette using a Zeiss Stemi Stereo microscope. Each specimen was examined for externally adhered MPs, rinsed with deionized water several times and placed into single wells of glass-coated polypropylene 96-well plates (Desforges *et al.* 2015). Hydrogen peroxide (30 %) was added to each well till covering each individual. Then plates were covered with glass slides and kept at 40°C until all organic tissue was removed (app. 4-6 h). After that, for the presence of MPs, plates were directly examined under a Zeiss Stemi Stereo microscope (zoom range 8:1, 0.63 objective with 259/10 ocular lenses), armed with a camera (Figure 2). When MPs were found, they were counted, and the colour and shape (i.e., fibre, fragment, and film) was noted. The largest cross sections of MPs were measured by an image analysis software. Microplastics were identified according to morphological characteristics and physical response features (Desforges *et al.* 2014).

Table 1. Distance from the shore, depths and coordinates of sampling stations and the sampling dates

Station	Distance (nm)	Depth (m)	Latitude (N)	Longitude (E)	Sampling dates
G2	2	650	41º 01’ 51”	38º 38’ 14”	17-18.08.2015 14-17.11.2015 09-10.02.2016 23-27.05.2016 02-03.08.2016
T2	2	400	41º 10’ 24”	39º 25’ 23”	
C2	2	400	40º 59’ 44”	40º 14’ 27”	
P2	2	450	41º 14’ 27”	40º 54’ 32”	
K2	2	120	41º 31’ 48”	41º 30’ 29”	
G8	8	1300	41º 06’ 07”	38º 34’ 39”	
T8	8	500	41º 15’ 37”	39º 21’ 07”	
C8	8	750	41º 04’ 02”	40º 07’ 46”	
P8	8	1500	41º 19’ 28”	40º 49’ 09”	
K8	8	350	41º 35’ 11”	40º 23’ 42”	
T15	15	1700	41º 21’ 04”	39º 15’ 27”	
P15	15	1500	41º 24’ 33”	40º 42’ 52”	

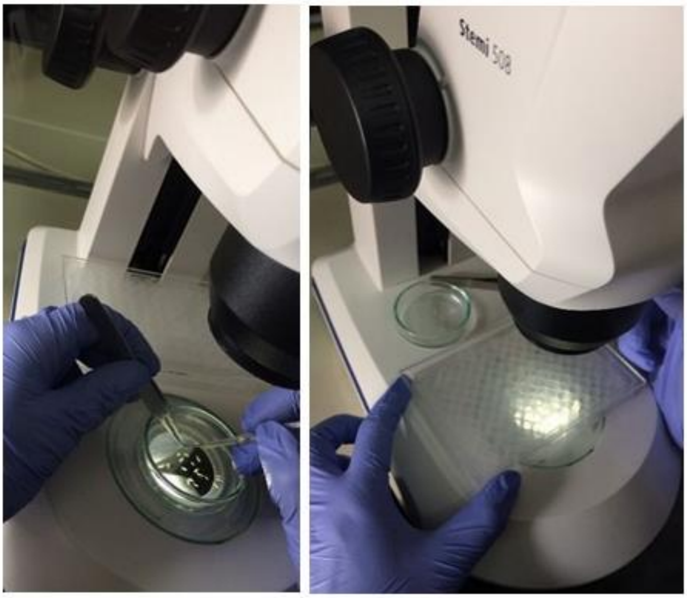

Figure 2. Analyses of microplastics in copepods

Microplastic ingestion encounter rate (ER) was calculated as total number of MP ingested, divided by the total number of copepods analysed (Desforges *et al.* 2015). One-way ANOVA was used to compare the MP encounter rates and size/shape/colour of MPs ingested between copepod species.

Assessment of Presence of MPs in European Anchovy

European anchovy (*Engraulis encrasicolus* Linnaeus, 1758) was obtained from cooperative research with local fishermen in January 2019. For each individual, the weight (TW, nearest 0.1 g) and the total length (TL, nearest 0.1 g) were recorded. The entire gastrointestinal tracks (GIT) of each fish from the upper part of the oesophagus to the anal opening was dissected and the weight (nearest 0.1 g) was recorded (Lusher *et al.* 2013). GIT was rinsed with Milli-Q water, transferred into the glass beakers and HNO_3 (63 %) was added to remove biological material (Desforges *et al.* 2015). Beakers were covered with aluminium foil and kept at 40°C till all the organic tissue removed. Then, dissolved solutions were filtered on 10-micron mesh and placed into petri dish with lids and dried using oven (temperature < 40 °C). Presence of potential MPs were visualised under a Leica SAPO Stereo microscope, and their images of were taken with an integrated digital camera. Microplastics were classified into shapes (fibres, fragments, films, foams and microbeads) and colour (black, blue, red, white, transparent, green, yellow, grey, pink and purple). The largest cross sections of MPs were measured and classified to five size classes (≤0.5 mm, 0.5-1 mm, 1-2mm, 2-5 mm). Suspected items were checked whether they were plastics or not using the hot needle test (Hermsen *et al.* 2018). GIT sampling and content analysis was conducted under strict clean-air conditions. The mean MP concentration was calculated (mp.ind^{-1}). The mean frequency of occurrence (FO %) of MPs in all examined GITs was calculated.

Contamination control

To prevent contamination, cotton laboratory coats were worn. Working surfaces and all equipment was cleaned by ultra-pure water before used. During all steps of the analyses, several procedural blanks were performed simultaneously with sample processing. To account for a potential air borne contamination, dampened PCTE filters in a petri dish were placed for every stage of the laboratory work. In case contamination was noted in control samples, particles were excluded from the data.

Results and Discussion

Microplastics in Copepods

After analysis of 2136 individuals of *A. clausi* and 2123 individuals of *C. euxinus*, a total of 6 and 8 MPs were found, respectively (Table 2). Microplastic ingestion encounter rate was calculated as 0.002 par/*Acartia* and 0.004 par/*Calanus* for *A.*

clausi, and *C. euxinus*. These results on MP ingestion encounter rate are lower compared to studies conducted in the NE Pacific Ocean (Desforges *et al.* 2015), in the East China Sea (Sun *et al.* 2017) and coastal waters of Kenya (Kosore *et al.* 2018). Fragments (50 %) and films (50 %) were found in *A. clausi*, whereas only fragments were found in *C. euxinus*. In the NE Pacific, the primary shape of MPs ingested by copepods was also found as fragment (Desforges *et al.* 2015).

Colour of MPs were red and black in *A. clausi* and red, black and blue in *C. euxinus*, in agreement with the results from Kenya coastal waters (Kosore *et al.* 2018) and NE Pacific (Desforges *et al.* 2015). Colour is an important factor that might increases the selectivity and attractiveness of MPs. The observed MP colours could be related to the colour of their natural prey (Wright *et al.* 2013).

The size of MPs varied from 0.104 to 0.153 mm (mean 0.121±0.128 mm) for fragments and 0.021 to 0.051 mm (mean 0.038± 0.015 mm) for films in *A. clausi* and 0.033 to 0.163 mm (mean 0.066±0.043 mm) for fragments in *C. euxinus*. The sizes of MPs ingested by the *A. clausi* and *C. euxinus* coincide with the size range of their prey (phytoplankton, microzooplankton and marine snow/aggregation) in their natural environment.

Table 2. Number of *Acartia* (*Acartiura*) *clausi* and *Calanus euxinus* analysed (N), total number (N), size (mm), shape and colour of microplastics found in copepods, encounter rates (ER=number of MPs/copepod).

Copepod		**Microplastic**				
Species	**N**	**N**	**Size**	**Shape**	**Colour**	**ER**
A.clausi	2136	6	0.121±0.128 0.038± 0.015	Fragment Film	Black Red	0.002
C.euxinus	2123	8	0.066±0.043	Fragment	Black Blue Red	0.004

No significant differences were found on MP ingestion by *A. clausi* and *C. euxinus* between sampling date and stations (one-way ANOVA, $p>0.05$), most possibly due to the low number of MPs found.

Microplastics in European Anchovy

In total, 57 MPs were found in GIT of 20 % (n=47) of the total number of European anchovy analysed (n=230). A maximum of three MPs was found in a single individual of European anchovy. The mean MP ingestion was 0.25 particles per fish (considering all the fish analysed, n=230) and was 1.21 particle per fish (considering the fish that ingested them, n=47). The mean MP ingestion by European anchovies in previous reports from Mediterranean varied between, and within geographic regions (Table 3).

Tree types of microplastics were found in the GIT of fish analysed; fibre, film (Figure 3) and fragment. No foam or microbeads were found. Fibres (53 %) were the primarily shapes of MPs, followed by films (37 %) and fragments (10%) (Figure 4). Fibres were also usually reported as the primary shape ingested by European Anchovies in the Mediterranean Sea (Table 3). Ingested MP size ranged between 0.07-4.94 mm, with the majority being < 2 mm (75 %). Our results for the size of ingested MPs are in the same range of size reported by Lefebvre *et al.* (2019) and Renzi *et al.* (2019) from the NW and Northern Mediterranean Sea, respectively.

Table 3. Comparison with previous studies from Mediterranean Sea (Number of fish analyzed (N), Frequency of occurrence (FO), Ingestion rate (IR), size (mm), primary shape and color of ingested microplastics).

Location	N	FO	IR	Size	Shape	Color	Reference
NW Mediterranean Sea	20	40	0.85	0.32 ± 0.10	-	-	Collard *et al.* 2015
Western Mediterranean Sea	105	15	0.07-0.33	0.12 ± 0.06	Fibre	Blue	Compa *et al.* 2018
NW Mediterranean Sea	84	11	0.11 ± 0.31	1.81 ± 1.52	Fibre	Red	Lefebvre *et al*. 2019
Western Mediterranean Sea	39	2.56	0.07± 0.26	-	-	-	Rios-Foster *et al.* 2019
Northern Mediterranean Sea	-	91	1.25	0.04-2.22	Fibre	-	Renzi *et al.* 2019
Eastern Mediterranean Sea	-	83.4	2.5 ± 0.3	-	Fragmnet	-	Kazaour *et al.* 2019
SE Black Sea	230	20	0.25 ± 0.57	1.55 ± 1.29	Fibre	Black	This study

A total of ten different colours of microplastics found in the GIT of the fish (Figure 5). The most prevalent MP colours were black (16 %), blue (13 %), transparent (13 %) and red (10 %). Blue and red were also reported to be the dominant colours of ingested MPs in European anchovies the Mediterranean Sea (Table 3).

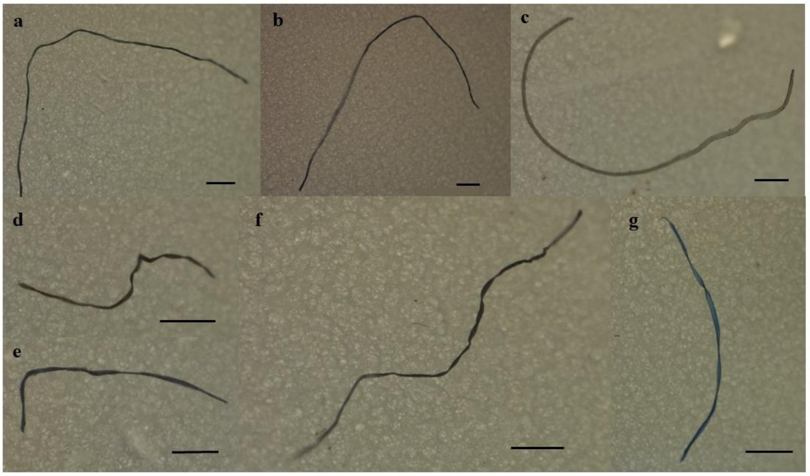

Figure 3. Examples of ingested fibres (a-c) and films (d-g) (Scale bar =200 μm)

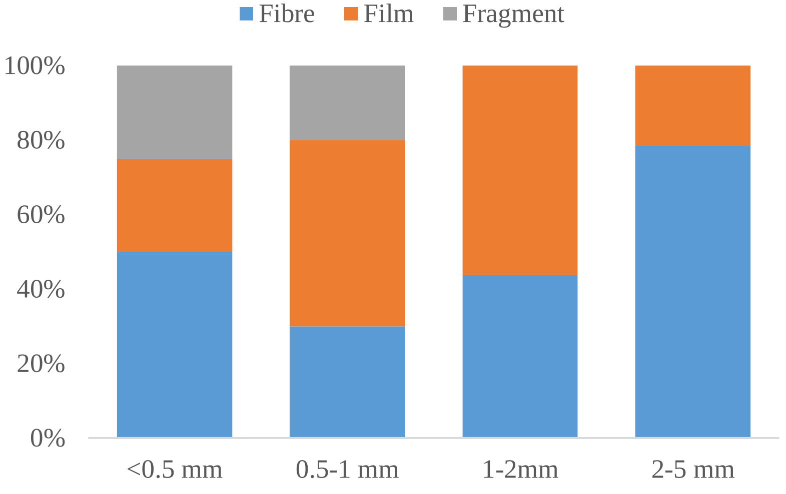

Figure 4. Size distribution of ingested microplastics

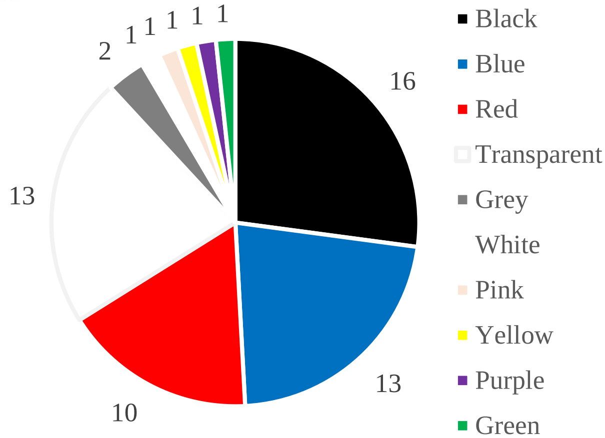

Figure 5. Colours of ingested MPs (%)

Conclusion

Recent studies have shown the presence of MPs in Black Sea, suggesting that plastic is bioavailable to commercially and ecologically important species. Here, we provide evidence of plastic ingestion by zooplankton and the commercially important species European Anchovy. Copepods are a key component of the pelagic food web and could be acting as a vector for MPs transfer to upper trophic levels. European anchovy is a filter-feeder with a high risk of ingesting MP both directly and indirectly (through zooplankton) and thus most likely to accumulate MP-associated contaminants. The effects of MP ingestion on vital functions of zooplankton and fish such as growth, reproduction, survival rates, nutritional behaviour, and life cycle needs to be understood and a public health risk by diet needs to be considered.

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Chemicals associated with plastics and their ecological risks

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Abstract

Because of its numerous social benefits, plastics hold an important place in human society. Plastic, a man-made material, is cheap, strong, durable, light weight and easy to produce. Plastics usually contain additives (e.g., plasticizers, surfactants, flame retardants, anti-microbials, UV filters), depending on the type of plastic (composition), synthesis route, and degree of material purification. Microplastic uptake can also lead to exposure of organisms to additive chemicals. Plastics debris, especially microplastics, has been found worldwide in all marine environment. Many researches has been studied on adsorbed pollutants on plastic pieces associated with microplastics. However, only a few studies have focused on plastic additives. These chemicals are incorporated into plastics, which they can leach out as most of them are not chemically bound. As a consequence of plastic accumulation and fragmentation in oceans, plastic additives could represent an increasing ecotoxicological risk for marine organisms. This study reviewed some important plastic additives identified in the literature, their occurrence in the marine environment. Phthalates (phthalic acid esters) **(**PAEs), organophosphates (OPEs) and bisphenol A (BPA) the most common plastic additives. In addition, the transfer of these plastic additives to marine organisms has been demonstrated in many studies. New research focusing on the toxicity of microplastics should include these plastic additives as potential hazards to marine organisms, and now more attention should be given to the transport and fate of plastic additives, considering that these chemicals can easily leak out of plastics.

Keywords: Plastic additives**,** phthalic acid esters, organophosphates, bisphenol A, microplastic

Introduction

Plastics production, which started in the 1950s, increased from 225 million tons in 2004 to 322 million tons in 2015 and increased by 43% in the last decade (Plastics Europe 2016). Plastic materials occupy an important place in many activities of human life. Many types of chemicals are mixed with polymers for plastic production. Plastic materials represent a huge group of organic-based polymers, and many different commercial varieties are available. Plastics usually contain additives (e.g. plasticizers, flame retardants, antioxidants, light and heat stabilizers, lubricants, pigments, antistatic agents, surfactants, anti-microbials, UV filters) depending on the type of plastic (composition), the path of synthesis and the degree of material purification (Baini *et al.* 2016; Hansen *et al.* 2013). These additives can significantly increase polymer properties and give some specific qualification (e.g., flexibility strength and color). Due to their physical and chemical properties, plastic spills are associated with a "chemical cocktail", including what should be plastic material (e.g., monomers and additives). These chemical products can leak at every stage of the life cycle of a plastic product (from production to use, disposal) and tend to accumulate in the environment (Baini *et al.* 2016). The uptake of microplastics by the organisms may also cause the organisms to be exposed to additional chemicals. Some of these additive chemicals may leak into the environment and are biologically available and toxic to marine organism. Organic additives can infiltrate both seawater and biological fluids. When additive chemicals leak into seawater, from plastic debris, they are bioavailable to marine organisms and that they can cause acute and sub lethal toxic effects in marine organisms, including algae and mussels (Loughlin 2018). This chapter is focused on some additive groups selected, based on concerns about the frequency of use and possible risks of the chemicals it contains. Current information for these substances used in plastic production and likely to be found in plastic end products has been compiled. Phthalic acid esters (PAEs), organophosphate esters (OPEs), bisphenol A (BPA) additive chemicals used to improve the mechanical performance of a plastic are discussed in this context.

Commonly used chemical additives in plastics

Plastic materials are not just plastic polymers. Formulas with different additives are used to improve the processing properties, performance and aging properties of the plastic compound (Hermabessiere *et al.* 2017). The type of additive depends on the plastic polymer and the requirements of the final product. Plastic additives are used in different typical amount rates (% w/w) as **functional additives** (plasticizers (10-70), flame retardants (3–25 (for brominated) 0.7-3), stabilizers, antioxidants and UV stabilizers (0.05-3), heat stabilizers (0.5-3), slip agents (0.1–3), lubricants (0.1–3; internal and external), anti-statics (0.1-1), curing agents (0.1-2), biocides (0.001-1) and blowing agents), **colorants additives** (soluble (e.g., azocolorants (0.25-5)), organic pigments (0.001-2.5), inorganic pigments (0.01-10), special effect), **filler additives** (up to 50) and **reinforcement additives** (15-30) (Hansen *et al.* 2013). Common plastic additives functions and potential effects are given in Table 1 (Hermabessiere *et al.* 2017).

Some organics such as Phthalates (PAEs), organophosphate esters (OPEs), and bisphenols (BPs) are widely used as an additive in a wide variety of products such as detergents (PAEs), textile products (OPEs, PAEs), dyes (OPEs, PAEs, BPs) foods containers (PAEs, BPs) and above all plastics (OPEs, PAEs, BPs) (Schmidt *et al.* 2020).

Table 1. Common plastic additives and their functions and potential effects

Additives	Function	Effects
Brominated Flame Retardants (BFR)	Reduce flammability in plastic. Also adsorbed on plastic from the surrounding environment.	Potential endocrine disruptors
Phthalates	Plasticizers to soften plastic mainly in polyvinyl chloride	Endocrine disruptors
Nonylphenol	Antioxidant and plasticizer in some plastics	Endocrine disruptors
Bisphenol A	Monomer in polycarbonate and resins, Antioxidant in some plastics.	Endocrine disruptors Endocrine mimic
Irganox®	Antioxidant in some plastics.	

In environmental studies, it has been determined that the most commonly used additive chemicals in plastic production are bromine flame retardants, phthalates used as plasticizers, nonylphenols, bisphenol A and antioxidants. Additives have recently started to attract attention as much as plastic particles and their transfer to marine organisms have been demonstrated in both laboratory and field studies. Plastic additive chemicals described with their associated octanol-water partition coefficient (K_{ow}). K_{ow} has been used for predicting how a chemical will concentrate in marine organisms and an increase in log K_{ow} indicates an increase in the potential bioconcentration in organisms (Hermabessiere *et al.* 2017; Net *et al.* 2015a).

Plasticizers have been used as polymer additives since the nineteenth century. The most important use of plasticizers is the plastic industry. Polyvinyl chloride (PVC), the main component of the plastic industry, is the third most produced synthetic plastic polymer after polyethylene (PE) and polypropylene (PP). In 2014, 8.4 million tons of plasticizers were produced in the global plastic market and 80-90% of the total production was used in the PVC industry (Chanda *et al.* 2007; Stepek *et al.* 1983).

Additives include inorganic fillers such as carbon and silica that reinforce the material, plasticizers to render the material pliable, thermal and ultraviolet stabilizers, flame-retardants and colourings. Many such additives are used in substantial quantities and in a wide range of products (Meeker *et al.* 2009). Due to the use of certain chemical additives during the manufacture of plastics, plastics can be carcinogenic or have potentially risk and harmful effects that could be carcinogenic or encourage endocrine disruption. Humans are exposed to the chemicals through the skin, nose, or mouth. Although the exposure level varies depending on geography and age, most individuals experience simultaneous exposure to lots of these chemicals (Thompson *et al.* 2010; Godswill and Godspel 2019).

Phthalic acid esters (PAEs)

Phthalic acid esters (PAE) or phthalates are a widely used as plasticizers in order to make plastics such as PVC more elastic and flexible (Yuan *et al.* 2002). Phthalates (PAEs) are phthalic acid (1,2-benzene dicarboxylic acid) esters with two carbon chains of different lengths and constitute the largest synthetic chemical class with a production volume of 6,000,000 tons / year (Xie *et al.* 2007). It is a family of synthetic compounds used as the main additive to improve the flexibility, transparency, durability and longevity of plastics (Campanale *et al.* 2020). Phthalates are known worldwide as the most produced and consumed plasticizers and make up about 92% of the produced plasticizers (Rahman *et al.* 2004; He *et al.* 2013). PVC can contain 10% to 60% phthalates by weight (Net *et al.* 2015a). Phthalates are not chemically bound to the polymer matrix, they can easily leach into the environment during manufacturing, use and disposal (Net *et al.* 2015b). PAEs have been found in a wide range of environments and this is of concern, since some phthalates have been defined as endocrine disruptors, even at low concentrations (Net *et al.* 2015a). Common phthalates and primary application are given Table 2.

Epidemiology and toxicology studies demonstrated that some PAE congeners, such as di-n-butyl phthalate (DBP), butyl benzyl phthalate (BBP), di(2-ethylhexyl) phthalate (DEHP) and their metabolites can act as environmental hormones that could cause instability in internal secretions and procreation (Kavlock *et al.* 2002). DEHP is considered an animal carcinogen that is also potentially carcinogenic to humans per a report from the International Agency for Research on Cancer. Due to the potential health and environmental risks, six PAEs, i.e., dimethyl phthalate (DMP), diethyl phthalate (DEP), di-n-butly phthalate (DBP), benzyl butyl phthalate (BBP), diethylhexyl phthalate (DEHP) and di-n-octyl phthalate (DOP), were listed as priority pollutants by the United States Environmental Protection Agency (U.S. EPA) (Li *et al.* 2017).

PAEs are among the most abundant organic plastic additives, which could be released to the environment during polymer degradation/aging (Meng *et al.* 2014; Net *et al.* 2015b; Paluselli *et al.* 2019). PAEs measurement has been carried out in many matrixes such as atmosphere (Lai *et al.* 2015), food/estuarine food web (Cao 2010; Brandsma *et al.* 2015), lake water (Gao *et al.* 2019; Zheng *et al.* 2014), fresh waters (Schmidt *et al.* 2019; Sung *et al.* 2003), drinking water (Ding *et al.* 2015), environmental water (Luo *et al.* 2012; Li *et al.* 2008; Ling *et al.* 2007; Wu *et al.* 2013), surface water (He *et al.* 2013; Song *et al.* 2016), marine water (Hu *et al.* 2014; Paluselli *et al.* 2018), treated wastewater (Al-Saleh *et al.* 2017; Clara *et al.* 2010), sediment (Cao *et al.* 2017; Wang *et al.* 2017; Xu and Li, 2008), wastewater treatment plant sludges (Zeng *et al.* 2014; Meng *et al.* 2014; Gao *et al.* 2014).

Table 2. Common phthalates and primary applications

Name/Abbreviation/Formula	Application
Di- n-butly phthalate / DBP / $C_{16}H_{22}0_4$	PVC, PVA and rubber
Diethylhexyl phthalate, (Di-2-Ethylhexyl Phthalate) / DEHP / $C_{24}H_{38}O_4$	PVC (dolls, shoes, raincoat, clothing, medical devices, plastic tubing and intravenous storage bags)
Diisononyl phthalate / DINP /$C_{26}H_{42}O_4$	PVC (teethers, rattles, balls, spoons, toys, gloves, drinking straws)
Diisodecyl phthalate / DIDP / $C_{28}H_{46}O_4$	PVC (electrical cords, leather for car interiors and PVC flooring)
Benzyl butyl phthalate / BBP / $C_{19}H_{20}O_4$	PVC, polyurethane, polysulfide (vinyl flooring, sealants, adhesives, car care products, automotive trim, food conveyor belts, food wrapping material and artificial leather)
Dimethyl phthalate / DMP / $C_{10}H_{10}O_4$	PVC, used in the manufacture of a variety of products including plastics, insect repellents, safety glass, and lacquer coatings
Diethyl phthalate / DEP / $C_{12}H_{14}O_4$	PVC, used as a plasticizer in products such as automobile parts, tools, and food packaging
Dibutyl phthalate / DnBP / $C_{16}H_{22}O_4$	Commonly used plasticizer, some nail polishes, also used as an additive in adhesives or printing inks
Diisobutyl phthalate / DiBP / $C_{16}H_{22}O_4$	Used as a plasticizer consumer products, including paints, lacquers, printing ink, pulp and paper, carpet, concrete, nail polish, and cosmetics
Benzylbutyl phthalate / BzBP / $C_{19}H_{20}O_4$	PVC, used in other products such as food conveyor belts, carpet tile, artificial leather, tarps, automotive trim, weather stripping.

Organophosphate esters (OPEs)

One of the most commonly used groups as a plasticizing and flame retardant additive is organophosphates. They are also known as organophosphate esters (OPEs). The additives are not chemically bound to the plastic polymer in almost any case; only some flame-retardants polymerize with plastic molecules and become part of the polymeric chain (Hahladakis *et al.* 2018). OPEs have the potential to easily leak into the environment through evaporation, corrosion and dissolution, since they are not chemically bound to the polymer product (Wei *et al.* 2015). Common organophosphates and their primary applications are given Table 3.

Flame-retardants have the function of cooling or protecting a material by preventing oxidation of flammable gases in the event of fire or by creating a layer of ash (Dufton 1998). Because bromide flame-retardants have limited use and are banned, organophosphorus compounds are widely used worldwide due to their flame retardant and plasticizing properties. Generally, halogenated OPEs are used as flame-retardants and halogen-free OPEs are used as plasticizers (Van der Veen *et al.* 2012). OPEs are also known to be used for many years in electronic equipment, plastic products, rubbers, textiles and building materials (Reemtsma *et al.* 2008). It has been observed in extensive studies on humans and animals that some OPEs exhibit biological effects, including in humans (e.g. hemolytic and reproductive effects of TCP and TCEP), neurotoxic, carcinogenic, mutagenic and hormone impairments (Andresen and Bester 2004; Lai *et al.* 2015; Zeng *et al.* 2014).

Table 3. Common organophosphates and primary applications

Name / Abbreviation / Formula	Application
Tripropyl phosphate / TPP / $C_9H_{21}O_4P$	Used as a plasticizer, in hydraulic fluid, as a solvent and extractant for metal ions and as a heat exchange age.
Tri-iso-buthyl phosphate / TiBP / $C_{12}H_{27}O_4P$	PVC, TiBP is used in hydraulic fluids, as strong wetting agent in the textile industry and as antifoam agent.
Tri-n-butyl phosphate / TnBP / $C_4H_9O)_3PO$	used as a plasticizer, in hydraulic fluid, as a solvent and extractant for metal ions, and as a heat exchange agent.
Tri (2-chloroethyl) phosphate / TCEP / $C_6H_{12}CI_3O_4P$	Flame retardant, added to consumer and industrial products for the purpose of reducing flammability.
Tris (2-chloroisopropyl) phosphate / TCPP / $C_9H_{18}CI_3O_4P$	Flame retardants, added to consumer and industrial products for the purpose of reducing flammability.
Triphenyl phosphate / TPhP / $OP(OC_6H_6)$	Flame retardants, added to consumer and industrial products for the purpose of reducing flammability.
2- ethylhexyl-diphenyl phosphate / EHDPP / $C_{20}H_{27}O_4P$	Used as a plasticizer. It is used in food packaging plastic wraps and tubing for sausages.
Tris (2-ethylhexyl) phosphate / TEHP / $C_{24}H_{51}O_4P$	General adhesives and binding agents for a variety of uses.

Metabolic toxicity of OPEs to other species are reported frequently, which indicates OPEs'potential health risks to human beings. For this reason, it has prohibited the use of tris-(2-chloroethyl) phosphate (TCEP) in products for children under the age of three since 2013. TCEP and tris-(1,3-dichloro-2-propyl) phosphate (TDCPP) have been banned from use in children's products and home furniture since 2014 because of their toxicity (Zhong *et al.* 2018). However, there is still a lack of information regarding temporal trends of OPEs, especially in the coastal area. Recently there is increased interest in understanding their environmental fate and transport. Research on OPEs in different matrices has been carried out in the world such as fish (Guo *et al.* 2017), water (Lee *et al.* 2018; Liu *et al.* 2013; Chung and Ding 2009; Bollmann *et al.* 2012), bottled water (Mousa *et al.* 2013), aquatic environment (Martínez-carballo *et al.* 2007), sediment (Wang *et al.* 2017; Zhong *et al.* 2018; Lee *et al.* 2018; Cao *et al.* 2012), air and soil (Kurt-karakus *et al.* 2018; Jian-xia *et al.* 2014; Mihajlovic *et al.* 2011).

The occurrence and fate of OPEs in the aquatic ecosystem is of great concern and prioritized issue due to their toxic and deleterious effects on water, sediments, and biota. Water solubility and octanol-water partition coefficient (log K_{ow}) are important physicochemical properties of organic pollutants that govern their behavior in the aquatic environment. Since most of the OPEs are lipophilic and difficult to dissolve in water. They have a tendency to bind to suspended particulate matters and accumulate in sediments (van der Veen and de Boer 2012).

Bisphenol A (BPA)

Bisphenols (BPs), known for their endocrine-disrupting properties, which have led to various national and international bans and regulations, are still used in the production of thermal paper, plastic bottles and food can linings, among other items (Danzl *et al.* 2009; Björnsdotter *et al.* 2017). Bisphenols have been detected in sediment and seawater samples (Pojana *et al.* 2007; Xie *et al.* 2018) as well as in the atmosphere, where the presence of bisphenol A (BPA) has been linked to plastic burning (Fu *et al.* 2010).

Bisphenol A (BPA) associated compounds (alkylphenols) with chemical formula $(CH_3)_2C(C_6H_4OH)_2$, are found in several products used in daily life such as dental sealants, cladding layers of tin cans, bottle caps, tooth adhesives, CDs and DVDs, electronic equipment, and vehicle parts. It is a solid, colorless and soluble in organic solvents. Bisphenol A (2,2-bis-(4-hy-droxyphenyl) propane, was first synthesized in 1905 and reported in 1936. BPA. It is obtained by condensing phenol with acetone using strong acidic ion exchange resin as a catalyst in gel form (Vandenberg *et al.* 2009; Wei *et al.* 2011). BPA is poorly soluble in water; 0.344 wt percent at 83 °C (Fiege *et al.* 2000). In addition, thermal papers contain BPA in free or unpolymerized form (2.3% by weight) and therefore BPA contamination can occur during paper recycling (Mendum *et al.* 2011; Geens *et al.* 2012; Russo *et al.* 2017).

Global production of BPA exceeds 3 million tons per year, of which 700,000 are produced and consumed in the European Union. Because of this huge use of these products, BPA is dispersed in several environments (soils, seawater, landfill leachates, sewage treatment plant discharges). Some studies have shown that BPA is bioaccumulative and affect the endocrine systems of living organisms and are harmful to human health (Ahmed 2016). BPA is an important non-naturally occurring commercial chemical used to improve the mechanical properties of plastics. BPA is used in the production of polycarbonate plastic (e.

g., lining layer of aluminium cans), epoxy resins, flame retardants and rubber chemicals, in the production of unsaturated polyester and polysulfone resins, thermal papers (plugs), food packaging products (canned coatings, canister coatings, plastic bottles, bottle caps), in various products used in daily life (Repossi *et al.* 2016; Tsai 2006; Vandenberg *et al.* 2009). BPA is also used as an antioxidant or plasticizer in other polymers (PP, PE and PVC). Many countries around the world, especially Germany, the Netherlands, the USA and Japan, have large BPA production capacities (Vandenberg *et al.* 2009; Wei *et al.* 2011). BPA consumption in the world is thought to be 7.7 million metric tons in 2015, and it is estimated to reach 10.6 million metric tons in 2016 with an annual growth rate of 8 million metric tons and 4.8% in 2022 (Almeida and Almeida-gonz 2018). One of the most common plastic additives found in marine environments is bisphenol A (BPA).

Many researches have been conducted on Bisphenol A in various matrices such as **biota**; fish (Basheer *et al.* 2004; Lee *et al.* 2015; Belfroid *et al.* 2002; Wei *et al.* 2011; Mita *et al.* 2011;), mussel (Gatidou *et al.* 2010; Belfroid *et al.* 2002), **water;** sea water (Belfroid *et al.* 2002; Heemken *et al.* 2001), fresh water (Belfroid *et al.* 2002; Kang and Kondo 2006; Staples *et al.* 2000; Kawahata *et al.* 2004; Hashimoto *et al.* 2005; Bolz *et al.* 2001; Stachel *et al.* 2003; Heemken *et al.* 2001) and **sediment** (Kawahata *et al.* 2004; Bolz *et al.* 2001; Heemken *et al.* 2001; Stachel *et al.* 2005; Peng *et al.* 2006).

For many years BPA was threatened human health. Detection of BPA in the natural environment, in drinking water, and food products has aroused the interest of many researchers since 1990. The same time, negative effect of this compound on human health was established. Consequently, in 1996 the European Commission as a substance of external origin classified BPA with a harmful effect on human health. Numerous toxicological and biochemical studies have confirmed that bisphenol A has estrogenic properties and an agonistic effect toward the estrogenic receptor. In recent studies bisphenol A was classified as a xenobiotic disturbing hormonal balance in humans and other animals, a so-called endocrine disruptor (Rykowska and Wasiak 2006).

Conclusions

In recent years, advances in materials science and engineering have led to widespread and diverse uses of plastics to provide cheaper, lighter, stronger, safer, more durable and versatile products and consumer goods that serve to improve our quality of life. Today, the presence of plastic material in the receiving environment, its effects on ecology and human health are better known. Recent work has shown that the oceanic gyres are not the accumulation endpoint of floating plastic debris, but merely an intermediate step, with plastics rapidly disappearing to as yet unknown sinks in marine ecosystems. Many kind chemical additives (e.g., plasticizers, surfactants, flame retardants, anti-microbials, UV filters), used in plastic is cause concern. In the use, disposal and recycling phase of plastic products, the environmental effects of various additives raise concerns and cause concern by many scientists. The main concern of plastics or microplastic pollution is whether it poses a risk to ecosystems and human health. Negative effects on organisms exposed to microplastics can be divided into two categories; physical effects and chemical effects. Limited information is available on the chemicals effects that are associated with microplastics. How toxic chemicals adsorb/desorb onto/from microplastics is not well known, but reasonable mechanisms include hydrophobic interactions, pH variations, the ageing of particles, and polymer composition. Furthermore, not enough studies have fully explained the primary sources of pollutants that are present on microplastics and whether their origin is extrinsic from the surrounding ambient space, intrinsic from the plastic itself, or, more probably, from a combination of both and from a continuous and dynamic process of absorption and desorption that is related to the spread of the particles into the environment and to their consequent exposure to weathering. Many chemicals classified as hazardous according to EU regulations are used in the manufacture of plastics. Bisphenol A, phthalates, as well as some of the brominated flame retardants (organophosphates) used to pack home products and food have been proven to be endocrine disruptors that can harm human health if swallowed or inhaled. It has been reported by scientists that plastic particles and additive chemicals cause very different problems such as drowning and death for marine organism. Finally, it is worth noting that the above contaminants are already included in the main European directives regulating the production and use of chemicals (REACH, European Water Framework Directive). Characterization and quantity of plastic additives associated with microplastics in the marine environment needs to be examined. However, little is known about the distribution, of these compounds in seawater, sediment as well as on their transfer in the marine food web, mainly because of analytical difficulties. Today, more research is needed about microplastics and additive chemicals pollution, especially in vulnerable ecosystems such as the Black Sea, which have a large number of freshwater inputs with high potential to transport plastic pollutants.

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Perspectives and challenges of implementation of Regional Action Plan on Marine Litter Management in the Black Sea

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Abstract

This paper will consider the challenges and legal gaps in the implementation of relevant provisions of the Regional Action Plan on Marine Litter Management in the Black Sea, adopted in 2018 by the Commission on the Protection of the Black Sea Against Pollution (BSC) and other relevant marine litter related documents. It will also provide some concrete recommendations on improving the implementation of BS ML RAP and achieving of good environmental status (GES) in the Black Sea basin as regards to marine litter and plastics. As indicates the recent report on the State of the Black Sea Environment, marine litter makes the Black Sea a particularly sensitive area for marine litter pollution and a microplastic hot spot. There is no doubt that marine litter becomes one of the main pollution problem along the coasts of the Black Sea, the sea itself and its bottom. There are more and more acknowledgments about contamination of leaving resources by plastics; therefore, marine litter is no longer an aesthetic problem, but seriously damages the living organisms and threatening the biodiversity of the Black Sea. At the same time, despite all the problems listed above, there is still very limited data on amounts of marine litter in the Black Sea and poor monitoring activities; the results of the local surveys (few national and couple of regional surveys implemented within dedicated marine litter projects) show that disposable packaging and short life or even single use plastic goods (like bottles, cans, caps) are predominant; the sources mostly are municipal waste/sewage, badly managed landfills, marine transport and ports, recreational activities in coastal areas, illegal and unreported fishing activities. Therefore, considering that marine litter is to a large extent cross-cutting and a transboundary issue, mostly due to enclosed sea basin and dynamic current system of the Black Sea, it must be further coordinated and addressed on the regional or sub-basin level.

Keywords: Marine litter, Bucharest Convention, Black Sea, Regional Action Plan, management measures, ecosystem approach, descriptors, ecosystem quality objectives

Introduction

In April 2020, the Convention on the Protection of the Black Sea against Pollution, also known as Bucharest Convention (Bucharest Convention 1994), celebrated its 28th Anniversary. There is no doubt that after the Convention and its Protocols were signed by all the Black Sea riparian countries, these documents became and continue to be the powerful instruments of International Environmental Law in the Black Sea Basin (Birnie 2009). Nowadays, the Bucharest Convention is one of the most known Regional Sea Conventions, establishing the legal ground for combating pollution from land-based sources and maritime transport, achieving sustainable management of marine living resources and pursuing sustainable human development in the Black Sea Region. The activities implemented so far by the relevant Convention bodies allowed to significantly increase the public involvement, address transboundary environmental issues and introduce the sound environmental decision-making related to the sustainable use of the Black Sea (Mrema 2006).

At the same time, given that the environmental science is being developed rapidly and after those almost thirty long years of the implementation of the Bucharest Convention's provisions, it is now obvious that some of the important issues related to the preservation of the precious Black Sea environment and sustainable management of its resources for different reasons had fallen out from the scope of the Bucharest Convention and its protocols. Meanwhile, some of the provisions face the need to be improved or reinforced. These issues relate to certain extent also to the management of marine litter and marine litter monitoring in the Black Sea basin (Makarenko 2012; 2014; 2015).

Policy framework analysis

- There were numerous attempts to address the issue of marine litter on the regional level in the Black Sea basin, at the same time, until 2018 there were no concrete legal instruments dedicated specifically to the management of marine litter. Moreover, the concept of marine litter problem and definition of "marine litter" itself, as a legal term was neither accepted nor was well known in the Black Sea community. Despite these challenges: In 2005, the Regional Activity on Marine Litter, supported by UNEP, was launched (UNEP 2005);
- During the following 3 years the two relevant Memorandums of Understanding (MoUs) between the BSC Permanent Secretariat (BSC PS 2016) and UNEP were implemented (BSC 2007);
- 2009 Report on Marine Litter in the Black Sea (incl. the text of the Draft Marine Litter Action Plan for the Black Sea) was elaborated and published (BSC 2009);
- Recommendations for updating the Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea, adopted in Sofia, Bulgaria on 17 April, 2009 (BS SAP; BSC TDA 2007; BSC 2009), on methodologies, monitoring and assessment, increased public awareness on marine litter in the Black Sea were introduced;
- The BSC joined as partner or sub-contractor in a range of EU-funded projects (Advisory Board of MARLISCO, CLEANSEA, PERSEUS, STAGES, MSFD Projects etc.), participated in Berlin Conference on

Marine Litter (International Conference on Prevention and Management of Marine Litter in European Seas 2013);
- In 2015, BSC joined and is still an active member of the UNEP Partnership on Marine Litter.

It is also worth mentioning that the Bucharest Convention and its Protocols contain several Articles relevant to marine litter, *inter alia*, Annexes to Protocol on Protection of the Black Sea Marine Environment Against Pollution from Land-Based Sources (LBS Protocol, 1994, in force) (Bucharest Convention, 1994) and Protocol on Protection of the Black Sea Marine Environment Against Pollution by Dumping (Dumping Protocol) (Bucharest Convention 1994) contain three lists of hazardous substances and matter which include those materials which constitute plastic marine litter. The new text of the LBS Protocol agreed upon in 2009 (BSC 2009), but which has not yet entered into force, includes a clear definition of marine litter (borrowed from UNEP), where litter was defined as "*any persistent manufactured or processed solid material which is discarded, disposed of, or abandoned in the marine environment and coastal areas*". The latest version of BS SAP (2009) incorporated the recommendations on fighting with marine litter, and presented a series of management targets (number 18, 19 and 20) (BSC 2009). Therefore, marine litter was only mentioned as one of the descriptors, as well as parameter of discharges under the EcoQO #4 in the BS SAP (2009).

At the same time, in the structure of the Black Sea Commission with its six Advisory Groups, there was never any specific Advisory Group on Marine Litter, instead, due to its crosscutting nature, all of them were dealing to a certain extent with the marine litter problematics. In 2006, a special session on marine litter was held during the meeting of the Pollution Monitoring and Assessment (PMA) Advisory Group. Since then, marine litter topic was never on the agenda of the BSC Meetings. Finally, in 2014, the Advisory Group on the Land-Based Sources of Pollution (LBS AG) at its meeting recommended to Black Sea Commission to apply for UNEP Global Initiative on Marine Litter (UNEP 2014), which was endorsed at BSC Regular Meeting in November 2014 (BSC 2014). Still, up to date, none of the reporting templates of the Advisory Groups contained any information on the content or amount of marine litter, which made it impossible to assess and to monitor the marine litter on the regional level.

In October 2016, the Black Sea Commission eventually adopted the Black Sea Integrated Monitoring and Assessment Program (BSIMAP) for 2017-2022 (BSC 2005; BSC 2016). It for the first time foresees certain harmonization with Marine Strategy Framework Directive (MSFD) (MSFD Directive 2008); defines the Good Environmental Status (GES) for the Black Sea (MSFD Directive 2008); provides the common lists of indicators and parameters of reporting coordinated with partners from UNEP, FAO General Fisheries Commission for

Mediterranean and Black Sea (GFCM), ACCOBAMS Agreement and the International Commission on the Protection of Danube River (ICPDR). Again, detailed monitoring program for marine litter was missing in its text and further efforts to introduce marine litter into the BSC agenda, i.e. elaborate the methodology of assessment and monitoring of marine litter specifically in the Black Sea and to develop the set of marine litter indicators, became very urgent.

Although marine litter was already mentioned as one of the descriptors, parameter of discharges and existing management target under the EcoQO #4 in the BS SAP 2009, (targets number 18, 19 and 20), there was a strong understanding that a separate document describing necessary actions, policy measures and monitoring program were needed for the sake of the entire Black Sea basin. Let alone the growing need to introduce and implement the European acquis communautaire, which is already binding for five countries of the basin and where marine litter is being assessed at least within provisions of the MSFD Directive as one of the descriptors of the Good Environmental Status of the European Seas (Borzel 2009).

During its 31st BSC Regular Meeting (7-8th October, 2015 in Istanbul) the Black Sea Commission "*welcomed the cooperation with UNEP and, in particular, implementation of marine litter related activities under the BSC PS - UNEP MoU*" signed between the Secretariats earlier in 2015 (BSC 2016). During this time, the first Drafts of Regional Action Plan on Marine Litter Management in the Black Sea and Marine Litter Monitoring Guidelines for the Black Sea (based on EC Joint Research Centre (JRC) experience) (BSC 2016) were finalized by nominated experts under agreement with UNEP (BSC 2016), but they were not adopted by the Black Sea Commission in October, 2016. The Black Sea Commission instead tasked the Permanent Secretariat to revise the documents against concrete actions, taking into account experience of other Regional Sea Conventions (RSCs) and relevant projects and organizations (including cooperation with EMBLAS II Project, which introduced the marine litter into its surveys).

During the same meeting, the Black Sea Commission also "*took note of the proposal of Bulgaria on the draft Regional Action Plan on Marine Litter Management in the Black Sea and asked ESAS/LBS/PMA AGs to consider it and to follow the issue".* The Commission also "*agreed that further activities on the Regional Action Plan on Marine Litter Management in the Black Sea will be included in the BSC Work Programme for 2015/2016*".

Aiming to address the environmental challenges in the Mediterranean and Black Sea regions, as well as to set up joint plans for future, Memorandum of Understanding between the UNEP Mediterranean Action Plan and the Commission on the Protection of the Black Sea Against Pollution (BSC 2016) was solemnly signed at the 19th CoP of Barcelona Convention in the city of

Athens (Barcelona Convention 1976). This important initiative came from the Republic of Turkey which is not only geographically connecting the Mediterranean Sea through the Bosporus Strait, Sea of Marmara and the Dardanelles Strait, but also, being a member to both Conventions, is constantly contributing to the successful implementation and enforcement of its provisions. This initiative was further supported by the members of the Black Sea Commission, Mediterranean countries and the UNEP. The aim of the MoU was to "*increase interaction and exchange of information and experts among both regions, as well as sharing the best practices on the topics of common concern*".

One of our major achievements of this MoU was an agreement with UNEP/MAP signed in December, 2016 proposing a number of activities under Marine Litter MED project (BSC 2016) to strengthen bilateral collaboration aimed to: 1) finalize the draft Regional Action Plan on Marine Litter Management in the Black Sea; 2) elaborate, further develop and finalize the Marine Litter Monitoring Programme for the Black Sea; 3) draft a joint work plan between UNEP/MAP and the BSC PS; 4) organize annual joint meetings between both Secretariats.

During the last couple of years both the above-mentioned documents were drafted under this Agreement and three bilateral meetings were held, as follows:

- Draft Regional Action Plan on Marine Litter Management in the Black Sea was adopted by the Black Sea Commission in October 2018 during its 34th Regular meeting in Istanbul, Turkey (BSC 2018);
- Draft Marine Litter Monitoring Programme for the Black Sea was not yet adopted, it is currently being considered by the national and international experts and is planned to be provided for adoption by BSC in the nearest future;
- The mechanism of regular bilateral cooperation between the Secretariats was established, which is now used as an example of successful collaboration between the Regional Seas on the global level;
- Three annual joint meetings between both Secretariats were held in 2017, 2018 and 2019, respectively; during these meetings joint work plans between the UNEP/MAP and the BSC PS were prepared and further successfully implemented (BSC 2019);
- Back-to-back to the third bilateral meeting on 12-13th December 2019 the Regional Verification workshop to support the establishment of the Black Sea Marine Litter Monitoring Programme and streamline the implementation of Regional Action Plan on Marine Litter Management in the Black Sea was held in Istanbul, Turkey. During the Workshop, the best practices in Mediterranean Sea were presented and it also served as a platform for consideration of draft Marine Litter Monitoring Guidelines for the Black Sea and discussion of implementation of Regional Action Plan on

Marine Litter management for the Black Sea, adopted during 34th BSC Regular meeting in October, 2018 (BSC 2018);

- BSC also joined the efforts of UNEP/MAP on the global level, within the work of UNEP Global Group on Indicators, in drafting the World Ocean Assessment Report II, within activities of Sustainable Ocean Initiative (SOI); implementation of European Union' Marine Strategy Framework Directive and reaching the Good Environmental Status of marine waters; circular economy and ecosystem services; agreements under relevant global and regional organizations covering our seas (i.e. General Fisheries Commission for Mediterranean (GFCM) (BSC 2012a) and ACCOBAMS Agreement on Conservation of Cetaceans in Mediterranean and the Black Sea) (BSC 2012b).

During the Regional Verification workshop the participants considered the Draft Guidelines on Monitoring of Marine Litter in the Black Sea environment and proposed to introduce minor changes to the marine litter common indicators, as follows (BSC 2019):

1. ECOQO4/11 C1. Composition and distribution of litter washed and/or deposited on shores, on the sea floor and floating at the surface of the Black sea, including transitional areas such as estuarine waters and beaches.
2. ECOQO4/11 C2. Composition and distribution of microlitter, mainly microplastics, at the surface of the sea, and possibly on beaches and sediments, including transitional areas such as estuarine waters and beaches.
3. ECOQO4/11 C3. Candidate Indicator: Composition and distribution of litter ingested by or entangling marine organisms focusing on selected mammals, and marine birds.

The participants considered progress in implementation of the Regional Action Plan on Marine Litter Management in the Black Sea and recommended to review the timelines in the Annex to the Regional Action Plan.

The participants considered the marine litter reporting templates provided by UNEP/MAP Secretariat and in line with them elaborated the proposal for amendments to relevant Annexes of the BSIMAP 2017-2022 (including draft marine litter-related Annual reporting template) to be presented to BSC for further consideration and possible adoption (Tables 1 and 2).

The marine litter also became a subject of a dedicated chapter "Marine litter" of BS State of Environment (SoE) Report 2009-2014 and is taken into account when drafting the Report on the Implementation of the BS SAP 2009 – so called SAPIR. As a result of elaboration of SAPIR, the BS SAP 2009 is planned to be updated and marine litter-related management targets will also be reconsidered in line with current requirements.

Table 1. Proposal for monitoring of ML

Type of ML	Status	Beach	Floating	Sea-floor
Plastic	M	2-4 times per year	2 times per year	once per year
Cloth/Textile	M	2-4 times per year	2 times per year	once per year
Metal	M	2-4 times per year	2 times per year	once per year
Rubber	M	2-4 times per year	2 times per year	once per year
Paper/Cardboard	M	2-4 times per year	2 times per year	once per year
Glass	M	2-4 times per year	2 times per year	once per year
Ceramics	M	2-4 times per year	2 times per year	once per year
Processed/worked wood	M	2-4 times per year	2 times per year	once per year

Table 2. PMA & LBS Regional Reporting Indicators

Agreed Criteria	**Beach Litter**	**Floating litter**	**Sea-floor litter**	**Comments**
Type				
Amount	(mandatory: Items/100m) (optional: items/km^2)	(Items/km^2)	(Items/km^2)	
Weight				
Size				
Composition (specification of items)				
Spatial distribution				
Source/Pressures				
Impacts on marine organisms (Optional)				
**Impacts on marine water quality*				
**Impacts on sea-floor*				
Measures				

**Proposed to be further discussed*

Meanwhile, Bulgaria and Romania, binded by the MSFD implementation, reported that main conclusions from the Initial assessment of the status of Bulgarian and Romanian parts of the Black Sea area regarding marine litter, are the following (BSC 2019):

- Not defined definitions for Good Environmental Status (GES) for Descriptor 10 (Marine litter);
- Insufficient data or no actual data for the most Descriptors for preparation of qualitative and quantitative assessment of the Black sea status at national and regional level. Difficulties to assess the data due to different level of aggregation;

- Need of additional gathered data and information on the base of more high frequency observations;
- Additional challenge is work on Descriptor 10 – Marine litter, for which there is huge lack of data at European level, especially for the Black sea marine region, indicators aren't fully developed. For the moment only beach litter, sunk litter and floating litter are monitored. Efforts are made for micro-litter. Indicators should be developed;
- Need of using modern scientific field and laboratory equipment.

Considering marine litter problem in Republic of Turkey, the "strategic action plan for marine litter" for Istanbul as a pilot region was prepared in 2013. Strategic action plans for all coastal cities are planned to be implemented (BSC 2019).

In regards to implementation of BS SAP 2009 and its management target no. 18 *"Amend national waste strategies and/or national coastal zone management plans with the aim of coastal and marine litter minimization",* which was listed in BS SAP as short and mid-term management target of medium priority, Romania reported that it has no national waste strategy for the time being, but the problem of the marine (and beach) litter is included in the MSFD as one of the descriptors for GES. Various coastal management plans, such as Urban planning for the Black Sea Coastal Zone (2010-2011), the Master Plan for severe protected areas (2007), etc were developed and implemented. A focus on the sustainable development is also taken by the Romania National Tourism Development master plan 2007-2026.

In regards to implementation of BS SAP 2009 management target no. 19 "*Develop regional and national marine litter monitoring and assessment methodologies on the basis of common research approaches, evaluation criteria and reporting requirements",* which was listed in BS SAP as short and mid-term management target of medium priority, it was reported that among the monitoring programmes developed under MSFD (and BS SAP), there is a sub-programme for marine litter. Romania started to monitor both beach and marine litter, but the problem of the microlitter still needs to be tackled.

In general, plastics is not yet addressed in the legally binding documents of the BSC, but efforts to coordinate the Plastic Strategy and implementation of UNEA-4 resolution on plastic litter and microplastics pollution are made through above mentioned activities under agreement with UNEP/MAP, mostly within BS Regional Action Plan for ML and Draft BS ML Monitoring Guidelines.

As it was already mentioned, in October 2018, at its 34th BSC Regular meeting, the BSC took a decision to adopt the BS ML RAP together with annexed Work Programme for the implementation of its activities/measures.

This document was initially prepared by the well-known expert nominated by the UNEP/MAP, same expert prepared similar action plans for Mediterranean Sea and some other regional seas, therefore, the approach followed in the BS ML RAP was completely compatible with global and European approaches towards preparation of RAPs relevant to management of marine litter. The document consists of preamble, 20 articles and Work Program annexed to its text. In accordance with provisions of the BS ML RAP:

- The implementation of the BS ML RAP will be facilitated with a "*number of international activities in which the Black Sea Commission (BSC) is taking part, among those(a) Joint Work Plan on Marine Litter between UNEP/MAP and the BSC PS (Joint Work Plan) and (b) Memorandum of Understanding (MoU) between UNEP/MAP and BSC PS*";
- It "*shall apply to discharges referred to in Article 1 of the LBS Protocol and any operational discharge from ships, platforms and other man-made structures at the Black Sea*";
- The overall objective of the BS ML RAP is to "*consolidate, harmonize and implement necessary environmental policies, strategies and measures for sustainable integrated management of marine litter issues in the Black Sea region*";
- The Contracting Parties to the Bucharest Convention "*may incorporate the provisions of the BS ML RAP into their national marine strategies, plans and/or programmes for the protection and rehabilitation of the Black Sea and the sustainable use of marine and coastal resources paying due attention to national, sectoral and intersectoral interactions*";
- BS ML RAP also requires that "*The Contracting Parties of the Bucharest Convention will elaborate and implement, individually or jointly, as appropriate, national and regional action plans (NAPs and RAPs) and programmes, containing measures and timetables for their implementation*", as well as they "*shall prepare National Biennial Reports on NAPs and BSC PS shall prepare Regional Biennial Reports on NAPs on the basis of National Reports*".

For the purpose of implementing the BS ML RAP, the Contracting Parties of the Bucharest Convention may adopt as appropriate the necessary legislation and/or establish adequate institutional arrangements to ensure efficient marine litter reduction and the prevention of its generation. To this aim, the Contracting Parties may:

- Establish institutional coordination, where necessary, among the relevant national policy bodies and relevant regional organizations and programmes, in order to promote integration;
- Review and revise the existing legislation related to marine litter and solid waste and implement the relevant legislation at the national level;

- Establish marine litter regional experts group (or task force) under BSC PS and stimulate activities relevant to marine litter management;
- Ensure close coordination and collaboration between national, regional and local authorities in the field of marine litter management and other relevant measures.

Article 8 of the BS ML RAP “Prevention of marine litter pollution” foresees that for Land-based Sources the Parties may base their urban solid waste management on reduction at source, applying the following waste hierarchy: prevention, preparing for re-use, recycling, other recovery, e.g. energy recovery and environmentally sound disposal. They may explore and implement to the extent possible the following prevention measures:

(a) Adequate waste reducing/reusing/recycling measures in order to reduce the fraction of plastic packaging waste that goes to landfill or incineration without energy recovery;
(b) Extended Producer Responsibility strategy by making the producers, manufacturer brand owners and first importers responsible for the entire lifecycle of the product with measures prioritizing the hierarchy of waste management in order to encourage companies to design products with long durability for reuse, recycling and materials reduction in weight and toxicity;
(c) Sustainable Procurement Policies contributing to the promotion of the consumption of recycled plastic-made products;
(d) Establishment of voluntary agreements with retailers and supermarkets to set an objective of reduction of plastic bags consumption as well as selling dry food or cleaning products in bulk and refill special and reusable containers;
(e) Fiscal and economic instruments to promote the reduction of plastic bag consumption;
(f) Establishment of Deposits, Return and Restoration System for beverage packaging prioritizing when possible their recycling;
(g) Establishment of procedures and manufacturing methodologies together with the plastic industry, in order to minimize the decomposition characteristics of plastic, to reduce micro-plastic;
(h) Improved solid waste infrastructure in order to reduce entry of litter into the marine environment; and
(i) Improve or develop permanent services for marine litter collection and removal along the entire coastline of the BS ML RAP area, including the populated and unpopulated sections of the shore.

They may explore and implement to the extent possible the following prevention measures:

(a) Establish as appropriate adequate urban sewer, wastewater treatment plants, and waste management systems to prevent run-off and riverine inputs of litter;

(b) Close to the extent possible the existing illegal dump sites on land in the area of the application of the BS ML RAP;
(c) Enforcement measures to combat illegal dumping in accordance with national and regional legislation, including littering on the beach, illegal sewage disposal in the sea, the coastal zone and rivers in the area of the application of the BS ML RAP; and
(d) Develop and implement measures aimed to prevent litter carried by rivers from deposition at sea.

For Sea-based sources, they may explore and implement to the extent possible:

(a) “Gear marking to indicate ownership” concept and ‘reduced ghost catches through the use of environmental neutral upon degradation of nets, pots and traps concept’, in consultation with the competent international and regional organizations in the fishing sector;
b) Organize training courses on ghost fishing;
(c) Contact the Permanent Secretariat of the Black Sea Memorandum of Understanding on Port State Control and carry out a Concentrated Inspection Campaign (CIC) focussing on how requirements for preventing marine pollution from ships (MARPOL Annex V) have been implemented. Such campaign is to be conducted in connection with the new amendments to Annex V of MARPOL convention related to products which are hazardous to marine environment (HME) and Form of Garbage Record Book adopted by resolution MEPC.277 (70) and which is effective from 01st March, 2018;
(d) The cost effective measures to prevent any marine littering from dredging activities, taking into account the relevant guidelines adopted in the framework of Dumping Protocol of the Bucharest Convention; and
(e) Apply enforcement measures by the Contracting Parties to combat dumping in accordance with national and regional legislation, including littering on the beach, illegal sewage disposal in the sea, the coastal zone and rivers in the area of the application of the BS ML RAP.

Article 9 defines the necessary measures for “Removing existing marine litter and its environmentally sound disposal” and foresees the following measures:

(a) “Fishing for Litter” environmentally sound practices, in consultation with the competent international and regional organizations, to facilitate clean up of the floating litter and the seabed from marine litter caught incidentally and/or generated by fishing vessels in their regular activities, including derelict fishing gears;
(b) Improve Port reception facilities in order to fully implement obligations arising from Annex V of the MARPOL Convention;
(c) Charge reasonable costs for the use of port reception facilities or, when applicable apply the No-Special-Fee system, in consultation with competent international and regional organizations, when using port reception facilities;

(d) Identify, in collaboration with relevant stakeholders, accumulations hotspots of marine litter and implementation of national actions for their regular removal and sound disposal;
(e) Where it is environmentally sound and cost effective, remove existing accumulated litter;
(f) Apply as appropriate Adopt-a-Beach or similar practices and enhance the public participation role with regard to marine litter management;
(g) Implement National Marine Litter Clean up Campaigns on a regular basis;
(h) Participate in International Coastal Clean up Campaigns and Programmes; and
(i) Participate in the Blue Flag certification by the Foundation for Environmental Education (FEE).

Article 10 “Other activities” recommends to implement also the following activities:

(a) Establishment of direct cooperation of Contracting Parties, with assistance of competent international and regional organizations, to address transboundary marine litter cases;
(b) Identification of international, regional and national potential financial sources and proposal of projects in order to raise funds. Allocation of essential funds for the implementation of marine litter projects;
(c) Establish marine litter baseline values, using available data in the Black Sea and in coordination with existing regional and global processes;
(d) Establish basin-wide marine litter reduction targets, based on available data from the Black Sea region and harmonized with regionally and globally defined targets. Indicators and thresholds regarding each target for the Black Sea region should be established, taking into account the specifics of the Black sea environment;
(e) Contracting Parties and BSC PS may identify financial sources and allocation of essential funds for the implementation of national and regional marine litter projects and ensure that relevant programmes and projects are properly incorporated in national budgets;
(f) BSC may support development and use of common basin scale models of circulation in connection with marine litter movement;
(g) Enhancement of usage of circular economy in marine litter management; and
(h) Establishment of institutional cooperation with various relevant regional and global institutions and initiatives.

The Part III – Monitoring and Assessment proposes to Contracting Parties to “*assess the impact of marine litter on the marine and coastal environment and human health, based on coordinated and, if possible, common agreed monitoring methodologies and programmes, environmental targets and indicators for assessment of the status of marine environment; prepare the Guidelines on monitoring of marine litter in the Black Sea; prepare National*

Marine Litter Monitoring Programmes; Implement Regional Marine Litter Monitoring Programme, as part of the Black Sea Integrated Monitoring and Assessment Program (BSIMAP); encourage the Contracting Parties to undertake, when appropriate, joint monitoring initiatives on a pilot basis, with the aim to exchange best practices, use harmonized methodologies, and ensure cost efficiency; encourage the Contracting Parties to support and take part in regional initiatives and projects lead by competent partner organizations in order to strengthen strategic and operational regional synergies; request the BSC PS to work further with relevant partner organizations, in order to strengthen technical support that countries might need to implement BSIMAP; the BSC PS will prepare and publish the Marine Litter Assessment in the Black Sea every five years using the results of the national monitoring programmes, using all other available relevant regional and international data; Regional Data Base on Marine Litter, based on national data bases, compatible with other regional or overarching databases will be established for the Black Sea; Contracting Parties shall prepare and publish Biennial Reports on National Marine Litter Monitoring Programmes...".

Under Article 14 "Enhancement of public awareness and education", *"the Contracting Parties will undertake, where appropriate, in synergy with existing initiatives in the field of education for sustainable development and environment and partnership with civil society, public awareness and education activities, with adequate duration and follow up, with regard to marine litter management including activities related to prevention and promotion of sustainable consumption and production"*. This foresees (a) Enhancement of public awareness and education by holding a set of national and regional awareness seminars/workshops, including higher and secondary education institutions involvement; and (b) Participation in UNEP Open online course on marine litter.

Under Article 16 "Regional and international cooperation", for the purpose of facilitating the implementation of the BS ML RAP the Permanent Secretariat is supposed to *"establish institutional cooperation with various relevant regional and global institutions and initiatives"*.

In line with Article 17, "the Contracting Parties will report on a biennial basis on the implementation of the BS ML RAP, in particular the implementation of the above measures, their effectiveness and difficulties encountered and data resulting from monitoring and assessment programmes. The BSC PS will prepare and distribute to Contracting Parties the structure for preparation of the National Biennial Reports. The Contracting Parties will review biennially the status of implementation of the BS ML RAP".

The Contracting Parties will implement the BS ML RAP, in particular the above activities and measures according to the deadlines indicated in the Work

Programme - Annex I) of the BS ML RAP, which includes: (a) relevant Articles; (b) Activities/ Measures; (c) Timetable; (d) Responsible Body; (e) Indicators; and (f) Cost.

Regarding enforcement of measures, *"the Contracting Parties shall take the necessary actions to enforce the measures in accordance with their national regulations and for the purpose of facilitating the implementation of the BS ML RAP the Permanent Secretariat will establish institutional cooperation with various relevant regional and global institutions and initiatives".*

Therefore, the BS ML RAP clearly describes all necessary measures and timelines needed for its successful implementation. At the same time, the participants of the Regional Verification Workshop, "*recommended to review the timelines in the Annex to the Regional Action Plan*", considering that some of the actions were already outdated and/or may not be implemented in time or in full. The lack of enforcement mechanism and concrete guidance may hinder successful, timely and coordinated implementation of the BS ML RAP.

For this reason, the BSC PS should take all necessary steps to provide Contracting Parties with clear reporting templates and deadlines, to make sure that the preparation of the first Regional Biennial Report by the BSC PC on the basis of National Biennial Reports on NAPs, currently planned in the Work Program for year 2022, will be running smooth and that the Regional Report will be comprehensive and exhaustive.

Another visible challenge of the BS ML RAP implementation is to ensure the close coordination between national, regional and local authorities in the field of marine litter management, allowing the proper revision of the existing national legislation in this regard.

There is also an assumption that the allocation of financial resources for BS ML RAP implementation in individual countries may differ from country to country, therefore, implementation of fiscal and economic instruments to promote the reduction of plastic bag consumption and improvement of solid waste infrastructures, foreseen by the Work Program, may be uneven or not properly reported.

Conclusions and Recommendations

Marine litter issues are not properly addressed and managed so far on the regional, national and global scales. Despite the lack of its monitoring and assessment in the Black Sea riparian countries, the need to reduce amount of marine litter entering the Black Sea, including plastics, is obvious.

There is no doubt that the Black Sea Commission plays significant role in harmonizing and coordinating the national efforts of Black Sea countries to improve management of marine litter on the regional and global level. The evidence of this significant progress is the adoption in 2018 of the Regional Action Plan on marine litter management for the Black Sea basin.

Despite the very clear formulations and deadlines, there are still challenges and gaps in the successful implementation of the BS ML RAP, relevant to both, organizational and financial aspects. That is why the introduction of stronger measures for marine litter monitoring and management in the Black Sea proper and its catchment basin, as well as enforcement of the provisions of the BS ML RAP is still on the agenda of the Black Sea Commission and its individual Contracting Parties.

Implementation of these measures, as well proper monitoring and reporting, must be very seriously taken into consideration and adequately implemented by all Black Sea countries, mostly by strengthening environmental policies for shipping and tourist industries and raising public awareness and involvement.

As regards to marine litter monitoring, despite the signature of BS ML RAP and other above mentioned regional commitments, there is still an urgent need to adopt the Draft Marine Litter Monitoring Guidelines for Black Sea, containing regional methodology for requirements of assessment and monitoring of marine litter in the Black Sea and to develop the set of indicators, thresholds and baselines for marine litter to be included in the upcoming BSC reporting requirements and related documents: BS SAPIR Report, next BS SoE Report 2015-2020, draft BSIMAP 2022-2027. The first step to adequately introduce and assess the marine litter, obviously, is the inclusion of this indicator into the annual country's reporting templates for relevant Advisory Groups, given the cross-cutting nature of the marine litter. Another step could be an active participation in the UNEP Global Initiative on Marine Litter, further implementation of the so called "Message in the bottle", adopted during the International Conference on Marine Litter (Berlin April 2013). There is also a room for cooperation with EU on the implementation of the MSFD Directive, since the Black Sea represents one of the European Regional Seas in the provisions of the MSFD, two countries are members of the EU, three more countries applied for EU membership and signed Association Agreements with EU and, therefore, are expected to comply with EU *acquis communautaire* and MSFD requirements, in particular. Last but not least, deepening of collaboration and further successful implementation of the MoU and dedicated arrangements on marine litter with UNEP/MAP (Barcelona Convention 1976).

Meanwhile, in order to better coordinate and harmonize all relevant efforts on the regional level, the Black Sea Commission should pay its utmost attention to implementation of the following measures:

- To coordinate the mechanism of implementation of BS ML RAP with relevant regional partners (BSEC, PABSEC, industries, academia, NGOs etc.);
- To harmonize approaches with other three European RSCs ML RAPs, as well as relevant fisheries organizations and initiatives on regional and global levels(UN activities, FAO (GFCM), CBD Convention, Regular process on Global Reporting (World Ocean Assessment II); Global Working Group on Indicators; EU MSFD Directive, Sustainable Ocean Initiative (SOI), Sustainable Development Goals (SDGs), Aichi Targets etc.);
- To harmonize the approaches on establishing the baselines and thresholds for marine litter and monitoring techniques on regional and global level;
- To encourage appropriate involvement of various authorities and other stakeholders (regional, national and local authorities from Fisheries and Aquaculture sector, Non-governmental organizations (NGOs) and civil society).

All the above mentioned measures are of paramount importance in the light of implementation of the BS ML RAP and other relevant regional and global documents and commitments in the field of marine litter management described in this article.

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