Detection and Analysis of Microplastics in Boat Marina and Eelgrass Bed on the Southern Coast of Norway

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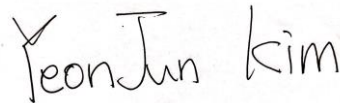
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Abstract

Microplastics are widely distributed around the world and are emerging as one of the most serious environmental problems worldwide. This study aimed to investigate the presence and sources of microplastics by human activities in two different marine environments in the boat marina (Site 1) and the eelgrass bed (Site 3) on the southern coast of Norway. Boat activities in Norway are active due to the long coastline. Boat marinas can be a potential source of microplastic due to the narrow entrance of the marina, which can trap and precipitate microplastics in tidal eddies. Eelgrass, also known as *Zostera marina*, is an extensive seagrass species distributed along the entire coastline of Norway. Eelgrass beds play an important role in marine ecosystems by providing important habitats for marine life, but they have recently become vulnerable to pollution, including microplastics. This study evaluated microplastic accumulation in the sediments of the boat marina and the eelgrass bed by FTIR spectroscopy. The sediment samples were collected from two sites and different types of microplastic polymers were identified. A total of 35 microplastics were found, with 17 microplastics in Site 1 (168.3 MPs/kg dry sediment) and 18 microplastics in Site 3 (1182.6 MPs/kg dry sediment). In addition, the average size of microplastics found on the southern coast of Norway was 1.76 mm. The shapes of microplastics were in the order of fragment, film, fiber, and foam. The study found no clear relationship between local human activities and the distribution of microplastics, highlighting the need for sustained efforts to reduce their presence in both areas. Additionally, the study emphasizes the importance of further research on microplastics in boat marinas and eelgrass beds and the need for predictive technologies and environmental guidelines to manage microplastics in the oceans. Finally, I urge policymakers, stakeholders, and the general public to take action to reduce the production, use, and disposal of single-use plastics, and to promote more sustainable and circular models of production and consumption.

Preface

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Abbreviations and Acronyms

<< ORGANISATIONS AND OTHER TERMS >>

CFR – The Code of Federal Regulations

COVID-19 – Coronavirus disease 2019

DTGS detector – Deuterated Triglycine Sulfate detector

FTIR – Fourier Transform Infrared Spectroscopy

GESAMP – Group of Experts on the Scientific Aspects of Marine Environmental Protection

GESAMP WG 40 – GESAMP Working Group 40

MPs – Microplastics

MSDS – Material Safety Data Sheets

NIVA – The Norwegian Institute for Water Research

OECD – The Organisation for Economic Co-operation and Development

OSPAR – The Convention for the Protection of the Marine Environment of the North-East Atlantic

SEM – Scanning Electron Microscope

UNEP – The United Nations Environment Program

UV – Ultraviolet

<< COMMON POLYMERS >>

ABS – Acrylonitrile Butadiene Styrene

CA – Cellulose Acetate

EVA – Ethylene-vinyl Acetate

PC – Polycarbonate

PE – Polyethylene

PET – Polyethylene Terephthalate

PEVA – Polyethylene Vinyl Acetate

PP – Polypropylene

PS – Polystyrene

PU – Polyurethane

PVA – Polyvinyl Alcohol

PVC – Polyvinyl Chloride

R – Rubber

SR – Silicone Rubber

1. Introduction

1.1 Plastics

Plastics are generally polymer compounds produced by combining monomers extracted from petroleum, and their manufacturing methods, types, and uses are diverse. The most common use of plastics is packaging materials (about 40%), and which are used in various fields such as construction, machinery, and agriculture (PlasticsEurope, 2019). The most common plastic polymers are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyurethanes (PU), polystyrene (PS) and polyethylene terephthalate (PET) based on global demand (PlasticsEurope, 2015). PP (24%), PE (21%), and PVC (19%), which accounted for the majority of the world's plastic production in 2007, were the most produced and used polymers (Andrady, 2011). Plastic, or synthetic resin, has low production costs, is not easily decomposed naturally, and has high plasticity, so its industrial utilization is close to infinity. Because of these characteristics, it has become an irreplaceable necessity for mankind in modern society. Plastic breaks down into small invisible pieces over time due to physical wear, weathering, UV, and temperature changes (Andrady, 2011).

Although plastic production and waste generation are increasing worldwide, the recycling rate is only 9% (OECD, 2022). Due to the COVID-19 lockdown, global plastic use decreased by 2.2% in 2020 compared to the previous year, but the use of plastic is expected to increase again with the economic recovery, especially in the medical sector and e-commerce sectors (OECD, 2022). Plastics account for 80% of marine waste, and marine plastic waste is expected to increase from 9 to 14 million tons in 2016 to 23 to 37 million tons in 2040 (UNEP, 2011). As the production, use, and emissions of plastics increase over time, there is a growing concern about plastic waste that decomposes slowly in the environment due to its non-perishable characteristics.

1.2 Microplastics

Microplastics (MPs) are classified as pieces of plastic fibers and granules between 1 μm − 5 mm (Frias & Nash, 2019; GESAMP, 2015). The need for classification arose as there

was previously no standard size for MPs, leading to discrepancies in comparative research (Carpenter & Smith Jr, 1972; Cole et al., 2011). The shape of MPs can appear in various forms such as spheres, pieces, fibers, etc., and large plastics can decompose into hundreds of small pieces of MPs via various environmental factors (Betts, 2008; Moore, 2008). MPs can consist of various materials such as PE, PP, PS, PVC, and polyvinyl alcohol (PVA). These constituent materials determine the density of MPs, approximately 0.91 to 1.38 g/cm^3 (Hidalgo-Ruz et al., 2012). About 15−31% of 9.5 million tons of plastic waste flowing into the sea every year is classed as MPs (Julien Boucher & Damien Friot, 2017).

MPs can be divided into primary and secondary MPs based on the generation process (Masura et al., 2015). Primary MPs are grains included in toothpaste, detergents, and microbeads used in cosmetics (Lee & Kim, 2018; Masura et al., 2015). Household goods and cosmetics such as facial cleansers, toothpaste, and detergents can contain 5,000 to 95,000 MPs per product (Napper et al., 2015). On the other hand, secondary MPs are formed by weathering or artificial breakage of large plastics (Browne et al., 2011; Masura et al., 2015). They are produced by being finely crushed by bio-degradation, photo-degradation, thermal oxidation, thermal decomposition, hydrolysis, etc. (Andrady, 2011). Of these, photo-degradation is the largest contributing factor and occurs more rapidly on the seashore than in seawater due to the influence of ambient temperature and oxygen concentration (Andrady, 2011)

1.2.1 Research trend on microplastics

The first study on MPs was published in 1972 by Carpenter and Smith Jr (1972) in the study of Plastics on the Sargasso sea surface. Since then, research on MPs has begun to surge resulting in Thompson and his colleagues resuming research on MPs at the Sargasso sea in 2004 (Thompson et al., 2004). Due to the ever-increasing issue of MPs, active research has increased to a great extent (Duis & Coors, 2016; Hale et al., 2020; Waller et al., 2017). The effects of MPs on living organisms in marine and freshwater environments began to be reported in detail in the 2000s. The ecological impact of plastics in the ocean remains unclear due to the diversity and vastness of the ocean and the lack of adequate sampling methods (Hale et al., 2020). Most studies on plastic debris have been conducted on the surface of the

ocean, but now, studies are being actively conducted in various ecological environments such as air, sediments, deep sea, and soils (Hale et al., 2020). MPs have even been found in Antarctica. These may have flowed in from outside the Antarctic Ocean and may have come from the personal care products of people engaged in tourism, legal fishing and scientific research (Waller et al., 2017). As such, since MPs exist in pristine and untouched locales, in-depth research on the detection of MPs should be continued.

1.2.2 Environmental pollution

MP pollution has emerged as a global environmental issue as it has gradually been revealed that plastic fragments are widely distributed throughout the Earth across the coast, remote islands, oceans, and polar regions (Barnes et al., 2009). GESAMP Working Group 40 (GESAMP WG 40), an international organization focused on mitigating plastic pollution has been operating since 2012, and in early 2015, the first report reviewed research trends and major issues of MPs (GESAMP, 2015). This movement of the international community strongly suggests the possibility that marine plastic pollution issues, including MPs, will lead to international preventative measures in future.

MPs are widely distributed around the world (Cole et al., 2013) and are emerging as one of the most serious environmental problems worldwide (Dunlap & Scarce, 1991). Plastic waste is a major threat to marine ecosystems along with climate change and reckless overfishing. The amount of plastic discharged into the ocean over the past few decades is also expected to increase with an increase in production, with a very high proportion of plastic in marine waste at 60−80% (Derraik, 2002).

As a result, many governments and institutions are warning that marine pollution caused by plastic poses a worldwide threat (GESAMP, 2016). Plastic is produced on land and after disposal (Hale et al., 2020), it flows into the sea in various ways and is exposed to the environment as marine sediment. In particular, the need for research on how plastic flows into the ocean, how it interacts with coastal and ocean movements, where it is intensively accumulated and how it is distributed, is being actively researched (Browne et al., 2011; Petroody et al., 2021).

1.3 Microplastics in boat marinas

Boating activity is active in Norway because of its long coastline. Boats are used not only as a means of transportation, but also for various purposes such as fishing, leisure activities, and sports. As the number of people using boats increased, the number of marinas also increased. Marinas are usually located close to the land with a calm water flow (Floerl & Inglis, 2003). However, boating activities can serve as potential sources of MPs in marine and riverine environments and may result in high levels of pollution pressure (Prata et al., 2021). Micro-sized pieces of acrylic polymer were present near the boat docks in the Douro estuary as well as in the sea docks (Prata et al., 2021). Researches into the cause of MPs found near boat marinas are still ongoing, and this paper aims to investigate whether MPs in boat marinas are associated with human activities.

1.4 Eelgrasses (*Zostera marina*)

Seagrasses serve multiple roles in the ocean, providing habitat, shelter, and nurseries, spawning, and foraging sites for marine animal communities (Bertelli & Unsworth, 2014; OSPAR, 2009). Underwater meadows created by seagrasses have a significant impact on food security, climate change mitigation, and biodiversity support worldwide (Unsworth et al., 2019).

The most extensive seagrass species in the Northern Hemisphere, including the North Atlantic and North Pacific Oceans, is *Zostera marina* (common name 'eelgrass')
, which is distributed along the entire coastline of Norway (Boström et al., 2003). Eelgrass beds provide important habitat and food resources for a diverse range of fish species, including those of commercial and recreational importance (Adams, 1976). Eelgrass beds are proposed to play a crucial role in the trophic function and overall productivity of different coastal areas with shallow water (Adams, 1976; Phillips, 1969). They also serve as a refuge for young fish and provide shelter from predators (Adams, 1976).

Howerver, the existence of MPs in seagrass beds has the potential to enter the bodies of herbivorous organisms, particularly those that consume seagrass leaves and organisms that feed on epiphytes present on the surface of seagrass leaves (Datu et al., 2019). Moreover,

MPs can adhere to the surface of seagrass blades, which can interfere with life activities such as photosynthesis and respiration (Gerstenbacher et al., 2022).

Seagrass populations have been declining worldwide, mainly due to high anthropogenic pressures such as reclamation and dredging (Short et al., 2011; Yang & Yang, 2009). Furthermore, seagrasses are threatened by causes such as global warming, ocean acidification, sea-level rise, and CO_2 (Orth et al., 2006), which reduce their growth, as well as human activities such as illegal harvesting and water pollution, which destroy their habitats. Therefore, the conservation and restoration of this plant is an essential issue for preserving marine ecosystem environments.

1.5 Aims of this study

According to previous studies, MPs are widely distributed in marine environments and can have various effects such as mortality and growth inhibition, and decreased fertility. While research on the impacts of MPs on single species has been conducted to a considerable extent, research on MPs present in both eelgrass beds and boat marinas has to date been insufficient. In addition, despite many recently reported studies, knowledge about the size distribution and composition of accumulated MPs in aquatic ecosystems is still significantly lacking. Since the marine environment is closely related to human activities, additional studies should be conducted on the effects of MPs on the overall marine ecosystem. The main of the study is to investigate the amount and type of MPs in sediments taken from an eelgrass bed in a marina and a more pristine eelgrass bed, serving as a reference location. Based on the results, I consider whether this finding is associated with anthropogenic activities. Eelgrass beds are greatly affected by ocean currents and have less human activity, while boat marinas are relatively less affected by ocean currents and have more human activity. Due to these geographical and environmental differences, I hypothesize that more MPs are found in the boat marina than in eelgrass beds. This study will also provide a better understanding of marine sediment investigations and will contribute to future research on MP detection, especially in the eelgrass beds and boat marinas.

2. Methods and Materials

I investigated MPs in the sea of Grimstad, which has abundant seagrass resources (mainly eelgrass). *Zostera marina* is most commonly distributed in Norway and is found along the entire Norwegian coast (Boström et al., 2003). However, due to the impact of human activities, seagrass beds are currently exposed to threats such as the fisheries industry, coastal construction, eutrophication and sediment load, and the global seagrass beds area is rapidly decreasing (Short et al., 2011).

2.1 Study area

Grimstad is a coastal municipality in Agder county bordering Skagerrak, located in the Southern part of Norway (Fig. 1). Grimstad is an active area with many visitors during summer and autumn in good weather. The area has coastal waterways of various sizes, productive fjords, camping areas and boat marinas. The town is also a popular destination for summer vacationers. Grimstad has municipal marinas at Saulebukt and Centrum for small boats (Grimstad kommune, 2022). The municipality has several shipping companies as well as active marine fishing boats and maritime-related companies (Business Region Kristiansand, 2022). For this reason, marinas and eelgrass beds in Grimstad, where human activities are common and samples can be easily obtained, were selected as the sampling sites.
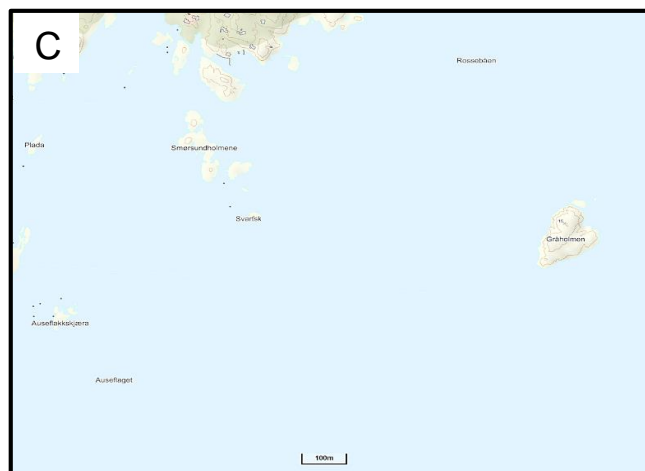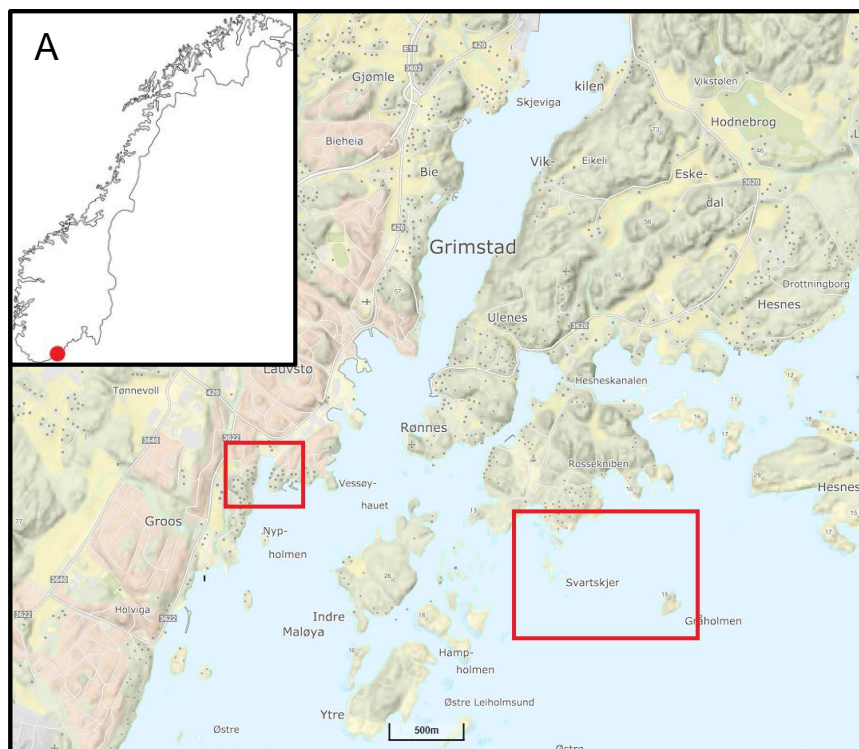
Figure 1. Maps of the sampling sites. *The maps are obtained from https://www.norgeskart.no.*
A) Grimstad, South of Norway. **B)** Site 1, boat marina (Grømbukta). **C)** Site 3, eelgrass bed about 2 km from Grimstad.

2.2 Sample collection

Two different sites were established around Grimstad (Table 1). Sediments were sampled at each of the two locations on September 16, 2021.

Table 1. Details on the sampling sites.

Sampling location	Geographical location	Station number	Latitude (N)	Longitude (E)	Depth (m)	Sediment color
Boat marina	Grimstad (Grømbukta)	1	N58.33319°	E008.58595°	1.7	2.5Y, 2.5/1 (Black)
Eelgrass bed	Sea of Grimstad	3	N58.33955°	E008.63011°	1.6	2.5Y, 3/1 (Very Dark Gray)

Site 1 was the innermost of the boat marina located in Grømbukta (Fig. 2A). There were about 50 boats moored at the boat marina. Site 3 was a typical eelgrass bed far from the boat marina about 30 minutes by boat from Site 1 (Fig. 2B). Numerous eelgrass beds could be seen on the boat from the sea to Site 3. The latitude and longitude of the sampling locations can be found in Table 1 and the depth of the two sites was about 1.6 m to 1.7 m. The sediment colors were determined with a Munsell soil color chart (Fig. 2C). Munsell soil color chart provides a way to evaluate and classify sediment color. The soil color of Site 1 was black and the soil color of Site 3 was very dark gray.

- e.g. At Site 3, **2.5Y** is the Hue (R(red)/Y(yellow)), 3 is the Value (lightness/darkness) and 1 is the Chroma (weak/strong).
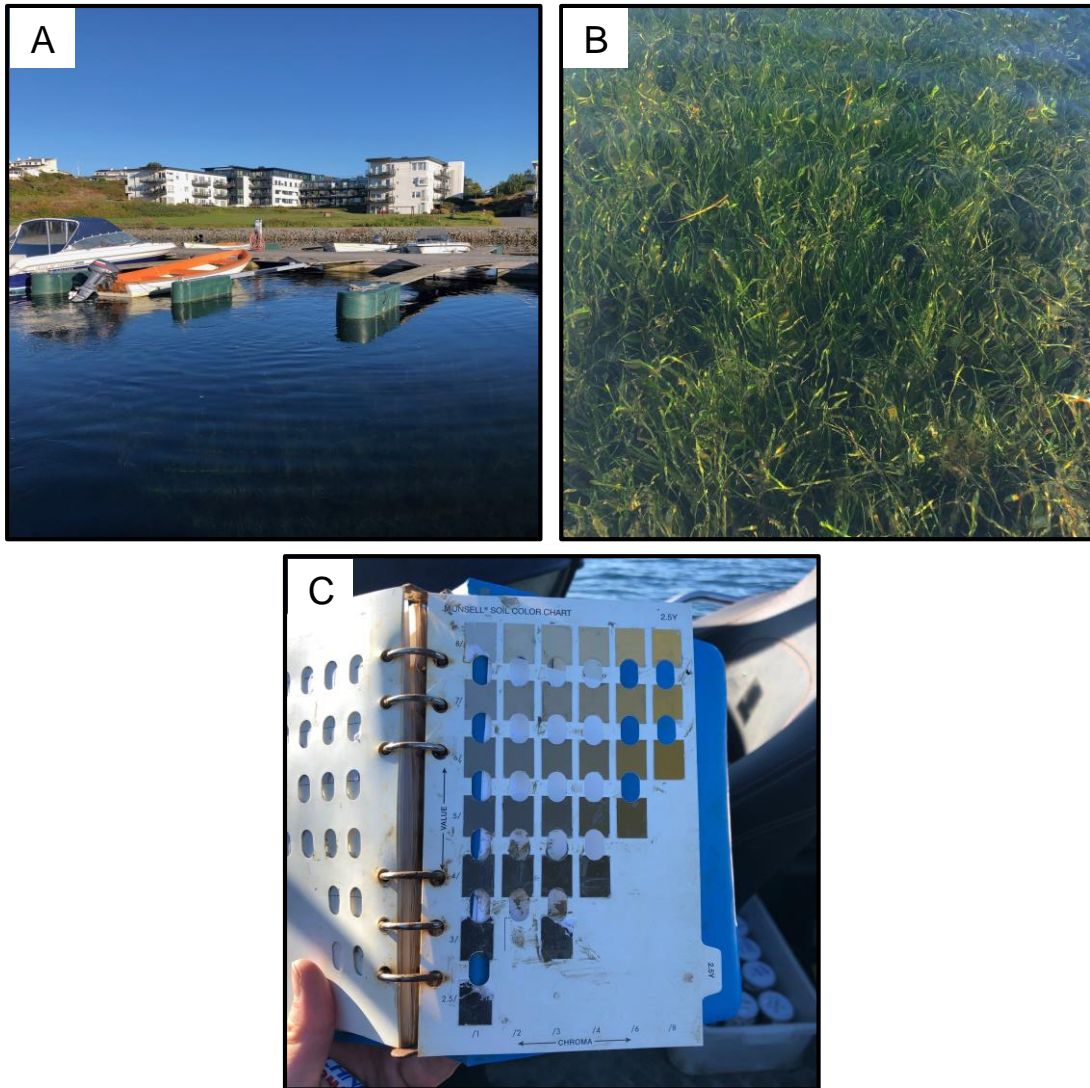
Figure 2. A) A boat marina in Grømbukta. **B)** An eelgrass bed in the sea of Grimstad. **C)** Munsell soil color chart for checking sediment colors.

The weather was sunny with no clouds, the temperature was 13.5 ℃, the wind speed was 3.5 m/s, and the precipitation was 0.0 mm. A small boat and necessary items were provided by the Norwegian Institute for Water Research (Norsk Institutt for Vannforskning / NIVA) for the sampling. After selecting an appropriate location to sample by boat, a drop camera was used to examine whether it was an appropriate location to grab and the condition of the sediments and eelgrasses. There are several methods of collecting sediment samples in water, and the Van Veen grab sampler was used in this experiment (Fig. 3A). Three grabs were attempted for each site, and sampling was performed under the same conditions. The grab had to be dropped straight from the middle depth of the water, otherwise the grab would not be deeply embedded in the eelgrass beds so the sediments could not be fully obtained. After a

few seconds, the grab was taken out and placed it in a large plastic box and opened the blank jar at the same time (Fig. 3B). The plastic and garbage in the water could be seen with the naked eye and the sediment produced an odour of hydrogen sulfide. Labeling was performed to distinguish jars. To correct for potential atmospheric MP contamination (e.g. synthetic fibers that are in the air), atmospheric blank jars were filled with particle-free water. These atmospheric blanks had to be left open for the same period that the sample was exposed to air. All samples were handled and closed as soon as possible to avoid unnecessary exposure to air.
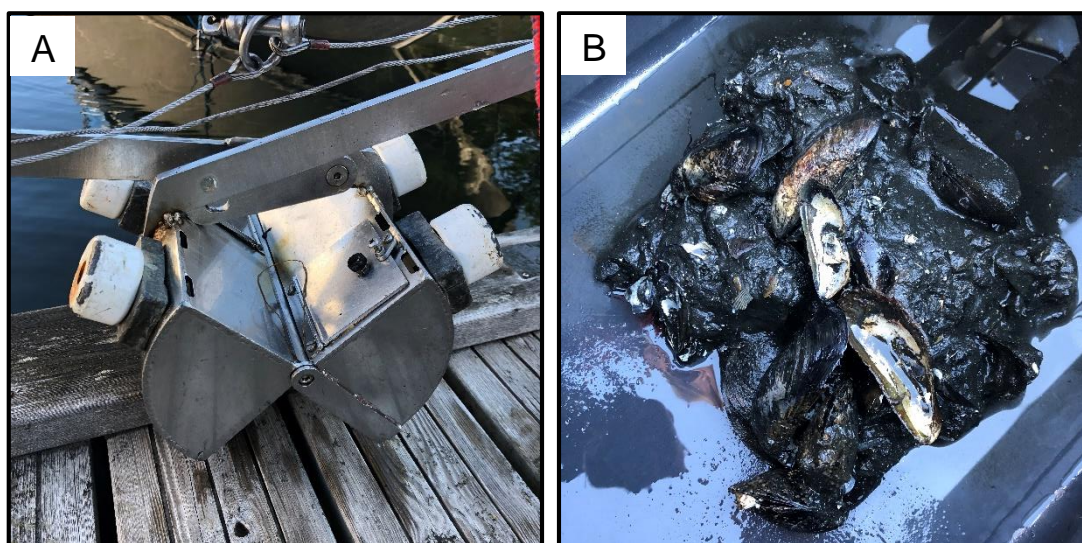
Figure 3. A) Opened Van Veen grab sampler. **B)** Samples taken from Site 1.

The lid of the grab was opened and the colors of the top sediments were compared to the Munsell color chart (Fig. 2C). Then, the grab was fully opened, the sediment was carefully poured into the box, and only the upper 2 cm was collected intact with a metal spoon. I filled the jar with abundant of samples, added 1 dl of filtered water to the blank jar, and closed each lid. The remaining sediment was collected in an additional jar for analyses of supporting parameters. I repeated this process three times of grab at the two sites. To prevent the contents from leaking out and contaminating the plastic lining of the lids, foil was used to cover the jar opening before the lid was tightly closed. Samples were refrigerated until laboratory work.

2.3 Microplastic extraction in the laboratory

Precautions taken to avoid contamination and to minimize errors were carried out during analysis and extraction. Equipment in glass or metal was used whenever possible. I wore a cotton lab coat, and wore organic cotton clothes instead of synthetic clothes. Double-destilled water, filtered through 1.0 μm glass microfiber filters, was used to rinse the lab equipment thoroughly before and after processing. All experiment was done in the fume hood to reduce contamination of the working environment. The protocol was simplified as a diagram (Fig. 4).
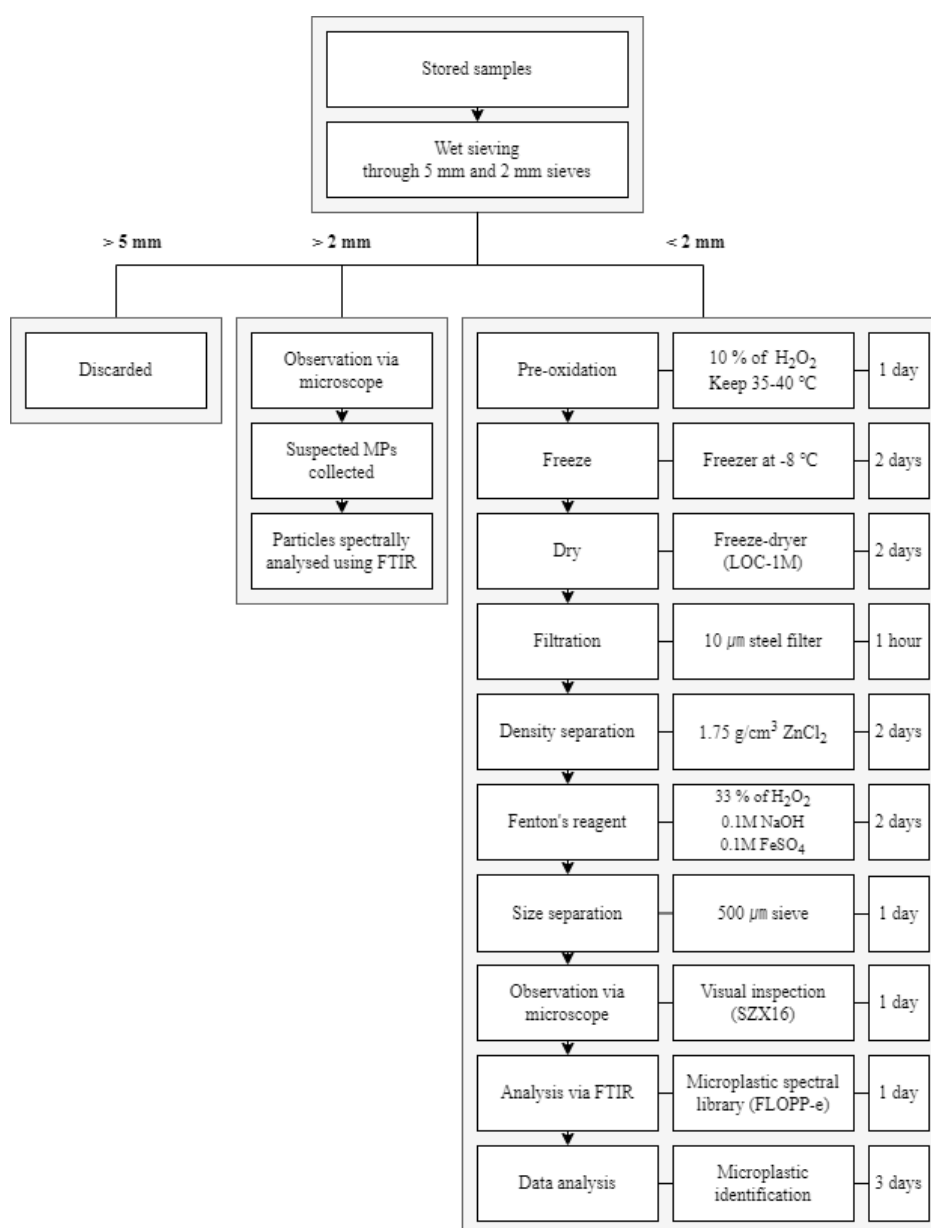
Figure 4. Protocol for the extraction of microplastics.

2.3.1 Wet sieving

The samples were wet sieved through 5 mm and 2 mm sieves, using particle-free water to rinse. Anything over 5 mm was discarded. Seaweeds, eelgrasses, shell fragments, and small twigs were found in the fraction 2−5 mm, were rinsed with a syringe, collected with a tweezer, and transferred to a glass bottle. The collected contents in the bottle were later investigated under a microscope. The contents of 2 mm or less contained in the crystallizer were separated into the water phase and the sediment phase after the sediment had settled. The water phase was transferred to a large beaker, where again, it was left to settle. The water phase from this settlement was filtered through a 10 μm stainless steel filter and the remaining settled sediment was scraped off and added to the sediment phase. After stirring the sediment phase evenly with a glass rod, it was transferred to another large beaker (5 L), and the pre-oxidation step was prepared.

2.3.2 Pre-oxdiation

This step was employed to oxidize the sediment phase. First, I calculated how much 33 % H_2O_2 can be added to the sample and water mixture to reach 10 %. Then, the beaker containing the sediment phase was transferred to the water bath. The temperature was kept between 35−40°C to increase the reaction, yet avoid it from turning violent. The oxidation reaction was observed while adding 10−20 ml of H_2O_2 at a time. When a large amount of peroxide (H_2O_2) is added, the reaction can become volatile and the contents can overflow the beaker. 20 ml H_2O_2 was added as the initial amount and stirred for 10 minutes using a glass rod. From there on, H_2O_2 (10−20 ml) was added every hour and stirred manually for 2 minutes. This process was repeated until no bubbles were formed. After all peroxide had been added, the beakers were left at room temperature until no more bubbling was observed. When the sediments were no longer bubbling and stabilizing, the water phase from this beaker was transferred to an empty beaker. This water phase was used again in the next "Filtration" step. The remaining sediment phase was transferred to a 1 L crystallizer. If a large amount of settled sediment was visually observed in the contents, the water phase was moved to another beaker as much as possible, and the sediment phase was poured into the 1 L crystallizer.

2.3.3 Freeze and dry

The crystallizer was completely frozen for two days. The sample was freeze-dried for about three days in a freeze-dryer (Fig. 5) and the model name was *LOC-1M* (Martin Christ, Osterode, Germany). I periodically checked whether the vacuum mbar of the equipment was between 0.1 and 1.

Figure 5. Freeze-dryer (*LOC-1M*) with a sample inside.

2.3.4 Filtration

I filtered the water phase obtained in the "Pre-oxidation" step. Steel filter (size 10 μm, Filtertek DK, Hørsholm, Denmark) was used as the filter. From a filter sheet, I manually cut out 47 mm diameter filter discs. After filtration, the steel filter with its contents was turned upside down in another beaker, added a small amount of $ZnCl_2$ until the filter was covered, and sonicated for 5 minutes. After holding the steel filter with forceps, the contents remaining in the filter were scraped using a metal spatula, and rinsed using a glass syringe containing $ZnCl_2$. This filter was stored in a small petri dish for future use. In this study, only substances suspected of being MPs filtered through the sieve were identified.

2.3.5 Density separation

1.75 g/cm^3 ZnCl$_2$ was used as the high-density separation liquid. Any higher density will make the solution so viscous that sediments have a hard time settling. When it was confirmed that the sample placed on the freeze-dryer was completely dried, the dried sample was crushed into small pieces with a glass rod and a pestle (Fig. 6). I put the sample in a new beaker and weighed it. In a large beaker with 500 ml of ZnCl$_2$, crushed sediments, and the filtrate from the water phase were added and stirred for 10 minutes with a rod (Fig. 7A). The contents remaining in the beaker were thoroughly rinsed out with 200 ml of ZnCl$_2$ into a separation funnel (Fig. 7A). I left it to settle overnight. The beaker was covered with foil to prevent contamination.
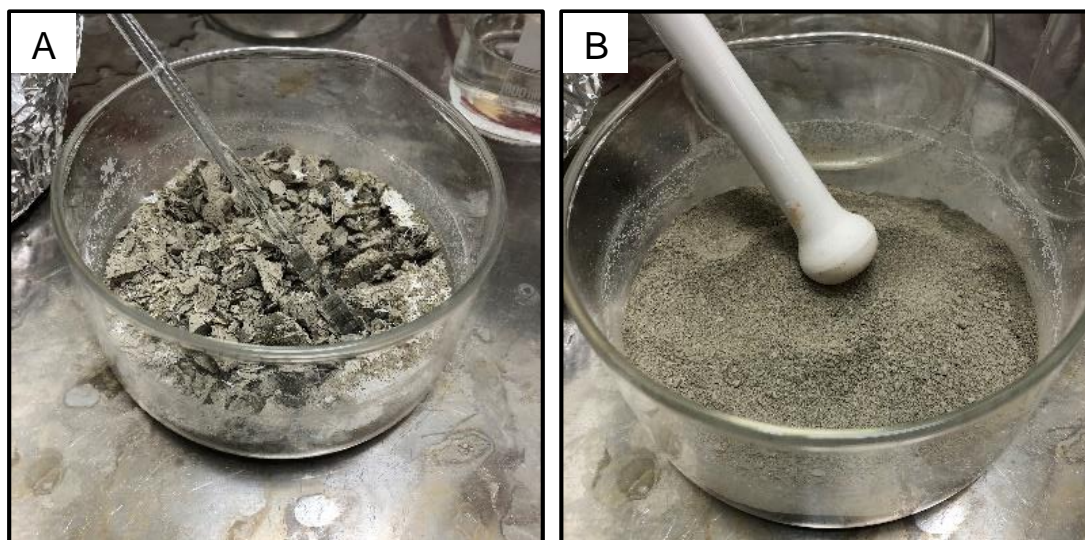
Figure 6. Finely ground samples.

The next day, the contents had separated by weight, and the sediment had settled to the bottom of the funnel (Fig. 7B). I carefully opened the stopcock and used a wire to eject the sediments. When the stopper was opened and transparent ZnCl$_2$ came out, the stopper was immediately closed and sediments resettled. The above process was repeated until about 5−10 cm of the sediments remained. I re-disturbed the sediments to ensure they were well mixed. Refilled with ZnCl$_2$ up to the widest part of the funnel and left it overnight to settle. I ejected the remaining sediment material whilst the top part including floating material was collected for further processing. The funnel was rinsed with ZnCl$_2$, and combined with the collected sample, was filtered onto a used steel filter. The steel filter was turned upside down, placed in a new beaker, and sonicated for 5 minutes to drop the contents attached to the steel

filter. The contents remaining on the filter were scraped off with a metal spatula. Filtered water was added into the beaker containing the sample until it became 100 ml.
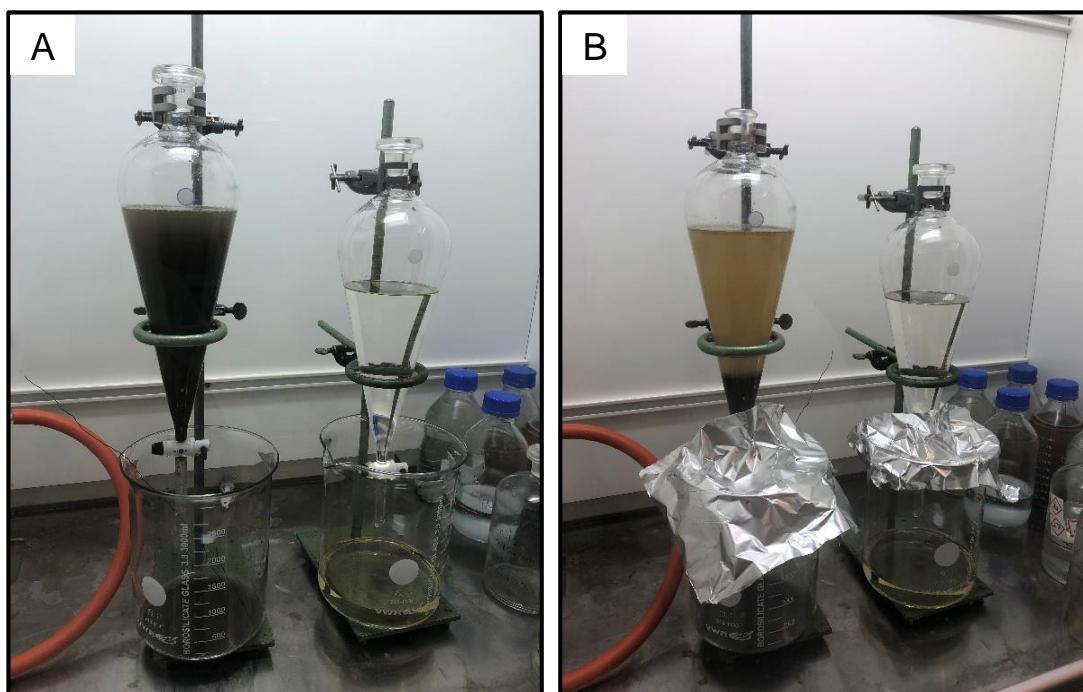
Figure 7. A) A mixture of $ZnCl_2$ and sediments. The color of the contents was almost black. **B)** The day after the contents were divided into two phases. The left funnels are for the sites, and the right funnels are for the blanks.

2.3.6 Fenton's reagent

In this step, the procedure was performed from the top to the bottom of Table 2, and the pH and temperature changes were monitored while adding the specified reagents. I measured the amount of solution using a cylinder (33% of H_2O_2 109.8 ml, 32.5 ml of 0.1M NaOH, 31 ml of 0.1M $FeSO_4$). The sample was placed in an ice bath before reagents were added to the sample beaker in the following order: NaOH, H_2O_2, $FeSO_4$. First, when NaOH was added to the sample, the pH rapidly increased to more than 10, and then the pH dropped to more than 2 by adding H_2O_2 and $FeSO_4$ in that order. A little later, the pH of the sample was maintained below 2 by adding H_2SO_4 with a dropper. The reagent was monitored to ensure pH remained <2, and the temperature stayed between 15−30°C. If below or above this pH, a precipitate can form, and the temperature >30°C can cause a violent reaction and damage the sample. I observed closely for 1 hour and regularly monitored for 4 hours.

Table 2. Changes in pH and temperature after adding reagents to each sample.

	Site 1	Blank 1	Site 3	Blank 3
Sample (H_2O)	pH 5.83	pH 6.63	pH 6.4	pH 5.47
NaOH	pH 11.27	pH 12.72	pH 12.44	pH 11.89
H_2O_2	pH 7.68	pH 8.12	pH 7.85	pH 7.51
$FeSO_4$	pH 2.82	pH 2.63	pH 2.52	pH 2.29
H_2SO_4	100 drops	15 drops	17 drops	18 drops
4 hours later	pH 2.09 / 6 °C	pH 1.97 / 11 °C	pH 1.89 / 18 °C	pH 1.95 / 17 °C
12 hours later	pH 1.95 / 21 °C	pH 2.12 / 19 °C	pH 1.99 / 18 °C	pH 2.03 / 10.5 °C

2.3.7 Size separation

The next day, when the sample was stable, the contents were poured through a 500 μm sieve. Anything over 500 μm was transferred to a petri dish with a tweezer. Particles suspected of being MPs were analyzed by "Microscope" and "FTIR" steps. The portion of the sample smaller than 500 μm was filtered through a 10 μm filter. The particles attached to the steel filter were observed under a microscope.

2.3.8 Microscope

Stereomicroscopy is a widely used method of identify MPs in the hundreds of microns in size (GESAMP, 2019). Microscope *OLYMPUS SZX16* (Olympus Corporation, Shinjuku, Japan) with a resolution of 900 line pair/mm was used (Fig. 8) so I could get more accurate information from the sample. Digital pictures of the samples under the microscope were taken. Samples suspected of being MPs were then analyzed by FTIR.

Figure 8. Microscope (*OLYMPUS SZX16*) with attached camera and analyze software.

2.3.9 Fourier-Transform Infrared Spectroscopy (FTIR)

The most common methods in the chemical characterization of MP particles are spectroscopy (e.g. FTIR, scanning electron microscopy (SEM) and Raman (GESAMP, 2019). Of these, I confirmed the chemical composition, size, shape and origin with FTIR spectroscopy. FTIR is a very powerful and reliable technique for confident identification of unknown samples. This method is suitable for sophisticated analysis to determine whether the particles previously observed under a microscope are actual MPs. FTIR spectrometer *PerkinElmer Spectrum*
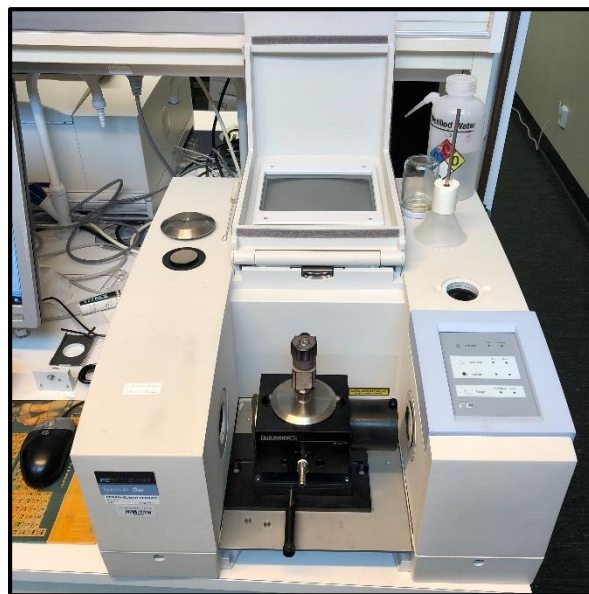
Figure 9. FTIR spectrometer (*PerkinElmer Spectrum One*).

One (PerkinElmer, Waltham, MA, USA) was used (Fig. 9). The IR spectra of every isolated particle, placed onto a crystal, were recorded in a wavenumber range of 4000–400 cm^{-1} and 32 scans were co-added for every spectrum. This instrument was used to interface with PerkinElmer Spectrum software to extract both qualitative and quantitative data from the spectra. I downloaded FLOPP-e (Rochman Lab, Toronto, Canada), the microplastic spectrum library. FTIR library of plastic particles sourced from the environment (FLOPP-e), containing 195 spectra across 15 polymer types. This library includes particles from a variety of sources, morphologies, and colors. After loading an individual piece of suspected plastic onto the IR stage, it was analyzed by the Deuterated Triglycine Sulfate detector (DTGS detector), I compared the spectral match results with the two MP data sets.

2.3.10 Data analysis

After loading an individual piece of suspected plastic, the deuterated triglycine sulfate (DTGS) detector collected its spectra, which were automatically compared to reference the spectrum library (FLOPP-e), resulting in a percentage match (Fig. 10). A score between 0 and 1 indicates the goodness of fit. If the correlation was 0.7 or higher, it was identified as

MPs. Match score below 0.7 was rejected and specified as unknown. The above process was repeated for all suspected plastic particles.
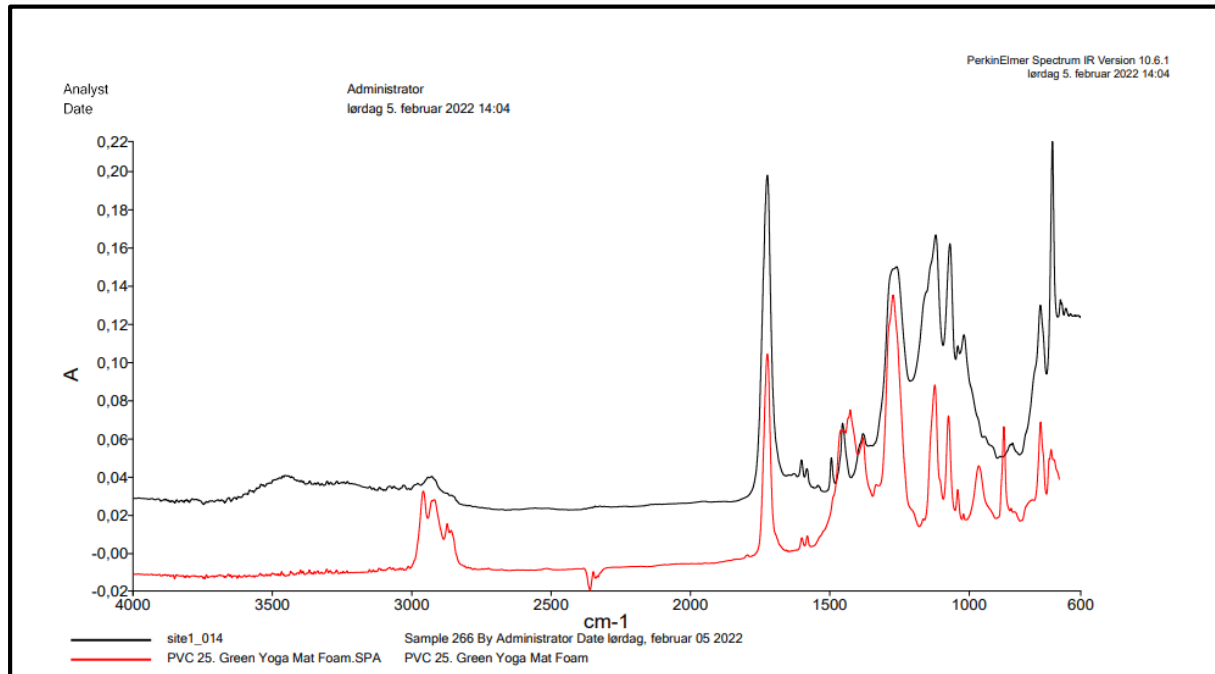
Figure 10. FTIR spectra of analyzed polyvinyl chloride (PVC) (red line) and reference FTIR spectra of PVC-polymer from the library (black line) (match score of 0.786662).

3. Results

In the case of MPs among the particles filtered by a steel filter, FTIR (Fourier Transform Infrared Spectroscopy) was used to determine the quality of all visible foreign substances individually. In the case of suspected plastic, the qualitative determination was performed by determining the priority plastic with a high matching rate against the spectrum library (FLOPP-e).

3.1 Filter

Particles of various colors are visible on the filter of Site 1, and the filter is densely covered with particles (Fig. 11A). On the other hand, on the Site 3 filter, fine sand, seashells, and sediments, were observed (Fig. 11C). In air, different kinds of fibers can be found. On the filters of Blank 1 and Blank 3, elongated, transparent substances were present (Fig 11B, 11D). Transparent substances appear to be vegetal fibers, whereas blue and orange materials are more likely to be animal or synthetic fibers (Fig 11B, 11D). Due to time constraints on the use of FTIR, it was not possible to accurately determine the composition of all materials I found.
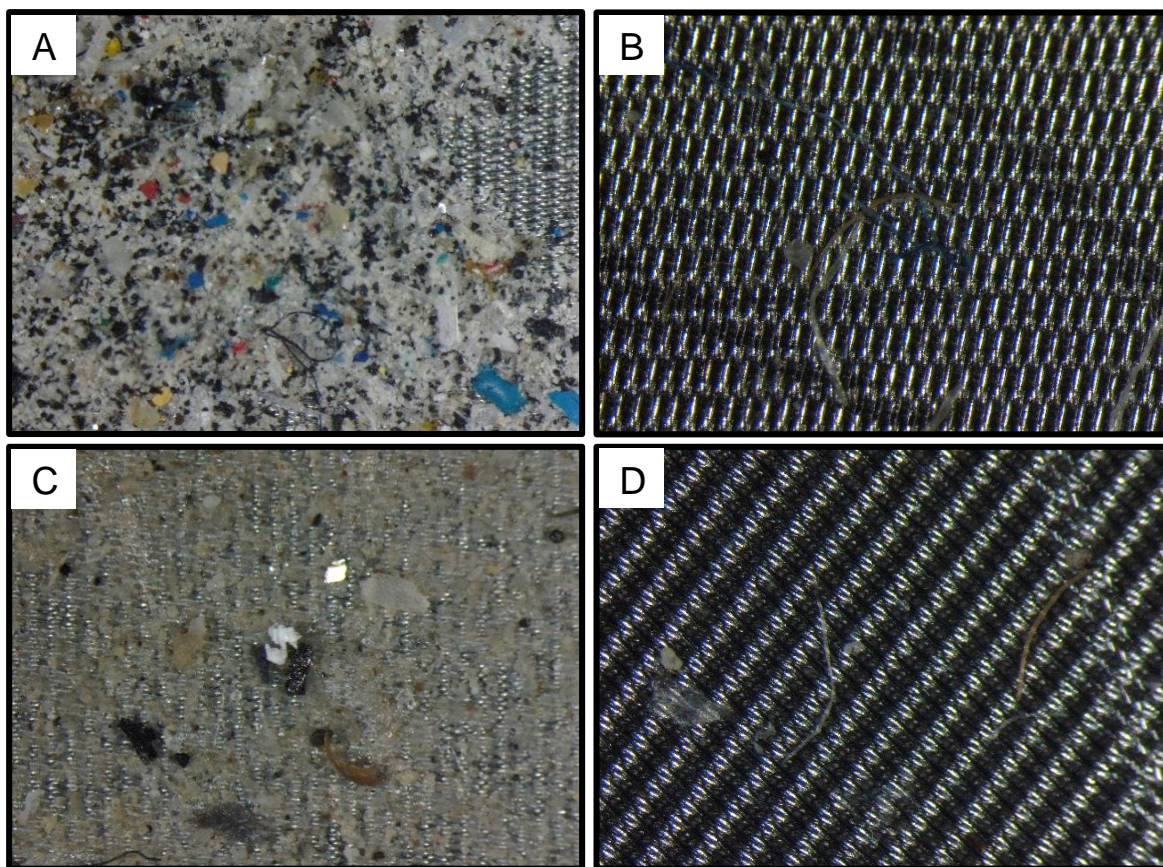
Figure 11. Microscope images of particles filtered through the steel filter. **A)** Site 1 filter (2.5x). **B)** Blank 1 filter (5x). **C)** Site 3 filter (2.5x). **D)** Blank 3 filter (5x).

3.2 Atmospheric blanks

No particles was found in Blank 1, 2 particles in Blank 3 >500 μm, and 3 particles in Blank 3 2−5 mm (Fig. 12). The three transparent particles found in Blank 3 2−5 mm were relatively large and had red dots, suggesting they were animal or vegetal fibers among natural fibers (Fig. 12C, 12D, 12E). The particles found in the blanks were not included in the results because the correlation of particles in the Blanks was below 0.7. So they were presumed to be natural fibers or unknown particles, not plastics.
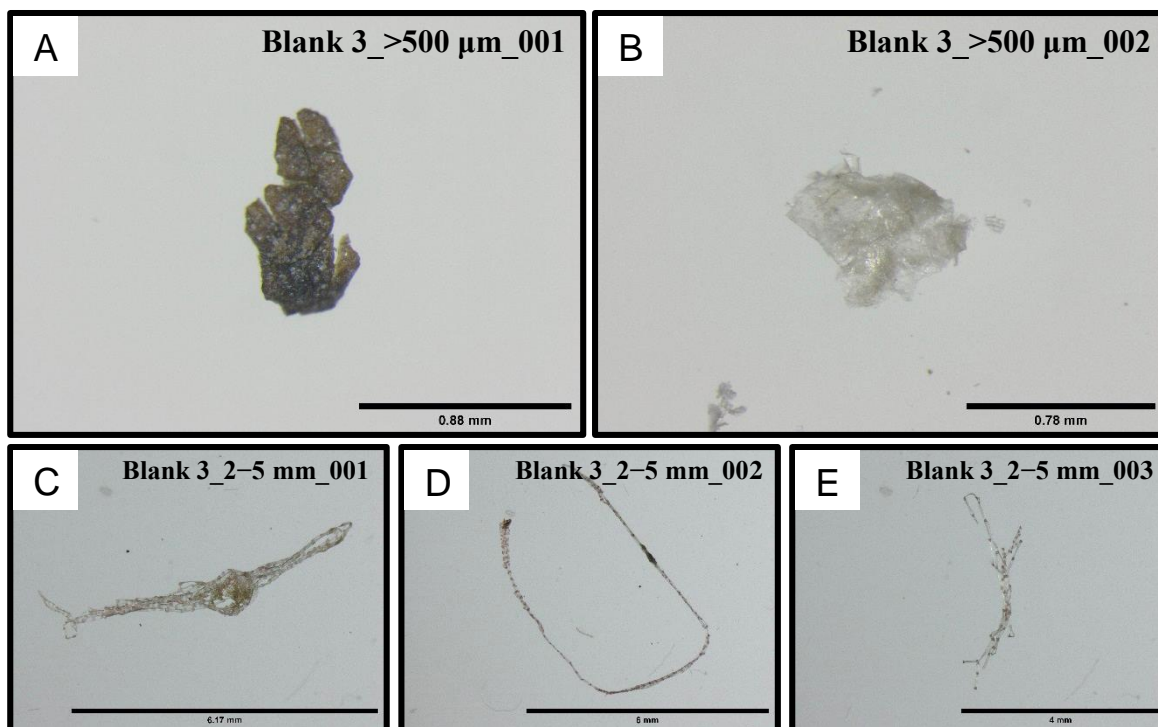
Figure 12. All Particles found in Blank 3.

3.3 FTIR

Representative polymer types are represented by IR spectrum (Fig. 13). Polymer types are determined according to the position and shape of the peak. In general, good or bad crystallinity can be from the width of the peak. The spectra of all the MP particles detected in the samples with reference spectra of particles are indicated in black and the sample spectra in red. Each compound has a somewhat characteristic IR spectrum, and if the IR spectrum measured from an unknown sample matches one of the known spectra, it is highly probable that these are the same material. Therefore, if the correlation was higher than 0.7, it was considered as MPs, and all samples with a lower correlation were excluded from the results.

A — Site 1_>500 μm_059 — Type: PC, Correlation: 0.95239 — 1.97 mm
B — Site 1_>500 μm_046 — Type: PE, Correlation: 0.754841 — 1.15 mm
C — Site 1_>500 μm_014 — Type: PVC, Correlation: 0.786662 — 2.5 mm
D — Site 1_>500 μm_027 — Type: PP, Correlation: 0.813062 — 1.6 mm
E — Site 1_>500 μm_031 — Type: PS, Correlation: 0.709721 — 2.05 mm
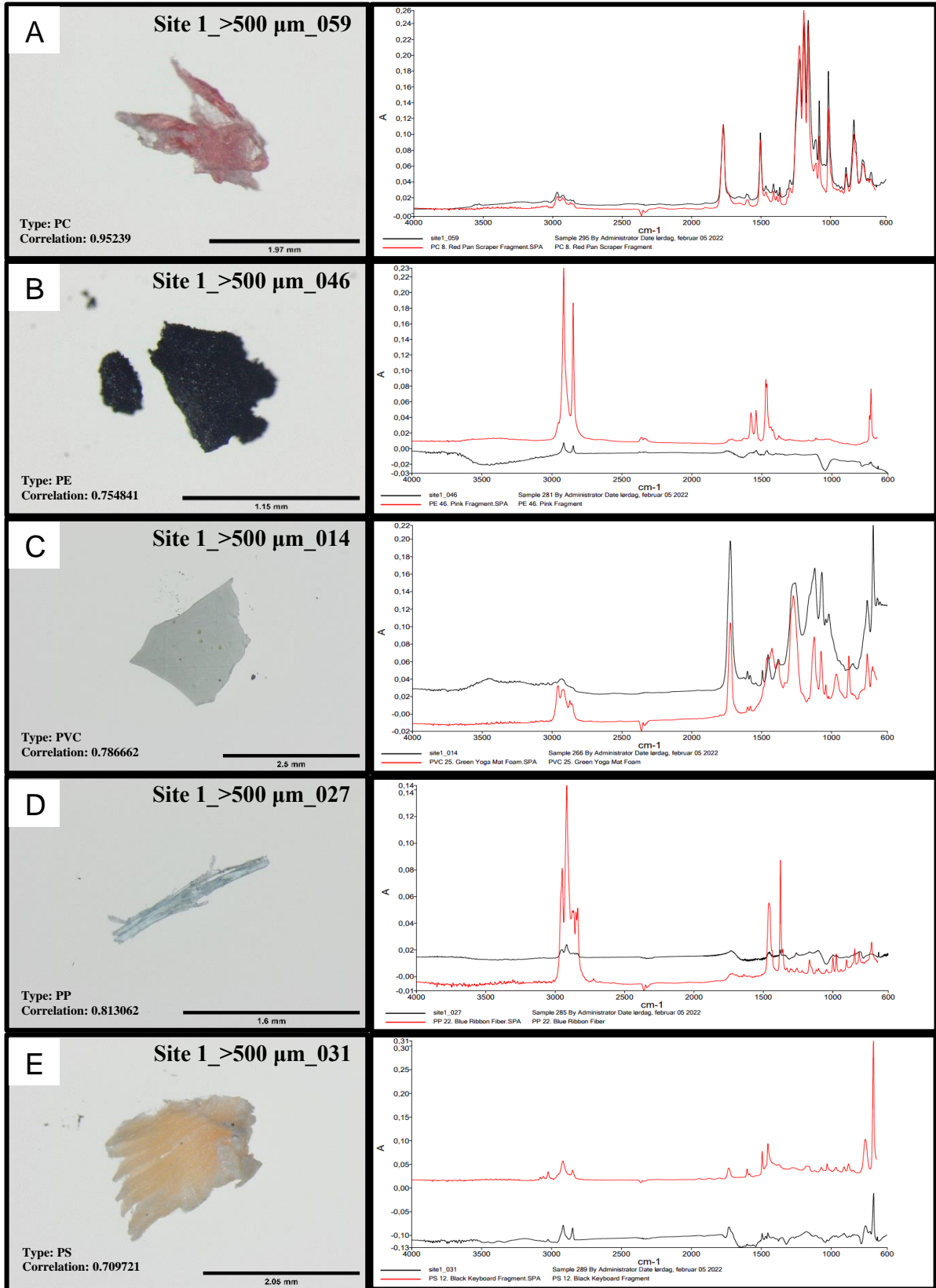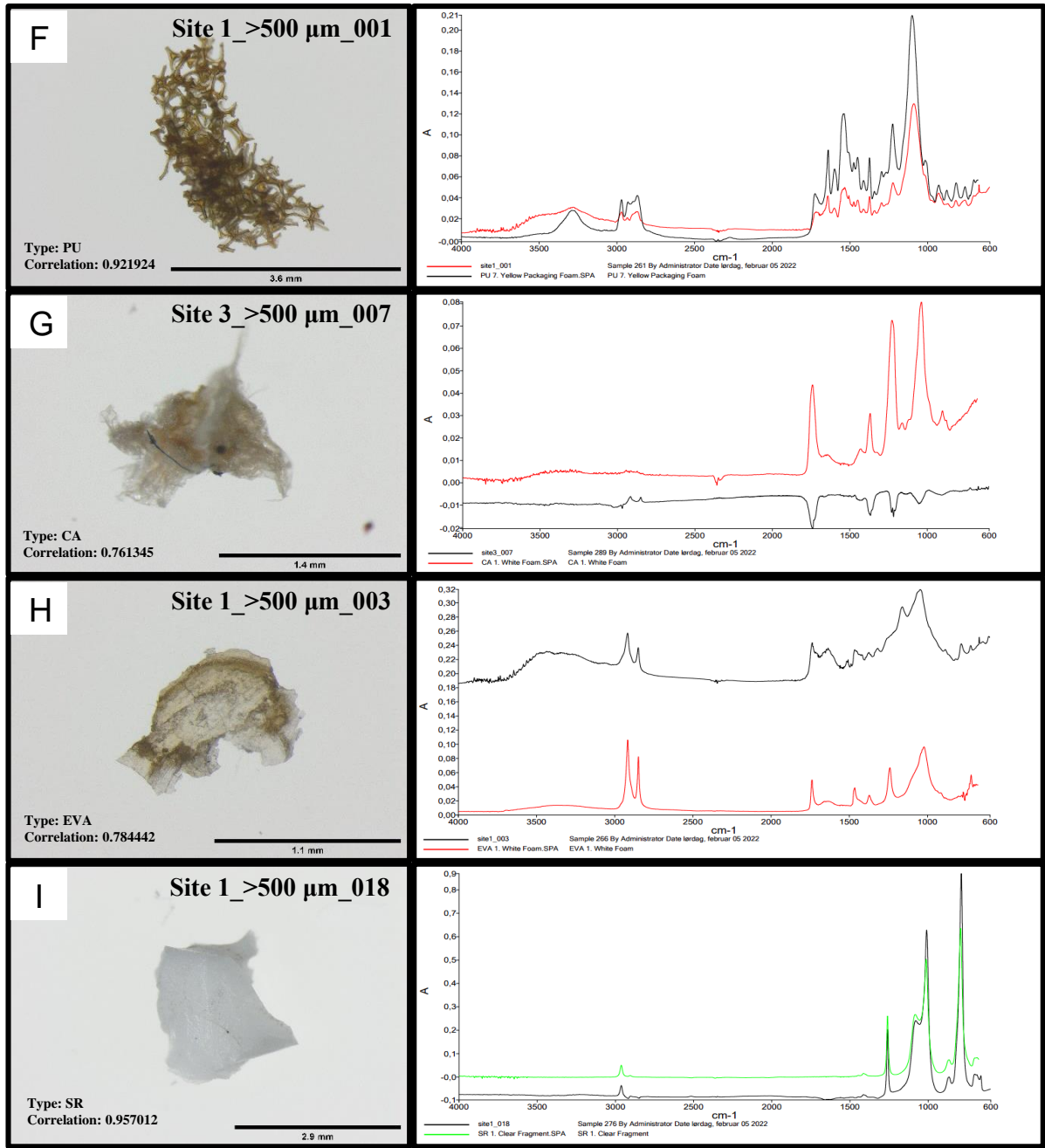
Figure 13. IR spectrum expressed as absorbance with particle images. A on the y-axis is absorbance, and the x-axis is wavenumber and its unit (cm^{-1}). **A)** PC. **B)** PE. **C)** PVC. **D)** PP. **E)** PS. **F)** PU. **G)** CA. **H)** EVA. **I)** SR**.**

3.4 Site 1 MPs >500 μm

Among the samples collected at Site 1, 78 particles over 500 μm were analyzed, and among them, 17 particles showed more than 70% concordance with the spectrum library (Table 3A). These 17 particles confirmed as MPs in our samples belonged to several groups (Fig. 11). PP was found the most with 4 (24%), and PC, PE, and SR were found the least with 1 (6%) each in Grømbukta. The sample with the highest correlation rate (96%) was No.018 (Table 3B). The particles identified as MPs ranged from 0.9 to 3.95 mm, and the smallest particle was No.028 (PS) and the largest particle was No.022 (PVC) (Table 3A). The average length of the MPs found was 1.74 mm at Site 1 >500 μm.

Table 3A. Information on microplastics collected from Site 1 >500 μm.

Location	Size (μm)	Sample ID (No.)	Length (mm)	Spectral match	Correlation
Site 1	>500	001	3.6	PU	0.92
Site 1	>500	003	1.1	EVA	0.78
Site 1	>500	005	1.4	EVA	0.82
Site 1	>500	014	2.5	PVC	0.79
Site 1	>500	018	2.9	SR	0.96
Site 1	>500	022	3.95	PVC	0.77
Site 1	>500	027	1.6	PP	0.81
Site 1	>500	028	0.9	PS	0.70
Site 1	>500	030	1.1	PP	0.77
Site 1	>500	031	2.05	PS	0.71
Site 1	>500	033	1.08	PP	0.73
Site 1	>500	034	0.95	PP	0.71
Site 1	>500	038	1.29	PU	0.78
Site 1	>500	046	1.15	PE	0.75
Site 1	>500	058	1.2	CA	0.73
Site 1	>500	059	1.97	PC	0.95
Site 1	>500	072	0.9	CA	0.72

Table 3B. Polymer's type and count from Site 1 >500 μm.

Polymer type	Polymer count	Percentage (%)	Average length (mm)
CA	2	12	1.05
EVA	2	12	1.25
PC	1	6	1.97
PE	1	6	1.15
PP	4	24	1.18
PS	2	12	1.48
PU	2	12	2.44
PVC	2	12	3.23
SR	1	6	2.9
Total	**17**	**100**	**-**

9 types of MPs were found in various shapes and colors from Site 1 >500 μm (Fig. 14). There were 61 particles found at Site 1 >500 μm that could not be confidently identified as MP. They had their closest match with the following polymers (e.g. Polyester (67% match), ABS (66% match), PEVA (44% match), etc).
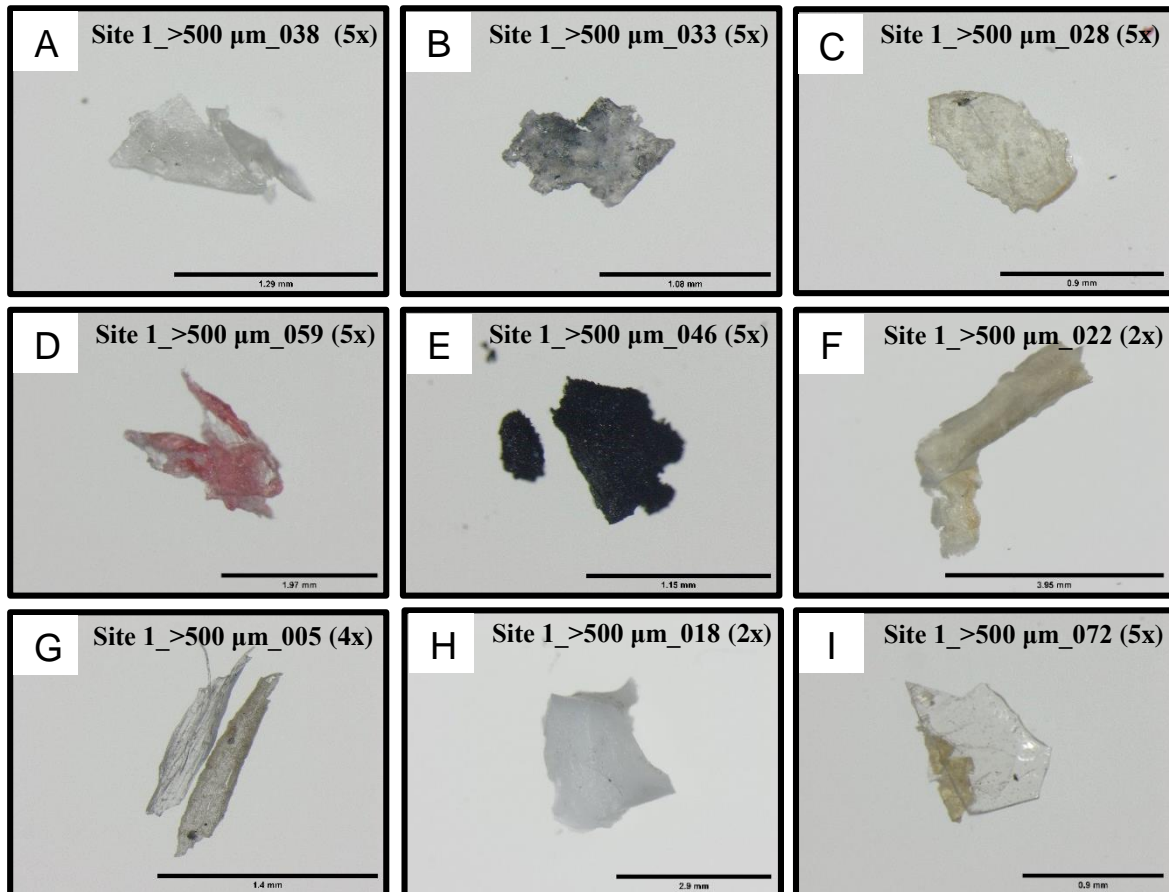
Figure 14. Examples of each microplastic type retrieved from Site 1 >500 μm. **A)** PU. **B)** PP. **C)** PS. **D)** PC. **E)** PE. **F)** PVC. **G)** EVA. **H)** SR. **I)** CA.

3.5 Site 1 MPs 2−5 mm

A total of 6 particles were observed, but none were identified as MPs. Plant stems are embedded in particles and the particles were composed of dense masses of gray fibers. These could be inferred to be cellulose acetate fibers or vegetal fibers, the former being an artificially made cigarette filter material.
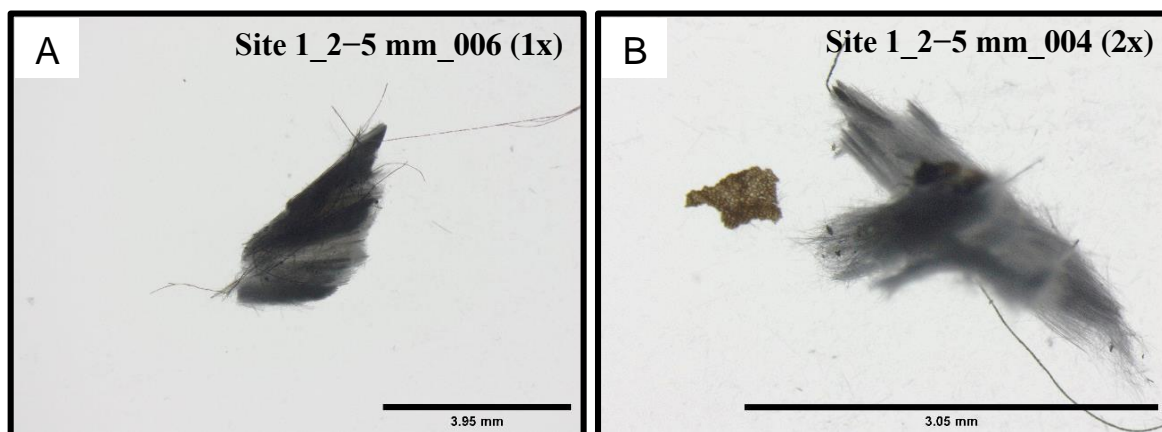
Figure 15. Fibers retrieved from Site 1 2−5 mm.

3.6 Site 3 MPs >500 μm

At Site 3 >500 μm, 16 out of a total of 21 samples were considered MPs (Table 4A). CA accounted for about 93.7% with 15, and it was the most commonly found plastic at Site 3 (Table 4B). Site 3 had a significantly higher percentage of CA compared to Site 1 (Table 3B, 4B). The samples with the highest correlation of about 0.81 were No.002, No.010, and No.011, all of which were CA (Table 4A). The length of samples varied from 0.88 to 3.15 mm, No.004 (CA) was the smallest particle and No.011 (CA) was the largest particle (Table 4B). The average length of the MPs found at Site 3 >500 μm was 1.67 mm. In the parts found in Site 3 >500 μm, most transparent film materials were attached to the fragments, which were mostly dark colors, such as brown or black (Fig. 16).

Table 4A. Information on microplastics collected from Site 3 >500 μm.

Location	Size (μm)	Sample ID (No.)	Length (mm)	Spectral match	Correlation
Site 3	>500	001	1.78	CA	0.75
Site 3	>500	002	0.96	CA	0.81
Site 3	>500	003	1.42	EVA	0.70
Site 3	>500	004	0.88	CA	0.79
Site 3	>500	005	1	CA	0.72
Site 3	>500	006	2.66	CA	0.80
Site 3	>500	007	1.4	CA	0.76
Site 3	>500	008	1.15	CA	0.80
Site 3	>500	010	1.6	CA	0.81
Site 3	>500	011	3.15	CA	0.81
Site 3	>500	012	1.32	CA	0.79
Site 3	>500	013	1.03	CA	0.76
Site 3	>500	016	2.95	CA	0.74
Site 3	>500	018	2.03	CA	0.75

| Site 3 | >500 | 019 | 1.75 | CA | 0.71 |
| Site 3 | >500 | 020 | 1.7 | CA | 0.76 |

Table 4B. Polymer's type and count at Site 3 >500 μm.

Polymer type	Polymer count	Percentage (%)	Average length (mm)
CA	15	93.7	1.69
EVA	1	6.2	1.42
Total	**16**	**100**	-
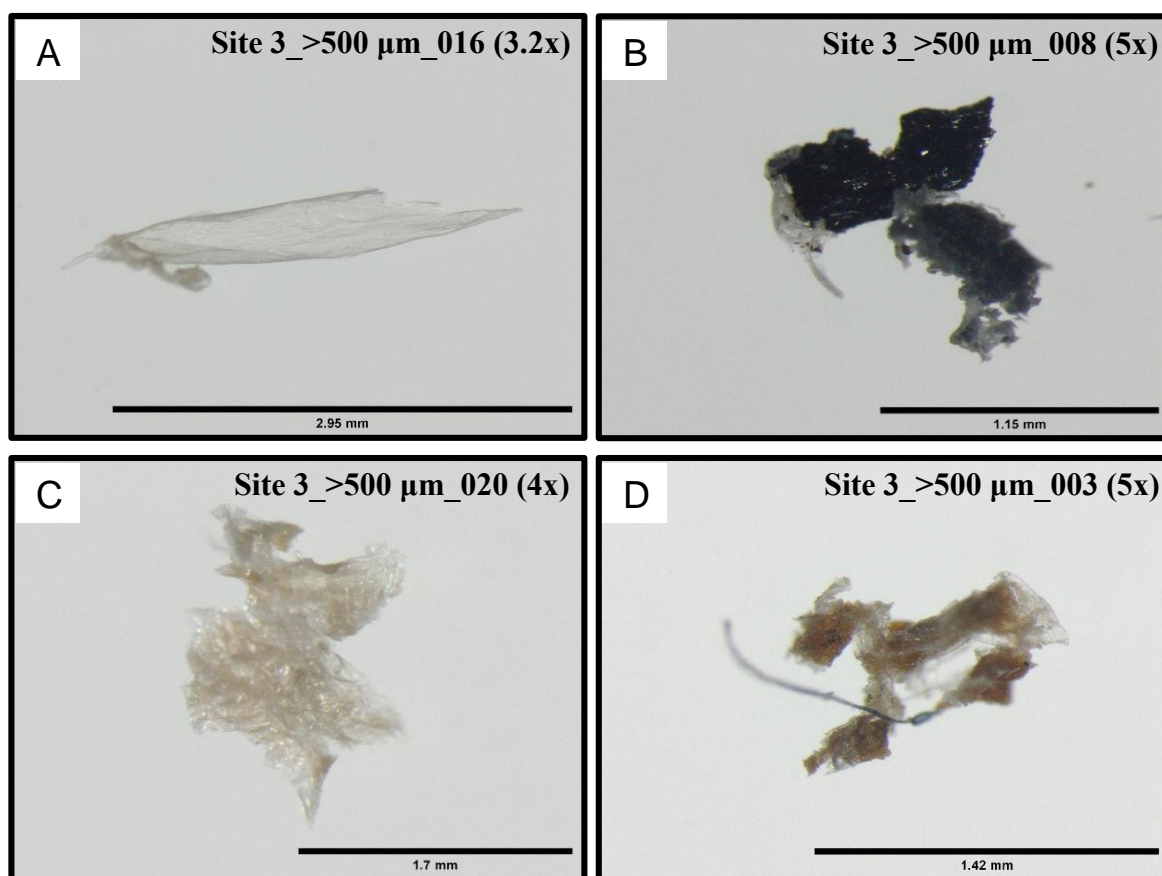
Figure 16. A selection of microplastics retrieved from Site 3 >500 μm. **A)** CA. **B)** CA. **C)** CA. **D)** EVA.

3.7 Site 3 MPs 2−5 mm

At Site 3 2–5 mm, 2 out of a total of 3 samples were estimated to be CA (Table 5B). All of them were over 2.3 mm in length and were white (Table 5A). Particle A had a hard and rough surface and B had a white and plain surface (Fig. 17).

Table 5A. Information on microplastics collected from Site 3 2−5 mm.

Location	Size (mm)	Sample ID (No.)	Length (mm)	Spectral match	Correlation	Converted rate (%)
Site 3	2–5	001	2.32	CA	0.72	72
Site 3	2–5	003	2.73	CA	0.81	81

Table 5B. Polymer's type and count from Site 3 2−5 mm.

Polymer type	Polymer count	Percentage (%)	Average length (mm)
CA	2	100	2.53
Total	2	100	-
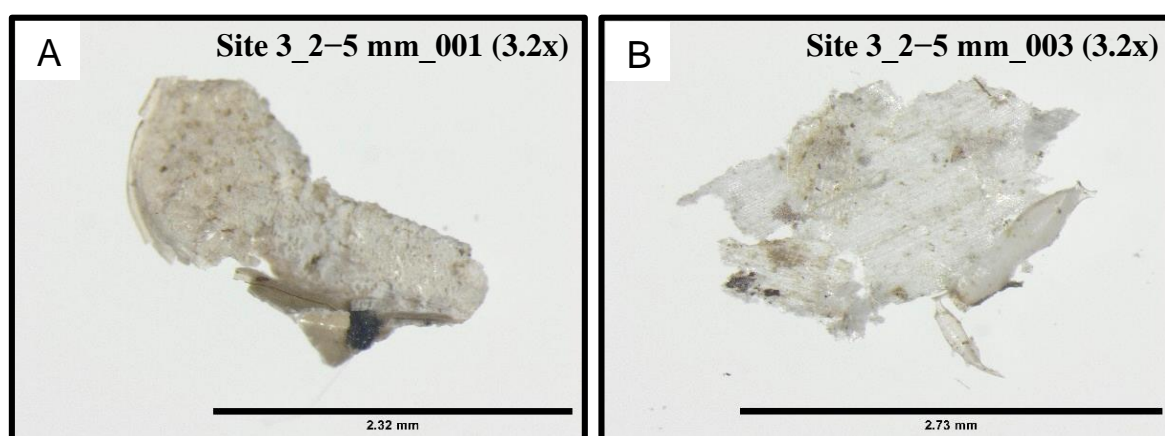
Figure 17. A selection of microplastics retrieved from Site 3 2−5 mm. **A)** CA. **B)** CA.

3.8 Polymer types and sizes

A total of 108 particles were collected from Site 1 and Site 3, and 35 particles were identified as MPs. The types of plastic, shape and color varied, but the most frequent type seemed to be CA with 19 (54%). PP came next with 4 (11.4%), followed by EVA with 3 (8.6%) (Fig. 18).
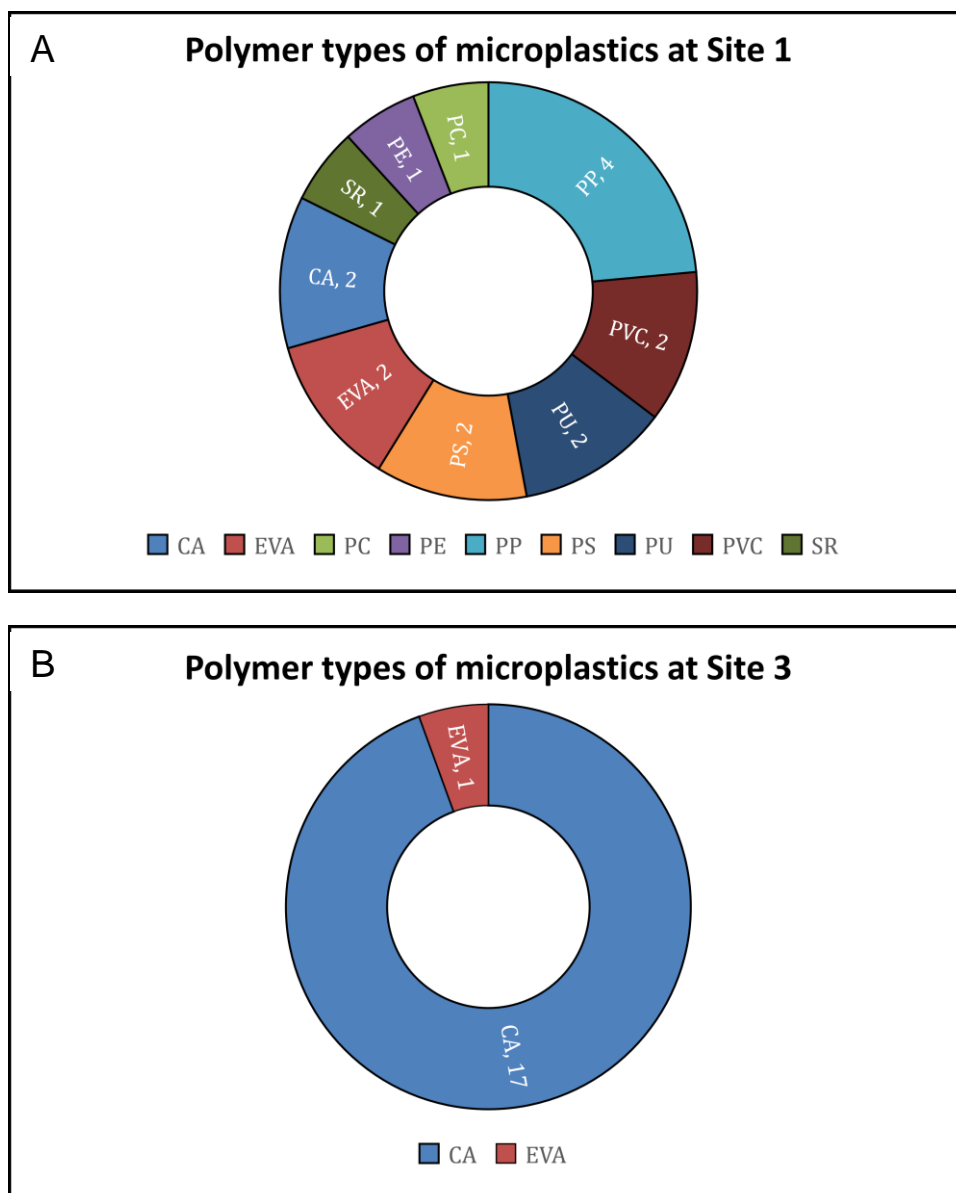
Figure 18. Distribution of polymer types of microplastics. **A)** Site 1 (Total 17). **B)** Site 3 (Total 18).

MPs detected using FTIR were classified into various polymer forms and were found to have an average length of 1.15 to 3.23 mm (Table 6). All particles collected at Site 1 and Site 3 were combined to obtain the average diameter. There was only one PE detected and it was the smallest at 1.15 mm. PVC was the largest at 3.23 mm on average. The larger the number of polymers, the shorter the average length in most cases.

Table 6. Size of microplastics from Site 1 and Site 3.

Polymer types	Polymer count	Percentage (%)	Average length (mm)
CA	19	54.3	1.71
EVA	3	8.6	1.31
PC	1	2.9	1.97
PE	1	2.9	1.15
PP	4	11.4	1.18
PS	2	5.7	1.47
PU	2	5.7	2.45
PVC	2	5.7	3.23
SR	1	2.9	2.9
Total	35	100	-

When observing the results in more detail, at Site 1, polymers were observed at a constant rate, and among them, 4 (24%) of PP were the most common (Fig. 18A). In Site 3, CA overwhelmingly accounted for the majority with 17 (94%) (Fig. 18B).

3.9 Classification of microplastics

The chart below shows the sample ID, color, length and type of the total 35 MPs I sampled (Fig. 19). In Site 1 >500 μm, various types of MP appeared, and most of them were shorter than 2mm except for PVC. At Site 3 >500 μm, CA was mostly black, brown or transparent. Among the CAs, transparent color was the longest, followed by brown and black. Site 3 2−5 mm were all white CA and were larger than 2 mm in length.

According to their shapes and features, the microplastics were categorized into fragments (hard and jagged), foams (lightweight and sponge-like), pellets (hard and rounded), films (thin plane of filmsy), and fibers (fibrous and tangled). Regarding the result, fragment (45.71%) was the most common, followed by film (25.71%), fiber (17.14%), and foam (11.43%), and was not found in pellet (Fig. 20A). The abundance of microplastic particles in terms of colors is in the order of transparent and brown (25.71%), black (20%), white (14.29%), red and blue (2.86%) (Fig. 20B).
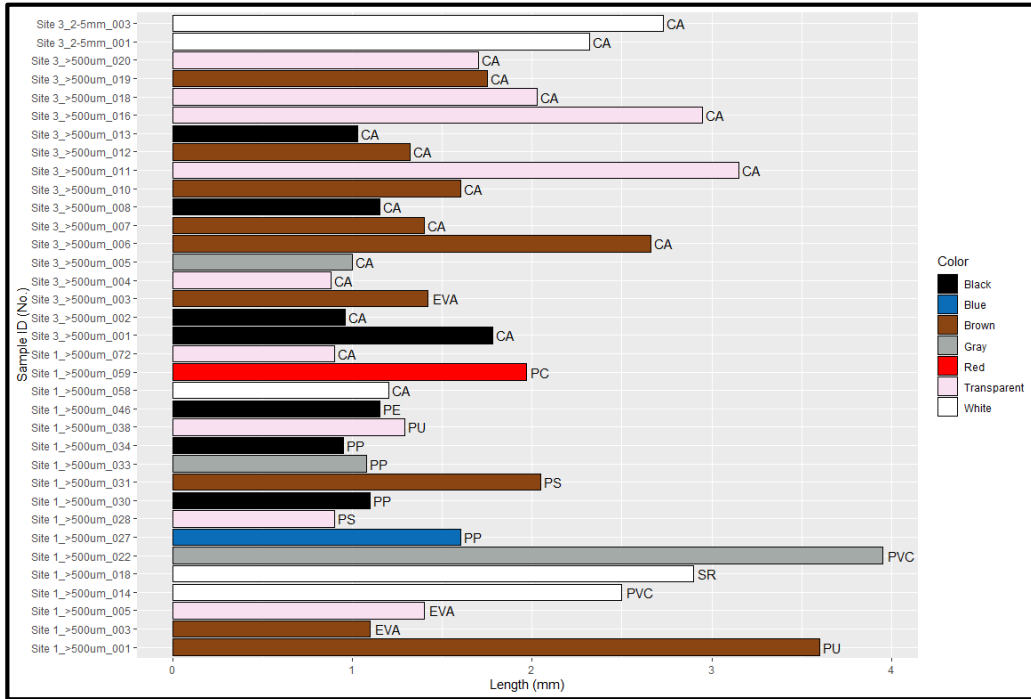
Figure 19. Sample ID, color, length and type of microplastics at Site 1 and Site 3.
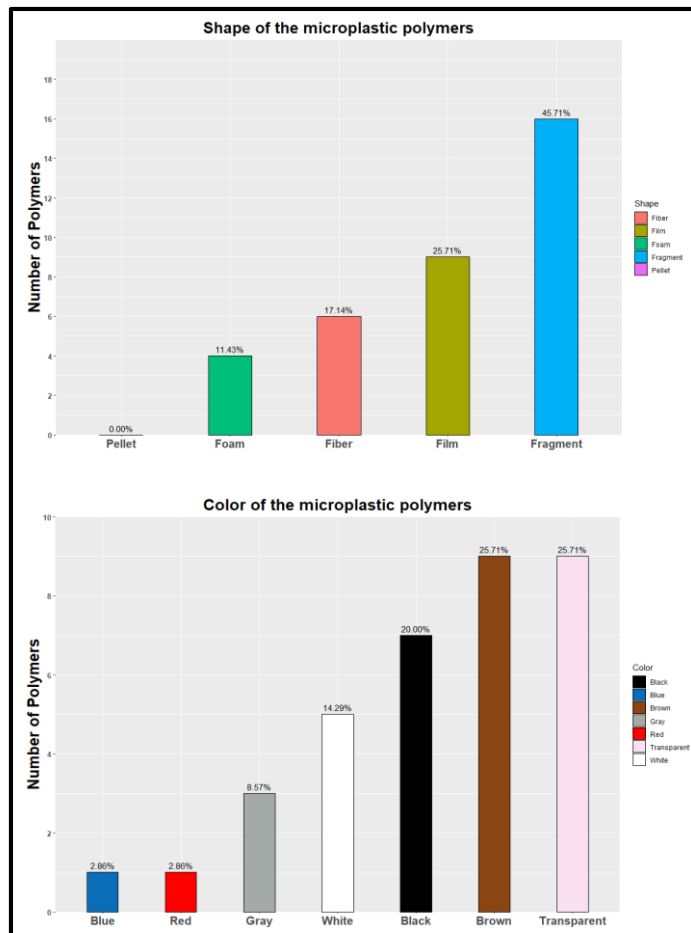
Figure 20. A) Shape of the microplastics at Site 1 and Site 3. **B)** Color of the microplastics at Site 1 and Site 3.

3.10 Microplastic concentration in Site 1 and Site 3

In regards to the MPs/kg dry sediment, it was calculated by dividing the number of MPs by the dry weight of the samples for each site. So, the MP concentration of Site 1 ($n = 17$) was 168.3 MPs/kg dry sediment while the concentration of Site 3 ($n = 18$) was 1182.6 MPs/kg dry sediment. In total, it is estimated that the average number of MPs found on the southern coast of Norway ($n = 35$) was 302.7 MPs/kg dry sediment in this study.

4. Discussion

Currently, MPs are detected in various ecological environments (e.g. sea, river, lake, air, etc) in Norway (Bert van Bavel et al., 2022). Among them, I focused my research on MPs present in the boat marina and the eelgrass bed on the southern coast of Norway. In this section, I interpret my results in depth, discuss their significance and limitations, and present new findings and interpretations of my study.

4.1 Correlations

In the Data Analysis process of 2.3.10, the number (0~1) that compares the results of one particle's spectra with the results of the reference is called correlation or match score. A match score ≥0.7 were accepted as MP. Plastics can be underestimated if the standard, which indicates the degree of compatibility with plastics, is set to 0.7, because <0.7 may actually be plastics. However, if the standard is 0.6, it increases the uncertainty of the plastic by that much, so plastics can be overestimated if the limits are not conservative enough (DNV GL, 2018). When samples were matched against the microplastic spectral library, all matches with a correlation ≥0.7 were accepted as MPs (Obbard et al., 2014). If there were multiple matches of ≥0.7, the best match was generally chosen. Matches with a correlation <0.7 were rejected and denoted as "unknown" particles. I still don't know what these particles are. This demonstrates the importance of performing polymer identification techniques such as FTIR to verify that the particles are MPs and to identify the polymer types (DNV GL, 2018).

4.2 Microplastic presence and source

4.2.1 Site 1 (Boat marina)

The total number of particles found in Site 1 was 84. Of these, 17 (20.2%) MPs were detected and the remaining (79.8%) were regarded as unknown particles. The boat marina is located close to land, so there is little ocean current, there is human activity, and it is a place where marine debris from the sea accumulates. All 84 particles may be MPs or be naturally

occurring organic materials. They still have the potential to pose a threat to the marine environment, and there is potential for further MP accumulation in deeper sediments.

In Palu Bay, Indonesia, the abundance of microplastics was compared among three sites: a tourism coastal area, an area with little influence from land activities, and a fishing boat marina (Widiastuti et al., 2021). MPs were most often found at boat docks by narrow margins but were evenly distributed at all three locations. My findings are consistent with these results, emphasizing the need for better management of plastic waste both locally and globally.

4.2.2 Site 3 (Eelgrass bed)

In Site 3, 18 (75%) of 24 particles were detected as MPs. The eelgrass beds are located in conditions where MPs can move in a variety of ways because of the active ocean currents. Therefore, it was expected that the MPs found in the eelgrass bed would be significantly lower than in the boat marina. However, my result (Fig. 18) shows that only the polymer types of MPs found in Site 1 and Site 3 differ, but the numbers are similar. The similarity in the numbers of MPs found in both Site 1 and Site 3, despite differences in the types of polymer MPs, suggests that MPs can accumulate even in eelgrass beds.

Seagrass beds act as a trap for MPs in the sea (Huang et al., 2020). In addition, MPs not only can be deposited in seagrass beds but may also adhere to seagrass leaves (Jones et al., 2020). For this reason, MPs could be sufficiently found even in eelgrass beds. Marine organisms living in eelgrass beds, where MPs accumulate, are exposed to environments where MPs exist, which can eventually affect fisheries and ecosystems (Huang et al., 2020).

4.3 Polymer types

4.3.1 Site 1 (Boat marina)

In Site 1, various polymers were evenly distributed (Fig. 18A). The reason is that various types and numbers of MPs were found in the marina, where the influence of ocean

currents was relatively small and the human influence was large. Among them, the most commonly found PP will be described.

Polypropylene (PP), which had the highest concentration at Site 1, is a major environmental pollutant in marine ecosystems and is one of the most prevalent MPs (Schwarz et al., 2019). PP is a component of ropes, bottle caps, fishing gear, packaging materials, and personal hygiene products (Jeyavani et al., 2022). PP, which is used in fishing activities such as ropes and nets, is more abundant in rural areas and may have been released by human activities near the coast (Jang et al., 2020). In addition, PP is known to be less prone to degradation when exposed to the environment compared to other plastics, which means it is likely to persist in the ocean, rivers, lakes, and other bodies of water for a long time (Alsabri et al., 2022). Therefore, PP may have a lasting impact on marine ecosystems and can be ingested by fish or other marine organisms, potentially affecting humans through the food chain. The durability and degradation of PP products may contribute to the generation and accumulation of large amounts of PP microplastics in areas with high human activity such as boat marinas or coastal areas.

4.3.2 Site 3 (Eelgrass bed)

Only two types of polymers, Cellulose acetate (CA) and Ethylene-vinyl acetate (EVA), were found in the eelgrass bed (Fig. 18B). CA is currently an environmentally friendly, biodegradable and versatile plastic. Considering that global production of CA materials was over 800,000 metric tons per year in 2008 (Puls et al., 2011), more than that will be produced today. CA is used in several applications such as in the cigarette industry and the textile. In particular, cigarette filters are made of CA (Lusher et al., 2017), which can take up to 10 years to decompose in nature, depending on environmental conditions (Kurmus & Mohajerani, 2020). Therefore, it is necessary to study how CA present in eelgrass beds is degraded, how fast it is degraded, and the factors affecting the decomposition process.

EVA is a plastic widely used in the wire and cable industry (Henderson, 1993). EVA copolymer is safe when used in food production, packaging or transportation, and it's not an especially dangerous material (CFR, 2012). EVA can contain up to 0.3% of the vinyl acetate used to make it, which is not hazardous under ordinary conditions (MSDS, 2011). However,

it is important to note that objects made from EVA may also contain additives that may have various hazards to add color or desirable properties. Since there is no study on the harmfulness of EVA in the marine ecosystem, studies related to EVA are gradually required.

As such, CA and EVA commonly found in eelgrass beds were found to be more environmentally friendly than PP found in boat marinas and were not particularly hazardous types of plastic. Eelgrass beds are mainly located in open areas where water flows, so various types of MPs are quickly degraded or may move to other areas. The particularly high proportion of CA in eelgrass beds compared to other microplastics may depend on a variety of factors, including the source of the microplastics, the size and density of the microplastics, and the method of collection. Unfortunately, I have not yet been able to find a specific study that found a specific microplastic (CA in this study) concentrated in eelgrass beds. Therefore, more research is needed, and such research is crucial for protecting marine ecosystems and understanding the impact of microplastics on the environment.

4.3.3 Morphology of microplastics

MPs can be found in a variety of shapes, including foils, foams, fibers, pellets and fragments (Hidalgo-Ruz et al., 2012). The shape of an MP can be a determinant of hazardous effects on the marine environment (Marrone et al., 2021).

The identification of the MP forms found in this study in the order of fragments, films, fibers, and foams shows that they exist in various forms (Fig. 20A). In particular, an interesting result is that no pellet shape was found. Fragments were the most abundant in the study, accounting for 45.74%, for various reasons. They combine the decomposition of large plastic waste (Cole et al., 2011), transportation on the surface of the water, and small size and lightness that are easy to expose and absorb to marine life. In addition, MPs found in various forms of film, fiber, and foam show the diversity of plastic pollution occurring in Norwegian seas and can provide important information in evaluating the sources of MPs and their impact on the marine ecosystem. Undiscovered pellets are small spherical plastic used as raw materials in the manufacturing process of plastics and are known as one of the main sources of MP pollution in the marine environment (Arias et al., 2023). The absence of findings in

this study could imply that the region's plastic manufacturing or transportation processes do not experience significant leakage.

4.3.4 Colors of microplastics

MPs are present in various colors (Martíet al., 2020). According to literature data, transparent and brown were the most common particles in our sampling and accounted for 25.71%, respectively (Fig. 20B). This result is consistent with the fact that transparent color was found most frequently compared to other studies (Marrone et al., 2021). Therefore, it can be inferred that most microplastics have a transparent color. In the results of this paper, transparent and white accounted for 40% of the total. A significant source of transparent and white particles can be plastic bags or cigarette filters widely used in everyday life. Colorful colors (red, blue, black, gray, brown) accounted for the remaining 60%, of which dark colors (brown, black, gray) accounted for 90.48%, while red and blue accounted for 4.76%, respectively.

This color distribution information can help identify the sources and sources of MPs and assess their impact on the environment. The fact that transparent colors are found suggests that plastic products used in everyday life are more likely to break down into MPs and be released. For example, transparent plastic products such as plastic bags can generate large amounts of MPs, which can affect marine ecosystems. In addition, colorful MPs were found, suggesting that products containing pigments or paints may appear as particles of that color when decomposed into microplastics.

4.3.5 Limitations of microplastics found in Site 1 and Site 3

The overall average length of MPs was 1.76 mm in this study, which corresponded to the standard of 1 μm to 5 mm for MP (GESAMP, 2015). It is difficult to generalize the shape and size of all polymer types from this result since for most samples the number of polymers found is not more than two. More diverse and large numbers of samples are needed for clear results. Since the CA ratio in Site 3 was overwhelmingly high, it is thought that this fact influenced the overall result even in the result when the results of Site 1 and Site 3 were

combined. Except for this fact, it was confirmed that the types of total MPs were evenly distributed in a similar ratio (Fig. 18).

According to the results of my study, 302.7 MPs/kg dry sediment was found in the southern coast of Norway ($n = 35$). For each site, 168.3 MPs/kg dry sediment was found on Site 1 ($n = 17$) and 1182.6 MPs/kg dry sediment in Site 3 ($n = 18$). Since the amount of dry sediment samples at each site was already about 6.6 times different from 100 g for Site 1 and 15.08 g for Site 3, this clearly differed in concentration when the number of MPs was identified similarly to my result. Various studies have shown that MPs are ubiquitous in marine sediments worldwide, with concentrations ranging from a single particle to hundreds of particles per kg of sediment. 97.2 MPs/kg dry sediment was found on the continental shelf of Belgium, 60 MPs/kg dry sediment on the beach of Brazil, and 177.8 MPs/kg dry sediment on the beach of Slovenia (Claessens et al., 2011; DNV GL, 2018; Laglbauer et al., 2014; Santos et al., 2009). Therefore, my result shows that MPs found on the southern coast of Norway are more abundant than in other countries compared to other studies. However, this comparison has limitations in making direct and accurate comparisons because the research methods are different.

4.4 Comparison to other studies

I hypothesized in this study that more MPs would have been found in sediment in boat marina with human activity. However, there was no significant difference in the number of MPs between boat marina and eelgrass beds (Fig. 18). This result supports the evidence from a previous study by Claessens that there is no clear relationship between human activity and concentrations of MPs (Claessens et al., 2011). MPs found in some partially enclosed boat marinas may be partially related to the marina's compartments, regardless of boat activities (Claessens et al., 2011). The low flushing rates in these areas, caused by the narrow entrance of the marina, can result in MPs becoming trapped in tidal eddies and eventually settling on the sea sediments (Yin et al., 2000).

Huang and his colleagues examined MPs in Xincun Bay and Li'an Bay, located in the southeast of Hainan Island in China, where there are fishing ports and seagrass meadows

(Huang et al., 2020). They found 39 MPs out of 155 particles, PE (48.7%) was the most dominant, followed by PP (33.3%), PA (10.3%), and PS (7.7%). In comparison, my results estimated that 35 out of 108 particles were MPs, CA (54.3%) accounted for almost half, followed by PP (11.4%), EVA (8.6%), and others. MPs were investigated with different collection methods and amounts in different geographic and climatic environments, but the common point is that PP is the second most frequently found MP. Through this finding, I can support the opinion that PP is one of the most frequently found MPs worldwide (Geyer et al., 2017).

The smaller the MPs are, the more likely they are to be ingested by tiny aquatic organisms and have adverse biological effects (Shim et al., 2018). In this study, MPs smaller than 1 mm accounted for approximately 14.3% of the total MPs. This result stands in stark contrast to the findings of Huang et al., in which MPs smaller than 1 mm made up over 98% of the total (Huang et al., 2020). The size of MP is mainly related to the local industrial structure, waste management practices, and other factors. The reason why the average size of MPs found in China is smaller than that found in Norway is believed to be due to the high population density and heavy usage of plastics in China over a long time, resulting in plastic debris being naturally weathered and worn down to smaller sizes. Therefore, the average size of MPs in China and Norway may differ as a result.

Most of the studies conducted have reported higher concentrations of PE compared to PP (Marrone et al., 2021). However, the MP polymer in our results has 4 PP and 1 PE, which is a contrasting result. PP and PE are easily found in surface waters around the world because they are less dense than other plastic polymers and float easily (Marrone et al., 2021). Because the number of MP found in our results is small compared to other studies, comparison and analysis with a larger number of samples may lead to similar results to other studies.

4.5 Future research on microplastic

MPs are an emerging environmental problem in the world. As COVID-19, which first emerged in 2019, continues to persist, the use of plastic has significantly increased due to the

rise in consumption of disposable plastics, COVID-19 test kits, and medical waste. As of August 2021, more than 8 million tons of pandemic-related plastic waste had been generated worldwide, with over 25,000 tons having entered the world's oceans (Peng et al., 2021). As such, the growing problem of plastics and MPs is increasingly threatening the world.

Research on technologies to reduce the number of MPs entering the oceans as well as those that remove MPs from the ocean is essential. In particular, in the problem of MPs in the sea, studies are continuously needed to identify the cause by examining the components, amounts, and characteristics of MPs present in boat marinas and eelgrass beds, which are generally unlit areas.

Studies confirming the relationship between human activities and MPs in boat marinas are lacking. Since a boat marina is a place where human activities will continue in the future, constant monitoring and appropriate measures against plastic waste dumping by people who enjoy leisure activities and tourists are required.

It is also necessary to investigate the impact of MP pollution on eelgrass beds, which play an ecologically important role in marine ecosystems (Den Hartog, 1970), and to explore ways to reduce contamination. For instance, robotic technology can be utilized in untouched eelgrass beds to collect plastic and MP. Comprehensive conservation efforts, including the implementation of nutrient management plans, the establishment of sanctuaries or protected areas, and public and resource manager education, are required to address the global seagrass crisis and preserve seagrass meadows (LARKUM et al., 2006).

Biological treatment technologies are being developed to decompose MPs in the ocean. Biodegradable plastics, which decay or dissolve, are continuously being developed and have the potential to secure a healthy market share over the next decade (Filiciotto & Rothenberg, 2021). Lastly, governments and companies need to actively pursue policies and measures to improve environmental policies and reduce the use of MPs. Education and information on the issue of MPs and their solutions are needed to improve people's awareness. Therefore, these future studies are essential going forward and should be accompanied by MPs sampling and analysis to be performed.

4.6 Methodology and sources of error

 Some aspects of the approach to experiments can affect data sampling, results, and accuracy. Notable issues include:

- Site 2

    Our original plan was to experiment with Site 2 as well. Site 2 was the same boat marina as Site 1, and was at the entrance of the boat marina. However, due to a lack of time and similar conditions to Site 1, I only experimented at Site 1 and Site 3, except for Site 2.

- Restriction on plastic use

    This experiment observes the distribution of MPs, but contains a message to refrain from overuse of plastics. Therefore, the use of plastics was excluded during the study. The only plastic I used was the plastic boxes. I used to store the samples on the boat (Fig 21). The reasons for using them were that they are easy to store while transporting samples to the laboratory, are not easily broken, are lightweight, and are clean to protect them from contamination.

Figure 21. Plastic boxes used for sample storage.

- Contamination

    In order to minimize the error in the results, I tried to prevent contamination during the analyses. In the extraction step of MPs in the laboratory, all laboratory equipment was washed three times with particle-free water to prevent contamination. All experimental procedures were carried out in the fume hood.

- Filtration

During filtration, the filter was not centered or the clamp was not tightened so there was a leak. The leakage liquid flowing along the flask minimized the loss of sample by undersetting a 1 L crystallizer. Then the leakage liquid was refiltered. In this process, the possibility of sample loss, contamination, or foreign matter entering could not be excluded.

- Filter paper

    After filtration, there was a high probability that MPs would potentially remain on the filter paper. Consequently, some particles may have been overlooked.

- Accuracy of FTIR

    There were a few cases where the graph curves and the figures were almost similar in successive samples. Site 3_>500 μm_010 had a correlation of 0.807128, followed by Site 3_>500 μm_011 with a correlation of 0.805975. The shapes of the two graphs were also quite matched. For this reason, in fact, successive samples may have similar components, but I think in this case it is significantly low. It may be the case that a piece of the previous particle got stuck on the crystal.

    Since the spectra were automatically compared with the reference spectrum library, potential misinterpretation may have affected some results. In addition to the incomplete spectrum library, other factors such as differences between the surface of the reference sample and the measurement target may result in lower correlations. If the surface of the sample is over-oxidized, the spectrum of the sample does not match well with the standard.

- Particles

    Particles from environmental samples are often irregular in shape, have uneven surfaces, and are vulnerable to impact. Some of the particles in this project were destroyed during transportation. Some particles were lost inside the petri dish, and there was a possibility that the position of the particles was changed when the petri dish was transported. The particles were small and difficult to handle with forceps and difficult to find when lost. Very small particles could not withstand the pressure of the forceps and some were destroyed.

- Size of microplastic

　　Typically, microplastics are less than 5 mm in size, so the finding of a significant amount of microplastics in the 2–5 mm particles in this experiment was expected. However, the result that no material was found in particles >500 μm at the boat marina suggests that the filtering method used in the experiment may not have been sensitive enough. Due to the extremely small size of microplastic particles, the filtering method used in the experiment should be as sensitive as possible to detect microplastics. Alternatively, it is possible that microplastics larger than 500 μm did not actually exist in the area being studied.

- Blanks

　　At Blank 1, the boat marina, there was little wind and no particles were found. Since Blank 3 was an eelgrass bed open to the sea, the wind was strong. Therefore, it is thought that 5 particles floating in the air on the sea wind were found in Blank 3. 5 particles found in Blank 3 were confirmed through FTIR analysis, but all were not MPs (Fig. 12). I estimated that airborne contamination was negligible for our results during the laboratory analysis phase. Other sources of contamination, such as reagents and containers, were also possible but not investigated. This was investigated by running the blank samples through all the same laboratory procedures as the environmental samples.

- Rubber (R)

　　There were three of R (Rubber) polymers with match score higher than 0.7 in Site 1, but R were excluded from this experiment because they are not classified as microplastics. Like the studies of Cao et al. (2022) and An et al. (2020), I also acknowledged R as MPs and thought a lot about whether to include it in the results. Plastic polymers typically possess long chains and are held together by tiny protons, which results in their reduced elasticity (ECHEMI, 2022). Nevertheless, rubber has a distinct molecular composition and characteristics compared to the plastics we are familiar with. The most obvious difference between rubber and plastic is that rubber is elastic, while plastic is not. For this reason, R was not included as a category of MPs in these results.

5. Conclusion

In the results of this study, a total of 35 particles were considered as MPs, and 17 and 18 were found in the boat marina (Site 1) and eelgrass (Site 3), respectively, and the number of MPs was similar. The average size of MPs was 1.76 mm, which was large compared to other studies. At the boat marina, not only MPs but also unknown particles were found in large quantities, while in the eelgrass bed, the particles discovered were not diverse in type, and most were identified as MPs. It was expected that MPs found in the boat marina with active human activities would be higher, but comparable amounts of MPs were found in the eelgrass bed. Microplastics comprising four shape types (fragments, films, fibers, and foams in that order) and in various color categories (40% white and transparent, 60% others) were identified in the boat marina and eelgrass bed on the southern coast of Norway. Therefore, the widespread occurrence of MPs on the southern coast of Norway was confirmed. In this paper, it was concluded that there was no clear relationship between local human activities and the distribution of MPs. This is due to the diverse types and forms of MPs present in the ocean, making it difficult to predict how they will affect the marine ecosystem. In particular, various efforts are required to reduce the presence of MPs found in both the boat marina, where various leisure activities take place, and the ecologically important eelgrass bed. Furthermore, there is a need for sustained interest and additional research on boat marinas and eelgrass beds, which are not well-selected research topics for MPs in the ocean. In order to manage MPs in the oceans in the future, it is necessary to obtain information and predictive technologies on the amounts and inflows, distribution, and behavioral characteristics of MPs. The potential harm of MPs to marine ecosystems should be quantitatively evaluated to establish environmental guidelines.

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