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Short communication

First observations on the abundance and composition of floating debris in the North-western Black Sea

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ABSTRACT

The occurrence of marine litter in the Black Sea region is poorly known and even less data have been reported on the abundance of floating debris. Here we present results from a ship-based visual survey carried out in the North-Western part of the Black Sea, providing the first preliminary data on the characteristics of floating debris in Romanian waters. High litter densities peaking to 135.9 items/km^2 were found in the study area (mean 30.9 ± 7.4 items/km^2). Probably due to the proximity of the Danube delta, natural debris were on average, much more abundant than anthropogenic litter in most surveyed locations (mean 141.4 ± 47.1 items/km^2, max 1131.3 items/km^2). Most of the 225 objects we sighted consisted of pieces of wood and other riparian debris (75.5%), however plastic items remained undoubtedly the most abundant type of litter, representing 89.1% of all sighted man-made items. The Black Sea is not exempt from the global invasion of floating debris, however data are still lacking and a basin-wide survey is urgently needed to identify accumulation areas and develop regionally effective solutions to the problem of marine litter.

1. Introduction

The ubiquitous presence of anthropogenic litter in the marine environment is now recognized as one of the most pervasive pollution problems affecting the world's oceans (Barnes et al., 2009; Eriksen et al., 2014; UNEP, 2009). Yet, the spatial coverage of the global survey effort is still markedly uneven, and in some regions, litter occurrence, abundance and distribution have been so far only scantily investigated. The Black Sea is one of these areas. Preliminary observations from local NGOs, governmental and private institutions seem to suggest pollution levels as heavy as the rest of the world seas (BSC, 2007; CIESM, 2014). However a systematic monitoring activity has not been carried out yet, and reliable scientific data are still scarce (UNEP, 2009; Kershaw et al., 2013).

Here, we briefly present results from a ship-based visual survey of floating macro-debris (>2 cm size) conducted in the north-western part of the Black Sea, with the main goal of providing a first snapshot on the local abundance and distribution of floating litter. Such data, apart from raising public awareness, are urgently needed to develop regionally valid and effective solutions for managing litter pollution in the entire Black Sea basin (BSC, 2009). Moreover, collection and dissemination of these data represent a first contribution to Black Sea monitoring under the guidelines required by the EU to achieve Good Environmental Status in European Waters by 2020 (Descriptor 10), as outlined under the Marine Strategy Framework Directive (MSFD 2008/56/EC).

2. Methods

The visual survey was conducted on board R/V Mare Nigrum during the research cruise CoCoBLAS 2014 (24–29 June 2014) run within the EC Project CoCoNet. The study area was located off the Romanian coast in the north-western part of the Black Sea, between the Danube delta and the port of Constanta (Fig. 1). As recommended by the Black Sea Commission (BSC, 2007), densities of floating debris were estimated using the line transect methodology (Buckland et al., 2005). Observations were all made by the same observer during daytime navigation (mean speed 7 knots) and in good weather conditions only (i.e. wind speed <20 knots). The observer surveyed the sea surface from the bow of the vessel (~4 m above sea level) and recorded size, type, position and perpendicular distance of all floating macro-debris (>2 cm) sighted on the ship

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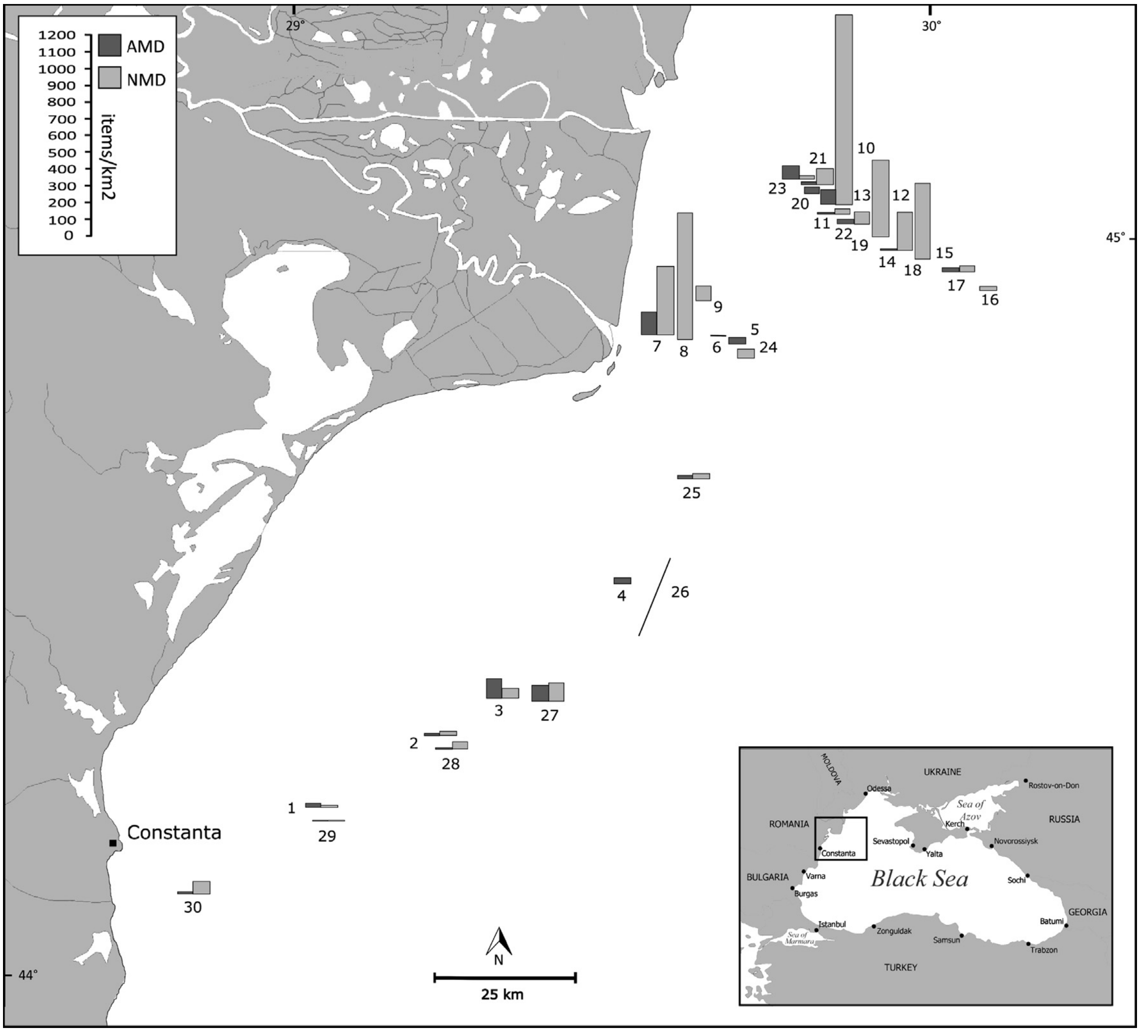

Fig. 1. Map of the study area (North-western Black Sea) showing the distribution of AMD (dark bars) and NMD (light bars) densities (expressed as number of items/km^2) in all surveyed transects. Solid lines without bar plot represent transects where no floating items were detected.

side opposite to the sun position. 7×50 binoculars were used to check identification of distant objects. Length and duration of transects slightly varied according to the ship operational schedule (mean duration time 28.1 ± 13.1 min). The distance sailed by the ship during each transect was calculated from GPS start and stop positions (mean length 6.2 ± 3.9 km). The record of every sighted item was then allocated to one of two major type categories: Anthropogenic Marine Debris (AMD) and Natural Marine Debris (NMD). AMD was further subdivided into styrofoam (expanded polystyrene), plastic (mainly fragments, plastic bags, bottles and containers) and others (e.g. manufactured wood, aluminium cans, rubber strips, glass bottles, paper and cardboard). NMD instead was classified as wood (mainly logs, trunks, branches and canes), algae (mainly branches of *Cystoseira* spp.) or others (e.g. dead insects, leaves, flowers, seeds and bird feathers). AMD and NMD densities (expressed as number of items/km^2) were computed over an area defined by the transect length and the Effective Strip Width (ESW) calculated through Distance Sampling analysis (Buckland et al., 2005) as reported in Suaria and Aliani (Suaria and Aliani, 2014). The ESW depends on the distance distribution of all items sighted along the ship track and takes into account the reduction of information due to increasing distance from the observer. During this survey, most objects were sighted within the first 10 m from the vessel (95% confidence interval 9.6–12.4 m) and an ESW of 10.93 ± 0.69 m) was obtained. Therefore this value was used for density calculations (i.e. the length of each transect was multiplied for an ESW of 0.011 km in order to obtain the effective surveyed area). Spearman's non-parametric correlation coefficient was used to test for significant correlation between the abundance of natural and anthropogenic debris across the study area. Results from AMD and NMD density calculations are reported in Table 1 and plotted in Fig. 1 for better visualisation.

3. Results and discussion

3.1. Abundance and composition of floating debris

A total of 30 visual transects were performed during the cruise, covering an overall survey length of 186.62 km. 225 floating items were sighted in the study area, the vast majority of which (75.5%) were natural objects (namely pieces of wood, canes, flowers, leaves, seeds, sedges, rushes and others typical riparian vegetation debris). Natural debris were on the whole, much more abundant than man-made litter in most surveyed locations, showing an average density of 141.3 ± 47.1 debris items/km^2 and maximum densities peaking to 1131.3 items/km^2 in front of the Danube delta. Litter densities were significantly lower and man-made items represented only 24.5% of all sighted objects. A mean of 30.9 ± 7.4 AMD items/km^2 and a

Table 1
Date, length, speed, duration, GPS start and stop positions, number of sighted items (n) and estimated AMD and NMD densities (expressed as number of items per km^2) for all surveyed transects.

Transect	Date	Start		Stop		Length (km)	Speed (kts)	Duration (min)	NMD		AMD	
		Lat	Lon	Lat	Lon				n	D (items/km^2)	n	D (items/km^2)
1	24/06/14	44.21536	29.02090	44.25295	29.10281	7.75	8.6	30	1	11.73	2	23.46
2	24/06/14	44.31096	29.23646	44.34848	29.31823	7.73	8.6	30	2	23.53	1	11.76
3	24/06/14	44.37236	29.37128	44.41018	29.45291	7.73	8.6	30	5	58.80	10	117.60
4	24/06/14	44.49970	29.60311	44.55967	29.64317	7.39	8.1	30	0	0.00	3	36.93
5	25/06/14	44.86237	29.84051	44.88306	29.84319	2.31	4.4	18	0	0.00	1	39.35
6	25/06/14	44.88107	29.83366	44.88158	29.80336	2.39	4.0	17	1	38.07	3	114.21
7	25/06/14	44.88266	29.72524	44.88001	29.70006	2.01	4.2	17	9	407.93	3	135.98
8	25/06/14	44.87937	29.73016	44.87444	29.78005	3.97	3.5	38	33	755.83	0	0.00
9	25/06/14	44.92361	29.76586	44.94410	29.79288	3.12	4.9	21	3	87.50	0	0.00
10	26/06/14	45.07614	30.05098	45.07022	30.06131	1.04	4.5	20	13	1131.29	1	87.02
11	26/06/14	45.05131	30.06234	45.04579	30.05616	0.78	4.9	5	0	0.00	0	0.00
12	26/06/14	45.04978	30.04160	45.06615	30.01655	2.68	5.2	23	0	0.00	0	0.00
13	26/06/14	45.07107	30.02399	45.02471	30.11245	8.65	4.1	60	3	31.52	1	10.51
14	27/06/14	45.01090	30.13444	45.00274	30.15435	1.81	2.7	15	9	452.22	0	0.00
15	27/06/14	44.98780	30.20264	44.97456	30.24151	3.39	4.3	27	17	455.45	0	0.00
16	27/06/14	44.96475	30.26343	44.93945	30.35773	7.94	4.1	60	2	22.91	0	0.00
17	27/06/14	44.95343	30.31659	44.98037	30.23059	7.40	8.1	30	3	36.86	2	24.57
18	27/06/14	44.99498	30.18530	45.03090	30.09630	8.06	8.4	30	20	225.69	1	11.28
19	28/06/14	45.03402	30.07815	45.04966	30.04992	2.82	5.9	14	0	0.00	0	0.00
20	28/06/14	45.08295	30.03336	45.09732	30.01323	2.25	8.1	10	0	0.00	1	40.45
21	28/06/14	45.08382	30.02860	45.05767	30.07867	4.89	7.7	21	5	92.95	1	18.59
22	28/06/14	45.05399	30.05878	45.08826	29.99286	6.43	8.2	24	5	70.71	2	28.29
23	28/06/14	45.08222	30.01530	45.05894	30.06222	4.50	7.8	17	1	20.19	4	80.75
24	29/06/14	44.90871	29.89630	44.79216	29.83651	13.79	9.8	45	8	52.74	0	0.00
25	29/06/14	44.71345	29.79613	44.63942	29.75877	8.75	9.9	30	3	31.18	2	20.79
26	29/06/14	44.57742	29.72844	44.47054	29.66776	12.82	10.1	42	0	0.00	0	0.00
27	29/06/14	44.41511	29.56342	44.35772	29.41704	13.27	10.8	40	16	109.63	14	95.93
28	29/06/14	44.33524	29.35741	44.28810	29.23781	10.86	11.4	30	5	41.84	1	8.37
29	29/06/14	44.24576	29.12452	44.18487	28.96904	14.12	11.8	40	1	6.44	1	6.44
30	29/06/14	44.13513	28.83967	44.10230	28.78023	5.99	11.3	21	5	75.93	1	15.19

maximum density of 135.9 litter items/km^2 were found throughout the study area. Such AMD values are nevertheless considerably high and generally comparable to what is being reported from many other offshore and coastal locations worldwide, including the Mediterranean Sea [e.g. Ryan, 2013; Suaria and Aliani, 2014; Thiel et al., 2013; Titmus and Hyrenbach, 2011].

Plastic items (mainly fragments, bags, containers and packaging) dominated waste materials accounting for 89.1% of all sighted objects, followed by other man-made objects (such as cork, fabric and glass), which represented 9.1% of all sighted items and by styrofoam fragments (1.8%). Such proportions are in good agreement with data already reported from the Black Sea, where plastic items typically constitute ~90% of all litter items found either on the seafloor or in coastal environments (BSC, 2007; Topçu and Öztürk, 2010; ARCADIS, 2013; Topçu et al., 2013), as well as with data reported from other parts of the world, confirming once again the worldwide predominance of plastic waste in the marine environment.

No previous data on the abundance of floating debris in Romanian waters exist. The only data available for comparison, were collected during a 2003 vessel-based survey of the neighbouring Ukrainian waters, where lower densities of 6.6 and 65.7 pieces of floating plastic per km^2 were reported between the northern part of the Danube Delta to the west and the Kerch Strait to the east, with most records pertaining to coastal waters off the Crimean peninsula (Birkun and Krivokhizhin, 2006).

3.2. Oceanographic features and litter movements

The surface circulation of the western Black Sea is characterized by a main cyclonic gyre (the Rim Current) taking water masses from north to south and by smaller mesoscale eddies and counterclockwise currents in the northwestern part of the shelf area (Oguz et al., 1993; Panin and Jipa, 2002). Data from oceanographic drifters evidenced long residence times, most likely related to the local Danube plume dynamics, on the Romanian shelf and in front of the Danube river mouth (Poulain et al., 2005). These structures may contribute to the retention of floating debris in the north-western part of the basin and might help to explain the observed debris densities.

Circulation patterns are consistent with the hypothesis that floating items arriving from the Danube mouth can be transported southward along the Romanian shores, also explaining the lower litter densities previously reported from the northernmost Ukrainian waters. Further offshore, the main cyclonic gyre in the central part of the basin and two pronounced nearshore anticyclonic eddies (Batumi and Sebastopol), might act as litter retention zones, whose existence however, needs to be verified. The use of numerical simulations to better highlight potential accumulation dynamics in enclosed basins, such as it has been recently done for the Mediterranean Sea by Mansui et al. (2014), would greatly improve our general understanding of the complex interactions between surface currents and litter movements in the Black Sea.

3.3. Litter sources and riverine input

The predominance of natural debris across the surveyed area is most noticeably due to the close proximity of the Danube river mouth. The accumulation of riparian debris is common in estuarine systems, where wood banks and drifting vegetation are often found in the vicinity of river deltas and estuaries (Sansores, 2001; Doong et al., 2011; Hinojosa et al., 2011). Human intervention nevertheless (meant as deforestation, riparian land use change, urbanization, land-clearing and forestry activities), can alter the input of natural debris in rivers and streams, either increasing or decreasing the amount of driftwood that eventually reaches the sea (Booth et al., 1996). The lack of previous temporal series regarding NMD quantities in the proximity of the Danube delta however, prevent us from drawing any conclusion about this topic.

According to previous studies, improper solid waste management and illegal marine and coastal dumping are the most important sources of anthropogenic litter in the Black Sea (Mee and Topping, 1998; Tuncer et al., 1998; Bakan and Büyükgüngör, 2000; Berkun et al., 2005; BSC, 2007; UNEP, 2009; Kershaw et al., 2013; Topçu et al., 2013). On Romanian shores for instance, a recent study by ARCADIS (2013) concluded, from items found at beaches near Constanta, that recreational and touristic activities (both land- and sea-based) represent the major litter sources, followed by coastal cities, navigation routes and the shipyards in Constanta and Mangalia. Unfortunately during our survey, physical collection of items was not possible, therefore it is difficult to infer any conclusion about litter origins, since many litter types (e.g. food packaging, bottles, containers and unidentifiable plastic fragments) may come from both land- and sea-based sources.

In all likelihood, river discharge plays an important role in defining also the amount and the composition of land originated litter that ends up in Romanian waters every year. It is well acknowledged that rivers transport large amounts of natural and anthropogenic debris from in-land sources to the ocean and coastal beaches (Rech et al., 2014) and that in the Black Sea an high percentage of pollutants (including synthetic materials) is potentially introduced by river currents (Tuncer et al., 1998; Bakan and Büyükgüngör, 2000; Topçu et al., 2013). Also the results of aerial surveys performed in 2002 in the north/north-eastern Russian shelf area, seem to suggest that a major quantity of marine litter comes to the Black Sea in late spring and early summer as the result of river run-off levels (BSC, 2007).

As a matter of fact, the north-western Black Sea receives freshwater from a large number of rivers, including the second, third and fourth major rivers in Europe (namely, the Danube, Dnieper, and Dniester), with an estimated total catchment area of the drainage basin of approximately 2,000,000 km^2, covering the territories of 22 different countries. The Danube alone, accounts for 60% of the total freshwater discharge to the Black Sea (Karageorgis et al., 2009) and it is likely responsible for a huge inflow of litter. A recent study conducted in a flowing stretch of the Danube between Vienna and Bratislava for instance, estimated an average input of small plastic fragments in the Black Sea of about 4.2 tons per day (Lechner et al., 2014). The authors however, pointed out that all other downstream countries feature lower standards in wastewater treatment if compared to Germany and Austria and that, because of their sampling system, large floating items (>5 cm) were probably underrepresented in their study. Hence the actual plastic load at the river mouth is potentially much higher.

No significant correlation between AMD and NMD abundances was identified by Spearman's correlation coefficient, indicating that at least during the present study, AMD and NMD were not accumulating in the same areas. NMD was more abundant in front of the Danube delta, while no accumulation pattern in AMD densities emerged from our data. So, whilst the Danube can be considered as the primary source of natural debris in our study area, AMD distribution was probably due to different inputs from multiple AMD sources. These findings have been recently confirmed by a study on benthic litter conducted in Constanta bay by Ioakeimidis et al. (2014). Even if very high densities of benthic litter were reported in front of the Danube mouth (1068 items/km^2), the percentage of land and vessel originated litter was almost the same, and no clear evidence of the Danube's importance as a source of litter was found by these authors.

Our survey area comprised both the Danube delta, where human population is restricted only to a few small villages, as well as very densely inhabited coastal zones. Constanta Bay for instance, receiving the impact of the second most populated city in Romania (425,916 inhabitants) and the biggest port in the Black Sea (14,066 arrivals in 2013), it's characterized by an extreme maritime traffic and by intense professional and recreational fisheries (Ioakeimidis et al., 2014). All these factors are known to represent additional litter sources and might all contribute, together with the Danube, to the total load of land- and sea-originated waste.

Regardless of its origin and distribution however, once litter arrives in the marine environment, currents and winds play a role in the cross-border transportation of floating and suspended items throughout the basin, making the problem of drifting litter a trans-boundary concern, which could be properly addressed only by means of a basin-wide approach involving the collaboration of all bordering states.

3.4. Final remarks

The Black Sea is an almost totally enclosed sea, surrounded by many industrialized countries, important shipping routes, with many fisheries and touristic areas, a dynamic surface circulation and a large drainage basin. All these factors make it very vulnerable to any kind of pollution, including marine litter. However, despite being widely recognized as a particularly sensitive area, it has not received sufficient attention regarding litter accumulation (BSC, 2007; UNEP, 2009).

Here we provided an initial insight into the levels of litter pollution in the north-western part of the Black Sea, showing that the abundance of floating macro-debris is as high as in other parts of the world. More research is needed to fully quantify the problem, find out the main sources, accumulation areas and transport dynamics, and finally develop appropriate measures to mitigate such pollution.

The MARPOL convention, under whose Annex V the Black Sea is defined as a "Special Area", and the Bucharest Convention for the Protection of the Black Sea against Pollution, together with the Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea (BS-SAP/2009), adopted by the six coastal countries, form a comprehensive framework for sustainable regional management. The effective enforcement of these international protocols should be substantially improved. For achieving the thorough coverage of the Black Sea, concerted regional strategies and actions specifically addressing the problem of marine litter are an urgent requirement and future challenge for international cooperation.

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