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Marine litter in the Nordic Seas: Distribution composition and abundance

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ABSTRACT

Litter has been found in all marine environments and is accumulating in seabirds and mammals in the Nordic Seas. These ecosystems are under pressure from climatic change and fisheries while the human population is small. The marine landscapes in the area range from shallow fishing banks to deep-sea canyons. We present density, distribution and composition of litter from the first large-scale mapping of sea bed litter in arctic and subarctic waters. Litter was registered from 1778 video transects, of which 27% contained litter. The background density of litter in the Barents Sea and Norwegian Sea is 202 and 279 items/km^2 respectively, and highest densities were found close to coast and in canyons. Most of the litter originated from the fishing industry and plastic was the second most common litter. Background levels were comparable to European records and areas with most littering had higher densities than in Europe.

1. Introduction

Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment" and it has been estimated that 5–13 million tonnes of litter enter the oceans each year (Jambeck et al., 2015). The litter found in the world's oceans is highly diverse but plastics are by far the most abundant material recorded (Derraik, 2002; Barnes et al., 2009; Sheavly and Register, 2007). Litter type and density vary greatly among locations and litter has been found in all marine habitats, from surface water convergence (fronts) down to the deep sea (Barnes et al., 2009). Recently there has been an increased focus on how litter is distributed in the seas and how it may affect the marine ecosystems (Pham et al., 2014). Distribution and accumulation is influenced by hydrography, geomorphology (Barnes et al., 2009; Galgani et al., 2000), prevailing winds and anthropogenic activities (Ramirez-Llodra et al., 2013). Hotspots of accumulation include shores close to populated areas, particularly beaches (Corcoran et al., 2009), but also submarine canyons, where litter originating from land accumulates in large quantities (Galgani et al., 2000; Mordecai et al., 2011; Pham et al., 2014; Woodall et al., 2015). The sources of litter are variable, depending on distance from shore (Galgani et al., 1995; Mordecai et al., 2011), oceanographic and hydrographic processes (Galgani et al., 1996) and human activities such as commercial shipping (Ramirez-Llodra et al., 2013) and leisure craft (Bergmann and Klages, 2012).

The Nordic Seas represent a large area ~ 3.000.000 km^2, including the Barents Sea and the Norwegian Sea, with a shelf and slope (50–4000 m) incised with canyons and troughs, bringing deep-sea close to the coast. The coastline is one of the longest in the world indented with very deep and long fjords. The population is and relatively small and the number of people and only a few industrial sectors contributes with litter to the system. Main activities are fisheries (including aquaculture), oil industry and shipping.

In this paper, we present the distribution and densities of marine litter based on video transects conducted by the Mareano mapping programme in the Nordic Seas, an area that has previously been underreported (Pham et al., 2014). Since 2006 Mareano has conducted more than 1778 video transects to document megafauna communities and their habitat. Litter has been recorded as part of this mapping. Based on this uniquely large dataset we provide a comprehensive overview of the density and composition of litter in different parts of the marine benthic ecosystems in the Nordic Seas. The results are compared with a review on the distribution and density of litter in European Seas (Pham et al., 2014), and the southern Atlantic and the Indian Ocean (Woodall et al., 2015).

2. Study area

The Norwegian Sea, a part of the North Atlantic Ocean, covers an area of about 1.5 million km^2. Its average depth is 1600 m, ranging from

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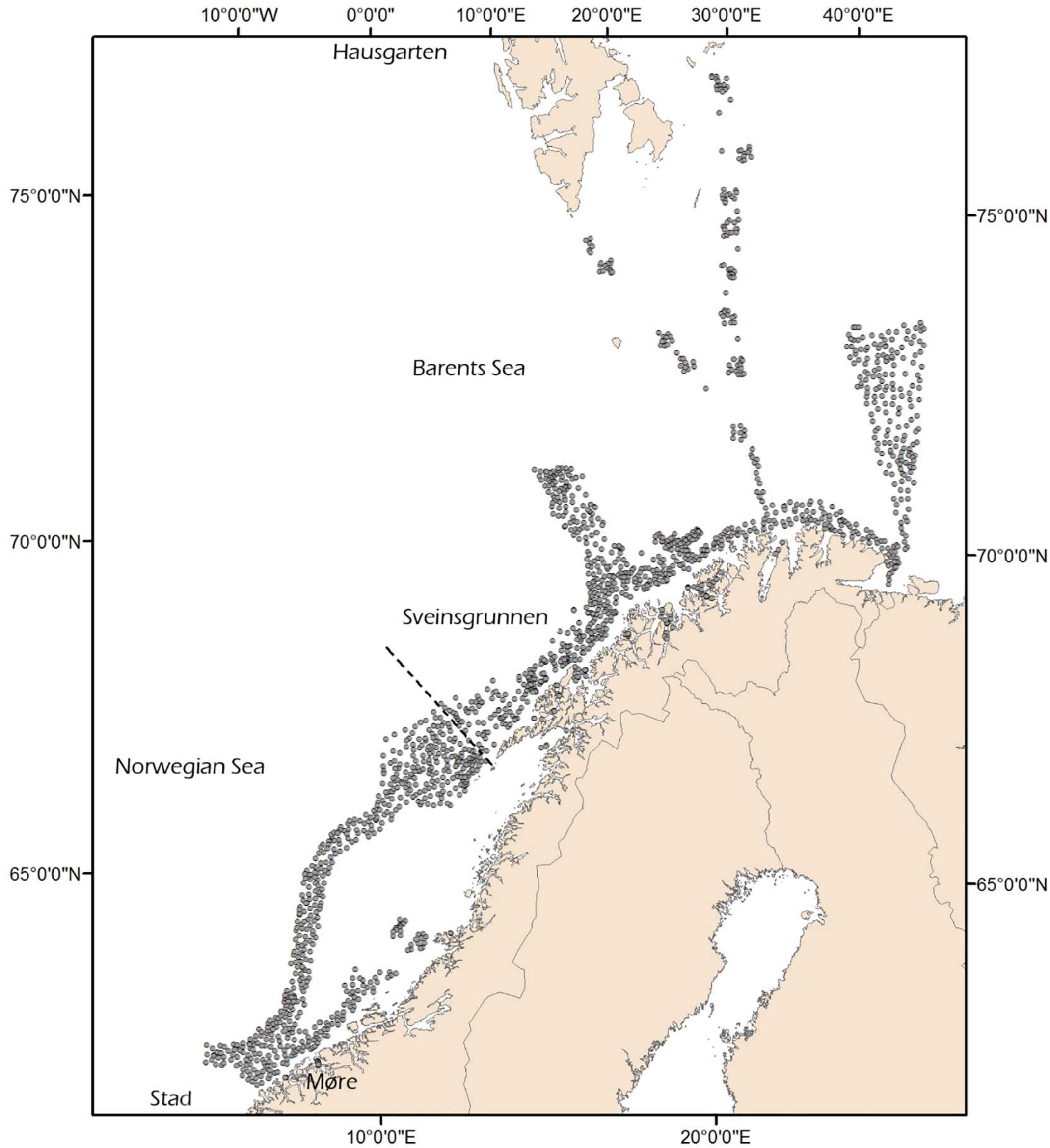

Fig. 1. Location of the 1778 stations sampled with video in the Nordic Seas (data from the Mareano programme 2006–2017). Dashed line marks the border between the Barents Sea and Norwegian Sea. Stations from inside the "Norwegian baseline" are defined as coastal observations.

Table 1
Video material used in the study with information on sampling year, number of cruise and video transects obtained from the two seas. All data is from the Mareano programme.

Year	No of cruises	Barents Sea	Norwegian Sea	Sum No of stations
2006	1	72		73
2007	2	141		143
2008	2	164		166
2009	1	133	1	135
2010	2	158	30	190
2011	3	32	169	204
2012	2		203	205
2013	3	98	123	224
2014	3	130	41	174
2015	2	58	79	139
2016	1	95		96
2017	1	51		52
Sum	23	1132	646	1778

shallow banks to deep-sea basins where the depth reaches 3000–4000 m. It borders the Barents Sea off the northern coast of Norway (Fig. 1), and with the waters of the North Sea to the southeast of the Faroe Islands. The Norwegian Current, a branch of the Gulf Stream, transports warm water to the north past the United Kingdom (UK), through the Norwegian Sea and on into the Barents Sea. The inflow of warm, saline Atlantic water to the Norwegian Sea is about eight million tonnes per second – eight times the discharge volume of all the world's rivers.

The Barents Sea is a high latitude shelf ecosystem located between about 70° and 80° N on the north-western corner of the European continental margin. It is a shelf area (about 1.6 million km^2, mean depth 230 m) bounded in west and north by deep basins of the Norwegian Sea and the Nansen Basin of the Arctic Ocean.

The bottom topography with banks and basins steers the currents and governs the distribution of water masses in the Barents Sea (Loeng,

Fig. 2. The tethered video platform "Chimaera". The frame of stainless steel (280 cm long and 160 cm high) allows for parking at the seafloor, and protects the cameras and lights in the front. The main camera is mounted inside a titanium housing attached to a pan and tilt unit. The acoustical transponder is located at the aft part of the platform to avoid obstacles to obscure the transmission of sound waves through the water. The net covering the top of the platform prevents the cable from entangling when parking on the seabed.

Table 2
Categories of litter and assumed average weight per item, used to convert from items observed to weight in this study.

	Weight per item (kg)
Ceramic and glass	0.4
Ceramic	0.3
Glass	0.5
Metal	1.0
Organic materials	0.4
Wood	0.5
Fabric	0.5
Paper	0.3
Plastics	0.4
Hard plastic	0.5
Soft plastic	0.3
Rubber	0.3
Fishing gear	1.0
Unspecified	0.5

1991). The Norwegian Current splits into two main branches, one flowing into and through the Barents Sea from southwest to northeast, the other flowing around the western and northern flanks of the Barents Sea as the West Spitsbergen Current (Skagseth, 2008; Ingvaldsen and Loeng, 2009; Ozhigin et al., 2011). Cold fresh Arctic waters arrive from the Arctic Ocean, entering the Barents Sea between Nordaustlandet and Franz Josef Land and between Franz Josef Land and Novaya Zemlya.

3. Material & methods

During 23 cruises, conducted by the Mareano programme between 2006 and 2017, 1778 video transects were annotated in the field with respect to occurrence of seabed types, fauna, trawl marks and litter (Fig. 1 and Table 1). This dataset was used to describe the distribution and content of litter in the Nordic Seas and total observed area in the Barents Sea and Norwegian Sea corresponds to 3.735.900 m^2 of seafloor.

The stations are selected based partly on a stratified randomisation (securing that the whole depth range and various marine landscapes were represented), and targeted locations (~25%) to make sure that rare conspicuous seabed features also are documented. Each video transect is 700 m long and the average field of view is 3 m. Video recording of the seabed was performed with a tethered video platforms that is equipped with a high definition color video camera (Sony HDC-X300) tilted forward at an angle of 45° during transect survey mode (Fig. 2). It also has two analog CCD video cameras, one forward-looking for navigation and one for surveillance of the cable. Two lazer beams (10 cm apart) are used for determining the width of the field view. The video rig is towed by the survey vessel at a speed of 0.7 knots and manually controlled by a winch operator at a height of around 1.5 m above the seabed.

Geopositioning for the video data is provided by a hydroacoustic positioning system (Simrad HIPAP and Eiva Navipac software) with a transponder mounted on the platform providing a position accurate to 2% of water depth. Navigational data (date, UTC time, positions and depth) were recorded automatically at 10-s intervals using the software CampodLogger (version 2.0.39) developed at IMR. This software is also used for real-time annotation of seabed observations of taxa, bottom types, signs of fishing impact, occurrence of litter and local geological seabed features when video recording. For details on the annotation see Buhl-Mortensen et al., 2015.

Litter was assigned to general categories comparable with standards used in previous studies (Pham et al., 2014; Tekman et al., 2017). Approximate weight of litter was estimated based on assumed average weight of one item of the different categories (Table 2). For each video transect, the total number of items observed in a litter class was multiplied with the assumed average weight, and total weight was estimated as the sum for all classes.

4. Results

4.1. Density and distribution

The overall distribution of litter in the study area is provided in Fig. 3. Of the 1778 video transects 488 (27%) documented litter and a total of 858 items of litter was recorded with an estimated weight of 775 kg (Table 3). The percentage of video transects with litter is comparable for the Barents Sea and Norwegian Sea, with 27 and 29% respectively. The mean density of litter for the whole area was 230 items/km^2, and the corresponding values for the Barents Sea and Norwegian Sea were 202 and 279 items/km^2. Dividing observations of litter into three density groups following the definition in Pham et al. (2014) based on European observations, we found low densities of litter (> 0–1000 items/km^2) at 23% of the video transects, both in the Norwegian and the Barents Sea (Fig. 4). Medium densities (1000–2000 items/km^2) were slightly more common in the Norwegian Sea (4.2%) than the Barents Sea (3.0%), and the proportion of observations with high densities (> 2000 items/km^2) were almost three times higher for the Norwegian Sea (1.9%) compared to the Barents Sea (0.7%).

4.1.1. Coast and offshore

Most of the videos were from offshore (1643 transects) compared to coast (135 transects) (Table 3, Fig. 4). In general, there were more videos with records of litter in coastal (34%), compared to offshore (27%)

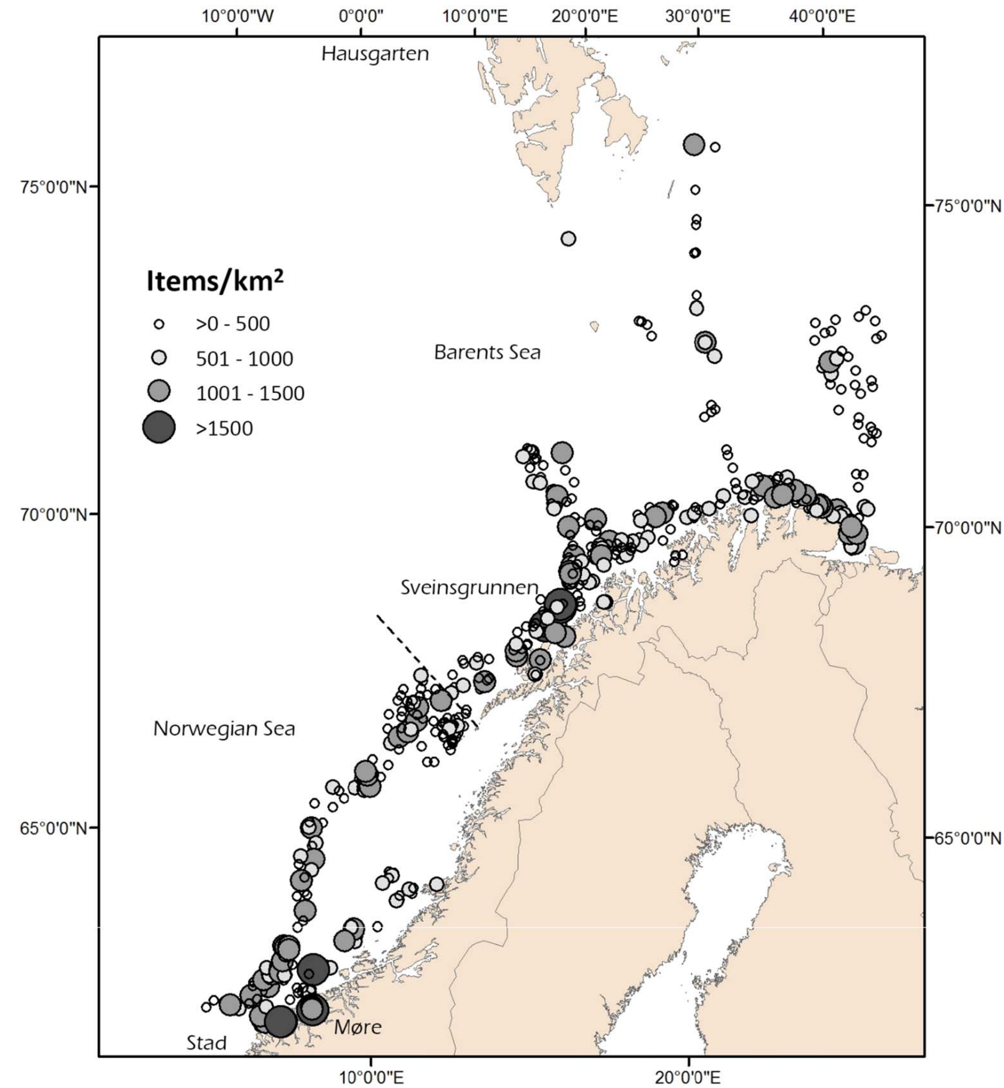

Fig. 3. Litter densities (kg/km^2) on 1778 video stations in Nordic Seas based on data from the Mareano programme from 2006 to 2017. Dashed line marks the border between the Barents Sea and Norwegian Sea.

areas. Highest density of litter was recorded near the coast in the southern part (Fig. 3), while it decreased towards north. The mean density of litter near the coast and offshore in the Barents Sea was 268 and 194 items/km^2 corresponding numbers for the Norwegian Sea was 2946 and 211 items/km^2. Litter density in coastal areas in the Norwegian Sea was 10 times higher than in the Barents Sea, while only slightly higher (38%) offshore.

A conservative estimate of total amount of litter in the Barents Sea south of Svalbard (523,600 km^2), using mean litter densities in offshore areas (194 items/km^2), is around 101 million litter items corresponding to 79 thousand tons. For the Norwegian shelf and slope between Stadt and Lofoten (area 141,500 km^2) the estimated amount of litter was 30 million items and 23 thousand tons.

Offshore litter densities are highest at depth from 900 to 1500 m corresponding to the lower slope (Fig. 5). In the coastal areas, densities are generally higher than offshore and three times higher or more at depths from 100 to 500 m.

The largest densities occurred close to the coast in areas with high maritime activity e.g. shipping and fisheries where 5 tons/km^2 was not uncommon. The amount of litter in the sea depends on local activities and in Norway main marine activities are fisheries, ship traffic, aquaculture and oil production. Areas with high density of litter, 2000 items or 1500 kg/km^2 or more, are in areas of high fishing intensity or in canyons and troughs (Fig. 9 and Table 5). The highest density was > 6000 items/km^2 which is 30 times the background value of 200 items/km^2 and was recorded in a trough offshore alongside a fishing bank “Sveinsgrunnen” and at the coast close to “Godøy”.

4.1.2. Marine landscapes

Litter was unevenly distributed in marine landscapes and density of litter on the deep-sea plain, continental slope and shelf was mainly below 200 items (160 kg)/km^2. Fjords and canyons had higher densities than other landscapes, indicating an accumulation effect (Table 4, Figs. 6, 9). In canyons densities were high and more than double the

Table 3
Litter densities in the Barents Sea and the Norwegian Sea at different depth intervals offshore and close to coast. Number of video stations, number and percentage with litter, area seafloor observed, total numbers of litter observed, and number and kilos observations per km^2 (see also Fig. 3).

	No. Stations	No. with litter	% with litter	Observed area (m^2)	No. of litter items	Items/km^2	kg/km^2
Barents Sea							
Coast							
< 100	13	4	31	27,300	7	256	220
100–200	35	11	31	73,500	29	395	302
200–500	71	19	27	149,100	31	208	160
Offshore							
< 100	54	11	20	113,400	13	115	101
100–400	726	189	26	1,524,600	283	186	144
400–700	102	31	30	214,200	49	229	187
700–900	48	15	31	100,800	21	208	175
900–1200	35	12	34	73,500	29	395	252
1200–1500	22	4	18	46,200	11	238	162
1500–1800	7	3	43	14,700	3	204	136
1800–2700	19	4	21	39,900	4	100	75
Barents Sea total	1132	303	27	2,377,200	480	230	174
Coast total	119	34	29	249,900	67	286	227
Offshore total	1013	269	27	2,127,300	413	209	154
Norwegian sea							
Coast							
100–200	6	5	83	12,600	22	1746	1667
200–500	10	7	70	21,000	77	3667	3352
Offshore							
< 100	16	3	19	33,600	5	149	149
100–400	379	123	32	798,000	203	255	205
400–700	154	25	16	323,400	46	142	102
700–900	32	5	16	67,200	6	89	60
900–1200	10	2	20	21,000	2	95	71
1200–1500	10	5	50	21,000	6	286	190
1500–1800	9	3	33	18,900	3	159	79
1800–2700	20	7	35	42,000	8	190	131
Norwegian Sea Total	646	185	29	1,358,700	378	678	601
Coast total	16	12	75	33,600	99	2706	2510
Offshore total	630	173	27	1,325,100	279	171	123
Grand Total	**1778**	**488**	**27**	**3,735,900**	**858**	**230**	**182**

density of shelf and slope areas (i.e. 460 items (340 kg)/km^2) and in fjords the density was three times higher (780 items and 680 kg/km^2). Litter accumulates in certain marine landscapes as troughs on the shelf and canyons where 2–3 tons/km^2 was observed. This is > 10 times the background abundance for the Barents Sea of 200 kg/km^2.

4.1.3. Composition

At offshore locations, the litter largely originated from fishing activities (nets, wires, etc.) (Figs. 7, 8) and it accumulated in depressions (Fig. 9). Fishing gear dominated in all landscapes except continental slope plain an in general, the amount increases towards the coast. Second comes rubber and plastic. Unfortunately, the unspecified class is rather large, due to difficulties of identification.

5. Discussion

The occurrence of litter on the seafloor has been far less investigated than in surface waters and on beaches. From the Nordic Seas previously, only four locations have been reported (Pham et al., 2014). The main reason is the challenge involved in sampling and recording of litter from the deep sea in arctic and sub-arctic waters, and that only recently managers and the scientific community have become aware of the vast problem litter presents to the marine ecosystem. Knowledge on litter accumulation in deep waters is poor, and our analysis of litter density, distribution and composition in Nordic Seas provides new and valuable information for an area particularly vulnerable to human pressure. We have integrated data from 23 cruises in an area with a small population, and under pressure from climate related changes.

Pham et al. (2014) suggest that both weight and number of items for litter quantification should be reported to better understand trends in littering. The EU Marine Strategy Framework Directive stresses that for monitoring litter in the marine environment, number is mandatory while weight is only recommended (Galgani et al., 2013). We have reported both on numbers and weight as quantification units by converting from number of items to weight using assumed average weight per item of different classes. Weight estimates from video observations however, introduces uncertainty. For number of items, certain litter categories may be overestimated (plastic or glass can disintegrate into many small pieces), and for weigh, the abundance of e.g. heavy wire vs. light plastic is not compared.

Background density (mean value for all stations) of litter for the Nordic Seas is 230 items/km^2 observed by video. This is slightly more than the density of 200 items/km^2 reported from the continental shelfs in the European waters by Pham et al. (2014). In areas with most littering on the Norwegian shelf the litter density was 4000–11,900 items/km^2 which is only paralleled in the European Waters by a

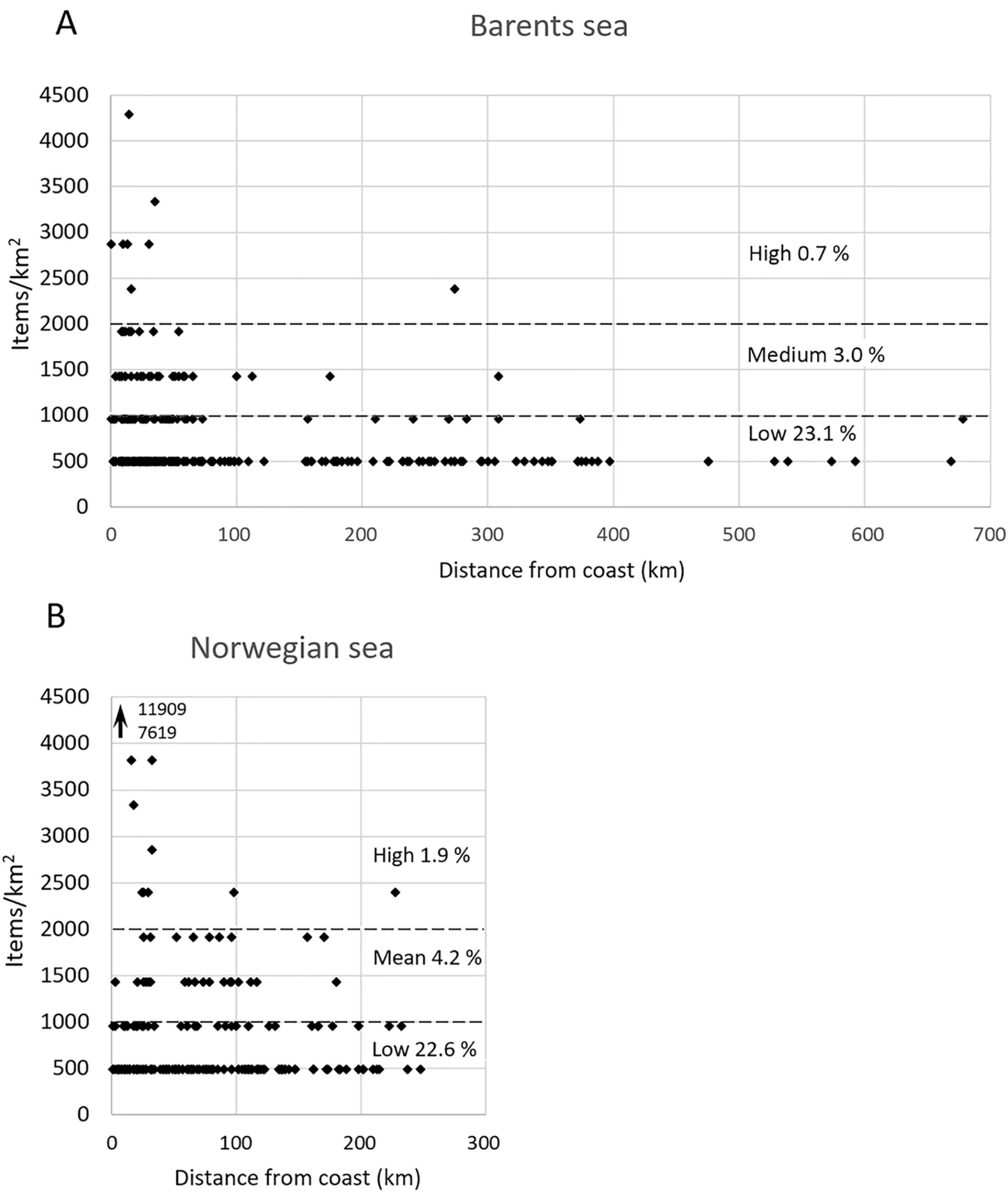

Fig. 4. Litter density (items/km^2) in relation to distance to coast. A: the Barents Sea, B: the Norwegian Sea. Dashed lines indicate density group: high > 2000, medium 1000–2000, and > 0–1000 items/km^2 and percentage of video transects within each group is provided (density groups are based on Pham et al., 2014).

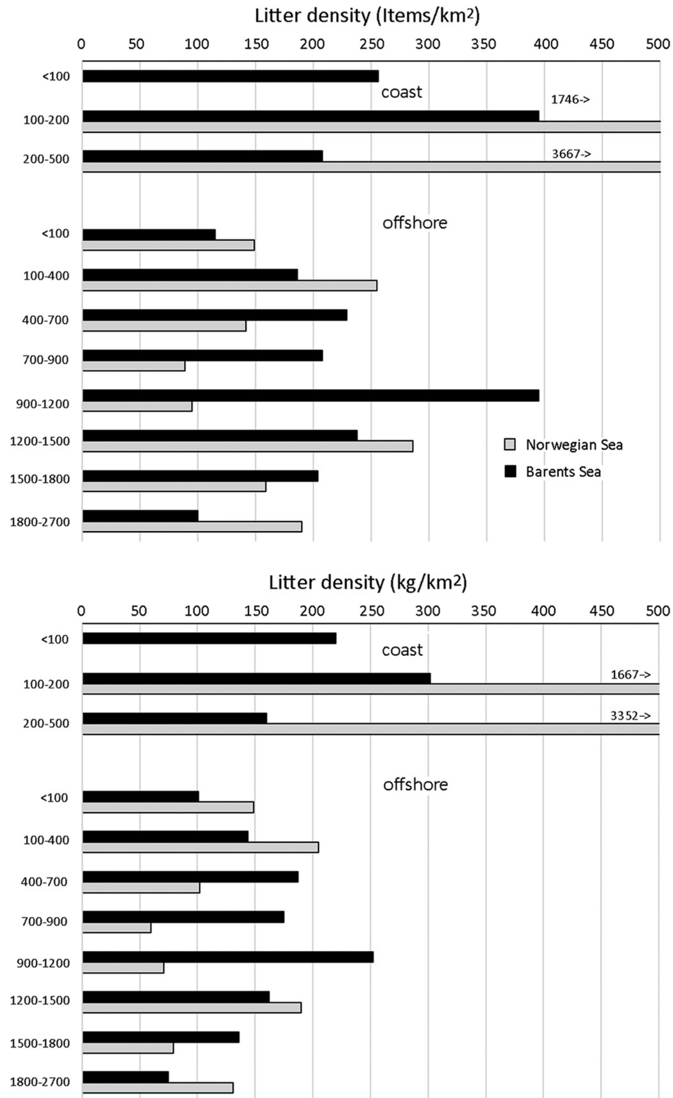

Fig. 5. Litter density in depth intervals for coast and open sea of the Barents Sea and Norwegian Sea. Litter is provided as items and weight (kg) per km^2 based on area covered by video.

maximum value of 6620 items/km^2 reported from the Lisbon canyon, Portugal (Pham et al., 2014). The highest densities in the study area is found at coast localities with high fishing related activities, this might also be the case for the Portuguese record.

Highest density of litter was found mainly in fjords and marine canyons, and on the strand flat close to the coast, which is in agreement with findings by Pham et al. (2014) and Woodall et al. (2015). Our finding of larger densities in canyons and trenches indicating that the lower litter density on the shelf plain was caused by near bottom currents and sloping terrain resulting in a transport to deeper waters. A similar situation has been reported from Monterey Bay where sediment and litter are swept off the continental shelf down into Monterey Canyon (Schlining et al., 2013).

Table 4
Litter densities observed in different marine landscapes. Number of video stations, area covered, and abundance of litter as: total number of litter observed, number and kilos of litter observed normalized to per km^2 (data from Mareano, see also Fig. 9).

Landscape	No stations	Observed area (m^2)	No of items observed	Items/km^2	kg/km^2
Fjord	78	163,800	128	781	682
Marine canyon	50	105,000	49	467	331
Strandflat	40	86,100	24	279	225
Marine valley	290	609,000	147	241	192
Shallow marine valley	291	611,100	130	213	164
Smooth continental slope	356	747,600	152	203	162
Continental shelf plain	619	1,299,900	219	168	132
Deep sea plain	14	29,400	3	102	85
Continental slope plain	40	84,000	6	71	39
Grand Total	1778	3,735,900	858	230	182

Shallower than 100 m offshore, litter densities are very low, while near coast, and in troughs and canyons densities are high, mostly represented by lost fishing gear. These observations indicate that distribution and composition is mainly driven by currents, topography and human activities. During a recent cruise, mapping vulnerable habitats (VMEs) on the shelf off the Faroes, 60 video transects were conducted. With the exception for 13 lost long-lines, no litter was observed (personal communication Petur Steingrund/ NovasArc project). On this shelf with high fishing intensity, strong currents will likely prevent accumulation of litter, which is supported by the observations of a downward transport to canyons. On the other hand, the Faroes have a very small population and are far away from heavily populated coasts.

Plastic was not the main litter in the study area, and fishery related litter was dominating. This agrees with findings from other areas with high fishing activities such as on oceanic ridges and seamounts (Pham et al., 2014 and Woodall et al., 2015). The main damage caused by lost fishing gear is entangling in corals or other complex habitats, ghost fishing, and physical damage to living organisms in general.

It is important to limit litter introduction at source by making it easy to deliver old fishing gear at port. Maps showing the occurrence of reefs and other structures that easily entangles nets and lines should be made available to the fishing industry for use with digital navigation systems. Cleaning up lost fishing gear in VMEs by dragging may cause as much damage as bottom trawling in such areas. Careful and gentle disentangling of lost fishing gear may be ineffective and costly. Environmental costs and benefits must be evaluated after appropriate mapping of the seabed before deciding on measures.

The numbers of reports on litter from remote and deep seas are increasing but are still very few. Our report is the first extensive overview provided from arctic and subarctic areas and it demonstrates clear differences between the Norwegian Sea and the Barents Sea and coast versus offshore litter densities.

Sources of litter and processes driving its distribution and

Table 5
Areas with highest load of litter. Number of videos, area covered, and litter densities as mean number of items/km^2 and kg/km^2. Data from Mareano except data from Hausgarten in the Norwegian Sea off Svalbard which is extracted from Bergmann and Klages (2012).

Locality	No. stations	Observed area (m)	No. of litter items	Litter (Items/km^2)	Litter (kg/km^2)
Open ocean					
TROMS II - Sveinsgrunnen ravine	2	4200	13	6190	2024
Sula revet	2	4200	10	4762	2024
NORDLAND VII - Bleiksdjupet	1	2100	9	4286	2762
Storneset	2	4200	9	4286	1786
Mørebanken	1	2100	8	3810	3810
Ytre Mørebanken - Eggakanten	2	4200	8	3810	1667
TROMS III	2	4200	8	3810	1500
Skjoldryggen	1	2100	5	2381	2381
NORDLAND VII - Hola	2	4200	10	2381	2143
Finnmark Øst	5	10,500	23	2190	1714
NORDLAND VI	2	4200	8	1905	1905
Nordland-Eggakanten	2	4200	8	1905	1500
Hausgarten (Bergman & Klages 2012)	4	8570	23	2683	1717
Coast					
Møre - Godøy	5	10,500	72	6857	6248
Varangerfjorden	2	4200	10	2381	1976
Møre - Julsundet	4	8400	19	2262	2119
Finnmarkskysten	1	2100	4	1905	1905

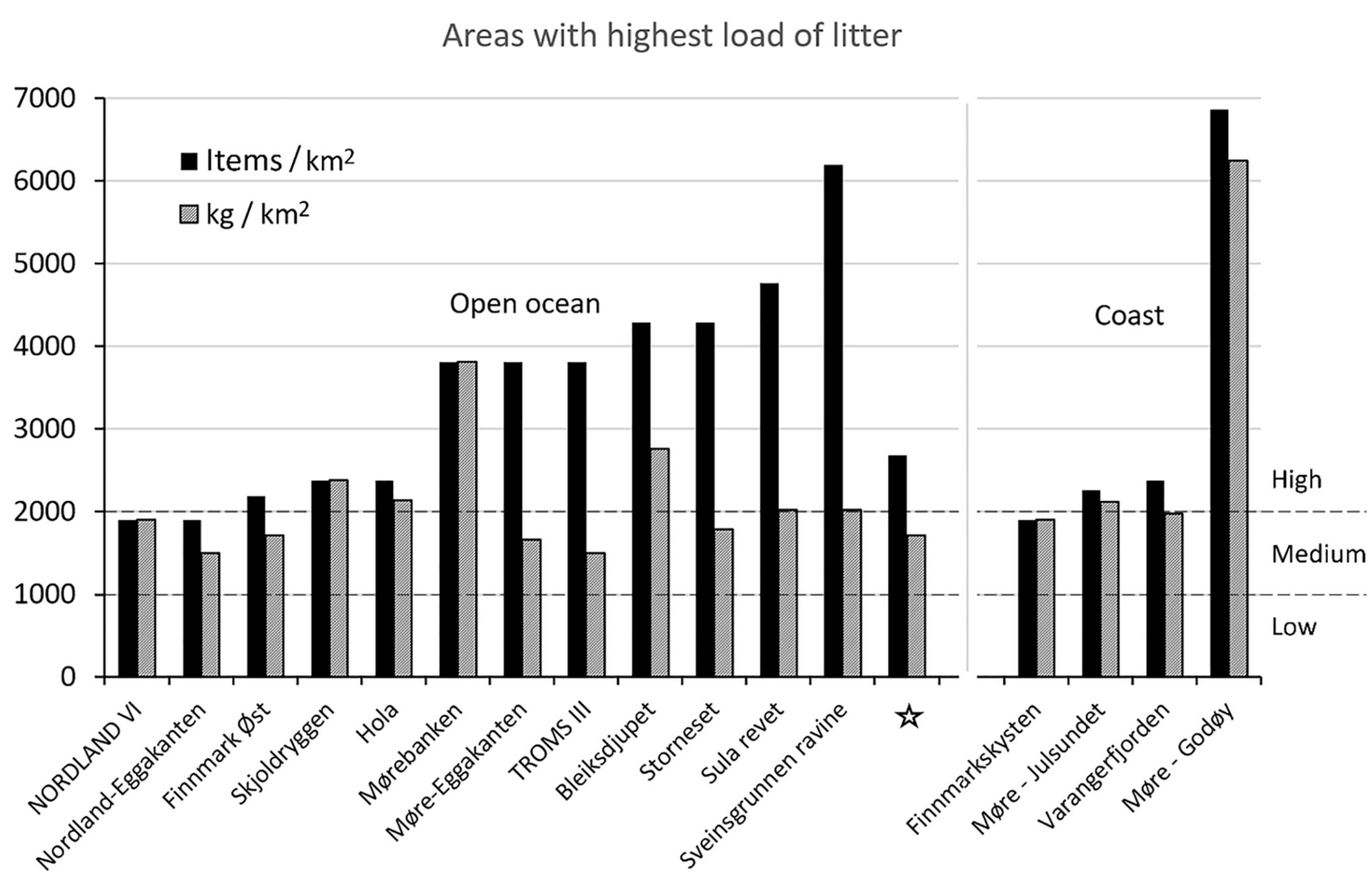

Fig. 6. Abundance of litter on the seafloor in areas with highest load. Litter is provided in numbers and weight (kg) normalized to observations/km^2 based on area covered by video. Star indicates: litter at Hausgarten in the Norwegian Sea off Svalbard from Bergmann and Klages (2012). Dashed lines indicate density groups of litter: high > 2000, medium 1000–2000, and > 0–1000 items/km^2 (density groups are based on Pham et al., 2014).

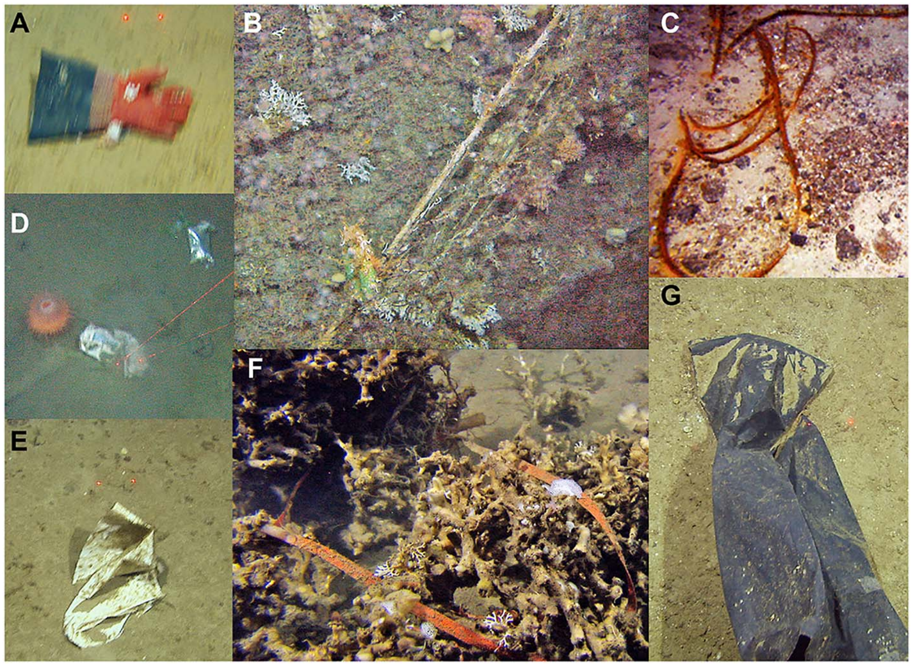

Fig. 7. Examples of litter observed on the seafloor in the Nordic Seas: A. rubber glove, B. gill net, C. trawl wire, D. Drinking cartons, E: soft plastic, F: Plastic straps, G: Plastic bag (Photo curtesy of Mareano-IMR).

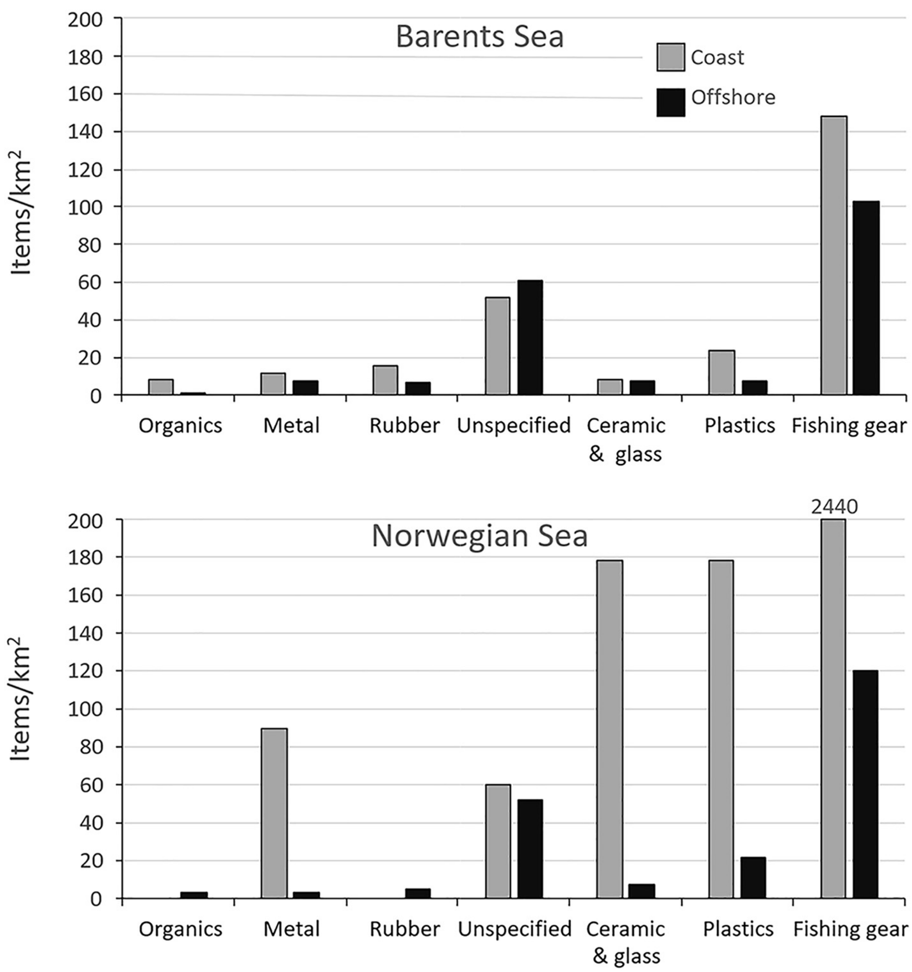

Fig. 8. Composition of litter in the Barents Sea and Norwegian Seas divided in off shore and coast based on 1779 video stations (see map Fig. 1).

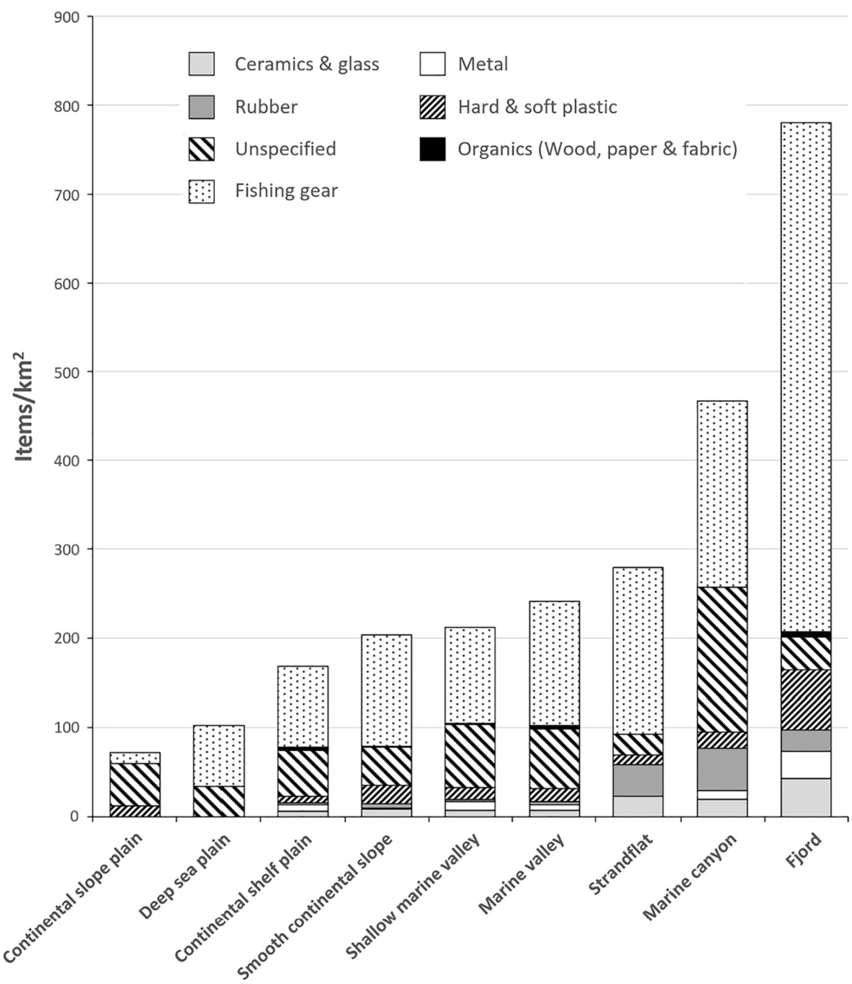

Fig. 9. Density and composition of litters the seafloor in different marine landscapes. Litter is provided as mean numbers of items/km^2.

accumulation, whether this is on beaches, in the marine food chain or in certain marine landscapes, will differ between regions and seas. Thus, to understand how litter affects the marine ecosystem more studies from a wider set of marine ecosystems is highly needed.

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