

Master's thesis



# Microplastics in the Coastal Environment of West Iceland

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## **Declaration**

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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Student's name

# Abstract

Microplastic particles in the marine environment and the effects on wildlife, human and ecosystem health are just beginning to be understood in a global setting. The presence of microplastics particle in West Iceland are evaluated to determine if there is a detectable gradient of decreasing plastic concentrations with increasing distance from the urban centres around Reykjavik. The study region includes sample sites within urban, semi-rural and rural coastal settings, with 4 sites at each type of location being sampled. Microplastic particles were found at 3 of the urban sites, 2 of the semi-rural sites and not detected in any of the rural locations. It is concluded that a decreasing concentration gradient that is based solely on distance travelled from the urbanized area of Reykjavik does not exist due to patchy distributions that could be the result of strong influences from ocean currents and offshore activities.

# Útdráttur

Plastagnir í umhverfi sjávar eru farnar að hafa áhrif á lífríki sjávar víða um heim. Umfang plastagna var metið í fjöru á Vesturlandi og kannað var hvort samband sé á milli magns plastagna og nálægðar við þéttbýli, með áherslu á Reykjavík. Rannsóknarsvæðið náði frá Reykjavík til Breiðafjarðar. Á hverju svæði voru tekin 4 sýni til rannsókna. Plastagnir fundust í 3 sýnum í nágrenni við Reykjavík, 2 sýnum við þéttbýli utan Reykjavíkur, en plastagnir fundust ekki í sýnum í fjöru í dreifbýli. Ekki fannst samband á milli fjarlægðar frá Reykjavík og magns plastagna. Líklegt er að hafstraumar hafi veruleg áhrif á útbreiðslu plastagna, auk þess sem líklegt er að notkun plasts á úthafinu hafi áhrif á útbreiðslu þess við Íslandsstrendur.

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# 1 Introduction

Anthropogenic pollution comes in many forms; chemical, air, noise, light, biological, and solid waste. Most of this pollution is generated in the developed world, but in many cases it is the developing nations that lack effective waste management systems often resulting in severely negative environmental impacts on regional scales. The fact that humanity is currently living in a “disposable era” has created a situation where we have negatively impacted nearly every environment on earth with some form of pollution. This is evident through not only chemical changes in air and water but in the deposition of solid waste pollution into many remote regions of the world. There are an estimated 8 million articles of human garbage entering the world’s oceans daily, and with increasing population growth in coastal zones that amount is only expected to increase (UNEP, 2005). The amount of human garbage entering the global oceans is an on-going problem that is worsening at an alarming rate despite international recognition, with management and prevention measures being particularly difficult to address (Gregory, 2009). Andrady (2011), points out that nearly one third of global plastic production is converted into disposable single-use items that are thrown away within one year of production and have been found to be the most common type of marine debris accumulating on beaches. This highlights the dangers of living conveniently, because these simple, cheap, easy to throw away plastic items are now considered to be among the most environmentally persistent materials ever manufactured. Despite recommendations by the internationally recognized MARPOL Annex V that address the dumping of solid waste into the ocean, the problem of garbage entering the world’s oceans from both unregulated land and sea-based sources continues to increase. This garbage is constantly circulating around the world and being deposited on beaches globally.

It has been documented that as much as 60 to 80% of marine debris washing ashore is plastic (Derriak, 2002). The cheap durable properties that make plastic such an all-pervasive and effective material are the same aspects that make it an environmental catastrophe when disposed of improperly. Current attempts at quantifying plastic debris (commonly with surface trawls) in the ocean is grossly underestimating the true amounts

of this debris because these techniques exclude mid-water and sediment locked particles that make up a huge proportion of plastics in the marine environment (Andrady, 2011). With increased understanding of the ocean environment, more issues are coming to light on the negative impacts of human activities on this critical ecosystem. Over the last decade, microplastics have taken centre stage in the world of ocean pollution issues due to their ubiquitous nature and an increasing awareness of the potential problems associated with their presence in the environment (Sutherland et al., 2009). To date there has never been an investigation into the presence, types, or quantities of microplastics along the Icelandic coastline.

Being a remote island in the North Atlantic with a sparse population does not, unfortunately, exclude Iceland from the threats and associated damages of marine litter on its beaches. Iceland has become an extremely competitive global manufacturer of various plastic materials and products that are primarily used in the fishing and marine transport sectors. Two of Iceland's major economic sectors, fishing and farming, rely heavily on plastic materials for improving harvest yields, storage, and product packaging. One large urban centre (Reykjavik) that is home to many different manufacturing industries coupled with international shipping routes and fishing activities located just off shore, make the Icelandic coastline potentially vulnerable to receive marine debris from a number of different direct and indirect sources.

With a thriving plastic industry in Iceland, and the fact that the raw pellets and powders used in the plastic manufacturing process are shown to be one of the primary contributors to microplastic in the ocean (Costa et al., 2010; Derriak, 2002), baseline knowledge on the possible presence of this material in the marine environment is critical for the responsible management of local and global impacts. There is currently, however, a dearth of information about plastics entering and already present in the Icelandic environment.

This paper describes a pilot project that is the first study of microplastic debris within beach sediments along stretches of the Icelandic coastline. In this paper, a thorough review of the current literature published on the issue will be provided covering the major themes of marine debris and its plastic component. The extensively documented affects of plastics interacting with wildlife will be used to introduce the

affects of microplastics on the environment. Emphasis will be placed on the potential for microplastics to act as a medium for persistent organic pollutants (POP's) to enter the marine food web. This will be followed with a brief discussion on the economic costs of marine plastics and their potential as vectors for sessile organism dispersal. Many management strategies for macro debris have been relatively successful after their integration into international law and policy, but the management of microplastic debris is still a field in its infancy and insights into this research and possible management opportunities will be given in the discussion and conclusions sections of this study.

## **1.1 Marine debris**

A major threat facing our oceans today is the growing problem of human derived marine debris. Coe & Rodgers (1997) describe marine debris, also known as marine litter, as any manufactured or processed solid waste material (typically inert) that enters the ocean environment from any source (as cited in Sheavly & Register, 2007; Santos, Friedrich & Ivar do Sul, 2009). This debris can come from a variety of different sources both land and marine based. Despite the fact that there are not many 'certain' worldwide statistics, the 2005 UNEP Marine Litter report estimates that approximately 6.4 million tonnes of debris enter the ocean annually. Up to 8 million items of debris enter the ocean everyday with 5 million of these items being discarded directly from ships out at sea. In the past there was compelling evidence that suggested large scale illegal offshore dumping and derelict fishing gear were the major sources of the marine based debris inputs. More recently studies have shown that current estimates point to land based sources as being by far the biggest contributor of manufactured materials entering the marine environment (Andrady, 2011; McIlgorm et al., 2011; Sheavly & Register, 2007).

With current estimates of land based sources accounting for up to 80% of the total debris that enters the oceans, it is found the vast majority of this material is being transported via sewage/drainage systems, natural waterways, wind and direct human littering (Derriak, 2002). The component of marine debris that is entering the ocean from marine sources often times comes from cruise ships, recreational boaters, commercial fishing and international shipping vessels that dump debris directly into the ocean (Cooper & Corcoran, 2010; Sheavly & Register, 2007; Derriak, 2002). Wind blown litter

and other debris items that get washed into various watercourses during storm events, account for a major portion of the land-based litter entering the ocean (Moore et al., 2011). The land-based source of marine debris that enters the oceans frequently and in large amounts originating as human litter can also be one of the easiest sectors to manage with public education and more efficient waste disposal programs (McIlgorm et al., 2011).

Barnes et al. (2010) conducted marine debris surveys in the regions around the Antarctic documenting plastic pollution in this pristine environment. One of the debris items found during this survey was of particular concern because it was colonized by sessile organisms that had never before been recorded in this region. Marine debris that is capable of being transported into remote regions from foreign sources is what makes this an international issue. Hazards to shipping, pollution adsorption, and concentrations of manufactured materials that outweigh naturally occurring organic marine debris are just a few of the associated concerns (Moore et al., 2001).

Studies on the marine debris epidemic over the past decade leave no doubt that on average the largest component of global marine pollution is made up of plastic materials, where the proportions reported consistently vary between 60% and 80% (Derriak, 2002). A review of the current literature by Sheavly & Register (2007) on marine debris items found world-wide indicate that the dominant types and sources of debris come directly from things that we consume like food wrappers, beverage containers, and cigarette butts. Items related to transportation and fishing activities however are also predominant in this environment. The hypothesis that consumption items are by far the largest contributor to marine debris from both land and marine sources is supported by a study of beach debris found on Scotland's coastline (Storrier et al., 2007). The authors found that in the presence of take away facilities (fast food restaurants) and storm water overflows there were significantly more litter items found on adjacent beaches.

## 1.2 Plastic debris

According to Plastics Europe (2011), the organization representing all European plastic manufacturers, the annual global production of plastic materials in 2009 increased by 15 million tones (6%) to 265 million tones in 2010. This confirms that the long-term trend in plastic production has been growing on average of 5% per year over the past 20 years and also shows that production has almost tripled since the early 1990's.

Marine debris, and in particular the component made up of plastic materials, is one of the world's most problematic and pervasive pollution problems affecting our oceans today (Sheavly & Register, 2007). Global plastic resin production over the past 40 years has increased 25-fold with less than 5% of this material being recovered (Sutherland et al., 2010).

In order to quantify the primary source of plastic fragments that are found stranded on beaches, previous studies have used two classification methods to show that debris is either derived from; (1) inland sources where material is transported to coasts by water courses, wind, drainage systems or human activity, or (2) directly from the oceans where low density debris floats and accumulates on coasts after being transported great distances (Corcoran et al., 2009; Frias et al., 2010).

Zarfl & Matthies (2010) estimated that plastic debris inputs to the Arctic Ocean range from 62,000 to 105,000 tonnes yearly based on the maximum volume transport of respective oceanic waters. Barnes & Milner (2005) documented that plastics were common on the shores of Svalbard (79°N) representing the northern most point where beached debris has been reported. Despite vast differences in geography and climate, concentrations of 0.2 debris items per meter of shoreline were similar to other North Atlantic Islands (Shetland, Iceland, and Faeroe Islands). This same study documented that in more southerly regions like the subtropics and tropics much higher concentrations of plastic materials are found, with often more than 1 item found per meter length of shoreline.

There is a common misconception that plastic debris in the ocean is only made up of materials that can be seen floating on the water's surface, when in fact a little more than 50% of all thermoplastics manufactured tend to sink in the marine environment (Moore, 2008). Sediment samples collected from different locations off of the Belgian

coast showed no significant differences in microplastic concentrations between offshore and inshore sediments with some of the sampling locations upwards of 20km off shore (Claessens et al., 2011). Galgani et al. (2000) showed that a high percentage of the debris found on the continental shelves around the UK were plastic materials that commonly occurred with a range of 50 to 90% of the total debris collected. Accumulation zones of marine debris on the ocean floor can be located far away from possible land-based sources as a result of hydrodynamic influences. This affect was documented in the Galgani et al. (2000) study when debris concentrations zones on the continental shelf were located as far away as 200 miles off the coast of Denmark. Larger items like beach toys, beverage bottles and food packaging can easily be influenced by wind and tidal patterns that distribute them offshore, but these same processes have been shown to carry smaller debris out to sea as well. Climatic and hydrodynamic influences on all scales will tend to collect plastic debris and then redistribute it into far off remote locations, which are often areas of critical wildlife habitat (Zarfl & Matthies, 2010).

### **1.3 Field studies**

In one of the earliest observations of wildlife ingesting plastic, Kenyon & Kridler (1969) noted that on the high waterline of a lagoon not directly connected to the sea, plastic items were found that could only have been the result of Laysan Albatrosses who died at that location with plastics in their stomachs. This suggests that concentrations of plastic can become so great in some habitats with particular species being vulnerable to these hazards, that animals suffering the ill effects might become transport vectors for plastic debris into adjacent environments.

McDermid & McMullen (2004) found that 43% of plastic pieces collected on the remote beaches of Midway Atoll in the central Pacific were 1 to 2.8mm in size. This makes these microplastics particles potentially available for accidental ingestion by planktivores at the base of the marine food web.

Thompson et al. (2004) found conclusive evidence for the potential of plastics particles to enter the marine food web when the researchers showed that three marine invertebrates ingested microplastics in their study. This was demonstrated through the use

of amphipods (detritivores), lugworms (deposit feeders), and barnacles (filter feeders) which were placed in aquaria with small amounts of microplastics being added. Over time, the invertebrates did in fact ingest the small plastic particles. It has also been documented that many plastic particles being ingested by planktivorous organisms do not resemble concentrated food sources due to fouling, because as plastic gets smaller in size through the process of degradation the occurrence of fouling is found less frequently (Moore et al., 2001). Recently it has been argued that plastic debris items will be consumed by various inexperienced juveniles or starving organisms in order to stave off hunger simply due to the resemblance of possible prey items (Brandao et al., 2011)

Endo et al. (2005) suggest that the primary concern regarding plastic ingestion by various organisms was the possibility that fragments could block the intestinal tract reducing food consumption, and increasing the chance of chemical exposure from the plastics themselves. Boerger et al. (2010) showed that 35% of the fish sampled in a region of the north pacific had plastic particles in their gut. The number of plastic pieces found ranged from 1 to 83 pieces per fish, with an average of 2.1 pieces per fish. The same study also found that the most common size of plastic found in the fish was 1 to 2.79 mm indicating that the microplastics that already exist in this region of the ocean certainly have the potential to influence the diets of resident planktivorous fish. The size range of the plastics particles found within the fish guts are identical to the ranges Moore et al. (2001) found on remote beaches of the Hawaiian Archipelago. Browne et al. (2008) raise an even greater concern when they demonstrated that microplastics not only were ingested by sessile organisms, but in the case of a mussel species, plastic particles were actually capable of entering the circulatory system where they persisted for up to 48 days.

If the plastics that small pelagic fish ingest do not pass through the digestive tract, then these non-nutritive elements will accumulate and result in starvation. If this affect is magnified with increasing microplastic accumulations in the marine environment then this could lead to significant reductions in certain world fish populations (Boerger et al., 2010). It has also been considered that in the case of mesopelagic fish that diurnally migrate through the water column in order to feed, an abundance of buoyant plastics in the gut will prevent them from returning to deeper waters after feeding (Boerger et al., 2010).



Plastic particles present within the water column will certainly exhibit many negative effects on wildlife, with evidence of starvation, entanglement and choking, but the residence time of plastics within certain species may present cascading affects that some fear will likely affect the whole marine food web (Boerger et al., 2010; Teuten et al., 2007; Zarfl & Matthies, 2010).

## **1.4 Microplastic**

There is an ongoing debate in the scientific community with regards to the proper nomenclature to be used when describing plastic fragments that are considered microplastic. The dispute centres on the size class description of fragments with some parties arguing that particles 5mm and less should be acknowledged as microplastics and other parties claiming it should be 1mm and less.

In 2008, scientists from around the world attended the first international conference on microplastics, where these particles were defined as 5mm and smaller (Betts, 2008). Costa et al. (2010) argue that items 20mm to 1mm should be classified as small plastic particles, not microplastics. This argument is based on the fact that these particles can easily be collected on beaches and identified without optical instruments. Costa et al. (2010) propose that microplastics be considered items less than 1mm, because these fragments cannot be sampled by hand and must be identified in a lab with the assistance of specialized equipment. The definition of microplastics being fragments 5mm and less is recognized throughout the current literature and continues to be the definition used by many international marine debris programs (Andrady, 2011; Frias et al., 2010; Gregory, 1996; Moore, 2008; Moore, Lattin & Zellers, 2011; Arthur et al., 2008; Zarfl & Matthies, 2010). Within this paper, the term microplastic refers to plastic materials that are 5mm and less in size.

Until recently, it was thought that the biggest contribution to the global inventory of microplastics particles in the marine environment came from the break down of larger plastic items out at sea or stranded in the beach environment. This idea was supported by studies showing that the photodegradation of large plastic items on beaches combined with chemical and mechanical weathering work to make plastic material brittle resulting

in it continually breaking down into infinitely smaller pieces allowing for the mechanisms of microplastic particle creation to take place (Cooper & Corcoran, 2010). The Cooper & Corcoran (2010) study noted that fragments <10mm in size were concentrated along strandlines suggesting that the degradation and embrittlement of plastic is initiated at sea, but these process are intensified once the debris reaches land. The physical process associated with saltation in the beach environment and the common occurrence of extreme temperature variations increases the rate of both chemical and mechanical breakdown (Corcoran et al., 2009).

Moore et al. (2011) quantified the abundance and density of plastic debris collected in two rivers that run through the city of Los Angeles. It was observed that microplastics were 16 times more abundant than debris greater than 5mm and in most cases these items were entering storm water and river systems because they were carelessly discarded into the environment or spilled during manufacturing and transportation activities.

Browne et al. (in press) attempted to quantify the amount of microplastics released into the wastewater from the household washing of synthetic textiles. The authors documented that as many as 1600 particles can be released from a single garment during a wash cycle, and with increasing trends in poly-based clothing, the current and future contributions of home washing to microplastic accumulations in the marine environment is going to increase.

There is also a growing trend where microplastic beads are added to consumer cosmetics and other toiletries where the materials act as lubricants, scrubbers, and colour enhancers not to mention the FDAs approval of their addition into chewing gum bases (Plastic Europe, website). Gregory (1996) outlined some issues associated with cosmetics acting as a source of microplastics that are due to differences in the treatment of municipal wastewater. Treatment procedures commonly use filters that are not designed to capture such small materials, and even though some may get trapped in sludge or oxidation ponds, the majority of cosmetic influenced microplastics will be discharged into marine waters with their floating characteristics allowing for transport over great distances.

## 1.5 Pollution interactions

With increasing research efforts focused on the health of the global oceans, there are growing concerns around plastics acting as potential pathways for organic pollutants to enter the marine food web. Current research (Endo et al., 2005; Teuten et al., 2007; Mato et al., 2001) provides the necessary evidence to conclude that plastics are capable of transporting organic contaminants into and around the marine environment. Carpenter & Smith (1972) suggest the possibility that plastics will absorb pollutants from the surrounding seawater with toxins potentially being absorbed into animal tissues after accidental ingestion. Since animals often retain plastic items in their gut for an extended period of time it is possible that they could potentially transport this pollution into adjacent environments.

Recent studies have indicated very similar findings, where plastics were found to absorb a variety of pollutants such as PCB, DDT, and PAHs and then potentially release them into animals, sediments and the water column in an attempt to reach equilibrium with uncontaminated environments (Mato et al., 2001; Teuten et al., 2007). Teuten et al. (2007) showed that even with such a strong attractiveness of phenanthrene to plastics, the addition of a small amount of contaminated plastic into a closed clean system results in a significant amount of the absorbed toxin to be released from the plastic particle into the clean sediment. Their research demonstrated that with the addition of a small amount of contaminated plastic fragments it is possible for large concentrations of hydrophobic contaminants to enter marine sediments. Thus the authors suggest that, due to the sorptive behaviour of plastics, they should be considered when analysing soil and sediment for POP contaminations. If the sediments are highly contaminated it is likely that the organisms living within these benthic environments are going to have the available pollutants concentrated within their tissues.

Teuten et al. (2007) investigated the possible consequence for organisms in the benthic environment that consume microplastics settled from the sea-surface as a result of fouling. Serious concerns with how the interface of the sea-surface microlayer (SML) between seawater and the atmosphere might influence POP's entering the marine food web have been expressed because plastic debris is often found floating in this layer of highly concentrated pollutants. Teuten et al. (2007) were able to show that with only a

small quantity of plastics in the SML, large quantities of phenanthrene can be absorbed, and with the addition of these particles into sediments they can greatly increase the phenanthrene in the benthic environment. When concentrations of 1ppm polyethylene, or of 14ppm polypropylene were added to plastic free sediment, it was estimated that phenanthrene tissue concentrations in lugworms (*Arenicola marina*) had increased by 80%.

A field absorption experiment conducted by Mato et al. (2001) used virgin plastic resin pellets deployed onto the sea surface in order to calculate the rates of pollution absorption onto plastic particles. The experiment showed that in the case of virgin plastic pellets the sorption rate of hydrophobic pollutants could be as much as two magnitudes higher than that of other suspended particles in seawater (Mato et al., 2001). Since plastic resin pellets, commonly referred to as nurdles, make up the feedstock for the plastic manufacturing industry and are made up of saturated hydrocarbon units their surfaces are non-polar and thus particularly attractive to hydrophobic pollutants (Mato et al., 2001). Therefore when buoyant plastic particles, especially resin pellets, are travelling around the ocean they can play an important role in the transportation of toxic substances that do not usually get transported by wind or ocean currents.

The unique role of plastics transporting toxins can be attributed to the fact that they do not experience the rapid degradation and sedimentation of natural debris to which pollutants might normally be attached (Zarfl & Matthies, 2010). Some pollutants like PAH that show a high affinity for organic matter could therefore be even more attracted to plastics due to their compressed hydrocarbon ingredients. This means that plastics drifting on ocean currents over long distances are very capable of transporting things like PAH into remote regions of the world (Zarfl & Matthies, 2010). Plastics not only absorb pollutants that are present in sea water, but the photodegradation and chemical decomposition process of plastics in the marine environment have also been shown to release other types of pollutants like flame retardants, plasticisers and other additives incorporated into different plastic materials (Mato et al., 2001).

Industrial zones and major ports are areas of specific concern because they often have high concentrations of plastic pollution and highly polluted SMLs. It has been shown that plastics that commonly occur in these locations can absorb high levels of

toxic substances over a matter of days (Mato et al., 2001). The resident time of plastic debris in polluted harbors is not infinite and more often than not these items will get caught in currents and tides where they can then enter offshore waters and get transported over great distances.

## **1.6 Floating refuge**

Concerns about the potential for non-native species attaching to floating plastics was mentioned in the early study of Carpenter & Smith (1972). The researchers noted that most plastics at their study site had populations of hydroids and diatoms attached, with some of the species having never been previously observed at these locations. Barnes & Milner (2005) documented colonization rates of 3 to 7% of the plastic debris found along the study site shorelines of northern polar islands. Two different organisms, the barnacle *Semibalanus balanoides* and the bryozan *Membranipora membranacea*, were found as living hitchhikers on debris as far north as 79°N in Svalbard. Barnes & Milner (2005) also noted that this was to the authors' knowledge by far the most extreme latitude ever before reached by hitchhikers on plastic.

## **1.7 Economic impacts**

McIlgorm et al. (2011) point out that there are currently very few studies published that take into account general costs of marine debris on society. There is a fairly extensive document that is produced through research conducted by OSPAR and the KIMO group on the economic impacts of marine debris in the North Atlantic (Mouat et al., 2010). Major costs due to marine debris have been attributed to things like damage inflicted on ships from entanglement or collisions, lost tourism and the associated costs of mechanical beach cleanups, clogged water intakes for industrial cooling and simply the loss of real-estate values from the poor aesthetics of garbage mounds in the coastal setting. There is great difficulty in calculating the costs of marine debris on society and the potential economic benefits of cleaning it up because there are so many indirect influences and costs. One specific challenge and an aspect that highlights marine debris

as a global issue is the fact that pollution in the marine environment is constantly on the move and that polluting sources mainly affect neighbouring environments, often times leaving little incentive for the polluters to prevent their pollution.

## **1.8 Management**

Moore et al. (2011) pointed out that under current California law materials that are less than 5mm in size are not considered to be trash subject to any regulations. This is simply a complete shortfall of the waste management program in this region. Considering that the authors in the above study documented well over 12,000 particles/m<sup>3</sup> of microplastic in one day entering the ocean from two municipal waterways this is a clear indication that microplastics are a significant component of municipal waste being dumped undetected into the marine environment, and should be considered in proper waste management programs.

There are policies and regulations in place on both global and regional scales that act to prevent the direct dumping of waste into the ocean, but in many cases careless behaviour still allows litter to be carried to the ocean from various modes of transport (Mouat et al., 2010). The provision of proper waste disposal facilities at ports can make a huge difference in preventing the illegal dumping of garbage at sea. A simple garbage collection bin conveniently located in a harbour is often times all it takes to prevent littering (Storrier et al., 2007). A very effective and relatively easy to employ method of plastic pollution management is with the use of debris booms on highly contaminated waterways collecting floating debris that would otherwise enter the ocean. This is a simple yet effective way to prevent large amounts of floating debris from entering the ocean and has shown significant results in many developing nations, but unfortunately this method does little to nothing in preventing microplastics from making their way to the ocean (Moore et al., 2011).

The first step in managing this problem is to understand the extent of it. Documenting sources, distribution patterns and the local, regional and global implications can allow us to develop an approach to will tackle the problem on all levels of its existence. This paper is the outcome of a pilot project focusing on microplastics in the Icelandic coastal environment. Emphasis is placed on the possibility that urban centres

will act as a source of plastic debris, and an investigation of how this pollution might travel into remote regions by way of current, wind and tidal influences is provided.

## **2 Objectives**

The objective of this project is to assess if the global trend of highly urbanized areas acting as large contributors to marine plastic debris in remote regions is evident in the Icelandic setting.

General observations taken while conducting field research are used to develop a greater understanding of how this type of marine debris might affect other aspects of the surrounding environment. The overall aim of this work is to shed light on a coastal marine issue that is receiving global attention but is not currently being investigated in the Icelandic context. The use of a cheap, effective and reliable sampling protocol will hopefully initiate further research and promote the establishment of future long-term monitoring programs for microplastics in the Icelandic environment.



## **3 Materials and methods**

The design of this research project incorporated both qualitative and quantitative data collection. As a preliminary investigation into the presence of microplastic particles in urban and rural locations throughout the Icelandic coastline, as much information as possible was gathered throughout field research that would contribute to a better understanding of the issue. Two methods were used; one quantitative and the second qualitative. Beach quadrates were systematically sampled following a predetermined sampling protocol, and the use of general observations on landscape, wildlife, human activities and settlement patterns were also incorporated into this study. These two research approaches compliment each other in providing a good representation of the dynamic nature in which plastic pollution exists along the Icelandic shoreline.

### **3.1 Sampling**

Recommendations made by Storrier et al. (2007) on conducting beach monitoring surveys for marine litter suggest that selecting a specific day such as the last Friday of the month is necessary to reduce the affects of environmental variables like winds, tides, and storms from influencing debris amounts within the strandline. In this study the single sampling event per site only allowed for a “snapshot” of the microplastic debris that will be present at a location at any given time.

The method chosen to investigate microplastic particles was adopted from a community based monitoring program used throughout the US and recognized by NOAA as the basis for their micro-litter monitoring program. Sieves are used to size class the materials while at the same time assisting in the separation of plastics from sediment. The collected debris is then classified into standard categories based on type. Due to limited time available for conducting fieldwork, and great distances required to travel to access study sites, the sampling of beach sediments was only done once, therefore potential variations over time and seasons are not assessed in this study.

Natural flotsam of both marine and terrestrial origin tends to accumulate along the high-tide strandlines where it is commonly referred to as “the wrack” (Gregory, 1996).

The sampling protocol in this project used a series of three quadrants  $1\text{m}^2$  per site, located in the high strandline (wrack line). Beach sediment was collected from the quadrants and then sieved into size classes. The resulting debris in the desired size classes was collected, labelled, and sorted at a later date. After the collected debris was sorted the resulting microplastic particles were classified and weighed.

### 3.1.1 Site selection

In order to determine the possible rate of marine plastics from Reykjavik washing ashore in remote regions along the Iceland coast, sites were chosen throughout Faxaflói and Breiðafjörður Bay. Due to sampling design it was necessary to have beaches composed of sand, and since most locations were not visited prior to sampling the National Land Survey of Iceland (Landmælingar Ísland) web site was used to identify the most likely locations of sandy beaches. The web site has an interactive aerial view satellite map that allows precise GPS coordinates to be taken on specific locations.

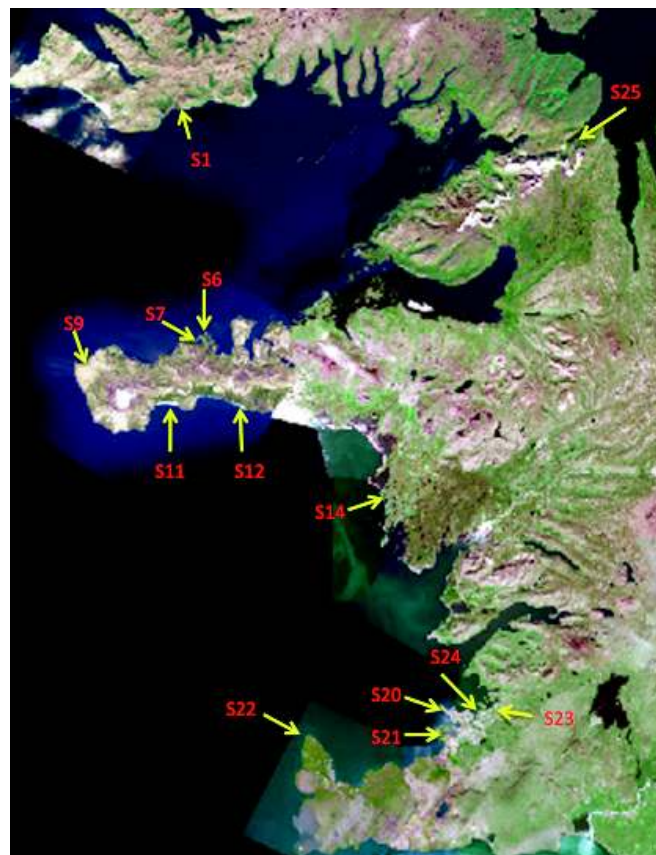


*Figure 3.1 Example of site establishment and randomization technique using satellite imagery*

This allowed for randomization of the sampling quadrates because the starting point was predetermined before arriving on site. The urban rural gradient was created

through the establishment of 24 sampling sites that covered a vast area from the developed landscapes surrounding Reykjavik to the remote regions of the south Westfjords.

The 24 established sites were visited over a 10-day period from August 16<sup>th</sup> – 28<sup>th</sup>, 2011 based purely on access to transportation, sampling equipment and availability of time. Upon arrival at the first three sampling sites, it became apparent that not all locations would be able to be sampled for various reasons. Some locations that looked like sandy beaches in satellite imagery had very sandy intertidal zones but cobble rock shorelines where the wrack debris would get deposited. This did not allow for sampling because a sandy substrate was required for the sampling protocol. Permission to access beaches on private land was also not always secured. In all, 12 sites were successfully sampled within the study area providing a good mix of urban rural influences (see Figure 3.2). Site 25 seen in figure 3.2 is not used in the ‘urban vs. rural’ study analysis, but was sampled for general observations and discussion purposes.



*Figure 3.2 Location of established study sites*

The regional study analysis incorporated 4 locations in the Reykjavik and surrounding area to be considered urban sites, 4 semi-rural sites are found in the vicinity of small communities, and 4 rural sites were sampled providing a nice gradient for site location vs. distance to city (see table 3.1).

*Table 3.1 Site distance to Reykjavik calculated by basic wind fetch*

Site	S1	S6	S7	S9	S11	S12	S14	S22
Distance (km)	215	187	185	155	103	89	55	37

### **3.1.2 Establishing quadrates**

In order to establish the location of the first sampling quadrate, the GPS unit (Garmin, eTrex Vista H) was followed using the predetermined coordinates until an accuracy of 2m was achieved. As soon as the GPS unit displayed an accuracy of 2m the quadrate was established, but if this location was not on the wrack line then a perpendicular line was travelled directly to the wrack line to locate the starting point. If upon arrival at the site it was discovered that the predetermined coordinates were located in the ocean or back behind a dune system, the wrack line was traversed until the highest accuracy reading was achieved and then the quadrate was established. The second quadrate was located 15 paces (~20m) to the right of quadrate #1 when facing the ocean, and the third quadrate was located the same distance to the left of quadrate #1 using the same technique. When pacing out distances, the location of the right foot after 20 paces was the centre of the sample quadrate. A nylon cord was used to isolate a 1m<sup>2</sup> plot parallel to the waters edge within the highest wrack line. A photo was taken of each quadrate from directly overhead and one from a side view in order to provide additional information on the location at a later date.

### **3.1.3 Sample collection**

Large natural debris like rocks and sticks were brushed clean of sand within the quadrat and then removed from the sample. If large trash items were found within the sample quadrat, they were brushed clean of sediment then labelled with site and quadrat number, and saved for further classification in the lab. A shallow metal scoop was used to evenly scrape the top 2cm of sand from the entire quadrat until a 7.5 litre sample was collected. This sediment was then passed through a 5mm metal sieve and again natural debris was discarded and any human trash collected and labelled for classification at a later date. The size class of the resulting sediment was <5mm and this material was then passed through a 1mm metal sieve. After all of the sediment has passed through the 1mm sieve the material left over both natural and anthropogenic was collected and labelled for further separation in the lab. The resulting sample was then all material in the size class of 1 to 5mm within the surface sediment of a sample quadrat.

If the sand was moist, the 1mm sieving had to be done wet. A small amount of sampled sediment was placed in the sieve and then the sieve was placed in water and shaken with particular care not to allow the edge of the sieve to go below the water's surface. This is because it could result in the release of any floating debris contained within the sieve walls. After the sediment <1mm had passed through the sieve screen all the remaining material was collected including any foams or floating scum in order to be dried and later sorted in the lab. This is a critical step in collecting all the microplastics in a wet sample because many types of plastic will float and if the sieve walls sink below the water's surface there is a chance that floating particles could be lost.

### **3.1.4 Separation and classification**

All samples that required wet sieving on location were then placed into glass baking dishes in the lab and allowed to dry for several days. Once dried, samples were placed onto a smooth, clean, dry, white surface and sorted. With the use of forceps and a 10x magnifying glass a visual inspection can readily separate manufactured materials from natural debris. For particles that could not be positively identified as either natural or plastic, a number of tests were performed in order to distinguish the composition.

Some simple tests were: a hardness test with a pin; floatation in seawater; if heat was applied, did it release a noxious smell; and, if a particle was still in question, it was investigated under a stereoscope at increasing magnification until positively identified.

Microplastic particles were separated into eight categories based on physical characteristics. Hard plastic fragments were separated into; nurdles, blocks, and others, filamentous pieces separated into; rope, packing band and cloth, with additional categories for film and foam particles.

The subcategories under the “Fragments” heading were used to identify and isolate two types of microplastics that are used in manufacturing processes (nurdles and blocks). The sub categories under the “Filaments” heading was used in order to identify and isolate two types of microplastics derived from the degradation of specific macroplastic items (rope and packing band). All particles in each category were counted and then weighed with an Ohaus-Explorer balance. If larger plastic items were found within a sample quadrant they were collected and classified based on the same physical characteristics as the microplastics, counted within their respective category and then weighed.

## **3.2 General observations**

Upon arriving at a sample site, and while travelling to sample locations special attention was paid to the surrounding landscape, local activities on the coast and in the water, as well as any possible influences from inland activities. This type of qualitative data was gathered in response to an overwhelming amount of the current literature concluding that land based sources of litter make up the majority of marine debris. If any industrial, commercial, and even residential activities were observed that could have potentially contributed to plastic pollution on the shoreline, these observations were documented. Because wildlife are known to often exhibit the first signs of the negative impacts from environmental disturbances, attention was given to document any type of wildlife plastic interaction throughout this study.

## 4 Results

### 4.1 Quadrants

#### 4.1.1 Primary hypothesis

The findings in this research project provide solid evidence that microplastic particles do exist along the Icelandic coastline. However, the sources and distributional patterns of these materials are more suggestive than definitive and based on the interpretation of the collected field data and observations made throughout the research. It does appear that human population centres located along coastlines influence the amount of marine debris present on the adjacent beaches as seen in table 4.1, but regional activities may also play a major role in plastic concentrations found on the Icelandic coastline.

*Table 4.1 Local population amounts on marine debris counts*

Sites	Nearest town km	Debris amounts		All plastic	
		Microplastic	Macroplastic	Combined	% study total
<b>Urban</b>					
S20	within town	34	5	39	2.9
S21	within town	0	0	0	
S23	within town	3	1	4	0.3
S24	within town	1251	3	1254	92
Site total		1288	9		95.2%
<b>Semi-rural</b>					
S6	8	3	2	5	0.4
S7	10	0	0	0	
S11	6	0	9	9	0.6
S22	5	16	31	47	3.4
Site total		19	42		4.4%
<b>Rural</b>					
S1	60	0	1	1	<0.1
S9	22	0	3	3	0.2
S12	25	0	3	3	0.2
S14	35	0	1	1	<0.1
Site total		0	8		0.4%
				1366	

Based on the numerical count of microplastic particles calculated per site type, (urban, semirural, rural) it would appear that there is a decreasing gradient of microplastic concentrations on beaches the further a site is located from the city centre of Reykjavik. When all aspects of the site locations are considered, this pattern of a decreasing gradient clear in the above data set does not actually exist. Figure 4.1 displays the total amount of plastic collected at each particular rural and semi-rural site, compared with the overall distance from site to Reykjavik.

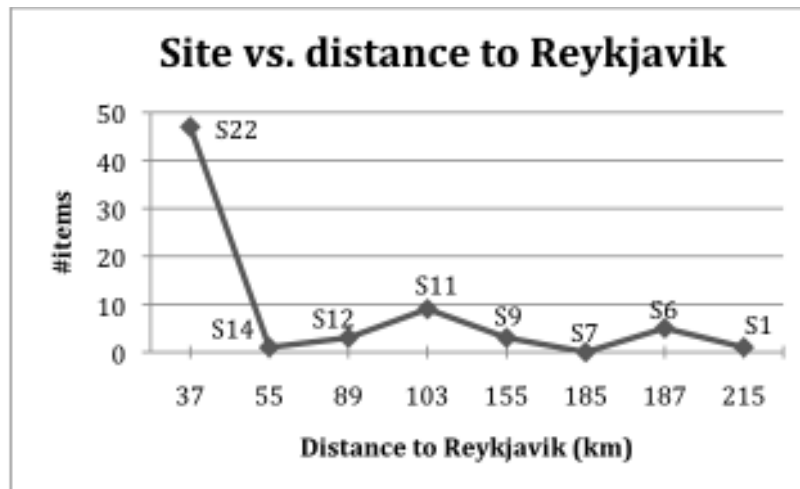


Figure 4.1 Total plastic concentrations vs. distance to urban centre

The above graph shows that a higher amount of plastic was found at the site closest to Reykjavik, and all other sites exhibited lower concentrations. This does not indicate a decreasing plastic gradient with greater distance travelled from Reykjavik, but that large differences were found between sample sites. These results are only seen when all sampled plastic items, both macro and micro in size, are combined. Site 22 had the highest amount of macroplastic items sampled throughout this study. The amount of large plastic items found at site 22 is three times higher than the next highest value found at the highly polluted urban site 24. When the collected plastic debris items are investigated using weight as the comparative value, a different aspect of the distributional characteristics can be observed.



Table 4.2 Weight of collected plastic material

Sites	Nearest town	Total weight in grams		All plastic	
		Microplastic	Macroplastic	Combined	% study total
Urban	km				
S20	within town	0.12	10.06	10.18	3.9
S21	within town				
S23	within town	<0.01	0.2	0.2	<0.1
S24	within town	1.51	0.04	1.55	0.6
Total		1.63	10.3		4.5%
Semi-rural					
S6	8	0.01	55.99	56	21.5
S7	10			0	
S11	6		22.81	22.81	8.7
S22	5	0.14	118.5	118.64	45.4
Total		0.15	197.3		75.6%
Rural					
S1	60		33.4	33.4	12.8
S9	22		1.28	1.28	0.5
S12	25		15.59	15.59	6
S14	35		1.44	1.44	0.6
Total		0	51.71		19.9%
				261.09	

When considering both the data displayed in numerical counts and by weight, it appears that the degree of local development does in fact influence the amount of plastic debris found on adjacent shorelines. The obvious pattern of trash being transported on ocean currents from the urban centre of Reykjavik into remote regions cannot be detected conclusively with the available data.

Therefore the primary hypothesis, that microplastic particles will be found in the regions of Faxaflói and Breiðafjörður Bay at a decreasing rate with increasing distance from Reykjavik due to transportation by ocean currents, must be rejected at this point.

### 4.1.2 Plastic Types

After a site was sampled and sorted, the microplastic particles found in each sample quadrant were combined under the designated type classifications and given as a total value for the site. The resulting classification of the sampled microplastics per site is shown in table 4.3, and figure 4.2. The sorted and combined data shows that the greatest

amount of particles found on the study beaches comes from rope, film, unidentifiable fragments and foam pieces respectively. Due to the limitations of a one time sampling event per site, these figures cannot be considered a definitive pattern of debris type, or average depositional amounts for a specific location. Rather, these figures represent a glimpse of the possible plastic pollution concentrations, and the potential for associated hazards to exist.

*Table 4.3 Total number of microplastic particles collected at each sampling site*

Site	Sample date	Fragments			Filaments			foam	film	Total
		nurdles	blocks	other	rope	packing	cloth			
S1	16/08/2011									
S6	17/08/2011				3					3
S7	17/08/2011									
S9	18/08/2011									
S11	18/08/2011									
S12	25/08/2011									
S14	24/08/2011									
S20	19/08/2011			2	1			31		34
S21	22/08/2011									
S22	22/08/2011				9			1	6	16
S23	23/08/2011			1			1		1	3
S24	23/08/2011	6	24	136	909			20	156	1251
Total		6	24	139	922		1	52	163	1307

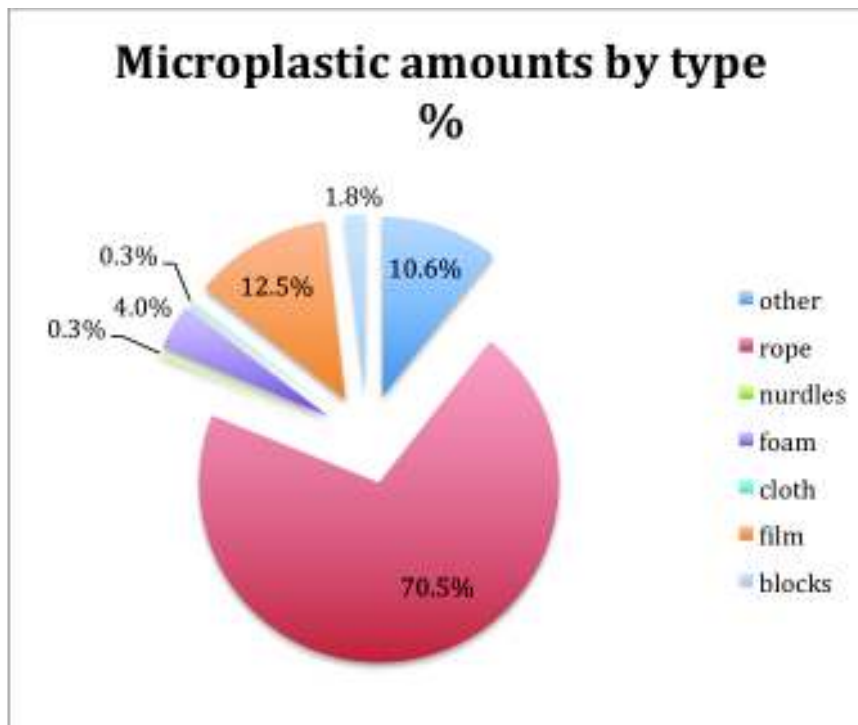


Figure 4.2 Percent of sampled microplastic by physical characteristics

The concentrations found at site 24 skew the data significantly, but could indicate a patchy distribution pattern. There is often extreme variability noted between sites, seasons, and sampling techniques in microplastic research. The physical classification method used here was not able to distinguish between residential and industrial sources since none of the particles could be positively associated with a specific process or clearly identified as the result of breakdown from larger debris items. The resulting conclusions are based on the ‘most likely scenario’ derived from the author’s interpretations and experiences in these locations.

The high value of microplastic found under the filaments section associated with ropes found in the presence of nurdles led to the hypothesis that such a specific type of particle, being found in such high concentrations and at one site, could only be the result of industrial or commercial activities. There is a chance that all the micro rope filaments are the result of larger rope items degrading, and this was taken into consideration through the macroplastic analysis.

In order to investigate the possibility that large plastic items may be breaking down and contributing a large amount of the microplastic particles found in a sample

quadrant, any large plastic items found in the samples were collected and sorted. The macroplastic items found within the sampling quadrates were then classified using the same categories based on physical characteristics as the microplastics in order to provide direct comparisons. Table 4.4 and figure 4.3 are used to display the results of this classification process with all debris items found in the three quadrates of a sample site being combined to give a site total. Nurdles and blocks are not expected to be found as macroplastic items because these are specifically microplastic particles that are commonly associated with the plastics manufacturing industry.

*Table 4.4 Total macroplastic items collected at each sampling site*

Sample site	Sample date	Fragments			Filaments			foam	film	Total
		nurdles	blocks	other	rope	packing	cloth			
S1	16/08/2011			1						1
S6	17/08/2011				2					2
S7	17/08/2011									
S9	18/08/2011			1	2					3
S11	18/08/2011			5	2	1			1	9
S12	25/08/2011			3						3
S14	24/08/2011				1					1
S20	19/08/2011			2			2	1		5
S21	22/08/2011									
S22	22/08/2011				31					31
S23	23/08/2011								1	1
S24	23/08/2011				2			1		3
Total				12	40	1	2	2	2	59

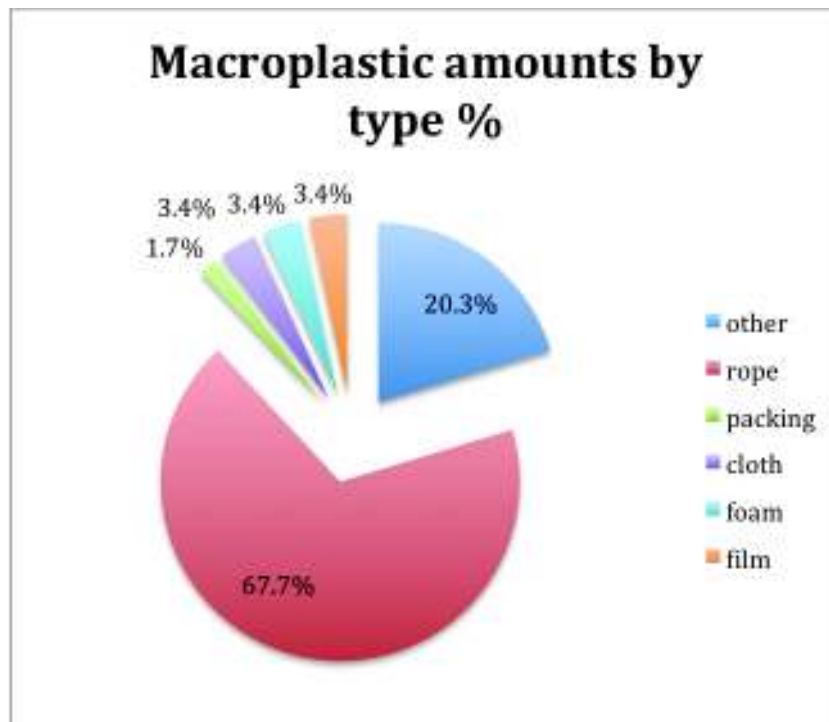


Figure 4.3 Total study macroplastic by characteristic

A similar pattern is shown with the large plastic items that were found. Most often debris fell under the filaments type with rope characteristics, and unidentifiable plastics had the second highest concentration. An interesting value is the significantly higher levels of large debris found at semi-rural site 22 and the next highest value at semi-rural site 11.

The results of the macroplastic classification data combined with the information collected on the proportions of microplastic characteristics, leads to the rejection of the secondary hypothesis that residential pollution will make up the primary source of microplastic particles found stranded along Icelandic beaches.

## 4.2 Qualitative observations

### 4.2.1 Site locations

There is an apparent spike in plastic accumulations seen in figure 4.1 at the semi-rural sites of 22, 11 and 6. These sites are located at the tips of prominent land features and inspired a further investigation into the potential causes of the relatively higher

values. Site 22 is located at the end of the Reykjanes peninsula, site 11 is located around the tip of the Snæfellsness peninsula, and site 6 is located on the north shore of the Snæfellsness peninsula within close proximity to a coastal community with a very active harbour. There is a chance that indirect factors associated with the hydrodynamics, topography and local activities around these prominent land features are influencing the amounts of debris found at these locations creating a patchy distribution within the study region.

Two explanations are provided based on field observations collected while conducting sample quadrants, and from general background knowledge of activities in this area. First, is the suggestion that these land features act as collection points for marine debris due to climatic and hydrodynamic forces concentrating at these locations. The physical characteristics of these landmasses means that there is always going to be high exposure on some of the beaches despite the prevailing wind direction. Secondly, and possibly more importantly is that there is a high level of fishing activity that occurs just offshore of these sites.

The waters just offshore from sites 22, 11, and 9 have some of the highest concentrations of fishing activity in Iceland due to their rich fishing grounds (based on Hafrannsóknastofnunin stock assessment, 2010). Since there is compelling evidence to show that fishing debris makes up a major component of the plastic pollution on regional beaches it might be assumed that there is a link between offshore activities and the amount of debris found stranded at specific locations. Information on local currents and harbour facilities might also play an important role in explaining the types and amount of plastic debris found related to fishing activities in certain locations.

The potential for currents to influence plastic distribution might be highlighted when site 24 is compared with site 23, located less than 3km away. The difference in microplastic concentrations between these two sites is astounding. There was 400 times more microplastic particles found at site 24 than 23. Nearly 85% of all the microplastics by weight and 70% of the particles by count, in the total study were found in three sample quadrates at site 24. At the same time larger plastic items found here were in very low concentrations similar to levels found at rural sites.

## 4.2.2 Collections in seaweed

It was observed throughout the study that microplastic particles located within the highest strandline are very often intertwined and deeply embedded in accumulations of natural wrack debris. This is because the action of Langmuir circulation patterns (appearance of foam streaks on waters surface) collect floating materials in the zone of convergence, and plastic material will become entangled within the seaweed and other flotsam collecting here.



*Figure 4.4 Wrack debris with associated plastics.*

When clumps of seaweed were located within sample quadrants special care had to be taken to ensure all sand was carefully brushed off of the vegetative material and back into the sample quadrat because many microplastic particles are located in this vegetation. Upon arriving at the location in figure 4.4, a large number of sheep were observed grazing on the seaweed at this site. This raised a number of concerns around the potential for livestock to accidentally ingest plastic marine debris.

## 4.2.3 'Site 25'

The photos in the above figure, 4.4, are taken from a section of the northern coastline and figure 4.5 below shows debris found at a discussion inspired sample site that provides insight on an area outside the study region.



*Figure 4.5 Plastic debris found at a northern remote site*

Site 25 was sampled outside of the original study region using the exact same sampling protocol for discussion purposes. This region was travelled many times prior to undertaking this research project, but the site did not fit into the original study design of investigating Reykjavik as a point source for microplastic pollution. Site 25 depicts a common occurrence along the shores of Húnaflói, that represents the eastern and northern shores of the Westfjords.

It is clear from the above photographs that a huge proportion of the debris found is nets and ropes. On the microplastic scale, this site is not nearly as polluted as urban site 24, but it is over twice as polluted as the second most polluted urban site 20, found in Reykjavik. When looking at larger macroplastic debris this site is by far the most polluted seen along any stretch of the coastline, both within the study region and through observations made while traveling the whole country.

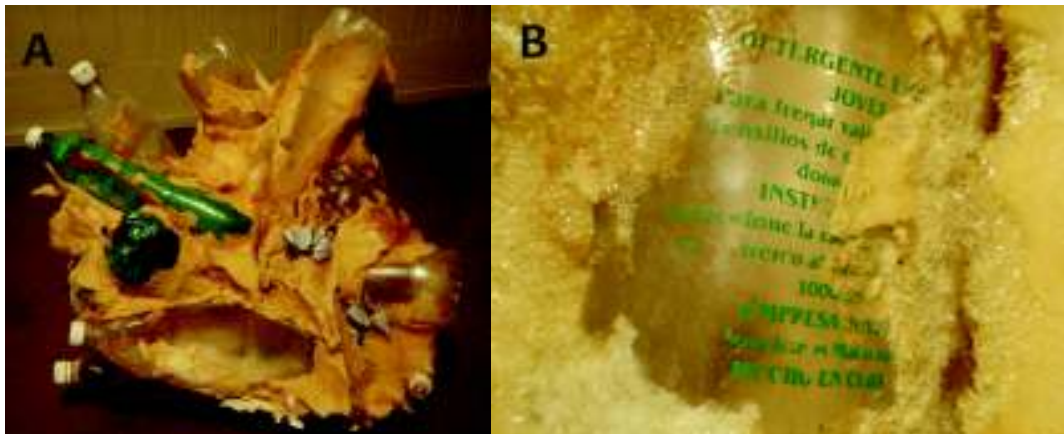
The total weight and amount of large debris collected at site 25 was almost equal to the grand total for all of the 12 study sites combined. To put it another way, the collection of all plastic debris found at the 12 study sites would just barely outweigh the garbage found here. The closest town is 35 km away by boat, and acts as the only significant harbor for well over 60 km. The author feels it is inappropriate to suggest that



all of this debris is caused by local residents in this remote region due to the huge quantities observed along vast stretches of coastline. This site calls for further research in order to try and determine if these plastics are derived from Icelandic sources or if this is debris from foreign sources accumulating due to ocean and climatic influences.

#### 4.2.4 Debris from afar

A large piece of plastic aggregate was discovered on the strandline of a beach located at the northern tip of Dýrafjörður, a very remote location in the Westfjords. It was noted by the landowner that the article in discussion here was not present a few weeks prior to the visit upon its collection. This indicates that it must have arrived only recently. The item was a collection of beverage bottles held together with insulating foam possibly to create a cheap buoy type device seen in figure 4.6. Attached was a collection of sessile organisms of unknown species in the goose barnacle family.



*Figure 4.6 Macroplastic item found in remote northwest region of Iceland*

When the above article was found, it was clear that since its deposition on the shoreline it had been undergoing mechanical degradation through the wave action experienced on the rocky shoreline. There were multiple chunks of foam and a few plastic bottles that had become detached and were scattered in the vicinity of the main larger piece. The small chunks of foam easily degraded into fine dust once handled and most of the beverage bottles located around the outside of the main mass where brittle and starting to crack due to chemical and photo degradation.

The item was collected in order to remove its presence from the environment, plus to further investigate its origin. In (B) of the above figure it can be seen that after a few layers of the outer foam are removed one of the labels could be read. The only legible label belonged to a detergent bottle that was manufactured in Cuba.

#### 4.2.5 Rope degradation

The largest amount of microplastic particles found by weight and number in this study is of a filament type material associated with either rope manufacturing or rope degradation. Observations made throughout this study suggest that one short length of careless or accidentally discarded rope from fishing activities, has the potential to contribute hundreds, thousands, maybe even more microplastic particles into the surrounding environment see figure 4.7.



*Figure 4.7 Example of plastic debris that forms microplastic particles.*

In the above figure the item in photo (A) was sampled from a semi-rural site. General field observations noted that there were many articles of similar form found in adjacent environments that exhibited various stages of decay like the item seen in photo (B). This is a very good representation of the type of microplastic filaments that are the direct result of breakdown processes on large poly based rope items that get stranded on beaches. This photo also highlights the potential for beaches with rocky or coarse substrates to potentially harbour a massive amount of microplastic pollution undetected deep within coarse substrates.

## 5 Discussion

Presently, 60% of the world's 7 billion people live in coastal areas with estimates of growth showing a total population of 8.3 billion by 2025, where 90% of this growth will occur in subtropical and tropical countries (Knap et al., 2002). This growth will undoubtedly result in greater pressures being placed on the land-sea interface of coastlines. Food production, transportation, climatic regulation, and oxygen production are some of the many vital services the ocean provides that we are putting in jeopardy for future generations. The world's oceans provide many direct health benefits to humanity, with recreational opportunities, a variety of nutritional resources, treatments for diseases, not to mention the reliance of over 2 billion people on seafood as their main protein source (Knap et al., 2002). These services are already being stretched to the limits, and exhibiting a declining ability to work as effectively as they have for hundreds of years. Poorly managed and over exploited ecosystems combined with the hazards associated with marine plastic results in the potential to severely affect the health of our global oceans.

Technological advancements have provided new opportunities to gain a better understanding of how human developments impact the environment. These advances in technology however have not come without costs. Unfortunately, with such huge leaps in technology and product development happening on a regular basis, outdated ideas and products are dumped just as fast as new ones are developed contributing to the proliferation of garbage of all kinds.

Iceland is one of the most pristine locations on earth, from its black sand beaches that back onto glacier laden volcanoes in the southern regions, to the remote rugged coastlines of the northwest fjords that open up to the Arctic Ocean. The wide range of applications and increased uses of plastic materials as a global resource has resulted in these materials carelessly being discarded in all types of environments. Whether it is a fishing buoy, drinking bottle, rubber glove or unidentifiable fragment, marine plastic pollution exists in Iceland.

## 5.1 Sampling methods

There are countless studies that document the ill effects of plastic ingestion and entanglement on wildlife with some dating as far back as the late 1960's (Kenyon & Krdler, 1969). The quantification of plastic particles in the pelagic environment has also been extensively studied with published material dating back to the early 1970s (Carpenter & Smith, 1972). After the international implementation of MARPOL Annex 5, published research on plastics in the marine environment began to decline during the late 80s early 90s (Ryan & Moloney, 1993). During this same time period garbage concentrations in the world's oceans and accumulations on beaches worldwide increased. With annual plastic production annually increasing, so was the component of plastic waste washing up on beaches. It became evident that MARPOL was not enough to resolve the issues of marine debris, and plastic trash re-entered the research spotlight. By the late 1990's and into early 2000 studies have focused on numerous aspects of the problem, yet even with increasing concerns, only recently has microplastic been given much consideration in major research labs.

Following the First International Conference on Microplastics in 2008, leading scientists from around the world agreed that a major step forward in microplastic research required an internationally recognized sampling protocol. The development of a sampling method with broad and comparable applications was a priority goal, but unfortunately such a protocol has yet to be published. The lack of coordinated research efforts might be the result of most studies looking to answer very specific research questions surrounding microplastics. The 'Catch 22' in this knowledge race is that studies continue to tackle tough questions with each researcher independently formulating and answering a question tougher than the previous one. This has left very little time for the development of a basic sampling technique that could be used by a variety of groups with a range of expertise, capable of producing reliable and comparable data.

With the issues surrounding microplastics being considered a problem with high variability, it appears as though the techniques used by various researchers to quantify and classify these little particles are also considered to be highly variable. A few researchers look at the micro debris floating in central gyres. Some investigate degradation behaviour based on the chemical matrix of various plastic materials. Others

focus on possible urban sources and sessile species consumption. Unfortunately, no available publications shed any light on the issue of developing a simple, easy to replicate, inexpensive method to quantify microplastics within beach sediments. Apparently one of the main goals in the First International Conference on Microplastics has proven to be more difficult to achieve than was originally thought.

Arthur et al. (2008) highlight that a major limitation in the mapping of global microplastic distributions, is that there is no current systematic way to inventory the release of these materials into the marine environment. This lack of knowledge could be explained by the fact that there is currently no commonly recognized sampling protocol for microplastics.

The sampling method used in the Thompson et al. (2004) paper titled “Lost at Sea: where is all the plastic?” was considered as a sampling protocol for this project because it is one of just a few publications quantifying microplastics in the beach environment. As this project developed, and the protocol was modified for an Icelandic application, Dr. Thompson advised that without photo spectrometry and intensive laboratory investigations, this sampling method would only positively identify approximately 30% of the collected particles as being of plastic origin. A sampling protocol that requires a significant amount of lab analysis with specialized equipment to achieve any reliable conclusions is not effective in promoting the establishment of long term monitoring programs. Although microplastic sampling protocols do exist, they are few and extremely resource intensive not fitting the global goal of a cheap, easily replicable protocol, that produces reliable data from a variety of groups conducting surveys.

The variability in deposited marine debris between beach types is outlined by Orr, Zimmer, Jelinski & Mews (2005) where it is shown that the fine grained surface of sandy beaches has a comparatively lower frictional surface compared to coarser rocky beaches and can result in a lower capacity for retaining wrack particles. The problem is that systematically surveying a rocky beach for microplastics would require a tremendous amount of effort in order to access the finer sediments buried beneath gravel and cobbles where microplastics are known to accumulate.

The University of Washington has been working in collaboration with the Port Townsend Marine Science Centre (PTMSC) in the development of a sandy beach sampling protocol for microplastics. Since it is a widely recognized fact that microplastics tend to concentrate along the highest wrack line of sandy beaches (Cooper & Corcoran, 2010), the PTMSC protocol is an ideal approach for investigating the presence of microplastic particles in the marine environment. The adoption of the PTMSC beach sampling protocol for this pilot project has not only made the study feasible, but it also allows for easy replication of the study in the future by others who might be interested by the current issues at hand.

## **5.2 Values of interest**

As seen in table 4.1, less than 5% of the total debris collected by numerical count was found at the semi-rural locations. When the sites are compared using debris weight as the comparative value (table 4.2) the semi-rural locations made up over 75% of the total debris collected indicating that larger or more dense items are found in these regions.

The fact that urban sites had the highest concentration of plastic items, but the lowest total weight brings to light the hidden danger of microplastics. Beaches can appear to be relatively clean but can be severely polluted with small, hard to see microplastic particles.

The current literature mentions challenges when trying to identify major sources of microplastic debris on beaches. A general approach to identifying debris is to separate plastic items that are based on consumption items in residential or recreational settings, and debris that could be the result of industrial or commercial activities (Ivar do Sul et al., 2011). For example, residential and recreational plastics could be assumed to be items like candy wrappers, beverage bottles, toys or other household related materials and commercial debris would be items like fishing gear, industrial packaging and oil containers (Sheavly & Register, 2007).

In an effort to try and identify the possible source of plastic debris in this study the use of a classification process that was based on the general physical characteristics of

an item was designed and used primarily for the microplastic investigation. This approach was used because these materials should not have any discernable identity. The category “other” under the fragments heading did nothing for assisting in the identification of larger debris items. This would have been the classification by default for any solid plastic items that could be associated with residential pollution, like drink bottles, plastic toys and other recreational debris. It is noted here by the author that despite the possible shortcomings of a simplified classification process, there was only one item out of 12 macroplastics collected and classified under the “other” heading that could be positively identified. This was an Applsin beverage bottle found at site 1, the most rural site in this study.

Despite some aspects of the categorization method being poorly designed for taking into account consumption items, the fact that both the micro and macroplastic items under rope filaments made up around 70% of the total debris, strongly suggests that commercial activities are the largest contributor of plastics in the marine environment around Iceland. Ivar do Sul et al. (2011) point out in their study that very often domestic debris items like drink bottles and food packages are commonly discarded from fishing vessels. Therefore estimates of debris items sourced from fishing vessels only considering fishing gear as the waste items from fishing activities will result in an underestimation of this sectors total contribution.

## **5.3 Urban influence**

With a sparsely populated coastline throughout the study region some rural sites are located in between semi rural sites, creating pockets of plastic free beaches between the semi-rural locations where plastic debris was found. This suggests that currents and local activities influence the patchy distribution found throughout the study region making it hard to conclude that a predictable decreasing pollution gradient exists with increasing distance from Reykjavik. Therefore both the micro and macro plastic debris found in northern remote regions, is more likely to be locally sourced than have Reykjavik as a point of origin.

The patterns observed in this study and the resulting data reaffirm the concept that population centres influence the amount of microplastic pollution found on regional beaches. Whether this is the result of more plastic items floating in the marine environment around urban beaches that eventually get stranded and breakdown into microplastic particles, or the direct input of microplastics entering industrial wastewater, this pattern does exist even with the smallest settlements of human population. These findings are supported by the 2011 study by Browne et al., where it is shown that a significant relationship exists between human population-density and the abundance of microplastics found in the surrounding marine environment.

The results here indicate there is more plastic debris accumulating on the beaches around urban centres by numerical count, but that debris collected at the semi-rural sites significantly outweighs the plastics found at the urban sites. This suggests that the plastic debris found in the semi-rural sites even though less frequent, is composed of either larger or denser plastic materials and urban centres have more microplastics which are extremely difficult to collect using conventional cleaning methods. This might be explained with the fact that in the populated areas around Reykjavik there is a greater community effort in dealing with stranded beach debris through voluntary cleanups or municipal waste management programs. Storrier et al. (2007) found that cleanup efforts have limited success because trash removed from beaches by volunteer groups usually gets quickly replenished, and regular cleaning programs cost municipalities large sums of money.

One particular site located in the surrounding metropolitan area of Reykjavík, site 24, is found to be heavily polluted with microplastic and gives the total concentrations of debris found under the urban classification type a very high, possibly biased value when compared to the actual urban average. This site is an interesting case that deserves further research efforts because of the extremely high amounts of microplastics found combined with the fact that relatively few large debris items were observed on this beach.





*Figure 5.1 Location of study sites 23 and 24 around urbanized area of Reykjavik*

The overwhelming majority of the microplastic material found here is of a filamentous characteristic indicating that it is from the degradation of ropes or a by-product of the rope manufacturing process.

The high concentrations of microplastics found within sediment at this site are nearly impossible to clean up with conventional efforts. Many more aspects of this particular site need to be investigated because this is an extremely polluted site and has the potential to contain higher than acceptable levels of POP concentrations in beach sediments.

One suggestion on further research is to investigate whether or not the materials used in constructing the road connecting Geldinganes to Gufunes on the existing isthmus, where site 24 is located, is built with materials dredged from a local harbour expansion project. It is possible that a historic harbour could have high concentrations of microscopic rope filaments from years of mooring vessels, and dredging activities in that type of location could potentially collect these particles and then deposit them into a new location. Claessens et al. (2011) found that throughout their study along the Belgian coastline the most common type of particle was plastic fibre and the levels were comparable between the beach and harbour sediments at sublittoral stations.

Another, more environmentally influenced suggestion is that due to the Coriolis effect site 24 actually acts as a microplastic sink, filtering the surface waters that are

collecting floating debris while travelling clockwise around the coastline of the Reykjavik area. It is possible to continually develop more dynamic theories around the causes of the high variance between sites 23 and 24, but the best solution is to conduct further research in this area.

Based on data collected throughout the study, with particular emphasis on site 24 and the patterns seen at semi-rural sites 22, 11 and 6, it is concluded that the major sources of microplastic pollution do not come from materials used in recreation or households purposes but is most likely sourced from commercial activities on, and around the marine environment.

## **5.4 Possible sources of microplastic**

Field observations in combination with the support of the data collected throughout this study has lead the author to believe that the majority of plastic debris found along the Icelandic coastline is coming from offshore fishing activity. It is not known however if this debris is coming directly from fishing vessels operating on local fishing grounds, or if observed accumulations are just patches of debris that were deposited after travelling on ocean currents that concentrate at the end of peninsulas where many sites were located. The hypothesis that offshore fishing activities around the research sites are greatly influencing the types of debris stranded on shore is supported by the Galgani et al. (2000) study where high amounts of fishing gear were commonly documented in zones of high fishing activity.

The fishing industry is Iceland's largest and most important economic sector, but also one completely reliant on the use of plastics for various lines, nets, floats, and lures. Therefore careless or accidentally discarded debris found stranded at sample sites originating from boats should not be a surprising discovery.

Ivar do Sul et al. (2011), concluded that there was no significant difference in the total number of items found between developed and undeveloped beaches in their study. This study also concluded that developed urban beaches had 70% of the documented debris being derived from locally consumed items like cigarette butts, beverage bottles, and plastic straws, and undeveloped rural beaches had 70 % of the debris from non-local sources with items like rigid fragments, ropes, caps, and polystyrene. Unfortunately, the

author of this current study feels it inappropriate to assume that the rope items found on the undeveloped rural and semi-rural beaches in Iceland should be considered to be derived from non-local sources due to the high levels of poly based rope used in local offshore activities.

The belief that high concentrations of microplastic particles found at site 24 come from nearby factories is derived from two observations. First, there is a major international manufacturer of poly-based rope and nets located within 10 km of the study site. Secondly, information presented by Mato et al., (2001) supports the idea that the presence of plastic nurdles, the feedstock for the plastics manufacturing industry, found in conjunction with many plastic shavings indicates that industrial activities are directly contributing to plastic debris found at this site. Figure 5.2 provides an example of the microplastic particles found at site 24 within one sample quadrant.



*Figure 5.2 Microplastic particles found at site 24 in quadrat 1.*

The source of the plastic bag like looking particles (films), from the above picture was greatly debated by the author, and despite a lack of any solid evidence it was finally concluded that this material found here is the type used in wrapping hay bails for livestock feed. This decision is based on the fact that the colour and texture of these plastic films are identical to the materials used in farming applications, and that these

plastic films are commonly seen caught in fences and vegetation after being transported by wind over the Icelandic landscape. Briassoulis & Dejean (2010), point out that the extensive and expanding use of plastics in agriculture activities has led to a rapid increase of plastic waste accumulating in rural landscapes. If this hypothesis is correct the author finds it very interesting that this type of plastic film material was only found at this one urban site, and not found at any of the rural or semi-rural sites. This fact alone provides support for one of the above theories where site 24 has become highly polluted because of patchy distributions influenced by ocean currents.

## **5.5 Collections in seaweed**

The importance of natural debris like macro algae and macrophytic wrack material collecting in convergence zones and ultimately being deposited on the high strandline is outlined by Orr et al. (2005), because it provides a significant amount of nutrients to the intertidal herbivore and decomposer communities. The fact that plastic materials are commonly found locked and entangled within mounds of beached seaweed and other macro algae materials, leads this author to believe that the intimate relationship between synthetic and natural material could act as a gateway for POPs to enter the food chain through indirect ingestion of hidden microplastics stuck on seaweed. Two questions are posed here based on this scenario: If plastics are capable of transferring pollutants into sediments in a relatively short time period, could this transfer happen equally as fast onto organic materials such as seaweed before this type of organic material decomposes? And at what rate do larger herbivores accidentally ingest plastic materials through the consumption of beached seaweed?

It is a common occurrence around Iceland to find sheep grazing on beached seaweed. This vegetation is sought after and consumed by livestock because of the high salt content. It could be assumed that the retention time for an accidentally ingested piece of plastic in the gut of an herbivore would be very short. Therefore the chance of accidentally ingested plastics leaching pollutants into the animal tissues of large livestock would be minimal. But, if beached plastics are capable of transferring hydrophobic POPs into larger organic debris as quickly as they are able to transfer toxins into beach

sediments shown by Teuten et al. (2007), then this could become a greater concern for Icelandic farmers due to biomagnification.

## 5.6 Debris from afar

The large piece of plastic aggregate discussed in section 4.2.4, found in a remote region of the Westfjords provides evidence for at least two of the major concerns associated with the increasing global plastic pollution problem; the transport of foreign species and pollution into remote regions. The article in discussion here had a number of barnacles seen attached to the outside of its surface and the only identifiable label on this item indicated that it was sourced in Cuba. This might suggest that a carelessly discarded piece of trash in Cuban waters has the potential to get caught in Gulf Currents and travel up towards Icelandic waters with a load of foreign species and pollution.

It has been demonstrated (Ingólfsson, 2000) that in Icelandic waters intertidal species rafting on floating clumps of seaweed can be transported considerable distances offshore. Materials like seaweed, wood, and clumps of turf have been shown to transport sessile organisms offshore but due to rapid degradation these distances are limited. The much slower degrading nature of plastic materials has been shown to provide a more pervasive shelter and mode of attachment that is capable of transporting organisms for longer time periods over greater distances (Minchin, 1996). Plastic are more likely to allow this sort of transport over natural debris because while floating in sea water plastic material typically doesn't degrade as fast as natural material, that is until it gets beached.

Marine plastics can be potential vectors for transporting aggressive invasive species (Gregory, 2009). It is shown in the above study that with the current quantity and increasing concentration of these non-biodegradable materials in the marine environment, the dispersal of opportunistic and invasive colonizers will be greatly enhanced. Barnes & Milner (2005), made a very important discovery with regard to foreign species in the north, and this was the observation of the exotic invasive barnacle species *Elminius modestus* found on beach plastics in the Shetland Islands. This could ultimately impact other north Atlantic nations in adjacent regions with frequent maritime traffic occurring between all Nordic countries.

The discovery of this item was both concerning and somewhat of a relief. The concerning aspect of this item is that it highlights much of what the literature mentions about pervasive plastic pollution. It is capable of traveling long distances before arriving in remote regions where it will break down after potentially transporting aggressive foreign species or toxins, and marine debris is a problem that crosses political and geographic borders with no simple management solution. The small sense of relief the author felt with this discovery of this item is that it cannot be assumed that every piece of marine litter found on Icelandic beaches is the direct result of careless behavior by the local residents, but some debris could potentially be the result of careless behavior from some far away neighbors.

## **5.7 Fauna**

There is no published data on plastics directly affecting wildlife in the Icelandic environment. A study however was being conducted in the spring of 2011 (Kuhn, pers. comm.) investigating the stomach contents of fulmars caught as by catch in the long-line fishery of Ísafjarðardjúp. A small portion of the birds sampled had plastics found in their stomach. This could suggest two things, either there is enough plastic in local waters to be ingested by birds, or it supports a theory hypothesized by Kenyon & Kridler (1969) that the persistent nature of plastics in wildlife means that it can be transported great distances and ultimately deposited into remote environments through animal fatalities.

Some additional interactions between plastics and wildlife were observed while conducting field research. Figure 5.3 shows a bird nest located in a rocky outcrop at rural site 14, and it can be seen in the photo that plastics are used in nest construction. It is interesting to note that the only piece of macroplastic found at this site was a rope used in long-line fisheries, and it is the same type of material observed within the bird nest combined with packing bands and many sections of barbed wire fencing.



*Figure 5.3 Bird nest with plastic debris used in construction*

The species of bird that lived in this nest is unknown, but it is most likely a large carnivorous species (based on bones and other evidence). If this is a species that returns to the same nest year after year there is potential for the plastic material in this nest to break down into microplastics over time, increasing the risk of ingestion by its fledglings. Through personal communications with local researchers conducting studies around Iceland it was noted that plastics have been documented, although unpublished, in a number of species from seals, harbour porpoises, and minke whales to foxes and fulmars. With more research efforts looking at wildlife and human interactions around Iceland there is likely going to be more discoveries of wildlife and plastic interactions. If organic pollutants in marine plastics become available to enter the marine food web or human consumption items, opportunities for livestock and wildlife to encounter these plastics must first take place.

## **5.8 'Site 25'**

All coastal nations are capable of receiving marine debris from neighbor states and far off locations. In Iceland clear evidence of this can be seen from the debris carried on currents from northern regions of Scandinavia and Russian that has been deposited on



the north shores. An impressively massive amount of driftwood has been carried from these regions as the result of inefficient forestry operations over the past many decades. This wood, often very big logs, travelled on ocean currents to get deposited in huge concentrations along the shoreline, and in some cases in quantities so large that they have significantly influenced local dune formations becoming an integral part of the coastal stability.

Site 25 is located in a relatively protected fjord setting that will have undoubtedly contributed to the high retention rate of marine debris, but it was chosen to sample based on the need to sample beaches with sand substrate. Concern over the local landscape geometry were described by Claessens et al. (2011), when it was shown that the elevated levels of microplastic found at their study sites were primarily linked to the geometry of the compartment (i.e. enclosed areas in harbors). With this concern taken into consideration there are many more exposed sites within the region of site 25 that exhibit identical plastic accumulations indicating that this particular site is not an anomaly.

The point in sampling this site outside of the original research region was to initiate discussions and follow up with some of the unexpected findings. Even though the overall findings of this study show that the level of human settlement does influence the amount of plastic debris found on adjacent coastlines, other factors play a huge role. This suggestion is supported by findings in the Storrier et al. (2007) paper where they noted that climatic conditions and tidal patterns acted as the greatest influence on the abundance of marine litter found at their study sites, but the effects of frontal systems on litter dynamics were unknown and warranted further examination. Site 25 reinforces a hypothesis that offshore activities, combined with climate and hydrodynamic patterns will be the greatest influences on the deposition and concentration levels of plastic found on the Icelandic coastline.

## **5.9 Management suggestions**

The first step to managing a problem with both local and global implications is to develop a thorough understanding of the issue and all the parameters that contribute to it. A quote in the paper by Sutherland et al. (2010) outlines the importance of developing a



sound base knowledge on the issue of microplastics because the full implications of this global issue are just starting to be discovered:

“For science to be relevant and useful, it must be offered at the appropriate times in decision-making processes. Excellent science completed after critical decisions have been made is of limited use (page 1).”

The majority of studies published to date include sections on managerial solutions to plastic pollution problems, but these solutions often have a directed focus on obvious point sources of plastic debris entering the marine environment, or they provide measures used to manage the accumulations and arrival of foreign debris. The variety of mitigation measures presented in the literature review will not be applied to the Icelandic coastline because the most important aspects of proper management are still unknown in this context. This study only provides suggestions and hypotheses on the sources of marine plastics in Iceland. The first step in better management would be further research. Since it was concluded that offshore fishing activities do play a role in the observed amounts of debris further research into the types of gear, locations of gear concentrations, and any relations between beach accumulations and specific fishing seasons would assist in potential prevention or mitigation management solutions.

Successful litter prevention measures documented by Storrier et al. (2007) were noted when the authors found the proximity to harbors and marinas did not significantly affect the amount of debris found on local beaches when adequate port reception facilities were available in the area. In this study the author did notice that in some locations around Iceland harbors and marinas provided clear, easy access to waste disposal bins, while in other locations these receptacles could not be found anywhere. Understanding how this might affect the behavior of local boat users and their approach to disposing of wastes while on the water could provide significant insight into debris accumulations found at specific locations.

Two ways of managing microplastic particles in the marine environment, are to prevent these particles from entering the marine ecosystem (Browne, 2011), and to prevent larger macroplastics that eventually become microplastics after degradation from entering the marine environment (Andrady, 2011). Policy and regulations are needed to

prevent microplastics from directly entering the ocean because they are mainly associated with industrial processes or municipal waste management and require a higher level of decision making in order to implement management solutions. The prevention of macroplastic debris from entering the ocean requires an approach that targets human behaviour. This is because much of the larger debris that enters the ocean is the direct result of careless uneducated actions by individuals or companies that do not understand the true implications of this pollution type in the environment.

Education is a very powerful and effective tool. If people understand the hazards associated with carelessly discarding their trash then they can act to prevent it from happening. Public outreach and school programs can teach the importance of a healthy ecosystem and educate the importance of preventing litter from entering the ocean. The plastics industry is working towards 100% recovery but is very far from reaching this goal. It takes many levels of societal participation to make this even a consideration, let alone a reality. From wise consumer choices to more efficient waste recycling programs the disposable era needs to change.

Marine debris, and plastic pollution in particular do occur along the coastline of Iceland, but compared to many other coastal nations the current impacts of this type of marine pollution are considered to be fairly minimal in this environment.

## **5.10 Future research**

Plastic pollution and microplastics in particular are not prevalent enough in the Icelandic landscape to be seriously affecting local or national economies. But if waste accumulations are permitted to increase the first sector that might receive direct negative impacts would be tourism. As the tourism sector annually increases its importance in the Icelandic economy, measures should be taken that ensure the reputation of a pristine wilderness is preserved, which is the foundation that most local tourism interest is built upon. Understanding the plastic pollution problem is the first step in tackling its sources. Santos et al. (2009) outline the importance of this pilot project when they state that, background information collected during preliminary investigations is the crucial first step in the future management and mitigation of marine debris.

The main research goals of this pilot project on microplastics in the marine environment were inspired by suggestions made in the Frias et al. (2010) paper. They suggest that future research efforts on microplastics should have as the main goals: (1) identify the size of plastic debris due to degradation, and (2) map out the abundance of microplastic debris in the beach environment. A third suggestion was that important research efforts be given to determining the POP concentrations of beached microplastic particles and their potential health effects on living organisms. This last suggestion is one of the most difficult issue to address, but based on the concentration of plastic particles found in seaweed and local patterns of livestock grazing habits it might actually be one of the most important issues affecting the local population of Iceland. The overall goal of this pilot project is to initiate some critical thinking about potential threats to our marine environment. Barnes & Milner (2005), suggest that the quantification of marine debris along coastlines allows for the extent of this problem to be realized and ultimately some of the causes of it to be resolved.

The importance of understanding the current levels and types of plastic pollution in the environment is due to the fact that these materials are not actually disappearing from the environment but are changing form. A study on floating plastic materials in the Western North Atlantic by Moret-Ferguson et al. (2010) indicated that plastic particles on the ocean surface are annually getting smaller in size possibly due to the amplifying affects of mechanical abrasion and photochemical breakdown with long resistance times in the ocean. The problems of plastic pollution in the marine environment are not going away they are just getting smaller. Corcoran & Biesinger (2009) found that the beach environment is an excellent setting for the degradation of plastic debris because few other natural environments combine such high degrees of both chemical and mechanical weathering. The also suggest that because of the fact that plastic does not degrade through mineralization particles may remain in the environment indefinitely, which is why it is so important to gain a basic understanding of the current amounts and depositional trends.

## 5.11 Summary

Despite the fact that both hypotheses in this study had to be systematically rejected, the final results and undertaking of field research has brought to light many new aspects of the growing plastic pollution problem on both the macro and micro scale in Iceland. Some of the patterns and trends found throughout this paper are similar to findings published in other studies. The overall situation observed throughout this study was that issues along these coastlines will be unique to this landscape, with local activities and other indirect factors influencing a dynamic relationship between the plastic pollution and its potential sources in Iceland.

Annual beach cleanups have become a common occurrence in coastal communities around the world. This is because an increasing amount of marine litter, primarily composed of plastic material is found washing up on global coastlines. There are many more negative aspects to this prevalent pollution, which for many years was primarily regarded as strictly being an aesthetic problem. Wildlife endangerment is a well known and well documented side effect of plastic pollution in the marine environment, but as the problem starts to affect the economics of industries and communities more attention has been given to the cause and necessary solutions to this problem. Research has shown that increasing plastic pollution has cost millions of dollars to the shipping and fishing industry adds maintenance costs to coastal municipalities while also deterring very important tourism to coastal communities, and when broken down into smaller microplastic particles has the potential to bioaccumulate organic pollutants in the marine food web.

Understanding the sources and possible sinks of local marine debris in Iceland is not only important for dealing with the potential of pollutants to enter our food web through marine sources but it also greatly affects the aesthetic value of the local landscape and this has the potential to affect the countries second most important economic sector, tourism. Marine debris found accumulating on coastal beaches has the potential to discourage people from fishing, boating, swimming or visiting specific locations (Sheavly & Register, 2007). With a major characteristic of the highly regarded Inspired by Iceland promotional campaign being the pristine beauty of untouched nature,

the tourism sector should be ambitiously acting at locating and preventing plastic pollution from entering the regional marine environment.

The outcome of this pilot project on marine pollution with a microplastic focus in Iceland, has shown that this may not be as big a problem as seen in other parts of the world, but microplastic pollution is found in Iceland and the most likely cause of these particles are the result of local activities. It is very likely that Iceland's largest economic sector employing the vast majority of the nation is inadvertently causing the greatest amount of plastic pollution found along the coastline. If specific locations, activities, or possibly individuals can be identified as the source of the plastic pollution in the Icelandic setting then measures can be taken to prevent the further contamination of the local marine environment. Only then can the nation of Iceland, an icon of untouched pristine wilderness, be self assured that all possible measures are being taken to prevent further contributions to the increasing catastrophe of plastic pollution in the global oceans. The hope is that this project has initiated some critical thinking on a global issue of infinite proportions with implications that are only just beginning to be realized.

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