2019

Microplastic in the gastrointestinal tracts of commercial North Sea species

THESIS RESEARCH REPORT

MARRIT STARKENBURG & AILYNN SWIERS

MICROPLASTIC IN THE GASTROINTESTINAL TRACTS OF COMMERCIAL NORTH SEA SPECIES

Thesis research report

Authors

Marrit Starkenburg
Coastal Zone and Marine Management
Major Marine Biology

University of applied science Van Hall Larenstein
Agora 1, 8934 CJ Leeuwarden

Ailynn Swiers
Coastal Zone and Marine Management
Major Marine Biology

University of applied science Van Hall Larenstein
Agora 1, 8934 CJ Leeuwarden

Thesis supervisors

Jorien Rippen
Lecturer, Coastal and Marine management
jorien.rippen@hvhl.nl

Ruben de Vries
Lecturer, Coastal and Marine management
ruben.devries@hvhl.nl

University of applied science Van Hall Larenstein
Agora 1, 8934 CJ Leeuwarden

Client

Susanne Kühn
Researcher, Wageningen Marine Research
Department of Environmental Sciences,
Aquatic Ecology and Water Quality Management

susanne.kuehn@wur.nl
Ankerpark 27, 1781AG Den Helder

Leeuwarden, 31 January 2019

Cover photo ‘plastic bottle fish’ resource: (Isiaka, 2018)

Acknowledgements

This is the thesis of Marrit Starkenburg and Ailynn Swiers bachelor's degree Coastal Zone and Marine Management. It has been possible to write this research paper with help of the Wageningen Marine Research centre in Den Helder, where we worked for Suse Kühn. We have analysed the gastrointestinal tracts of 1034 individual marine species, to discover if they contained microplastic. We worked from October till December in Den Helder and mid-December we went back to the university to finish our thesis. This document shows the results of the laboratory research of the fish guts and includes the analysis of the international governmental policies measurement that are in place to tackle the microplastic problem in the North Sea area.

It would not have been possible to realise this product without the help of others. First, we would like to thank our supervisors from the university: Jorien Rippen and Ruben de Vries. They have helped us from the beginning with our proposal have been giving feedback during our writing process of this thesis. Their feedback helped us create the best results for this thesis report.

Second, we would like to thank Suse Kühn, who took a chance on us by giving us the job. We have been able to work in Den Helder with much joy in the cold autumn months. During our laboratory work we took up quite a lot of space and made the lab smell like fish. Especially in the beginning we were thankful for the employees who were also working in the laboratory during this time. A special thanks to Olivier and Bianca who were always available for a fun chat and were willing to help when we had trouble with identifying what kind of diet we found.

And last but not least, we would like to give a special shout-out to three friends who helped reading over our concept version. To Welmoed Starkenburg, Maggie de Dominicis and Hayley Cormack thank you for reading our reports and giving an outsider's point of view upon our writings. With their help we hope to have generated a clear report that can be understood whomever is interested in reading about microplastic problems in the North Sea.

Marrit Starkenburg & Ailynn Swiers
Leeuwarden, the Netherlands
31 January, 2019

Summary

Microplastic is becoming more accessible for ingestion by marine life due to its growing availability within the food chain. Although research on microplastic is growing, it remains limited. More research is needed to be able to fully understand the effects of microplastic upon marine organisms and human food quality and safety. The aim of this thesis is to deliver the spatial distribution and abundance of microplastic uptake in the North Sea by the selected commercial marine North Sea species. Together with an advice on what possible opportunities are for the current Marine Strategies of the North Sea Member States on GES concerning microplastic to enhance the reduction of microplastic emission. To reach this aim microplastic abundance has been examined in the gastrointestinal tracts of eight different commercial North Sea species: the Atlantic herring, Atlantic cod, haddock, Atlantic whiting, Atlantic mackerel, plaice, Norway pout and Atlantic lobster. These gastrointestinal tracts were dissolved in KOH, the residue was analysed under a microscope for distinctive colours and shapes that might represent plastic particles or fibres. These possible plastics have been documented and analysed for significant differences between species and location. Furthermore, the assessment of the European Commission reports of Article 16 PoMs of each Member State were used to create a clear overview on how each Member State intends to achieve GES on D9 and D10 regarding microplastic. To find possible opportunities for the North Sea Member States to contribute to the reduction of microplastic emission, the legislation of three countries have been analysed: Australia, Canada and the United States. The present study shows that there is a difference in the average numbers that have been observed in the gastrointestinal tracts of the selected North Sea species between these species and between the locations. All eight different species had individuals that contained microfibres and seven out of the eight contained particles. Only haddock did not contain any potential plastic particles. The highest frequency of occurrence for both microfibres and particles was found in Atlantic cod. Lack of data on microplastic pressures makes it difficult to develop a proper measure to tackle these pressures. D9 has no focus on microplastic and D10 has only on few occasions microplastic included within their GES. The United Kingdom and France have not included microplastic in their measures. The Netherlands and Denmark are working toward a phasing out of microbeads in cosmetic products. Germany has three new measures for microplastic, focussing on developing a more stringent waste water treatment, prohibiting the use of microplastic products in designated locations and reducing emission and input of microplastic particles in the environment. However, with all the measures presented no explanation is given into how this will be achieved, as data is still limited. Therefore, all countries are focused upon gathering information about the origin of microplastic and gather a complete scope for the next assessment. There are no opportunities to be gained for the Member States, when comparing it with foreign legislations.

Acronym list

BD	Birds Directive
D9	Descriptor 9
D10	Descriptor 10
CFP	Common Fisheries Policy
EEZ	Exclusive Economic Zone
FT-IR	Fourier Transform Infrared Spectroscopy
GES	Good Environmental Status
HD	Habitats Directive
IBTS	International Bottom Trawls Surveys
IBTSWG	International Bottom Trawl Survey Working Group
I&W	Dutch Ministry of Infrastructure and Water Management
JPI Oceans	Joint Programming Initiative Healthy and Productive Seas and Oceans
MSFD	Marine Strategy Framework Directive
NOAA	National Oceanic and Atmospheric Administration
PoMs	Programme of Measures
TAP	Thread Abatement Plan
UWWTD	Urban Waste Water Treatment Directive
WMR	Wageningen Marine Research
WFD	Water Framework Directive

Table of Contents

1 Introduction

The oceans are of significant socio-economic importance for the world's human population, providing jobs, recreation and food (Costanza, 1999). Yet the presence of anthropogenic pollution in the oceans through marine debris is threatening wildlife, hampering human activities and reducing the recreational value of coastlines (Fleet, Van Franeker, Dagevos, & Hougee, 2009). It is estimated that worldwide 80 percent of global marine debris originates from land while the remaining percentage originates from marine vessels (Andrady, 2011; Jambeck et al., 2015). For the North Sea the percentages are different. A beach clean-up on Texel showed that around 40 percent of the debris found originates from marine vessels (Van Franeker, 2005). Dutch beach surveys executed on the beaches of Bergen, Noordwijk, Veere and Terschelling between 2010 to 2015 showed that 55.3 percent of marine debris found during the clean-ups consisted of plastic materials (Hougee & Boonstra, 2010). Beached plastic debris only represents a fraction of the total input. More than two-third of plastic ends up on the seabed, half of the remainder floats on the surface and the other half washes up on beaches (Gallo et al., 2018). The annual production of plastic grew from 1.5 million tonnes in the 1940s, to 335 million tonnes in 2016 (Plastic Europe, 2018). Plastic production grows five percent per annum. Consequentially the amount that gets discarded increases as well (Andrady & Neal, 2009). The latest estimate in 2010 describes that annually between 4.8 to 12.7 million metric tonnes entered the marine environment (Borrelle et al., 2017; Jambeck et al., 2015).

Many stakeholders suffer from economic consequences caused by marine debris. Coastal municipalities must deal with the costs of beach clean-ups. The tourism sector suffers due to tourists avoiding the polluted beaches. Fisheries have excessive bycatch of marine debris damaging their gear and ship propellers get blocked and damaged (Bergmann, Gutow, & Klages, 2015; Mouat, Lozano, & Bateson, 2010).

Simultaneously, marine debris has considerable effects on marine ecosystems. Marine species get entangled which hinders them from moving, feeding and breathing. In addition, debris often gets ingested by many marine species mistaking them for food. Plastic may accumulate in their gastrointestinal tracts and lead to a reduced fitness of many organisms, which affects reproduction and survival or may cause instant mortality (Kühn, Bravo Rebolledo, & Van Franeker, 2015; Laist, 1997; Van Franeker & Kühn, 2018).

Marine plastic debris has a long lifespan and is able to persist for decades continuously weathering down into smaller plastic particles (Hopewell, Dvorak, & Kosior, 2009; Law & Thompson, 2014; Van Sebille et al., 2015). Plastic debris can be divided into four groups: microplastic (<5mm), mesoplastic (>5mm) macroplastic (<1m) and megaplastic (>1m) (GESAMP, 2016). Microplastic are plastic particles smaller than five millimeters, that can be categorized as primary and secondary microplastic. Primary are plastic particles created to be small like pre-production pellets, microbeads and microfibres from clothing (Arthur, Baker, & Bamford, 2009; Cole, Lindeque, Halsband, & Galloway, 2011; Dris, Gasperi, Saad, Mirande, & Tassin, 2016). Secondary microplastic are particles that have been fragmented from macroplastic (Andrady, 2011). These microplastic are of concern as it is uncertain what its exact effects are on the marine environment (Browne et al., 2011). Microplastic are able to accumulate several hydrophobic persistent organic pollutants from seawater or can leach out organic additives (Ivar Do Sul & Costa, 2014; Teuten, Rowland, Galloway, & Richard, 2007). Marine species that have ingested plastic particles may be affected by these chemicals. The chemicals are able to disturb the endocrine systems and could bioaccumulate and transfer between trophic levels (GESAMP, 2015, 2016; Hauser et al., 2015; Hunt, Sathyanarayana, Fowler, & Trasande, 2016; Teuten et al., 2009). Particularly microplastic ingestion by small filter-feeders causes concern as it may ultimately affect human food quality and safety (Gallo et al., 2018; Law & Thompson, 2014; Ma et al., 2016; Teuten et al., 2009; Van Sebille et al., 2015).

Microplastic is becoming more accessible for ingestion by marine life due to its growing availability within the food chain (Kühn et al., 2015; Rummel et al., 2016). Plastic ingestion has been widely documented throughout the food web, also in the North Sea (Fleet et al., 2017; Kühn et al., 2015). Several North Sea species have been found with microplastic in their systems including: the blue mussel *(Mytilus edulis),* lugworms (*Arenicola marina),* the brown shrimp *(Crangon carngon),* the eiderduck *(Somateria mollisma)* and the fulmar *(Fulmarus glacialis)* (De Witte et al., 2014; Devriese et al., 2015; Ens et al., 2002; Van Cauwenberghe, Claessens, Vandegehuchte, & Janssen, 2015; Van Franeker & The SNS Fulmar Study Group, 2013). Within North Sea fish species researchers have found microplastic in the gastrointestinal tract of several demersal and pelagic fish including the Atlantic cod (*Gadus morhua*), Atlantic mackerel (*Scomber scombrus*), whiting (*Merlangius merlangus*) and Atlantic herring (*Clupea harengus*). (Collard, Gilbert, Eppe, Parmentier, & Das, 2015; Foekema et al., 2013; Lusher, Mchugh, & Thompson, 2013; Rummel et al., 2016).

Although research on microplastic is growing, it remains limited (Browne et al., 2015). More research is needed to be able to fully understand the effects of microplastic upon marine organisms and human food quality and safety. Researching the spatial distribution of microplastic in North Sea seafood can help form the right management strategies per country. Different measures can be formed when possible hotspots or locations of microplastic uptake are identified.
The European Commission adopted an EU Action Plan for a circular economy in 2015 which stated the commitment to ‘prepare a strategy addressing the challenges posed by plastics throughout the value chain and taking into account their entire life-cycle’ (EU Commission, 2015, p. 14). As of January 2018, the European Commission has adopted new measures and obligations within the third part of the package of measures to implement this action plan. It is called the Plastic Strategy and focuses on the stimulation to decrease the percentage of waste entering marine environments (EU Commission, 2018e). On the 24th of October 2018 the European Parliament approved the ban on single-use plastics in the European Union as part of this strategy. Disposable plastic products will be banned on the European market by 2021 (Straver, 2018). This prohibition complements the Marine Strategy Framework Directive on the marine litter descriptor of the Good Environmental Status (EU Commission, 2018g)**.**

The EU Marine Strategy Framework Directive (MSFD) requires Member States to reach Good Environmental Status (GES) by 2020. GES consists of eleven descriptors of which two are relevant to the problem of marine microplastic. These two descriptors include contaminants in seafood (descriptor nine) and marine litter (descriptor ten). The criteria for descriptor nine states that contaminants in seafood for human consumption may not exceed levels that are established by Union legislation or other relevant standards. Descriptor ten has as criteria that properties and quantities of marine litter may not cause harm to the coastal and marine environment. To achieve GES by 2020, each Member State is required to develop a Marine Strategy on how they intend to achieve GES. These strategies ought to be kept up-to-date and reviewed once every six years (EU Commission, 2017d, 2017c). The GES strategies of the Member States are complex because each country has a separate strategy. Currently there is no clear overview of the strategies from the North Sea Member States regarding microplastic in seafood.

As of 2010 the fulmar has been designated as an Ecological Quality Objective (EcoQO) for North Sea marine debris to measure Good Environmental Status (EU Commission, 2010; European Union, IFREMER, & ICES, 2010; MSFD-TSGML, 2011). The OSPAR system of Ecological Quality Objectives (EcoQOs) has been developed to provide operational targets and indicators to support the assessments of ecosystem health and direction of management actions (OSPAR, 2010). Wageningen Marine Research (WMR) does research on possible trophic transfer of microplastic between fish and seabirds.

Problem description

It has been widely recognized that the rapidly increasing amounts of marine plastic debris are causing problems. However, current studies are mainly focused on the presence and effects of macroplastic and often do not consider microplastic. WMR has conducted research on microplastic uptake by North Sea prey fish, to better understand the potential of microplastic trophic transfer (O'Donoghue, 2017; Van Werven, 2016). However, more knowledge is needed on the abundance and spatial distribution of microplastic uptake by commercial North Sea species.
In addition, a clear overview is lacking on how GES will be achieved with the current Marine Strategies of the North Sea Member States concerning marine microplastic. Foreign countries use a different format when regulating microplastic in their environments. These other regulations might provide opportunities for the North Sea Member States to enhance the reduction of microplastic emission.

1.1 Problem statement

Knowledge is limited on the abundance and spatial distribution of microplastic uptake by commercial North Sea species. In addition, there is no clear overview of the current Marine Strategies and the possible opportunities for the measures from the North Sea Member States to achieve GES concerning microplastic in North Sea emission.

1.2 Aim

The aim of this thesis is to deliver the abundance and spatial distribution of microplastic uptake in the North Sea by the selected commercial marine North Sea species. Together with an advice on what possible opportunities are for the current Marine Strategies of the North Sea Member States on GES concerning microplastic to enhance the reduction of microplastic emission.

1.3 Research questions

Under supervision of Susanne Kuehn, researcher at WMR, a thesis research has been conducted that contributes to the Joint Programming Initiative (JPI) Oceans PLASTOX-project by examining microplastic abundance in the gastrointestinal tracts of eight different commercial North Sea species. These species include: the Atlantic herring, Atlantic cod, haddock, Atlantic whiting, Atlantic mackerel, plaice, Norway pout and Atlantic lobster. This thesis research contains two main research questions, both divided into two sub-questions.

Main question one: "What is the spatial distribution in the North Sea and the abundance of microplastic within the gastrointestinal tract of the selected commercial North Sea species[1]?".

- What is the spatial distribution in the North Sea and the abundance of microplastic in the gastrointestinal tracts of the selected commercial North Sea species?
- What is the difference in microplastic abundance in the gastrointestinal tracts between the selected commercial North Sea species?

Main question two: "What are the current Marine Strategies for Good Environmental Status of the North Sea Member States[2] considering microplastic in North Sea seafood and what are possible opportunities to enhance the reduction of microplastic emission?".

- What are the current Marine Strategies of the North Sea Member States on the Good Environmental Status concerning microplastic in North Sea seafood?
- What are possible opportunities for the North Sea Member States to enhance the reduction of microplastic emission?

[1] Selected commercial North Sea species: Atlantic herring, Atlantic cod, haddock, Atlantic whiting, Atlantic mackerel, plaice, Norway pout and Atlantic lobster

[2] North Sea Member States: Netherlands, Germany, Belgium, France, UK and Denmark

2 Background information

This chapter is divided into four sections with the first section explaining the Marine Strategy Framework Directive (MSFD). The second and third section discuss the direct and indirect stakeholders that have an influence upon this thesis. The fourth and last section explains how sustainability is applicable to this thesis.

2.1 Marine Strategy Framework Directive

On June 17th 2008, the MSFD was adopted by the European Commission (EU Commission, 2008). The MSFD was created in order to protect the marine environment across Europe in an effective way. Member States were presented with detailed criteria and methodological standards in order to help implement the Marine Directive (EU commission, 2017).

The MSFD aims to achieve a Good Environmental Status (GES) of the EU's marine waters by 2020. It is mandatory for each Member State to develop a strategy for its marine waters, also known as the Marine Strategy. The Marine Directive follows an adaptive management approach, meaning that each Member State is required to review and update the strategies every six years. The first cycle started in 2012, and the second in the beginning of 2018. The action that were be taken over the years can be found in figure 1. (EU Commission, 2018f)

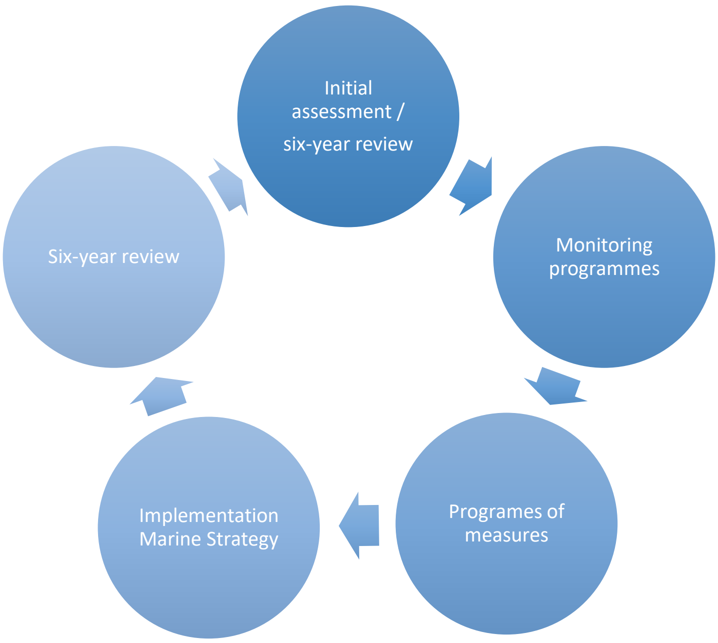


Figure 1: GES process example of the cyclic management approach used for the Marine Directive cycle. The first cycle started with the initial assessment in 2012 and from 2018 onwards, this cycle will be repeated untill 2024. The six-year review has been executed in 2018 and in 2019 the monitoring programmes will begin. ***(EU Commission, 2018f)***

The first step of the cycle is to report the initial assessment. In this document Member States give a clear current environmental status of their national waters, determine what a Good Environmental Status means for their marine waters and establish environmental targets and associated indicators to achieve GES by 2020. Furthermore, the environmental impact and socio-economic analysis of human activities in their waters have been analysed and reported in this assessment (EU Commission, 2017e). Two years later the Member States are required to have established a monitoring programme to assess the environmental status of the marine waters (EU Commission, 2017f). The Programme of Measures

(PoMs) follows up the monitoring programmes, the requirements are set in article 13 of the MSFD (EU Commission, 2018d, 2018h). Each Member State should address each MSFD descriptor in the PoMs and its measurement that will be applied to ensure GES. The last two steps include implementation of the Marine Strategy and the six year review/initial assessment (EU commission, 2017).

2.2 Direct stakeholders

Direct stakeholders are all the stakeholders that the project is directly linked with. These are JPI Oceans and the Dutch Government Agencies. WMR executes research and does monitoring for the PLASTOX-project with the funding received from the Dutch government.

JPI Oceans

The Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) is an intergovernmental platform, open to all EU Member States and Associated Countries with the participation of international partners on actions of shared interest. The concept of joint programming is an initiative of the European Commission for implementation of the European Research Area (ERA). The aim of this concept is to tackle the challenges that cannot be solved solely at national level (JPI Oceans, 2018b).

Germany proposed the pilot action “Ecological Aspects of Microplastics” in the Management Board of the JPI Oceans in February 2013. This was adopted within the “Interdisciplinary Research” of GES (no. 5 of the 10 JPI strategies) for the protection of marine habitats and the safety of marine resources and seafood. The scope of the pilot action is defined as the methods, monitoring and effects of microplastic. Ten Member Countries of JPI Oceans (Belgium, Germany, Spain, France, Ireland, Italy, Netherlands, Norway, Portugal and Sweden) have launched a joint effort on microplastic. Four selected projects have been funded (7.7 million Euro) for a three-year period starting January 2016: BASEMAN, EPHEMARE, PLASTOX and WEATHER-MIC (JPI Oceans, 2018a).

BASEMAN	Defining the baselines and standards for microplastic analyses in European waters
EPHEMARE	Ecotoxicological effects of microplastic in marine ecosystems
PLASTOX	Direct and indirect ecotoxicological impacts of microplastic on marine organisms.
WEATHER-MIC	How microplastic weathering changes transport, fate and toxicity in the marine environment

PLASTOX (Plastics & Toxicity) is a project which investigates the ingestion, food-web transfer, and ecotoxicological impact of microplastic, together with the persistent organic pollutants, metals and plastic additive chemicals associated with them, on key European marine species and ecosystems. The project combines laboratory tests, field-based observations and manipulative field experiments at stations which represents a wide range of European marine environments (Mediterranean-, Adriatic-, North-, and Baltic Sea and the Atlantic) to study the ecological effects of microplastic (JPI Oceans, 2017). The current study contributes to the investigation of microplastic ingestion.

Dutch Government Agencies

The Dutch Ministry of Infrastructure and Water Management (I&W) has a coordinating role relating to governmental issues of the North Sea environment. Therefore, the I&W is involved in the development of environmental monitoring systems for the Dutch Exclusive Economic Zone (EEZ). I&W has commissioned several projects to Wageningen Marine Research (WMR), which worked towards the Fulmar-Litter-EcoQO. The current projects that WMR works on are assigned by I&W, through its governmental section Rijkswaterstaat Water, Traffic and Environment (RWS-WVL). The funds and periodic goals for the Fulmar-Litter-EcoQO are assigned by RWS-WVL. (Van Franeker & Kühn, 2018; Van Franeker, Rebolledo, & Meijboom, 2014)

2.3 Indirect stakeholders

Indirect stakeholders are listed in this paragraph, these stakeholders are indirectly contributing to the microplastic pollution within the North Sea which relates back to the current project.

Fisheries

Fishing vessels that are registered in the EU fishing fleet register have equal access to all the EU waters and resources that are managed under the Common Fishery Policy (CFP) (EU Commission, 2018i). The aim for the CFP is to ensure that fishing and aquaculture are economically, environmentally and socially sustainable. Furthermore, they provide a source of healthy food for EU citizens (EU Commission, 2018i). The North Sea is one of the busiest seas in the world and is used for fishing, it is Europe's main fishery area where over 5 percent of international commercial fish are caught (Bonn Agreement, 2018). Microplastic pollution in fish species can affect the fishery industry by the increase of polluted fish that cannot be sold. The fishery sector is mostly sceptic on the actual microplastic uptake and the possible influence this might have on the species (Vissersbond, 2017). However, it is important for the fishery sector as well that microplastic uptake is monitored regularly.

Aquaculture

Aquaculture is a grossing business in Europe and offshore aquaculture is a futuristic opportunity for countries bordering the North Sea. There are many developments when it comes to offshore aquaculture, however when microplastic uptake becomes a reoccurring problem within marine species, the aquaculture sector will have the same issues as the fishery sector. (Pascual, Ecorys & Martina Bocci, & MSP-platform, 2018)

Food Safety Authorities

Food safety authorities are there to safeguard the health of animals and plants, and to make sure that the food and consumer products are safe and follow the legislation in the field of nature (ANSES, 2019; BVL, 2019; DVFA, 2019; Mattilsynet, 2019; NVWA, 2019). This includes microplastic contamination in seafood. On request of the German Federal Institute for Risk Assessment, the European Food Safety Authority (EFSA) investigated the presence of microplastic in food and seafood. The results showed that more research is needed on toxicokinetic effects and toxicity of microplastic uptake in the gastrointestinal tracts of marine species. (EFSA, 2016)

Shipping Industry

As mentioned before, the North Sea is one of the busiest seas in the world (Bonn Agreement, 2018). Hamburg (DE) and Rotterdam (NL) are two of the world's largest shipping harbours in the world. With 7600 cargo ships sailing and passing through the North Sea on a yearly basis loss of debris is inevitable (MSP-platform, 2019). On January 2nd of 2019 the MSC Zoë lost 291 containers on the North Sea, just above the Dutch Wadden islands (WUR, 2019). Resulting in debris being afloat in the North Sea and covering the beaches of the Dutch Wadden islands (NOS, 2019).

Urban Industries

The main contributors on microplastic pollution into the North Sea are the urban industries (Graca, Szewc, Zakrzewska, Dołęga, & Szczerbowska-Boruchowska, 2017). Especially via waste waters of sewers it has been discovered that microplastic particles are able to enter the marine environment (Dris et al., 2015).

2.4 Sustainability

JPI is an intergovernmental platform, the PLASTOX-project is committed to research the direct and indirect ecotoxicological impacts of microplastic on marine organisms. Therefore, this thesis is not focused on making profit. This thesis is focused on gathering information upon the microplastic uptake within the commercial North Sea species. This could influence people who get their income from resources of the North Sea, an estimated 850.000 people. (MSP-platform, 2019)

In order to protect the European environment, the European government is working on a strategy to minimalize the impact of microplastic in the environment. Each Member State looks at what measures should be set up to reduce the impact of microplastic in the North Sea. The end goal is to reach a Good Environmental Status within the North Sea. (EU Commission, 2018f)

3 Materials and Methods

During the International Bottom Trawl Survey (IBTS) in January and February 2018, 915 fish and 119 lobsters were collected from the North Sea (figure 1). The IBTS is executed annually in the North Sea, Skagerrak and Kattegat under the coordination of The International Bottom Trawl Survey Working Group (IBTSWG). The purpose of these surveys is to provide standardised and consistent data. With this data spatial and temporal changes can be examined of the biological parameters of commercial fish species and of the relative fish abundance and distribution. (ICES, 2012) The individuals were mainly captured in the Dutch, German and UK EEZ of the North Sea. Only one location has its origin in the Danish EEZ, and two locations are unknown due to missing coordinates.

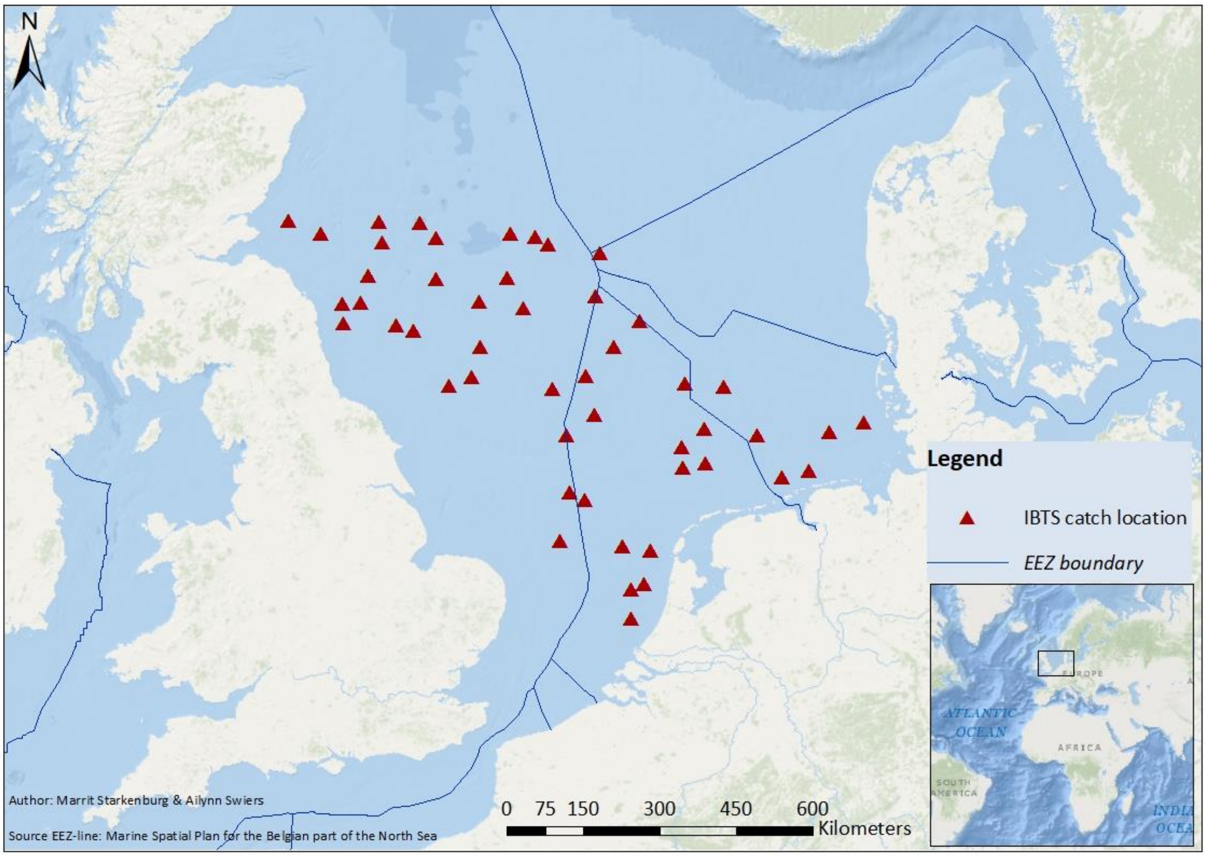


Figure 2: 2018 IBTS catch location in the North Sea within the EEZ boundaries. Two catch locations of lobster samples have not been included in this map due to unknown catch location coordinates.

3.1 Species description

Gastrointestinal tracts of 1034 individual marine species that had been preserved in ice were available for analysis. These include seven commercial North Sea fish species and one commercial lobster species: Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), whiting (Merlangius *merlangus*), Atlantic mackerel (*Scomber scombrus*), Norway pout (*Trisopterus esmarkii*), plaice (*Pleuronectes platessa*) and the Norway lobster (*Nephrops norvegicus*) (table 1 & figure 2). The gastrointestinal tracts of some fish and all lobsters still needed to be removed from the organism before analysis of the contents could be done.

Table 1: Gastrointestinal tracts available on ice of seven commercial North Sea fish and one commercial lobster species

Species	Latin name	Available
Atlantic herring	*Clupea harengus*	371
Atlantic cod	*Gadus morhua*	34
Haddock	*Melanogrammus aeglefinus*	121
Whiting	*Merlangius merlangus*	53
Atlantic mackerel	*Scomber scombrus*	47
Norway pout	*Trisopterus esmarkii*	39
Plaice	*Pleuronectes platessa*	250
Norway lobster	*Nephrops norvegicus*	119

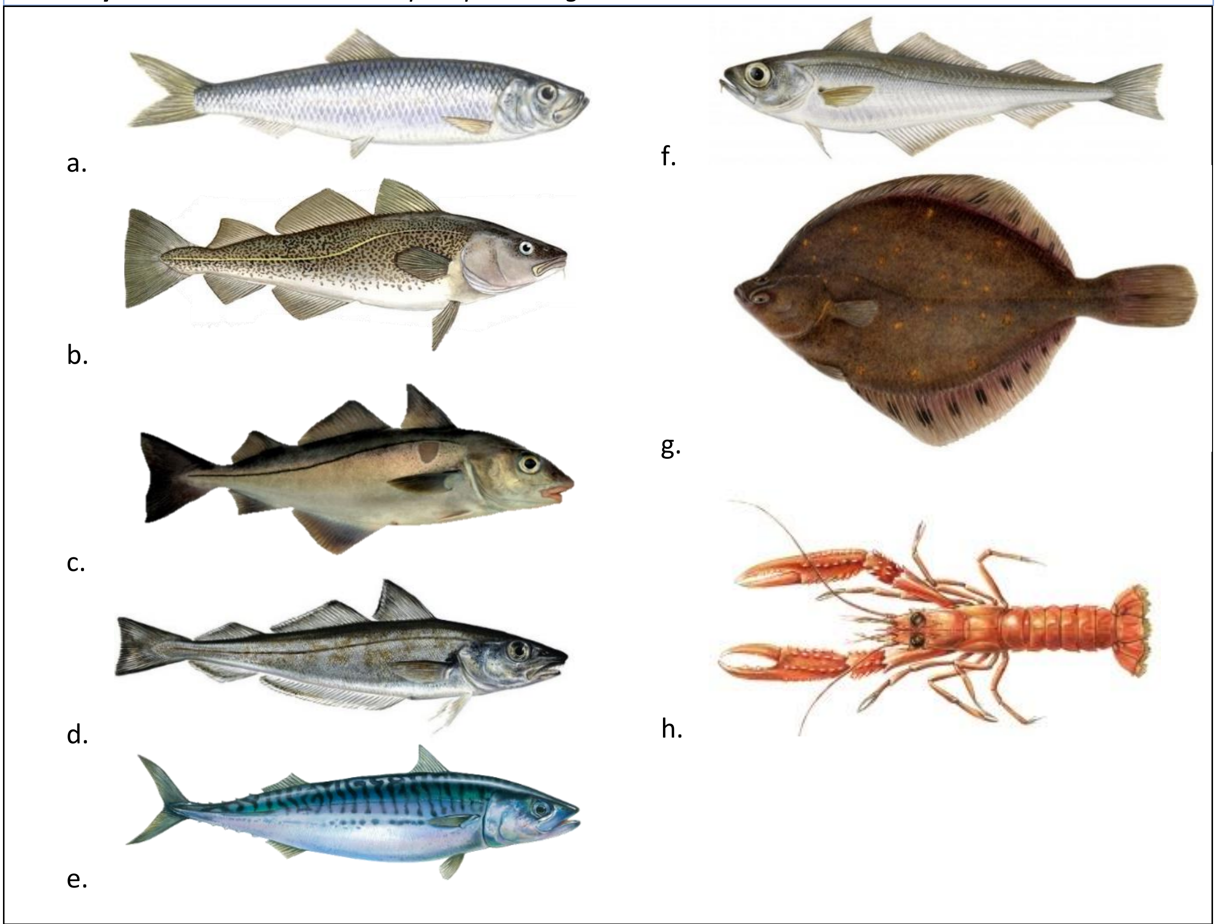


Figure 3: Analysed species: a) Atlantic herring (*Clupea harengus*), b) Atlantic cod (*Gadus morhua*), c) haddock (*Melanogrammus aeglefinus*), d) whiting (*Merlangius merlangus*), e) Atlantic mackerel (*Scomber scombrus*), f) Norway pout (*Trisopterus esmarkii*), g) plaice (*Pleuronectes platessa*) and h) Norway lobster (*Nephrops norvegicus*).

3.2 Data collection

The first 20 individuals of every species were examined through individual dissolution with potassium hydroxide (KOH) to obtain a frequency of occurrence of microplastic per sample. KOH dissolution is an effective and rapid method which dissolves tissue while leaving potential plastic particles intact. Multiple studies that have tested the KOH dissolution confirm the method as being effective (Foekema et al., 2013; Karami et al., 2017; Kühn et al., 2016). Because no plastic particles were found during the individual dissolution, another 10 were dissolved individually. After 30 individuals little to no plastic pieces were found. In order to be most time effective this was followed by batch dissolution of maximum 30 individuals from the same location. Numbers differed per batch due to the number of fishes caught per location. Time spent in the lab has been documented with details of the samples that have been prepared and examined. During handling of the samples, lab coats and gloves were worn.

When the gastrointestinal tract was still inside the organism, the organism was cut open with a scissor at the ventral line from the anus to the head and unfolded open. The gastrointestinal tract was removed with a pair of tweezer and scissors. Next the gastrointestinal tract was placed into a glass jar with KOH solution, while the remainder of the organism was discarded. All petri dishes were rinsed with Milli-Q water, then kept closed until needed. The petri dishes and sample jars were labelled (figure 4 & 5). This label was provided with the station code, species and individual sample numbers. The sample was covered in a 1 Molar per Litre (or 56 grams/Litre) KOH solution, followed by an incubation time of 48 to 72 hours at room temperature. When samples or batches contained a lot of tissue a 5 Molar per Litre (280 grams/Litre) KOH solution was used and the samples were incubated over a longer time period until dissolved.

When the solution was dissolved it was transported to the fume hood where it was sieved over a 30 µm sieve. The residue within the sieve was rinsed with Milli-Q into a beaker. The fluid with the residue was poured into a Bogorov counting chamber (figure 6), where it was analysed under a microscope for striking colours and shapes that might represent plastic particles or fibres. The Bogorov needed to be rinsed with Milli-Q before use and transported upside down. Potential plastic particles were saved and photographed using a Zeiss Achromat S 0.63x microscope with integrated AxioCam MRc camera. Fibres were not saved due to probable contamination and to save time, unless the fibre seemed too thick to be air contamination such as the fibres in Appendix-I. After sample analysis, the control was analysed as well to determine if there was any air-borne contamination.

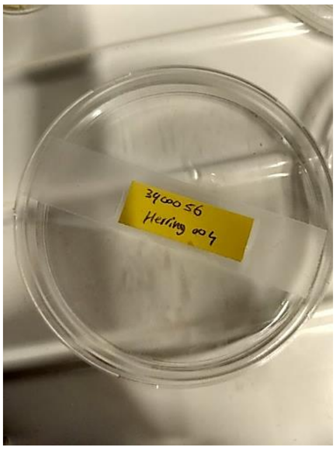


Figure 4: Label control petri dish

Figure 5: Label sample jar

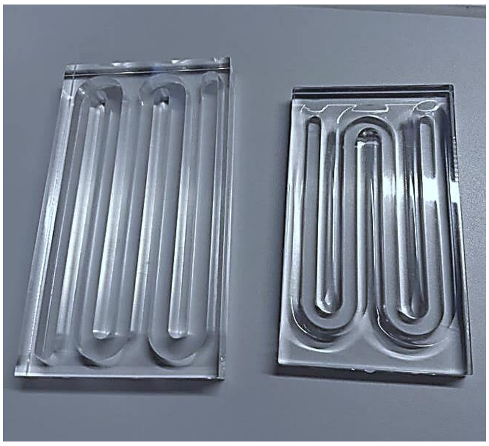


Figure 6: Bogorov counting chamber

Air-borne contamination

Every sample had a control petri dish adjacent with every step that was taken to examine air-borne plastic contamination through, for example, clothing fibres. The dish was filled with Milli-Q water to keep the air contamination fibres within the dish. When the sample was exposed to open air the control dish was exposed as well. The control dish was analysed under the microscope and the number of fibres was documented right after the associated sample. Because there was a significant difference ($U=44474$, $p=0.004$) in fibres between the samples and the controls, it is assumed that the observed fibres in the samples did not all come from air contamination. To account for the fibres that do come from air contamination a new variable has been created in which the control fibres have been subtracted from the sample fibres to a minimum of zero. Further analysis has been performed with this new variable and is referred to as 'fibres' or 'microfibres' throughout the rest of this report.

3.3 Data analysis

After collection, the data was statistically analysed on differences using IBM SPSS Statistics version 25. Differences were considered significant at $p<0.05$. Before performing any tests, the dependent variables 'particles' and 'fibres' were tested on normal distribution with the Kolmogorov-Smirnov. Both variables had a significance of <0.05, which means the data is not normally distributed and nonparametric tests were used.

A map was created with the collected data of both microfibres and particles using Esri ArcGIS 10.51 to display spatial distribution of the total number of counted microplastic from the gastrointestinal tracts. Because the dependent variables are not normally distributed, the non-parametric Kruskal-Willis test was used to test if there was a significant difference in microplastic (both particles and fibres) abundance in the gastrointestinal tracts of the selected North Sea species between the North Sea countries. The non-parametric Kruskal-Willis test was used to test if there was a significant difference in microplastic (particles and fibres) abundance in the gastrointestinal tracts of the selected commercial North Sea species.

3.4 Policy assessment

All North Sea Member States are required to develop a Marine Strategy on how they intend to achieve GES by 2020. Each Member State has reported these strategies under their article 16, the Programme of Measures (PoMs). The European Commission has an assessment on these measures. All these reports have been used to create a clear overview on how each Member State intends to achieve Good Environmental Status on D9 and D10 regarding microplastic. In addition, a short elaboration on this table has been written for every North Sea Member State.

Afterwards, a literature study was executed on possible opportunities for the North Sea Member States to contribute to the reduction of microplastic emission. This has been done by investigating other countries outside the European Union where policies upon microplastic are possibly in a more developed stage. Three countries have been selected for this analysis: Australia, Canada and the United States. During this assessment it has become clear if the MSFD measures differ compared to legislative bodies of these countries. Canada, Australia and the United States have been selected by means of accessibility of the documents and because of the English language.

To find governmental documents several keywords were used during the literature research. Via Google and Google Scholar documents were found via the following words: ‘microplastic, microplastic pollution, microplastic discards, environment, legislations, bans, government, bills, laws, constitution, federal laws, national laws, citizen science, research’. With these search words governmental documents were found, which were used to search for more information via the references used in the reports. With these documents a chapter has been written on the regulations used in foreign countries. With the results it was possible to determine if there are still further opportunities and strategies the North Sea Member States can use to improve upon their own regulations.

4 Results

This chapter includes the results of the abundance and spatial distribution analysis of microfibres and plastic particles found within the samples of this research. It also contains the results of the policy assessment through literature analysis.

4.1 Abundance & spatial distribution

In 1034 gastrointestinal tracts a total of 22 potential plastic particles (Appendix-I) were found. From these 1034 individuals, 2 percent contained particles. Most of these particles originate from samples that were collected in the EEZ of the United Kingdom, however the highest frequency of occurrence was found in Denmark with 29 percent (table 2). Particles had been found in seven out of eight different species, only the Haddock did not contain any potential plastic particles (table 3). The highest frequency of occurrence was found in Atlantic cod with 15 percent.

Table 2: Number and frequency of occurrence of particles and microfibres found in samples per country

Country	Individuals	Particles occurrence (%)	No. particles	Microfibres occurrence (%)	No. microfibres
Netherlands	355	1	4	47	168
Germany	145	1	1	12	17
United Kingdom	470	2	10	48	227
Denmark	21	29	6	95	20
Unknown	43	2	1	0	0

A total of 432 microfibres were found in the samples. Out of all the individuals, 42 percent contained microfibres. The frequency of occurrence was highest in Denmark with 95 percent (table 2). All eight different species had individuals that contained microfibres, the highest frequency of occurrence was found in Atlantic cod with 179 percent (table 3).

Table 3: Number and frequency of occurrence of particles and microfibres found in samples per species

Species	Individuals	Particles occurrence (%)	No. particles	Microfibres occurrence (%)	No. microfibres
Atlantic cod	34	15	5	179	61
Atlantic herring	371	1	4	26	95
Atlantic mackerel	47	6	3	136	64
Haddock	121	0	0	42	51
Norway lobster	119	3	3	12	14
Norway pout	39	3	1	105	41
Plaice	250	2	5	30	74
Whiting	53	2	1	60	32

Particles

Spatial distribution of the samples with particles has been displayed in figure 7. Most plastic particles have been found in samples from the only catch location in Denmark with six particles, followed by three particles within the Dutch EEZ.

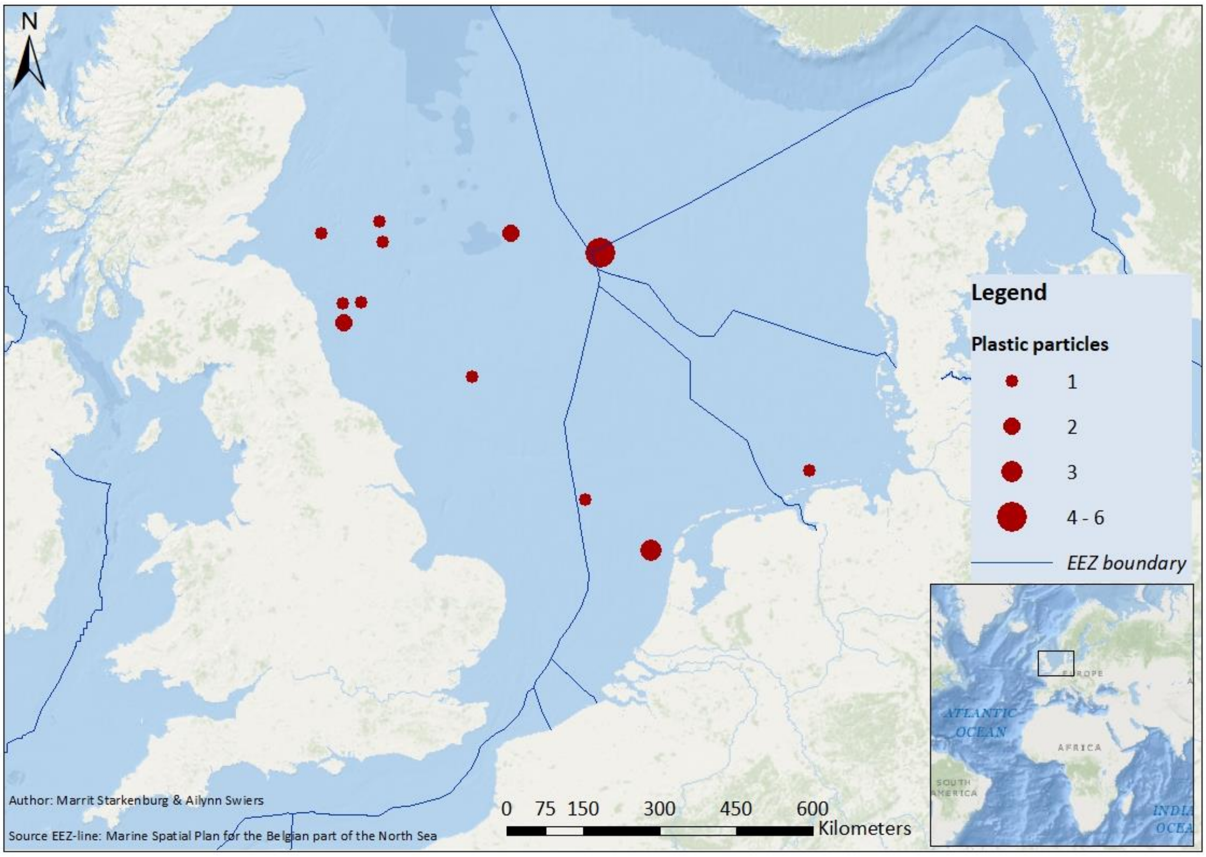


Figure 7: Spatial distribution of the total number of particles observed within the samples on location within the EEZ.

There is a significant difference (H(4)=78.996, p<0.001) in the average number of plastic particles between countries (figure 8). Almost all the locations are significantly different from each other, only the United Kingdom – Germany (p=1.000) and Denmark – Unknown (p=0.151) do not have a significantly different average number of plastic particles.

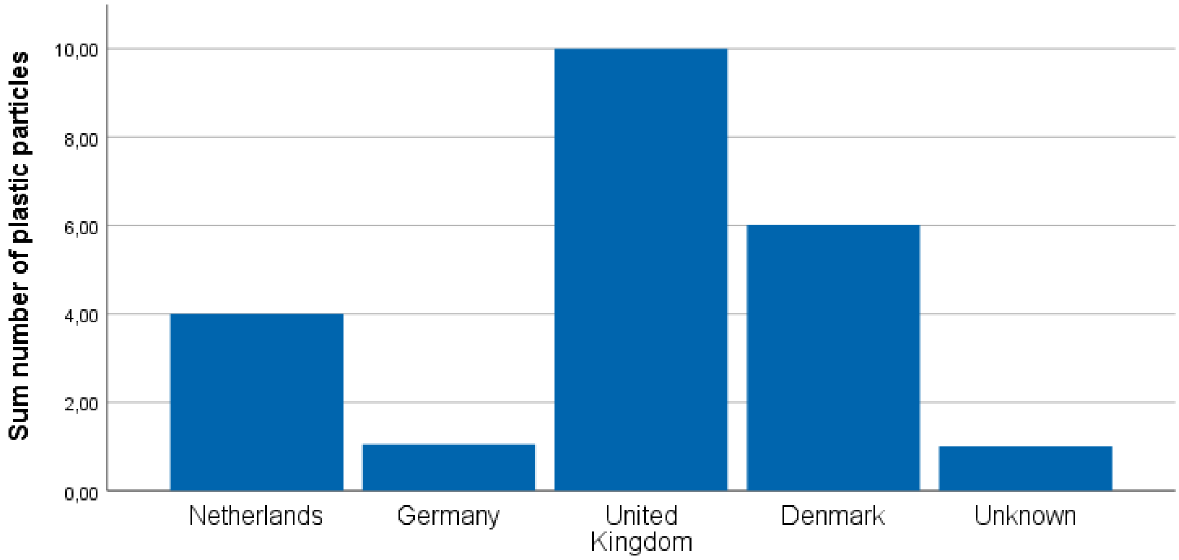


Figure 8: Sum number of plastic particles per country. Netherlands 17 locations (n=355), Germany 6 locations (n=145), United Kingdom 25 locations (n=470), Denmark 1 locations (n=21), Unknown 2 locations (n=43)

There is a significant difference (H(7)=33.446, p<0.001) in the average number of plastic particles between species (figure 9). Haddock (0.00 ± 0.00) is significantly different from the Norway lobster (0.025 ± 0.131), Atlantic herring (0.011 ± 0.060) and Atlantic cod (0.147 ± 0.360). All the other species do not have a significant difference in the average number of plastic particles.

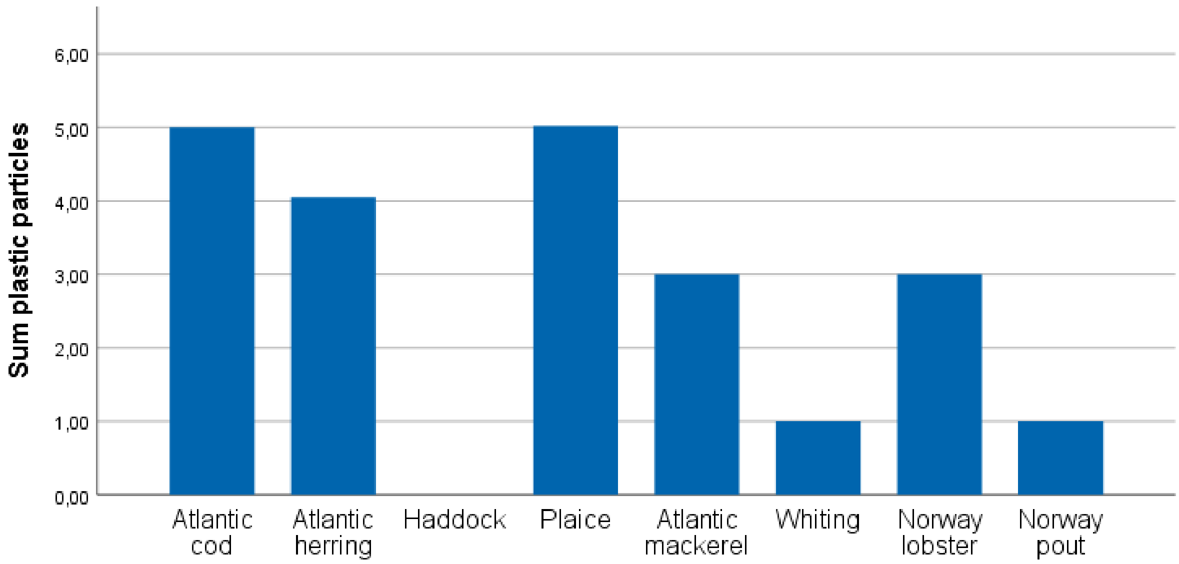


Figure 9: Sum number of plastic particles per Species. Atlantic cod (n=34), Atlantic Herring (n=371), Haddock (n=121), Plaice (n=250), Atlantic Mackerel (n=47), Whiting (n=53), Norway lobster (n=119), Norway pout (n=39)

Fibres

The most plastic fibres were found in samples from one location within the Dutch EEZ, close to the border with the EEZ of the United Kingdom with 79 fibres. This location is highlighted with black outline within the map below (figure 10).

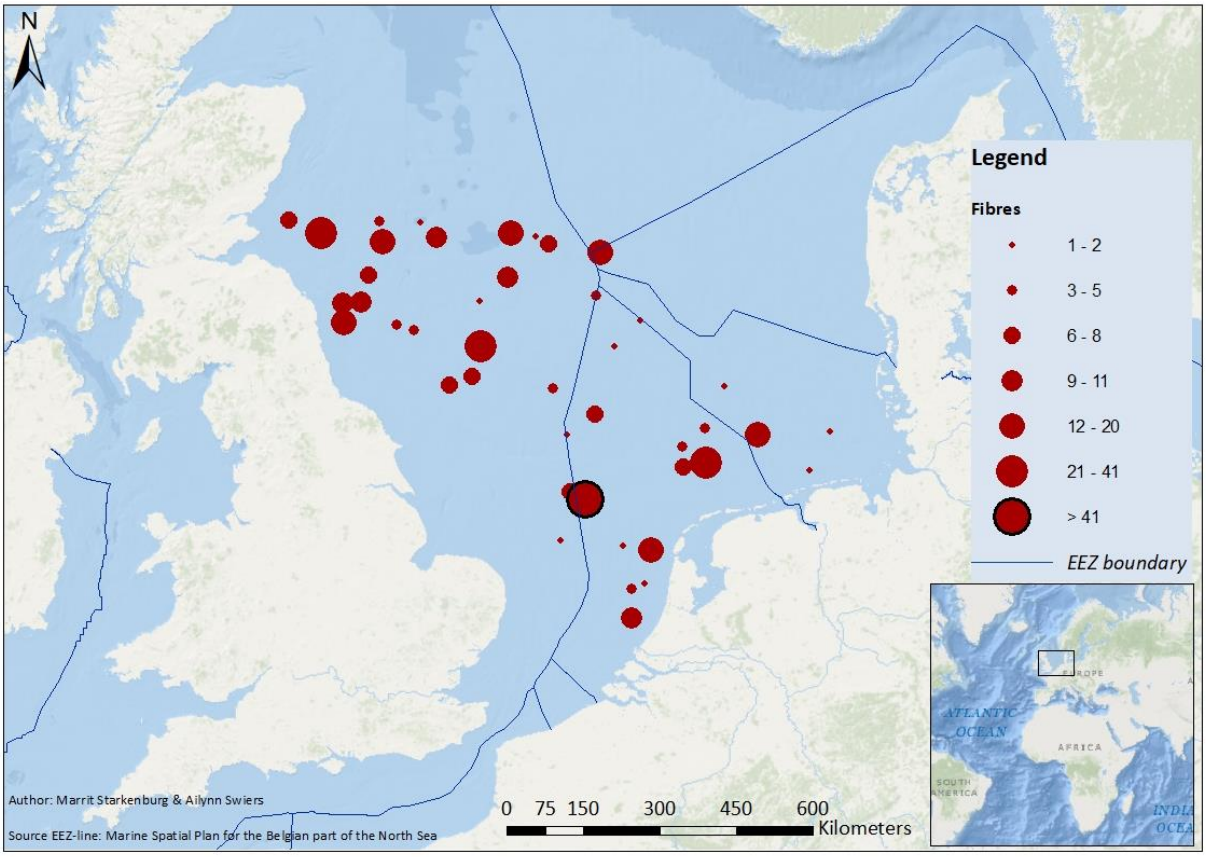


Figure 10: Spatial distribution of the total number of microfibres observed within the samples on location within the EEZ.

There is a significant difference (H(4)= 30.168, p<0.001) in the average number of microfibres between the different countries (figure 11). The average number is significantly different between the unknown locations (0.00 ± 0.00) and all the countries. There is no significant difference between all the other countries.

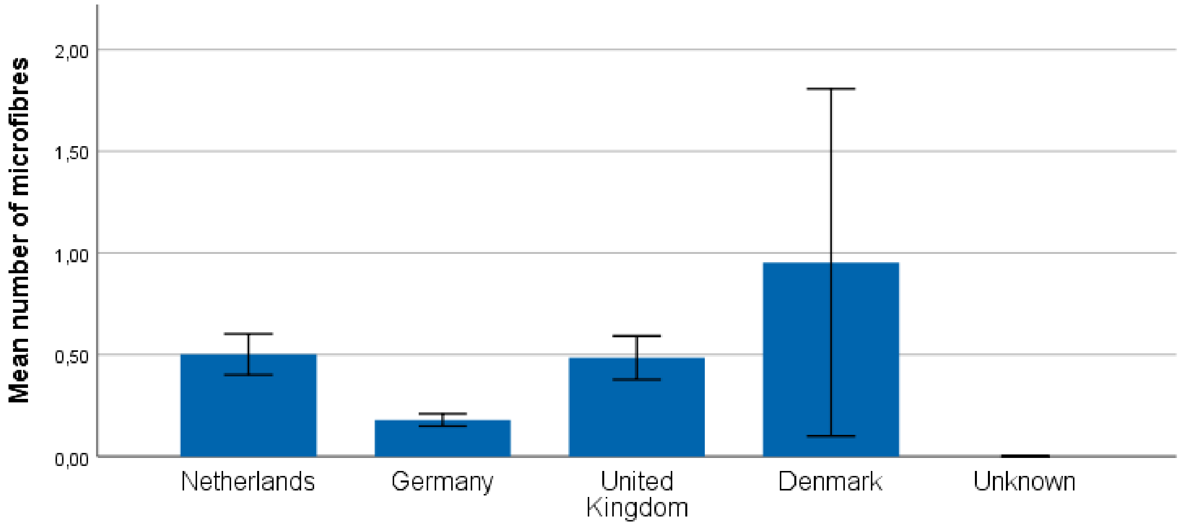


Figure 11: Mean number of microfibres per country with SE. Netherlands 17 locations (n=355), Germany 6 locations (n=145), United Kingdom 25 locations (n=470), Denmark 1 locations (n=21), Unknown 2 locations (n=43)

There is a significant difference (H(7)=46.135, p<0.001) in the average number of microfibres between the different species (figure 12). The average number in Norway lobster **(**0.118 ± 0.473) is significant different from all the other species except for Atlantic mackerel. All the other species do not have a significant difference in average number of microfibres.

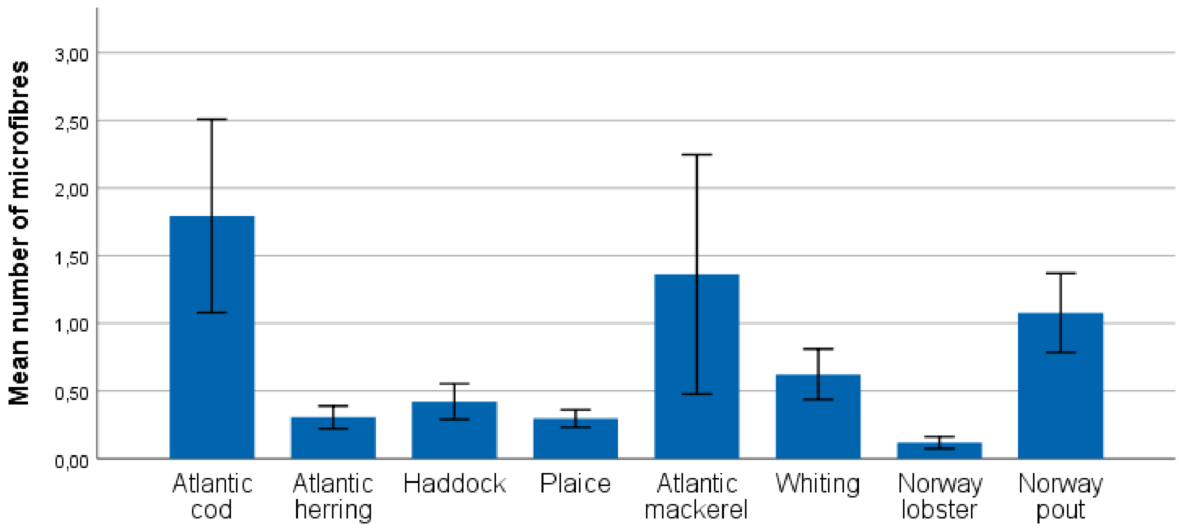


Figure 12: Mean number of microfibres per species with SE. Atlantic cod (n=34), Atlantic Herring (n=371), Haddock (n=121), Plaice (n=250), Atlantic Mackerel (n=47), Whiting (n=53), Norway lobster (n=119), Norway pout (n=39)

4.2 Policy assessment

This paragraph presents the results of the policy assessment that has been executed. Starting with an overall description on the MSFD regarding measures to achieve GES. Followed by an elaboration on the reported measures of the North Sea Member States for descriptor nine and ten concerning microplastic, followed by possible opportunities for these Member States to enhance the reduction of microplastic emission.

Marine Strategy Framework Directive

The MSFD (2008/56/EC) has several important phases in its first cycle, one of these is the introduction of the Programme of Measures (PoMs) that had to be adapted by 2016 (EU Commission, 2018d). The MSFD elaborates on existing Directives and policies by offering a platform to enable the expansion on existing measures and to ensure coherence between policies. This is why the measures are often existing initiatives or ongoing policy implementations from the Member States. Approximately 25 percent of all measures are labelled as 'new' measures that are specifically created under the MSFD. Crossovers between certain laws occur often with the Waste Framework Directive (directive 2008/98/EC), the Common Fisheries Policy (CFP), the Water Framework Directive (2000/60/EC) (WFD), the Birds Directive (2009/147/EC) (BD), the Habitats Directive (92/43/EC) (HD), the Urban Waste Water Treatment Directive (91/271/EC) (UWWTD). (EU Commission, 2018h) Figure 13 shows an overview of the included directives of the MSFD.

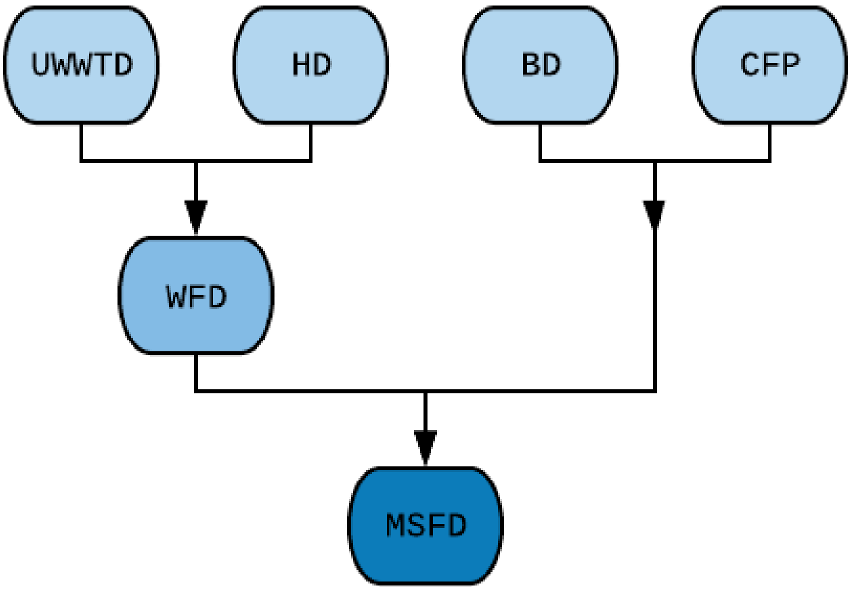


Figure 13: Overview of the existing directives that are elaborated on in the MSFD to enable expansion of existing measures and to ensure coherence between policies.

Descriptor 9 - 'Contaminants in Seafood'

Descriptor 9 (D9) points its focus on the prevention of contaminants in seafood. The Marine Directive states that the GES will be reached when the toxic concentration of all contaminants is below the maximum levels set for human consumption. Concentrations of contaminants within marine species and seafood, that exceed the normal levels, are indicators of a bad environmental status. (EU Commission, 2016)

Contaminants within seafood can come from different sources and human activities. These activities are directly or indirectly connected to the marine environment, for example accidental waste spills from marine vessels, offshore platforms or spills that are from land-based origin. D9 is often linked with Descriptor 8 (D8) (contaminants) and the EU REACH regulation (Registration, Evaluation, Authorisation and Restriction of Chemical substances) (EU Commission, 2017b; European Union, 2006). D8 has measures that also tackle activities of D9, therefore not many new measures are found in this descriptor. Microplastic have not been included for contaminants in seafood by the Member States (France, the United Kingdom, Germany, the Netherlands, Belgium and Denmark) (EU Commission, 2017a, 2017b, 2018b, 2018c, 2018a; Miljostyrelsen, 2017).

Descriptor 10 - 'Marine litter'

Descriptor 10 (D10) focusses on marine litter in coastal and marine environments, to prevent harm being done to these environments. To tackle marine litter, Member States often refer to some existing European Union laws, particularly on waste management, urban waste water or port reception facilities. Measures that are most commonly stated include beach clean-ups, 'fishing for litter' and raising awareness. (EU Commission, 2018h)

Within their measures, Member States include both the reduction of marine litter emission into marine and coastal areas as well as the removal of existing litter. These efforts are mostly focussed on macro-litter as not all Member States account for micro-litter as well. Very few Member States mention direct measures on micro-litter and some do report indirect measures to address knowledge gaps on micro-litter to support defining the pressure and its potential impact. (EU Commission, 2018d) Table 4 shows an overview on the measures for D10 regarding microplastic that have been reported by the North Sea Member States**.**

Table 4: Marine Strategies of the North Sea Member States on D10 considering Microplastic. Category 1a: existing, 1b existing not yet implemented, 2a new, 2b completely new. ***(EU Commission, 2017b, 2017a, 2018c, 2018a, 2018b)***

	Category	Strategies
Belgium	1a	Land-related measures (policies and Directives): Waste Directive, Water Framework Directive, Urban Wastewater Directive, Packaging Framework Directive, policy plan of the Flemish region, policy on waste from coastal municipalities.
	1a	Monitoring of marine litter conference OSPAR (also considered within the follow-up programme of the MSFD).
Denmark	1a	Finance Act has earmarked funding to clarify the sources, scope and impacts of microplastic.
	1a	European cosmetics industry has voluntarily decided to phase out the use of microplastic in their products.
France	-	No measures for microplastic available.
Germany	1b	More stringent waste water treatment.
	2a	Avoiding the use of primary micro-plastic particles.
	2a	Reducing emissions and inputs of microplastic particles.
Netherlands	1a	Voluntary reduction of emissions of microplastic in cosmetic products.
	2b	Commitment to EU ban on microplastic in cosmetics and detergents.
United Kingdom	-	No measures for microplastic available.

Belgium

Belgium reports two already existing measures considering microplastic, that both have an indirect effect on microplastic in the environment. These measures focus on raising awareness and increasing knowledge. The first (M15) refers to land-related measures of existing policies and directives. Concerning microplastic the measure focusses solely on raising awareness. The second measure (M21) is a monitoring measure to increase knowledge on microplastic. This could have an indirect effect on microplastic, however this does not directly affect the emission of microplastic. No new measures have been reported for microplastic. Belgium reports that the properties and quantities of marine debris do not cause harm to the coastal and marine environment. Belgium expects that GES will be achieved by 2020 as all proposed measures will be contributing. (EU Commission, 2017a)

Denmark

There is no EU commission assessment available on the PoMs due to Denmark missing the deadline of the European Commission. The only indirect measure given within the summary is the No-Special Fee policy, which allows fisheries to disregard their garbage at the harbour for no extra costs. (Miljostyrelsen, 2017)

In total there are two measures within the MSFD list where microplastic are specifically mentioned within the description. The first one is ANSDK-M054-EX, which states defacing of microplastic in cosmetic products. The second is ANSDK-M051-EX, which mentioned monitoring of marine debris including microplastic. (EIONET, 2015, 2019; Miljostyrelsen, 2017)

France

Marine litter is a relevant issue within the sub regional marine waters of France. Even though there are measures in place for microplastic there are no new measures added in the MSFD for microplastic. France's masures in D10 of the MSFD is focused on the reduction of plastic pollution in marine waters to limit spreading of macroplastic. In the future France will develop a strategy for reduction of microplastic in a direct new measure. In order to be able to develop this measure research is needed to gather information about the quantities and the impact microplastic has upon the French marine environment. (EU Commission, 2018a)

Germany

Germany reports two new measures, both of which have a direct effect on microplastic in the environment. The first new measure (M418-UZ5-03) aims to prevent primary microplastic particles to enter the environment. Through prohibiting use of these products in environmentally open areas and lastly, to establish alternative products. Furthermore, this measure focuses on microplastic that enter the environment from sources that are land based and from marine vessels. The second new measure (M424-UZ5-09) works toward the development of cost-efficient retention system for microplastic. The last measure that focusses on microplastic (M004-WFD) was an existing but not yet implemented measure. It looks at urban activities and aims to upgrade the municipal waste water treatments for reduction of material and microbial removal. Germany has reported that it is uncertain if the GES will be reached by 2020, due to insufficient knowledge about the effects of the measures. (EU Commission, 2017b)

Netherlands

The Netherlands reports two technical measures considering microplastic which both relate to one action; reduction on microplastic in cosmetics. Both measures have a direct effect on the reduction of microplastic. The first measure (ANSNL-M033) is an existing measure that requests the Dutch cosmetic companies to voluntarily avoid the use of plastic microbeads for their products. The second measure (ANSNL-M071) is a completely new measure that elaborates on the previous measure by promoting an EU ban on microplastic in cosmetic products and detergents. When adopted, this would directly affect microplastic by reducing the emission into the marine environment. The Netherlands reports that the properties and quantities of marine litter do not cause harm to the coastal and marine environment and that all measures will aid in reaching GES by 2020. (EU Commission, 2018b)

United Kingdom

The United Kingdom mentions that micro-litter is an issue in its marine environment, however, the Member State does not report any measures regarding microplastic. The United Kingdom expects that GES will be achieved by 2020 for the North East Atlantic. (EU Commission, 2018c)

Global opportunities

This paragraph includes the result of the analysis of possible opportunities for new measures that can be applied to the PoMs of the North Sea Member States, to reduce microplastic pollution. Foreign countries have started to adapt policies to reduce marine debris and microplastic. Furthermore, initiatives within the countries focusing on microplastic pollution are presented.

Australia

Threat Abatement Plan for the Impacts of Marine Debris on Vertebrate Marine Life (2017) provides a coordinated national approach on the implementation of measures to prevent the impacts of marine debris that are harmful to vertebrate marine life. Within the Thread Abatement Plan (TAP) actions for microplastic are listed, to create a better understanding of the origin and the impacts of microplastic on marine life and environment. (Australian Government, 2017)

The Department of the Environment and Energy is working on a voluntary phase-out of microplastic use within cosmetic products, an assessment showed that 94 percent of cosmetic products are plastic free. By 2025 all Australian packaging should be 100 percent recyclable, compostable or reusable. (Australian Government, 2018, 2019). Other legislations concerning plastic pollution all focus on reducing the total number of plastic entering the environment (Australian Government, 2018).

United States

In 2015 the House of Representatives of the United States passed the Microbead Free Waters Act of 2015, has been passed by the Senate (FDA, 2017; GPO, 2015). In July 2019 all cosmetic products should be plastic free in the stores of the United States (US). The National Oceanic and Atmospheric Administration (NOAA) is commissioned and funded by the US government to monitor the marine debris on the American coastlines.

Canada

Canada enforced a ban upon use of microplastic within cosmetic products by enlisting microplastic to the List of Toxic Substances under the Canadian Environmental Protection Act 1999 (Canada Gazette, 2015). This resulted in a ban of manufacture, import and sale of microbeads within cosmetic products by July 1th, 2019. Since 2015 Canada has been working towards microplastic being removal from cosmetic products (Government of Canada, 2018). Canada has no other measures concerning microplastic (Pettipas, Bernier, & Walker, 2016; Walker, Pettipas, Bernier, & Xanthos, 2016).

Opportunities for the North Sea Member States

Australia uses a voluntarily phasing out policy towards cosmetics being microplastic free, Europe is following the same approach (Kentin, 2018)**.** US and Canada went for a total ban on the sale of microplastic in cosmetic products. With these measures US and Canada are hoping to stop the wash-off of microbeads into the environment. A total ban will enhance the process of reducing microplastic emission into the environment.

However, the Netherlands and Denmark have decided on a voluntarily phasing out of microbeads in their products. Therefore, there are no real opportunities to be gained for the North Sea Member States.

5 Discussion

The present study shows that there is a difference in the average numbers that have been observed in the gastrointestinal tracts of the selected North Sea species between these species and between the locations. The North Sea Member States have implemented a limited number of new measures to mitigate microplastic within the environment, and study of legislation in Australia, Canada and the US showed that there are no new opportunities to be gained for the Member States.

Microplastic encounters

Low numbers of potential plastic particles have been observed, however, the previous studies of Van Werven (2016) and O'Donoghue (2017) showed little to no microplastic. Van Werven did not find any plastic particles in sprat. O'Donoghue did find more particles in sprat, however, the other species that were analyzed did not contain any microplastic, including whiting. This could be due to the very small sample sizes of these species.

There is a variation within literature on the reported frequency of occurrence of particles that have been observed within marine species. (table 5). Within the current study the highest frequency of occurrence of potential plastic particles has been observed in the Atlantic cod (15%). Foekema et al. (2013) did also observe the highest frequency for the Atlantic cod, with a similar frequency that had been found in the current study. Conversely, Rummel et al. (2016) did not detect any plastic in Atlantic cod that originated from the North Sea. Studies report different occurrences for Mackerel (Foekema et al., 2013; Rummel et al., 2016), the occurrence of the current study lies right between these occurrences. Very low frequencies have been found during the current study for the Atlantic herring and whiting. Other studies report similar low frequencies for herring and whiting. For the species Norway lobster, Norway pout and plaice from the North Sea no studies have been found on microplastic ingestion. Welden et al. (2018) does report a high occurrence of microplastic for plaice from the Celtic Sea, however this occurrence includes fibres that could originate from air contamination. There are findings of microplastic ingestion by Norway lobster (Murray & Cowie, 2011), however, this was an experimental setup with continues supply and is not relatable to the current study.

Table 5: Percentage of occurrence of particles observed in the selected North Sea by other studies

Species		Location	Occurrence particles (%)	Reference
Atlantic cod	Demersal	North Sea	0	Rummel et al., 2016
		North Sea	13	Foekema et al., 2013
Atlantic herring	Pelagic	North Sea	0	Rummel et al., 2016
		North Sea	0	Hermsen et al., 2017
		Northern Baltic Sea	1.8	Budimir et al., 2018
		North Sea	2	Foekema et al., 2013
Atlantic mackerel	Pelagic	North Sea	<1.2	Foekema et al., 2013
		North Sea	13.2	Rummel et al., 2016
Haddock	Demersal	North Sea	6	Foekema et al., 2013
Plaice	Demersal	Celtic Sea	50	Welden et al., 2018
Whiting	Pelagic	North Sea	0	Hermsen et al., 2017

		North Sea	6	Foekema et al., 2013

Diet & feeding habitat

Diet might have an impact on microplastic ingestion. Rummel et al. (2016) suggests that filter feeders such as herring and mackerel might be more likely to ingest microplastic than other marine species due to their unselective filter feeding behaviour. The cod is an unselective opportunistic feeder that feeds on almost anything (Rummel et al., 2016). Flatfish such as plaice, take a mouthful of sediment that is sifted through the gills. Plastic particles that have been mixed with the sediment might be taken up while feeding (Claessens, Meester, Landuyt, Clerck, & Janssen, 2011). Feeding habitat might be an important factor as well, because the concentration of microplastic was measured highest in the top layer (Goldstein, Titmus, & Ford, 2013). This would suggest that pelagic species have more microplastic available for ingestion than demersal species. The effects of diet and feeding habitat on microplastic uptake have not been tested during the current study. However, there does not seem to be an effect as there are no clear differences in frequency of occurrence between demersal and pelagic species, and between feeding behaviour.

Origin of microplastic

There is no certainty that the collected potential plastic particles and microfibres are from actual plastic or from other materials as Fourier Transform Infrared Spectroscopy (FT-IR) has not been executed. FT-IR is necessary to be able to verify the consistency of the collected potential plastic particles (Budimir, Setälä, & Lehtiniemi, 2018; Foekema et al., 2013; Hermsen, Pompe, Besseling, & Koelmans, 2017; Rummel et al., 2016) Because these analyses are costly and time consuming the facility in Germany can only be visited once or twice a year. The most recent moment WMR went to Germany to analyse samples was during the summer of 2018. Therefore, verification of the collected particles through FT-IR will be executed around spring/summer 2019.

Air contamination

Air contamination is a common problem when researching microplastic. Multiple studies (Lusher et al., 2013; Welden, Abylkhani, & Howarth, 2018) report high counts of microplastic, although these often include fibres that in all probability have entered the samples through air contamination. Because of the uncertainty of air contamination, multiple studies have disregarded all fibres to avoid over-estimation (Budimir et al., 2018; Foekema et al., 2013; Kühn et al., 2018). Within the current study possible air contamination of fibres has been taken into account by including control samples.

There is a possibility that there has been air contamination with the particles as well. Some of the detected particles consist out of a comparable structure such as parafilm or scotch tape (appendix I). Hermsen (2017) used strict quality assurance criteria to control contamination during the study and discovered microplastic in only one out of 400 individuals. The fish were rinsed thoroughly beforehand to reduce contamination risk from the plastic bag containments. This has not been the case with this study, meaning contamination is possible from the plastic bags.

Spatial distribution

Even though most particles have been found in Danish samples it cannot be concluded that these particles originate from Danish marine environments, because the catch location in the EEZ of Denmark is very close to the border with the United Kingdom. Furthermore, the invisible EEZ borders are no borders to marine species, as they migrate through the North Sea.

General remarks on analysis procedure

The batch samples were not equal in number of individuals, because the available amounts differed between coordinates. Additionally, the initial individual 30 samples do not originate from the same coordinate. This means these individual samples could not be put together to form another batch. To take these things into account, the batches have been divided through the number of individuals within the batch to get a frequency of occurrence on microplastic uptake and data analysis outcomes that are reliable.

The samples contained large amounts of diet, which was not prior the case with previous pilot studies (O'Donoghue, 2017; Van Werven, 2016). This could possibly be explained by the fact that these studies analysed sprat, which is a very small species that does not eat a lot. In addition, the samples of O'Donoghue (2017) have been collected during a different season. Due to these unexpected amounts of diet within the samples it becomes harder for an untrained eye to distinguish plastic fibres from organic materials. This may have caused for outliers within data of the herring and one location of the Netherlands, as these were the first few samples that have been analysed.

Research shows that 10% KOH does not affect the consistency of different types of microplastic (Kühn et al., 2016). However, during the current study a higher concentration of KOH has been used for the bigger samples. No research has been done yet on the effect of higher concentrations KOH on microplastic. It may be able to degrade plastic particles if higher solutions are being used.

Measures on microplastic

Even though microplastic is becoming a topic that has been acknowledged (Eriksen, Thiel, Prindiville, & Kiessling, 2018). Scientists have proven that it has become a global problem, whether it is from primary or secondary microplastic, new measures on mitigating microplastic in the environment are still limited (Lam et al., 2018). Many enforcements made upon marine debris is focused on reducing numbers of macroplastics entering the environment (Eriksen et al., 2018; Lam et al., 2018; Pettipas et al., 2016) .

Once microplastic enters the stream and oceanic water it is almost impossible to remove these particles from the environment (Eriksen et al., 2018). Therefore, it is important to tackle the problem upstream before it enters and to develop a method to control the input of microplastic into the environment (Eriksen et al., 2018). Around the world there is a movement towards change, to reduce the use of plastic products. However, there was no new legislation on microplastic found when looking into the Australian, Canadian and the United States strategies. The North Sea Member States are using the same strategies when comparing them to the foreign countries. Australia and Denmark are using a phasing out strategy for microbead within cosmetic products, the Netherland is promoting a ban for the use of microplastic particles within cosmetic and detergent products (Australian Government, 2017; EU Commission, 2018b).

Member States

It can be appointed that Norway has not been considered within the assessment of the measures within GES. The European Commission has an easy access to documents, like the assessments of the Programme of Measures of the Member States be found(EU Commission, 2017a, 2017b, 2018c, 2018b, 2018a). Norway, on the other hand, is not a Member State of the European Union, therefore is not bound to follow the MSFD legislations.

Another argument could be made about the Member States that are connected to the river deltas of Europe. As is widely known, plastic transports itself by currents, wind and rivers. As about 80 percent of marine debris found in oceanic water are from land-based origin (Siegfried, Koelmans, Besseling, & Kroeze, 2017). Besides the North Sea Member States there are nine countries (Norway, Sweden, Switzerland, Liechtenstein, Austria, Italy, Luxembourg, Czech Republic and Poland) that are connected to rivers ending up in the North Sea. As microplastic should be stopped by the source it should be mentioned that these countries should focus on microplastic reduction. (Eriksen et al., 2018) For this research only Member States bordering the North Sea have been reviewed, as the scope of the research area is the North Sea.

6 Conclusion

This chapter includes the conclusion of the research thesis. The answers of the sub-questions have been processed within the answer of the main research questions.

What is the spatial distribution in the North Sea and the abundance of microplastic within the gastrointestinal tract of the selected commercial North Sea species?

The present study shows that there is a difference in the average numbers that have been observed in the gastrointestinal tracts of the selected North Sea species between these species and between the locations. Most potential plastic particles and microfibres were encountered in samples that originate from the Exclusive Economic Zone (EEZ) of the United Kingdom. Although, when looking at the frequency of occurrence Denmark contained the most microfibres and particles per individual. Denmark did only have one catch location at the border of the EEZ with UK. To be able to suggest that most microplastic has been found in Denmark, samples need to be collected from more locations through the Danish EEZ. All eight different species had individuals that contained microfibres and seven out of the eight contained particles. Only haddock did not contain any potential plastic particles. The highest frequency of occurrence for both microfibres and particles was found in Atlantic cod.

What are the current Marine Strategies for Good Environmental Status of the North Sea Member States considering microplastic in seafood from the North Sea and what are possible opportunities to enhance the reduction of microplastic emission?”.

Member states have included microplastic measures within their strategy to reach Good Environmental Status, nonetheless, these measures presented are limited in numbers. Lack of data on microplastic pressures makes it difficult to develop a proper measure to tackle these pressures. Descriptor 9 has no focus on microplastic and for descriptor 10 limited measures are included within their GES for microplastic. The United Kingdom and France have not included microplastic in their measures. The Netherlands and Denmark are working towards a phasing out of microbeads in cosmetic products. Germany has three new measures for microplastic, focussing on developing a more stringent waste water treatment, prohibiting the use of microplastic products in designated locations and reducing emission and input of microplastic particles in the environment. However, with all the measures presented no explanation is given into how this will be achieved, as data is still limited. Therefore, all countries are focused upon gathering information about the origin of microplastic and gather a complete scope for the next assessment.

As for opportunities, the countries that have been revised do not have a more developed strategy to mitigate microplastic. Canada and the United States have a ban upon microplastic in cosmetic products. As Europe is working towards a voluntarily phase out of microplastic within cosmetic products, it is not really an opportunity for the Member States.

7 Recommendations

During the execution of this research several things caught the attention and might be interesting to take into consideration for future research. This thesis started in the laboratory to gather the first data. During data sampling it was noticeable that some of the materials were not optimal.

Because the samples of this research were bigger than the samples from previous research, the sieve that was provided was too small (diameter 5cm). Therefore, it took more time to properly sieve all the fluids and occasionally spillage occurred. In order to save time and prevent spillage, it is recommended that a larger sieve is used for the bigger samples (diameter 10cm).
Secondly, samples that contain a higher biomass should be placed in bigger jars. With this study the jars were often too small to properly fit a somewhat larger sample together with the necessary amount of KOH. The bigger variant of the jar was often too big to be able to properly rinse out the sample from the jars. Jars of a medium size should be available as well to minimise the chance of losing parts of the sample.
When larger samples need to be dissolved, it is recommended that a higher concentration of KOH is used (5mol) for an optimal dissolution. The KOH 1molar did not function for the samples that contains more biomass. In addition, it could be applicable to beforehand test the impact of higher concentration KOH and longer incubation time on plastic consistency. As some of the samples had to stay two to three weeks in the jar before it was completely dissolved.

In order to prevent air contamination, it is recommended that during laboratory work, clothing consisting of organic materials are worn. The use of plastic tools should be prevented as much as possible. For example, the fish were kept in plastic bags, parafilm was used to cover the sample, and the glass jars had plastic lids. When use of plastic bags for containment, the samples should be rinsed thoroughly before analysis.

It is highly recommended that all data are entered on a weekly basis to avoid mistakes within the dataset.

And lastly, when future analyse is executed by untrained people it is recommended to use around 20 practise samples. This will give the researcher time to practice identifying fibres from organic materials, like bones and fatty strings.

For future reference this data can be used for research on the trophic transfer studies for the Fulmar-Litter-EcoQO. Which is currently conducted by Suse Kühn and Jan van Franeker in Den Helder.
This data can be used as a reference for spatial distribution and abundance of particles in the North Sea, in order to develop structured measures to mitigate microplastic in the environment. Considering the policy assessment, no possible opportunities have come from this analysis because the foreign countries are not in a more developed stage compared to the North Sea Member States. Even though, it is recommended that in the future Member States keep developing their measures while observing the international progress on microplastic legislations to achieve GES.

Bibliography

Andrady, A. (2011). Microplastics in the marine environment. https://doi.org/10.1016/j.marpolbul.2011.05.030

Andrady, A., & Neal, M. A. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1526), 1977–84. https://doi.org/10.1098/rstb.2008.0304

ANSES. (2019). Anses - Agence nationale de sécurité sanitaire de l’alimentation, de l’environnement et du travail. Retrieved January 7, 2019, from https://www.anses.fr/en

Arthur, C., Baker, J., & Bamford, H. (2009). *Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*. Tacoma. Retrieved from www.MarineDebris.noaa.gov

Australian Government. (2017). *Threat Abatement Plan for the impacts of marine debris on Vertebrate Marine Life (2017)*. Retrieved from http://www.environment.gov.au/system/files/consultations/5101e251-39d3-4b07-92b0-c22289f5c437/files/draft-tap-marine-debris-2017.pdf

Australian Government. (2018). Plastics and packaging | Department of the Environment and Energy. Retrieved January 20, 2019, from http://www.environment.gov.au/protection/waste-resource-recovery/plastics-and-packaging

Australian Government. (2019). Plastic microbeads. Retrieved January 20, 2019, from http://www.environment.gov.au/protection/waste-resource-recovery/plastics-and-packaging/plastic-microbeads

Bergmann, M., Gutow, L., & Klages, M. (2015). *Marine Anthropogenic Litter*. Retrieved from https://link.springer.com/content/pdf/10.1007%2F978-3-319-16510-3.pdf

Bonn Agreement. (2018). Greater North Sea and its Wider Approaches. Retrieved September 6, 2018, from http://www.bonnagreement.org/about/north-sea

Borrelle, S. B., Rochman, C. M., Liboiron, M., Bond, A. L., Lusher, A. L., Bradshaw, H., & Provencher, J. F. (2017). Opinion: Why we need an international agreement on marine plastic pollution. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(38), 9994–9997. https://doi.org/10.1073/pnas.1714450114

Browne, M. A., Chapman, M. G., Thompson, R. C., Amaral Zettler, L. A., Jambeck, J., & Mallos, N. J. (2015). Spatial and Temporal Patterns of Stranded Intertidal Marine Debris: Is There a Picture of Global Change? *Environmental Science & Technology*, *49*, 7081–7094. https://doi.org/10.1021/es5060572

Browne, M. A., Crump, P., Niven, S. J., Teuten, E. L., Tonkin, A., Galloway, T., & Thompson, R. C. (2011). Accumulations of microplastic on shorelines worldwide: sources and sinks. *Environmental Science & Technology*, *45*(21), 9175–9179. https://doi.org/10.1021/es201811s

Budimir, S., Setälä, O., & Lehtiniemi, M. (2018). Effective and easy to use extraction method shows low numbers of microplastics in offshore planktivorous fish from the northern Baltic Sea. *Marine Pollution Bulletin*, *127*(August 2017), 586–592. https://doi.org/10.1016/j.marpolbul.2017.12.054

BVL. (2019). BVL - Federal Office of Consumer Protection and Food Safety. Retrieved January 7, 2019, from https://www.bvl.bund.de/EN/Home/homepage_node.html;jsessionid=1FA9EC8FB72DDA376E27C5224F7CE9B3.2_cid340

Canada Gazette. (2015). Canada Gazette – GOVERNMENT NOTICES. Retrieved January 28, 2019, from http://canadagazette.gc.ca/rp-pr/p1/2015/2015-08-01/html/notice-avis-eng.html

Claessens, M., Meester, S. De, Landuyt, L. Van, Clerck, K. De, & Janssen, C. R. (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin*, *62*(10), 2199–2204. https://doi.org/10.1016/j.marpolbul.2011.06.030

Cole, M., Lindeque, P., Halsband, C., & Galloway, T. S. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*, *62*(2588–2597), 10. https://doi.org/10.1016/j.marpolbul.2011.09.025

Collard, F., Gilbert, B., Eppe, G., Parmentier, E., & Das, K. (2015). Detection of Anthropogenic Particles in Fish Stomachs: An Isolation Method Adapted to Identification by Raman Spectroscopy. *Archives of Environmental Contamination and Toxicology*, *69*(3), 331–339. https://doi.org/10.1007/s00244-015-0221-0

Costanza, R. (1999). *The ecological, economic, and social importance of the oceans*. *Ecological Economics* (Vol. 31). Retrieved from www.elsevier.com/locate/ecolecon*

De Witte, B., Devriese, L., Bekaert, K., Hoffman, S., Vandermeersch, G., Cooreman, K., & Robbens, J. (2014). Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. *Marine Pollution Bulletin*, *85*(1), 146–155. https://doi.org/10.1016/j.marpolbul.2014.06.006

Devriese, L. I., van der Meulen, M. D., Maes, T., Bekaert, K., Paul-Pont, I., Frère, L., … Vethaak, A. D. (2015). Microplastic contamination in brown shrimp (Crangon crangon, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. *Marine Pollution Bulletin*, *98*(1–2), 179–187. https://doi.org/10.1016/J.MARPOLBUL.2015.06.051

Dris, R., Gasperi, J., Rocher, V., Saad, M., Renault, N., & Tassin, B. (2015). Microplastic contamination in an urban area: a case study in Greater Paris. *Environmental Chemistry*, *12*(5), 592. https://doi.org/10.1071/EN14167

Dris, R., Gasperi, J., Saad, M., Mirande, C., & Tassin, B. (2016). Synthetic fibers in atmospheric fallout: A source of microplastics in the environment? *Marine Pollution Bulletin*, *104*(1–2), 290–293. https://doi.org/10.1016/J.MARPOLBUL.2016.01.006

DVFA. (2019). The Danish Veterinary and Food Administration. Retrieved January 7, 2019, from https://www.foedevarestyrelsen.dk/english/Pages/default.aspx#

EFSA. (2016). Presence of microplastics and nanoplastics in food, with particular focus on seafood. *EFSA Journal*, *14*(6). https://doi.org/10.2903/j.efsa.2016.4501

EIONET. (2015). *Bilag 1-Nye indsatser Bilag til indsatsprogrammet-Nye indsatser*. Retrieved from http://cdr.eionet.europa.eu/dk/eu/msfd_pom/msfd4text/envwrlkeq/Annex_1_and_2_Danish_Summary_Report.pdf

EIONET. (2019). Reporting requirement on Programmes of Measures under MSFD Article 13. Retrieved January 26, 2019, from http://cdr.eionet.europa.eu/Converters/run_conversion?file=dk/eu/msfd_pom/ansdk/envwiduaw/Measures__1.xml&conv=534&source=remote#d10119001e1655

Ens, B. J., Borgsteede, F. H. M., Camphuysen, K., Dorrestein, G. M., Kats, R. K. H., & Leopold, M. F. (2002). *Eidereendsterfte in de winter 2001/2002*. Wageningen. Retrieved from http://edepot.wur.nl/89236

Eriksen, M., Thiel, M., Prindiville, M., & Kiessling, T. (2018). Microplastic: What Are the Solutions? (pp. 273–298). Springer, Cham. https://doi.org/10.1007/978-3-319-61615-5_13

EU commission. (2017). Our Oceans, Seas and Coasts. Legislation: the Marine Directive. Retrieved December 13, 2018, from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

EU Commission. (2008). *Establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN

EU Commission. (2010). *COMMISSION DECISION of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956) (Text with EEA relevance)*. Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:232:0014:0024:EN:PDF

EU Commission. (2015). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS - Closing the loop - An EU action plan for the Circular Economy*. Brussels. Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

EU Commission. (2016). Our Ocean, Seas and Coasts - Descriptor 9: Contaminants in Seafood. Retrieved January 16, 2019, from http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-9/index_en.htm

EU Commission. (2017a). Article 16 Technical Assessment of the MSFD 2015 reporting on Programme of Measures Belgium Report. Retrieved from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/pdf/Art 16 assessment.zip

EU Commission. (2017b). Article 16 Technical Assessment of the MSFD 2015 reporting on Programme of Measures Germany Report. Retrieved from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/pdf/Art 16 assessment.zip

EU Commission. (2017c). *COMMISSION DECISION (EU) 2017/ 848 - of 17 May 2017 - laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D0848&from=EN

EU Commission. (2017d). Law - EU Coastal and Marine Policy - Environment - European Commission. Retrieved September 11, 2018, from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

EU Commission. REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT The first phase of implementation of the Marine Strategy Framework Directive (2008/56/EC) The European Commission's assessment and guidance /* COM/2014/097 final */ (2017). Brussels: European Commission. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0097

EU Commission. REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL assessing Member States' monitoring programmes under the Marine Strategy Framework Directive COM/2017/03 final (2017). Brussles: European Commission. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:3:FIN

EU Commission. (2018a). Article 16 Technical Assessment of the MSFD 2015 reporting on Programme of Measures France Report. Retrieved from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/pdf/Art 16 assessment.zip

EU Commission. (2018b). *Article 16 Technical Assessment of the MSFD 2015 reporting on Programme of Measures Netherlands Report*. Retrieved from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/pdf/Art 16 assessment.zip

EU Commission. (2018c). *Article 16 Technical Assessment of the MSFD 2015 reporting on Programme of Measures UK Report*. Retrieved from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/pdf/Art 16 assessment.zip

EU Commission. (2018d). *COMMISSION STAFF WORKING DOCUMENT Accompanying the document Report from the Commission to the European Parliament and the Council assessing Member States' programmes of measures under the Marine Strategy Framework Directive*. Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018SC0393&from=EN

EU Commission. (2018e). *COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT Reducing Marine Litter: action on single use plastics and fishing gear*. Brussels. Retrieved from http://ec.europa.eu/environment/circular-economy/pdf/single-use_plastics_impact_assessment.pdf

EU Commission. (2018f). Our Oceans, Seas and Coasts - The Marine Strategy Framework Directive reporting. Retrieved January 6, 2019, from http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/implementation/reports_en.htm

EU Commission. (2018g). *Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the reduction of the impact of certain plastic products on the environment (Text with EEA relevance)*. Brussels. Retrieved from http://ec.europa.eu/environment/circular-economy/pdf/single-use_plastics_proposal.pdf

EU Commission. (2018h). *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND TO THE COUNCIL assessing Member States' programmes of measures under the Marine Strategy Framework*

Directive. Brussels. Retrieved from http://www.ourocean2017.org

EU Commission. (2018i). The Common Fisheries Policy (CFP) | Fisheries. Retrieved September 4, 2018, from https://ec.europa.eu/fisheries/cfp/

European Union. (2006). *REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL*. Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1907&from=EN

European Union, IFREMER, & ICES. (2010). *Marine Strategy Framework Directive - Task Group 10 Report Marine Litter*. https://doi.org/10.2788/86941

FDA. (2017). The Microbead-Free Waters Act: FAQs. Retrieved January 21, 2019, from https://www.fda.gov/cosmetics/guidanceregulation/lawsregulations/ucm531849.htm

Fleet, D., Dau, M., Gutow, K., Schulz, L., Unger, M., & Van Franeker, J. A. (2017). *Wadden Sea Quality Status Report Marine litter*. Wilhelmshaven. Retrieved from http://qsr.waddensea-worldheritage.org/node/29/pdf

Fleet, D., Van Franeker, J., Dagevos, J., & Hougee, M. (2009). *Marine Litter 2009 Common Wadden Sea Secretariat Trilateral Monitoring and Assessment Group*. Retrieved from http://www.waddensea-secretariat.org/sites/default/files/downloads/03.8-marine-litter-10-08-25.pdf

Foekema, E. M., De Gruijter, C., Mergia, M. T., Van Franeker, J. A., Murk, A. J., & Koelmans, A. A. (2013). Plastic in North Sea Fish. *Environmental Science & Technology*, *47*(15), 8818–8824. https://doi.org/10.1021/es400931b

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., … Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. *Environmental Science Europe*. https://doi.org/10.1186/s12302-018-0139-z

GESAMP. (2015). *Sources, fate and effects of microplastics in the marine environment (Part 1)*. London. Retrieved from http://www.gesamp.org/publications/reports-and-studies-no-90

GESAMP. (2016). *Sources, Fate and Effects of Microplastics in the Marine Environment (Part 2) | GESAMP*. London. Retrieved from http://www.gesamp.org/publications/microplastics-in-the-marine-environment-part-2

Goldstein, M. C., Titmus, A. J., & Ford, M. (2013). Scales of Spatial Heterogeneity of Plastic Marine Debris in the Northeast Pacific Ocean. *PLoS ONE*, *8*(11), 80020. https://doi.org/10.1371/journal.pone.0080020

Government of Canada. (2018). Microbeads. Retrieved January 28, 2019, from https://www.canada.ca/en/health-canada/services/chemical-substances/other-chemical-substances-interest/microbeads.html

GPO. Public Law 114-114, 114th Congress (2015). Authenticated U.S Government Information. Retrieved from https://www.congress.gov/114/plaws/publ114/PLAW-114publ114.pdf

Graca, B., Szewc, K., Zakrzewska, D., Dołęga, A., & Szczerbowska-Boruchowska, M. (2017). Sources and fate of microplastics in marine and beach sediments of the Southern Baltic Sea—a preliminary study. *Environmental Science and Pollution Research*, *24*(8), 7650–7661. https://doi.org/10.1007/s11356-017-8419-5

Hauser, R., Skakkebaek, N. E., Hass, U., Toppari, J., Juul, A., Andersson, A. M., … Trasande, L. (2015). Male Reproductive Disorders, Diseases, and Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union. *The Journal of Clinical Endocrinology & Metabolism*, *100*(4), 1267–1277. https://doi.org/10.1210/jc.2014-4325

Hermsen, E., Pompe, R., Besseling, E., & Koelmans, A. A. (2017). Detection of low numbers of microplastics in North Sea fish using strict quality assurance criteria. *Marine Pollution Bulletin*, *122*(1–2), 253–258. https://doi.org/10.1016/j.marpolbul.2017.06.051

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2115–2126. https://doi.org/10.1098/rstb.2008.0311

Hougee, M., & Boonstra, M. (2010). *OSPAR Beach Litter Monitoring in the Netherlands 2010-2015*. Retrieved from https://www.noordzee.nl/project/userfiles/BM_16.05_Annual_report_2010_2015_OSPAR_Beach_Litter_Monitoring_In_the_Netherlands.pdf

Hunt, P. A., Sathyanarayana, S., Fowler, P. A., & Trasande, L. (2016). Female reproductive disorders, diseases, and costs of exposure to endocrine disrupting chemicals in the European Union. *Journal of Clinical Endocrinology and Metabolism*, *101*(4), 1562–1570. https://doi.org/10.1210/jc.2015-2873

ICES. (2012). *Manual for the International Bottom Trawl Surveys Revision VIII*. Retrieved from www.ices.dkinfo@ices.dk

Isiaka, T. (2018). Microplastic pollution is all around us - SustyVibes. Retrieved September 25, 2018, from https://sustyvibes.com/microplastic-pollution-is-all-around-us/

Ivar Do Sul, J. A., & Costa, M. F. (2014). The present and future of microplastic pollution in the marine environment. *Environmental Pollution*, *185*, 352–364. https://doi.org/10.1016/j.envpol.2013.10.036

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science (New York, N.Y.)*, *347*(6223), 768–71. https://doi.org/10.1126/science.1260352

JPI Oceans. (2017). *PROJECT PERIODIC REPORT Direct and indirect ecotoxicological impacts of microplastics on marine organisms*. Retrieved from https://www.sintef.no/projectweb/plastox/

JPI Oceans. (2018a). Ecological aspects of microplastics. https://doi.org/10.1016/j.envpol.2018.01.028

JPI Oceans. (2018b). What is JPI Oceans? Retrieved September 10, 2018, from http://www.jpi-oceans.eu/what-jpi-oceans

Karami, A., Golieskardi, A., Choo, C. K., Romano, N., Ho, Y. Bin, & Salamatinia, B. (2017). A high-performance protocol for extraction of microplastics in fish. *Science of the Total Environment*, *578*, 485–494. https://doi.org/10.1016/j.scitotenv.2016.10.213

Kentin, E. (2018). *Banning Microplastics in Cosmetic Products in Europe: Legal Challenges*. Leiden. https://doi.org/10.1007/978-3-319-71279-6_34

Kühn, S., Bravo Rebolledo, E. L., & Van Franeker, J. A. (2015). Deleterious Effects of Litter on Marine Life. In *Marine Anthropogenic Litter* (pp. 75–116). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-16510-3_4

Kühn, S., Schaafsma, F. L., van Werven, B., Flores, H., Bergmann, M., Egelkraut-Holtus, M., … van Franeker, J. A. (2018). Plastic ingestion by juvenile polar cod (Boreogadus saida) in the Arctic Ocean. *Polar Biology*, *41*, 1269–1278. https://doi.org/10.1007/s00300-018-2283-8

Kühn, S., Van Werven, B., Van Oyen, A., Meijboom, A., Bravo Rebolledo, E. L., & Van Franeker, J. A. (2016). The use of potassium hydroxide (KOH) solution as a suitable approach to isolate plastics ingested by marine organisms-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/). *Marine Pollution Bulletin*, *115*, 86–90. https://doi.org/10.1016/j.marpolbul.2016.11.034

Laist, D. W. (1997). Impacts of Marine Debris: Entanglement of Marine Life in Marine Debris Including a Comprehensive List of Species with Entanglement and IngestiOn Records. https://doi.org/10.1007/978-1-4613-8486-1_10

Lam, C.-S., Ramanathan, S., Carbery, M., Gray, K., Vanka, K. S., Maurin, C., … Palanisami, T. (2018). A Comprehensive Analysis of Plastics and Microplastic Legislation Worldwide. *Water, Air, & Soil Pollution*, *229*(11), 345. https://doi.org/10.1007/s11270-018-4002-z

Law, K. L., & Thompson, R. C. (2014). Microplastic in the seas, concern is rising about widespread contamination of the marine environment by microplastics. *Science*, *345*(6193), 144–145. https://doi.org/10.1126/science.1254065

Lusher, A. L., Mchugh, M., & Thompson, R. C. (2013). Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Marine Pollution Bulletin*, *67*(1–2), 94–99. https://doi.org/10.1016/j.marpolbul.2012.11.028

Ma, Y., Huang, A., Cao, S., Sun, F., Wang, L., Guo, H., & Ji, R. (2016). Effects of nanoplastics and microplastics on toxicity, bioaccumulation, and environmental fate of phenanthrene in fresh water *. *Environmental Pollution*, *219*, 166–173. https://doi.org/10.1016/j.envpol.2016.10.061

Mattilsynet. (2019). The Norwegian Food Safety Authority. Retrieved January 7, 2019, from https://www.mattilsynet.no/language/english/

Miljostyrelsen. (2017). *Danmarks Havstrategi*. Retrieved from http://cdr.eionet.europa.eu/dk/eu/msfd_pom/msfd4text/envwrlkeq/Danish_Summary_report_MSFD_POM.pdf

Mouat, J., Lozano, R. L., & Bateson, H. (2010). *Economic Impacts of Marine Litt er*. Retrieved from www.iStockphoto.com/matsou,

MSFD-TSGML. (2011). *Marine Litter Technical Recommendations for the Implementation of MSFD Requirements MSFD GES Technical Subgroup on Marine Litter 2 | P a g e*. Luxembourg. https://doi.org/10.2788/92438

MSP-platform. (2019). North Sea General Introduction to the North Sea. Retrieved January 6, 2019, from https://www.msp-platform.eu/sea-basins/north-sea-0

Murray, F., & Cowie, P. R. (2011). Plastic contamination in the decapod crustacean Nephrops norvegicus (Linnaeus, 1758). *Marine Pollution Bulletin*, *62*(6), 1207–1217. https://doi.org/10.1016/j.marpolbul.2011.03.032

NOS. (2019). 1300 objecten gevonden in sonarzoektocht naar containers | NOS. Retrieved January 28, 2019, from https://nos.nl/artikel/2269077-1300-objecten-gevonden-in-sonarzoektocht-naar-containers.html

NVWA. (2019). Nederlandse Voedsel- en Warenautoriteit. Retrieved January 7, 2019, from https://www.nvwa.nl/

O'Donoghue, M. A. (2017). *Microplastic ingestion in North Sea prey fish And implications of fibre contamination*. Retrieved from https://hvhl-my.sharepoint.com/personal/ailynn_swiers_hvhl_nl/Documents/Thesis/Rapporten WMR/O'Donoghue_Microplastic ingestion in NS prey fish_FINAL.pdf

OSPAR. (2010). *The Ospar system of Ecological Quality Objectives for the North sea*. Retrieved from https://qsr2010.ospar.org/media/assessments/EcoQO/EcoQO_P01-16_complete.pdf

Pascual, D. M., Ecorys & Martina Bocci, & MSP-platform. (2018). *Sector Fische: Marine Aquaculture*. Retrieved from https://www.msp-platform.eu/sites/default/files/sector/pdf/mspforbluegrowth_sectorfiche_aquaculture.pdf

Pettipas, S., Bernier, M., & Walker, T. R. (2016). A Canadian policy framework to mitigate plastic marine pollution. *Marine Policy*, *68*, 117–122. https://doi.org/10.1016/j.marpol.2016.02.025

Plastic Europe. (2018). *Plastics-the Facts 2017 An analysis of European plastics production, demand and waste data*. Wemmel. Retrieved from https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

Rummel, C. D., Löder, M. G. J., Fricke, N. F., Lang, T., Griebeler, E. M., Janke, M., & Gerdts, G. (2016). Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. *Marine Pollution Bulletin*, *102*(1), 134–141. https://doi.org/10.1016/j.marpolbul.2015.11.043

Siegfried, M., Koelmans, A. A., Besseling, E., & Kroeze, C. (2017). Export of microplastics from land to sea. A modelling approach. *Water Research*, *127*, 249–257. https://doi.org/10.1016/J.WATRES.2017.10.011

Straver, F. (2018, October 24). Europarlement wil eind aan plastic wegwerpspul | TROUW. *Trouw*. Retrieved from https://www.trouw.nl/groen/europarlement-wil-eind-aan-plastic-wegwerpspul~ab2eda7a/

Teuten, E. L., Rowland, S. J., Galloway, T. S., & Richard, T. C. (2007). Potential for Plastics to Transport Hydrophobic Contaminants. *Environmental Science & Technology*, *41*(22), 7759–7764. https://doi.org/10.1021/ES071737S

Teuten, E. L., Saquing, J. M., Knappe, D. R. U., Barlaz, M. A., Jonsson, S., Bjorn, A., … Takada, H. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2027–2045. https://doi.org/10.1098/rstb.2008.0284

Van Cauwenberghe, L., Claessens, M., Vandegehuchte, M. B., & Janssen, C. R. (2015). Microplastics are taken up by mussels and lugworms living in natural habitats. *Environmental Pollution*, *199*, 10–17. Retrieved from https://www.journals.elsevier.com/environmental-pollution/editors-choice-monthly-selections/microplastics-are-taken-up-by-mussels-and-lugworms

Van Franeker, J. A. (2005). *Schoon Strand Texel 2005. Onderzoeksresultaten Van De Schoonmaakactie Van Het Texelse Strand Op 20 April 2005.* Wageningen. Retrieved from http://edepot.wur.nl/19515

Van Franeker, J. A., & Kühn, S. (2018). *Fulmar Litter EcoQO Monitoring in the Netherlands - update 2017*. Den Helder.

Van Franeker, J. A., Rebolledo, E. L. B., & Meijboom, A. (2014). Fulmar Litter EcoQO monitoring in the Netherlands - Update 2012 and 2013, (September), 56. https://doi.org/10.13140/RG.2.1.4380.4242

Van Franeker, J. A., & The SNS Fulmar Study Group. (2013). *Fulmar Litter EcoQO monitoring along Dutch and North Sea coasts-Update 2010 and 2011*. Texel. Retrieved from www.imares.wur.nl

Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B. D., Van Franeker, J. A., … Law, K. L. (2015). A global inventory of small floating plastic debris. *Environmental Research Letters*, *10*(12). https://doi.org/doi:10.1088/1748-9326/10/12/124006

Van Werven, B. (2016). *Microplastic ingestion by North Sea Sprat*. Retrieved from https://hvhl-my.sharepoint.com/personal/ailynn_swiers_hvhl_nl/Documents/Thesis/Rapporten WMR/Thesis report Bernike van Werven.pdf

Vissersbond. (2017). Geen plasticprobleem in Noordzeevis - Nederlandse Vissersbond. Retrieved December 13, 2018, from https://www.vissersbond.nl/geen-plasticprobleem-in-noordzeevis/

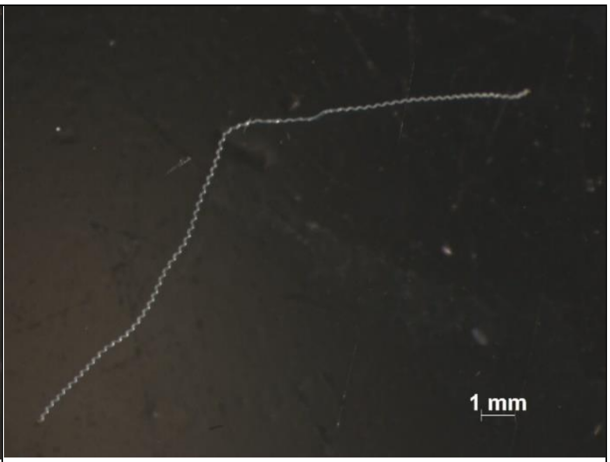
Walker, T. R., Pettipas, S., Bernier, M., & Xanthos, D. (2016). *Canada's Dirt Dozen: A Canadian policy framework to mitigate plastic marine pollution*. Retrieved from https://www.researchgate.net/publication/311732880

Welden, N. A., Abylkhani, B., & Howarth, L. M. (2018). The effects of trophic transfer and environmental factors on microplastic uptake by plaice, Pleuronectes plastessa, and spider crab, Maja squinado. *Environmental Pollution*, *239*, 351–358. https://doi.org/10.1016/j.envpol.2018.03.110

WUR. (2019). Vijf vragen over de impact van de containerramp met de MSC Zoë. Retrieved from https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksinstituten/marine-research/show-marine/Vijf-vragen-over-de-impact-van-de-containerramp-met-de-MSC-Zoe.htm

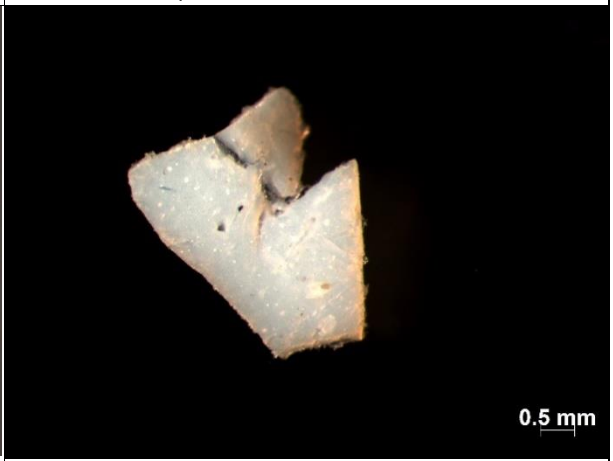
Appendix – I, Photos plastic particles

MAC005 sample1 - NL

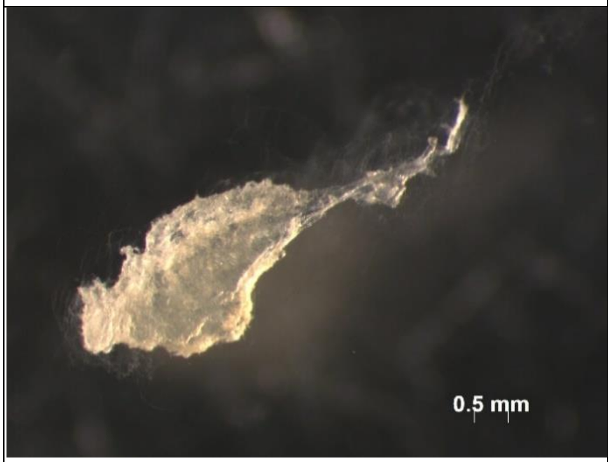


MAC005 sample 2 - NL

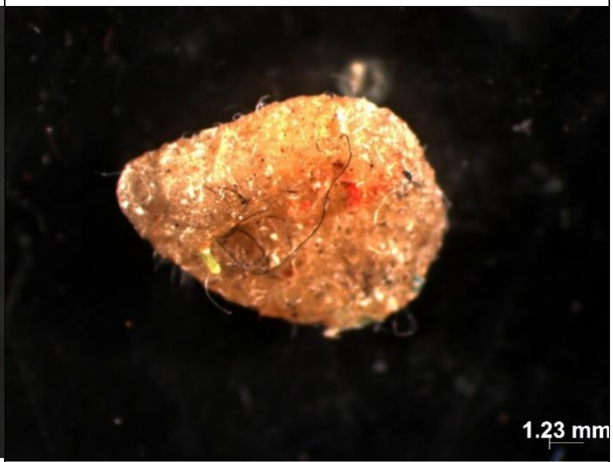
HER524 - NL



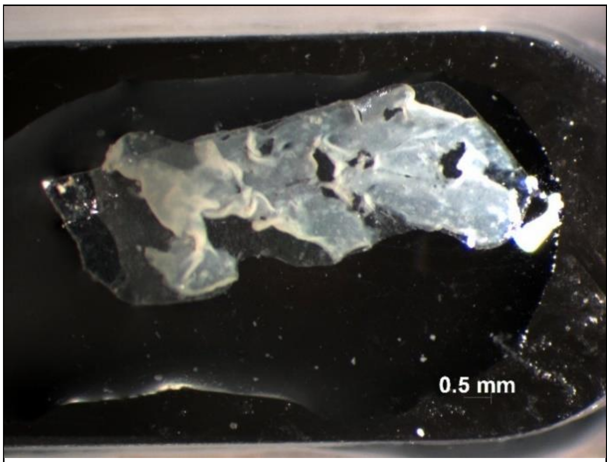
WHG012 - NL



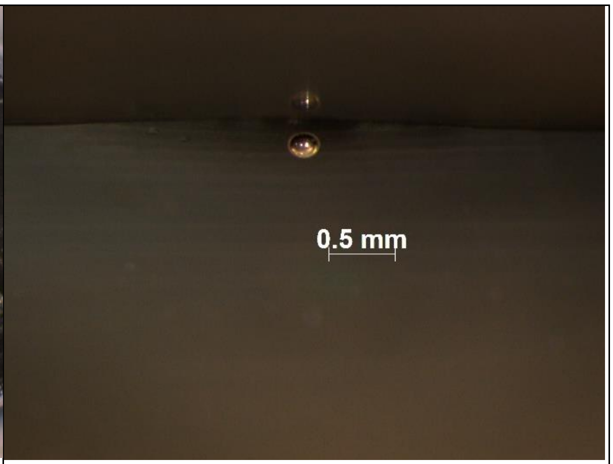
HER_B014 - DE



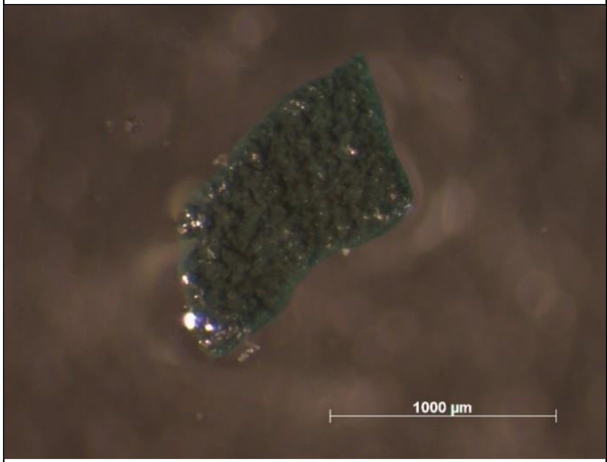
HER_B04 - UK



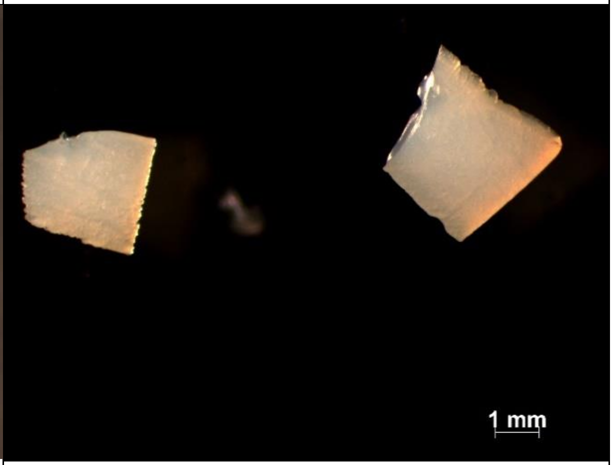
COD007 - UK



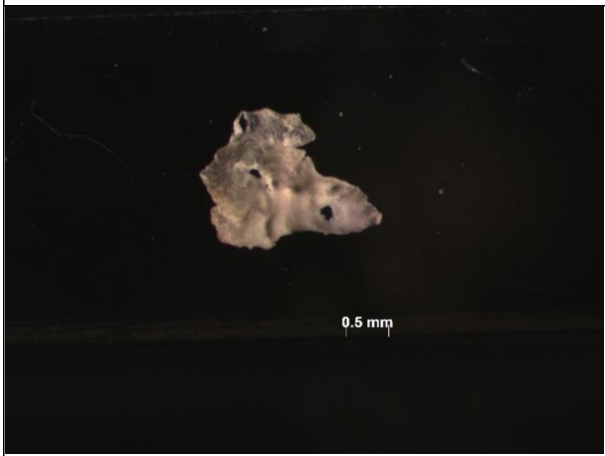
COD012 - UK



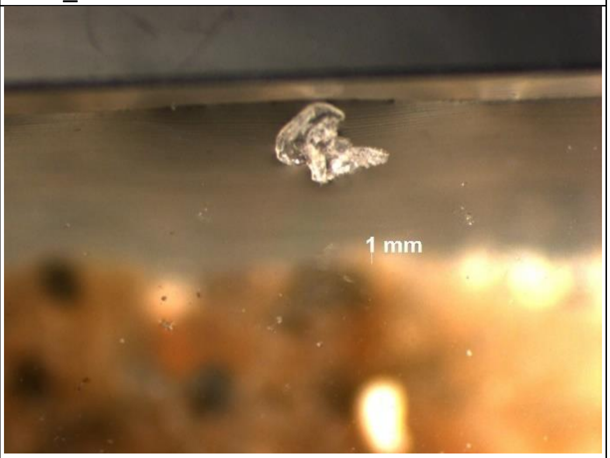
LOB_B05 - UN



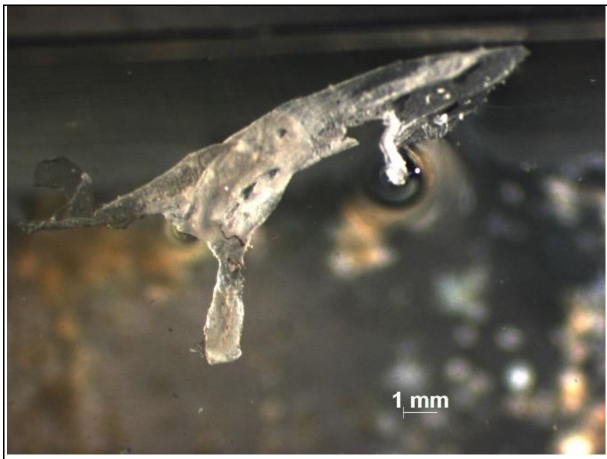
HER_B15 - UK



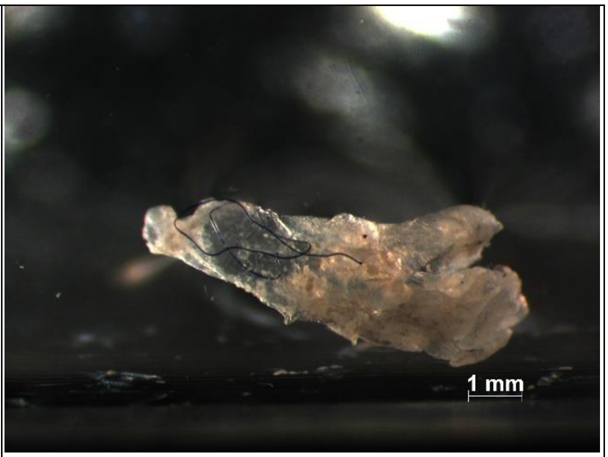
PLE207 - UK



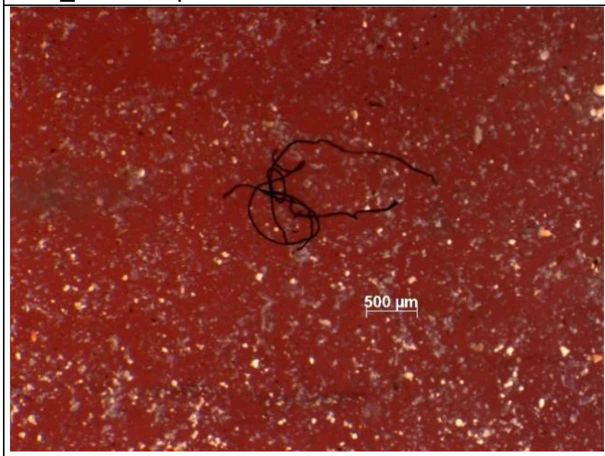
PLE_B27 sample 1 - DK



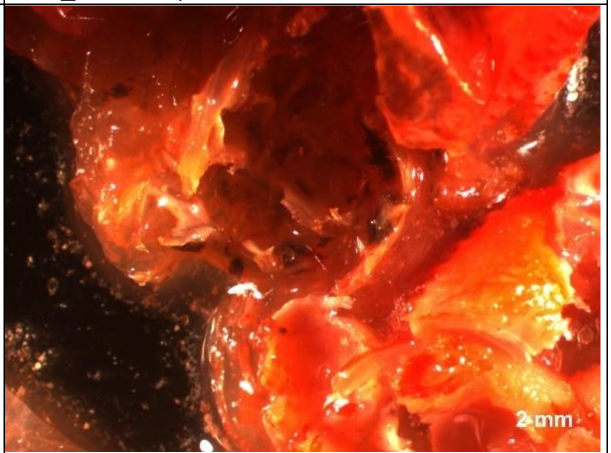
PLE_B27 sample 2 - DK



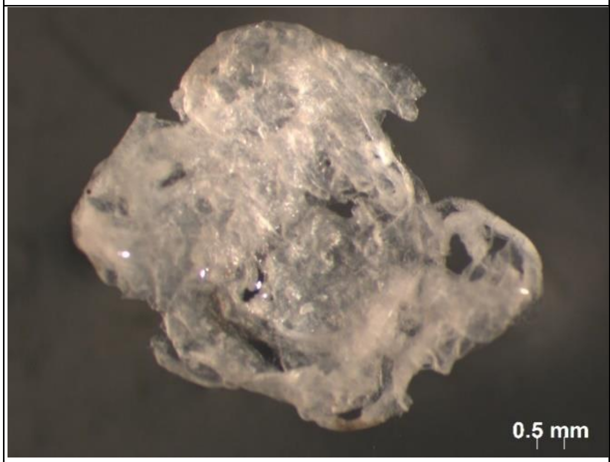
PLE_B27 sample 3 - DK



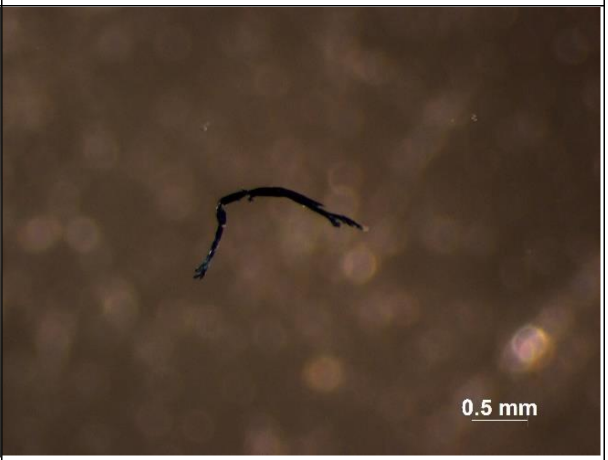
COD027 - DK



COD029 - DK

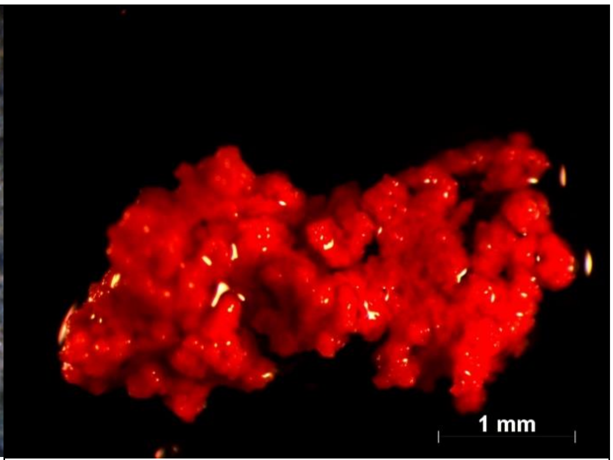


COD026 - UK

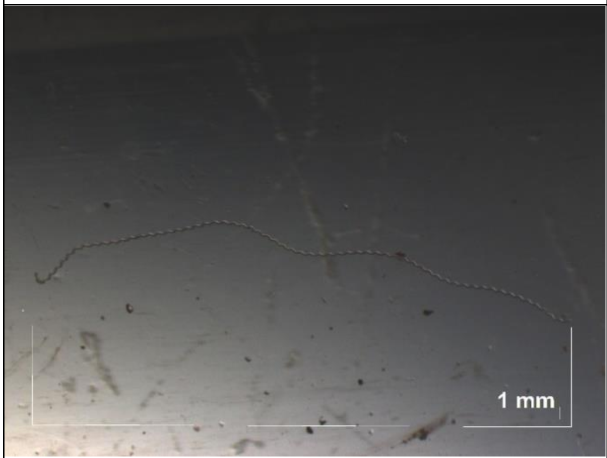


MAC024 - UK

LOB002 - UK



LOB026 - UK



NOP045 - UK