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Tracking Microplastics from Artificial Football Fields to Stormwater Systems

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Preface

This Master's thesis is Ran Li's degree project in Environmental Management and Physical Planning at the Department of Physical Geography, Stockholm University. The Master's thesis comprises 30 credits (one term of full-time studies).

Cooperation with WSP Sverige AB.

Supervisors have been Stefano Manzoni at the Department of Physical Geography, Stockholm University, Lea Levi and Hjördis Steen at WSP Sverige AB. Examiner has been Salim Belyazid at the Department of Physical Geography, Stockholm University.

The author is responsible for the contents of this thesis.

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Björn Gunnarson
Vice Director of studies

Abstract

Microplastic pollution as a global environment problem in marine systems has substantially raised public concern in recent years. In 2016, the Swedish Environmental Protection Agency performed a study about potential sources and pathways of microplastics spreading to the marine environment. Microplastics from artificial turfs have been recognized as the second most important source of microplastic emission in Sweden. Between 1640 to 2460 tons per year of microplastics are estimated to be lost from artificial turfs. The lost microplastics are potentially transported to stormwater wells by runoff during rainfall events, eventually reaching marine environments. This study aims to track microplastics from artificial turfs to stormwater wells.

Since the research of microplastic in stormwater has so far shown to be limited, field work and laboratory analysis have been developed in this study. Four artificial football fields located in Stockholm municipality were taken as sampling sites. First, pathways for microplastics from artificial turfs to stormwater were investigated. Second, the characteristics of microplastic granulates infill used in the football fields have been analyzed. Finally, stereo microscopy was used to visually identify microplastics in stormwater.

The results showed that rainfall as a driving force of runoff process contributes to microplastics transport from artificial turfs to stormwater. During this transport process, a fraction of microplastics is captured by the soil. The size of microplastic granulates identified not only in stormwater but also in stormwater sediments is typically between 1 mm to 3 mm. Due to its limitations, stereo microscopy is quite a subjective method for identifying microplastics and thus not suitable for quantitative analysis, since microplastic particles are comparable in size to and visually difficult to differentiate from organic particles co-occurring in stormwater.

In order to accurately quantify the amounts of microplastics transported to stormwater systems from artificial turfs, it is necessary to develop new methods for microplastics identification. This study presented an attempt in this direction, highlights its limitations, and discusses more suitable alternatives.

Key words: microplastics, artificial turfs, stormwater, runoff, rainfall, Sweden.

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1 Introduction

Over the past half century, the production and application of plastics has exponentially increased, which has resulted in large amounts of plastic litter directly discharged in water bodies, particularly into sea (IVL, 2017). Plastic production in the world increased from 1.5 million tons in the 1950s to 335 million tons in 2016. Approximately 10% of the plastic produced annually ends discharged into the marine environment (Alimba & Faggio, 2019). Large pieces of plastic litter can further be degraded into very small pieces (less than 5 mm) of plastic, which are abundant in aquatic ecosystems.

Small plastic particles in aquatic environments were first taken into consideration in the 1970s after quantities of small particles were discovered on the surface of the Sargasso Sea (Carpenter & Smith, 1972). The term microplastic was first introduced by Thompson et al. (2004) to describe small plastic particles collected from sediments around Plymouth, UK. Microplastics are now becoming recognized worldwide, with occurrence on the surface of open oceans, lakes, shorelines and sediments, often at exceptionally high concentrations. For instance, microplastics concentration in the main stream of the Yangtze River in China was reported to be up to 1.36×10^7 items per square kilometer and that so far is the highest value noted in the available literature (Zhang et al., 2015). In 2014, the accumulation of microplastics in world's ocean was estimated to 15 to 51 trillion particles, with a weight between 93 to 236 thousand metric tons (Sebille et al., 2015).

Microplastic in the aquatic environment has attracted attention in recent years as a major global environmental concern. In an attempt to raise awareness, National Geographic magazine has published a series of articles on the microplastics crisis, including an eye-catching photo of a green-glowing plastic fragment ingested by a water flea (Royte, 2018). Land-based debris and human activities on the sea and ocean are considered as the main sources of plastic debris. In 2015, the Swedish Environmental Protection Agency has been assigned to identify Swedish sources of microplastics in the sea and propose measures for their reduction and handling. According to the study done by Swedish Environmental Institute IVL (2017), the largest emissions of microplastics in Sweden are released from road wear and abrasion of tires. The same study has reported artificial turfs as the second largest source of microplastics, and drew attention to further investigations of spreading of microplastics from artificial turfs.

The use of artificial turfs as substitutes for nature-grass playgrounds has become more and more popular in the recent years. Loss of microplastics from artificial turfs was estimated to be around 1640-2460 tons per year, however the data about loads reaching the marine environment are scarce (IVL, 2017). Microplastics from artificial turfs are discharged to stormwater during precipitation events which can be then recognized as a pathway of transporting microplastics to marine environment, but the volumes are still estimated with high uncertainty (IVL, 2017). Stormwater as a pathway transfers microplastics further to aquatic environments having an influence on its organisms, ecosystems as well as human health. In order to better understand environmental impacts of microplastics from artificial turfs it is necessary to improve knowledge about pathways of their spreading and loss that occurs on their way to stormwater. This master thesis aims to investigate possible methods for tracking microplastics from artificial turfs to stormwater networks.

1.1 Microplastics

1.1.1 Definition of microplastic

In general, microplastic is defined as any piece of plastic smaller than 5 mm to 1 μm in size along its longest dimension (Crawford & Quinn, 2017). The majority of materials in microplastics include polyethylene (PE), polypropylene (PP), Polyvinylchloride (PVC), polyethylene terephthalate (PET), polystyrene (PS), and polyamide (PA) (Bannick et al., 2019).

Microplastics can be divided into two categories according to their origins. Primary microplastics are intentionally produced as raw materials which are used as abrasives in applications such as cosmetics, personal caring and cleaning products (Crawford & Quinn, 2017). Many primary microplastics are released directly into the aquatic environment. Secondary microplastics are unintentionally produced by deriving from large pieces of plastic debris (Crawford & Quinn, 2017). An important group of secondary microplastics can be formed through fragmentation of plastic items as a result of solar ultraviolet light and mechanical means such as tidal waves. They may also be produced during washing of synthetic clothes, construction works or maintenance of plastic items.

Several studies on microplastic sources from Sweden and Norway have defined microplastics as a broad and general term without reference to a specific term (Sundt, et al., 2014 & IVL, 2017). Sundt et al. (2014) use term microplastic when referring to a wide range of particles including solid polymer particles and synthetic organic particles. In this study, ‘microplastic’ is used as the broad definition including ‘microplastic products’ that follows the same practice as in Sundt et al. (2014) and Magnusson et al. (2017). ‘Microplastics’ in this study includes petroleum by-products, man-made polymers, as well as synthetic rubbers e.g. EPDM (Ethylene Propylene Diene Monomer), silicone and polyurethane (Sundt, et al., 2014).

1.1.2 Sources of microplastics in Sweden

In order to reduce microplastics in the marine environment, in 2015 the Swedish Environmental Protection Agency was assigned to identify the sources and pathways of microplastics release in Swedish marine environments (IVL, 2017). Microplastics present in the sea come from various land and sea sources, and reach the sea through different pathways such as transport in natural water bodies, stormwater effluents, or as fragments from plastic litter.

Microplastic derives from land-based sources contributes about 80% of the total microplastic emission, which is higher than that from sea-based sources (Andrady, 2011). According to the research from IVL Swedish Environmental Research Institute, the primary source of microplastics in Sweden derives from roads and tires, and the second from artificial turfs (IVL, 2017). Other sources of emission include industrial production and handling of plastic pellets, synthetics washing, boat hulls and littering. However, the contribution of the microplastic load in the sea is not only depending on the sources of emission but also on their pathways towards the sea. Microplastics can be retained in the pathways, for example microplastics produced by laundry will be retained by water treatment plants.

Pathways of microplastics reaching Swedish coastal waters are via wind transport, stormwater, and water treatment plants as well as those that are directly discharged from ships (IVL, 2017). However, it is difficult to identify the percentage of microplastics transported to marine environment from different sources due to scarcity of quantitative data. Hence, currently the total microplastic discharged by Sweden to the sea cannot be estimated.

1.1.3 Environmental impacts of microplastics

Considering the small size of microplastics, the risk of it being ingested by wild-life is high. Microplastics in the marine environment can be ingested passively or actively by a wide range of organisms from small invertebrates to large mammals. Schmid et al. (2018) found that 13.7% of 14 fish species from Amazon River estuary carries microplastics. Ingestion of microplastics affects life activities such as feeding, digestion and reproduction, and even leads to mortality directly by entanglement and choking, especially in fish in larval stage (*ibid*). Microplastics ingested by primary consumers can be accumulated through marine food webs and thus ingested by secondary consumers (do Sul & Costa, 2014) including humans. In addition, microplastics have the ability to concentrate a considerable amount of waterborne toxic pollutants, which exacerbates toxicological hazards to marine organisms along ingestions (Wang & Wang, 2018).

Microplastics not only have an impact on organisms individually, but also effect ecosystems negatively at various levels. Microplastics accumulate in the sediments, where small organisms such as lugworm have non-selective feeding. Sediments with microplastics ingested by these small organisms could reduce the primary productivity and energetic reserves and thus have influence on benthic habitat structure (Guzzetti et al., 2018). Moreover, microplastics in marine environment have potential impact on nutrient cycling and ecosystem functioning. Zooplankton as a pivotal role in nutrient cycling is vulnerable to microplastics ingestion. Microplastics ingested by zooplanktons could decrease the density and velocity of their faecal pellets (Cole et al., 2016). The vertical movement of these faecal pellets is important for transportation of carbon, nutrients and organic matter, which are an important part of food production chain and carbon storage in oceans (Turner, 2015).

It is now well-known that microplastics can be accumulated in different ecosystems and transferred within food webs (Carbery et al., 2018). With everything mentioned above it is indicative that high concentrations of microplastics pose risks for human food security. Animals of commercial interest such as fish and shrimp containing microplastics could be consumed by human as seafood, which is a potential route for human exposure to these particles (Barboza et al., 2018). Even though microplastics have been observed in several seafood products, the adverse effects of microplastics on human following ingestions are still not well understood (Wright & Kelly, 2017). Thus, subsequent long-term effects of microplastic on human health should be researched further.

1.2 Microplastics from artificial turfs

1.2.1 Characteristics and use of artificial turfs

Artificial turfs are surfaces made of synthetic fibers with the characteristic of natural grass fields, and the technology has developed in four generations (***Figure 1***). In the late 1960's the first-generation artificial turfs with polyamide (nylon) began to be used as playing surfaces. The second-generation brought polypropylene straw and sand as a replacement applied from 1977 to 1995. With the development of artificial turfs, the third-generation artificial turfs with polyethylene and different fillings used today are more similar to natural grass (Twomey et al., 2018). The fourth-generation was introduced in 2006, which are made by polyethylene complex, sand and pad. Artificial turfs have the advantages of stability, safety and weather resistance. Hence artificial turfs are more and more popular to be used in football arenas, playgrounds and sports fields in recent years.

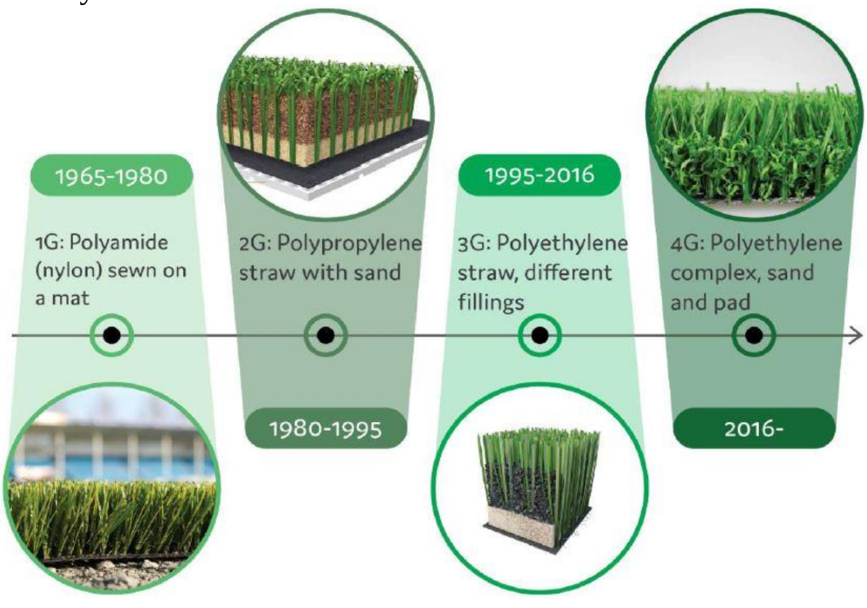

Figure 1 The development of artificial turfs. (source: NTNU, 2018)

During the last ten years, the construction of artificial turf fields has increased in Sweden. According to IVL Swedish Environmental Research Institute there are approximately 1336 artificial turf fields in Sweden in 2016, in which 50% are artificial football fields with 7140 m^2 for 11 players (IVL, 2017). The total area of artificial turf fields in Sweden is estimated to around 6,056,580 m^2 (*ibid*). However, the number of new large artificial football fields in Sweden has recently been declining after the rapid development in last decades, while construction of small sports fields made of artificial turfs, with size of around 800 m^2, is increasing rapidly in recent years (*ibid*).

The life span of artificial turf is within a range of 8 to 15 years depending on the using frequency and maintenance (IVL, 2017). Components of artificial turfs could be degraded due to sunlight, water and wind, so artificial turfs reaching their life span should be disposed of. Landfilling as the default disposition for scrap rubbers has been banned in EU countries since 2006 (Cheng et al, 2014). At present, in some cases the spent rubber is used as fuel supplement for heating, although toxic emissions would be released during burning. However, a potential solution is to move life spanned artificial turfs to smaller football areas or recycle them for new artificial turfs.

1.2.2 Characteristics of microplastic granulates

Artificial turfs generally consist of different layers of straws, rubber granulates and crushed stones as shown in ***Figure 2*** (Fleming et al., 2015). The top layer of an artificial turf is made of straws with a mixture material of polypropylene (PP), polyamide 6, polyolefiner, and polyurethane (PUR) (Wredh, 2014). Straws with the length of 3-6 cm are typically filled with sands and rubber granulates, in order to make the straws stand up (IVL, 2017). Materials of rubber granulates vary depending on the design of the surface, and the size of granulates varies from 0.8 mm to 3 mm (Bujak, 2018). There is a rubber pad layer below the straws, which promotes shock absorption and reduces the risk of injuries. The bottom layer is made of crushed stones which are underlain by soil.

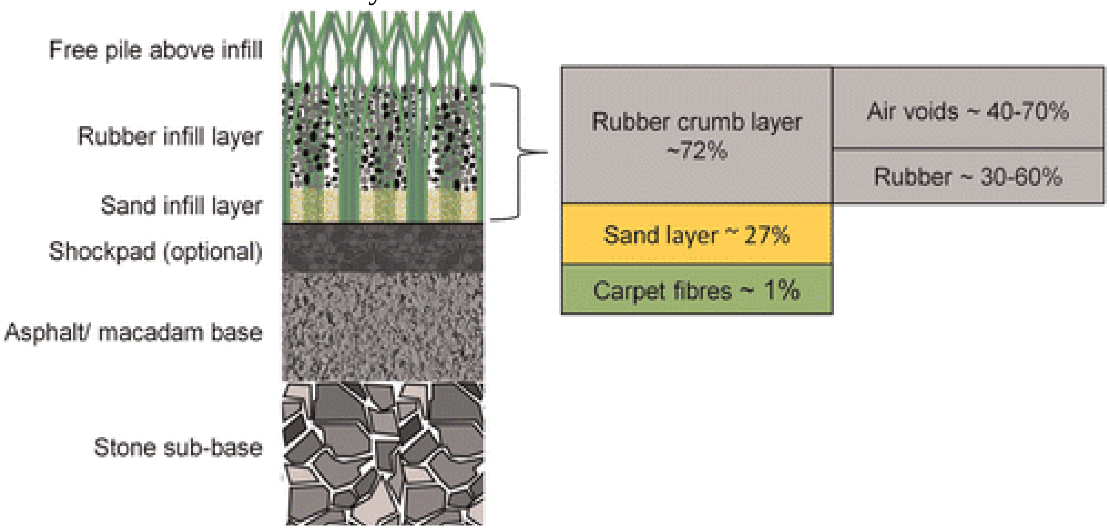

Figure 2 Structure of the third-generation artificial football field. (Fleming et al., 2015)

Rubber is an important filling material for artificial turfs, and its main function is to provide shock absorption and desirable playing characteristics. The amount of rubber infill for an artificial turf depends on the size and function of the field, as well as the type of rubber. An 11-player artificial football field of 7881 m^2 can contain 51 to 87 tons of rubber granulates (Magnusson, 2015).

Traditional rubber fillers consist of three types of granulates, which are styrene butadiene rubber (SBR), thermoplastic elastomer (TPE) and ethylene propylene diene (EPDM). In recent years some other organic fillers such as cork and coconut have been used as alternatives (Fjordefalk, 2018). However, the applicability of these organic fillers is still in the investigating stage.

SBR granulates are rubber from recycled tires, and they in the past they were the most popular filling material previously due to the low price and good properties (Bujak, 2018). SBR granulates with the size of 0.5 to 2 mm are resistant to acid, alkali and alcohol. However, SBR has been found containing black carbon and zinc oxide which can cause environmental hazards as well as negative influences on human’s health (Magnusson, 2015). Hence, other granulate materials such as EPDM and TPE are becoming more popular in recent years. EPDM is a kind of new manufactured industrial rubber with high resistance to sunlight and heat, which is particularly suitable for outdoor environments (Wredh, 2014). TPE is made of a mixture of plastic and rubber with the size of 0.5 to 4 mm. TPE is an environmentally friendly alternative as it can be recycled with melting and reforming (Gustafsson, 2017).

1.2.3 Loss of microplastics from artificial turfs

Environmental risks associated with artificial turfs have been recognized in recent years. Wear and tear of the artificial turfs result in the loss of rubber infill. IVL estimated that artificial turfs in Sweden lose between 0.28 and 0.42 kg of rubber per m^2 per year on average, amounting to a total of 1640-2460 tons of infilled granulates lost per year, which has therefore become the second source of microplastics after tire wear (IVL, 2017). Loss of infilled granulates can be removed via people’s shoes and clothes, melting of snow cleared from the field, drainage, as well as through runoff. Microplastics taken away by shoes and clothes may end up in the water treatment plants after washing the clothes. During snow melting, microplastics can spread outside the artificial turfs. In addition, microplastics lost from artificial turfs through the mentioned pathways are reaching stormwater, which is further reaching marine environments. However, it is uncertain how much of the lost microplastics are transported eventually by stormwater since data on microplastic content in stormwater are scarce.

Filtration methods are now being applied, in order to capture microplastics lost from the artificial turfs and reaching the stormwater. Setting filter bags into stormwater wells is an effective way to capture granulates from artificial turfs. Filter bags are fixed with granulate traps, and held in the well by means of clamping rings and guide plates (***Figure 3***). Filter bags with 0.4 mm pores can capture particles larger than 0.4

mm and at the same time water can flow through the filter bag to the well. Granulates captured by filter bags can be collected and returned to artificial turfs as reused infill, which could therefore reduce spread of most microplastics. Microplastics that are smaller than 0.4 mm cannot be captured by filter bags, and can still flow through pores into stormwater.

Figure 3 Granulate Trap with Filter Bag. (source: Unisport, 2018)

1.3 Microplastics in stormwater

Due to the different ways of microplastics loss including the loss from artificial turf fields, stormwater may accumulate numerous microplastic particles. The amount of microplastics present in stormwater depends on the design of artificial turfs and the availability of filtration appliances (Fjordefalk, 2018). Although some filtration systems have been introduced in several municipalities of Sweden, their effectiveness is still uncertain as the information of microplastics in stormwater is lacking. Therefore, increasing research on microplastic fate in stormwater is necessary to assess the spread of microplastics from artificial turfs as well as designing reasonable mitigation measures.

In order to better understand environmental impacts of microplastics, a number of studies have focused on monitoring quantity and quality of microplastics in freshwater systems and aquatic environments during the last few years (Wang & Wang, 2018). However, studies on microplastics in stormwater are fewer than those in freshwater systems and aquatic environments. Recently, a few theoretical studies have assessed methods for microplastic identification in stormwater from artificial turfs. Methods of quantitative analysis of microplastics from artificial turfs are at the beginning stage of development, and applied projects are quite limited. IVL Swedish Environmental Agency has researched microplastics in stormwater sediments from artificial turfs in 2019. Stereo microscopy has been used as technique to quantify microplastics. Research Institutes of Sweden (RISE) started sampling stormwater with pumps to identify microplastics from artificial turfs in 2019. ICP-MS, FT-IR and electron microscopy were used as techniques in their quantitative analysis. Practical research is less and quantitative estimation is still scarce.

Hence, in this study, some practical measurements have been used to assess the occurrence of microplastics from artificial turfs reaching stormwater, in order to attain a better understanding of the spread of microplastics from artificial turfs and be able to adapt the filtration methods accordingly.

1.4 Aim of the study

The aim of this study is to investigate the spread of microplastics generated by artificial football fields through stormwater systems. Lacking established protocols for microplastic identification and quantification, a research method to identify microplastics from artificial football fields to stormwater has been designed. Properties of microplastic granulates have been assessed and quantities of microplastic contents in different stormwater wells have been estimated. The research questions guiding this work were:

1) What are the characteristics of microplastic particles from artificial turfs?
2) How are microplastics transported from artificial turfs to stormwater?
3) Is it possible to identify microplastics in stormwater with inexpensive methods?

2 Materials and methods

In order to quantify microplastics that are spread from artificial football fields through stormwater systems, four 11-people artificial football fields in Stockholm municipality (Stockholm kommun, Sweden) were taken as sampling fields. Sampling wells were selected according to topology and distribution of stormwater pipes. Microplastics analysis method was developed with information obtained through literature review. Samples were first filtrated in laboratory at the department of Physical Geography at Stockholm University. Subsequently, the samples were sent to Retch Technology in Germany to identify microplastics under stereo microscopy and Camsizer P4.

2.1 Literature review

In this study, the first step was to research reports published by different environmental organizations and institutions in order to evaluate the current level of understanding of microplastic pollutions caused by artificial turfs. The second step was to read through literature that focuses on analytical methods to identify microplastics. Literature review was performed using databases such as Science Direct, Google Scholar and Web of Science. The search keywords used were: ‘microplastics’, ‘water’, ‘marine environment’, ‘artificial turfs’, ‘environmental impact’, ‘stormwater’.

2.2 Sites description

In this study, four artificial football fields in Stockholm municipality were taken as site fields for taking the samples and in order to study the loss of microplastics that reach stormwater network. All four measurement sites are 11-people football fields with an area of 7881 m^2 and located in west of the capital Stockholm. Their names are: Åkeshovs IP, Bromstens IP, Sp ånaga IP and Grimsta IP (***Figure 4***). Water samples were taken from downstream stormwater main holes.

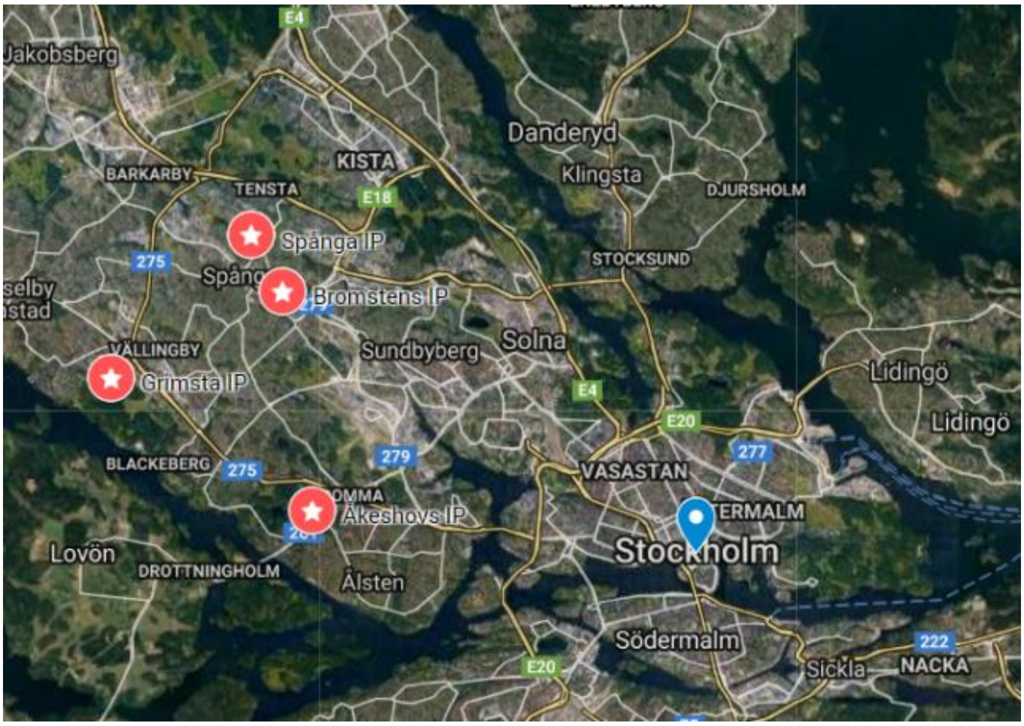

Figure 4 Location of four football fields equipped with artificial turf. (source: Google map)

2.2.1 Åkeshovs IP

Åkeshovs artificial football field is located in the west of Stockholm, 9.3km far from Stockholm centre. Water samples were taken from stormwater wells which are located in the south-east of artificial football field with the lowest elevation 8.14 m (***Figure 5***). The two stormwater wells shown in (***Figure 5***, blue points) are connected to each other. Elevation and flooded areas of Åkeshovs IP is shown in ***Figure 6***. Runoff flows along with the terrain from north (8.62 m) to south (8.14 m). Microplastics from artificial football turf can be transported into stormwater wells by rainfall with the longest route extending over 193 m and the shortest route over 153 m (***Figure 6***).

Figure 5 Satellite map of Åkeshovs IP and location of stormwater wells. (source: Google map)

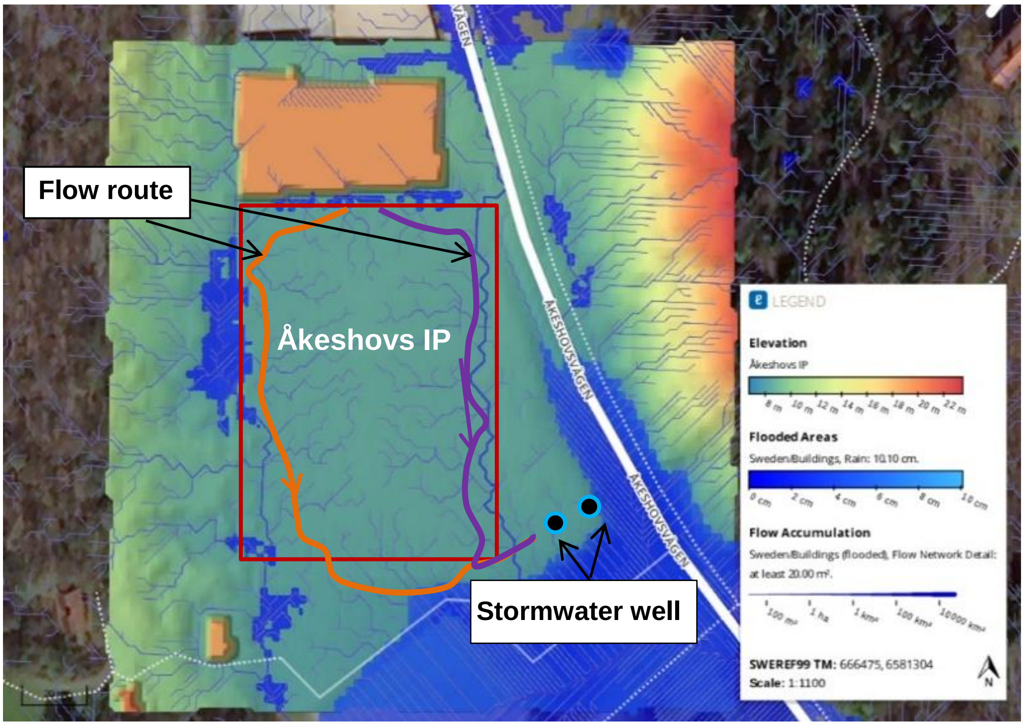

Figure 6 Elevation and flooded areas of Åkeshovs IP. (source: Scalgo Live)

2.2.2 Bromstens IP

Bromstens artificial football field was constructed in 2014, and is located in the north of Sundbyberg, south of Spånga IP. Next to the artificial football field is an 11-people natural grass field (***Figure 7***). The terrain descends from northeast (4.81 m) to southwest (3.65 m). Water samples were taken from two stormwater wells located in the southwest of the area. Microplastics from Bromstens IP could be transported to the stormwater wells downstream by runoff, over a grass-covered football field (***Figure 7***). The longest flow distance is 180 m and the shortest flow distance is 111 m. Elevation of the area and rainfall flow directions are shown in ***Figure 8***. The presence of the grass field might lower microplastic impact at this site by capturing particles in runoff water.

Figure 7 Satellite map of Bromsten IP and location of stormwater wells. (source: Google map)

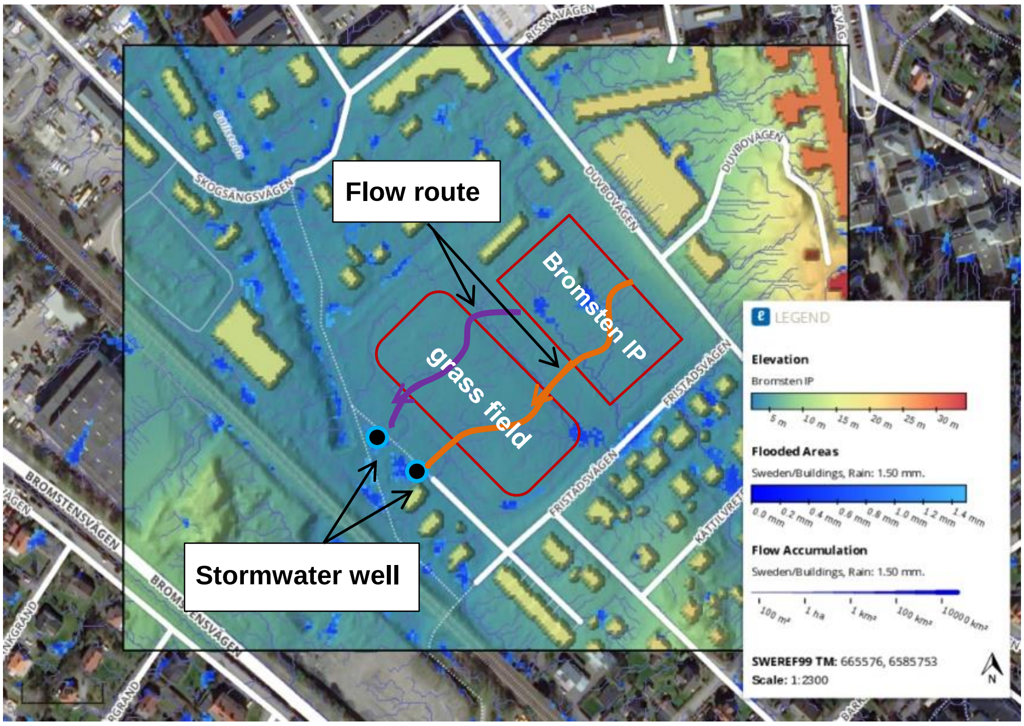

Figure 8 Elevation and flooded areas of Bromsten IP. (source: Scalgo Live)

2.2.3 Spånga IP

Spånga artificial football turf was inaugurated in 1977 with TPE infilled ranging from 0.5 mm to 2.7 mm. It is located in the north of Sundbyberg, and is a regional facility for football, bandy and athletics. The terrain of Spånga area descends from southwest to northeast. Water samples were taken from two stormwater wells located in the northeast of the area (***Figure 9***). One stormwater well is located in the northeast corner of artificial football field, and microplastic granulates could be observed flowing into this stormwater well directly (personal observation from the site visit). The other stormwater well is 60 m away from the well located in the northeast corner, which is the main well for the whole area. Microplastics from Spånga artificial football field is assumed to be accumulated into the stormwater well located in the corner, and then spread to the main stormwater well. Elevation map and the flow routes of microplastics from Spånga IP are shown in ***Figure 10***.

Figure 9 Satellite map of Spånga IP and location of stormwater wells. (source: Google map)

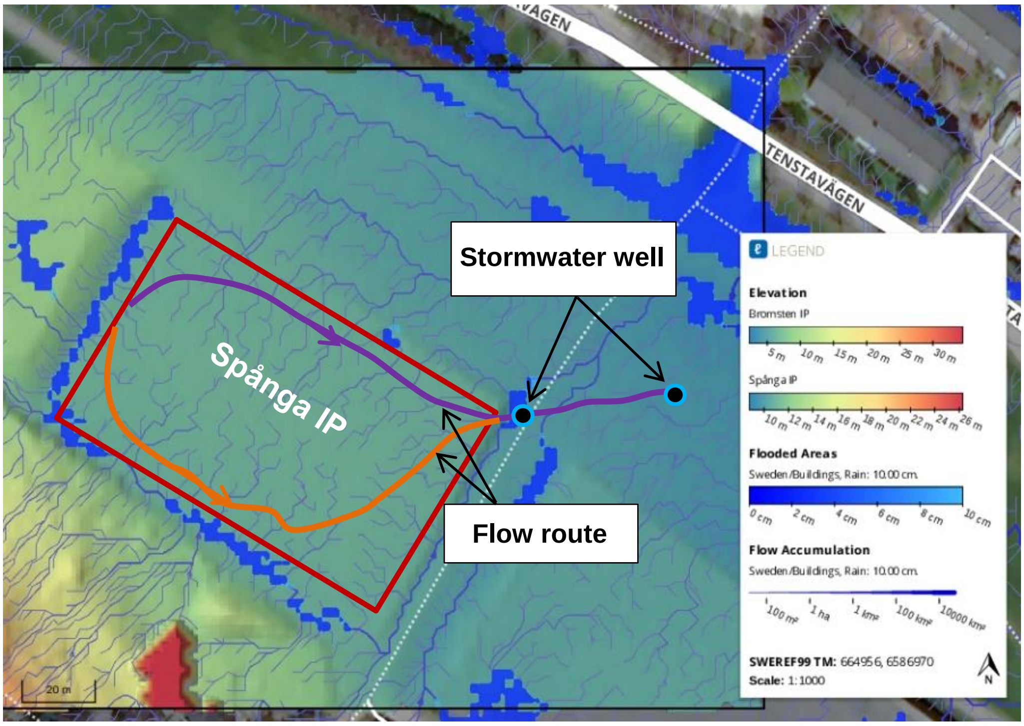

Figure 10 Elevation and flooded areas of Spånga IP. (source: Scalgo live)

2.2.4 Grimsta IP

Grimsta artificial football field is the home stadium of IF Brommapojkarna located in Vällingby. The latest expansion took place between 2015 and 2017 with a total capacity of 5,000 people. The terrain of the area is high in the south and low in the north, with elevation of 19.89 m and 18.02 m respectively. Water samples were taken from one drainage water well located in the northeast corner of the football field, and two stormwater wells located further north with lower elevation 18.02 m (***Figure 11***). The northeast stormwater well is the well that collects water from the basin area. Microplastics from Grimsta artificial football field transport partially to the drainage well through underground pipes. Another part of microplastics transport is carried to stormwater wells by surface runoff. Elevation map and the flow routes of microplastics of Grimsta IP are shown in ***Figure 12***.

Figure 11 Satellite map of Grimsta IP and location of stormwater wells. (source: Google map)

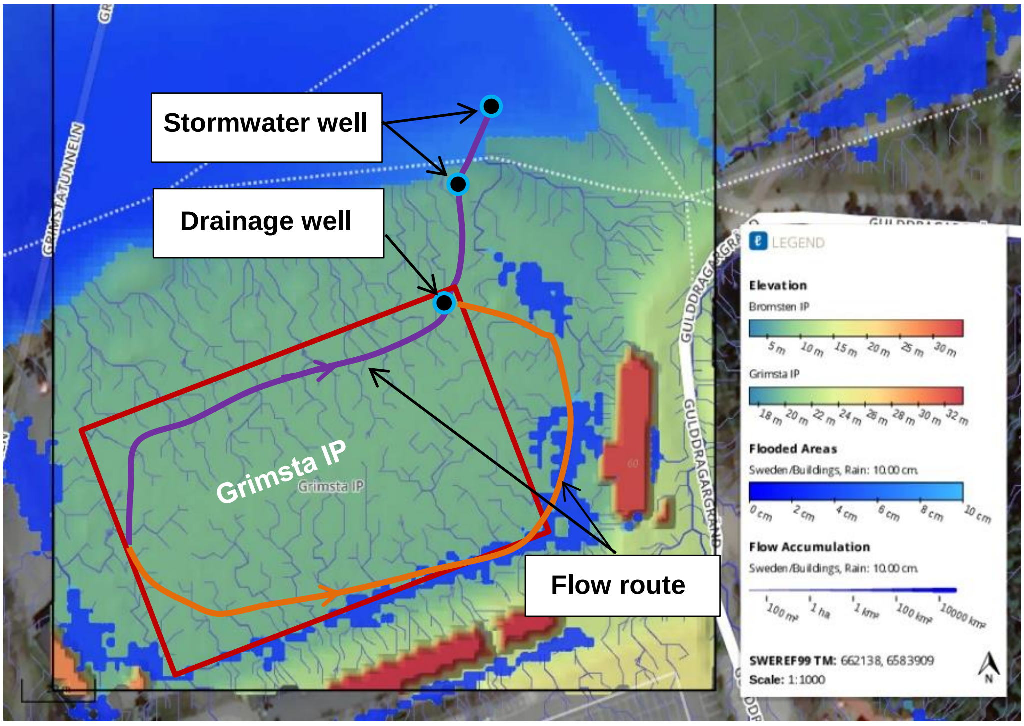

Figure 12 Elevation and flooded areas of Grimsta IP. (source: Scalgo live)

2.3 Sample collection

2.3.1 Granulate sampling

To understand the physical properties of microplastic granulate in artificial turf fields, granulates were randomly collected from the four artificial turf fields. It is important to have in mind that granulates can be damaged by wear and tear of long-term use before entering a stormwater system, or can be degraded into smaller pieces in stormwater itself due to transport. Granulate samples from four sites were artificially fragmented by mortar for five minutes respectively in the laboratory to simulate the wear and tear process, in order to have a better understand of the properties between raw granulates and old granulates. In this study, eight granulate samples are analyzed in total (two for each field; one of raw material and one fragmented).

2.3.2 Water sampling

Distribution of microplastics in water depends on their properties such as shape, size and densities, and environmental conditions such as water density and wind (Prata et al., 2019). The density of microplastic granulates varies between 0.9-1.53 g/cm^3 (Bujak, 2018). Microplastics tend to float on the water surface even though particles have higher density, which happens because air bubbles attached to the particle surfaces can lift the particles to water surface (*ibid*). In this study, samples were taken from surface water with water dispenser, using 500 ml dark glass bottles as containers.

Water samples were taken on the March 13th, March 25th and March 31st respectively from all four sites and under different weather conditions between measuring dates. Each main hole was opened by removing the metal cover lid and expected for the pipe connections within it in order to detect the direction of the flow. Then the water sample was taken from the upstream flow directly from the pipe opening. For collecting water samples, a plastic bottle installed on a telescope stick (***Figure 13***) was used. Samples were stored in 500 ml dark glass bottles and transported to the laboratory.

Figure 13 Lea Levi collecting stormwater. (photo by: Ran Li)

Meteorological data was obtained from Swedish Meteorological and Hydrological Institute (SMHI). Weather conditions are reported in

Table 1 (temperature data from Stockholm-Bromma station and precipitation data from Stockholm station). Precipitation data on March 31st was collected from WSP station located in Gullmarsplan, Stockholm due to data bias from SMHI.

Table 1 Sampling date and time, and meteorological conditions

Sample Time	Temperature (°C)	Precipitation (mm)	Number of bottles
2019-03-13 17:00	2.7	5.3	9
2019-03-25 7:00	1.8	0	12
2019-03-31 9:00	3.9	0.2	17

Water samples were taken from stormwater wells that are connected with the artificial turf fields. Two stormwater wells were selected in each of the artificial turf field. One sample per stormwater well were taken on March 13th, and two samples per well were taken on March 25th and 31st to avoid contingency. In addition, 100 ml drainage sample was taken in Grimsta on March 13th, and one sediment in the well was taken in Åkeshov on March 31st. No sample was taken from Åkeshov on March 25th because the stormwater wells were dry.

2.4 Sample preparation

2.4.1 Filtration

Filtration is an effective approach applied to separate microplastic particles from water samples by use of a filter medium through which only liquid can pass. The medium utilized for filtration includes a funnel, a filter paper and a vacuum system (***Figure 14***), where microplastic particles can be retained in the filter paper (Crawford & Quinn, 2017). The pore size of the filter paper used in this study is 10 µm, which means in this research microplastic particles with a range from 10 µm to 5 mm could detected. Any particles smaller than the lower limit of the mentioned range could not be detected and thus taken into consideration for analysis. Complications can happen during the filtration process since stormwater samples are contaminated with debris and soils that can clog the filter paper. However, because the volume of water sample is small in this study, risks of blockage is assumed to be avoided.

After the filtration, curved mouth washing bottle was used to wash out particles from filter papers into 50 ml glass bottles. The samples were then dried in a dry-cabinet at 50°C to evaporate water. Here it is important to note that the main decomposition temperature of microplastic polymers is between 375 and 500°C (Dümichen et al., 2017). Under condition of 30 to 100°C, water can be evaporated while the polymers would not be degraded (*ibid*).

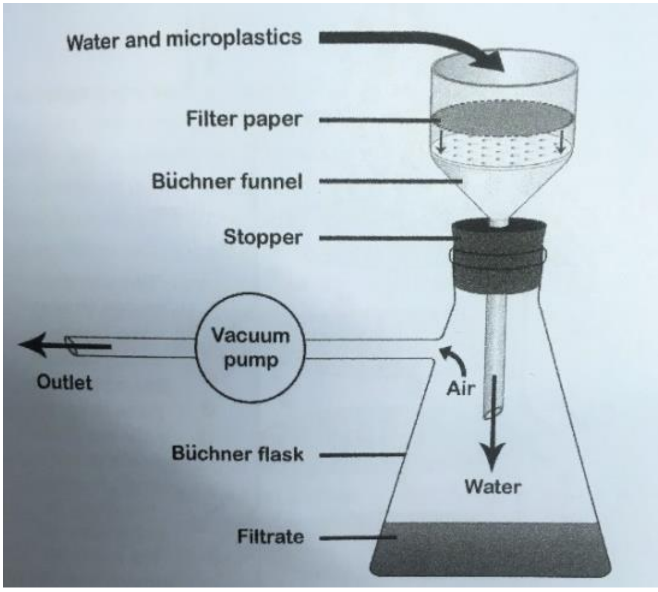

Figure 14 A vacuum filtration system.
(source: Crawford & Quinn, 2017)

2.4.2 Centrifugation

Sediments have been suggested as a long-term sink for microplastics (Van Cauwenberghe et al., 2015). Density separation is a common method to isolate microplastics from sediment samples. Centrifugation was applied in this study to separate microplastics from the sediment sample and in order to research distribution of microplastics in stormwater.

Stormwater samples were filled into centrifuge tubes to do centrifugation with 4000 r/min rotating speed for 4 minutes. In addition, clean water with plastic granulates was centrifuged as blank control. After the centrifugation was done, the supernatant was extracted and dried in the dry-cabinet to obtain microplastic particles.

2.5 Microplastic identification

2.5.1 Visual analysis with stereo microscopy

Stereo microscopy is a variant of optical microscopy designed for sample observation with low magnification. Stereo microscopy can provide three-dimensional erect and laterally-correct image, typically light reflect from the surface of object rather than transmit through it. A stereo microscopy produced by WILD Company with an enlargement up to 40x was used in study to evaluate type and appearance of microplastic particles from water samples (***Figure 15***).

Veronika Köhler from Extrakta Strauss GmbH analyzed and took photos dried water samples with stereo microscopy at laboratory Extrakta Strauss GmbH in Germany. Samples were observed with 6.4x, 16x, and 40x magnification respectively. According to the scale ruler, particles with a size range between 1mm to 5 mm were considered as microplastics. Symbols '○', '+', '++', '+++', '++++' were used to record the quantity estimation of microplastics in different samples. '○' represented zero microplastic were found. '+' represented that several scattered particles of microplastics can be identified in a photo. '++' represented that an amount of microplastics was concentrated in only one part of the photo. '+++' represented an amount of microplastics that was spread in several concentrated areas of the photo. '++++' represented a larger amount of microplastics that almost covered the whole photo. The same indexing was used to analyze the impurity contents of the samples. '○' represented the sample was clean. '+' represented that a few sand and soil were found, and the filter paper was grey (after filtration). '++' represented that an amount of black particles were mixing with microplastics, and the filter paper was black (after filtration). '+++' represented an amount of black particles and some fibers were found, and filter paper was black (after filtration). '++++' represented an amount of black particles and fibers were found, and filter paper was black (after filtration).

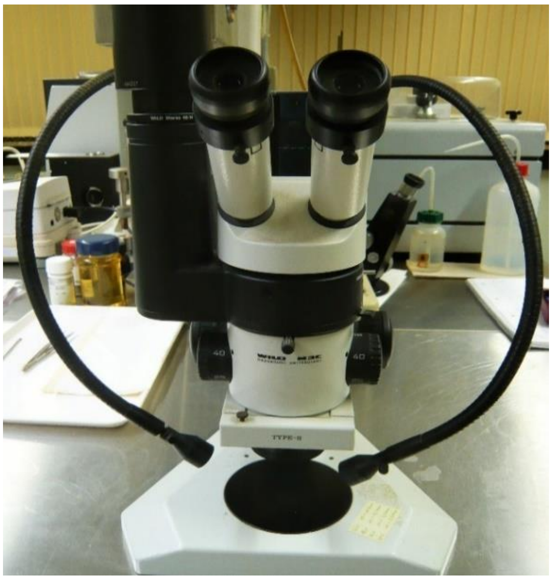

Figure 15 Wild M3C Microscopy at Extrakta Strauss GmbH.
(photo by: Veronika Köhler)

2.5.2 Particle size analysis with Camsizer

In this study, Camsizer P4 was used to analyze the characteristic of microplastic granulates from different artificial turf fields. Camsizer P4 as one shown in the ***Figure 16*** produced by Retsch GmbH is a particle sizer for analysis of particle size and particle size distribution in a defined sample. The principles of measurement are laser diffraction and dynamic image analysis. Camsizer P4 works with two cameras and makes 3D pictures for each particle while the sample falls through the case funnel. Eight granulate samples were analyzed with Camsizer P4 by Veronika Köhler at the laboratory Extrakta Strauss GmbH in Germany. Each sample was tested by three times in order to avoid bias and the data used for analysis was the median data.

Figure 16 The Camsizer P4 dynamic image analyzer.
(source: Retsch GmbH)

3 Results

3.1 Pathways for microplastics from artificial turfs to stormwater

At the selected field sites, runoff due to rainfall is a main pathway transporting microplastics to stormwater wells during the summer and autumn, while in the spring microplastic accumulated in cleared snow can be transported by meltwater. Microplastics from artificial football fields spread following the terrain slope to stormwater wells during rainfall. ***Figure 17*** shows the observation of microplastics spread from Åkeshovs IP after rainfall. It can be seen that large amount of microplastics are spread on the road and soils surrounding Åkeshovs IP due to rainfall-runoff process. These microplastics could be transported further downstream by runoff and stormwater system to stormwater wells.

Figure 17 Microplastics spreading route from Åkeshovs IP. In the photographs, microplastic is easily identified as the bright green fragments (photo by: Ran Li).

Microplastics granulates were observed in close surroundings of stormwater wells, which also indicates that stormwater wells are one of the destinations to which microplastics are transported by runoff and where lost part of microplastics from artificial football fields can be found. The stormwater well located in the northeast of the Spånga artificial football field has the shortest straight distance to artificial football field among the four investigated sites, with a straight distance of 7 m (***Figure 9***). ***Figure 18*** shows microplastics from Spånga IP transported to the nearest stormwater well. More microplastic granulates and plastic straws had been collected in this stormwater well compared to the farther one located 50 m away. Stormwater wells located close to the artificial football fields have higher likelihood of trapping and concentrate microplastics if the topography allows for the runoff to flow through that path.

Figure 18 Stormwater well located in Spånga IP collecting microplastics. (photo by: Ran Li)

Snow clearance removes a large amount of microplastic granulates, which can be an indirect pathway of transporting microplastics to the stormwater system. The cleared snow is gathered around the artificial football field as shown in ***Figure 19***. Microplastic granulates are left as snow melts. This 'microplastic-rich snow' has been observed in Bromsten IP and Spånga IP during field work. Some of these microplastic granulates can spread to stormwater via snow melting and wind transport, but the quantity is uncertain. The remaining microplastic granulates are either recycled as waste or refilled into the artificial football field.

Wind spreading is also one of pathway through which microplastics are transported to stormwater. The amount and exact paths of microplastics transported this way are challenging to observe and quantify. The movement distance and direction of microplastics depend on wind speed and direction. Wind can not only spread microplastics from artificial football fields to stormwater, but also move microplastics from surrounding soils to stormwater. In contrast, grass-covered surfaces trap microplastics as shown in ***Figure 17***.

Figure 19 The 'microplastic-rich snow' located in Bromsten IP. (photo by: Ran Li)

3.2 Properties of microplastics from artificial football fields

3.2.1 Size distribution of the granulates

Table 2 shows the median size of granulates from four artificial sites. Median size of fragmented granulates is larger than raw granulates. Åkeshov IP has the largest median size of granulates infill, and Spånga IP has the smallest granulates infill. The size of raw granulates is similar comparing between Bromsten IP and Grimsta IP. However, median size difference between raw granulates and fragmented granulates are largest in Grimsta IP. The size difference is 792.3μm.

Table 2 Median size of granulates of the each sample.

Site	Median size of raw granulates (μm)	Median size of fragmented granulates (μm)
Åkeshov	2155.38	2684.82
Bromsten	1702.92	1896.25
Spånga	1638.71	1659.86
Grimsta	1722.92	2515.22

Figure 20 shows the size distribution of the granulates (G) from the four artificial football fields. Value P3 represents the percentage of granulates in different size intervals (blue bars), and value Q3 represents the cumulative sum in percentage (orange lines). All the detected granulates have diameters smaller than 5000 μm (5 mm), and can thus be defined as microplastics. Approximately 90% of the detected granulates are between 1 mm to 3 mm in size, and 1.3% are larger than 3 mm. Granulates with a size of 1 mm to 2 mm account for the highest proportion, especially in Spånga IP and Grimsta IP, where more than 60% of granulates are within that range. The size of granulates from Åkeshovs IP is different compared to the other sites, with 32.4% granulates between 1 mm to 2 mm and 39.5% between 2.3 mm to 3 mm. All granulates from Spånga IP and Grimsta IP are less than 3 mm.

Figure 21 shows the size distribution of the fragmented granulates (FG) that simulate wear under field conditions. The proportion of large granulates in the fragmented samples is higher than that of raw granulates, although all the granulates are less than 5 mm as well. Approximately 81% of the destroyed granulates are concentrated between 1 mm to 3 mm, and 14 % are between 3 mm to 5 mm. In Åkeshovs IP, size of granulates between intervals of 1 mm to 2 mm, 2.5 mm to 3 mm, and 3.1 mm to 5 mm are account for more than 20% respectively. In the other three artificial turfs, granulates between 1 mm to 2 mm in size are dominant; however, the proportion of this size class is smaller compared to raw granulates. It should be noted that fragmented granulates between 3.1 mm to 5 mm are 28% more frequent than raw granulates from Grimsta IP.

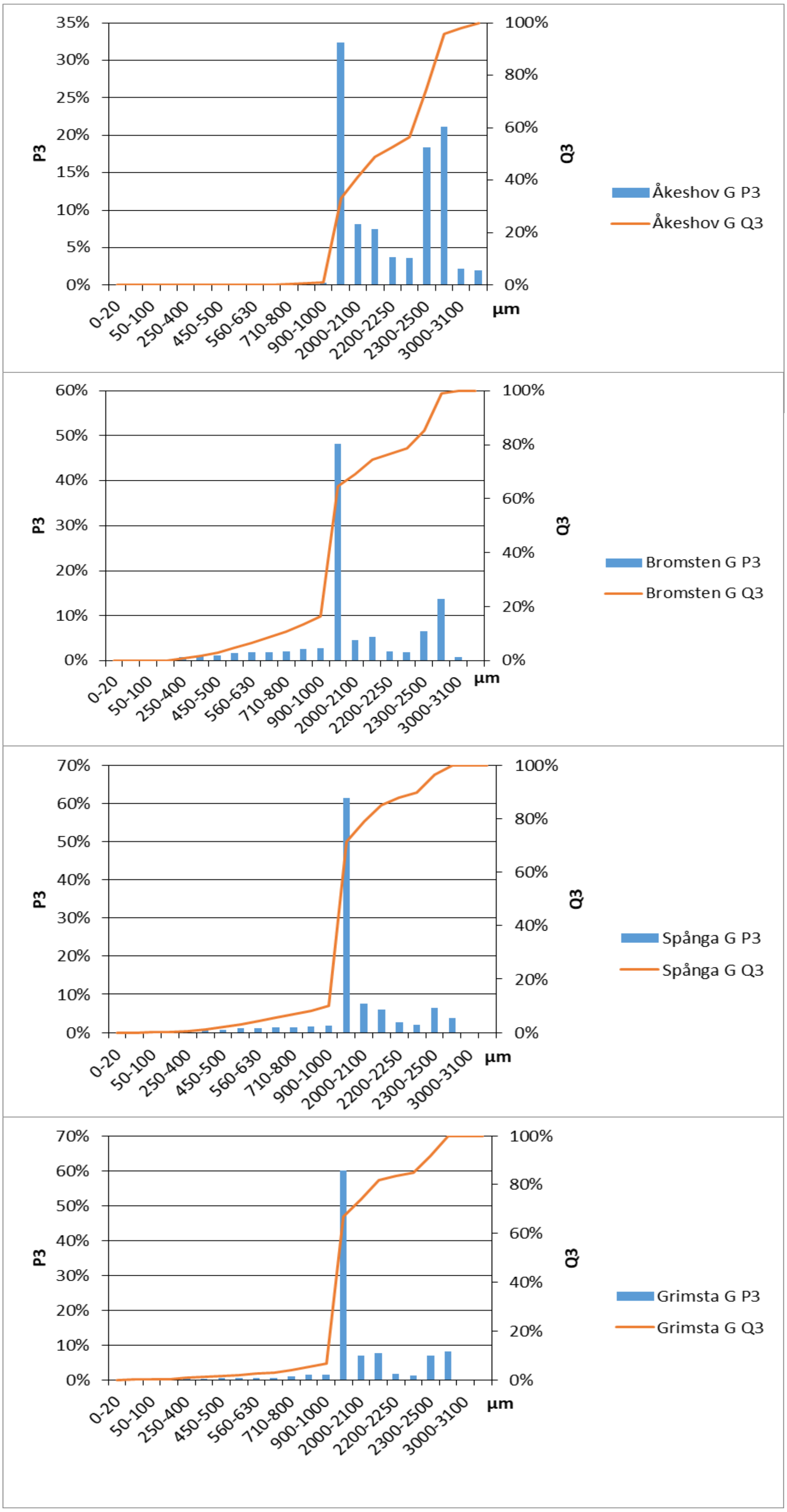

Figure 20 Size distribution of granulates from four artificial turf sites.

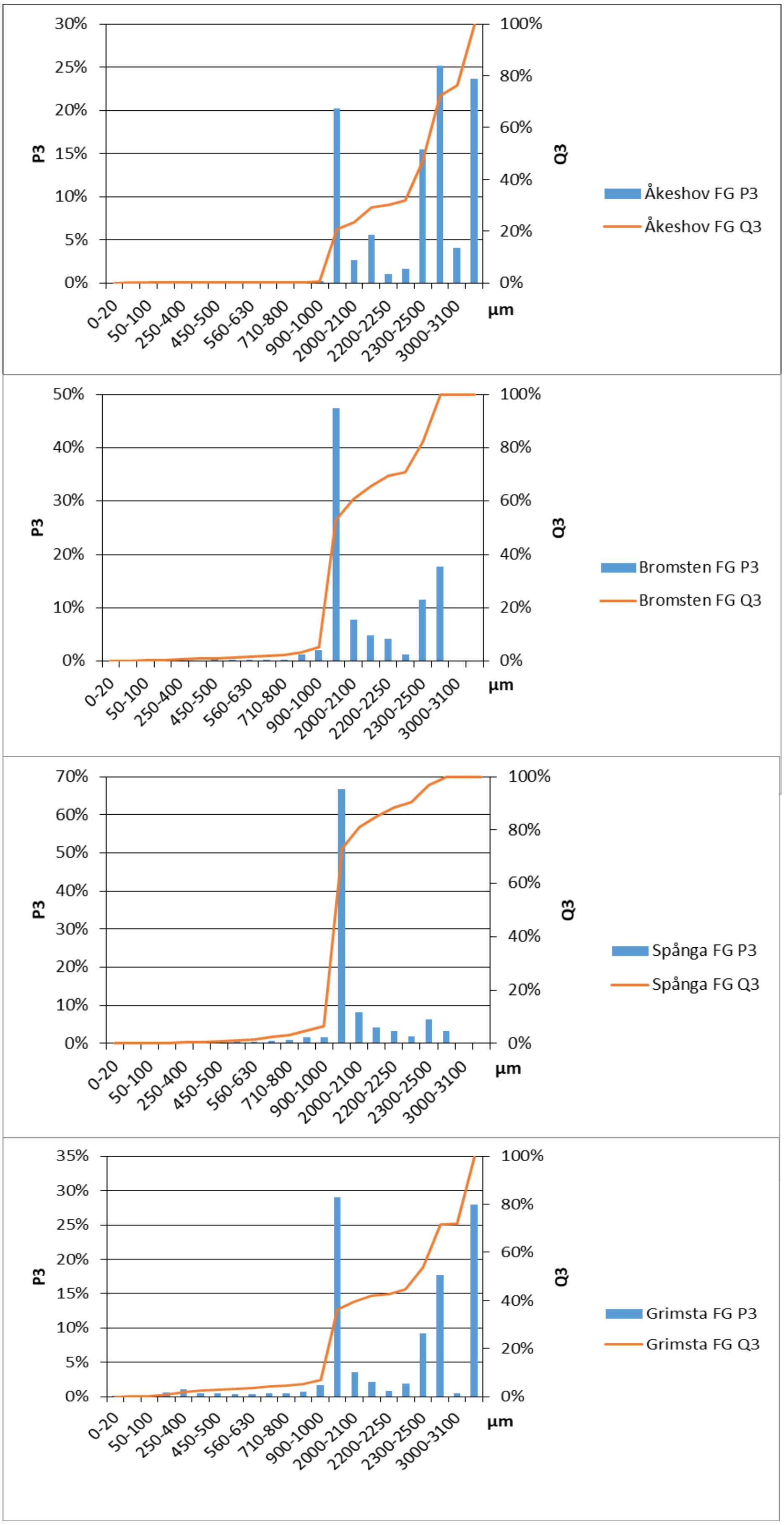

Figure 21 Size distribution of fragmented granulates from four artificial turf sites.

3.2.2 Shape properties of the granulates

Shape of the granulates from artificial football fields is between rectangular and spherical. ***Figure 22*** shows the average spherical index of the granulates, and b/l3 is the shape parameter of the granulates. If b/l3 equals to one it means that the granulates in one size range are perfectly spherical. On the other hand, if b/l3 equals zero it means that the granulates look different from different angles, for example cubic or triangle shape

The median spherical index of granulates from four artificial football fields is between 0.586 to 0.655, which means the shape of granulates is comparable to a sphere, but it also shows some edges. Granulates from Spånga IP are more spherical than those from the other sites. The spherical index of fragmented granulates is higher than that of raw granulates, except from Åkeshov IP. Granulates from Åkeshov IP became more angular after wear, unlike granulates from the other three artificial turfs that became more spherical.

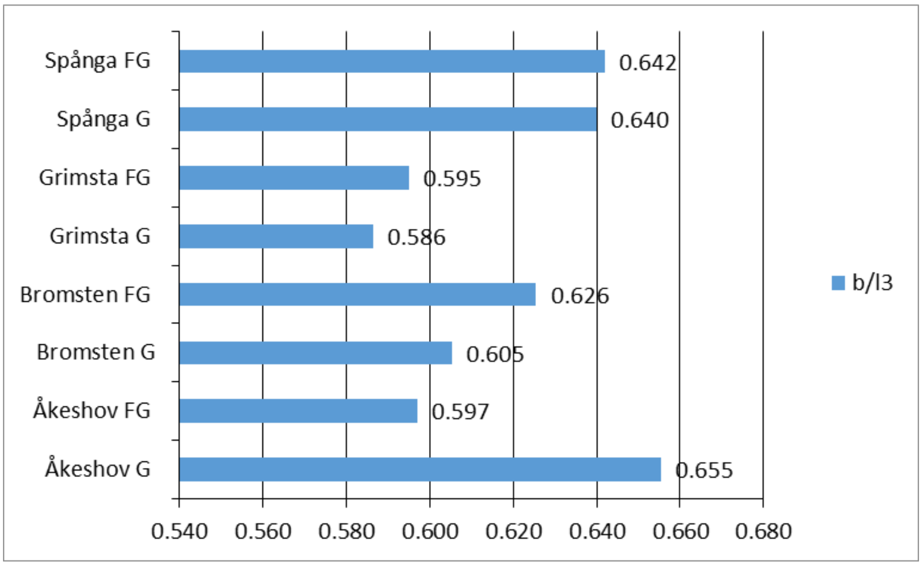

Figure 22 Median spherical index of granulates from different sites and subjected to either no treatment (F) or simulated tear and wear (FG).

3.2.3 Distribution of microplastic granulates in stormwater

In this study, although water samples were taken directly from the flow from a pipe opening into the body of a main hole, there could still be some sediment mixed with stormwater caught within a sample. In order to investigate distribution of microplastics in stormwater, experiments were simulated in the lab.

Distribution of microplastic granulates in stormwater under different conditions shows in ***Figure 23***. Microplastic granulates are floating on the surface of water when they flow into the water as the ***Figure 23a*** shows. In ***Figure 23b*** illustrates how using centrifugation to simulate the shaking process, microplastic granulates accumulated on the bottom. However, if microplastic granulates were added into the stormwater with sediment, mixed sediments and microplastic granulates can be distributed both on the surface as well as in the bottom, as the ***Figure 23c*** shows.

The simulation experiments illustrate that these microplastic granulates can exist both on the surface of stormwater and in the sediment of stormwater wells. These microplastics could be transported into surface of stormwater by rainfall, and during the heavy rain and wind these microplastics would be mixed into sediments. Hence, once microplastic granulates reach the stormwater wells, they are distributed between the stormwater surface and in the sediments. Since the density of microplastics is similar to organic materials as well as water, separation of microplastics from stormwater is difficult.

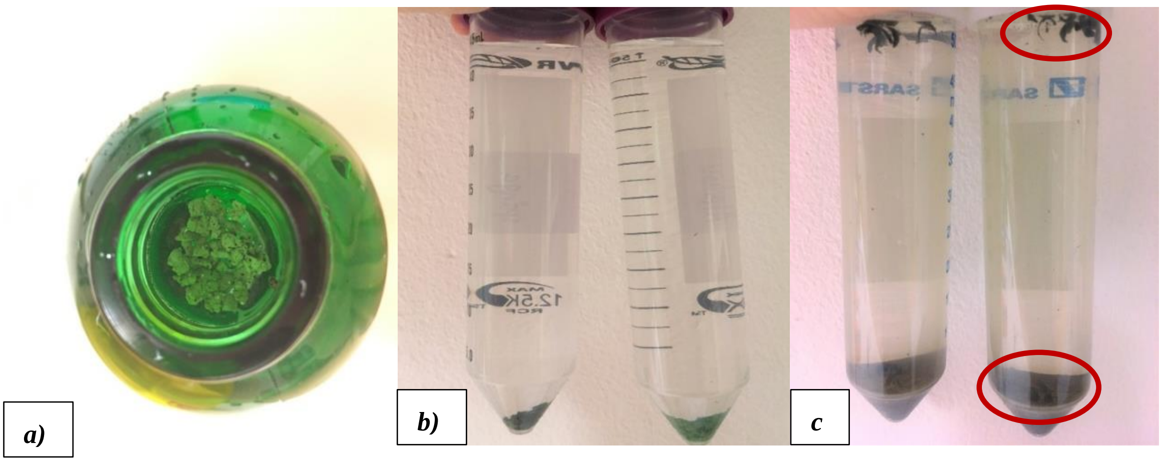

Figure 23 Distribution of granulates in stormwater under different conditions.

a) Microplastics granulates concentrated on the top of stormwater (without centrifugation).

b) Microplastics granulates concentrated at the bottom of stormwater (after centrifugation).

c) Micriplastics granulates present both on the top and at the bottom in stormwater sediments (after centrifugation).

3.3 Identification of microplastics in stormwater samples

3.3.1 Water samples under stereo microscopy

Figure 24 shows dried stormwater samples under naked eyes. After filtration, particles with size larger than 10 µm remain in samples including microplastics, sands, soils, plastic straws and other unknown organic materials. However, the amount of microplastic, sediments and other materials in samples from different sites is different. For instance, microplastic granulates and artificial grass straws can be seen by naked eyes in Spånga samples, but Grimsta samples are clean and nothing can be seen.

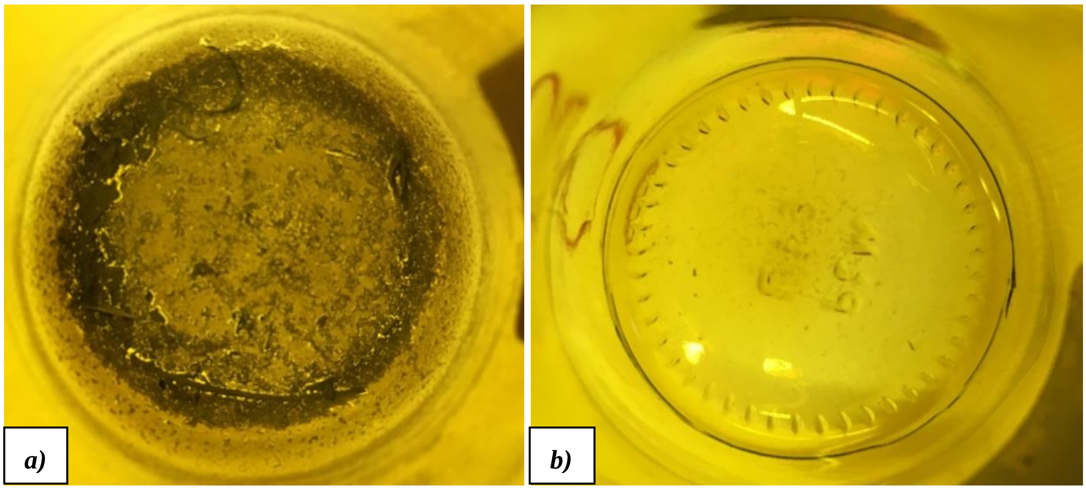

Figure 24 Dried stormwater samples under naked eyes. (photo by: Veronika Köhler)
a) *Spånga sample (3-31); b) Grimsta sample (3-31)*

Figure 25 shows the pictures of a water sample under stereo microscopy with different magnification. Greenish particles are found under microscopy, which could be identified as microplastics subjectively. However, stereo microscopy cannot identify microplastics quantitatively since large amount of fibrous material (possibly roots) and soil are mixed and intertwined with microplastics. Soil and sand with microplastic dimensions could be easily be mistaken as microplastics. Fibrous materials are found in all analysed water samples, though their origin is unknown. The presence of these fibres has influenced the identification of microplastics.

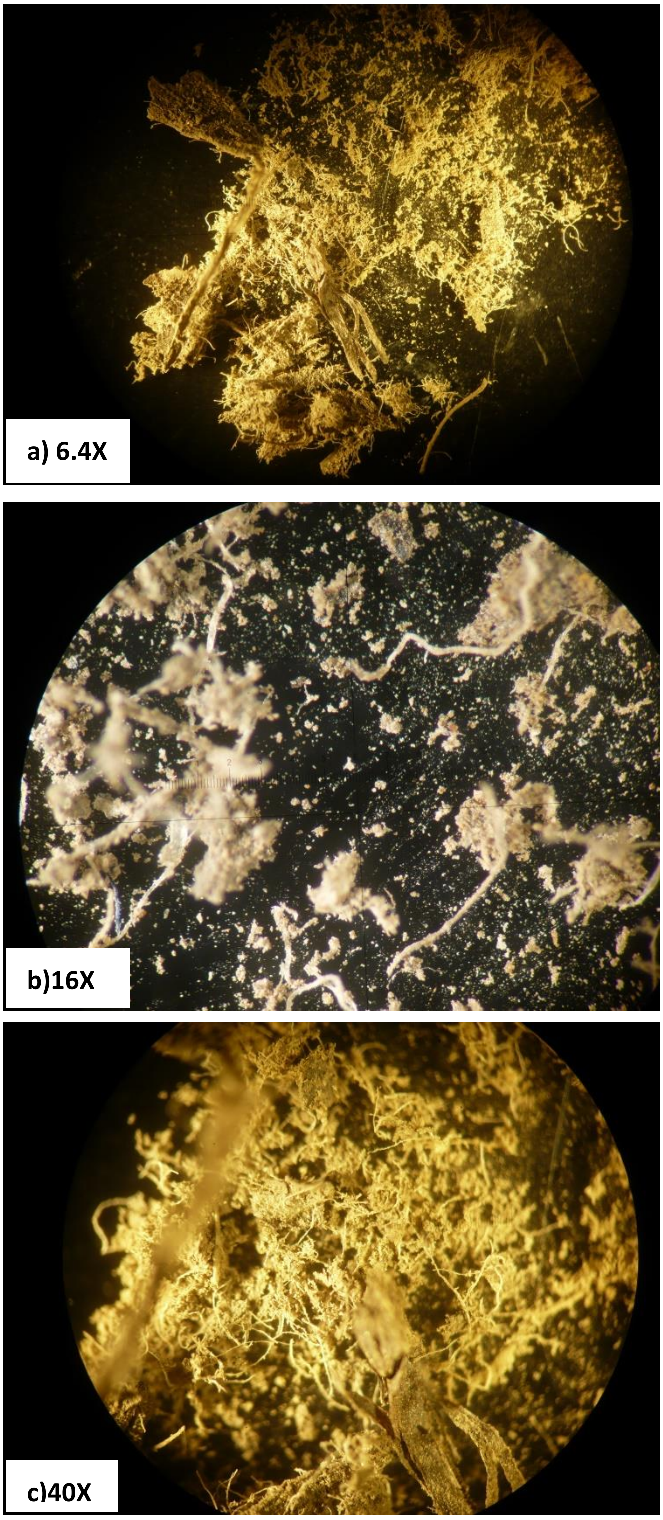

Figure 25 Spånga sample (3-31) under stereo microscopy with different magnification (6.4x, 16x and 40x). (photo by: Veronika Köhler)

3.3.2 Occurrence of microplastics in stormwater samples

According to the pictures of water samples under microscopy, ***Table 3*** and ***Table 4*** indicate microplastic content and impurity in different stormwater samples respectively. 'SW1' is the stormwater well closer to the artificial turf and 'SW2' is the stormwater well further away. '+' is used to indicate the microplastic and impurity content in samples (additional '+' allow a qualitative ranking of the samples); '○' means zero microplastic or zero impurity in samples.

Microplastic content is similar to impurity content. Stormwater wells with high impurity content have also higher likelihood to have more microplastics. In the study of eight stormwater wells, stormwater well 1 from Spånga IP (located in the northeast) has the highest microplastic content, as well as stormwater with highest impurity based on my visual identification approach. Stormwater wells located close to the artificial football fields are more likely to contain high microplastic content, as found in samples from Spånga IP and Grimsta IP (***Table 3***). Microplastic contents are similar for the two stormwater wells in Åkeshovs IP and Bromsten IP, possibly because the two stormwater wells are located close to each other (distances are 5 m and 30 m respectively).

In addition, microplastic content and impurity content could be influenced by precipitation. It has rained on March the 13th with 5.2 mm (***Table 1***) and stormwater wells in Bromsten IP contained more microplastics on that day compared with the other days (***Table 3***). On March 25th there was no water in stormwater wells from Åkeshovs IP. On March the 31st there was a small rain event (0.2 mm); hence, the results are almost the same as on March 25th.

Compared to stormwater wells, the content of microplastics is higher in drainage wells. Drainage wells located in Grimsta IP shows greenish particles mixed with sediments, which are more frequent than in the stormwater wells. Furthermore, in the case of the same stormwater well sediments contain more microplastics than surface water.

Table 3 Microplastic Content Index in Stormwater Samples

Date	Åkeshovs IP			Bromsten IP		Spånga IP		Grimsta IP		
	SW 1	SW 2	sediment	SW 1	SW 2	SW 1	SW 2	SW 1	SW 2	Drainage
3-13	++	++		+++	+++	+++	++	+	+	++++
3-25				+	+	+++	++	+	○	
3-31	++	++	+++	+	+	+++	++	+	○	

Table 4 Impurity Content Index in Stormwater Samples

Date	Åkeshovs IP			Bromsten IP		Spånga IP		Grimsta IP		
	SW 1	SW 2	sediment	SW 1	SW 2	SW 1	SW 2	SW 1	SW 2	Drainage
3-13	+++	+++		+++	+++	+++	++	++	++	++++
3-25				++	++	+++	++	+	○	
3-31	+++	+++	++++	++	++	+++	++	+	○	

4 Discussion

4.1 Uncertainties, knowledge gaps, and outlook for future work

In this study, the evaluation of microplastics in stormwater was quite limited and was done under several assumptions due to difficulties in extracting microplastics from stormwater and separation from suspended materials (mineral or organic). The size of microplastic granulates from artificial football fields are mainly between 1 mm to 3 mm. However, there are soil particles in the same size range as microplastics (e.g., sand grains), which could be visually identified as microplastics by mistake. During filtration, filter paper with 10 μm mesh could extract all the particles larger than 10 μm, including organic and mineral fragments of various origin, which makes identification of microplastics with microscopy even more challenging and demanding. Nowadays, filtration and density separation are commonly used as separation method, but it is challenging to operate them in practice due to the fact that the density of microplastics is similar to the density of stormwater and that there are organic particles similar to microplastics that can be found in the samples. Moreover, microplastics can be easily stuck within sediments in stormwater. Therefore, new techniques of separating microplastics from stormwater based on the unique characteristics of microplastics need to be developed.

The source of microplastics in stormwater added uncertainty in this study. Although stormwater wells were selected based on the location, topography and data about water system around artificial football fields, these fields are not the only potential source of microplastics. Microplastics could also originate from other sources such as road wear and abrasion of tires. Microplastics found in stormwater samples have possibility to be transported by runoff also from nearby roads. Therefore, unless microplastics in the artificial turfs are marked or unambiguously identified, microplastics collected in stormwater could have originated from other sources.

Transportation of the samples from the field to a laboratory can also increase the uncertainties of the results. A part of microplastics might be lost during the filtration process, because microplastics could be absorbed by filter paper. Apart from filtration, long-distance transportation to a laboratory in another country (in this case Germany) is another risk for microplastics loss. Small microplastic fragments can be easily attached to sample bottles or other surfaces and for this reason the identification of microplastics should avoid long distance transportation.

Due to time and weather limitations, stormwater samples were only taken on three different weather conditions in this study. Even though the small number of samples might not be sufficient enough to draw conclusions about the relationship between microplastic content and weather conditions, they could still be indicative and represent an important step towards assessing microplastics content and behavior in stormwater. In future studies, stormwater samples are suggested to be taken continuously during the whole year, always following the same protocol to ensure homogenous sample quality.

Since there are interference factors in field measurements, lab simulation experiments could support future studies. For example, it would be interesting to test how turf responds to various types of artificial conditions. Preparing a square surface of artificial football turf and simulating runoff with clean water would help identifying how many microplastic fragments would be lost from artificial football turf. In this way, not only precipitation amounts and intensity could be controlled, but also interference from other particles would be effectively avoided.

4.2 Methods for microplastics identification

In recent years, with the increasing attention on microplastics, the discussion on the identification of microplastics has also increased. Based on experience gained in this work (Section 3.2.3) combined with a literature review (Section 2.1), in this section advantages and disadvantages of available methods for microplastics identification are discussed.

In this study, stereo microscopy was used to identify microplastics, which is an economic and simple method to assess morphological characteristics of microplastics. However, the stereo microscopy has shown to be neither suitable for quantitative analysis nor identification of microplastics from stormwater samples, and the assessment was conducted using an approach that is quite subjective. The challenging and difficult part of this study was to visually distinguish microplastics from other particles of similar size and shape, especially for the samples that contain organic particles (root fragments, plant detritus) as in this study. Hence, spectroscopic approaches are required for microplastic quantitative analysis.

Spectroscopic methods for microplastic identification include scanning electron microscopy (SEM), Fourier-transform infrared (FT-IR) spectroscopy and Raman spectroscopy. SEM is a technique that characterizes surface morphology of microplastics by the interaction of an electrons beam with the sample in order to measure the secondary ions (Rocha-Santos & Duarte, 2015). X-ray radiation can also be detected by scanning electron microscopy. This radiation can be analyzed with a specially designed spectrometer, so-called scanning electron microscopy-energy dispersive X-ray spectrometer (SEM-EDS), which measures the x-ray radiation emitted from the sample. Plastic particles can be separated from organic particles because of the specific, high carbon concentration contained in plastics (Bujak, 2018). SEM-EDS can be used to analyze SBR, EPDM, TPE and plastic straws, providing granulates with light color (*ibid*).

FT-IR microscopy is often used to identify the polymeric composition of the microplastics. FT-IR has the low requirement for sample preparation, and clean-up sample is enough. Microplastic analyses with FT-IR are well established and the results are reliable. However, the equipment and sample processing are expensive and professional persons are required with data processing. As for microplastic granulates in artificial turfs, FT-IR can only be used for analyzing TPE granulates as well as plastic straws, which is not suitable for SBR and EPDM granulates due to their black and rubber materials (Bujak, 2018).

The technique of Raman spectroscopy (RS) resembles the FT-IR and involves a sample being irradiated with a monochromatic laser that creates vibrations in a molecule. Raman spectra provide information about bonding within the material and about networking structures (Rocha-Santos & Duarte, 2015). Small particles, including even dark particles between 1 to 20 µm can be analyzed by RS with high spatial resolution. Furthermore, RS can fast perform chemical mapping with automatic data collection (Li et al., 2018). However, the analysis by RS is time consuming and although RS can detect type of particles theoretically, the method has not been applied in microplastic identifications yet.

According to the literature review, in recent years FT-IR and SEM are common quantitative methods of microplastic identification in oceans. Since microplastics has been one of the most discussed environmental problems in recent years, and more and more applied studies have been conducted, quantitative identification of microplastics is improving in terms of accuracy, simplicity and economy. However, relatively fewer studies present methods and results on microplastics in stormwater, motivating further research in this area.

4.3 Mitigation measures of microplastics in stormwater

As artificial turfs have been studied as an important source of microplastics, municipalities and research institutes in Sweden have become aware of the environmental impacts of artificial turfs and some mitigation measures have been proposed to decrease the emission or transport of microplastics. On one hand, loss of microplastics can be reduced from the source by regular maintenance of artificial turfs. On the other hand, they can also be captured during their transport along different pathways.

Nowadays the most commonly used artificial turfs are the third-generation turfs with rubber infill granulates, which results in a large amount of loss of microplastics. Loss of microplastics has been observed spreading to the environment through mechanical snow removal, stormwater, and when mixed or trapped in sand. Reducing the snow removal in winter is a simple and effective measure to avoid spreading of microplastics. Matches and trainings can be coordinated between several artificial football fields in winter with an overall booking arrangement in order to reduce snow removal in total. Regular maintenance of artificial football fields can not only increase their life span, but also can be used as a measure to prevent spreading of microplastic granulates. During maintenance, deep-cleaning can help to remove unwanted particles from the artificial turfs and increase available store depth for microplastic granulates. Besides maintenance, reducing the quantities of microplastic granulates used for infill is a direct way to mitigate loss of microplastics. Lidingö municipality has positive experience of using granulates made of natural materials such as coconut and cork. Some manufacturers have proposed the fourth-generation artificial turf without granulates, which prevents the spread of microplastics from the source. However, the application effect of the fourth-generation products is still under test. In Germany and the Netherlands, eight fourth-generation artificial turfs were replaced after several years due to fiber release (Krång et al., 2019). Recently, a fourth-generation artificial turf has been built in Stockholm with only sand infill, and it has met the expectations of environmentally-friendly requirements (*ibid*). Choice of infill granulates of artificial turfs should be considered based on site conditions, function requirements, price, as well as environment and sustainability.

Technical installations are effective ways to reduce the spread of microplastics through several different pathways. Installation of underlying sealing layers can be proposed to reduce spreading of microplastics. Most artificial football fields are well drained and are opened at the bottom, allowing part of the water to be transported through the drainage pipes while the rest flows directly to the groundwater and from tehre eventually to surface recipient (Krång et al., 2019). Underlying sealing layers should ensure water purification before it flows to drainage pipes.

Filtration installations surrounding stormwater wells are also effective measures to capture microplastics. Some municipalities have installed filter bags in stormwater wells to avoid microplastics reaching stormwater. In general, the pore size of a filter bag is 0.4 mm which can capture ca 99% microplastics from artificial turfs according to the properties of granulates. The filter bags need to be emptied regularly to avoid clogging the trap. Since filter bags are effective and inexpensive installations, they can be widely used in stormwater wells and drainage wells surrounding artificial turfs. However, the capacity of the filter bags and the installed locations should be considered in practice. Besides filtration bags, a filtration well installation is proposed in order to capture smaller microplastics. All the stormwater and drainage water are led to the filtration well (***Figure 26***) with filter materials such as sand, and during filtration not only microplastics but also metals or other particles can be settled before flowing out of the well. In order to avoid clogging, the filtration well should be installed in a bigger well with a balancing function that allows bigger particles to be deposited. However, the filtration well is difficult and expensive to be installed especially for the existing pipe system.

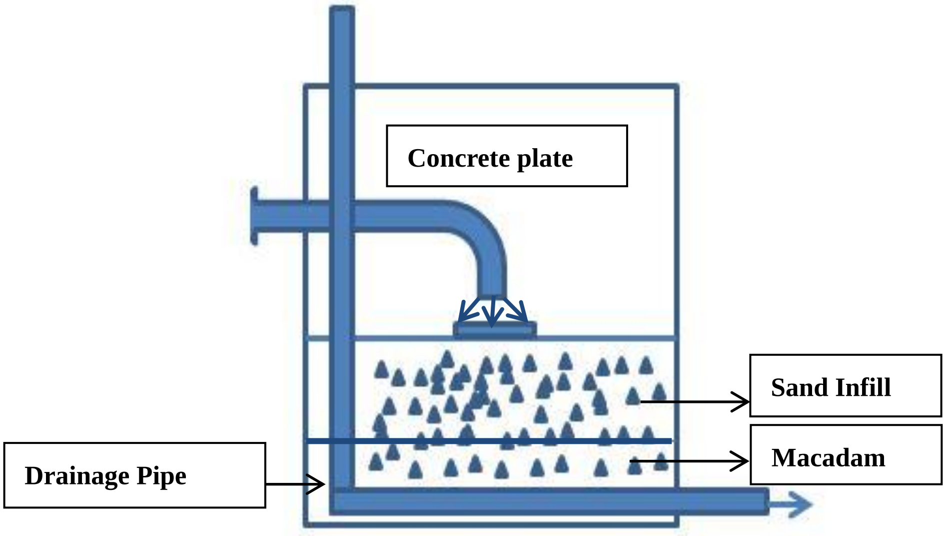

Figure 26 Filtration well installation.
(Reference: Skiss inspired by drawing by Skellefteå kommun)

Microplastics from artificial turfs are generally small and low-density particles, and they are difficult to be separated from sediments once mixed. Hence it is better to capture microplastics before they get transported from artificial turfs. When compared with other existing techniques for preventing microplastics loss, filter bags are the most economical and effective method at present. Based on the available literature data, filter bags are worth promoting as measures to mitigate microplastics entering stormwater. At the same time, the development of alternative material for microplastic granulates is essential as well, since microplastics from artificial turfs could be settled in surrounding soils, which are difficult to be degraded and have persistent negative impact on environment.

5 Conclusions

Microplastics from artificial turfs, as the second source of microplastics in Sweden, have attracted much attention in recent years. Stormwater is considered as one of the most important pathways transporting microplastics to environment and in particular ecologically-sensitive surface water bodies. However, because of challenges in the quantitative analysis of microplastics in stormwater, how much microplastic from artificial turfs reaches the stormwater is still unknown.

Approximately 90% of microplastic granulates from artificial turfs analyzed in this study from the four sites in Stockholm is between 1 mm to 3 mm. The density of microplastics is similar to stormwater and organic materials, and they can exist both on surface and in sediments of stormwater. Thus, microplastics are difficult to be separated from stormwater samples. Further development of method for separation of microplastics is necessary for quantitative studies in the future, because the approach developed here includes subjective evaluations that should be avoided.

Microplastics from artificial turfs flow with runoff along with the terrain slope to stormwater wells by. Stormwater wells located closer to an artificial turf capture more microplastics compared with stormwater wells further away. It has been detected that a certain amount of microplastics get stuck in soils during their spreading through rainfall-runoff process.

Stereo microscopy has shown as limited and rather subjective method for microplastic identification in stormwater samples as quantifying microplastics by naked eyes due to presence of other particles with characteristics similar to microplastics is very challenging process. Thus, the obtained results are more indicative than they could be used for conclusive purposes. In order to quantify microplastics transported from artificial turfs to stormwater, marking microplastic granulates and analyzing stormwater samples with electron microscopy are suggested. At present, although spread of microplastics from artificial turfs has been on the agenda in various municipalities and institutes, research perspectives and practical quantitative investigations of microplastics in stormwater are still scarce or in their initial phases. Hence, it is important to encourage, share and discuss obtained results as well as to cooperate in tracking and quantitatively analyzing microplastics spreading and loss. In this way one can adapt and develop future solutions with the best available technology.

6 References

Alimba, C.G. and Faggio, C. (2019). *Microplastics in the marine environment: current trends in environmental pollution and mechanisms of toxicological profile.* Environmental toxicology and pharmacology, 68, pp. 61-74.

Andrady, A.L. (2011). *Microplastic in the marine environment.* Marine Pollution Bulletin, 62, pp.1596-1605. Available at: https://www.ivl.se/webdav/files/Rapporter/C183.pdf (Accessed: 25 January 2019).

Bannick, C.G., Szewzyk, R., Ricking. Schniegler, S., Obermaier, N., Barthel, A.K., Altmann, K., Eisentraut, P. (2019). *Development and testing of a fraction filtration for sampling of microplastics in water.* Water Research, 149, pp.650-658.

Barboza, L.G.A., Vethaak, A.D., Lavorante, B.R., Lundebye, A.K. and Guilhermino, L. (2018). *Marine microplastic debris: An emerging issue for food security, food safety and human health.* Marine pollution bulletin, 133, pp.336-348.

Bujak, K. (2018). *Kartläggning av analysmetoder för mikroplaster från konstgräsplaner*. KTH kemi, bioteknologi och hälsa, Kungliga Tekniska Högskolan.

Carpenter, E.J., Smith, K.L. (1972). *Plastic on the Sargasso Sea Surface*. Science, 175(4027), pp.1240-1241.

Carbery, M., O'Connor, W. and Palanisami, T. (2018). *Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health*. Environment international, 115, pp.400-409.

Cheng, H., Hu, Y. and Reinhard, M. (2014). *Environmental and health impacts of artificial turf: a review.* Environmental science & technology, 48(4), pp.2114-2129.

Cole, M., Lindeque, P.K., Fileman, E., Clark, J., Lewis, C., Halsband, C. and Galloway, T.S. (2016). *Microplastics alter the properties and sinking rates of zooplankton faecal pellets.* Environmental science & technology, 50(6), pp.3239-3246.

Crawford, C.B., Quinn, B. (2017). *Microplastic pollutants*. Dutch: Elsevier, p.101.

Do Sul, J.A.I. and Costa, M.F. (2014). *The present and future of microplastic pollution in the marine environment*. Environmental pollution, 185, pp.352-364.

Dümichen, E., Eisentraut, P., Bannick, C.G., Barthel, A.K., Senz, R. and Braun, U. (2017). *Fast identification of microplastics in complex environmental samples by a thermal degradation method.* Chemosphere, 174, pp.572-584.

Fjordefalk, V. (2018). *Reningsmetoder för dagvatten innehållande mikroplaster från konstgräsplasner.* KTH kemi, bioteknologi och hälsa, Kungliga Tekniska Högskolan.

Fleming, P.R., Forrester, S.E. and McLaren, N.J. (2015). *Understanding the effects of decompaction maintenance on the infill state and play performance of third-generation* *artificial grass pitches*. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of sports engineering and technology, 229(3), pp.169-182.

Gustafsson, N. (2017). *Gummigranulat på konstgräsplaner – En miljörisk till följd av spridning via dagvattensystemet.* Examensarbete. Lunds Universitet.

Guzzetti, E., Sureda, A., Tejada, S. and Faggio, C. (2018). *Microplastic in marine organism: environmental and toxicological effects*. Environmental toxicology and pharmacology, 64, pp.164-171.

IVL Swedish Environmental Research Institute. (2017). *Swedish sources and pathways for microplastics to the marine environment.* Available at: https://www.ivl.se/webdav/files/Rapporter/C183.pdf (Accessed: 21st January 2019)

Krång, A., Olshammar, M., Edlund, D., Hållén, J., Stenfors, E., and Friesen, L.W. (2019). *Sammanställning av kunskap och åtgärdsförslag för att minska spridning av mikroplast från konstgräsplaner och andra utomhusanläggningar för idrott och lek.* IVL, Swedish Environmental Institute. Available at: https://www.ivl.se/download/18.57581b9b167ee95ab9919a1/1552466299144/C359.pdf (Accessed: 5th May 2019)

Li, J., Liu, H. and Chen, J.P. (2018). *Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection.* Water research, 137, pp.362-374.

Magnusson, Simon. (2015). *Systemanalys av konstgräsplaner*. Teknisk rapport, Luleå Tekniska Universitet.

NTNU, SIAT-Centre for Sport Facilities and Technology (2018). *Report for the purchasing group of The Swedish Association of Local Authorities (SKL) -Market analysis artificial turf 2018-08-31*. Available at: https://skl.se/download/18.14e6bd221659c5ebbe1f3ea/1535983839750/Marknadsanalys-konstgr%C3%A4s-market-analysis-artificial-turf.pdf (Accessed: 15th April 2019)

Prata, J.C., da Costa, J.P., Duarte, A.C. and Rocha-Santos, T. (2018). *Methods for sampling and detection of microplastics in water and sediment: a critical review.* TrAC Trends in Analytical Chemistry, 110, pp.150-159.

Rocha-Santos, T. and Duarte, A.C. (2015). *A critical overview of the analytical approaches to the occurrence, the fate and the behavior of microplastics in the environment.* TrAC Trends in Analytical Chemistry, 65, pp.47-53.

Rossi, F., Gribsholt, B., Gazeau, F., Di Santo, V. and Middelburg, J.J. (2013). *Complex effects of ecosystem engineer loss on benthic ecosystem response to detrital macroalgae*. PloS one, 8(6), p. e66650.

Royte, E. (2018). *We know plastic is harming marine life. What about us?* National Geographic, 2018(6). Available at: https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-health-pollution-waste-microplastics/ (Accessed: 1st April 2019)

Schmid, K., Winemiller, K.O., Chelazzi, D., Cincinelli, A., Dei, L. and Giarrizzo, T. (2018). *First evidence of microplastic ingestion by fishes from the Amazon River estuary*. Marine pollution bulletin, 133, pp.814-821.

Sebille, E.V., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Franeker, J.A.V., Eriksen, M., Siegel, D., Galgani, F., Law, K.L. (2015). *A global inventory of small floating plastic debris.* Environmental Research Letters, 10(12), P.124006.

Skellefteå kommun, Bygg och miljökontoret. Online document available at: https://www.skelleftea.se/default.aspx?id=5061from. (Accessed: 5th June 2019)

Sundt, P., Schulze, P.E. and Syversen, F. (2014). *Sources of microplastic-pollution to the marine environment*. Mepex for the Norwegian Environment Agency. Available at: https://www.miljodirektoratet.no/globalassets/publikasjoner/M321/M321.pdf .
(Accessed: 17th June 2019)

Swedish Environmental Agency. (2017). *Microplastics*. Available at: http://www.swedishepa.se/Environmental-objectives-and-cooperation/Swedish-environmental-work/Government-commissions/Reported-2017/Microplastics/.
(Accessed: 25th January 2019)

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W.G., McGonigle, D., Russell, A.E. (2004). *Lost at sea: where is all the plastic?* Science, 304, p.838.

Turner, J.T. (2015). *Zooplankton fecal pellets, marine snow, phytodetritus and the ocean's biological pump*. Progress in Oceanography,130, pp.205-248.

Twomey, D.M., Petrass, L.A., Fleming, P. and Lenehan, K. (2018). *Abrasion injuries on artificial turf: A systematic review.* Journal of science and medicine in sport. (article in press).

Van Cauwenberghe, L., Devriese, L., Galgani, F., Robbens, J. and Janssen, C.R. (2015). *Microplastics in sediments: a review of techniques, occurrence and effects. Marine environmental research*, *111*, pp.5-17.

Wang, W. and Wang, J. (2018). *Investigation of microplastics in aquatic environments: An overview of the methods used, from field sampling to laboratory analysis.* TrAC Trends in Analytical Chemistry, 108, pp. 195-202.

Wredh, G. (2014). *Miljö- och hälsorisker med konstgräsplaner, Examensarbete avancerad nivå Miljö- och hälsoskydd*, 15 hp 2014. Institutionen för naturgeografi och kvartärgeologi, Stockholms Universitet.

Wright, S.L. and Kelly, F.J. (2017). *Plastic and human health: a micro issue?* Environmental science & technology, 51(12), pp.6634-6647.

Zhang, K., Gong, W., Lv, J., Xiong, X. and Wu, C. (2015). *Accumulation of floating microplastics behind the Three Gorges Dam*. Environmental pollution, 204, pp.117-123.