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Update on ongoing studies of non-fishing activities in the NRA: Seabed macrolitter (2024 preliminary data)

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We updated the records and densities of seabed macrolitter in the NAFO Regulatory Area (NRA; Divs. 3LMNO) based on opportunistic sampling conducted during the 2024 EU–Spain/Portugal groundfish surveys. This study provides an updated information on seabed macrolitter for Divs. 3LMNO. These data were obtained through specific log forms and according to the protocol summary sheets, both developed during the NEREIDA project. A total of 388 valid bottom trawl hauls were analysed (45-1482 m depth). Litter was found in 32.2% of the valid hauls, with mean densities of 16.6±47.1 items km^{-2} and 52±758 kg km^{-2}. Fisheries related litter was the most abundant litter (52.2%). Plastic, metal and other anthropogenic litter were the next most abundant group categories, accounting for 29%, 8% and 4% of the total seabed litter items recorded, respectively. Fisheries was found to be the main source of seabed litter (58%), followed by galley waste (4%) and operational waste (1%). However, 37% of items were of uncertain source. Whereas in most cases the fisheries-related litter was composed of small fragments of rope, in other cases it was composed of entire fishing gears (e.g., pots from fisheries not managed by NAFO). The results from this study provide an updated information on the distribution of seabed litter in Divs. 3LMNO and will help to improve the current protocol for collecting seabed macrolitter data and to implement best practices in groundfish surveys conducted in the region.

1. Introduction

The United Nations Environment Programme (UNEP) defines marine litter as "*any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment*"[1]. Nowadays, marine litter is a recognized worldwide problem that affects the marine environment in several ways such as economic loss, degradation of habitats and impact on biota (Pham *et al.,* 2014). The large quantities of litter reaching the deep ocean floor is a major issue

[1] **https://www.unep.org/topics/ocean-seas-and-coasts/regional-seas-programme/marine-litter**

worldwide, yet little is known about its sources, patterns of distribution, abundance and, particularly, impacts on the habitats and associated fauna (UNEP, 2009). Benthic habitats and ecosystems, such as the Vulnerable Marine Ecosystems (VMEs) (FAO, 2009), may be therefore affected or damaged by marine litter (Pham *et al.,* 2014, Canals *et al.,* 2021 and references therein), as the sea bottom is considered a long-term sink for marine litter (Woodall *et al.,* 2014; Egger *et al.,* 2020; Kaandorp *et al.,* 2020).

Most of the previous literature about seabed litter has studied areas close to the coast (see e.g., Neves *et al.,* 2015; Moriarty *et al.,* 2016; Lopez-Lopez *et al.,* 2017; García-Rivera *et al.,* 2018; Cau *et al.,* 2022), and studies on deep bottoms and locations remote from land are relatively few (see e.g., Pham *et al.,* 2014, Vieira *et al.,* 2015; Woodall *et al.,* 2015; García-Alegre *et al.,* 2020; Parga Martínez *et al.,* 2020; Ryan *et al.,* 2020). Even remote areas of the sea floor have been found to accumulate litter, and previous studies suggested that seabed litter is ubiquitous on raised benthic features, such as seamounts (Woodall *et al.,* 2015). The most common litter types found on the deep–sea floor in remote areas of the Atlantic Ocean are fishing gear, soft plastic (e.g., bags), hard plastic (e.g., bottles, containers), metal (e.g., tins, cans), and glass/ceramics (Ramirez-Llodra *et al.,* 2011; Woodal *et al.,* 2015; García-Alegre *et al.,* 2020).

Marine litter is also a matter of concern for the NAFO Commission and Scientific Council (e.g. NAFO Commission Request #9[2]). To address the concerns about seabed litter in the NAFO Regulatory Area, the Spanish Institute of Oceanography (IEO) started to monitor in year 2006 the spatial and temporal distribution of seabed litter in the Flemish Pass (Division 3L) using data from the European groundfish surveys. A study was conducted in Division 3L (see García-Alegre *et al.,* 2020), in which an extensive seabed litter database was analyzed (Durán Muñoz *et al.,* 2020). Based on that study, NAFO WG-ESA[3] recommended to Scientific Council that standardized protocols for marine litter data collection should be implemented by all Contracting Parties as part of their groundfish surveys conducted in the NAFO Regulatory Area (NRA), to facilitate the on-going monitoring and assessment of seabed litter (NAFO, 2019).

In addition, during 2024, a study was presented to provide updates on the spatial and temporal distribution of seabed litter in the NRA, based on relevant information collected by IEO between 2018 and 2023 from EU-Spain/Portugal groundfish surveys in Divisions 3LMNO (Abalo-Morla *et al.,* 2024). This was in response to the NAFO Commission's request to continue monitoring and providing updates resulting from relevant research related to the potential impact of activities other than fishing, existing strong arguments that justify the need to conduct new studies to better understand the non-fishing activities occurring in the NAFO context. Therefore, to continue providing updates on seabed macrolitter, this study aims to (i) characterize marine macrolitter on the seabed in these regions and (ii) analyze its spatial distribution across Divs. 3LMNO, based on EU-Spain/Portugal groundfish surveys 2024 data.

[2] **COM Request #9** (2024)**: "***The Commission requests the SC to monitor and provide regular updates on relevant research related to the potential impacts of activities other than fishing in the Convention Area, subject to the capacity of the Scientific Council"* (NAFO, 2024).

[3] NAFO Working Group on Ecosystem Science and Assessment (WG-ESA).

2. Materials and methods:

2.1 Study area

This study was conducted in the NW Atlantic Ocean within the Northwest Atlantic Fisheries Organization (NAFO) Regulatory Area, Divisions 3LMNO (Figure 1). The study area includes the Flemish Pass channel, the Flemish Cap offshore bank, and the Grand Banks of Newfoundland, including their slopes. The study area holds various types of valuable habitats and ecosystems, such as deep-water corals and deep-sea sponge grounds (see Murillo *et al.,* 2011, 2012).

2.2 Survey data

Seabed litter data used in this study were collected and gathered from 3 different European groundfish surveys[4], conducted on board R/V *Vizconde de Eza* between late spring and summer during 2024 (Figure 1):

1. The EU-Spain and Portugal Flemish Cap groundfish survey, conducted by the Instituto Español de Oceanografía (COV-IEO, CSIC) together with the Instituto de Investigaciones Marinas (IIM) and Instituto Português do Mar e da Atmosfera (IPMA), sampled the Flemish Cap (NAFO Div. 3M) between 128 - 1428 m depth, with a total of 186 tows (181 valid). The bottom trawl gear type used was the Lofoten (Vázquez *et al.*, 2014).
2. The EU-Spain 3NO groundfish survey, conducted by the Instituto Español de Oceanografía (COV-IEO, CSIC), sampled the Grand Bank of Newfoundland (NAFO Divs. 3NO) between 45 - 1460 m depth, with a total of 116 tows (112 valid). The gear used was the Campelen 1800 otter trawl net (McCallum and Walsh 1994; Walsh *et al.,* 2001).
3. The EU 3L groundfish survey, conducted by the Instituto Español de Oceanografía (COV-IEO, CSIC), sampled Div. 3L between 117 - 1482 m depth, with a total of 95 tows (94 valid). The gear used was the Campelen 1800 otter trawl net (McCallum and Walsh 1994; Walsh *et al.,* 2001).

[4] These surveys are relevant to provide key data on the presence, distribution, and abundance of seabed litter. Although they are primarily intended for fisheries stock assessment, other ancillary ecosystem information is also collected, such as data on Vulnerable Marine Ecosystems indicator species, or seabed litter, which the earliest records dating back to as early as 2006.

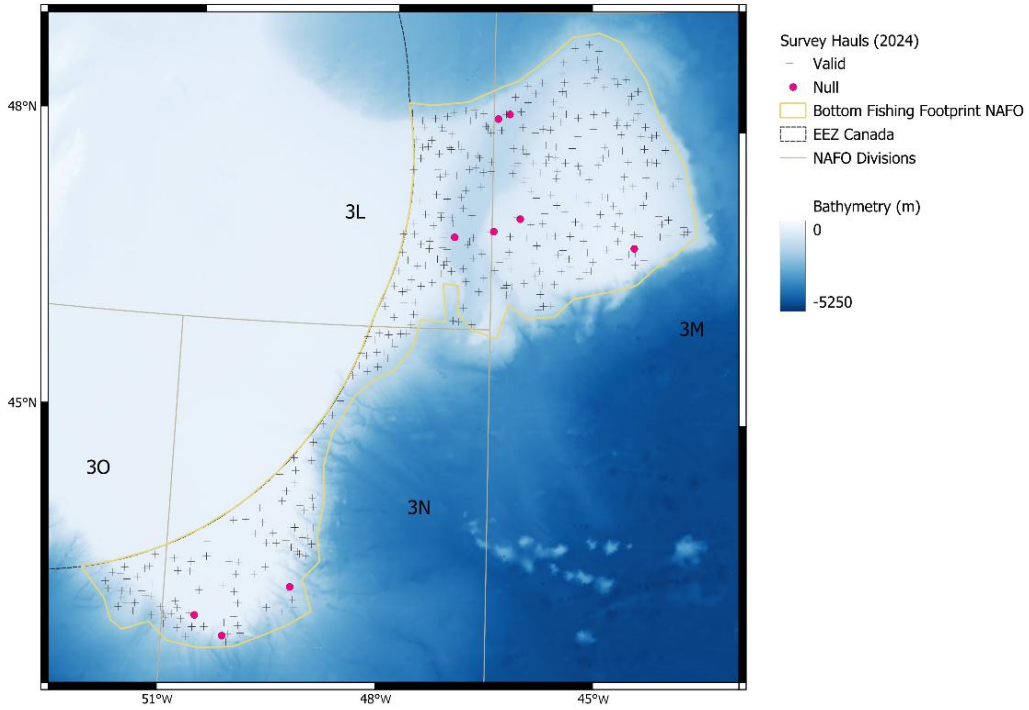

Figure 1. Map showing valid (black crosses) and null tows (magenta circles) conducted during the European groundfish surveys during 2024. The bathymetry (in blue scale), the boundaries of the bottom fishing footprint in the NAFO NRA (yellow line), the Canadian Economic Exclusive Zone (EEZ) (dashed black line) and the NAFO Divisions (grey line) are also shown.

2.3 Data collection

Based on the recommendation of the Scientific Council to the NAFO Commission that standardized protocols for the collection of seabed litter data should be implemented by all Contracting Parties as part of their groundfish surveys, the Spanish Institute of Oceanography (IEO) developed a protocol to be used in all the EU groundfish surveys in the NRA. The objective of implementing a protocol was to extend the seabed litter data collection started in year 2006 (García-Alegre *et al.,* 2020) in the Flemish Pass (Div. 3L) to the other areas sampled by the EU surveys: Flemish Cap (Div. 3M) and the Grand Banks of Newfoundland (Divs. 3NO), using the same methodology. This protocol was first implemented in Divs. 3LNO (2018) and Div. 3M (2019) as a pilot experiment and its application continued until 2025 (included). An ongoing study is been conducted to review and improve the seabed litter data collection protocol and forms.

According to the current protocol, after each haul, all seabed litter items collected and retained by the bottom trawl gear were examined, categorized, counted, weighed, sized, photographed (if possible), and recorded onboard the research vessel. Any evidence regarding the source of seabed litter was also recorded. For each haul, trawl gear characteristics, location, date, time and depth at start and end of trawl were also recorded.

Additionally, available spatial information about bottom fisheries effort (both regulated by NAFO and by the coastal State, Canada) was compiled. Cumulative fishing effort of groundfish fisheries operating in the NRA during 2016-2022 was obtained (Garrido *et al.,* 2023). Spatial data on snow

crab fisheries overlapping with NAFO NRA bottom fisheries footprint was obtained from DFO in the framework of ATLAS project, and consisted of a percentile effort layer for 2005-2016.

2.4 Data analysis

Seabed macrolitter data was included in a database, according to the master file containing all the updated categories and codes of the seabed macrolitter records collected to date by the IEO in the NRA, which was developed in 2024 (Abalo-Morla *et al.,* 2024). A cross-check of the seabed macrolitter database with the photographic records collected, was also carried. Part of this work has been carried out within the framework of the 2025 training internship agreement between the CSIC and the University of Vigo. The criteria for counting seabed litter items was as described in the ICES Manual for Seafloor Litter Data Collection (ICES, 2022). According to ICES, litter that arises from the survey itself, such as items released from the gear or the vessel during the trawl (e.g., codend strings, pieces of net, plastic floats from the trawl gear), were excluded from the analysis (ICES, 2022).

In order to simplify the analysis, seabed litter items were classified into seven litter group categories (Table 1), based on their material composition, degradability and original activity, namely: Plastics, Rubber, Metal, Fisheries related litter, Glass/Ceramics, Organic litter and Other anthropogenic litter (Modified from OSPAR, 2007 and ICES, 2022). The latter included processed wood, textiles, paper/cardboard, clothing, ropes made of natural fibers, and other anthropogenic litter not fitting into the other litter group categories. Fisheries derived items (i.e., pieces of longlines, nets, bobbins, floats, pots, hooks) were incorporated into a separated group category, as done in previous research (Pham *et al.,* 2014; Lopez-Lopez *et al.,* 2017; García-Alegre *et al.,* 2020; Abalo-Morla *et al.,* 2024). Additionally, it was determined whether synthetic ropes and/or entangled monofilaments could be associated with fisheries or not, and were accordingly assigned to the pertaining litter group category. Within each category, litter debris was identified to determine their source by following Veiga *et al.,* 2016.

Haul data were then standardized as density per square km (both by number of seabed litter items and weight) and both represented for each trawl and averaged for sampling strata, according to the NAFO stratification scheme (Doubleday, 1981). These density values were calculated by the swept area, obtained by multiplying the distance trawled by the net and the estimated horizontal opening (Campelen 1800 swept area in Divs. 3LNO; see García-Alegre *et al.,* 2020) or by the haul path estimated by haul locations (Lofoten swept area in Div. 3M) (Abalo-Morla *et al.,* 2024).

3. Results and discussion

3.1 Characterization of marine litter on the seabed

Litter debris was found on 32.2% of the total valid trawls analyzed (n=388). Approximately 238 litter items were encountered across all surveyed sites, with an estimated total weight of 800 kg. Plastic and fishing related litter items were the most frequently found in the study area, which is consistent with the pilot study conducted in Div. 3L (García-Alegre *et al.,* 2020) and the study conducted in Divs. 3LMNO (Abalo-Morla *et al.,* 2024). Of the trawls with presence of litter, 59.2% had occurrence of fisheries related litter (Table 1). In most cases fishing-related litter consisted of small fragments of rope and entangled monofilaments, followed by fragments of fishing gear (e.g. hooks, lines, pieces of

net, bobbins, floats) or entire fishing gears (e.g. pots, nets). Similar results were observed in García-Alegre *et al.,* (2020) for Division 3L and in Abalo-Morla *et al.,* (2024) for Divisions 3LMNO.

Fishing related litter accounted for 52.5% of litter items recorded, followed by plastic which accounted for 29% of the total. Metal (8.4%), organic litter (2.5%), rubber (2.5%) and glass/ceramics (1.3%) were the least common. Items classified as "other anthropogenic litter" accounted for 3.8% of the litter items encountered in sites surveyed and included processed wood, paper/cardboard, clothing, ropes made using natural fibers, and other uncategorized anthropogenic litter (Table 2). Our results are in line with previous studies conducted in the remote areas of the North Atlantic Ocean, in which fishing related litter, plastics associated with food packaging and metals were the most predominant (Woodall *et al.,* 2015; García-Alegre *et al.,* 2020; Abalo-Morla *et al.,* 2024).

Seabed macrolitter found has been linked to a possible ocean-based source (Veiga *et al.,* 2016), according to previous studies in the region (García-Alegre *et al.,* 2020; Abalo-Morla *et al.,* 2024). The main ocean-based sources of litter identified were fisheries (58%), litter from operational waste of shipping and offshore activities (4%); and litter from non-operational galley waste of shipping, fisheries and offshore activities (1%) (OSPAR, 2007). However, the 37% of litter was of uncertain source (i.e., plastic bags, pieces of plastic, rubber, and metal, car tires, and clothes). In Divisions 3MNO no operational waste was found, and no non-operational waste was found in Divisions 3NO either.

Table 1. Percentage of trawl tows with seabed litter occurrence per Division and for the entire study area. Percentage of hauls with seabed litter occurrence by litter group category is shown. Seven litter group categories were considered: plastic, rubber, metal, glass/ceramics, fishing-related litter, organic litter, and other anthropogenic litter. Seabed litter densities regarding the number of items (items/km^2) and weight (kg/km^2) per Division are also shown.

Division	Litter occurrence (%)	Hauls with litter occurrence by group category (%)							Mean density (items/km2)	Mean density (kg/km2)
		Plastic	Rubber	Metal	Glass/ Ceramics	Fishing related	Organic	Other		
3L	39.3	20	2.4	1.6	0	13.6	2.4	0	18.4 ± 30.3	29.8 ± 166.4
3M	27.1	12.8	0.8	1.6	1.6	25.6	0	2.4	15.1 ± 61.0	7.3 ± 32.3
3NO	34.5	12.8	1.6	1.6	0	20	0	2.4	14.5 ± 27.0	137.7 ± 1387.3
3LMNO	32.2	43.2	4.8	4.8	1.6	59.2	2.4	4.8	16.6 ± 46.6	50.8 ± 759.8

Table 2. Frequency of seabed litter and mean densities over the study area regarding the number of items and weight recorded, for each group category.

Group category	Frequency of items (%)	Mean density (items/km2)	Frequency of weight (%)	Mean density (kg/km2)
Plastic	29.0	4.7 ± 14.1	1.7	1.0 ± 11.1
Rubber	2.5	0.4 ± 3.2	4.3	2.3 ± 28.9
Metal	8.4	1.4 ± 20.7	1.4	0.8 ± 14.2
Glass/Ceramics	1.3	0.2 ± 3.0	0.1	0.04 ± 0.8
Fishing related litter	52.5	8.4 ± 21.2	91.8	47.8 ± 768.0
Organic litter	2.5	0.4 ± 5.0	0.003	0.001 ± 0.02
Other anthropogenic litter	3.8	0.6 ± 4.8	0.2	0.1 ± 1.7

3.2 Spatial and temporal distribution

Strata with higher seabed litter occurrence were located on west and southeast Flemish Pass and on the slopes of the Grand Banks of Newfoundland, but were more evenly distributed along the slopes of the Flemish Cap (Figure 2). Regarding litter items, higher densities (items/km^2) by strata were found on northwest Flemish Cap, southeast Flemish Pass, and slopes of the Grand Banks of Newfoundland. Also, higher densities of items (items/km^2) by haul were found on north and east Flemish Pass, north Flemish Cap, and along the slopes of the Grand Banks of Newfoundland (Figure 3). In terms of litter occurrence and densities (kg/km^2) the highest values were found in Divisions 3LNO, mainly on the slopes of the Grand Banks of Newfoundland, on the northern and eastern slopes of Flemish Pass, and on the northwest Flemish Cap. The results obtained in Division 3L are in line with a previous study in the region, which highlighted that the highest presence and densities of seabed litter were found in the north and northeast of the Division 3L (García-Alegre *et al.,* 2020). Results obtained in Divisions 3NO are also in line with a previous study which highlighted the highest presence of litter on the slopes of the Grand Banks of Newfoundland (Abalo-Morla *et al.,* 2024). Results obtained in Division 3M suggest that increasing seabed macrolitter effort has been done in this area during recent years, as the densities of items (items/km^2) were higher than the previous study (Abalo-Morla *et al.,* 2024) (see Table 1). No significant differences among Divisions or strata were found regarding densities in kg/km^2 or items/km^2 (Kruskal-Wallis, *p-value* >0.05).

The spatial distribution of fishing related litter showed that most records of fishing related items might be associated with areas of higher fishing effort, particularly on the northern and southern slopes of the Flemish Pass and the south-western slopes of the Grand Banks of Newfoundland, but also in west Flemish Cap (Figure 4). Therefore, an uneven distribution of fishing related items was recorded. Although synthetic ropes related with fishing activities as well other remnants of fishing gears were evenly distributed along the Flemish Cap, on the Flemish Pass and the Grand Banks of Newfoundland were mainly recorded on the slopes close to areas of cumulative groundfish fishing effort. Entangled monofilaments were recorded nearby or on the area of higher cumulative fisheries effort of the groundfish fisheries in both Divisions 3O and 3L. Floats were recorded once on the south slopes of Grand Banks (Div. 3N), nearby the areas where groundfish fisheries operates. Nets were found on the northeast Flemish Pass and on the Grand Banks platform, respectively, both close to or overlapping areas of cumulative groundfish fishing effort (Figure 4). Longlines and remnants of longline gears were recorded on the slope of the southwest part of the Grand Banks (Division 3N), close to the areas operating longline groundfish fisheries (Figure 5). Pots were recorded in the western part of the Flemish Pass, close to the Canadian EEZ, overlapping the areas where the snow crab fishery operates (Figure 6). Therefore, in Division 3L fishery-related litter items were identified as being associated with both NAFO managed and non-managed fishing activities, in accordance with previous studies (García-Alegre *et al.,* 2020; Abalo-Morla *et al.,* 2024). These results support the previous study (Abalo-Morla *et al.,* 2024).

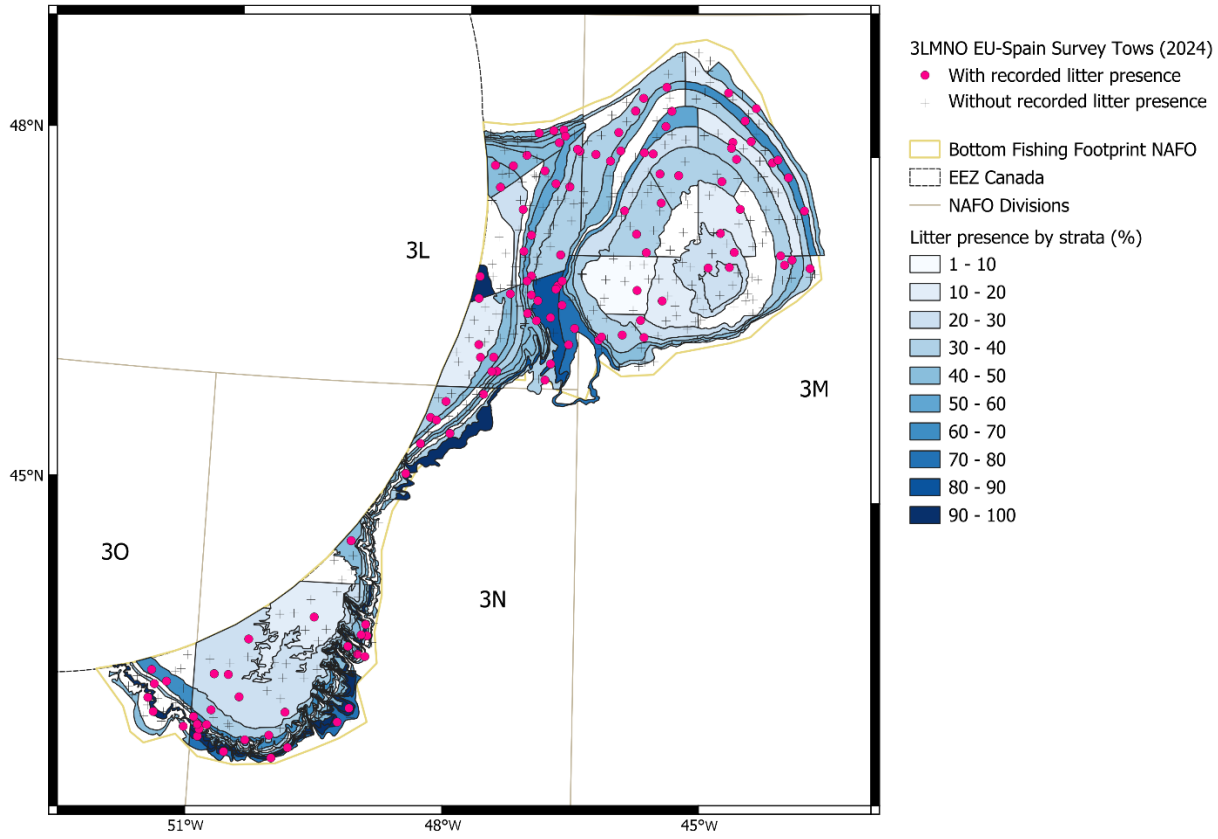

Figure 2. Spatial distribution of hauls with seabed litter presence (magenta circles) or absence (black crosses) recorded during 3LMNO EU groundfish surveys (2024). In the background, the percentage of tows with litter presence by sampling strata (according to the NAFO scheme) is shown (in blue scale). The boundaries of the bottom fishing footprint in the NRA (yellow line), the Canadian Economic Exclusive Zone (EEZ) (dashed black line) and the NAFO Divisions (grey line) are also shown.

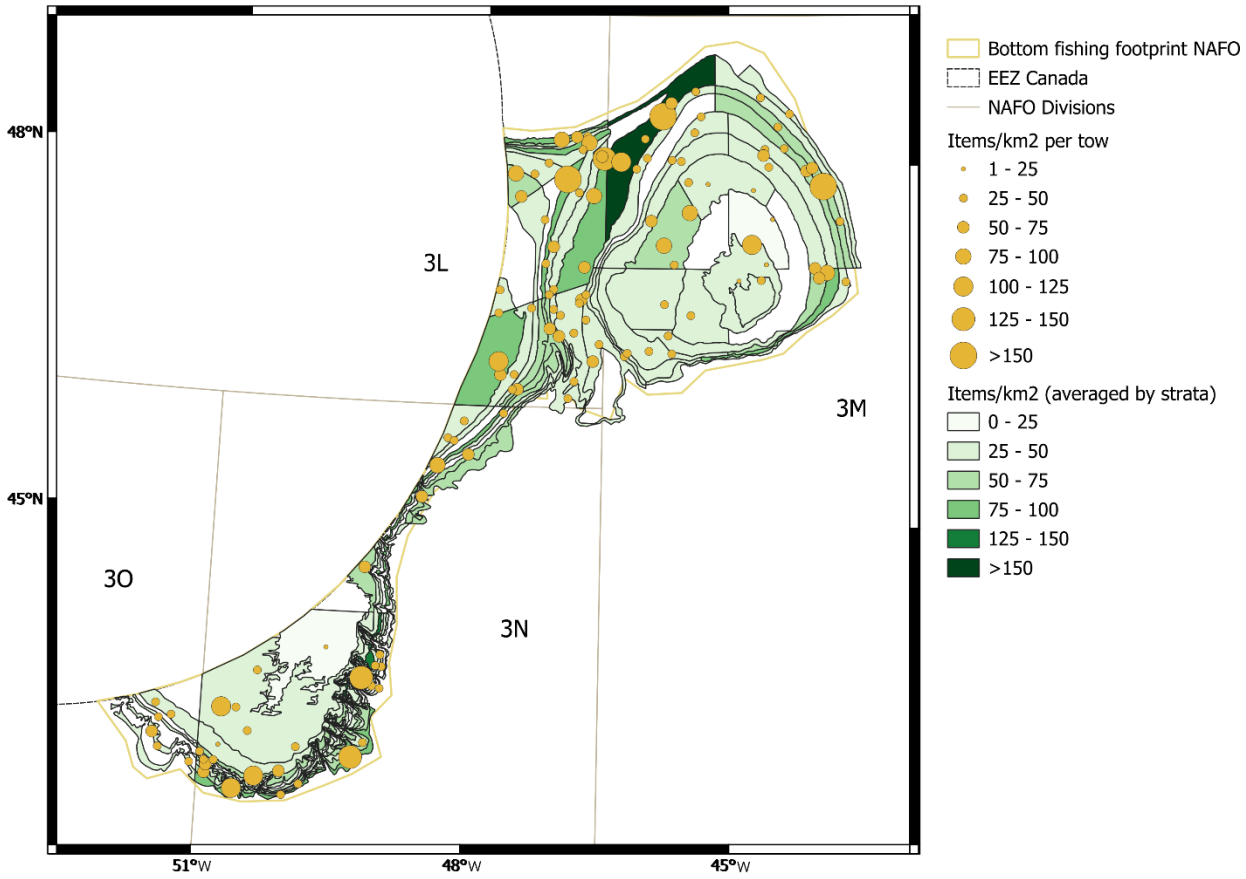

Figure 3. Seabed litter densities (number of items/km^2) per tow (yellow points) and averaged by sampling strata (in green scale) recorded during the scientific bottom trawl surveys conducted in Divisions 3LMNO during 2024.

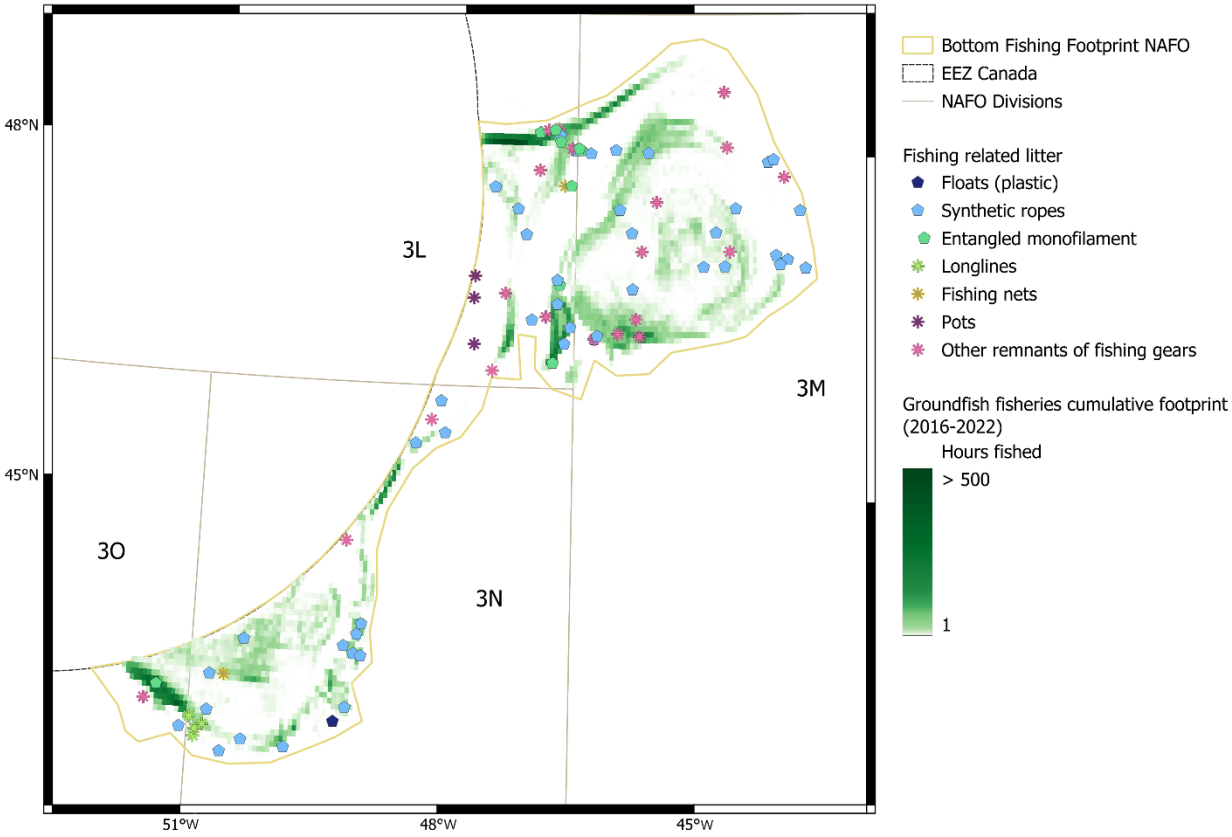

Figure 4. Spatial distribution of fishing related seabed litter by items. The cumulative fishing effort of groundfish fisheries operating in the NRA during 2016-2022 (green scale; Garrido *et al.,* 2023) is displayed. The boundaries of the bottom fishing footprint in the NAFO NRA (yellow line), the Canadian Economic Exclusive Zone (EEZ) (dashed black line) and the NAFO Divisions (grey line) are also shown.

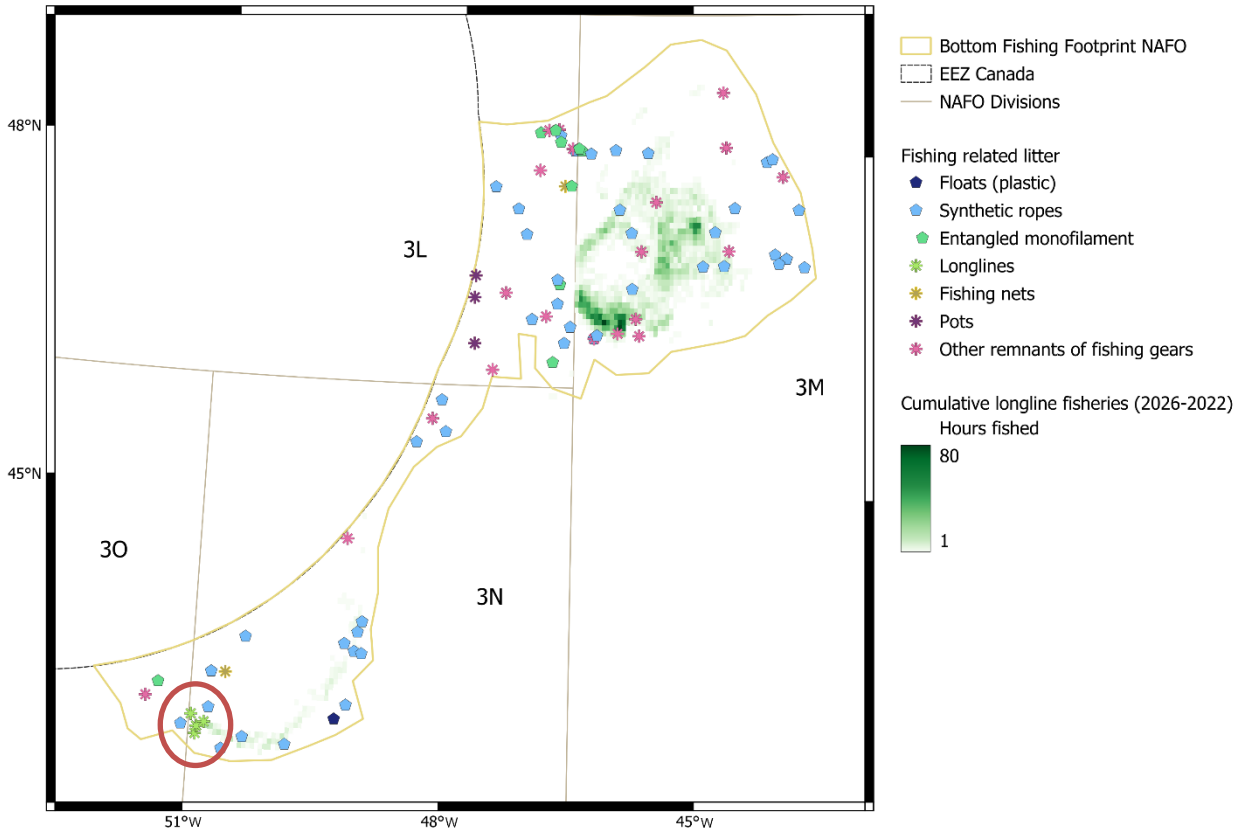

Figure 5. Spatial distribution of fishing related seabed litter by items. The cumulative fishing effort of groundfish longline fisheries operating in the NRA during 2016-2022 (green scale; Garrido *et al.,* 2023) is displayed. Longline-related litter items are highlighted with a red circle. The boundaries of the bottom fishing footprint in the NAFO NRA (yellow line), the Canadian Economic Exclusive Zone (EEZ) (dashed black line) and the NAFO Divisions (grey line) are also shown

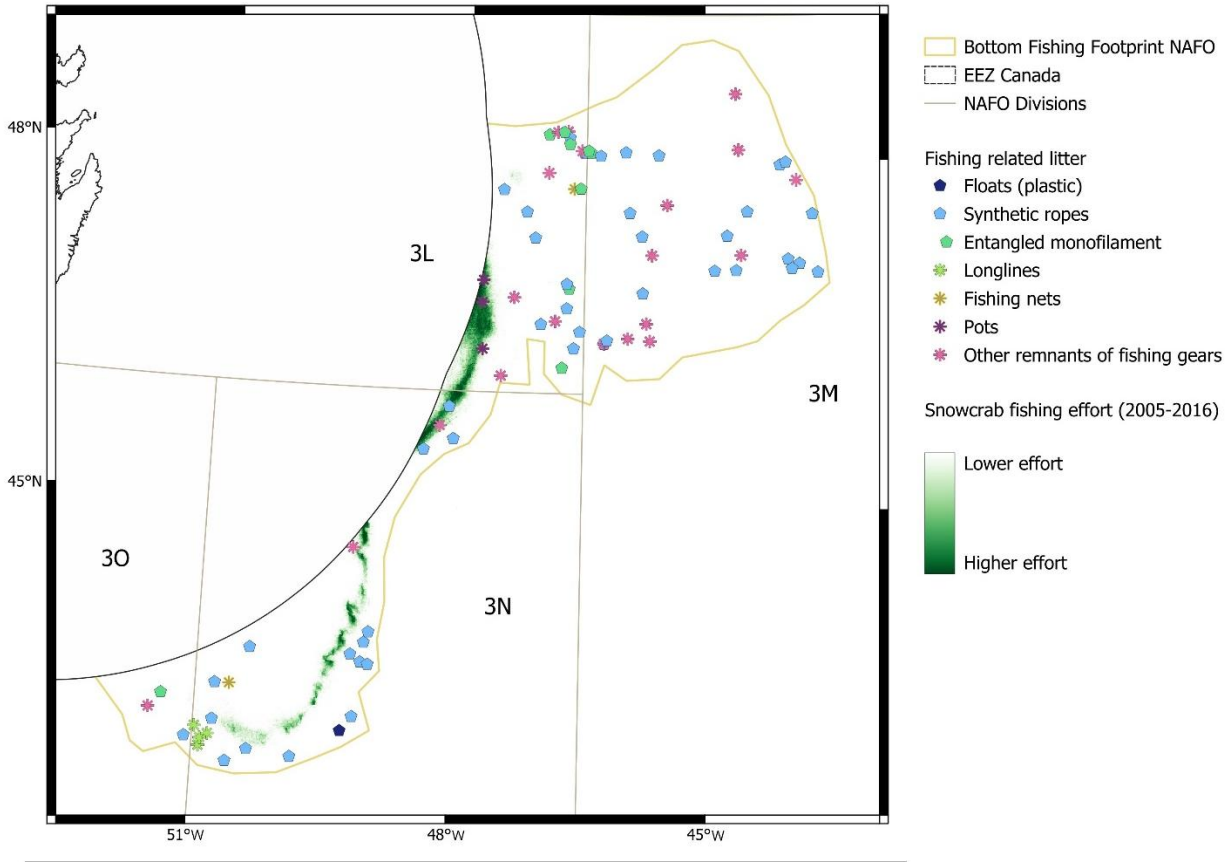

Figure 6. Spatial distribution of fishing related seabed litter by items. The percentile effort layer for 2005-2016 of snow crab fisheries (green scale) is displayed. The boundaries of the bottom fishing footprint in the NAFO NRA (yellow line), the Canadian Economic Exclusive Zone (EEZ) (dashed black line) and the NAFO Divisions (grey line) are also shown

4. Main outputs, challenges and future work

Results obtained showed that plastics and related fishing litter were the dominant types of litter found in the study area, similar to other research (Buhl-Mortensen and Buhl-Mortensen, 2018; García-Alegre *et al.,* 2020; Abalo-Morla *et al.,* 2024). Previous studies highlighted that the distribution and effects of abandoned, lost and discarded fishing gear (ADLFG) had risen substantially over past decades with the rapid expansion of fishing effort and fishing grounds, and the transition to synthetic materials used for fishing gear (Derraik, 2002).

There are some limitations to the data collected from EU groundfish surveys, as the priority of these surveys is to assess fish stocks rather than litter accumulation. Additionally, trawls only cover soft sediment trawlable areas, leading to sampling limitations in rocky areas. Small objects may not be sampled by fishing gear. Furthermore, how well the different types of gear sample litter is not yet well understood (Barry *et al.,* 2022). Despite this, the Spanish Institute of Oceanography (IEO) developed a protocol for seabed litter data collection, to be used in all the EU groundfish surveys in the NRA. This protocol is still being revised and improved with the objective of providing a standardized sampling protocol for such surveys. In addition, it should be noted that sampling effort

of seabed macrolitter has apparently increased in recent years, particularly following the review of the protocol as part of the NEREIDA project.

In summary, this study contributed to NAFO Commission Request #9[5] with an update on seabed litter data. The results contributed to the characterization of marine litter on the seabed and provided new insights into its spatial distribution across Divs. 3LMNO. Outputs from this study will help in conducting ongoing research on seabed litter in the region, whose aim is to (i) update the knowledge about its spatial distribution; (ii) determine the main sources; (iii) elucidate the potential drivers of distribution; (iv) improve the current protocol and data forms for data collection, and (v) provide recommendations and good practices. An update from this study is expected to be presented during next WG-ESA meeting, scheduled for November 2026.

Acknowledgments

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[5] **COM Request #9** (2024)**: "***The Commission requests the SC to monitor and provide regular updates on relevant research related to the potential impacts of activities other than fishing in the Convention Area, subject to the capacity of the Scientific Council"* (NAFO, 2024).

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