Master's thesis

Occurrence, Prevalence, and Classification of Fishing Related Marine Debris in Iceland's Westfjords

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Ísafjörður, February 2020

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45 ECTS thesis submitted in partial fulfilment of a Master of Resource Management degree in Coastal and Marine Management at the University Centre of the Westfjords, Suðurgata 12, 400 Ísafjörður, Iceland

Degree accredited by the University of Akureyri, Faculty of Business and Science, Borgir, 600 Akureyri, Iceland

Printing: Háskólaprent, Reykjavík, February 2020

Declaration

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

Amy O'Rourke

Abstract

Over the past few decades, Western attitudes and values have generally been trending towards greater protection of terrestrial and aquatic environments. A topic increasingly attracting government, media, and public attention—and the present study's focus—is accumulation of human garbage in the ocean. Such refuse, much of which stems from global fishing industries, can harm aquatic flora and fauna, either directly (e.g., choking, entanglement) or by entering the food chain or leaching toxic compounds into the ecosystem. Before this mounting concern can be halted, researchers must first find out a) which sorts of debris are most common and b) which sectors produce the most waste. In Iceland, however, these regionally-variable factors have yet to be the focus of extensive academic inquiry. To fill this gap in the literature, this project develops and tests a taxonomy of common marine debris types in the North Atlantic. By counting refuse washed ashore on 6 beaches in Iceland's Westfjords region, this exploratory study has found that Abandoned, Lost or Discarded Fishing Gear (ALDFG; namely, floats, ropes, trawl, gill net, line, lures, etc.) constitute the vast majority of fishing related local marine debris. These findings illuminate problem areas in current waste management and suggests fishing-related materials should be continuously monitored to mitigate the risks they pose to the aquatic environment. Although Iceland has strict waste management protocols for its fisheries, clearly more needs to be done. Future research building on these preliminary findings should more thoroughly unravel how fishing-related refuse becomes marine debris. The findings of such research could identify specific fishing (and other) operations at high-risk for producing marine debris, and, thus, inform future management.

Útdráttur

Seinustu áratugi hafa viðhorf og gildi vestræna heimsins hallað sí meira að frekari vernd umhverfisins bæði í hafi og á landi. Viðfangsefni sem fær aukandi athygli ríkisstjórna, fréttamiðla og almennings- og er einnig viðfang þessarar rannsóknar- er úrgangur af mannavöldum í hafinu. Úrgangurinn, sem á meiri hluta að rekja til sjávarútvegs, er skaðlegur dýra- og plönturíki hafsins, annað hvort beinlínis (sem dæmi köfnun, flækjun) eða með því að verða hluti að matarkeðjunni eða dreyfa eiturefnum í vistkerfið. Áður en hægt er að draga úr þessu mikla vandamáli verða vísindamenn að fyrst finna út a) hvaða rusl er algengast og b) hvaða geirar framleiða mesta ruslið. Á Íslandi hinsvegar eiga þessir svæðisbundnu þættir eftir að vera viðfangsefni í íterlegri akademískri rannsókn. Til að fylla upp í þennan skort hefur verið framin rannsókn á mismunandi flokkum úrgangs hafsins í Norður Atlantshafi. Með því að telja og flokka rusl sem rekið hefur upp á land í 6 fjörum á Vestfjörðum, hefur þessi rannsókn komist að stór meiri hluti úrgangs í sjónnum er Yfirgefinn, týndur eða fleygður fiskibúnaður (YTFF; það er; flot, reipi, togaranet og tálknanet.) Þessar niðurstöður sýna fram á vandamál í úrgangsaðferðum og leggur til að fiskibúnaður ætti að vera undir stöðugu eftirliti til að minnka neikvæðu áhrifin sem hann hefur á sjávarlíf. Þó svo að Ísland hafi strangar reglur varðandi úrgang í sjávarútvegi, er greinilegt að meira þarf til. Framtíðar rannsóknir byggðar á þessum niðurstöðum ættu að komast ítarlega að því hvernig úrgangur í fiskveiðum verður að hafúrgangi. Þessar niðurstöður gætu einnig bent á hvaða veiðar og aðrar starfsrækslur eru líklegastar til að skapa hafúrgang sem hægt væri að benda framtíðareftirliti á í þessum málum.

To Eleanor Gardner & Evelyn O'Rourke

Foreword

Though this study sought to understand the nuanced sources of marine debris, it was primarily motivated by a desire to both enact tangible environmental change and encourage others to do the same. The project's impetus stems from personal optimism: while the poor state of beaches in Iceland and beyond may be discouraging, I am thankful to be able to witness and respond to them. This research ultimately supplied an opportunity to channel negative feelings into something productive. In addition to protecting wildlife and improving visual quality, beach cleaning is an immensely rewarding, meditative, and personally meaningful activity.

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List of Acronyms and Definitions

ALDFG: Abandoned, Lost and Discarded Fishing Gear

FAO: The Food and Agriculture Organization of the United Nations

HDPE: high density polyethylene (synthetic polymer)

LÍÚ: The Federation of Icelandic Fishing Vessel Owners

Macroplastics: Plastics greater than 5mm at their longest dimension and readily visible to the naked eye

Microplastics: Plastics less than 5mm at their longest point. Microplastics may be manufactured in this size or result from the degradation of macro or primary plastics (FAO, 2017)

Nanoplastics: microplastic particles below one micrometer (1 μm) in size that result from the degradation of macro or micro plastics (e.g., Gigault et al., 2018; Andrady, 2011)

PBTs: persistent, bio accumulative and toxic contaminants. Plastics act as a sink for PBT's and may desorb the long-lasting toxins when ingested (e.g., Engler, 2012; FAO, 2017)

PE: Polyethylene, a synthetic polymer commonly used to manufacture trawl nets in Iceland (Reykjavík Maritime Museum, 2018).

PET or PETE: polyethylene terephthalate is a synthetic polymer from the polyester family. PETs are denser than seawater and susceptible to bio-fouling, which are factors that cause them to often sink to the ocean floor (Ocean Portal & Jambeck, 2018).

SRD: Sewage-related debris

SFS: Samtaka fyrirtækja í sjávarútvegi or Fisheries Iceland

UNEP: United Nations Environmental Programme

Acknowledgements

I would first like to thank my brother, Sean O'Rourke, for his support, patience, academic prowess (and subsequent guidance), and for using his vacation to collect beach debris with me. Second, I would like to acknowledge the fishermen who have shared their experience, insights, and dedication to the sea with me: Tryggvi Svanbjörnsson, Kristófer Reynisson, Arngrimur Húni Guðmundsson, and those who partook in candid conversations with me: Thank you. My advisor, Georg Haney, offered valuable patience and guidance for which I am thankful. Finally, to my friends and family, near and far, for their unceasing support.

1 Introduction

Throughout the 100,000 years modern humans have existed on our planet, an uncountable number of us have relied heavily on the ocean's resources. This is especially true in Iceland, where a thousand years ago, the abundance of cod in the North Atlantic greatly facilitated this island's colonization. Even in the age of globalization, Earth's oceans continue to drive prosperity in our species. For example, oceanic trade routes have brought economic opportunities and a higher standard of living to many humans. However, the marine species with whom we share our planet—and who sustain lucrative fishing industries—have not reaped the same benefits. An estimated 5-12 million metric tonnes of plastic, the primary component of most debris, makes its way into the ocean annually, posing a significant threat to aquatic flora and fauna (Jambeck et al., 2015)—as well as fishing sectors. Media stories about 'garbage whorls' are ubiquitous (Montgomery, 2017; Gabbatiss, 2018). The growing number of plastic is an especially worrying occurrence; a study conducted in the North Pacific Central Gyre found 35% of planktivorous fish to have ingested plastic (Boerger et al., 2010), while 62.5% of surveyed king mackerel (*Scomberomorus cavalla*), an important edible fish off the coast of Brazil, were found to have ingested plastic pellets (Miranda & Carvalho-Souza, 2016). These examples exemplify the global and pervasive nature of marine debris. The 5 Gyres Institute further demonstrated the ubiquitous nature of marine pollution by sailing from Bermuda to Iceland, where the research crew identified micro plastic pollution in all surface trawl samples, including those collected in the sub polar gyre just south of Iceland. These findings contributed to a dataset on estimated global plastic pollution (Clevenger, 2014; Eriksen et al., 2014; 5 Gyres Institute, 2014).

It may seem reasonable that the industries who profit the most from aquatic species would do the most to protect these animals, but research indicates the fishing sector contributes significantly to marine debris due to their heavy reliance and use of synthetic materials (i.e., nylon for gillnets and line, polyethylene (PE) for buoys, seine and trawl nets, high density polyethylene (HDPE) in crates, etc.,) (Reykjavik Maritime Museum, 2018; FAO, 2017; Pichel et al, 2007; Macfadyen, Huntington, & Cappell, 2009). A 2018 study on the composition of debris constituting the Great Pacific Garbage Patch found 46% of its mass to be from fishing nets, with fishing industry related debris making up a majority of other debris (Lebreton et al., 2018). This contradicted previous studies which estimated fishing gear to constitute approximately 20% of marine debris globally (Lebtreton et al., 2018). Fisheries and aquaculture are recognized as contributors to marine pollution, but the scale of their contribution remains relatively spatially variant or unknown (FAO, 2017).

In Iceland, fishermen abide by strict protocols with regards to waste management and disposal while at sea. Despite this, fishing gear continues to appear in the marine environment. Though Abandoned, Lost, or Discarded Fishing Gear (commonly shortened to ALDFG) is recognized as a significant source of marine debris in the North Atlantic (OSPAR, 2017), the specific fishing sectors (i.e., line fishing/jigging, gillnetting, longlining, bottom trawling, purse seining, trapping, etc.) producing the most waste has yet to be a topic of academic investigation in Iceland, despite the significant amount of commercial fishing conducted in its waters.

The accumulation of debris, the majority of which is non-degradable plastic, is unsustainable; marine debris threatens to smother the oceans, wreaking economic, social, and environmental damage (e.g., Sheavly & Register, 2007; Moore, 2008; Engler, 2012;). However, in some parts of the world, including Iceland, research has only just begun to tackle the specific composition and sources of marine debris. Given the dramatic spatial variation in the composition of marine debris (Galgani, Hanke, & Maes, 2015), there is insufficient information on regional contributors. To address the problem of oceanic refuse and fill these gaps in the literature, the present study develops a preliminary marine debris classification scheme—a first step towards improving our understanding of the specific practices and fishing sects that contribute to marine debris. Given that marine industries and debris vary across the globe, a 'one-size-fits-all' refuse taxonomy is not possible; so, this study solely considers marine debris in Iceland. This classification scheme is the culmination of data collection from 24 shoreline cleanups to quantify marine refuse and identify the breadth of fishing-related materials washing ashore.

1.1 Objective

The objective of this thesis is to develop a classification scheme centered around materials used in Iceland's commercial fishing industry. This classification can be used to identify how different fishing sects, and the fishing industry overall, contribute to the degradation of the marine environment through pollution. The frequency with which materials associated with different operations (i.e., different types of fishing, fish processing) appear, and whether they are used in the water, or enter the ocean despite being used solely on boats or land, identifies probable pathways the refuse takes to becoming debris. This information can be used to discern high-risk operations, gauge the effectiveness of waste management, and in aggregate, inform engagement with industry players and other stakeholders. Shoreline cleanups were conducted to gain insight into which fishing-related materials frequently wash ashore. This data was used to create classification sections and subsections. In total, 24 official shoreline cleanups (i.e., those with meticulous documentation) were conducted, as well as upwards of 20 supplemental cleanups (i.e., those conducted outside the data collection period that still garnered pertinent, if more anecdotal, information). Versions of the classification scheme were retroactively applied to collected materials, and tested during supplemental cleanups, to inform the classification's final form.

1.2 Scope

The scope of the present study encompasses materials related to the fishing industry in Iceland's Westfjords. For the purpose of this study the definition of the fishing industry refers to the "catching and farming, processing and exporting [of fish and commercially valuable invertebrates]" (Knútsson & Gestsson, 2006). Gear used by foreign fishermen is not distinguished from debris of local origin; this study aims to distinguish between specific fishing sources, country of origin aside. While fishing gear from different sects can be specifically sourced (i.e., based on country of origin, intended species/selectivity) doing so is beyond the scope of this study, which rather aims to give the average beach-cleaner a basic sense of the fishing related debris they may come across. Further, this study assesses the composition of marine debris that has washed ashore; it does not account for debris that has sunk to the seafloor, remains floating at sea, has been ingested by marine life, remains in the water column, or has broken down and/or is too small to be seen with the naked eye. These materials are important to consider for their impact on marine habitats and organisms, but macro-debris that has washed ashore is the focus of the present study. Finally, the present study aims to implement simple, replicable data collection methods to be used alongside voluntary or organized beach clean-up efforts. Further, the data obtained can be used to engage community members to stimulate change in behavior and practice.

1.3 Research Questions

Given this study's aforementioned objective and scope, three research questions have emerged that this study hopes to explicitly or implicitly address:

1. What is an effective classification system to document fishing-related marine debris in Iceland's Wesfjords?
2. Which measures can be taken to improve best practice in specific fishing sects in Iceland's Westfjords with regards to marine debris?
3. What is the state of marine debris management in Iceland's Westfjords?

1.4 Research Implications

This study's findings will have both pragmatic implications and contribute to academic literature. Understanding which parts of the fishing industry create the most waste guides management by identifying problematic areas and investigating sources. This study's findings also contribute to scholarly literature by providing scientific data on marine debris in Iceland's Westfjords, and providing a framework for researchers to conduct similar studies in other regions. Further, the present study provides results that could inform studies in the Westfjords or elsewhere in Iceland to build upon or test findings. Future engagement with fisheries players utilizing collected data is important to understand what they know about marine debris and what they are willing or able to do to reduce it (Harley et al., 2015). Identifying which fishing-related materials compose marine debris can inform mitigation measures by identifying high-risk operations and materials.

1.5 Limitations

The present study does indeed provide a snapshot of fishing gear that washes ashore in Iceland's Westfjords, yet a number of factors limit its generalizability. The materials collected during shoreline cleanups are limited in their ability to fully represent fishing-related marine debris around Iceland. Though the Westfjords are surrounded by prominent fishing grounds, the materials collected in are not an exact representation of all fishing-related debris that may be found across Iceland. Fishing grounds for herring (*Clupea harengus*) and norway lobster (*Nephrops norvegicus*) are predominantly found off Iceland's southern coast (Marine Institute, 2017). Fishing for these species is generally conducted using Danish seines or gillnetting, and lobster pots or trawl nets, respectively. These types of fishing gear, partially unaccounted for in the classification scheme, may appear near Iceland's southern coast, though not in the Westfjords. This limitation is addressed by including an 'other' category.

Second, the present study is limited by the amount of Icelandic fishing and/or pollution-related information that is available in English. The author is an English-speaking foreigner and thus cannot fully make use of the information offered by Icelandic authorities, primarily LÍÚ (The Federation of Icelandic Fishing Vessels) and SFS(Fisheries Iceland), as well as media or academic literature published solely in the Icelandic language. Finally, the amount of research that has been conducted in Iceland's Westfjords is limited as a sparsely populated region with finite people and resources.

1.6 Outline

In order to fulfill my research objective, this thesis is partitioned into 6 chapters. Chapter one (Introduction) has introduced this study's topic and provided brief context on the importance of marine debris management in Iceland. Chapter two (Literature Review) explores relevant literature to detail a) the effects of marine debris on aquatic organisms and b) the state of marine debris management and current fisheries practice in Iceland. The literature review also brings to light significant knowledge gaps on the topic and possible areas for increased inquiry. Chapter three (Methods) outlines the development of methodology and how data collection was conducted and a classification scheme developed. Chapter four (Results) outlines the results of the data collection and how it informed the resultant classification scheme. Chapter five (Discussion) expands upon the results by situating the literature and exploring their implications for the local and global marine environment. Finally, chapter six (conclusion) summarizes and concludes the study.

2 Literature Review

Over the past five decades, people have been growing increasingly concerned with the amount of human refuse that makes its way into marine environments and how such debris can influence aquatic flora and fauna (e.g., The International Convention for the Prevention of Pollution from Ships, (IMO, 1973); The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention")(OSPAR, 1998)). In recent years, this topic has been gaining more and more media (e.g., Great Pacific Garbage Patch; Blue Planet II), academic (e.g., International Marine Debris Conference; Plastic Oceans International Conference), and governmental attention (e.g., OSPAR Regional Action Plan; G20 Action Plan on Marine Litter; UNEP, 2013). In order to determine how marine debris affects oceanic ecosystems, however, the first step is investigating which types of refuse are present in such environments. The present study is an exploration of the sorts of refuse that wash ashore on beaches in Iceland's Westfjords region. To discuss literature relevant to this topic, I have split my literature review into four sections. First, the concept of marine debris is broadly defined and expanded upon. Then, specific environmental threats (i.e., ghostfishing and plastic) are explored, followed by a description of how marine debris is managed, with a focus on both voluntary and policy agreements. I subsequently unravel the role of the fishing industry in the production and management of marine debris, and conclude with consultation that has been done with relevant stakeholders and methods of communication that could prove useful moving forward.

2.1 Ubiquity and Prevalence of Marine Debris

Marine debris, also referred to as marine litter, is a broad term referring to anthropogenic waste that has either intentionally or accidentally entered the marine environment (e.g., Löhr et al., 2017). Such debris has been observed on an ongoing basis across the world, from deep ocean trenches to the coastline of uninhabited parts of the Arctic (e.g., Laist, 1987; Bergman & Klags, 2012; Bergman et al., 2017) and Antarctic (Auman, Woehler, Riddle, & Burton 2004). The United Nations Environment Programme classifies marine debris as either of land or sea origin (UNEP, 2005), with further classification often based on material—e.g., plastic, aluminum, or glass (Galgani, Hanke, & Maes, 2015).

The proliferation of marine debris increased exponentially following Western society's widespread adoption of plastic materials in the 20th century (Braun, 2003; Walsh, 2002). Plastic globally constitutes the majority of debris, though distribution and composition vary significantly with location—ranging from over 37,000 items for a 50m stretch of beach after a typhoon in Papua New Guinea, to 67 items per 1000m stretch of beach within the OSPAR region (Smith, 2012 as cited in Galgani, Hanke, & Maes, 2015; Aniansson et al., 2007). Recent estimates suggest plastic items compose up to 95% of marine debris from the seafloor to shorelines around the world (Galgani et al., 2015). The transition towards plastic fishing gear has occurred in tangent with humankind's increased use of plastic as an inexpensive, versatile, and durable material. Nets that were once made of natural fibres (e.g., cotton or, in Iceland, wool) have been replaced with longer-lasting models made of synthetic fibres, such as nylon or polyester (e.g., Oxvig & Hansen 2007). Older, non-plastic types of fishing gear that made their way into marine environments would usually biodegrade relatively quickly; plastic, however, is impervious to natural degradation and persists as micro or nano particles, giving it a greater timespan to affect nearby ecosystems (Tokiwa et al., 2009; Mattsson, Haddsson, & Cedervall 2015).

2.2 Iceland

Fishing is pillar of the Icelandic economy, but while the adoption of fishing gear made of plastics has been cost-effective to the marine sector, since it is an inexpensive and durable material, its longevity makes the fishing industry a primary contributor to marine debris in the region (e.g. Kienitz, 2013; The Central Bank of Iceland, 2016; Þórðarson & Viðarsson, 2014). Figure 4 shows location, catch, and fishing effort based on gear type around Iceland. As depicted, the most prevalent types of gear around Iceland (a, b, c, d) include bottom trawls, longline, jiggers, and gillnet. Seines and pelagic trawls are used less than jiggers, bottom trawls, gillnetting, and longline (Hafrannsóknastofnun, 2017).

Previous studies have identified an increased fishing presence in the sample region to be positively related to the amount of debris associated with the fishing industry (e.g., Edyvane, 2004, as cited in Durovich, 2018). These findings have been consistent with studies conducted in Iceland's Westfjords: Kientz (2013) identified 55-65% of marine debris sampled in Hornstandir to be broadly attributable to fisheries and aquaculture, while Durovich (2018) found 41% of marine debris washing ashore in ISA to be attributable to fisheries and aquaculture. A study conducted by Kühn & Franeker (2012) further demonstrates the ubiquity of plastic in Icelandic aquatic ecosystems. They found plastic, though in particles too miniscule to source, in the stomachs of Northern Fulmars (*Fulmarus glacialis*) located in Iceland's Westfjords.

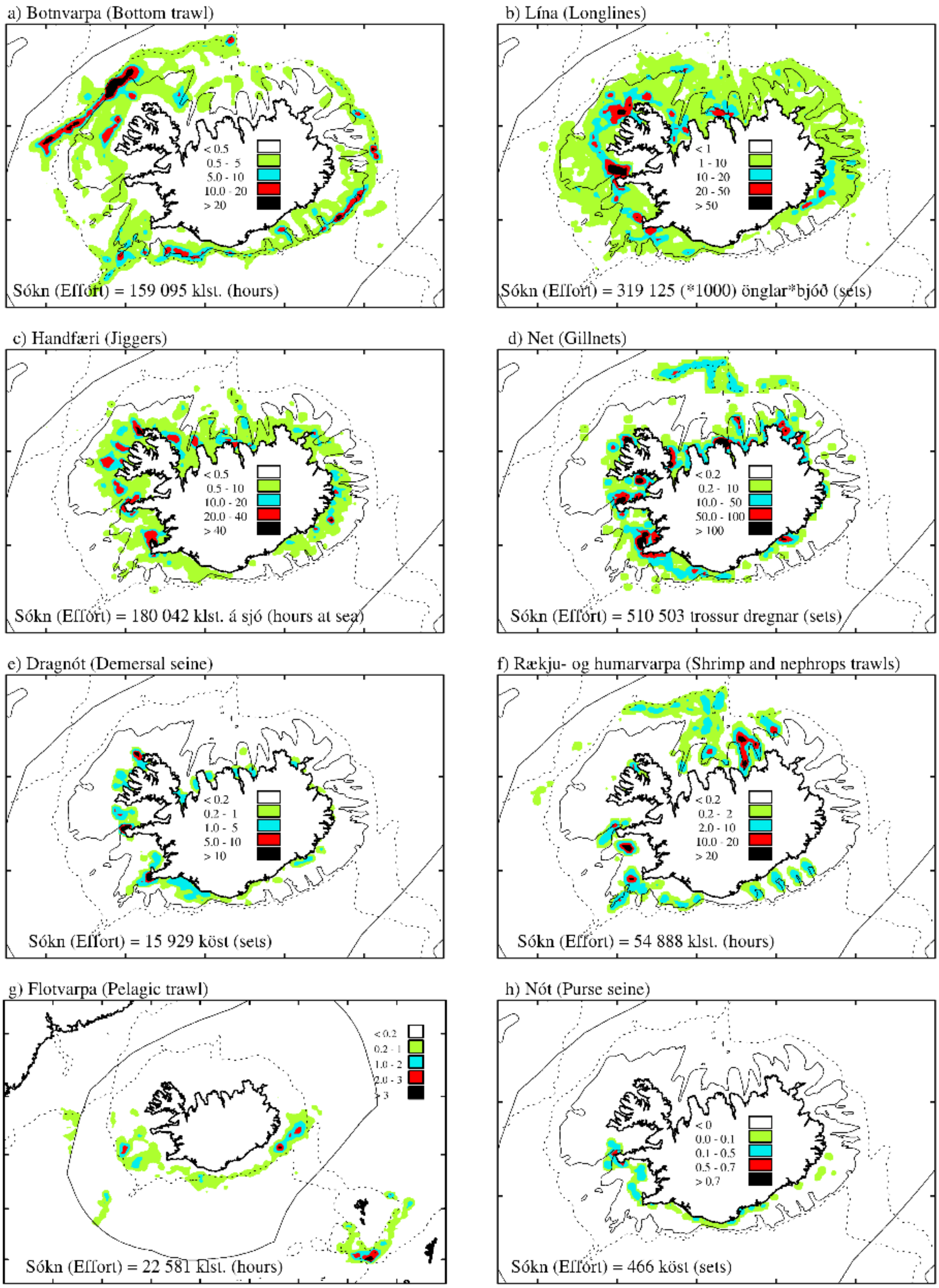

Figure 2.1 Catch and fishing effort based on gear type around Iceland (Hafrannsóknastofnun, 2017)

A large body of research has identified the fishing industry to be a primary contributor to marine debris in Iceland, as well as the greater North Atlantic area (OSPAR, 2014; Kienitz, 2013; Galgani, Hanke, & Maes, 2015; Vieira et al., 2014). There is limited information available, however, on the specific types of fishing gear ending up in the marine environment. Given that knowledge of specific high-risk operations can inform mitigation measures, this is a significant gap in available literature. Fishing gear, the vast majority of which is made of synthetic polymers, is at high risk for being lost or discarded and becoming marine debris. Numerous factors contribute to the accumulation of fishing gear as marine debris, including human negligence, accidents, and the harsh, unpredictable conditions fishers and their gear interface with (Huntington, 2016). A local trawlerman discussed the challenge of keeping track of net cuttings though emphasized fishermen's strict adherence to regulations regarding waste disposal.

Knowing the specific types of fishing materials entering the marine environment identifies further ways that it can be prevented. Identifying that the majority of marine debris surfacing around Iceland is broadly attributable to the fishing industry is insufficient for improving best practice, making this an important avenue for exploration. There is insufficient information regarding the classification of marine debris and identification of particularly problematic materials in Iceland—a need this present study addresses.

2.3 OSPAR

OSPAR, named after the Oslo (1972) and Paris (1974) Conventions focused on addressing marine pollution, "is the mechanism by which 15 Governments [Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom] & the EU cooperate to protect the marine environment of the North-East Atlantic" (OSPAR, 2019). OSPAR put forward a standardized method for assessing marine debris on beaches with an accompanying survey sheet and OSPAR identification number (OSPAR, 2010). The sections of OSPAR's survey/documentation sheet include plastic, rubber, cloth, paper/cardboard, wood, metal, glass, pottery, sanitary waste, medical waste, and faeces (OSPAR, 2010).

Based on conducted surveys, OSPAR identified the following factors to be the primary sources of marine debris on beaches in the OSPAR region: 1) fishing, including aquaculture, 2) galley waste (non-operational waste), 3) shipping (operational waste), 4) sewage/sanitary-related waste, and 5) public littering (Aniansson et al., 2007). Attributing marine debris to these and other 'use-categories,' such as tourist litter, sewage, or fishing gear, can inform important reduction and mitigation measures (Galgani et al., 2015).

OSPAR has conducted surveys of the wider North Atlantic and found that over 90% of marine debris is made of plastic in surveyed areas, with a significant amount stemming from the fishing industry (OSPAR, 2017; Lozano & Mouat 2009). At present, many types of fishing gear are made out of plastic, such as trawl nets made of synthetic polymers like polyethylene terephthalate (PET) and high density polyethylene (HDPE), gillnet, made of nylon, and buoys, often made of polyethylene (PE) (Bertelsen & Ottosen, 2016; Polyform, 2015). OSPAR largely classifies debris based on material type (Figure 2.2) and has commented gaps in its data, identifying that "Main sources of litter (e.g. fisheries) are apparent from the data; however a detailed identification of sources will require the allocation of the OSPAR items to sources at a regional level"(2017).

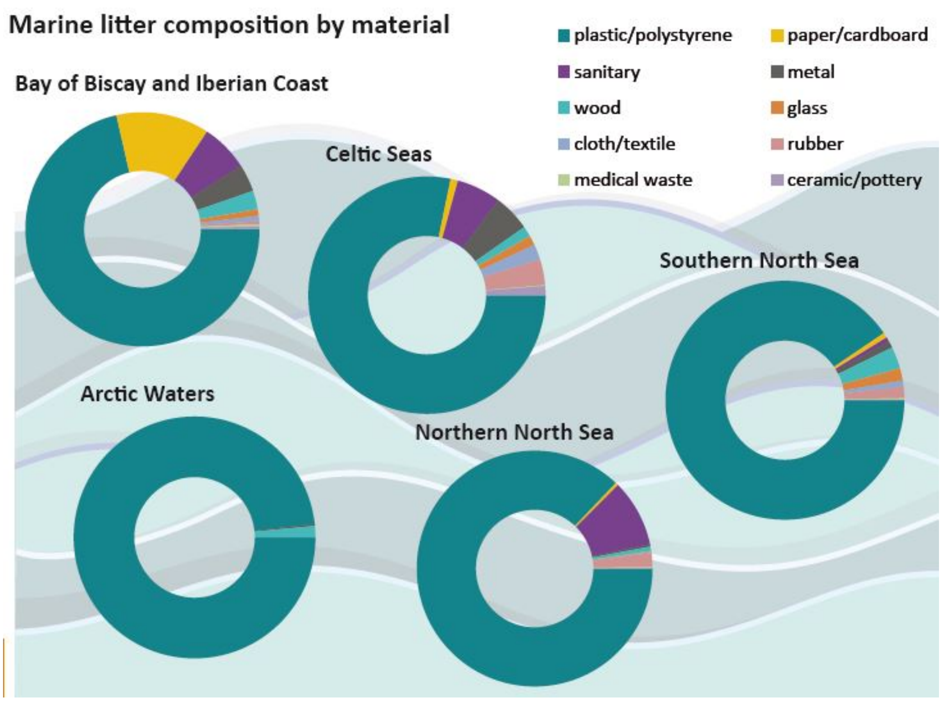

Figure 2.2 OSPAR Marine litter composition based on material (2017)

OSPAR conducted 18 100m surveys within Iceland from 2016 to 2017. Collected debris was classified by material type (e.g., Plastic/Polystyrene, rubber, cloth, metal, etc.) (Figure 2.3). The percent of materials classified as plastic/polystyrene ranged from 44.6% to 61.8%, though less than 5% of items were attributed to the fishing industry. 5% is low when compared to similar studies in Iceland which found the majority of debris to be made of plastic, though were able to source a significantly greater percentage to fisheries and aquaculture (e.g., Kienitz, 2013, Durovich, 2018). The majority of items (>50% on average) were sourced as "other"(Figure 2.4). The frequency with which materials were classified as "other" suggests room for improvement in terms of debris identification and classification; the overlap between plastic/polystyrene items and those sourced as "other" when comparing the two graphs suggests that the majority of plastic was either unidentifiable or unattributable to a specific class. "Fishing and Aquaculture" is a broad category, yet very little debris was attributed to it in a region with high fishing presence.

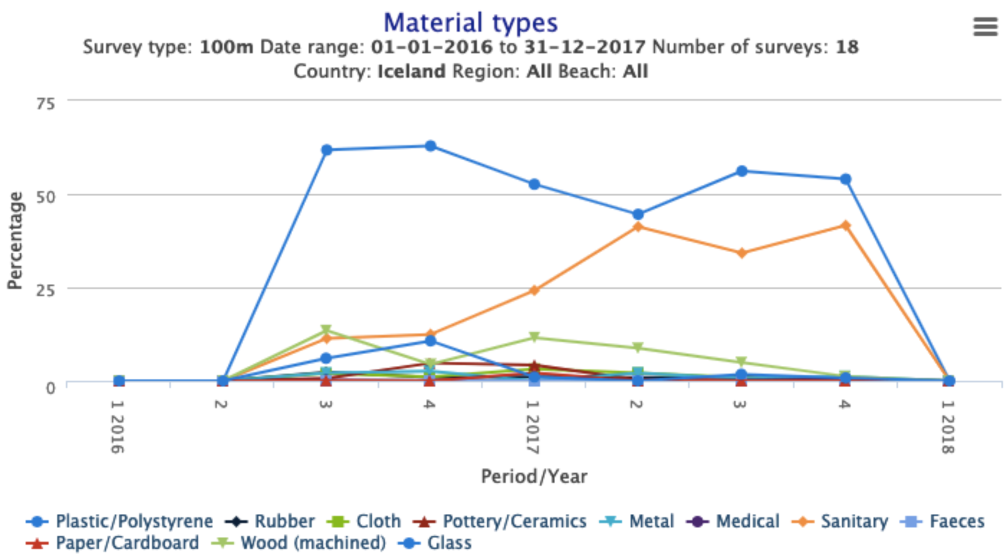

Figure 2.3. Material types of collected debris from OSPAR 2016-2017 surveys in Iceland (OSPAR 2017)

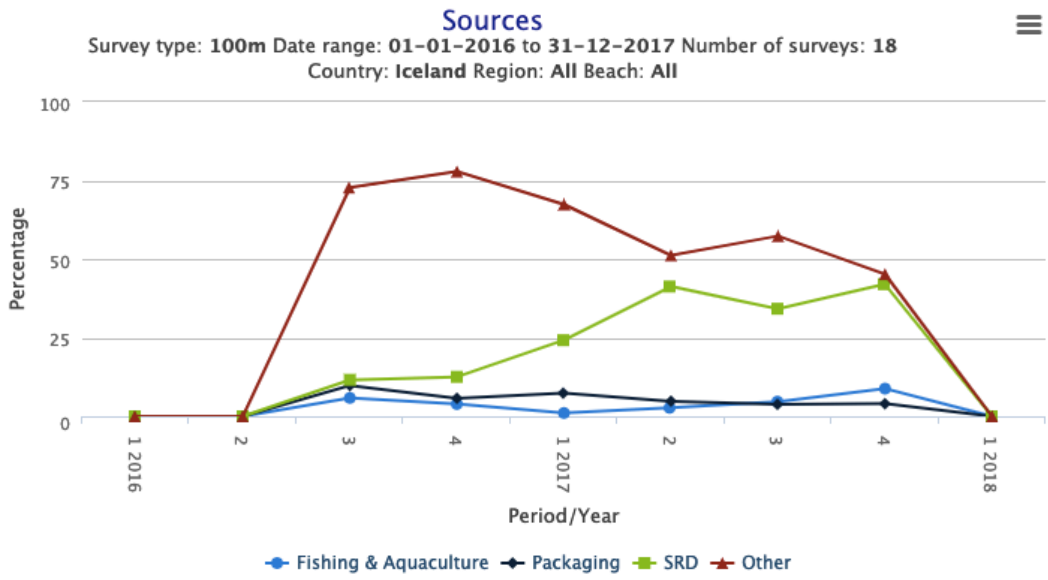

Figure 2.4. *Sources of collected debris from OSPAR 2016-2017 surveys in Iceland (OSPAR, 2017)*

2.4 Threats/Implications of Fishing Related Debris

The introduction of fishing gear to aquatic ecosystems poses a number of specific threats to flora and fauna, such as through ghost fishing, entanglement, or ingestion of plastic. Such threats are well documented in regions across the globe, such as 204 instances of entanglement during a 2000-2013 study on the grey seal in the Atlantic (Sayer et al., 2015), 28 instances of entanglement of the western grey whale identified between 1995-2005 in Russia (Bradford et al., 2009), and 226 fish caught over 9 months in a monitored derelict gillnet in the UK (Kaiser et al., 1996). Evidence of plastic related mortality has been documented around the globe (e.g., Jamieson et al., 2019), including in Iceland (e.g., Kühn & Franeker, 2012; Basran, 2014). Charla Basran utilized scar-based analysis to identify probable instances of entanglement of humpback whales (*Megaptera novaeangliae*) sited in Northern Iceland's Skjálfandi Bay. Documenting instances of lethal and non-lethal fishing gear complications, as well as plastic ingestion, help gauge the impact and implications of marine debris and underline why it must be addressed.

While identifying specific gear responsible for entanglement events can be challenging if not reported by the fishers, some of the specifically identified gear used in the referenced studies is also used in Iceland (i.e., gillnetting).

When fishing gear enters the marine environment and becomes debris, it compromises the wellbeing of the benthic and pelagic habitat in a number of ways. The primary distinction between entanglement and ghost fishing is that ghost fishing is lethal. Entanglement may result in long-term damage but not necessarily death.

Ghost fishing occurs when fishing gear continues to function without human control, with definitionally lethal consequences for coastal or marine animals (i.e., fish, invertebrates, seabirds, mammals) (Matsuoka, Nakashima, & Nagasawa, 2005). In other words, when abandoned, lost, or otherwise discarded fishing gear (ALDFG), also known as derelict fishing gear (DFG) entraps marine fauna, resulting in unintended mortality through, for instance, suffocation or starvation, ghost fishing has occurred. Instances of ghost fishing have been confirmed for numerous gear types, including nets (trawl, seines), gill netting, and traps (Matsuoka et al., 2005; Brown & Macfadyen, 2007). The primary solution to ghost fishing identified is the prevention of derelict gear. Further possible solutions include gear retrieval or designing gear to degrade (Matsuoka et al., 2005; Brown & Macfadyen, 2007).

Information on mortality rates caused by gear no longer under a human control is scarce and difficult to obtain because it is uncontrolled and unmonitored (NOAA, 2015). In addition to killing non-target species and endangering both endangered and protected species, marine organisms impacted by ghost fishing are often of commercial value to fisherman (NOAA, 2015). Thus, beyond causing unintended deaths, and indicating the loss of valuable gear, ghost fishing has economic ramifications, such as potential revenue loss. Though relatively undocumented, due to the presence of plastic and derelict fishing gear in Icelandic waters, lethal instances of ghost fishing likely happen here.

2.4.1 Harm Caused by Plastic

As discussed, the vast majority of marine debris is plastic (e.g. Galgani et al., 2015). Plastic poses various threats to marine ecosystems. Aquatic animals can become entangled in derelict fishing gear, or they can ingest plastic materials, subsequently absorbing harmful compounds which can accumulate through trophic levels (Law et al., 2010). When plastic particles are consumed by animals unable to digest them, these materials can accumulate in organisms' stomachs, making them feel artificially satiated, depleting their nutritional intake, and, thus, inducing starvation (e.g., Ocean Portal & Jambeck, 2018). Plastic used in fishing gear (e.g., in buoys, trawl nets, gillnetting, or jig line), or from other sources, degrades into smaller and smaller particles over the span of years, decades, or longer; plastic is impervious to natural degradation and so persists in the oceanic environment (e.g., Law et al., 2010; Stelfox, Hudgins, & Sweet 2016). These nano- and microplastics can more easily enter the food chain—and eventually make their way into humans (e.g., Andrews, 2012). Micro- and nano plastics may be produced to this size, or result from the degradation of larger plastics (e.g., Lusher, Hollman, & Mendoza-Hill 2017).

Chemicals commonly added to plastics include phthalates, used to make plastic more durable; nonylphenols, commonly used as an antioxidant, and flame retardants (Lusher et al., 2017). These additives are not chemically bound to plastics, allowing them to leech into the environment (e.g., Stringer & Johnson, 2001; Gewert, Plassmann, & MacLeod, 2015; Hermabessiere et al., 2017). Further, plastics absorb persistent, bioaccumulative and toxic contaminants (PBTs) from the environment, increasing the perceived hazard of ingestion by aquatic fauna (e.g., Lusher et al., 2017). Given plastics harmful effects, some scholars have even called for plastic to be classified and treated as hazardous waste (e.g., Rochman et al., 2013).

2.5 Management

Given the threats posed by marine debris, it is important to manage this sort of refuse. In regard to fishing-related debris, some theorized short-term solutions addressed in the literature include: a) improving waste management on-board fishing vessels and at ports,

b) increasing accessibility to recycling services, c) expanding use of Fishing for Litter schemes, and d) incentivizing bringing waste to shore. Long-term solutions centre around gear redesign (Löhr et al., 2017).

2.5.1 Policy and Voluntary Agreements

Iceland is an OSPAR Contracting Party, meaning that it ratified the Convention for the Protection of the Marine Environment of the North-East Atlantic (or the OSPAR Convention) and is legally-bound by decisions the commission makes (OSPAR, 2015). Although the OSPAR Convention does not explicitly discuss fishing gear, it has adopted a Regional Action Plan (RAP) for the Prevention and Management of Marine Litter (OSPAR, 2014). Action 36 of this RAP aims to improve best practice within the fishing industry, "[with attention to] various aspects including dolly rope, waste management on board, waste management at harbours, operational losses/ net cuttings, [and] code of practices" (OSPAR, 2014).

Iceland also abides by the Port Reception Facilities (PRF) Directive, which requires every European port to have appropriate waste reception facilities available to vessels (European Maritime Safety Agency, 2019). In a marine litter management questionnaire conducted by the Centre for Environment, Fisheries, and Aquaculture Science (CEFAS) Iceland listed this as its primary practical solution to fishing waste management, in addition to recycling nets made of plastic (Mengo, 2017). Iceland estimated that 90% of fishing nets are recycled, with the majority of the industry taking part in preventative measures (Mengo, 2017). The 90% estimation was corroborated by Sverrisson (2014) who suggested that as of 2014, approximately 85% of fishing nets are recycled. An important distinction was made in the 2017 Fisheries Iceland report, which specified that 90% of fishing gear brought to the country's ports is recycled (figure 2.5) (Fisheries Iceland, 2017). Little to no information, however, is available on the amount of produced and used fishing gear that actually returns to port. Given the lack of data regarding gear loss, gear recovery, and the generally unreported nature of improper gear disposal, figures on the amount of marine debris the fishing industry has contributed to is unavailable (Hennøen, 2016). Fisheries Iceland's 2017 environmental report does not discuss lost /derelict fishing gear, though it does cite the industry's compliance with waste disposal policies.

Approximately 90% of the fishing gear received in the country's ports was recycled

Disposal of fishery waste organised by Fisheries Iceland in 2016 (kg)

Material / Type	Quantity	Recycling	Landfill
PE/PP/PEP trawls	517,731	517,731	
PA Multifilament midwater trawls	132,620	132,620	
PA Multifilament seine material	380,250	380,250	
Net cuttings PA Monofilament	42,250	42,250	
PA impregnated lines	36,000		36,000
PES PE + PA head and foot ropes and cables	18,000	12,400	5,600
Floats	4,800	4,800	
Rockhoppers	90,680		90,680
Scrap iron	75,000	75,000	
Total	**1,297,331**	**1,165,051**	**132,280**

Source: Guðfinnur Johnsen, Fisheries Iceland.

Figure 2.5. Breakdown of the type and quantity of fishery waste recycled and sent to landfill in 2016 (Fisheries Iceland, 2017)

In 2005, the Federation of Icelandic Fishing Vessel Owners (LÍÚ) (now SFS or Fisheries Iceland) entered into a voluntary agreement with the Icelandic Recycling Fund (Úrvinnslusjóður) to manage and facilitate the recycling of fishing gear. Fishing nets became exempt from recycling processing fees and the Federation of Icelandic Fishing Vessel Owners became responsible for net collection stations (Sverrisson, 2014). This agreement is based on article 8 of the Processing Charge Act, which aims to "create economic conditions for the reuse and recycling of waste for the purpose of reducing the waste sent for final disposal and ensuring appropriate disposal of noxious substances" (Bauer & Fischer-Bogason, 2011). Ships compliance with existing policy depends largely on the availability of waste reception services.

Fisheries Iceland, in their 2017 environmental report, describe the primary drivers of technological innovation being the price of oil, the desire to reduce oil consumption, and the goal of increasing catch capacity (Fisheries Iceland, 2017). They cite society's demand for environmental responsibility as an additional motivating factor. Time and innovation have given rise to increased fuel efficiency, with further reductions forecasted (Fisheries Iceland, 2017).

As outlined by MacFayden et al., there are numerous reasons why it is difficult to estimate the amount of ALDFG in the marine environment. Some of these reasons include the deliberate disposal of fishing equipment; gear loss during unreported or unregulated fishing; poor management; lack of monitoring; insufficient or lack of recording of gear loss; poor experimental design on research; and lack of data regarding total levels of gear loss (Hennøen, 2016; Macfayden et al., 2009).

Anecdotal information collected during conversations with local fishermen highlights their commitment to protecting the ocean and following existing legislation. Given the hectic and dangerous nature of their work environment, however, the safeguarding of trawl cuttings and other garbage is a priority, but not *the* priority. One fisherman who works aboard a trawler says they collect and store garbage when it is hauled up, but ultimately they are there to fish—not clean.

2.6 Stakeholder Engagement

As outlined by Hartley et al., (2015) it is important to understand and implement the fisheries perspective into future management and policy, particularly stemming from what they know about marine debris and what they are willing to do to reduce it (2015).
 Beyond fishers, there are a multitude of stakeholders who play a role in the development/maintenance of best practice. Such stakeholders can include port operators, gear designers, fishers, fisheries managers and regulators, seafood companies, or researchers. Stakeholders extent beyond industry players though, and include governments and the citizens that compose the general public. Each play a key part, offering "different

perspectives on the actions required to facilitate solutions” (Hartley, Holland, Pahl, & Thompson, 2015). Figure 2.6 from the Global Ghost Gear Initiative (Huntington, 2017)

STAKEHOLDER GROUP	ROLE	BEST PRACTICE AREAS
Gear designers and manufacturers	Design, production and sale of fishing gear	Embedded traceability; research into, and use of / integration of biodegradable materials for use in the marine environment; incentives to return redundant / used gear.
Fishers	Individuals and crew catching seafood at sea	Reduced soak times; gear use limits in high-risk areas and during high-risk times; marking and identification of fishing gear; responsible storage of gear; reporting of lost gear, guidance on lost / abandoned gear location and retrieval.
Fisheries organisations	Non-statutory organisations representing fishers	Code of practices specific to fisheries; spatio-temporal agreements with other metiers; monitoring of fishing gear losses; communication protocols.
Port operators	Bodies operating and managing fishing ports	Accessible, low-cost gear and litter disposal facilities; integration into recycling initiatives; better awareness of responsible disposal opportunities; implement 'check out-check in' gear inventories where appropriate.
Fisheries managers and regulators	Management bodies setting policy, plans and regulations for fishing activities	Designation of spatio-temporal restrictions in high risk areas; development of appropriate gear marking and identification regulations; development of technical regulations to reduced ghost fishing potential in high risk areas; conducting impact assessment to gauge unintended consequences of management actions on gear loss and ghost fishing.
Fisheries control agencies	Body or agency responsible for enforcing fisheries regulations	Establish registry and database of lost / abandoned gear; enforcement of gear marking and identification regulations.
Fisheries and marine environment research	Research and development	Development of biodegradable materials acceptable to fishers, but effective at reducing gear-catching ability after control is lost.
Seafood ecolabel standard and certificate holders	Setting and maintaining standards for responsible sourcing of seafood	Gear loss and its consequences (eg ghost fishing) need to be included in all seafood sustainability standards, with supporting guidance provided where necessary.
Seafood companies	Fleet operators, processors, wholesalers and retailers	Encouraged to ensure that their seafood sourcing avoids high risk fisheries and that they participate in relevant initiatives eg gear recycling (see case study in Section 3.9.3) where possible.
NGOs	Advocates for sustainability and good practices	Coordination of advocacy, actions and information gathering; contributing to a centralised ALDFG / ghost fishing information hub / forums; organising ALDFG recovery in vulnerable areas.

Figure 2.6. Identification of stakeholder groups, their roles, and areas of best practice with regards to the reduction of global ghost gear (Huntington, 2017).

identifies stakeholders, their role, and best practice that can be followed in order to reduce the occurrence, harm, and prevalence of ghost gear.

In answer to a questionnaire regarding Iceland’s marine debris management practices, an Icelandic representative responded that there is general awareness that the fishing industry is a source of marine debris (Mengo, 2017), though there is limited knowledge on the specific sources of debris stemming from this industry. In a 2015 survey conducted across

Europe by the Centre for Environment Fisheries and Aquaculture Science (CEFAS), industry and governmental players were seen as "somewhat unmotivated to help [with the issue of marine debris]" (Hartley et al., 2015). This deals with the public's perception of industry and governmental players and presents an opportunity to establish better communication and establish a more positive image. In consultation with stakeholders, the Global Ghost Gear initiative identified regulatory approaches to be the favored means of ghost gear management (Huntington, 2017).

2.7 Ongoing Research

With recent technological advancements, fishing gear is increasingly designed to be more durable. Although this means it will need to be replaced less frequently, creating less waste (or burden for recycling plants), if highly durable gear mistakenly enters the marine environment, it will remain there for a long time. Research into gear that will biodegrade after being underwater for a certain amount of time has been ongoing (e.g. Swift, 1993; Kim et al., 2016) A team of Korean researchers presented a biodegradable alternative to traditional gillnets which are made of synthetic polymers, though more research is required to make the new option's fishing efficiency comparable to conventional nets (Kim et al., 2016).

At the 2018 Arctic Circle Conference, John McGeehan shared his team's work on an enzyme that feeds off of and degrades the synthetic polymer polyethylene terephthalate (PET) (Austin et al., 2018). PET, the chemical name for polyester, is one of the most common plastics manufactured worldwide; it is found in bottles, clothing, and fishing gear. While such research presents an area of opportunity to adopt more biodegradable fishing gear, treating it as a panacea risks perpetuating the cycle of waste production and improper disposal. Producing biodegradable waste still means that waste is entering the environment, potentially threatening wildlife, it will just be around for less time. Instead, we should work towards reducing all waste. The researcher explained that the claims of a 'plastic-eating bacteria' have been sensationalized by the media (i.e. "Plastic-Eating Bacteria May Save Our Oceans -Have Scientists Stumbled upon the solution to plastic waste? (Phade, 2018)) The enzyme degrades PET slowly, though presents a promising opportunity to return plastics to their component parts, thus decreasing the need for extraction of oil and manufacturing of virgin PET (Austin, et al., 2018).

3 Methodology

The aim of this study is the development of a classification scheme and photo guide to better understand oceanic refuse, specifically that coming from the fishing industry. This is accomplished through the development of a system through which to filter data (i.e., classification scheme). As the classification scheme is intended to frame research into marine debris, the primary goal of this exploratory study is the development of methodology.

This chapter outlines how the methodology was developed. First, data collection was conducted through shoreline cleanups around Iceland's Westfjords. The debris collected informed the development of a classification scheme because it acted as a dataset to examine and extract a scheme from. This classification scheme and photo guide were created to a) expand knowledge gained from shoreline cleanups given the lack of specificity of other survey sheets with regards to fishing related debris, b) help future researchers or members of the general public undertaking shoreline cleanups identify, classify, and represent marine debris they find, and c) identify areas for potential improvement with regards to the fishing industry and its waste management. Given this study uses the number of units of debris collected to form a taxonomy representative of fishing related debris washing up in the Westfjords, it employs a quantitative, descriptive, and inductive research design. Shore cleanups were conducted to get a sense of the manmade materials present in the oceanic environment. An understanding of common materials was gained and used to form a classification scheme which can be used as a tool to communicate with stakeholders and improve fishing related waste management.

To describe the methodological processes that informed this study's research design, this chapter is partitioned into 4 sections. First, the underlying motivations for this research are discussed. Second, this study's procedure is outlined, including site selection, cleanup and protocol, and the various stages of classification scheme formation. This is followed by discussion of the methods of data analysis and description final classification scheme.

3.1 Motivation for Research

Residing in Ísafjörður, Iceland, a coastal village, has afforded the author the opportunity to witness the ways in which humans directly interface with the marine environment. The various fauna with whom we share our coastal community (e.g., seals, whales, whelks, fish, crustaceans, seabirds)—and who sustain lucrative tourism and fishing industries—are subject to the effects of waste created by humans and their industries. Developing a classification scheme that helps evaluate the effectiveness of waste management protocols in Iceland's fishing industry and therefore potentially identify waste streams leading to oceanic pollution can inform the ways industry players interact with the natural world. The development of this thesis' methodology seeks to identify specific areas of improvement with regards to anthropogenic impacts on the marine environment.

Birds picking at seaweed polluted with ingestible plastic and nesting materials entwined with debris are visible signs of the impact of improper management. Coast-dwelling birds are valuable indicators for the prevalence of marine debris within the animal kingdom because they are easily visible (e.g., Franeker & Law, 2015). When coastal birds are viewed interacting with marine debris, which in and of itself signifies an opportunity to improve waste management, this suggests other less readily visible organisms (i.e., fish, invertebrates, marine mammals) are also being affected by anthropogenic debris; seabirds can be an effective biological indicator of the presence of plastic pollution. OSPAR lists the Fulmar as a formal indicator of plastic pollution levels in an area based on the amount of plastic they have ingested (OSPAR, 2008). Seeing coastal birds interacting with marine debris was a significant motivator for the present study.

Figure 3.1 Oystercatcher (Haematopus ostralegus) nesting near plastic debris in the Strandir region. (Photo taken by Sean O'Rourke, 2019).

Identifying the breadth of impact marine debris has on broader oceanic organisms, however, is more challenging, making indicator species valuable. Shorelines, similarly to seabirds, can be accessible to humans, and therefore act as an indicator and point of access to the marine environment. Walking along the Ísafjörður beach, green threads entangled with seaweed are recognizable as being made from the same material as the netting and ropes that adorn the fishing vessels around the towns' harbour. Upon noticing these thin fibers, their prevalence within bundles of seaweed the tide had accumulated became apparent (Figure 3.2). Sifting through seaweed revealed a significant amount of human-made material. Such visible indicators served as the primary motivation for this thesis.

Figure 3.2. A commonly found green fibre entwined in seaweed in Ísafjörður. (Photo taken by Amy O'Rourke, 2018).

The present study outlines a methodology developed with simplicity and accessibility in mind. Simplicity is achieved by focusing on beaches as sites for data collection, rather than the seafloor or pelagic column, allowing this study to be replicable by future researchers, as well as the general public. Accessibility is important because this study aims to develop a tool that could be useful for a broad array people; accessibility is important when developing a management and educational tool for various stakeholders, including the general public.

3.2 Site Selection

Different sites with unique locales and geomorphological characteristics were visited to obtain a cross-section of debris washing up in the Westfjords. Cleanups conducted during the data collection period were rigorously documented. Supplemental cleanups were conducted prior to and following the data collection period and provided general, if more anecdotal or confirmatory insights, rather than quantitative data to evaluate.

Data collection was conducted at accessible beaches (i.e., sites a vehicle could be parked within 100m of) within the Westfjords region of Iceland. This study area was chosen due to proximity to Ísafjörður, where the author resides. Furthermore, no research to date has sought to quantify fishing-related marine refuse in this locale, despite the importance of healthy marine environments to local tourism and industry (e.g., fishing).

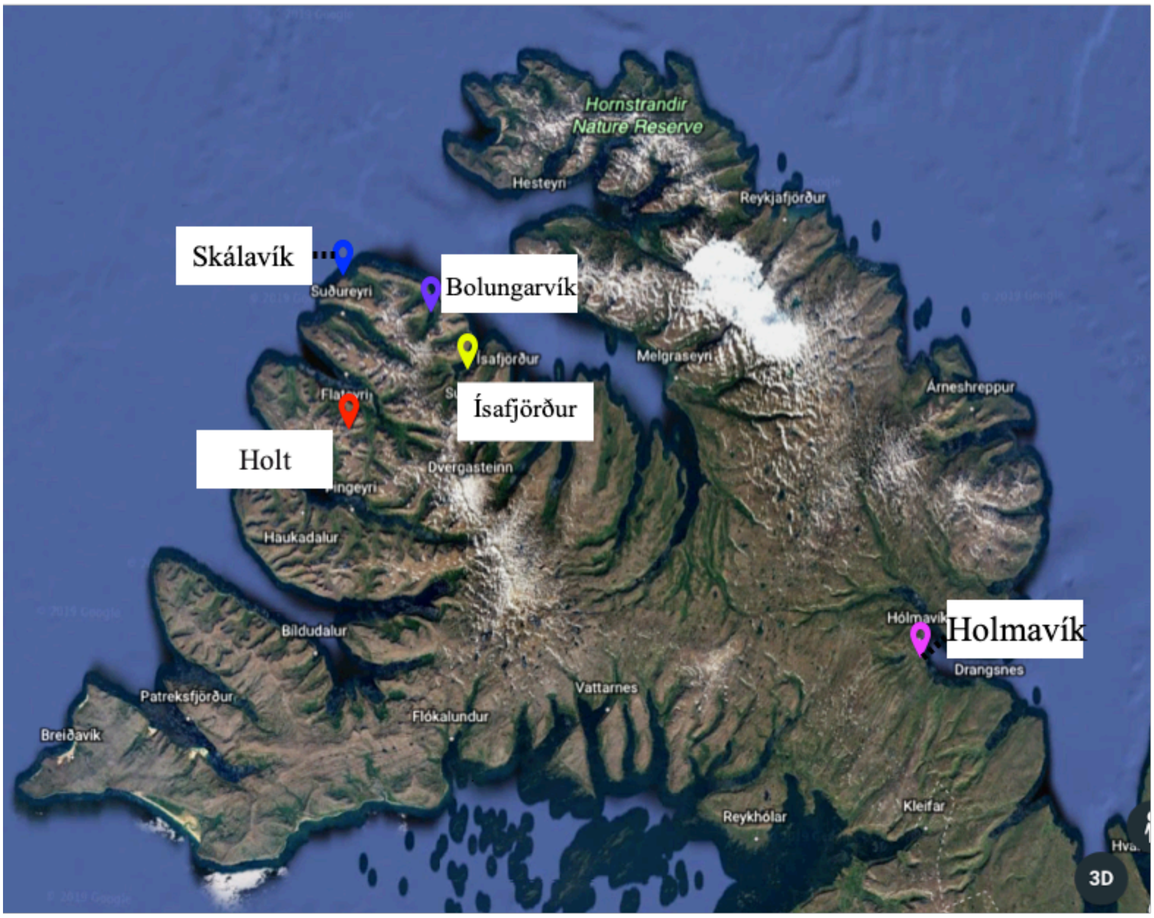

Figure 3.3. Map of the Westfjords with surveyed beaches labeled. Red: Holt; Pink: Holmavík; Purple: Bolungarvík; Blue: Skálavík; Yellow: Both Ísafjörður beaches, being close in proximity (Map created using Google Maps, 2019)

Transect locations were chosen based on accessibility and proximity to Ísafjörður. Sites were repeatedly visited if they yielded a relatively significant amount of debris (i.e., a larger amount of debris than other sites)as obtaining the greatest number of debris units provided the most data to work with and subsequently extract an informed classification scheme from. Though some sites yielded little debris, visiting different locations was important in order to see a) whether different debris was washing up in different locations and b) what debris was consistent across locations. Table 1 outlines characteristics of the data collection sites.

Table 1 Brief outline of data collection sites within the Westfjords

	Isafjordur North beach	**Isafjordur industrial beach**	**Bolungarvik**	**Skalavik**	**Holt**	**Holmavik**
Proximity to town	Within town	Within town	Within and extending past town border	13 km to Bolungarvík	~10km to Flateyri	Within town borders
Waste water outlet (y/n)	Yes	Yes – within 200 m	Yes	Yes – drainage pipes on beach	No	Yes
Topography	Combination sand and rocky	Rocky	Combination fine sand, rocks	Combination sand and rock	Fine sand, dunes	Predominantly sandy
Exposure to open sea (y/n)	Yes	No	Yes	Yes	No	No
Prevelent wildlife area	No	No	Arctic Tern Nesting area – protected species	Tern and oystercatcher nesting ground - unprotected	Eidar duck nesting area - protected	No

A significant amount of debris was retrieved at the Bolungarvík and Skálavík beaches, and given their relative proximity to the author's home, they were sites of repeated/ongoing data collection. Shoreline cleanups were also conducted at Holt beach, though an initial site examination and data collection yielded little debris. A second visit was conducted which verified Holt's status as relatively inconsequential in terms of usable data within the data collection timeframe. It was excluded as a site of future data collection. The same conclusion was reached for Holmavík after two shoreline cleanups similarly yielded little debris.

The sites visited within the data collection period were not hotspots, though there was still debris washing up there. Supplemental cleanups conducted after the data collection period revealed marine debris 'hotspots' surrounding the Strandir region.Supplemental cleanups were conducted near the Strandir region, where an almost surreal amount of debris was collected due to the surrounding currents (Kienitz, 2013).

3.3 Example Shoreline Cleanup Procedure

Given the exploratory nature of this study, and emphasis on the resultant classification scheme, outlining the procedure followed serves to exemplify one possible method of data collection/shoreline cleanup. This methodology deals primarily with the classification of data rather than its collection. Beach cleanup procedures are effectively described in other literature, such as in OSPAR's guidelines for monitoring marine debris on the beaches in the OSPAR maritime area (2010). It is, therefore, beyond the scope of this study to lay out methods of site selection and debris collection. The general procedure followed to collect data is outlined to describe the process through which a classification scheme was formed. While the procedure followed at Bólungavík and Skálavík is the focus of this section, data collected at all sites (Table 1) during the data collection period inform the classification scheme.

The present study focuses on macro debris (i.e., debris that can be seen with the naked eye), because there is a greater chance of it being identified, as opposed to micro-particles that can tell you little more than their material. Further, focusing on macro debris makes the present study accessible and replicable by the general public. Therefore, shoreline cleanups were conducted based on the collection of macro debris.

In accordance with OSPAR guidelines (2010), landmarks and access points were utilized to dictate the beginning and end of transects for clean ups. Google Earth was later used to mark the exact beginning and end of transects and obtain GPS co-ordinates, though a 10m deviation in Google Earth locations should be noted (OSPAR, 2010). Due to time limitations and unfeasibility of covering the whole beach in one day, Bolungarvík beach was divided into three transects. Excluding the inlet, Bolungarvík beach is a ~1300m stretch of beach, approximately 980m of which was surveyed. The transects were marked by access points: BOL1 and BOL2 began at the same location (i.e., the path where a vehicle could be parked) and proceeded in opposite directions. BOL2 ended at the next access point, a road closer to the port. The third transect, BOL3, was marked by the curvature of the beach: it was an easily distinguishable inlet. Using easily recognizable landmarks/geographical features was a reliable and easy-to-use method of delineation and ensured consistency throughout repeated cleanups. The employed method of data collection combined aspects of standing stock assessments and accumulation studies outlined and utilized by the National Oceanic and Atmospheric Administration of the United States (Lippiatt, Opfer, & Arthur, 2013) in order to accumulate information on the materials washing ashore.

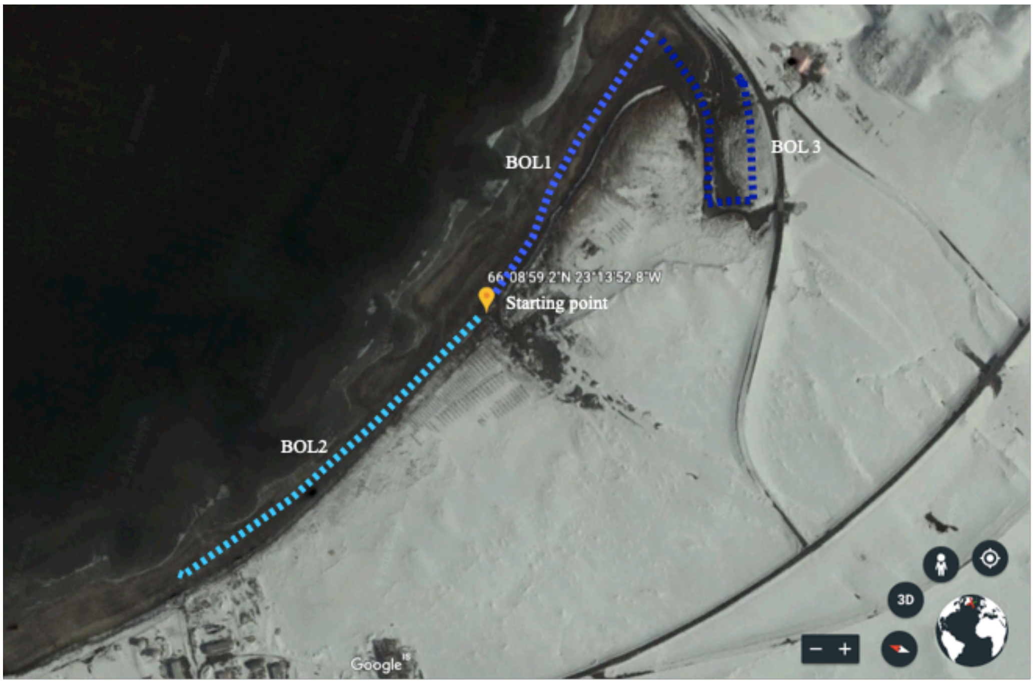

Figure 3.4. Map of Bolungarvík beach, transects are marked by coloured lines (Map created using Google Earth, 2019)

A similar procedure was followed at the Skálavík beach. The survey area began at the easily identifiable orange storm refuge hut, and extended west until the beach curved and turned to predominantly rock. This covered an approximately 600m long stretch, extending from the bottom of the hill until the low tide mark.

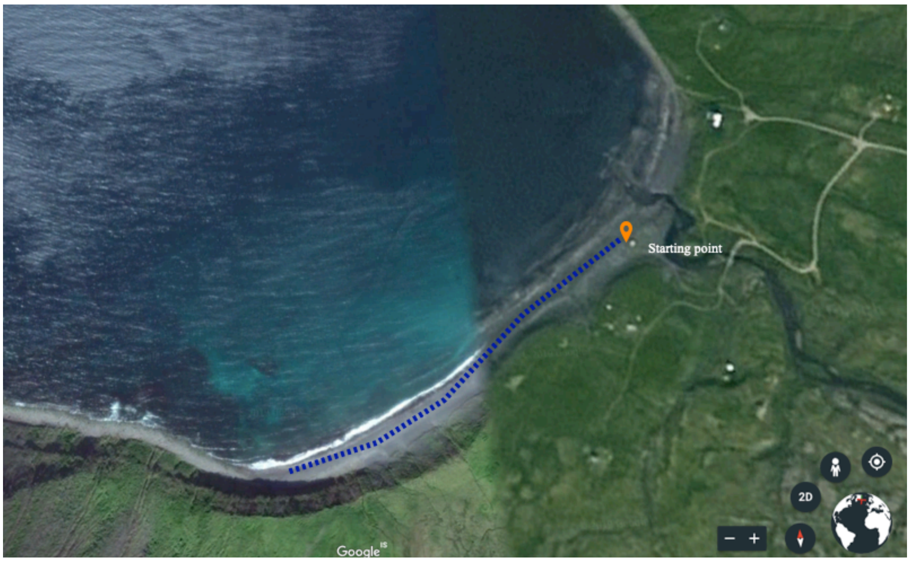

Figure 3.5 Map of Skálavík beach marking the traversed transect. (Created using Google Earth, 2019).

3.3.1 Data Collection

The purpose of data collection within this study was to gain an understanding of the different fishing related materials present in the Westfjords' marine environment. Selected sites were thoroughly examined to ensure the majority of present debris was accounted for.

For the majority of transects, collected materials were documented (i.e., written description and photograph) after on-site data collection had concluded. This is contrary to OSPAR survey guidelines, which outline the importance of on-site documentation at the instance debris is collected in order to ensure accuracy (2010). However, the inductive nature of the present study necessitated later analysis of collected debris. As the study progressed with the development of a taxonomy and reference guide, on-site identification and note-taking became possible. Making notes on-site, during debris collection, ensures the information is fresh and all relevant data and observations are documented, and, as OSPAR notes (2010), prevents collected debris from becoming entangled and potentially skewing quantification. Going through debris after the shoreline cleanup, however, also has benefits. For example, later counting provides an opportunity to lay out, sort, and thoroughly document findings. Further, extensive note-taking during cleanup was often not possible due to inclement weather conditions. If conditions were not windy, the preferred (i.e., most efficient and thorough) method of documentation was to lay out collected debris on a tarp for counting, classifying, and taking photos. This allowed the data to still be fresh and consistent, without the addition of a documentation pause each time a new piece of debris was collected. Thus, both of the methods used in this study—i.e., on-site and off-site documentation—have benefits and shortcomings.

Data collection involved traversing the area from the water to the back of the beach along a zigzag path parallel to the waterline. Seaweed and rocky areas were examined for caught debris. The path was traversed twice: once away from the starting point, and a second time on the way back to the starting point. If the buckets used for debris collection filled prior to completing the transect, the location was marked using available items (e.g., a backpack or sweater). Buckets would then be emptied at the starting point, and data collection would be resumed from the indicated point. Personal judgement was utilized to determine whether additional surveying along the transect was required. Data collection was completed when unable to visually locate any further debris. Having to empty both buckets (20L and 10L) was a common occurrence when cleaning the Bolungarvík and Skálavík beach transects. At other sites, such as Holt and Holmavík, this rarely transpired.

Shoreline cleanups were often conducted at low-tide, based on the idea that high-tide sweeps in debris and leaves it on the beach after retreating. Further, there was simply more shoreline visible to work with at low-tide (Fig 3.6). This proved beneficial, as debris would become stuck in seaweed and rocks that would be covered at high tide. While conducting surveys at low-tide allows more caught debris to become visible, it is more time efficient to conduct surveys at high-tide. OSPAR (2010) suggests that conducting surveys 1 hour after high-tide allows the greatest amount of debris to be quantified in the shortest time. The majority of the debris encountered throughout clean ups was small enough to carry in buckets, though occasionally large sections of net too large or heavy to be removed were found. If unable to move a piece of debris, its photo would be taken *in situ*, and data collection would resume. This tended to occur when debris became lodged between large rocks on sites exposed to the open sea.

Figure 3.6 Section of trawl netting exposed during low-tide at Bolungarvík beach (Photo taken by Amy O'Rourke, 2018)

The following materials proved useful for efficient and effective debris collection and documentation: waterproof and protective gloves, knife/scissors, tarp, camera, waterproof shoes, layered clothing, clipboard/notepad, and writing utensils. While these are the materials the present study utilized during data collection, shoreline cleanups can be simple and use whatever supplies individuals have available to them.

3.4 Data Analysis

Data analysis was an ongoing process and was conducted, in different forms, as data collection occurred. The following section discusses the development of a data analysis system.

3.4.1 Familiarization with Materials

Fishing vessels in Iceland commonly use a diverse array of equipment that can present a challenge for identification and classification by someone lacking knowledge of the fishing sector. Familiarization with common marine debris was an important precursor to the development of a taxonomy. Icelandic fishing gear catalogues (i.e., Vonin, Fjardanet 2019) and literature on fishing technology (e.g., Bertelsen & Ottosen, 2016; Boopendranath, 2012) proved useful in this endeavor. Touring local fishing vessels and watching videos of commercial fishing activities was also an important component of contextualizing the gear found and learning about the fishing industry beyond books. Further, local fishermen were able to provide background information on the use and prevalence of various materials in experience garnered from years commercial fishing vessels.

During initial shoreline cleanups, the debris were gathered and then sorted at a later date. Sorting through debris initially involved writing down each item (e.g., glove, Q-tip, orange rope, small section of green netting) and photographing it. The debris would then be divided into suspected fishing gear and other/consumer waste. The fishing gear and unknown materials were, during the duration of initial official cleanups, sorted through with Georg Haney, MSc. of Hafrannsóknastofnun (The Marine Research Institute), who provided expertise on the identification of gillnetting, trawl netting, longline, and other marine sector materials. It was generally apparent which debris was consumer waste (common types of consumer waste include: plastic bottles, food packaging, and tobacco containers). Consumer waste was never attributed to the fishing industry because it is challenging to differentiate between consumer waste from fishers and from elsewhere with any degree of certainty. If unclear whether an item was related to the fishing industry, or there was a noticeably high number of it (i.e., greater than 5 pieces), the debris would be set aside for further examination. On a number of occasions residents of Ísafjörður and the surrounding area shared their knowledge of local industries or activities that could explain certain debris.

A substantial image catalogue of fishing-related marine debris was developed during consultation and debris identification. The resultant catalogue of labelled images served as a reference tool for subsequent transects and contributed to a Photo Guide (appendix B). This guide is intended to work alongside the classification sheet, teaching the user the basics about different types of fishing gear and what they may look like as marine debris. Identifying different debris types was the most significant hurdle encountered, but can be overcome with the help of knowledgeable individuals or a photo guide. Thus, this guide may prove valuable to future researchers conducting similar studies, or members of the general public conducting shoreline cleanups.

3.4.2 Quantification of Marine Debris

Quantification of marine debris in this study is based on accessibility as well as the idea that weight is not directly proportional to the amount of harm discarded fishing gear may cause. Given that much of the material being collected was lightweight, quantifying by kilograms or grams may not accurately represent the amount of debris found, though the merits or weight versus unit count remain contested. The gear washing up on shorelines was generally lighter, such as gillnetting, floats, or netting. This lent validity to the decision to represent data by units (i.e., one unit equals one piece of debris). UNEP and OSPAR both employ this method of quantification (Cheshire & Adler 2009; OSPAR, 2010), though UNEP/IOC's survey guidelines discuss the problems associated with unit based quantification. For example, large items are equated to much smaller ones, and fragmented portions of what used to be a single item are each counted (2009). They identify quantification based on weight as more useful when large items are collected. This study, however, chose to employ the unit-system for the sake of accessibility (i.e., no scale or weighing equipment is required) and because the majority of items being found were relatively small.

Using a unit-based system, a fragment of tangled gillnetting counts as one unit, as would an entire trawl net—potentially a source of bias. An entire trawl net was never found, however, and significantly heavy or large debris were rarely found, so the degree that this inconsistency systemically distorted findings, or gave an inaccurate picture of the marine debris, is limited. For this reason, it was appropriate to base the quantification system on the most common items found, as doing so gave the most accurate representation of the collected marine debris. Unit based quantification is favoured in the present study because it requires no specialized equipment and is therefore a replicable model for the general public, though, if feasible, it is valuable to represent findings using both weight and count as both have merits.

The largest debris units found have been colloquially termed 'beach blobs:' entangled bundles of different fishing materials. Seven beach blobs were found the first time data collection was conducted at Skálavík beach. As can be seen in Figures 3.7, 3.8, and 3.9, most beach blobs were comprised of longline, gillnetting, and miscellaneous ropes tangled together. These conglomerates constituted a quantification challenge, as they presented as one mass of debris though were clearly made of different materials. If different types of debris within the beach blob could be identified, each would be counted individually as one unit, while special note was made of the conglomerate. If unable to identify the component materials, the beach blob was described in detail. Such conglomerates were not appearing frequently.

Figure 3.7 A 'beach blob' comprised of longline, gill net, miscellaneous rope found at Bolungarvík beach (Photo taken by Amy O'Rourke, 2018)

Figure 3.8 A beach blob comprised of longline and miscellaneous rope, found at Skálavík beach (Photo by Amy O'Rourke, 2018)

Figure 3.9 Beach blob found at Skálavík beach composed primarily of longline. (Photo by Amy O'Rourke, 2018)

3.5 Classification and Taxonomy

Classification sheets utilized for documenting debris collected during shoreline cleanups (i.e., UNEP, OSPAR,) have not included a detailed taxonomy of fishing related materials. UNEP/IOC identifies a debris class for fishing and boating items which includes buoys, net, fishing related (lures, sinkers), monofilament line, and rope (Cheshire & Adler, 2009) while OSPAR's survey sheet includes fishing materials (i.e., net pieces, rope, fish boxes, floats and buoys) within the plastic/polystyrene category (OSPAR, 2010). While identifying the component material is important in understanding the impact and longevity of the debris, identifying the source aids prevention measures. In response to UNEP and OSPAR's survey sheets, and broader classification gaps within classification literature, the present study develops a taxonomy to be specifically applied to fishing related debris in order to identify when gear may become debris, and particularly risky operations.

A system of classification designated for fishing related debris started to emerge while grouping similar debris. Debris was initially grouped based on an identifiable feature, like the fishing sect it was used for, or marked as miscellaneous if unidentifiable or used across fishing sects. The final classification sheet is derived from numerous preliminary renderings. The first iteration of the classification scheme had five debris categories: fishing, fish processing, consumer waste, other, and large debris. Previous iterations of the classification sheet can be seen in tables 2 and 3.

Fishing # of Units (Tally)		Total
Gillnetting		
Longline		
Trawl netting		
Monofilament		
Rope cuttings		
Flotation		
Fish Processing (i.e. conveyor pieces, bins/bin fragments, plastic planking, bin labels)		
Consumer waste		
Other		
Notably large debris		

Description	Approximate size

Table 2 First iteration of the fishing debris survey sheet

Date: Tide: Transect Length:

Location:

Sect Specific Fishing Gear # of Units (Tally)		Total
Gillnetting		
Jigging		
Longline		
Trawl netting		
Other		
Industry Wide Fishing Gear		
Misc. rope		
Flotation		
Other		
Fishing Related		
Bin/fragments / inner foam		
Labels		
Processing plastic (conveyor piece,)		
Marine gear (gloves, boot)		
Packaging (Straps,)		
Other		
Consumer Waste/Other		

Table 3 Fifth iteration of the fishing debris survey sheet

The notably large debris section in the preliminary version of the survey sheet was intended to account for the quantification bias of counting units instead of weight. This was determined to be beyond the classification schemes intention; the aim of this classification is to help determine which processes/operations are contributing to marine debris, identifying risky sects in the fish catching, processing, and shipping industry. In this sense, the size of debris is not the primary concern.

4 Results

In total 24 official shoreline cleanups were conducted, from which this sections' results were obtained. Results are divided in to three sections: first, the final iteration of the survey sheet is presented. Second, quantitative survey results for all collected debris are shown. These results are represented outside of a classification system in order to, firstly, demonstrate aggregate, broad results, and secondly, to demonstrate the application of the classification scheme in displaying information. Next, the results of inductive research are outlined; the new taxonomy is applied and used to represent collected data.

4.1 Final Survey Sheet

Commonalities persist throughout the iterations of the survey sheet and into its final form. For instance, there has consistently been an emphasis on distinguishing, as much as possible, the source of the debris (i.e., the sect or use of the gear). The final classification scheme (table 4) is divided into two overarching sections. The two most general categories are operational and non-operational fishing related materials. Operational materials are defined as fishing gear that directly interfaces with the water; Operational gear actively facilitates fishing. Some examples of operational gear include trawl net cuts, jig line, lures, longline segments. Non-operational, the second overarching category, accounts for materials used for the processing, packaging, and distribution of catch. In other words, materials that are not intended to enter the water. Some examples include fish boxes, fish box labels, packing straps, conveyor pieces. It is important to have these two categories because debris from the fishing industry does not come exclusively the act of fishing—fishing involves non-operational activities that generate waste that must be managed .

Date: Tide: Transect Length:

Location + GPS:

Count the number of units and tally each individual piece, totaling for each category. See photo guide for examples and category descriptions

Operational: Sect Specific Fishing Gear	# of Units (Tally)	Total
Gillnetting		
Jigging		
Longline		
Trawl netting/cuts		
Other		
Industry Wide Fishing Gear		
Misc. rope		
Flotation		
Other		
Non-Operational: Fishing Related/Processing		
Bin/fragments		
Labels/Bin tags		
Processing plastic (conveyor piece)		
Marine gear (gloves, boot)		
Packaging		
Other		
Consumer/Industrial Waste + Other		

Table 4 Final iteration of the fishing debris survey sheet

The operational fishing gear category is further divided based on material or use. For instance, gear used strictly within the longlining sect (i.e., headline, snoods, hooks) is contained within the longline section. There are categories for operational materials used industry-wide such as flotation and miscellaneous rope. Operational gear is designed to directly interface with the water and marine environment. As this gear is being put into the water, it stands to reason that it is at risk of becoming debris due to entanglement, inclement weather conditions, net mending, etc. The second category, non-operational gear, is that which is not intended to enter the water (i.e., conveyor pieces, bins, bin labels, packing straps, gloves). Such materials presence as marine debris speaks to on board waste management or containment problems. The distinction between operational and non-operational gear is important because both are readily used within the fishing industry, but in different areas; debris from the fishing industry does not come exclusively from the act of fishing—fishing involves non-operational activities that generate waste that must be managed.

The subsections in the operational category account for gear that is attributable to a specific sect of the fishing industry (i.e., gillnetting, longlining), as well as operational gear used industry wide (i.e., misecellaneous ropes, flotation). Collected debris identified three major sects contributing significantly to marine pollution: gillnetting, longline, and trawling. This section also includes a *sect-specific other* subsection to account for items beyond these. For instance, aquaculture planks (figure 3.10) fall into the *sect-specific other* subsection because they are attributable to a specific fishing sect, but there was only once instance when they were collected.

Figure 4.1 Two aquaculture planks beside a bundle of longline and bag of other debris collectd at Skalavik beach. (Photo taken by Amy O'Rourke, 2018)

This classification scheme was retroactively applied to all collected materials. It was then tested on an ongoing basis during supplemental cleanups .

4.1.1 Use of Classification

This section outlines the materials that should be noted under each subsection. The Photo Guide (Appendix B) is intended to be used in conjunction with the survey sheet. The photo guide depicts how different materials may appear as marine debris, and is divided based on classification sections. The user is to utilize their personal judgement in conjunction with the photo guide when identifying and classifying debris.

The first subsection within operational gear is gillnetting. Gillnet of all different colours and sizes should be noted here. The second subsection is jigging. While lures and sinkers are used with jig fishing, it is challenging to determine with certainty their explicit source. Despite this, lures can be noted under the jigging subsection, as can the monofilament line associated with handline/jig fishing. The longline subsection accounts for segments of longline headline, snoods (i.e., the thinner rope extending from the headline), and hooks. It may be difficult to distinguish the explicit source of hooks, though often appear connected to snoods. The trawling subsection includes nets with all different mesh sizes and colours, including nets used for purse seining. If the debris can be identified to belong to a specific fishing practice that is not accounted for in the above subsections, it should be noted in the *other* section.

The second section within operational gear is for gear used industry wide. This is flotation, miscellaneous rope, and other. Miscellaneous rope includes all ropes, fragments, and frayed pieces that cannot be attributed to another category. Flotation contains buoys of all types, buoy pieces, ring floats, aluminum, steel, or plastic bobbins, and other similar materials. Some buoys are all-purpose, while others, such as mooring floats, have more specific purposes. For classification purposes and to identify the broad, industry-wide use and risk of pollution associated with flotation materials they were given their own category. Further, many hard-shell buoys are filled with foam substances like expanded polystyrene (EPS) or polyurethane. It can be challenging to distinguish between pieces of foam from buoys, plastic floats, and foam which could come from inside of fish transport bins. For the purpose of this classification, all foam should be counted under flotation. Styrofoam presented a categorization challenge as there are buoys made out of styrofoam, though the material is also readily used for packaging, both in and beyond the fishing industry. For the purposes of this study, styrofoam should go under 'packaging' unless it is identifiable as a styrofoam buoy, though it is important to note the challenge of sourcing styrofoam with certainty.

The non-operational gear section accounts for materials used for the processing, packaging, and distribution of catch: gloves, plastic packing/styrofoam, packing straps, fishing bin labels, bins, plastic conveyor belt pieces, plastic sheeting, etc. Identifying the presence of these materials as marine debris is a first step: further investigation may then reveal if they are being accidentally lost, dumped, and how best to prevent this.

4.2 Total Debris

Of all 1202 units of debris collected and documented during the data collection period, 55% is broadly attributable to the fishing industry (Figure 4.1). All other debris found, from consumer, industrial, undistinguishable, or other, accounts for the remaining 45%. These results support the assumption that the fishing industry is responsible for the majority of marine debris in Iceland's Westfjords, necessitating a more in-depth understanding of what constitutes this broad category.

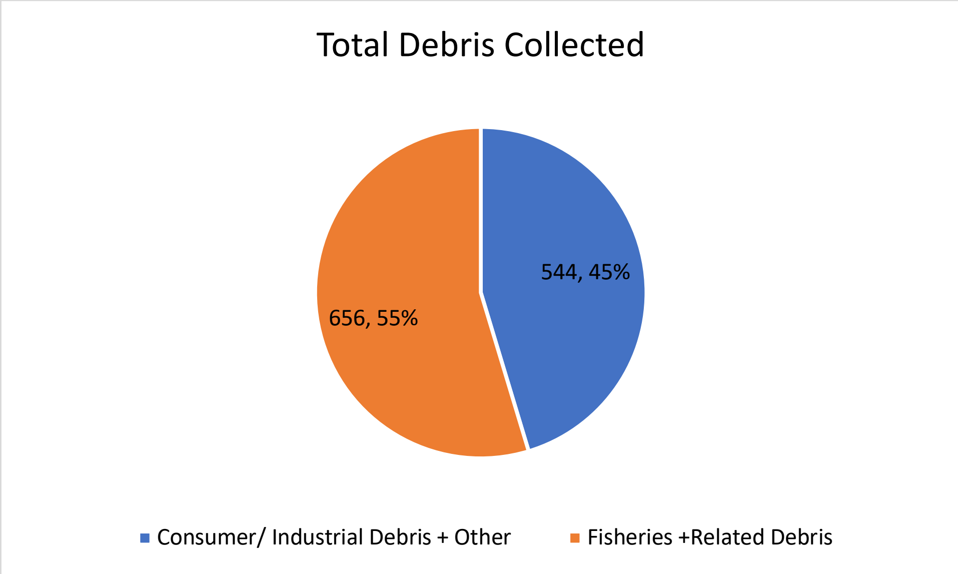

Figure 4.2 Percent and units of total debris collected by general source

4.3 Application of taxonomy

The classification table used in the survey sheet (table 4) includes a breakdown of types of fishing gear and related materials, as well as a section to tally debris unrelated to fishing. The following section outlines the occurrence of different types of fishing gear and applies the classification scheme on all documented debris.

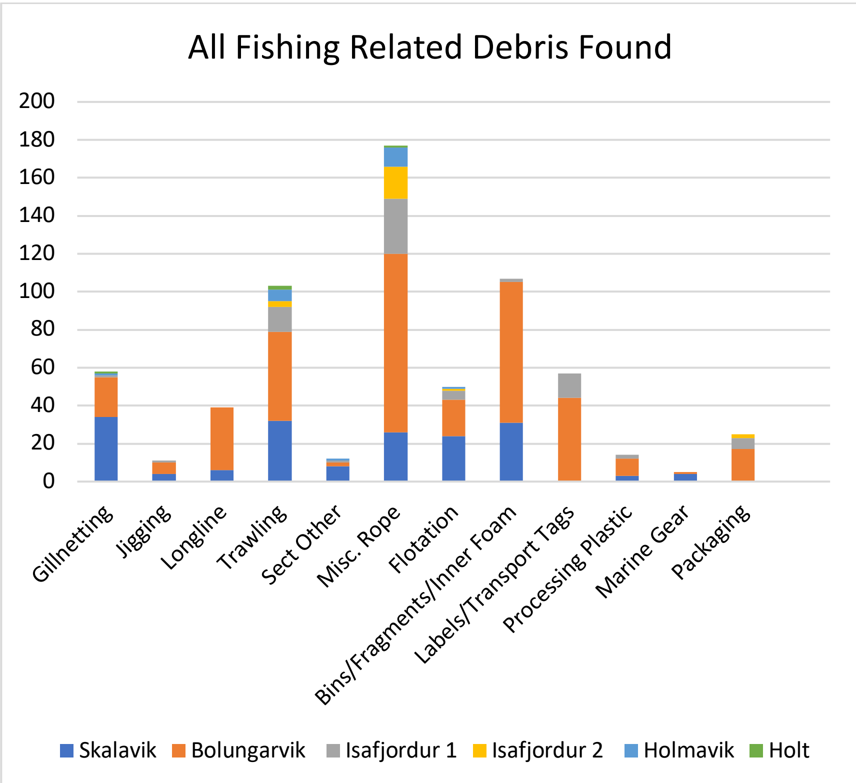

Figure 4.3 The amount (in units) of fishing related debris found at all sites

Fishing related debris found across all sites is detailed in Figure 4.2. This chart utilizes the uncategorized subsections of the classification scheme. The same information is represented below divided into operational and non-operational gear.

The two broad categories of taxonomy are operational and non-operational fishing/fishing related gear. As discussed, operational fishing gear is that which directly interfaces with the water; operational gear actively facilitates fishing. Figure 4.3 details the types of operational fishing debris collected.

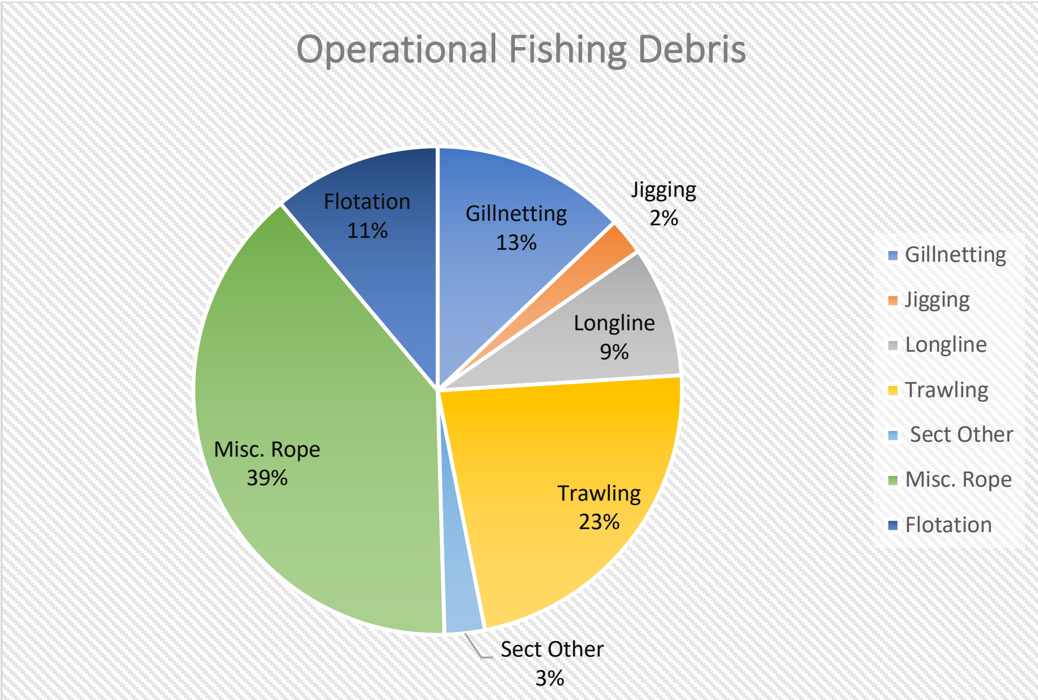

Figure 4.4 A breakdown of operational fishing debris collected as a percent of total operational gear

Non-operational gear is that which is never intended to enter the water and includes materials used for the processing, packaging, and distribution of catch. Figure 4.4 outlines the types and corresponding percent of non-operational fishing materials found.

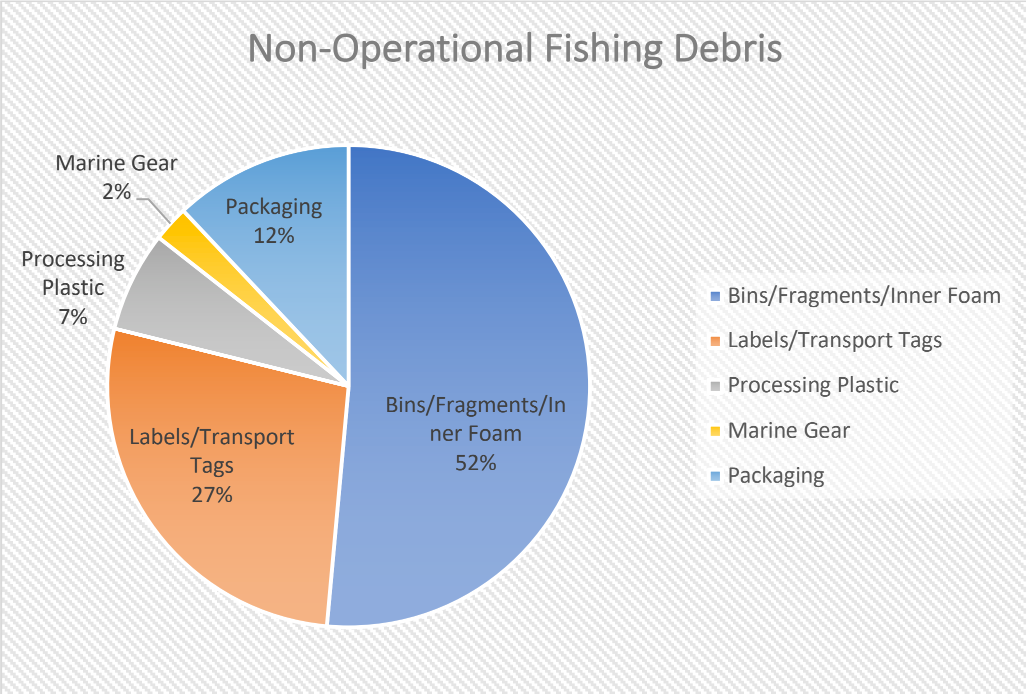

Figure 4.5 A breakdown of non-operational fishing debris collected as a percent of total non-operational materials

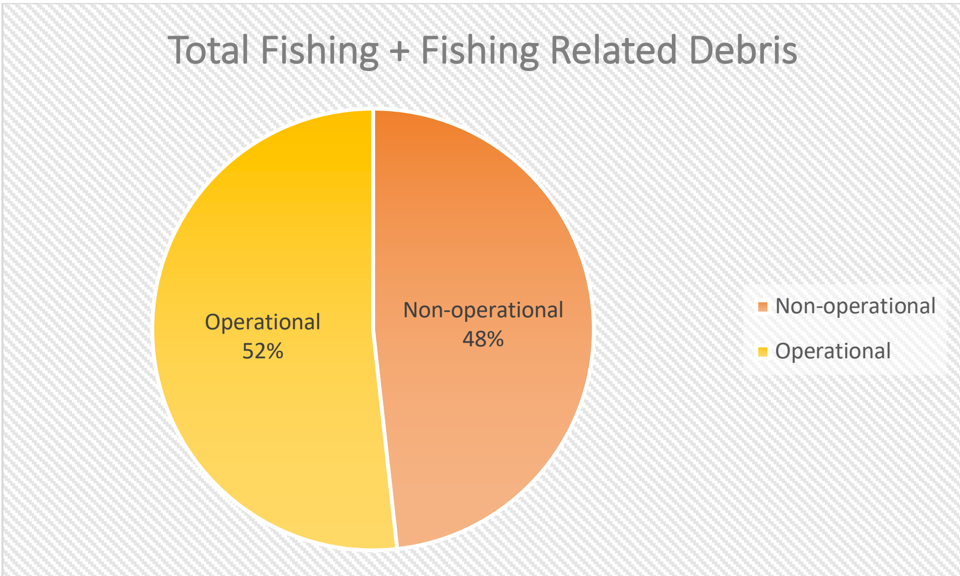

Figure 4.6 Total operational vs. non-operational debris as a percent of total fishing + fishing related debris collected

Figure 4.4 shows the relatively even split between operational and non-operational debris collected. This demonstrates the importance of taking non-operational debris from the fishing industry into account. While gear directly involved in the act of fishing may constitute what is generally thought of as fishing debris, non-operational materials make up a significant portion.

4.4 Consumer, Industrial, & Other Debris

The appearance of particular items associated with human hygiene or sanitation draws attention to the need for improved water treatment facilities and/or increased public education. Q-tips, feminine hygiene products, and baby wipes were often found close to urban settlements. One condom was found during the duration of the study. Two types of commonly used items collected frequently are Q-tip sticks and disposable purple gloves. These were found in surprising numbers—61 and upwards of 11, respectively—on the Ísafjörður and Bolungarvík beaches – the two sites close to sewage outlet pipes and that yielded the most usable data.

Determining the source of common debris is an important part of management. The proximity of Ísafjörður and Bolungarvík beaches to wastewater outlets suggests that hygiene items, such as Q-tips, were flushed down the toilet or entered the wastewater stream by similar means. The disposable purple gloves (Figure 5.1) are commonly used on docks, and during fish processing, though are also used in hospitals, kitchens, etc,. One fisherman describes his use of disposable purple gloves underneath thicker work gloves. The disposable gloves are available to and used by fisherman, though their source and path to the ocean cannot be stated with certainty as though are used widely outside of the marine sect. However, given their use within the fishing industry, and presence as marine debris, it seems likely they are improperly discarded during fish processing at harbours or at sea. Further investigation is required.

Figure 4.7 One of many disposable purple plastic gloves collected. (Photo taken at Ísafjörður beach by Amy O'Rourke, 2018).

Figure 4.8 Two white plastic Q-tip sticks (centre) amidst other collected debris. (Photo taken by Amy O'Rourke, 2018)

Figure 4.9 One of many plastic blue Q-tip sticks collected. (Photo taken by Amy O'Rourke, 2019)

While sewage treatment to remove inorganic matter would decrease the amount of debris in the marine environment, the majority of Iceland is sparsely populated, making it hard to justify the costly implementation of sewage treatment infrastructure. Outside of Reykjavik and Akureyri there is little to no sewage treatment (Figure 5.8). There is not the population to feasibly support the costly construction of treatment infrastructure. Debris collected during the course of this study that is suspected to come from sewage outlets includes Q-tip sticks, disposable wipes, dental floss, feminine hygiene products and wrappers, and condoms.

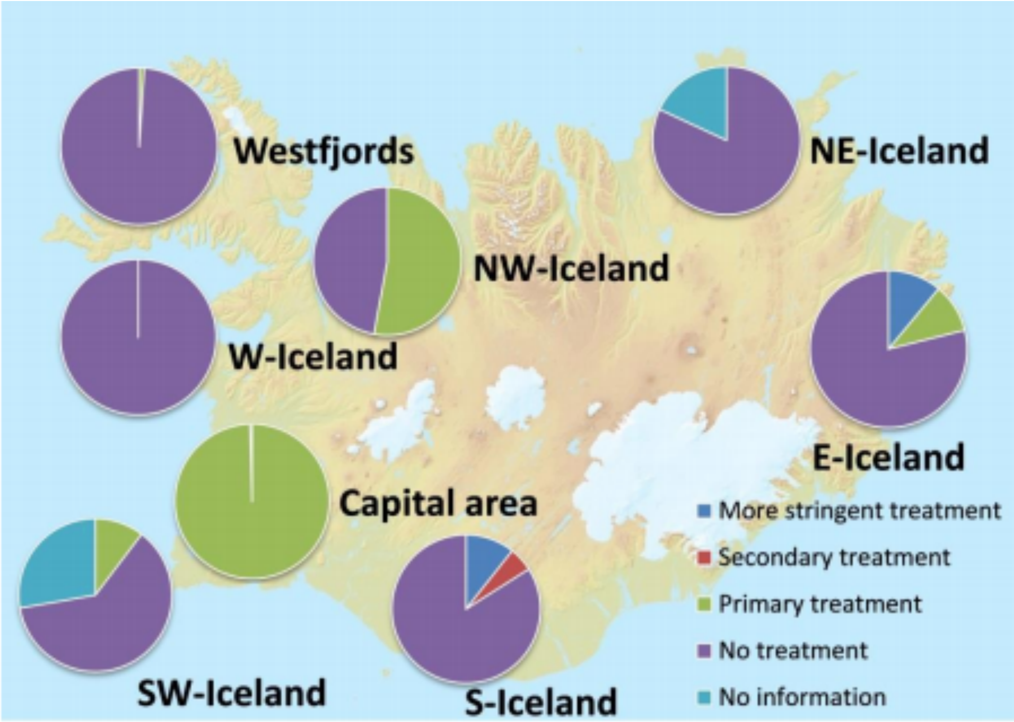

Figure 4.10 Map of sewage treatment levels across Iceland (Environmental Agency of Iceland, 2013)

Similar to the aforementioned debris of likely wastewater origins, other human-affiliated sorts of refuse were also found near settlements. For example, upwards of 35 shotgun shells were collected at the Bolungarvík beach. While shotgun shells were not in and of themselves unusual findings, their close spatial distribution along the Bolungarvík beach was out of the ordinary, compared to other transects. The plastic casings appeared in numerous colours with varied states of wear (Figure 5.4). Further, countless cigarette filters were found across all sites. Supplemental cleanups were conducted in the Westfjords and NE Iceland around harbours, docks, beaches, and readily frequented swaths of coastline, where cigarette filters were found to be ubiquitous.

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Figure 4.11 Shotgun shells (bottom left) collected from one outing at Bolungarvik (Photo taken by Amy O'Rourke, 2018)

The survey sheet (Appendix C) includes a 'consumer waste / other' section to ensure other debris, like shotgun shells and cigarette butts, is accounted for if the survey sheet is not used in conjunction with a, for instance, OSPAR survey sheet. There is a 'notes' section on the back of the survey sheet where further information can be listed. This includes observations on wildlife, unusual finds, geomorphic observations, the general state of the beach, or items that were repeatedly found that could indicate a larger issue. In most instances, proximity to urban areas seemed to significantly impact the composition of 'other' waste found and is an area for continued investigation. The finding of such studies could improve how settlements handle refuse. While Leite et al., cite proximity to urban centers as proportional to abundance of marine debris (2014), other studies have contended this (e.g. Free et al., 2014; Ioakeimidis, 2014), as did observations made during supplemental cleanups in the remote Strandir region. Proximity to settlements initially appeared important when seeking to differentiate between debris washing ashore, and land-sourced beach debris. For example, drink cans, cigarette butts, and popsicle sticks were commonly collected items at the Ísafjörður and Bolungarvík beaches, whereas these were collected less frequently at more isolated locations, such as Skálavík beach. This did not hold true for all locales though, as supplemental cleanups conducted in the isolated Strandir region revealed all manner of consumer, industrial, and miscellaneous waste.

Near Hornstrandir there is significant variation in the debris washing up at different locales. For instance, two particular supplemental cleanups were conducted near the Strandir region: At one, the vast majority of debris consisted of hard plastics fragments. Here, upwards of 15 shoe soles were found (Figure 4.11)

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Figure 4.12 Shoe soles collected in the strandir region during supplemental cleanups. (Photos taken by Amy O'Rourke, 2019)

At the second beach, less than 3 km away, the majority of debris consisted of ropes and netting (Figures 4.12, 4.13). Shotgun shells were found in significant numbers at both sites. If data collection was conducted at these sites the aggregate and site specific results would have been different.

Figure 4.13 Rope, netting, crates + more debris collected near Strandir (Photo taken by Amy O'Rourke, 2019)

Figure 4.14 Netting and rope strewn across a beach near Strandir prior to cleanup. (Photo taken by Amy O'Rourke, 2019)

5 Discussion

The resultant classification scheme and photo guide are intended to expand the base of knowledge on fishing operations that contribute to marine debris in Iceland, and the information that can be obtained from shoreline clean ups. This chapter discusses the debris collected from the fishing industry as well as other debris which appeared in significant numbers. Possible pathways debris follows to enter the marine environment is then explored, followed by discussion of the effectiveness of the classification scheme and where it fits among other survey sheets. Management recommendations are then discussed, followed by how to effectively disseminate clean up results. Finally, avenues for future research are explored.

5.1 Understanding Most Commonly Collected Fishing Debris

The present study is an exploratory dive into what types of fishing gear are continuously washing up on Iceland's shores. The results indicate that most debris entering the marine environment from the fishing industry comes from miscellaneous ropes, which is consistent with previous studies in Iceland (Kientz, 2013; and abroad (Unger. Further, this makes sense given the ubiquity of ropes across the marine sector and their multitude of purposes—e.g., securing vessels, fastening floats, stabilizing gear, etc.,. While Within my classification scheme 'Miscellaneous ropes' falls under the 'Industry-wide gear' category. Given that ropes are used across the fishing industry and wider marine sector, there are a number of sources from which they could be lost or discarded and enter the marine environment. Due to the number of vessels using ropes in their everyday operations, and the broadness of the 'miscellaneous ropes' category, it makes sense that this type of debris appeared most frequently. The majority of modern ropes are made of synthetic polymers —commonly in twisted or braided strands of smaller threads. Ropes fray with age and continued use, degrading them into smaller and smaller plastic fibers.

Flotation, also ubiquitous throughout industrial and marine sectors, appeared frequently during data collection. Because flotation materials are widely used, and functional floats do not sink, it makes sense that they would often be washed ashore by waves—increasing the frequency with which they were collected. Given the buoyancy of floats, floatation related materials , and other materials less dense than seawater, they may be disproportionally represented at beach cleanups, since they may be more likely to wash ashore than heavier gear that sinks to the seafloor (e.g., Barnes & Milner, 2005; Unger & Harrison, 2016). This could present a significant gap in data and would necessitate beach cleanup results to be observed alongside marine debris collected from, for example, bottom trawling, to give a complete picture of fishing related materials entering the marine environment and becoming debris. One study conducted in Norwegian waters found that the majority of debris on the seabed was from the fishing industry, though it could not be recognized or sourced beyond that (Buhl-Mortensen, 2018). Future research wishing to determine the overall amount of human refuse in marine contexts may wish to employ data collection methods that are able to measure debris on and under the ocean's surface.

Numerous human and natural factors affect the types of marine debris that actually reach the shore, such as debris buoyancy and oceanic currents (e.g., Barnes & Milner, 2005; Buhl-Mortensen, 2018). Given the higher chance of buoyant debris washing ashore (Unger & Harrison, 2016), flotation related materials may be more accurately represented in this study than other materials; this study's results solely reflect a portion of total marine debris. The amount of debris on the seafloor and in the greater oceanic environment is far larger than that which washes ashore . Thus, one limitation of the present study is that only shore debris was counted.

Cuttings from trawl nets, as well as trawl repair lines, were the next most likely debris to appear during data collection. As the results reflect, 23% of operational fishing debris was attributable to the trawling sect. Understanding the composition of fishing gear that washes ashore can, in some instances, shed light on how that gear was lost, though consultation with the fishing industry is necessary to better understand how these materials continue to enter the marine environment. For example, consultation with fishermen regarding how trawl cuttings enter the water would be valuable. A clean, cut-down net or piece of repair line suggests intent (Hartley et al., 2015). In other words, the line may have entered the marine environment during net repair after inadequate disposal of waste materials. If this is indeed the case, Iceland could adopt more stringent marine refuse disposal and monitoring policies, for example, by increasing fines and monitoring or incentivizing bringing refuse to shore. However, trawl gear may also be lost due to inclement weather or other unavoidable conditions (e.g., Huntington, 2016).

In 2017, the Icelandic Transport Authority (2018) documented 1621 registered vessels in Iceland—consisting of 842 undecked vessels, 735 decked, and 44 trawlers. A breakdown of vessel numbers and types across all Icelandic regions is available in appendix D. These numbers show the size of fleet and provide context for the types of fishing gear appearing as marine debris. As outlined in this section, the amount of debris attributable to a specific fishing sect appears proportional to the amount of related debris found.

5.2 Impact on Wildlife

Certain organisms living in specific environments (i.e., rocky intertidal zones, sandy flats,) means they are exposed to the debris that tends to accumulate there. The Bolungarvík beach lies beside a grassy nesting area adjacent to cliffs where hundreds of birds congregate. This is to say, there were constantly birds—guillemots, gulls, terns, oystercatchers present in the area. Without entering the water, these were the animals I was able to consistently observe interfacing with the marine environment and, in some instance, suffering due to human refuse. On one occasion, a juvenile guillemot (*Cepphus grille)* whose beak was tangled in green plastic fibers was found (Figure 5.1). It was deceased. Upon picking it up to collect the debris, it became apparent that the bird had consumed part of the plastic line and presumably choked on it. Because Bolungarvík beach a) is near a nesting area for Arctic terns (*Sterna paradisaea*), and b) is generally an area frequented by many birds of different species, this study's findings raise concerns these and other animals' wellbeing. Due to the ongoing appearance of debris that can pose a hazard to birds, such as the juvenile guillemot, the municipality of Bolungarvík may wish to improve beach clean-up efforts or take measure to reduce waste ending up on beaches. Future research on the direct impacts of marine debris on local wildlife will better inform efforts to mitigate harm by local authorities.

Figure 5.1 Juvenile guillemot found on Bolungarvik beach with its beak tangled in deteriorated rope. The fibres had been partially ingested. (Photo taken by Amy O'Rourke, 2018)

Human refuse also affects other marine and coastal species. On one particularly notable shoreline cleanup at the Bolungarvík beach, 7 gulls were found that had been shot dead, and one with a mangled wing that appeared to have been shot but was still alive. Within Iceland, it is not illegal to kill seagulls, though it is a crime to leave an animal injured to fend for itself (Althingi, 1994). Upon returning the next day, the injured gull was gone, though the shotgun shells remained. This instance demonstrates one way shotgun shells make their way in to marine environments. Discarded shotgun shells pose further risks to marine species by degrading into microplastic particles.

Figure 5.2. Deceased bird with plastic fibres in and around its body near Strandir. (Photo taken by Amy O'Rourke, 2019)

5.2.1 Timeline

Humans have introduced vast quantities of synthetic materials into the natural world at a rate with which it cannot adapt to. Some shoreline birds, like the oystercatcher, have bills fine-tuned through adaptation to filter food from the water column In Charles Darwin's book "On the origin of species, by means of natural selection" he expressed surprise that the organisms he examined were able to evolve and adapt over the relatively short timeline put forward by religion during his time (1859). We now know, and Darwin put forth, that life on earth had millions of years to evolve and adapt. Humans, as modern society currently exists, as people of production and industry, have existed for a fraction of a fraction of this time. Plastics—unfamiliar, pervasive, and new materials to the world—have entered, and continue to enter, natural environments across the globe at the expense of organisms exposed to them.

5.3 Communicating Cleanup Results

Committing to addressing the issue of marine debris requires understanding. Identifying that the majority of marine debris surfacing around Iceland is broadly attributable to the fishing industry is insufficient for improving best practice. We have to understand it more than that. Management should be informed by identifying specific operations contributing.

Ultimately, the classification scheme is a means of communicating information. There are numerous ways the classification scheme could inform communication with different stakeholders. For instance, identifying the materials becoming marine debris provides an opportunity for gear designers to look into alternate, perhaps biodegradable materials like bioplastics for bin labels. Making use of the survey sheet accessible to an array of people means there is a broad number of ways that information could be used. Social media may be used to inform the general public on high-risk operations, which may lead to a grassroots movement calling for change.

Monitoring the materials becoming debris is important for gauging the effectiveness of changes and regulations. Specific classification lets us communicate with stakeholders more effectively because it illustrates the smaller points making up the big picture, contributing to a fuller understanding.

There are various means through which the results of shoreline cleanups can be communicated, with multiple avenues for resultant change and action to explore.
In the age of globalization findings from shoreline cleanups can be disseminated widely through the use of social media and news sources, though it is also important to open small-scale communication (i.e., identifying and communicating the waste management concerns in specific communities). The survey sheet developed in this study can be used to inform conversations and disseminate information on the magnitude of pollution stemming from specific fishing related operations. It is a tool with which to present specific findings to, for example, local politicians, port reception facility officers, or fisheries representatives.

During the duration of this study, a few avenues have been explored, ranging from e-mailing local politicians regarding the installation of cigarette butt receptacles, to constructing a display of debris found at the beach for World Ocean's Day. These have not been specific to the fishing industry, though demonstrate two simple instances of outreach. The purpose of the present study's photo guide and classification scheme is to be for anyone to use however they see fit. Information can be conveyed by means of art, essay, presentation, and so on. The methods of communication outlined during this study are inexhaustive.

5.4 Management Recommendations

To reduce the negative effects of marine refuse on wildlife, as well as to humans, it is important to take steps to manage this environmental threat. The Global Ghost Gear Initiative indicates management of marine debris falls under three categories: prevention, mitigation, and cure (2017). Prevention involves understanding the materials frequently entering the marine environment and avoiding high-risk situations. Classifying and sourcing will help us more fully understand the sources of marine debris, and therefore help prevent it, which is the management area the present study deals with. Mitigation involves lessening the duration fishing-associated debris is in the environment, as well as reducing its negative effects. Cure involves removing marine debris from the environment, as is done with Fishing for Litter schemes (North Sea Directorate of the Dutch Government, 2000) and beach cleanups. By identifying problem areas and types of marine refuse frequently appearing as marine debris, the results of this study can be used to inform the prevention stage, as well as future studies investigating how other stages should be addressed.

Over the course of this study numerous items appeared that, when considering their intended use and length of time they are used, could be replaced with other materials. Plastic is durable and waterproof, allowing fishing gear to last and benefit the owner financially, however, not all materials (i.e., single use or disposable items: disposable gloves, fishing bin tags, etc.,) need to be made of material with plastic's longevity.

Fishing bin tags could be replaced with a more readily degradable material or one that allows it to be continuously remarked and reused. Fishing bin tags, of the materials never intended to enter the water, appeared as marine debris with the highest frequency.

Iceland Responsible Fisheries is a certification process that lets consumers know that their product is sourced from a responsible source. Other such seafood certification programs exist, such as The Ocean Wise Seafood Program, Marine Stewardship Council Certification, and more. Given the rise in concern for marine debris and its environmental impacts there is an opportunity for fishing/seafood/aquaculture companies to incorporate debris collection and use it as a marketable tool. Fisheries Iceland should incorporate an assessment of waste management practices/port reception facilities in its Environmental Review.

A significant amount of debris collected during the duration of this study could have been prevented through education. Educating communities on the sewage facilities in their town, or lack thereof, is necessary to inform the public on the impact of human action. For example one may not know that flushing Q-tips, condoms, or wipes down the toilet sends them to the ocean where they can cause harm.

5.5 Effectiveness

The present classification scheme provides a preliminary means to organize fishing-related marine debris. It serves its purpose in that all collected debris identified to be related to the fishing industry has a place within the classification. The classification is intended to aid management by identifying high-risk operations. The resultant classification scheme can be used in conjunction with OSPAR's beach survey sheet to more specifically source fishing-related debris. This classification can be used to address a prominent gap in the documentation of marine debris: it is designed to familiarize the user with specific fishing and fishing related debris and enable them to document it.

5.6 Future Research

Future researchers should investigate the relationship between amount of marine debris from a certain fishing sect and the prevalence of that type of fishing vessel in order to identify disproportionately problematic areas and better inform marine policy.

While conversation with fishermen has been employed to identify various materials, this study has not delved deeply into fishermen's perceptions of marine debris. Regional dialogue on what stakeholders, such as fishermen, understand about marine debris and what they are willing to do to reduce it is important (Hartley et al., 2015). For instance, a study could be conducted with the direct involvement of fishermen and port operators in Iceland. It is important to ask involve those on the front line and ask how fishers and vessel operators think marine debris can be reduced.

Questions to ask could include the following:

1. Is fishing gear entering the marine environment as debris avoidable?
2. Is marine debris a present, past, or current concern?
3. Can you identify flaws in current waste management aboard fishing vessels?

Figure 5.3 Bucket of net cuttings aboard a local trawler. (Photo by Amy O'Rourke, 2019)

The views of active fishermen on possible streams of waste entering the marine environment is a necessary route of further investigation. Discussion with fishermen and those doing work related to the processing, packaging, and distribution of seafood is necessary because they may provide useful insights on the feasibility of waste management protocols, material alternatives, etc. While this study frequently found trawl cuttings, trawl repair line, fishing bin labels, and packing straps, why these materials are frequently entering the marine environment cannot be said with certainty. This study aids in the identification of specific waste management problems within the fishing industry, but doing so is a first step in solving the problem.

Research needs to be conducted on the most common pathways marine debris finds to the ocean. If such research deems complete avoidance of ALDFG as unfeasible, research should center around minimizing the harm caused by fishing gear entering the marine environment, alternative/biodegradable material options, and gear marking. Gear marking helps identify parties responsible for debris and therefore holds them accountable.

6 Conclusions

This study has aimed to identify the varying degrees with which different fishing sects are contributing to marine debris in the Westfjords through the development and application of a classification scheme for fishing-related marine debris. This study has verified that material used to actively facilitate fishing, as well as related materials pertaining to the processing, sale, and distribution of catch, is present and pervasive in Iceland's Westfjords. This study developed and tested a classification scheme for use during shoreline cleanup to better define and communicate the types of fishing related materials appearing on shorelines as debris. The resultant classification scheme is intended to be used as a tool to identify operations at a high-risk for contributing to marine debris, and to inform communication and future management.

Based on shoreline clean-ups within the Westfjords, flotation, trawl netting, gillnetting, and miscellaneous rope – materials with operational roles in the fishing process, account for a significant portion of marine debris washing ashore. Given that these materials are actively interfacing with the water, encountering them as marine debris seems partially unavoidable, though it is the authors belief that management protocols need to be refined to better interrupt the path of fishing related materials into the ocean. Non-operational materials never intended to enter the ocean, including fishing bin labels, gloves, packing straps, styrofoam, and packaging were consistently collected over the duration of this study. Identifying the presence of such materials, on a significant scale and beyond a random event, is indicative of problematic management practices.

At its most basic, I intend for the classification scheme and corresponding photo guide to be used by anyone, with any knowledge of marine debris or fishing gear. Beach clean ups are powerful because they are accessible. One just needs a bucket or bag, and a pair of gloves ,and they have a powerful tool at their disposal to effect change. Beach clean ups become more powerful when we can maximize the data extracted from them. This study has developed a means of specifically identifying and sourcing debris. The classification scheme and accompanying photo guide allow us to look closer to get at more specific and practical solutions; sourcing fishing related debris to identifiable operations and sects provides information with which to inform management, future research, and policy.

Identifying a problem is the first step to solving it. If we want to decrease the amount of marine debris created by the fishing industry, we must first ascertain where, specifically, that debris is coming from. Only then can we begin exploring strategies to address these problem areas. While seeing beaches strewn with debris can be discouraging, I remain optimistic because we have tools at our disposal to effect change. We just have to use them.

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Appendix A: Ethics Clearance

Research ethics training and clearance letter

Háskólasetur Vestfjarða
University Centre of the Westfjords

Research ethics training and clearance

University Centre of the Westfjords
Suðurgata 12
400 Ísafjörður, Iceland
+354 450 3040
info@uw.is

This letter certifies that **Amy Elizabeth O´Rourke** has completed the following modules of:

(x) Basic ethics in research
(x) Human subjects research
(x) Animal subjects research

Furthermore, the Masters Study Committee has determined that the proposed masters research entitled **Categorization of beach debris and management protocols for Iceland** meets the ethics and research integrity standards of the University Centre of the Westfjords. Throughout the course of his or her research, the student has the continued responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

University Centre of the Westfjords ethics training certification and research ethics clearance is valid for one year past the date of issue.

Effective Date: 15 June 2018
Expiration Date: 15 June 2019

Prior to making substantive changes to the scope of research, research tools, or methods, the student is required to contact the Masters Study Committee to determine whether or not additional review is required.

Appendix B: Photo Guide

A marine debris photo guide intended to aid the user in the identification of fishing related debris.

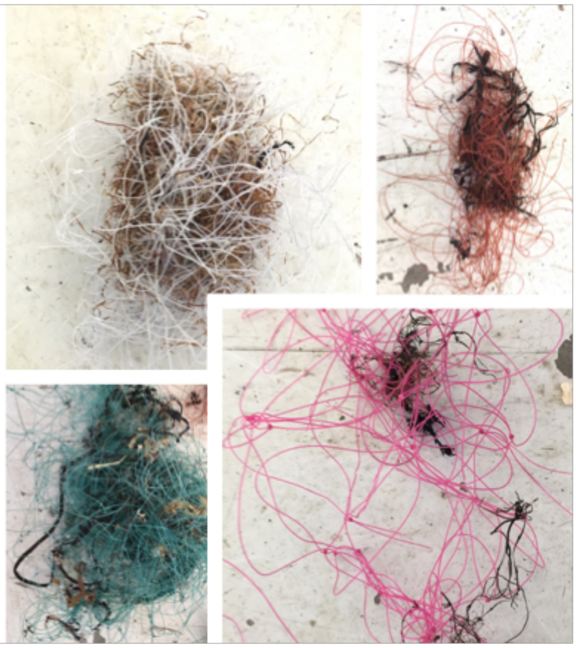
MARINE DEBRIS PHOTO GUIDE

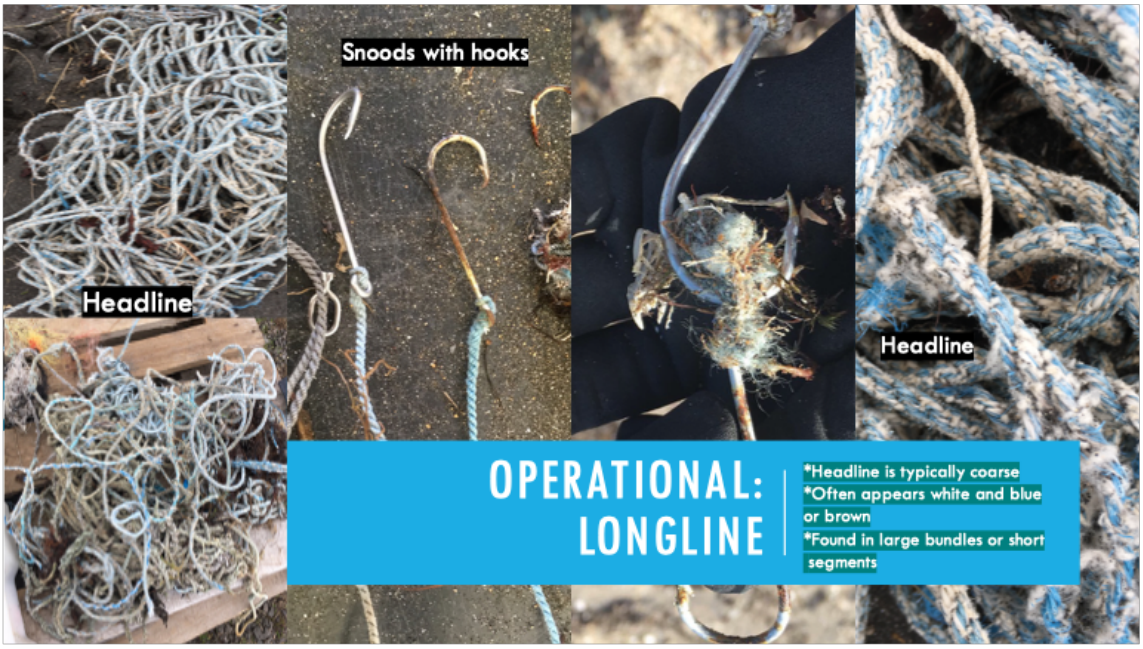
This guide is meant to aid in the identification of fishing related marine debris, though is not definitive. User should utilize personal judgement.

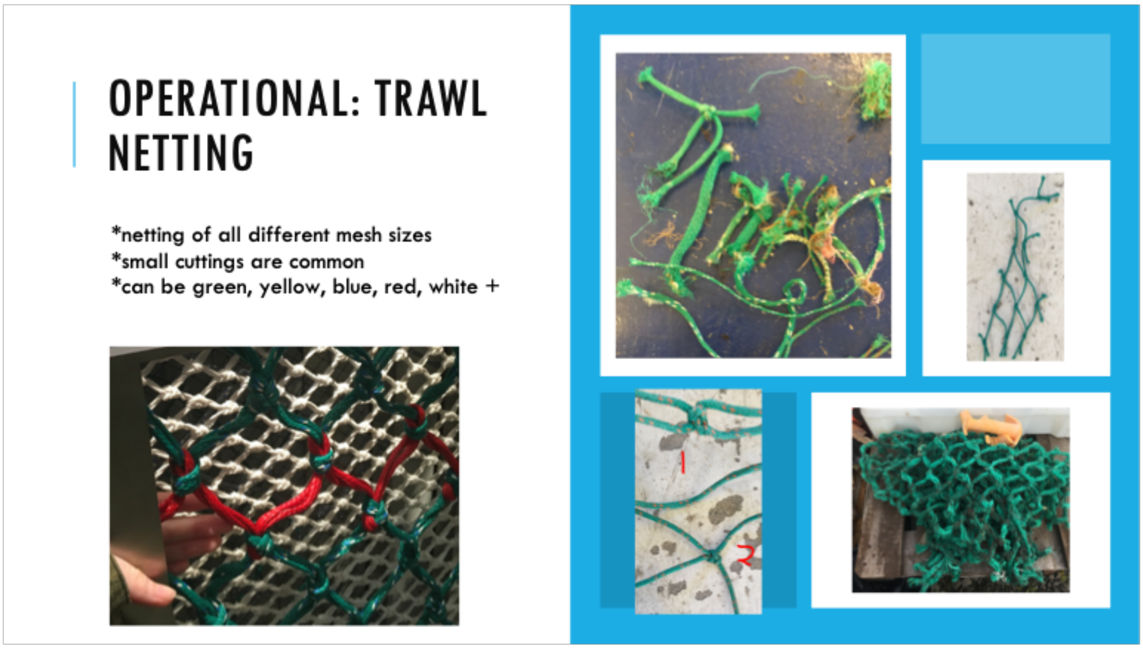
OPERATIONAL GEAR: GILLNETTING

*Frequently becomes entangled in beached kelp

*Appears in many different colours

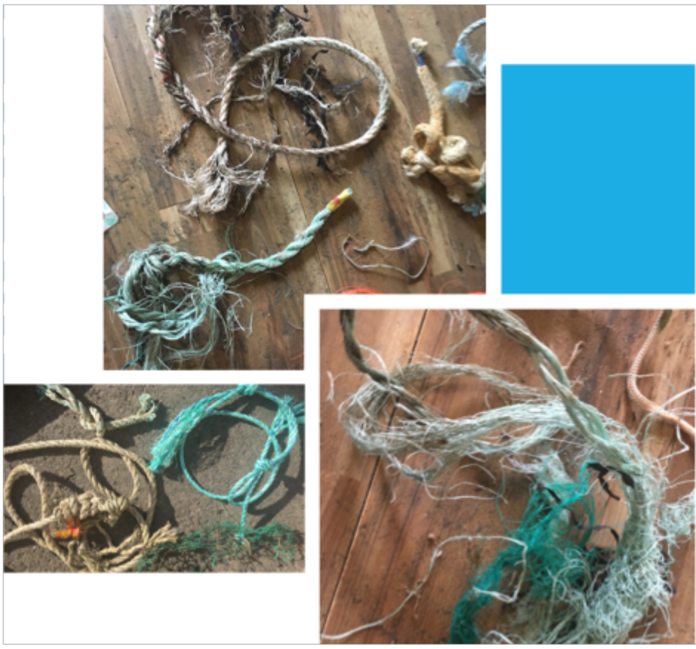



Headline
Snoods with hooks
Headline
OPERATIONAL: LONGLINE
*Headline is typically coarse
*Often appears white and blue or brown
*Found in large bundles or short segments

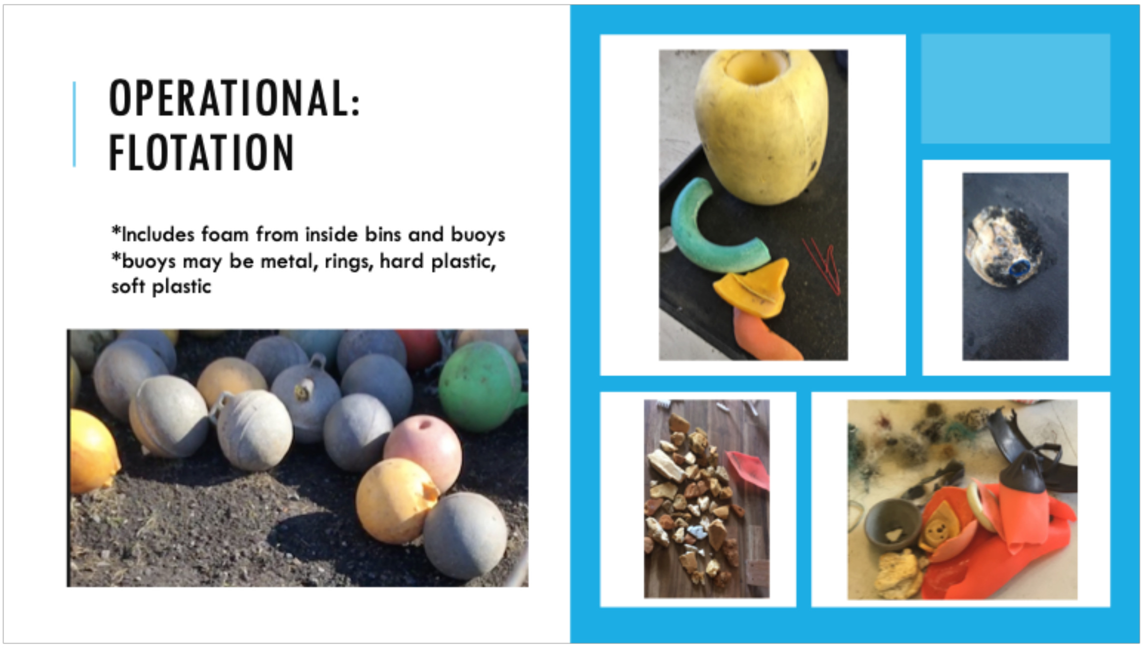

OPERATIONAL: TRAWL NETTING
*netting of all different mesh sizes
*small cuttings are common
*can be green, yellow, blue, red, white +

OPERATIONAL: JIGGING

*Monofilament, thicker than gillnet
*includes lures



OPERATIONAL: MISC. ROPE


OPERATIONAL:
FLOTATION
*Includes foam from inside bins and buoys
*buoys may be metal, rings, hard plastic,
soft plastic


NON-OPERATIONAL GEAR:
MARINE WEAR

NON-OPERATIONAL: BINS, BIN FRAGMENTS, BIN LABELS

NON-OPERATIONAL: PROCESSING PLASTIC

*includes conveyor pieces, plastic worktop slabs

NON-OPERATIONAL: PACKAGING

*includes packing straps, plastic sheeting, styrofoam

BEYOND FISHERIES: OTHER COMMON DEBRIS

Q-Tip sticks – generally blue or white

Popsicle sticks

Shot-gun shells – wide variety of colours

Appendix C: Survey sheet and classification

The fishing related debris classification/survey sheet developed in this study

Date: Tide: Transect Length:

Location + GPS:

Count the number of units and tally each individual piece, totaling for each category. See photo guide for examples and category descriptions

	Operational: **Sect Specific Fishing Gear** # of Units (Tally)	Total
Gillnetting		
Jigging		
Longline		
Trawl netting/cuts		
Other		
	Industry Wide Fishing Gear	
Misc. rope		
Flotation		
Other		
	Non-Operational: **Fishing Related/Processing**	
Bin/fragments		
Labels/Bin tags		
Processing plastic (conveyor piece)		
Marine gear (gloves, boot)		
Packaging		
Other		
	Consumer/Industrial Waste + Other	

Notable findings (i.e., deceased/entangled wildlife, unidentifiable debris, large debris, numerous specific object, etc.):

Appendix D: Fishing Fleet

A breakdown of the number and distribution of vessels in Iceland in 2017

The fishing fleet by region and type of vessels 1999-2017		
		2017
		Number of ships
Total	**Whole country**	1621
	Capital region	119
	West	290
	Westfjords	394
	Northwest	128
	Northeast	225
	East	235
	South	74
	Southwest	156
Undecked vessels	**Whole country**	842
	Capital region	69
	West	163
	Westfjords	231
	Northwest	63
	Northeast	101
	East	125
	South	22
	Southwest	68
Decked vessels	**Whole country**	735
	Capital region	42
	West	123
	Westfjords	160
	Northwest	60
	Northeast	113
	East	107
	South	47
	Southwest	83
Trawlers	**Whole country**	44
	Capital region	8
	West	4
	Westfjords	3
	Northwest	5
	Northeast	11
	East	3
	South	5
	Southwest	5

Information in table refers to December 31st each year.		

(Source: Icelandic Transport Authority, 2018)

Háskólasetur
Vestfjarða
University Centre
of the Westfjords