Comparative statistical analysis of seafloor litter data for the North Sea

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Introduction

The Marine Information and Data Centre (Informatiehuis Marien - IHM) is a collaborative venture between the Department of Waterways and Public Works (Rijkswaterstaat), the Ministry of Infrastructure and Water Management, the Ministry of Agriculture, Nature and Food Quality, and the Ministry of Defense. The IHM serves as a platform for finding and sharing North Sea data and information. For the Marine Strategy Framework Directive (MSFD) monitoring is required to retrieve necessary marine information and data.

In June 2022 the department of Biometris of Wageningen University and Research was approached by IHM to perform a statistical check of the monitoring of marine litter. Biometris is a department with mathematicians and statisticians with a long standing experience in applying statistical and mathematical techniques to a broad range of applications. The aim of the cooperation was to have an independent quality evaluation of the current monitoring of marine litter supervised by the Marine Strategy Framework Directive (MSFD).

The aim of this project is to answer the following questions:

- To give a quality assessment of the current way of monitoring sea litter in the North Sea.
- To indicate possible improvements of the monitoring of sea litter in the North Sea.

The project has been executed in two phases. Phase 1 was a broad inventory of the current monitoring and use of data for monitoring marine litter. In this phase, research topics were formulated to evaluate in phase 2. We start this report with a short summary of phase 1, directly followed by a comprehensive report of phase 2. We will wrap this report up with the main conclusions and recommendations.

We would like to conclude this introduction by emphasizing that the field of monitoring marine litter was completely new for us. There are many sources of information and scientific papers available. We could not incorporate all this information into this report. The focus of this report is a statistical check and investigation of the available data of monitoring seafloor litter. Our thanks go out to Willem van Loon (Rijkswaterstaat) and Ralf van Hal (Wageningen Marine Research) who gave us a valuable and useful introduction to the available resources for monitoring seafloor litter in the North Sea.

Short summary phase 1

In phase 1 a broad range of topics has been discussed with experts in the field. Starting point in these talks was the descriptor 10 (D10) of the MSFD. In D10, marine litter is defined as; "any persistent, manufactured or processed solid material that is discarded, disposed of, or abandoned in the marine and coastal environment. The provisions of MSFD D10 aim to protect the marine environment against harm caused by litter". Within D10 there are several criteria to monitor the marine environment. Some of these criteria are in a more developed stage than others. The focus of phase 1 was on D10C1: Marine litter in the environment. Within D10C1 a distinction is made between beach litter and seafloor litter. The criteria D10C2 and D10C3 are briefly discussed as well. These criteria focus on micro-litter and litter ingested by marine animals.

However, focal point was criterion D10C1. The monitoring of D10C1 is done within the OSPAR (OSlo and PARis convention) monitoring programs. OSPAR is the mechanism by which 15 governments and the EU cooperate to protect and monitor the marine environment of the North-East Atlantic.

D10C1 - Beach litter

The criterion D10C1 is the most crystallized of the mentioned criteria. Since 2001 litter counts per 100 meter of beach are performed four times each year at many locations in Europe. A threshold value of 20 items per 100 meter of coastline has been accepted at the EU and OSPAR level (van Loon W. (2020)). This threshold is ambitious because at many locations in Europe the counts do not reach the threshold. However, it clearly promotes the development of the necessary marine litter reduction measures. So, for this criterion a large amount of data for many locations and times are available. Extensive research of modelling and forecasting has been done on these data, for example the work of Dennis Walvoort and others of Wageningen Environmental Research (Hanke G. (2019)). He developed the R package `litteR` (Schulz et al. (2019)) and applied a negative binomial generalized linear model for these kind of data.

In initial discussions in phase 1 the idea came up to make the current research and assessment of beach litter the topic of phase 2. Plenty of data and application of statistical models could have been a good topic to perform a statistical check and quality assurance of the current monitoring program. At the end of this discussion it was decided that the added value of new research about this would be limited. The OSPAR monitoring framework has been implemented and finalized already to a great extent. Research of monitoring seafloor litter was considered a more needed topic for phase 2.

D10C1 - Seafloor litter

The part of D10C1 related to seafloor litter is still more in development. For example, there is no threshold value defined yet for a good environmental status. In 2017 there has been agreement about guidelines for monitoring litter at the seafloor. The monitoring of seafloor litter has been done by the International Bottom Trawl Survey (IBTS). The IBTS is in the first place a statutory task to monitor the fish stocks. During this survey, the litter which is captured in the nets is categorized and reported. It has to be noted that the nets are not specially designed to catch seafloor litter. Monitoring has been performed by many research institutes from different European countries. Data are stored in the so-called ICES DATRAS database.

Because of the limitations of catching seafloor litter with the IBTS, in recent years data for seafloor litter has also been collected by the Beam Trawl Survey (BTS). These surveys are meant for benthic fish species, like flatfish, which live on the seabed instead of in the water column. Although the nets used in these surveys are also not designed for catching seafloor litter, it is expected that with these surveys a higher percentage of seafloor litter can be caught.

A first comparison of the two ways of monitoring seafloor litter has been reported in "Monitoring of Seafloor Litter on the Dutch Continental Shelf" by Joey Volwater and Ralf van Hal (Volwater and Hal (2022)). They indeed found a higher number of litter items per km^2 in the BTS compared to IBTS. For IBTS they estimate the probability of catching the litter from the seafloor lower than 5%. They stated that the numbers of items found by both ways of monitoring should be considered a large underestimation of the actual litter on the seafloor. Besides that, because of the design of the nets, some types of litter can be caught more easily than other types of litter.

Preparation phase 2

In the final part of phase 1, research topics were formulated. An extended comparison of IBTS and BTS data and a more detailed modelling of the spatial distribution of seafloor litter data were chosen as the main topics of interest for this project. In the next section, six research topics are formulated which should be answered in phase 2.

Research topics phase 2

The six research topics for phase 2 are as follows:

1. Comparison of seafloor litter composition between IBTS and BTS data per year (2020, 2021 and 2022). Visualization of percentages of items per square kilometer of the different material categories of seafloor litter (plastic, rubber, cloth/textile, etc.) for IBTS and BTS. Following Article 8 of the GES guidance (European Commission (2022)), the classification to EU functional groups "SUP" and "FISH" will be added as well.
2. Two comparisons between IBTS and BTS for total counts will be made:

- 3rd quarter IBTS with BTS per year.
- 1st and 3rd quarter within 1 year of the IBTS data.

3. Similar analysis as point 1, but then accumulated over the years (2020-2022).
4. Spatial analysis per category of total items found and/or the probability of the presence and absence for both data sets (IBTS 3rd quarter and BTS) per year for 2020-2022. This only applies to the area where seafloor litter has been collected with both methods.
5. Determining possible hot spots (places where there is a lot of seafloor litter) per category over the three years. And when there are, a comparison of these hot spots between both methods of monitoring.
6. Statistical analysis now often uses the presence and absence of seafloor litter per category. Research will be done into the advantages and disadvantages of this approach compared to an analysis with the number of items found per category.

Data

For this project data of IBTS and BTS are used for the Greater North Sea for the years 2020, 2021 and 2022. This allows for a sufficiently wide spatial data coverage. Data are downloaded from the ICES DATRAS database. Ralf van Hal (Wageningen Marine Research) kindly did some final checks and conversions of the data. For the IBTS, data are available in the first quarter (Q1) and the third quarter (Q3). For BTS only data in the third quarter (Q3) are available. Data are collected by different research institutes. Figure 1 shows the available data and spatial distribution of the measurements points for both IBTS and BTS for Q3 in 2022.

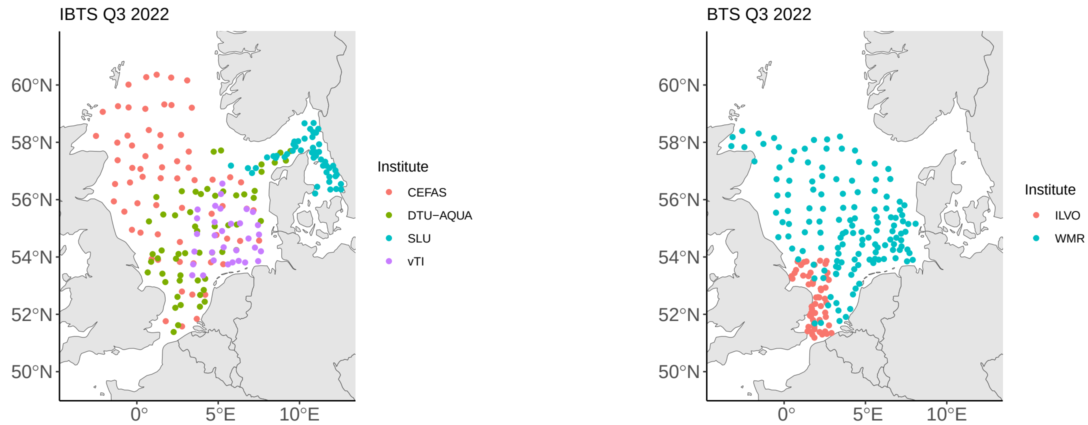

Figure 1: *Spatial distribution of measurement points for IBTS (left) and BTS (right) for Q3 2022. Points are colored by institute which performed the monitoring.*

The data of the Institute Marine Research (IMR) from Norway are discarded in this research, mainly because the information of the fished area for each haul was missing. The number of items found was also extremely low. This might be caused by the location of fishing, completely in the north of the area of interest.

The variable of interest in this research is the number of items per square kilometer. This can be total counts of all categories, or counts for specific material and functional categories. The original number of items of seafloor litter are per haul. Because the length of each haul is not the same, the number of items are converted to a fixed area. The choice within the OSPAR agreements is number of items per square kilometer.

Classification of litter

The classification of marine litter is according to guidelines of the ICES. There are eight categories of litter (Plastic, Rubber, Cloth, Paper, Wood, Metal, Glass, and Undefined). Within these categories there are many subcategories. Besides these categories, two additional functional groups are used in this report, which are based on EU Joint litter list (https://mcc.jrc.ec.europa.eu/main/photocatalogue.py?N=41&O=457&cat=all). Based on the ICES litter types, two EU seafloor litter categories, consisting of several ICES categories, are used in this report: EU SUP and EU FISH.

The EU SUP group contains the ICES classification categories: A1: plastic bottle, A3: plastic bag, A4: plastic caps/lids, and A13: sanitary towels/tampon. The EU FISH consists out of: A5: plastic fishing line (monofilament), A6: plastic fishing line (entangled) and A8: plastic fishing net. Also A16: other fishing related plastics, belongs to EU FISH. However, this last category was not present in the data set for this project.

Characteristics of the data

Sea litter data are often characterized by a special distribution of the data. The number of items of litter found are often quite sparse. In many haules no litter is found at all. This is especially the case when looking at separate categories of seafloor litter. In addition, the distribution of the data is typically skewed to the right. When litter is found, the number of items of litter per square kilometer can sometimes be extremely high. A good example of this can be found in the third quarter of 2022 of the BTS data. In figure 2 the data of the third quarter of the years 2020, 2021 and 2022 is visualized for total counts square kilometer and log total counts square kilometer for the BTS data.

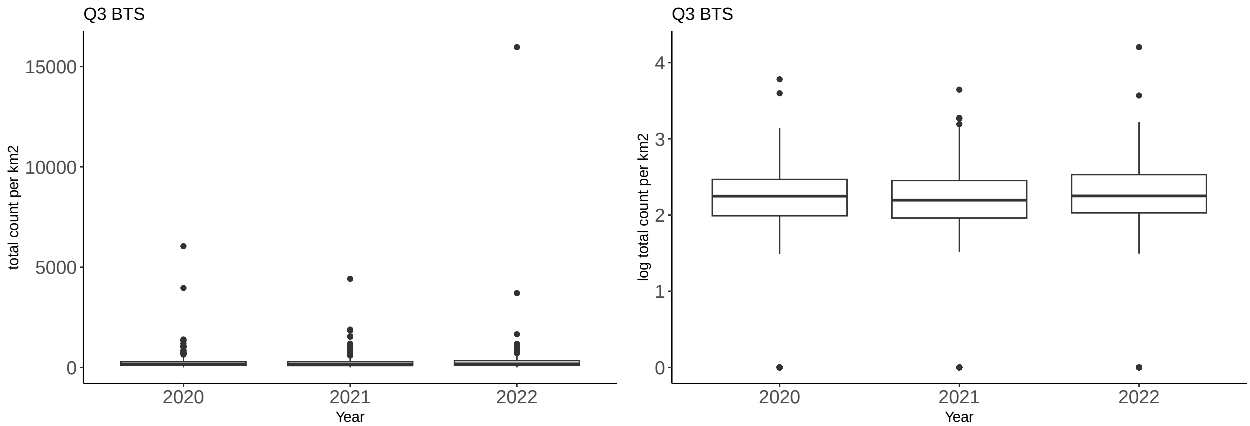

Figure 2: *BTS total counts per km2 and log total counts per km2, 2020 - 2022.*

For Q3 BTS in 2022 there is one observation that is clearly outlying. This outlier is a haul made by ILVO that contained four different types of litter. The outlier is caused by an A5 (monofilament) count of 13613 items per square kilometer. The visualization is heavily affected by not only this outlier, but also by the counts around 5000 items per square kilometer. There are several solutions to cope with these high values. In the graph on the right the log_{10} values of the number of items have been plotted. Because log_{10} of 0 does not exist, we added to every total count 1 item per square kilometer. It can be seen that now the extreme values are much less extreme. On the other hand, the observations with no items at all seem to become outliers in this case. They can be seen as single dots in figure 2 at value 0. This single dot represents all hauls with no items at all. This can be explained by the conversion of the number of items for each haul to number of items per square kilometer. When one item is found in a haul, for a haul with an average fished area, this results in a count of at least 40 items per square kilometer. There are 17, 8, and 9 hauls with 0 items per square kilometer for 2020, 2021 and 2022 respectively.

So, these data have a special character. In this report a pragmatic but statistically correct approach will be applied. Different approaches of the data will be considered, such as an analysis on the original scale of the data, log scale or trimming the data by ignoring the highest values in the data set.

Research topic 1

In this section research topic 1 will be answered. Research topic 1 has been formulated as follows:

Comparison of seafloor litter composition between IBTS and BTS data per year (2020, 2021 and 2022). Visualization of percentages of items per square kilometer of the different material categories of seafloor litter (plastic, rubber, cloth/textile, etc.) for IBTS and BTS. Following Article 8 of the GES guidance (European Commission (2022)), the classification to EU functional groups "SUP" and "FISH" will be added as well.

The focus of this research topic is the composition of the seafloor litter. Therefore the total counts per square kilometer over all hauls are used. This numeric is less suitable for other purposes, for example the number of hauls is not the same for the different ways of fishing (IBTS and BTS), for the different quarters within a year, and for the different years. The percentages for the eight main material categories (Plastic, Rubber, Cloth, Paper, Wood, Metal, Glass and Undefined) are visualized for the 3 years (2020, 2021 and 2022). The different colors in the graphs correspond to IBTS Q1, IBTS Q3 and BTS Q3.

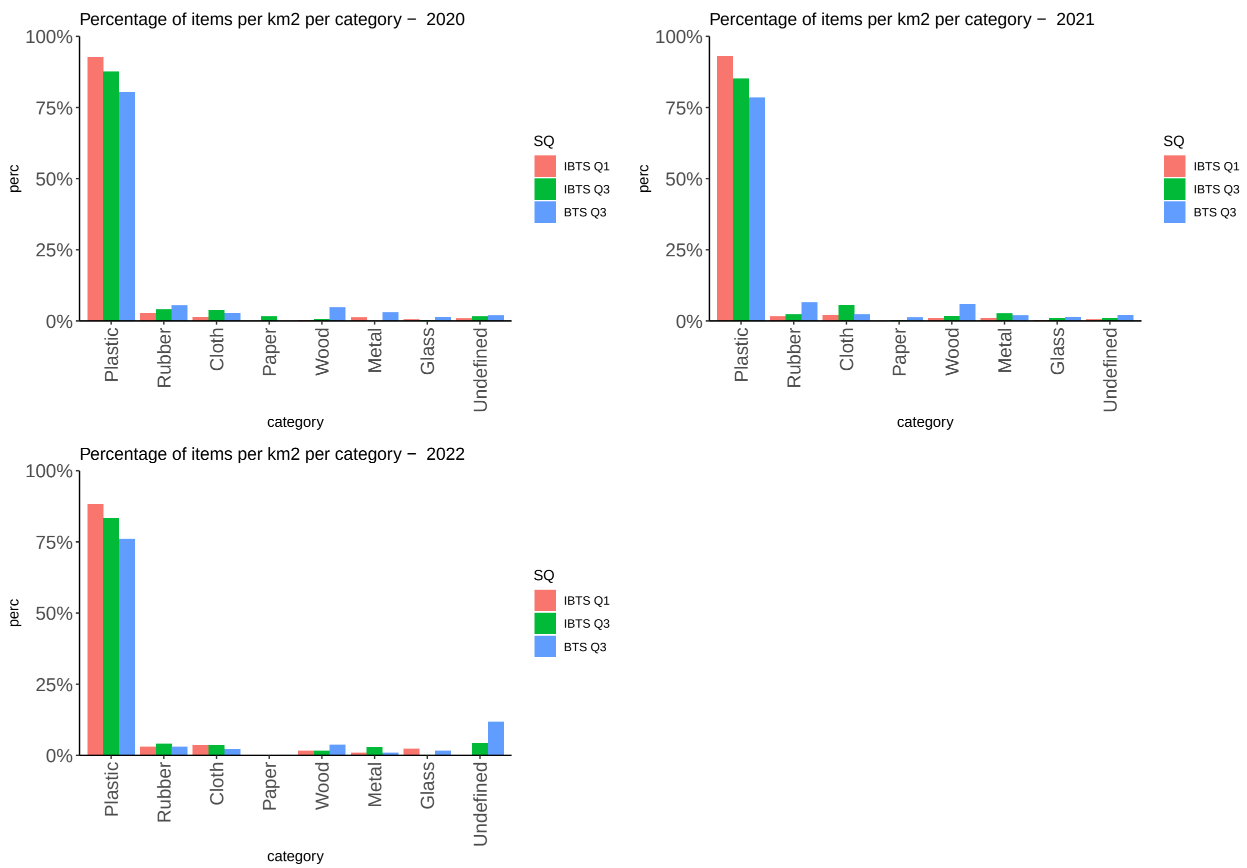

Figure 3: *Percentages for 8 main categories for 2020, 2021 and 2022.*

The main conclusions from figure 3 are:

- The category Plastic has the largest total counts per square kilometer, and therefore the highest percentages of the seafloor litter.
- There is quite a consistent pattern over the years 2020, 2021 and 2022. The outcomes per year show only small differences.
- For BTS data, the percentages found in other categories than Plastic seem to be a bit higher. However, Plastic is still by far the largest contributor.

In article 8 of the GES guidance two summarizing categories are introduced: SUP and FISH. In figure 4, the total counts for these categories are visualized for the years 2020, 2021 and 2022.

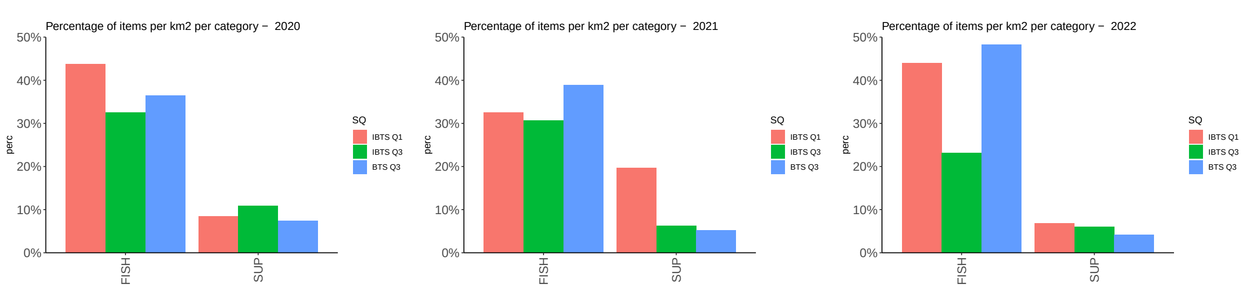

Figure 4: *Percentages for FISH and SUP for 2020, 2021 and 2022.*

The main conclusions from figure 4 about the percentages of the categories SUP and FISH:

- For all years, methods and quarters of collecting data, the category FISH has much higher percentages than SUP. This is mostly caused by the contribution of monofilaments.
- Differences between years can be seen, especially for percentage SUP IBTS Q1 2021, and percentage FISH IBTS Q3 2022.

Checking effect of hauls with high number of items

In the section Characteristics of the data we noted that some hauls resulted in a very high number of items per square kilometer. Especially for the composition of the seafloor litter, and the percentages for the different categories, it will be interesting to investigate how the composition changes when high values are removed from the data. To assure that the amount of change is large enough, a limit of 250 items per square kilometer has been taken as threshold. That means that every count for each haul in a subcategory (like A5: monofilament) above 250 items per square kilometer has been removed. This doesn't mean that we assume that each observation of more than 250 is incorrect, we merely want to check the effect on the percentages of items per category of the removal of these observations. The graphs with the 8 categories are repeated in figure 5.

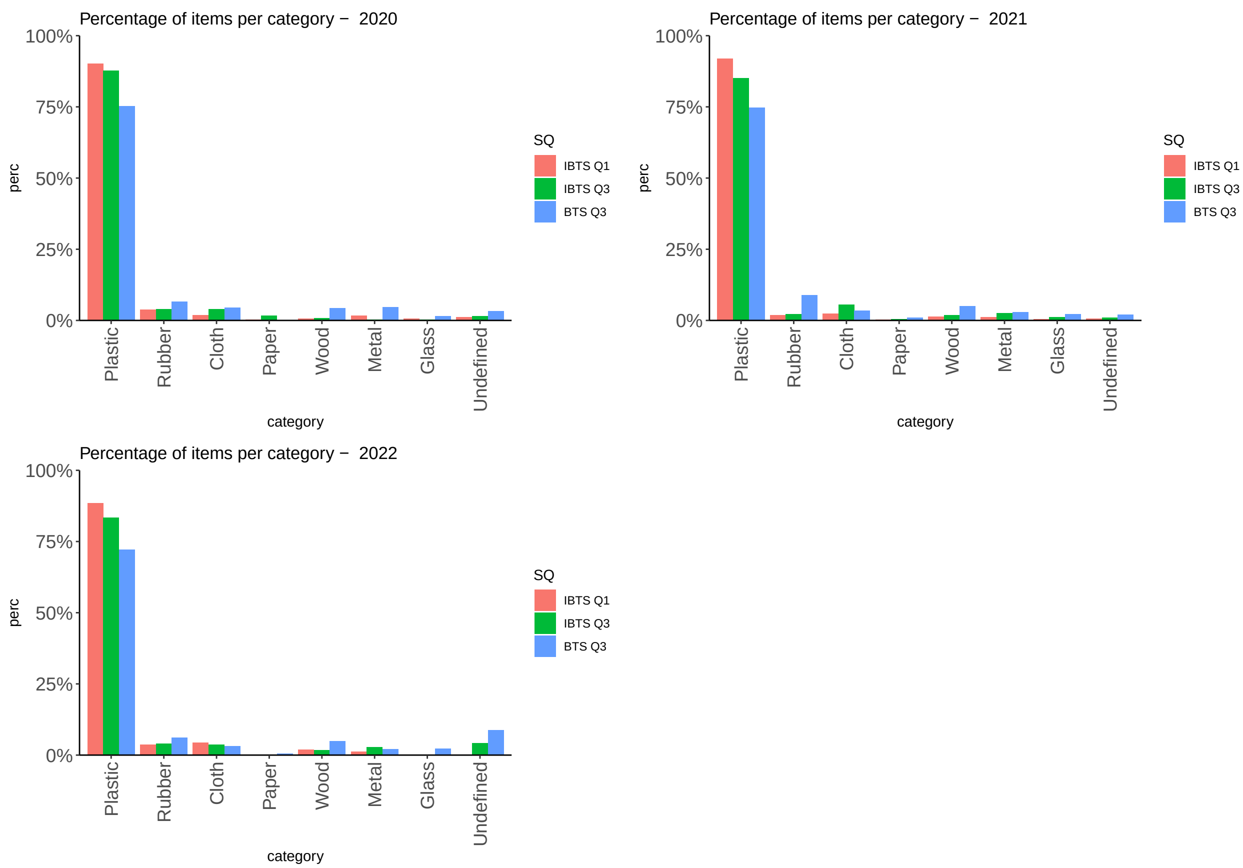

Figure 5: *Percentages for 8 main categories for 2020, 2021 and 2022 after removal of observations with count of 250 or higher per km2.*

Even with this quite low threshold of 250 items per kilometer, there are only very small differences in the percentages between the figures 3 and 5. So, the large counts of items do not influence the average composition of the seafloor litter.

Figure 6 shows that the percentages for FISH and SUP after removal of the observations with a count of 250 or more per square kilometer are more equal over the years than in 4. It seems that high values within subcategories of plastics do influence these percentages.

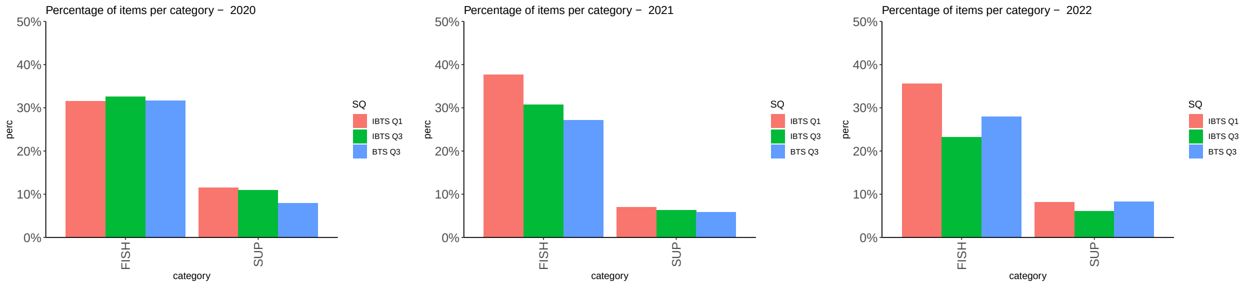

Figure 6: *Percentages for FISH and SUP for 2020, 2021 and 2022 after removal of observations with count of 250 or higher per km2.*

Research topic 2

The second research topic focuses more on the (total) counts.

Two comparisons between IBTS and BTS for total counts will be made:

- *1st and 3rd quarter within 1 year of the IBTS data.*
- *3rd quarter IBTS with BTS 3rd quarter per year.*

Comparison 1st and 3rd quarter IBTS

In figure 7 total counts for the first and third quarters of the years 2020-2022 are plotted. On the left the total counts. On the right, the log values of these total counts to have a better idea about the values in the box of the boxplots.

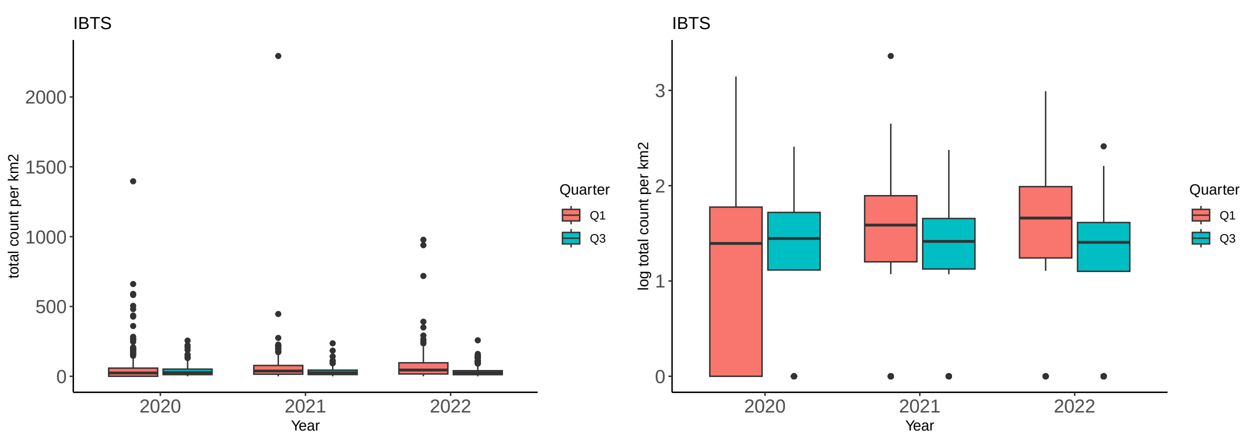

Figure 7: *IBTS total counts per km2 and log total counts per km2, 2020 - 2022.*

In figure 7 it can been seen that Q1 contains higher values than Q3. The medians (thick horizontal line in the box) of the total counts per square kilometer are not that different from each other. In figure 8 the boxplots are split up for the different institutes.

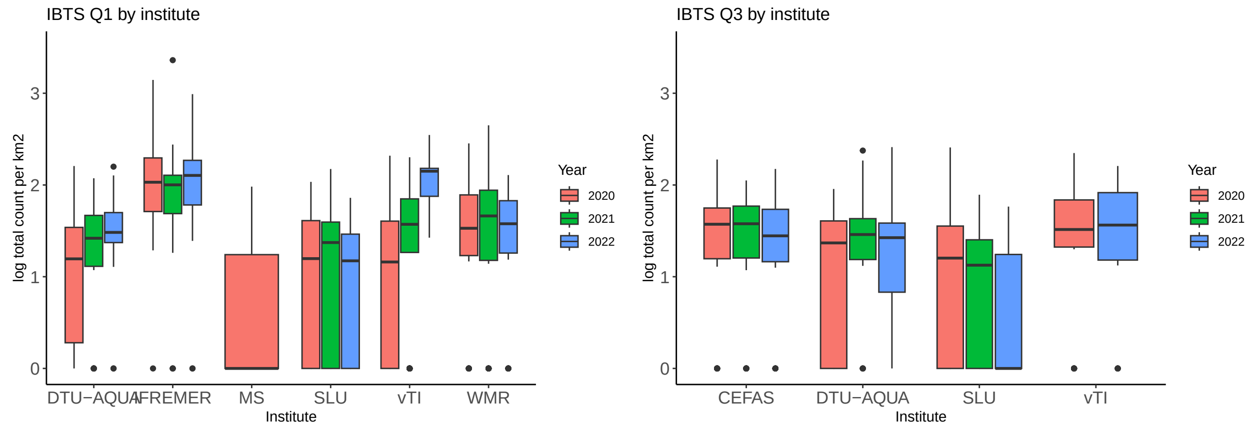

Figure 8: *IBTS log total counts per km2 by institute, Q1 and Q3.*

Figure 8 shows that the high values for total count per square kilometer are observations from the institute IFREMER (France). It cannot be concluded directly that this institute has a different way of measuring the seafloor litter. It could also be the case that the locations where IFREMER is fishing have a higher number of seafloor litter than the locations where the other institutes are fishing. To test this, all hauls of IFREMER are selected which are in an area covered by both IFREMER and at least one of the other institutes. In this same area all hauls of the other institutes are selected. In this way 70 observations for IFREMER and 77 for other institutes (CEFAS, DTU-AQUA, vTI and WMR) are found over the years 2020-2022 in Q1. In figure 9 these observations are visualized.

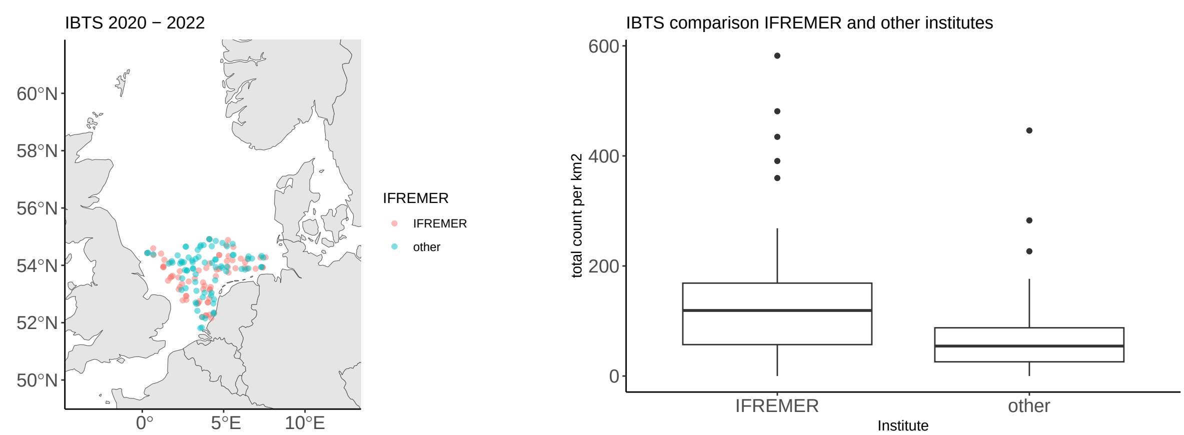

Figure 9: *Spatial distribution of measurement points for the overlapping area between IFREMER and other institutes for data over 2020 - 2022 (left). Total counts per km2 for IFREMER versus all other institutes in Q1 over 2020 - 2022 (right).*

```
##
##  Wilcoxon rank sum test with continuity correction
##
## data:  count_tot by IFREMER
## W = 3940, p-value = 1.386e-06
## alternative hypothesis: true location shift is not equal to 0
```

From this selection of observations of hauls with overlap with other institutes it can be concluded that the total counts are significantly higher (p-value of the Wilcoxon rank sum test < 0.05) for IFREMER than for the other institutes in this area.

Table 1: *Mean of total count per km2, median of total count per km2 and n for BTS and IBTS Q3 for 2020 - 2022*

	BTS			IBTS		
	2020	2021	2022	2020	2021	2022
mean	293.1	275.40	372.85	36.62	32.27	32.12
median	176.1	155.86	177.05	26.92	25.03	24.44
n	203.0	202.00	195.00	207.00	174.00	203.00

Comparison 3rd quarter IBTS and BTS

The second comparison of this research topic is between IBTS and BTS in Q3. This is interesting because it is hypothesized that BTS can catch more seafloor litter than IBTS. To test this hypothesis we want the comparison between IBTS and BTS to be as fair as possible. Therefore we eliminate the time factor by comparing identical quarters. In figure 10 the total counts per square kilometer on the original and log scale are shown.

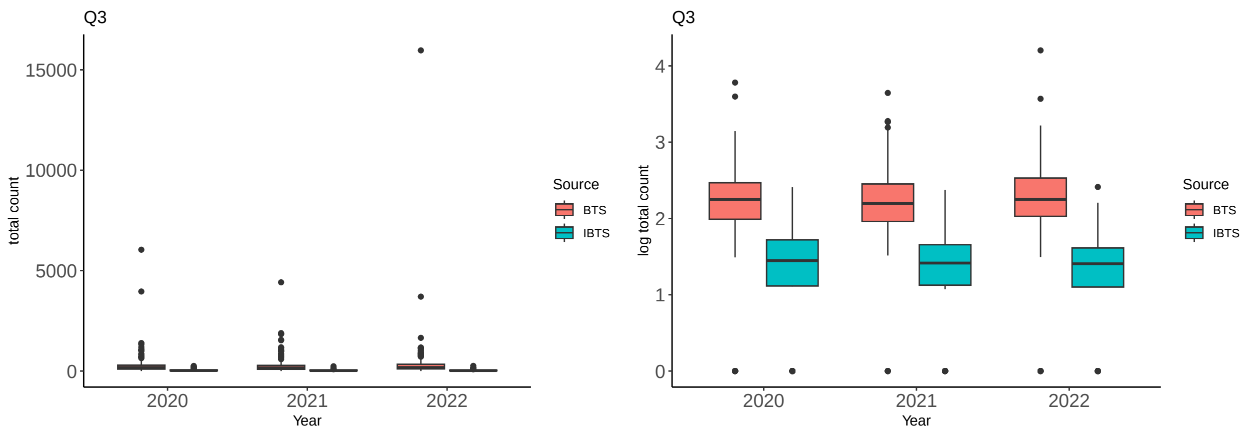

Figure 10: *BTS and IBTS Q3 total counts per km2 and log total counts per km2, 2020 - 2022.*

Over the three years a very consistent difference between BTS and IBTS can be found in Q3. As found earlier and hypothesized, BTS catches more seafloor litter than IBTS.

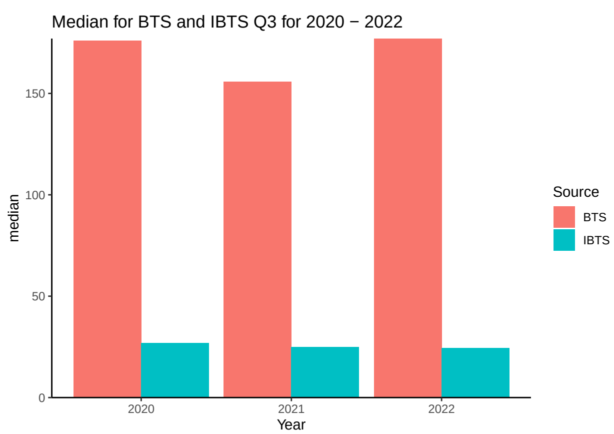

Figure 11: *Median of total count per km2 for BTS and IBTS Q3 for 2020 - 2022*

The BTS data are collected by two institutes: ILVO (Belgium) and WMR (the Netherlands). As has been done for the IBTS data, also the BTS data can be visualized for the two institutes separately (see figure 12).

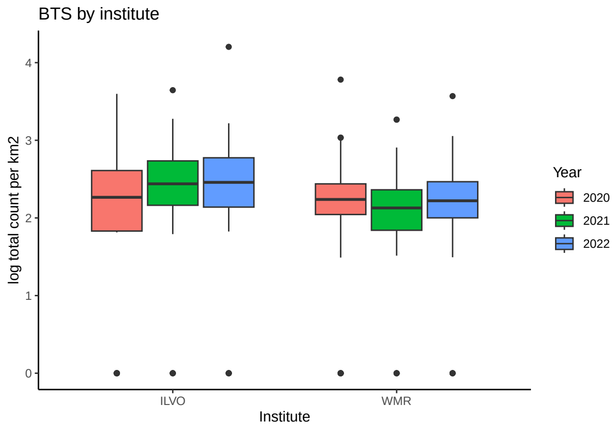

Figure 12: *BTS log total counts by institute, 2020 - 2022.*

We see slightly higher log total counts per km2 for ILVO. The reason for this (again) could be that the area of fishing is different for ILVO from WMR. Therefore, hauls in the area covered by both ILVO and WMR are collected. This results in 95 observations for IVLO and (only) 22 for WMR. The medians of the total counts per square kilometer are 202 for ILVO and 166 for WMR. The Wilcoxon rank sum test to test the difference between the two institutes does not give a significant result (p-value = 0.2744).

```
##
##  Wilcoxon rank sum test with continuity correction
##
## data:  count_tot by ILVO
## W = 1202, p-value = 0.2744
## alternative hypothesis: true location shift is not equal to 0
```

Research topic 3

The idea of this research topic was that accumulation over the three years (2020-2022) will give a more reliable and stable picture of the composition.

Similar analysis as point 1, but then accumulated over the years (2020-2022).

In the section of research topic 1, we already concluded that the composition over the years is quite stable. So, when answering this research topic similar results are expected. In figure 13 the results over the 3 years are presented.

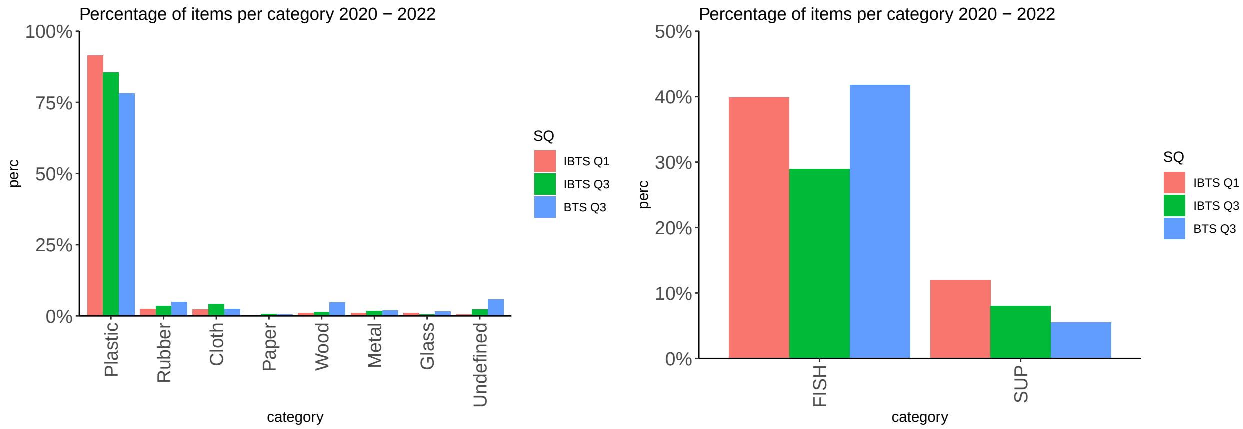

Figure 13: *Percentages for 8 main categories and FISH/SUP over the years 2020 - 2022.*

As was already expected a similar composition over the 3 years was found to the composition of each year separately.

Research topic 4

The spatial distribution of seafloor litter is an important topic. In this section the spatial distribution will be investigated for each year separately. The research topic was formulated as follows:

Spatial analysis per category of total items found and/or the probability of the presence and absence for both data sets (IBTS 3rd quarter and BTS) per year for 2020-2022. This only applies to the area where seafloor litter has been collected with both methods.

Based on the previous results and preliminary results of this section, the elaboration of these research topics has been slightly adapted. It was not possible to do a spatial analysis per category per year, because for some categories only a really low number of items were found. In the section about research topic 5, a spatial analysis per category will be done, aggregated over the 3 years.

We already concluded that the total counts and the number of items found in each category are higher for BTS than for IBTS data. Therefore, making maps only for the area which both methods (IBTS and BTS) have in common is no priority anymore. Maps are made in a convex hull for all available data points for both methods separately. Probability maps of presence and absence are not relevant anymore, especially for BTS. See for further explanation of this topic the section about research topic 6.

There are many methods of spatial interpolation. Based on the number of items caught and the corresponding spatial coordinates maps are constructed. In this research the R package `LMMsolver` (Boer (2023)) has been used. This package makes use of P-splines to model the spatial data, which results in smooth spatial trends of seafloor litter. Because the distribution of the number of items is skewed to the right, the spatial trends were modeled on the log values of the counts. The maps for total counts for the IBTS data are plotted in figure 14. The dots on the maps indicate the number of items on the original scale. Red dots are observations with more than 100 number of items per square kilometer.

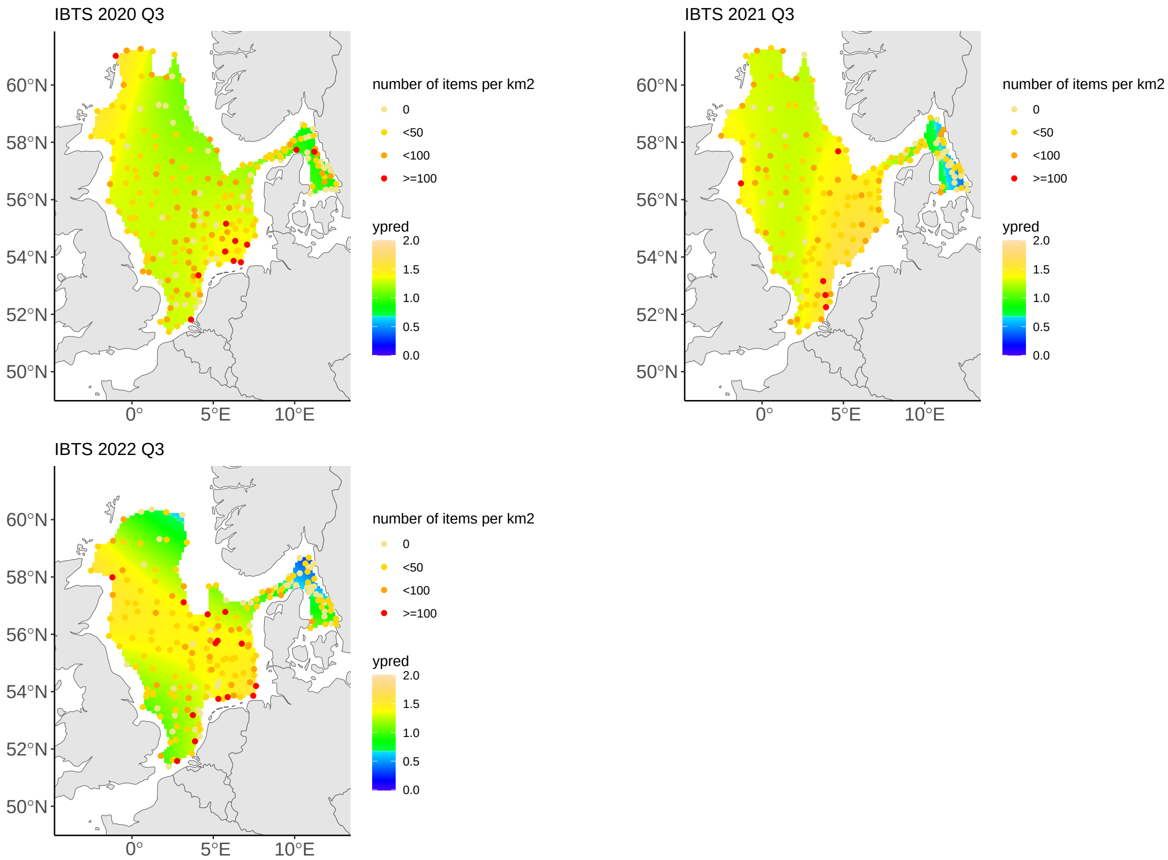

Figure 14: *Maps of log total counts per km2 (ypred) for IBTS data Q3 for the years 2020, 2021 and 2022.*

In figure 15 the maps for the BTS log total counts per square kilometer are provided.

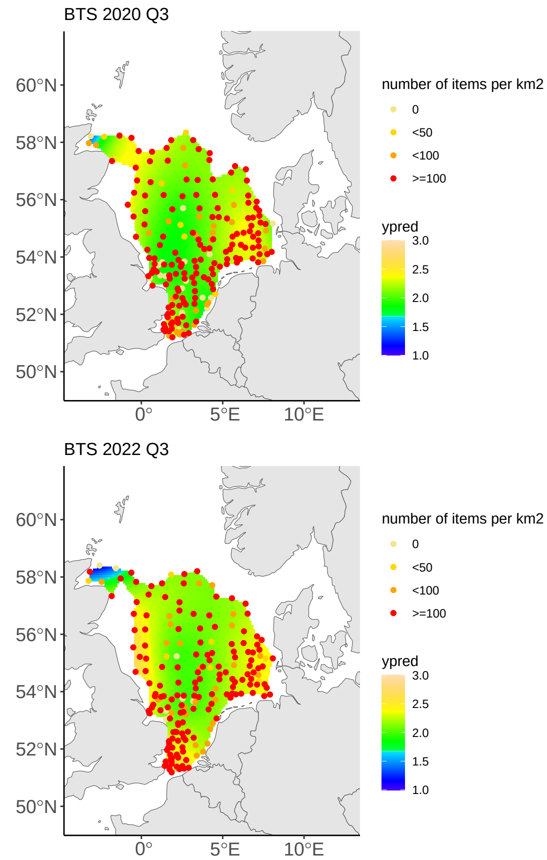

Figure 15: *Maps of log total counts per km2 (ypred) for BTS data Q3 for the years 2020, 2021 and 2022.*

Again it can be seen that the total counts per square kilometer are higher for BTS data than for IBTS data. There are far more red dots in figure 15. Regarding IBTS data, no specific spatial pattern can be determined. There are some high values off the coast of The Netherlands in all three years. Some high values are very close to hauls in which no items were caught at all. So, on a very short spatial distance the total counts can vary a lot.

For BTS data, systematic high values can be found near the English Channel. Furthermore, higher values seem to occur more close to the coast than in the middle of the North Sea. This can be observed most clearly for the year 2022.

It should be noted that for every spatial interpolation technique, the predictions at the border of the area have the highest uncertainty (the highest standard error).

Finally, as seen before, the total counts per square kilometer are dominated by plastic. In the next section analyses of separate categories will be carried out as well.

Research topic 5

Research topic 5 has been formulated as follows:

Determining possible hot spots (places where there is a lot of seafloor litter) per category over the three years. And when there are, a comparison of these hot spots between both methods of monitoring.

When possible hot spots are to be found, data with the highest number of observations are the most promising. Therefore, the focus in this section is on the BTS data. In the previous section total counts per square kilometer were the variable of interest. In this section counts per square kilometer for the categories Rubber, Clothing / Textile, Wood, and Metal will be investigated in the first place. These categories have the highest counts after the category Plastic. In figure 16 maps are given for the four above mentioned categories.

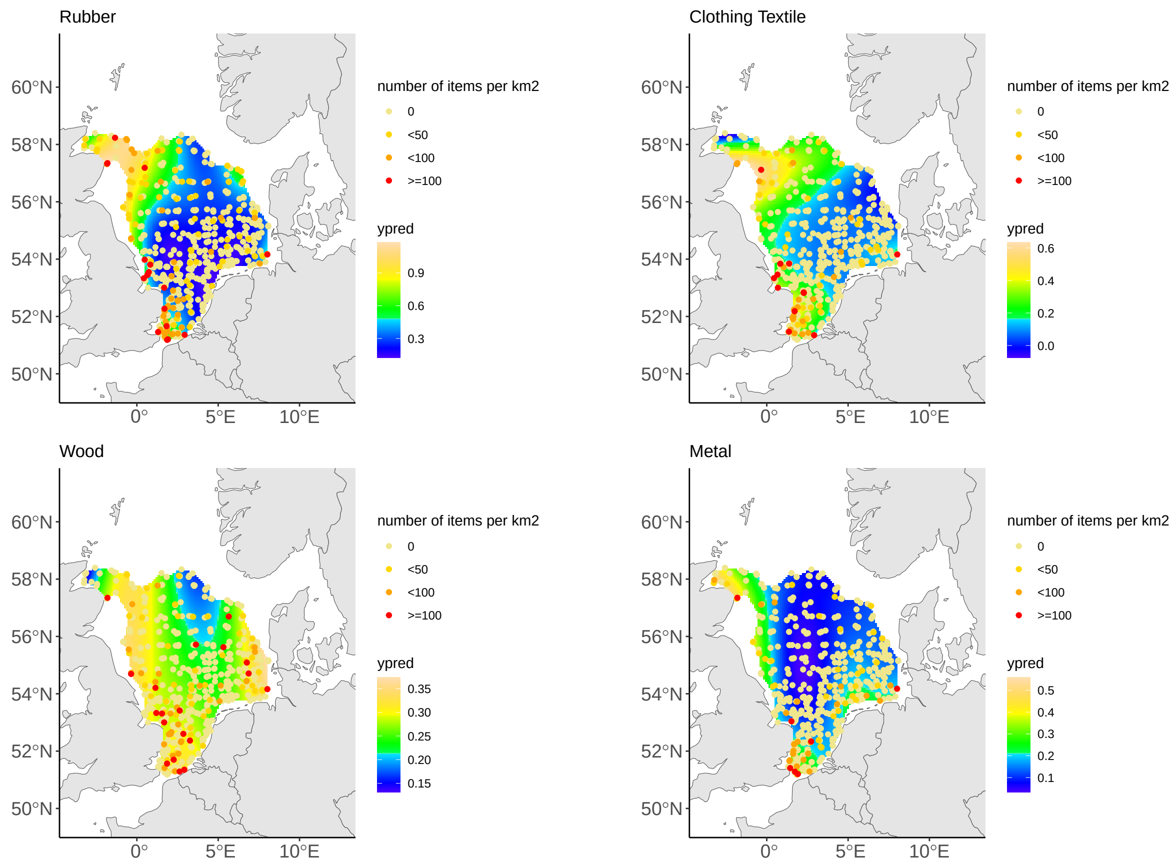

Figure 16: *Maps of log counts per km2 (ypred) for BTS data over all 3 years (2020-2022) for 4 different categories of seafloor litter.*

Accumulating over the three years (2020-2022) and focusing on specific categories seems to result in a more pronounced spatial distribution of items. In general it looks as if these items are found more close to the coasts. For all 4 categories the area off the coast of South-East Great Britain has higher values. Wood seems to be more widely distributed over the complete area of fishing for the BTS data.

The categories FISH and SUP were introduced recently. The category SUP has low values for the number of items. The map for this category does not give a clear picture, which can be explained by the low number of items found. The category FISH has much higher numbers of items and the map is plotted in figure 17. The category FISH is an aggregation of subcategories of Plastic. It is interesting to compare the map of the category FISH with the map of the category Plastic (a summation of all subcategories of Plastic). This last map is also included in figure 17.

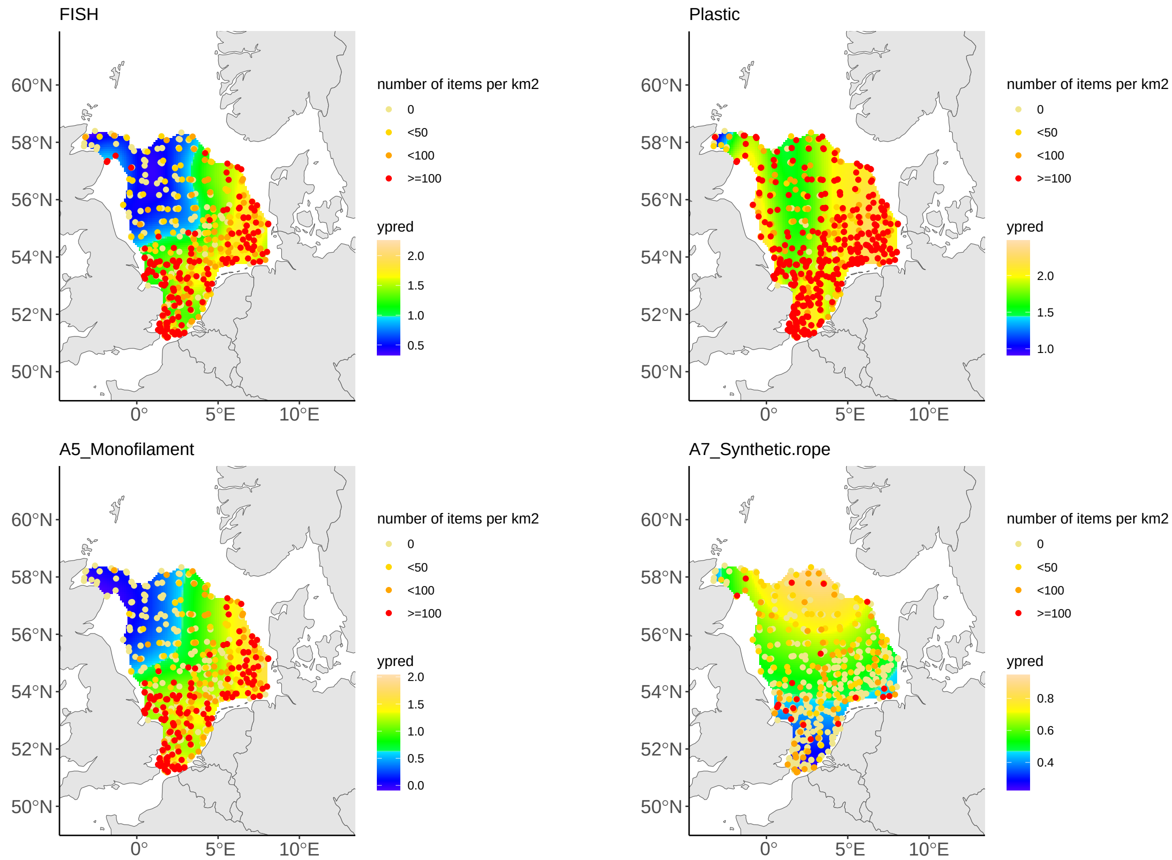

Figure 17: *Maps of log counts per km2 (ypred) for BTS data over all 3 years (2020-2022) for categories FISH, Plastic, A5 Monofilament, and A7 Synthetic.rope.*

The difference between the maps for the categories FISH and Plastic is striking. In the two bottom maps of figure 17 an explanation for this can be found. The category FISH is dominated by the category A5_Monofilament. The category Plastic is a summation over all subcategories of Plastic, of which A5_Monofilament is only one of several large subcategories. This summation is done for each haul. For many hauls different types of plastic are found. These different types of plastic do have a different spatial distribution across the area of interest. For example the category A7_Synthetic.rope shows a very different spatial pattern than the spatial pattern for the category A5_Monofilament. The summation over all plastic gives a more homogeneous spatial pattern than for the category FISH.

Comparison with IBTS

We assumed in the previous section that BTS data would be better suited for creating spatial plots than IBTS data because of the higher number of items found for BTS. To confirm this assumption we replicate figures 16 and 17 for IBTS Q3.

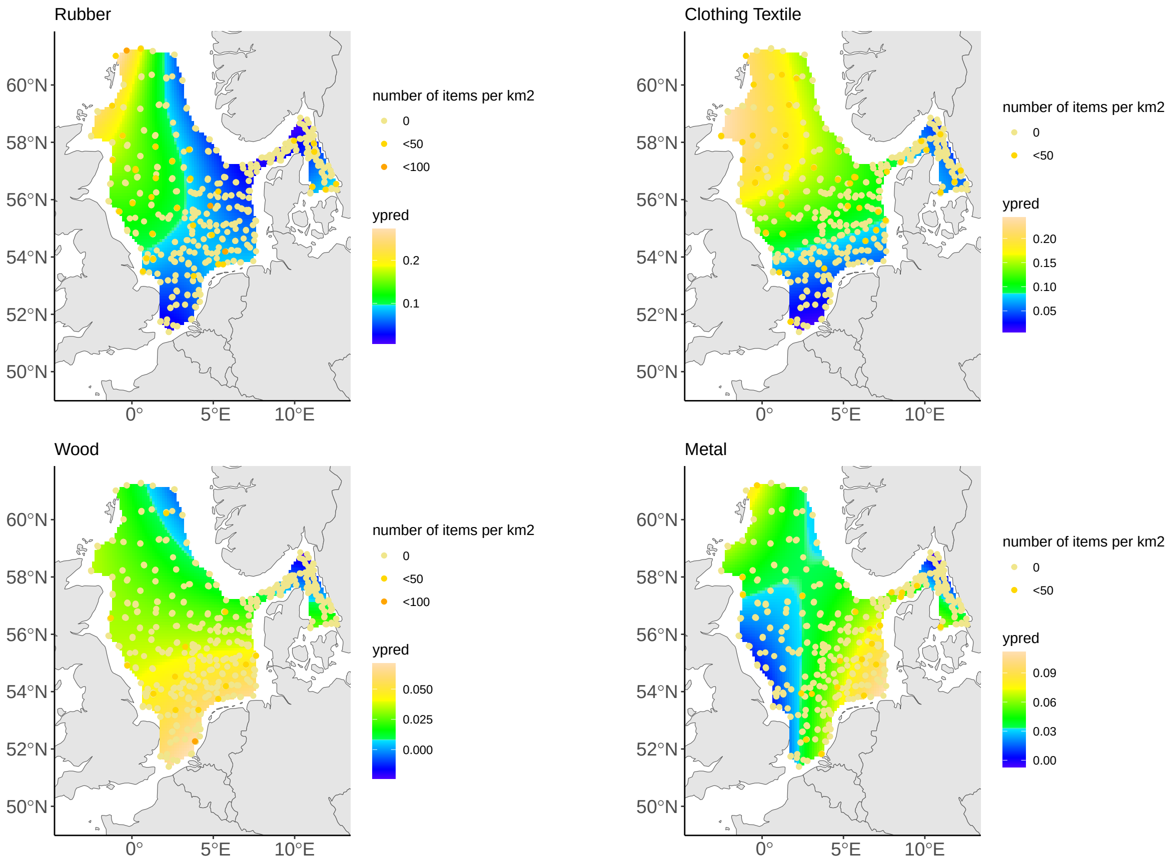

Figure 18: *Maps of log counts per km2 (ypred) for IBTS Q3 data over all 3 years (2020-2022) for 4 different categories of seafloor litter.*

Comparing the spatial maps for BTS and IBTS the general spatial patterns are somewhat similar, especially for Rubber. Here we have to keep in mind that the fished area for the two is not identical. Furthermore the numbers of items found per square kilometer are low for IBTS.

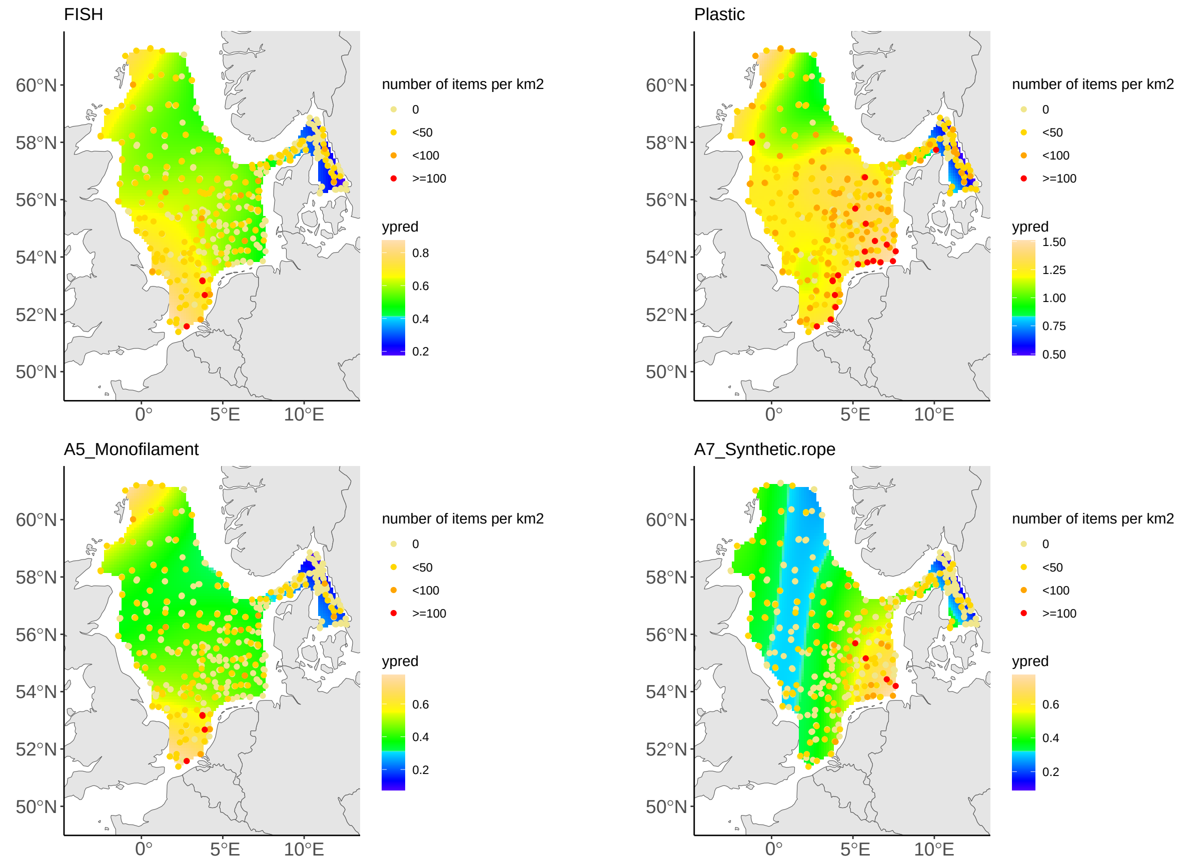

Figure 19: *Maps of log counts per km2 (ypred) for IBTS Q3 data over all 3 years (2020-2022) for categories FISH, Plastic, A5 Monofilament, and A7 Synthetic.rope.*

The map for the material category Plastic (top right) is quite similar for IBTS compared to BTS. The total numbers of items per square kilometer are smaller, but the general spatial pattern is similar, especially if we focus on the area where BTS and IBTS overlap. There is a striking difference however when we zoom in further to FISH. There the area off the coast of Germany, that showed a high amount of items per square kilometer for BTS, shows lower numbers for IBTS. As for BTS, FISH is dominated by A5_Monofilament, so we see a similar difference in the plots for A5_Monofilament. The map for A7_Synthetic.rope on the other hand shows a reverse pattern. For BTS the numbers of the German coast were relatively low, whereas for IBTS the numbers are high.

As can be seen in figure 1, for IBTS the area off the German coast is mainly measured by vTI. The difference in the spatial patterns for FISH might be caused by a different way of classifying by vTI compared to the other institutes. To check this we look at the data for IBTS Q3 over all years and compare how the classification of plastic is done by vTI compared to the other institutes.

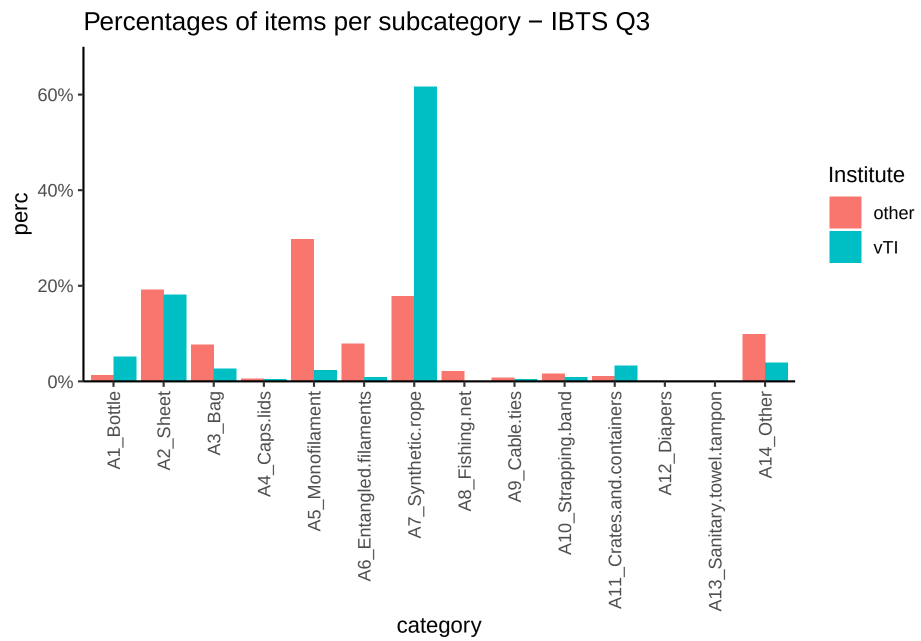

Figure 20: *Classification of Plastic for IBTS Q3 data over all 3 years (2020-2022) for vTI versus other institutes.*

From figure 20 it is clear that about 60% of the plastic caught by vTI is classified as A7_Synthetic.rope. The percentages for the two main subcategories that are part of FISH, A5_Monofilament and A6_Entangled.filaments, are very small. This isn't conclusive evidence that items are misclassified by vTI, it could also be that the items they caught did consist of a lot of A7_Synthetic.rope. However, again, this shows the importance of a uniform way of classifying items.

Research topic 6

The final research topic is:

Statistical analysis now often uses the presence and absence of seafloor litter per category. Research will be done into the advantages and disadvantages of this approach compared to an analysis with the number of items found per category

During the execution of the project, this research topic has fallen out of the scope of the project. Presence and absence data analysis could make sense when the number of items found are low. Otherwise information is lost, because the number of items found will be replaced by present or absent. So, when one item is found in one haul it will be equal to an observation with 10 items in one haul. This loss of information is considered undesirable, and therefore this question is disregarded.

Conclusions and recommendations

In this report data of the IBTS and BTS monitoring programs has been investigated for the years 2020 to 2022. In phase 1 of this project six research topics have been formulated. These six research topics served as guidance for the implementation of phase 2 of the project. During the execution of the project it turned out that deviations should be made, sometimes because the research topic was less relevant than thought in phase 1, sometimes because results showed promising new findings which were prioritized within the limited time of this project.

The amount of data collected is impressive, both for the number of observations, and for the number of variables (categories) which are distinguished. Furthermore there are the two different monitoring programs of IBTS and BTS. All together many possible statistical analyses can be applied. The character of the data is quite specific. There are many zeros, and the data distribution which is skewed heavily to the right. There are many statistical ways to deal with these kind of data. Within the scope of this project, it was not possible to have an extensive comparison of these statistical methods.

The number of articles and reports about sea litter, and seafloor litter is impressive. In this project the aim wasn't to integrate all this information. The project should be seen as an independent research of the available data for the monitoring programs of IBTS and BTS. Of course, driven by the research topics formulated together with IHM and Rijkswaterstaat.

Bearing in mind the limitations above, the following main conclusions can be drawn. These conclusions will be accompanied by some recommendations.

- Plastic is by far the material category with the highest counts per square kilometer. The composition, the percentages over the main categories (Plastic, Rubber, etc) of seafloor litter, is not affected much by the outliers (see research topic 1).
- The typical distribution of the data (skewed to the right), should be kept in mind for the statistical analysis. There are many ways of dealing with this. Just reporting the mean value for the number of items per square kilometer is highly sensitive to the outliers in the data. The median is a better measure of the central value for the number of items (see table 1).
- Taking the log values of the number of items is an adequate way of dealing with the skewed distribution. Both for visualization of the data (see for example figure 7) and for making maps of the counts. Log values are preferred over trimming the observations for the highest 5% of the data, because values are discarded with this method. Taking the log reduces the influence of the high values on the analysis, for example for the spatial interpolation for research topics 4 and 5.
- As already concluded earlier when comparing IBTS and BTS data, BTS data includes more seafloor litter than IBTS data. Not only in the total counts of items per square kilometer, but also for the different categories, for example for the category Wood (see figure 3). When we compare the medians of the total counts, 7 times as much seafloor litter is found by BTS monitoring. Therefore, monitoring seafloor litter by BTS seems to be preferred above IBTS. As is already known, the IBTS monitoring of seafloor litter has a very low catching rate. It has been estimated that less than 5% of the seafloor litter is caught by the nets used in the IBTS monitoring program. Even though more seafloor litter is caught in the BTS program, it will still be an underestimation of the total amount of seafloor litter.
- In research topic 1 the composition of the seafloor litter for the different institutes is compared. We concluded that IFREMER (France) has higher total counts of seafloor litter per square kilomter. This can be (partly) due to the location of fishing. However, figure 9 shows the distribution of total counts per square kilometer for the area which is overlapping with other institutes. The complete distribution of total counts per square kilometer is significantly higher for IFREMER. It is worthwhile to further investigate this issue. Of course, it is extremely important that all institutes count and report the seafloor litter in exactly the same way. Also in research topic 5 it seems that there are differences between institutes. In this case for the classification of subcategories of plastics with a much higher percentage of A7_Synthetic.rope reported by vTI (Germany; see figure 20).
- The spatial distribution of the (log) total counts per square kilometer does not give a clear spatial pattern for both IBTS and BTS data plotted for every year separately. Focus on BTS data aggregated over the 3 years does give spatial patterns and hot spots for specific categories. The most striking is the relatively new category FISH. This category shows a clear spatial trend for number of items found. The spatial distribution for the litter group FISH shows a clear relation with the distribution of litter type A5 (monofilament). The spatial distribution of seafloor litter across the area of the North Sea is not the same for different categories. The spatial pattern is very different for category A5 from the spatial pattern for category A7 (synthetic rope; see figure 17). For the sum over all subcategories of plastic a map with limited gradient and hot spots is found.

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