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Preliminary results on seabed litter distribution on Flemish Cap (Div. 3M), Flemish Pass (Div. 3L) and Grand Banks of Newfoundland (Divs. 3NO).

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We analyzed seabed litter densities in the NAFO Regulatory Area (NRA; Divs. 3LMNO) using six years of demersal trawling data from the EU-Spain/Portugal groundfish surveys (period 2018–2023). This study provides a preliminary updated information and a baseline information on seabed litter for Div. 3L and Divs. 3MNO, respectively. A total of 1936 valid bottom trawl hauls were analysed (40-1481 m depth). Litter was found in 16.7% of the valid hauls, with mean densities of 6.7±18.5 items km^{-2} and 7.7±121.5 kg km^{-2}. Fisheries was found to be the main source of seabed litter, and 41.8% of the hauls with litter presence showed litter included in the fisheries-related litter group category. 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). Plastic, metal and other anthropogenic litter were the next most abundant group categories, accounting for 63.6%, 12.9% and 8.3% of the total seabed litter items recorded, respectively. The results from this study will provide information on the distribution of seabed litter in Divs. 3LMNO and will help to improve the current protocol for collecting seabed litter 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

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

(Pham *et al.,* 2014). The large quantities of litter reaching the deep ocean floor is a major issue 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 gears, 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).

The present study aims to continue 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. This is 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 (e.g. COM Request #9), existing strong arguments that justify the need to conduct new studies to better understand the non-fishing activities occurring in the NAFO context. Therefore, given the importance and value of the IEO database, the main objective of this study is to extend the analysis done in a previous study (García-Alegre *et al.,* 2020) temporarily in Flemish Pass (Div. 3L), and spatially to other areas sampled by EU-Spain/Portugal groundfish surveys: Flemish Cap (Div. 3M) and the Grand Banks (Divs. 3NO). The present analysis contributed to (i) characterizing marine litter on the seabed in these regions, and (ii) analyzing the spatial distribution of seabed litter in Divs. 3LMNO.

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[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 2018 – 2023 (Table 1; Figure 1):

1. The EU-Spain 3L groundfish survey, conducted by the Instituto Español de Oceanografía (IEO, CSIC), sampled Div. 3L with a total of 298 tows (291 valid). The gear used in Division 3L was the Campelen 1800 otter trawl net (McCallum and Walsh 1994; Walsh *et al.,* 2001). Depth ranged between 116- 1491 meters. Due to the pandemic COVID-19, during 2020 and 2021 surveys were no conducted in Division 3L. During 2022 the survey was not conducted due to technical issues.

2. The EU-Spain and Portugal Flemish Cap groundfish survey, conducted by the Instituto Español de Oceanografía (IEO, CSIC), together with the Instituto de Investigaciones Marinas (IIM, CSIC), and Instituto Português do Mar e da Atmosfera (IPMA), sampled the Flemish Cap (NAFO Div. 3M), with a total of 1101 tows (1087 valid). In Division 3M the bottom trawl gear type used was the Lofoten (Vázquez *et al.*, 2014). Depth ranged between 128 – 1470 meters.

3. The EU-Spain 3NO groundfish survey, conducted by the Instituto Español de Oceanografía (IEO, CSIC), sampled the Grand Bank of Newfoundland (NAFO Divs. 3NO), with a total of 570 tows (558 valid). The bottom trawl gear used in Divisions 3NO was the same as that used in Div. 3L (Campelen 1800 gear type). Depth ranged between 40 – 1460 meters. Due to the pandemic COVID-19, survey during 2020 there was not conducted in Divisions 3NO.

[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.

Table 1. Summary of sampling: years with survey (✓); years without survey (✗). Reasons for not conducting the survey were: COVID-19 pandemic (*) technical issues (**).

	2018	2019	2020	2021	2022	2023
Div. 3L	✓	✓	✗*	✗*	✗**	✓
Div. 3M	✓	✓	✓	✓	✓	✓
Divs. 3NO	✓	✓	✗*	✓	✓	✓

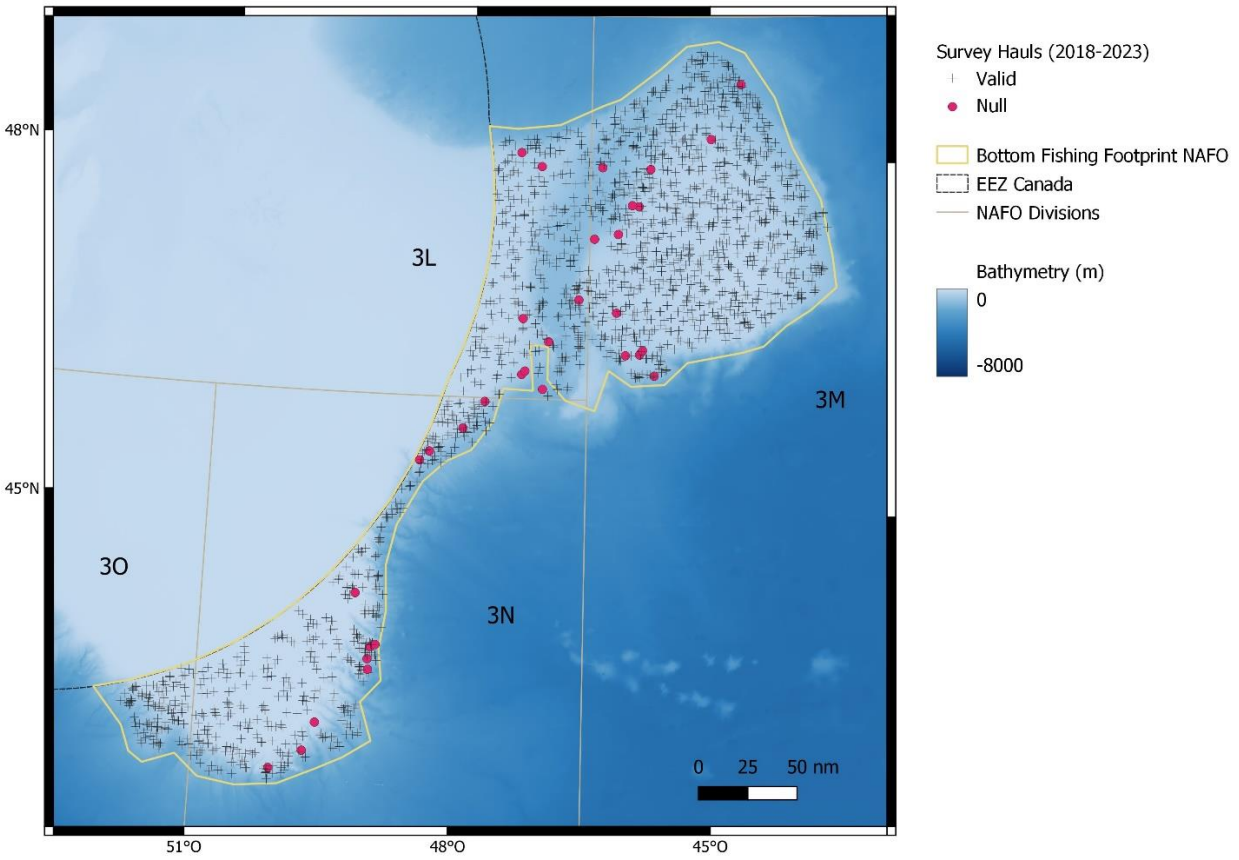

Figure 1. Valid (black crosses) and null tows (pink points) conducted during the European groundfish surveys from 2018 to 2023. The bathymetry (in blue scale), the boundaries of the bottom fishing footprint in the NAFO NRA (yellow line), the Canadian Economic Exclusive Zone (EEZ) (dashed black line) 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 2023 (included). An ongoing study is been conducted to review and improve the seabed litter data collection protocol.

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 queen-snow crab fisheries overlapping with NAFO NRA bottom fisheries footprint was obtained from Statistical Services, Fisheries and Oceans Canada (DFO) and consists of commercial landings data from 2012 to 2021. Data is available at: **https://gisp.dfo-mpo.gc.ca/arcgis/rest/services/FGP/Eastern_Canadian_Commercial_Fishing/MapServer//24** .

2.4 Data analysis

A comprehensive review, update and standardization of the list of seabed litter categories and codes was performed, with particular attention to the existing data recorded in the NAFO Regulatory Area (NRA), to obtain a standardized master file. That master file contains all the updated categories and specific codes of the records collected to date by the IEO in the NRA. A cross-check of the groundfish survey data collection form with the database was carried out to ensure that seabed litter database did not contain any typing errors, in which case they were removed or corrected. A cross-check of the seabed litter database with photographic records was also carried out to ensure that all items matched the records in the database. The criteria for counting seabed litter items was done 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 2), 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, refractory material (with alumina), 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). 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.

Haul data were then standardized as density per square km (both by number of seabed litter items and weight) and represented for each trawl and year and averaged for sampling strata, according to the NAFO stratification scheme (Doubleaday, 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).

3. Results and discussion

3.1 Characterization of marine litter on the seabed

Litter debris was found on 16.7% of the total valid trawls analyzed. A total of 528 litter items were encountered throughout all sites surveyed. Plastic and fishing related litter items were the most frequently found in the study area, which is consistent with the pilot study conducted in 3L (García-Alegre *et al.,* 2020). Of the trawls with presence of litter, 41.8% has occurrence of fisheries related litter (Table 2). 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.

Plastic accounted for 63.6% of litter items recorded, whilst metal accounted for 12.9% of the total. Remnants of fishing gear (7.8%), organic litter (4.4%), rubber (1.7%) and glass/ceramics (0.4%) were the least common. Items classified as "other anthropogenic litter" accounted for 8.3% of the litter items encountered in sites surveyed and included processed wood, paper/cardboard, clothing, alumina-based refractory material, ropes made using natural fibers, and other uncategorized anthropogenic litter (Table 3). 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).

Table 2. 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.

Division	Litter occurrence (%)	Hauls with litter occurrence by group category (%)						
		Plastic	Rubber	Metal	Glass/ Ceramics	Fishing related	Organic	Other
3L	27.1	45.5	1.3	3.8	1.3	57.0	5.1	8.9
3M	9.5	36.5	5.2	20.8	0.0	36.5	0.0	17.7
3NO	28	63.5	2.0	12.8	0.7	37.2	2.7	13.5
3LMNO	16.7	51	2.8	13.0	0.6	41.8	2.5	13.6

Table 3. 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 (item/km2)	Frequency of weight (%)	Mean density (kg/km2)
Plastic	63.6	2.6 ± 8.3	1.1	0.06 ± 0.5
Rubber	1.7	0.1 ± 1.7	3.8	0.3 ± 10.2
Metal	12.9	0.8 ± 7.9	26.8	2.0 ± 87.4
Glass/Ceramics	0.4	0.02 ± 0.3	0.2	0.01 ± 0.5
Fishing related litter	7.8	2.1 ± 8.4	56.4	4.4 ± 79.9
Organic litter	4.4	0.3 ± 5.7	4.1	0.3 ± 9.3
Other anthropogenic litter	8.3	0.6 ± 4.1	20.1	0.3 ± 5.3

3.2 Spatial and temporal distribution

Strata with higher seabed litter occurrence were located on the northern and eastern slopes of the Flemish Pass and on the slopes of the Grand Banks of Newfoundland, but were evenly distributed along the slopes of the Flemish Cap (Figure 2). Similar results are shown by the higher densities of number of items (items/km^2) by haul and by strata (Figure 3). In terms of litter occurrence and density of seabed litter items, the highest densities were found in Divisions 3LNO, mainly on the slopes of the Grand Banks of Newfoundland, and on the northern and southern slopes of Flemish Pass. The results obtained in Division 3L are in line with the 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). Significant differences among Divisions were found regarding densities in kg/km^2 (Kruskal-Wallis = 105.44, df = 2, *p-value* = < 2.2e-16); and in items/km^2 (Kruskal-Wallis = 106.56, df = 2, *p-value* < 2.2e-16). Pairwise comparisons between Divisions showed that there were significant differences in seabed litter densities between Division 3M and Divisions 3LNO (Wilcoxon rank test; *p-value* < 0.0001).

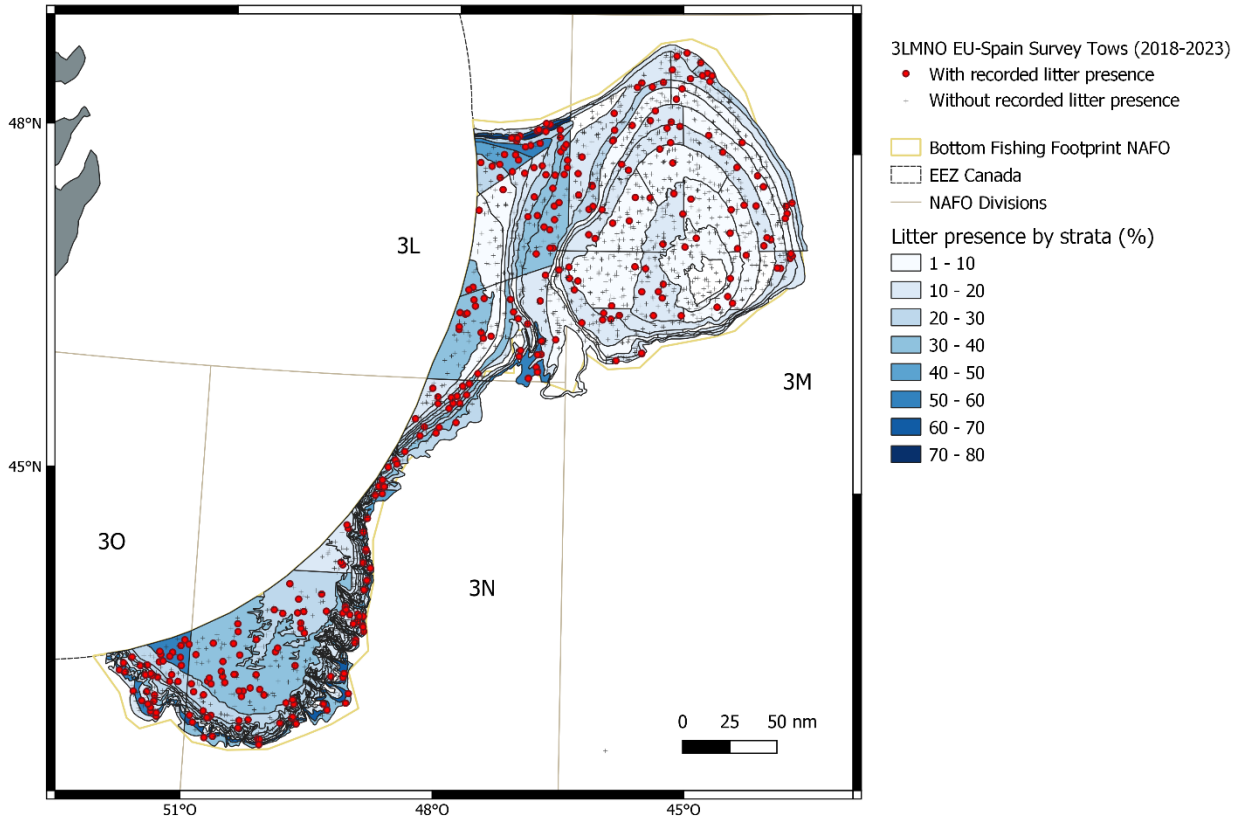

Figure 2. Spatial distribution of hauls with seabed litter presence (red points) or absence (black crosses) recorded. In the background, the percentage of tows with litter presence by sampling strata (according to the NAFO scheme) is shown (in blue scale). The boundaries of the bottom fishing footprint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

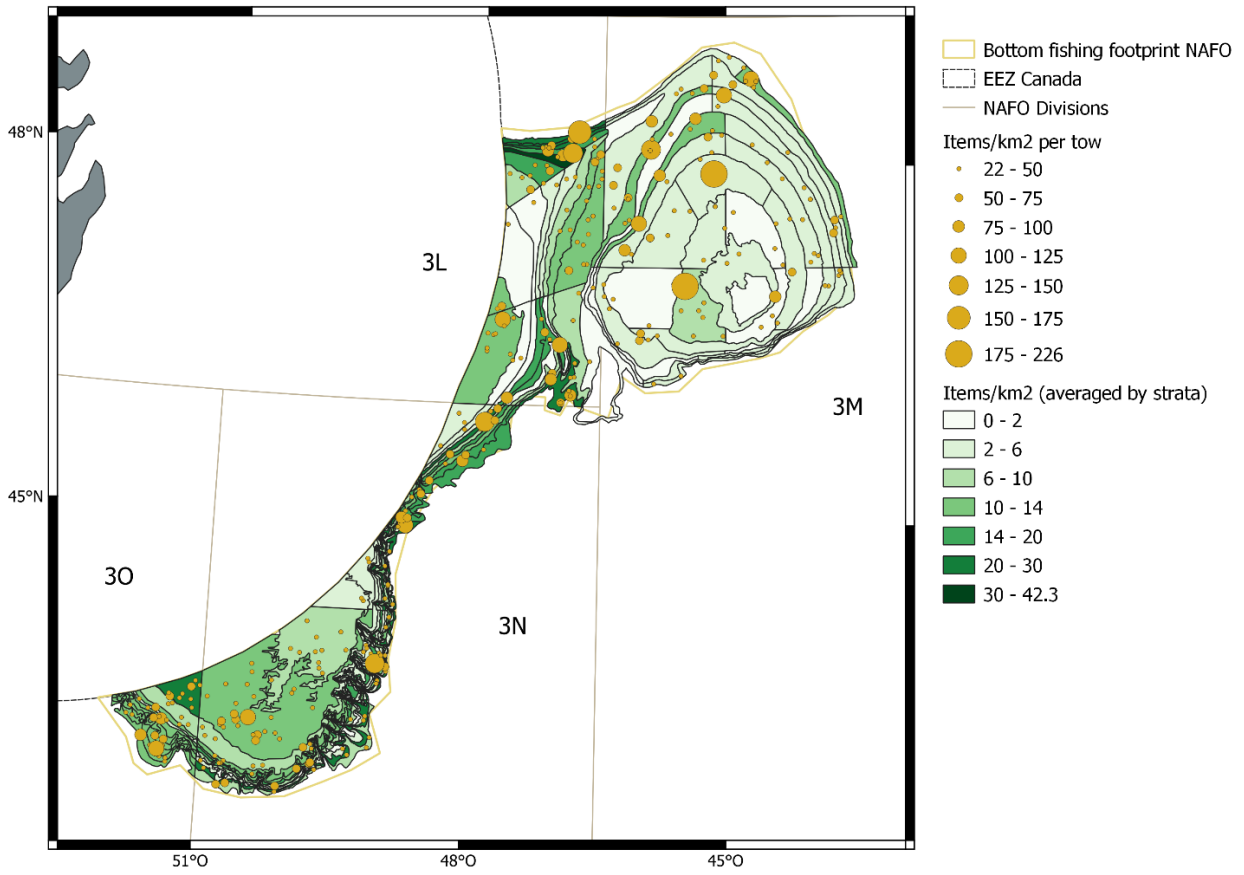

Figure 3. Seabed litter densities (number of items/km^2) per tow (yellow points) and averaged by sampling strata (in green scale) recorded during the scientific bottom trawl surveys conducted in Divisions 3LMNO during 2018-2023.

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 slopes of the Flemish Pass and the south-western slopes of the Grand Banks of Newfoundland (Figure 4). An uneven distribution of fishing related items was recorded. Although synthetic ropes related with fishing activities were evenly distributed along the Flemish Cap, on the Flemish Pass and the Grand Banks of Newfoundland were mainly recorded on the slopes. Similar distribution was recorded to entangled monofilaments and single monofilaments, but these records were always recorded nearby or on the area covered by the cumulative fisheries effort of the groundfish fisheries. There are few records of bobbins and floats along the study area, both on slopes and plains, but always nearby the areas where groundfish fisheries operates. Few records of nets were located on the south and east of Flemish Cap and Flemish Pass, and in the slopes of the southwestern part of the Grand Banks (Division 3O). Longlines were mainly recorded on the slope of the southwest part of the Grand Banks (Division 3O), two of them close to the areas operating longline groundfish fisheries. Other remnants of fishing gears were mainly recorded on the southwestern part of the Grand Banks (Division 3N), close to the queen-snow crab fishery and the groundfish fisheries operating areas. Pots were found in the western part of the Flemish Pass, close to the Canadian EEZ, over the areas with the highest landing recordings of the queen-snow crab fishery. 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 study (García-Alegre *et al.,* 2020).

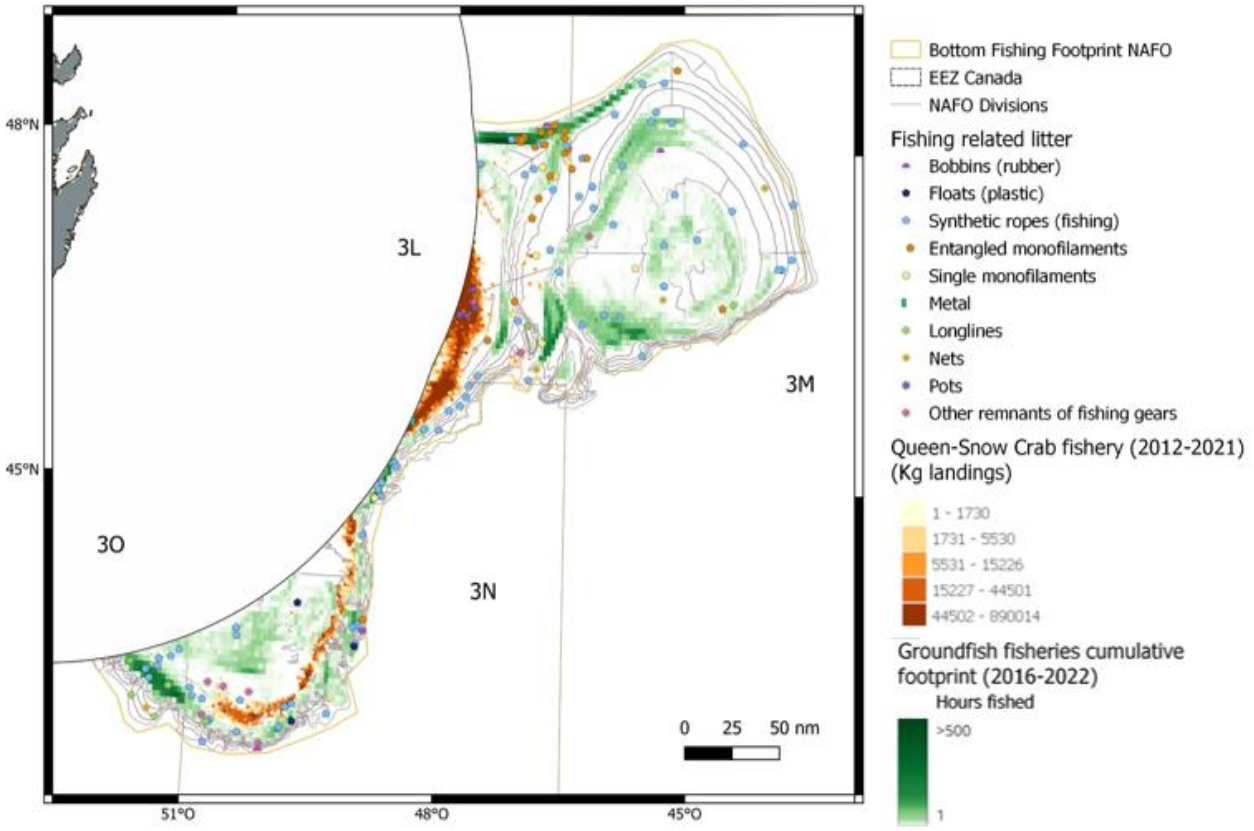

Figure 4. Spatial distribution of fishing related seabed litter by items. The cumulative fishing effort of groundfish fisheries operating in the NRA during 2016-2022 (green scale; Garrido *et al.,* 2023) and the landings (in kg) of the queen-snow crab fisheries (orange scale) are displayed. Data on queen-snow crab fisheries was obtained from Statistical Services, Fisheries and Oceans Canada (DFO) and consists of commercial landings data from 2012 to 2021. Each cell in a 2-minute hexagonal grid (approx. 10km^2 cell) shows the total weight (kg) of landings summed over the ten-year period. The boundaries of the sampling strata (light grey lines), 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.

3.3 Protocols for seabed litter data collection

Based on the recommendation of the Scientific Council to the NAFO Commission (NAFO, 2020) that standardized protocols for the collection of seabed litter data should be implemented by all Contracting Parties (CPs) as part of their groundfish surveys, 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. The objective of implementing a protocol was to extend the seabed litter data collection started in year 2006 in the Flemish Pass (Div. 3L) (García-Alegre *et al.*, 2020) to the other areas sampled by the EU surveys: Flemish Cap (Div. 3M) and the Grand Banks of Newfoundland (Divs. 3NO), using a common methodology. This preliminary protocol was first implemented in Divs. 3LNO

(2018) and Div. 3M (2019) as a pilot experiment. Its application continued until 2023 (included), after which it will be reviewed and improved with the objective of providing a standardized sampling protocol for such surveys. This is part of the ongoing study referred to in this report.

Protocol at a glance

According to the current sampling protocol, after each haul, all seabed litter items collected and retained by the bottom trawl gear are examined, categorized, counted, weighed, sized, photographed and recorded on board the research vessel (Diagram 1). Any evidence regarding the source of litter is also recorded. For each haul, the characteristics of the trawl gear, location, date, time and depth at the start and end of the trawl are also recorded, as well as other general information about the haul.

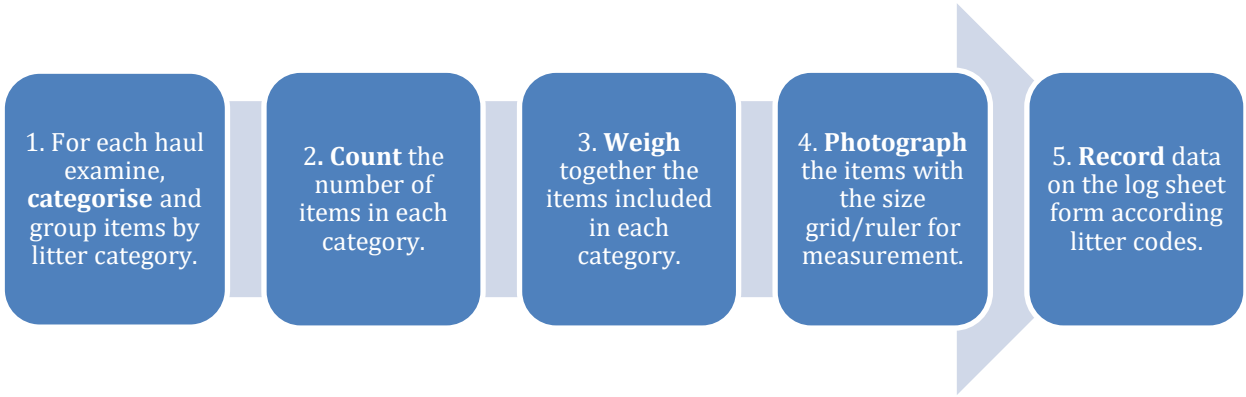

Diagram 1. Suggested sequence of steps for on-board collection and recording of seabed litter data.

In this context, it should be noted that have a common protocol agreed with other CPs for the collection of seabed litter in the NRA would facilitate the standardisation of monitoring practices. This would help to reduce differences in data collection and classification procedures, which would improve the comparability of the data and allow its assessment on a regional scale.

This fact encourages us to prepare and continue working on a new revised protocol, based on a previous review of protocols and manuals used in different areas by different groups (e.g. ICES, 2022). A comprehensive review, update and standardization of the list of marine litter categories and codes is also necessary, with particular attention to the existing data recorded in the NRA, in order to produce a standardized master file. Cross-checking the information collected on board with the seabed litter database and the photographic records has allowed us to identify typographical errors and guide the drafting of the improved protocol and best practices according to the needs and gaps identified. On this basis, for example, the criteria for counting litter items for further analysis, in the study referred to in this report, was carried out as described in the ICES Manual for Seafloor Litter Data Collection (ICES, 2022).

Recognising that seabed litter data are collected and recorded during groundfish surveys for stock assessment, which may be subject to time constraints and poor weather conditions, the procedures in the manual are intended to be simple and user-friendly, and will be presented accompanied by a photographic guide to facilitate a better categorisation of the different items.

4. Main outputs, challenges and future work

Preliminary results obtained showed that plastics and related fishing litter were the dominant types of litter found in the study area, similarly to other research (Buhl-Mortensen and Buhl-Mortensen, 2018; García-Alegre *et al.,* 2020). Previous studies highlighted that the distribution and effects of abandoned, lost and discarded fishing gears (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 gears (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 and trends. Additionally, trawls only cover soft sediment trawlable areas, leading to sampling limitations in rocky areas. Small objects may not be sampled by fishing gears. Furthermore, how well the different gears types sample litter is not yet well understood (Barry *et al.,* 2022).

In summary, this study contributed to characterize marine litter on the seabed, and provides preliminary information about spatial distribution of seabed litter in 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 spatial distribution of seabed litter; (ii) determine the main litter sources; (iii) elucidate the potential drivers of seabed litter distribution; (iv) improve the current protocol and data forms for seabed litter 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 2024.

Acknowledgments

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