Master's thesis

Scar-based analysis and eyewitness accounts of entanglement of humpback whales (*Megaptera novaeangliae*) in fishing gear in Iceland

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Declaration

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

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Abstract

Entanglement in fishing gear, or bycatch, of cetaceans is a global issue causing thousands of injuries and mortalities each year. Humpback whales (*Megaptera novaeangliae*) are one of many cetacean species that become entangled, often non-lethally, in various types of fishing gear, which has detrimental impacts on the whales and can cause damage to the gear. Scar-based analysis can be used to determine the estimated number of humpback whales in a population that have been previously entangled in fishing gear. For this study, scar-based analysis, as well as a survey of fishermen aimed to collect eye-witness entanglement accounts, were conducted to estimate the percent of the Icelandic North Atlantic humpback whale subpopulation that has been entangled in fishing gear, and to learn about these events taking place in Icelandic waters. To conduct scar-based analysis, photographs of individual humpback whale flukes and caudal peduncles were taken in Skjálfandi Bay, Iceland and were examined for evidence of wrapping scars and notches which are indicative of entanglement. Results of the scar-based analysis determined that a minimum of 41.8% of the Icelandic subpopulation has been previously entangled. The survey aimed at fishermen reported 6 eye-witness entanglement accounts involving humpbacks interacting with a variety of fishing gear including seine nets, hook-and-line gear, and gillnets. Though further research into entanglement issues in Iceland should be conducted to gain a clearer understanding of the impacts on the whales and the fishermen, results from this study suggest that there is significant entanglement of this subpopulation. These results could warrant some mitigation and management strategies. The development of an entanglement reporting system could aid in gathering data to make informed management decisions. This study suggests the introduction of regulations to keep fishing activities at a safe distance from whales. Further investigation into the use of whale-safe fishing gear such as weak links for gillnet lines and whale-safe hooks for longline and hook-and-line fishing is also suggested.

Keywords: Entanglement, humpback whales, Iceland, scar-based analysis, management.

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1 Introduction

It is globally well-know that there are many unintentional interactions between the commercial fishing industry and an array of marine organisms, which can lead to undesired consequences (Read et al. 2006). Of particular concern to managers and conservationists alike in recent years is the issue of marine mammal entanglement in fishing gear. Entanglement in fishing gear, also commonly referred to as “bycatch”, is considered to be one of the leading causes of human-induced mortality in cetaceans (NOAA, n.d. a). Entanglement poses the risk of immediate mortality from drowning to some smaller marine mammals, while for larger cetaceans, who may be better able to free themselves from all or part of the gear, entanglement poses risks such as infection from injuries caused by entangling gear, and malnutrition and potentially starvation due to inability to feed properly (NOAA, 2011). There is also the possibility that the stress caused from a past entanglement event that did not result in significant injury or mortality can have other detrimental effects on the animal, such as lowering reproduction rates (NOAA, 2011). Entanglement of cetaceans has been studied and monitored in many parts of the world. Scar-based analysis, and fishing gear and habitat data has been used to study entanglement rates and relative threats of fishing gear entanglement of critically endangered North Atlantic right whales (*Eubalaena glacialis*) along the east coast of North America (Knowlton et al., 2005, Angelia et al., 2011). Entanglement events and bycatch rates of minke whales (*Balaenoptera acutorostrata*) have been well studied in Korean waters (An et al., 2010, Song et al., 2010). Entanglement of humpback whales (*Megaptera novaeangliae)* in particular, has be extensively studied and monitored in the Gulf of Maine (Robbins and Mattila, 2004) and the east coast of Canada (Volgenau et al., 1995), Hawaii (Mazzuca et al., 1998), Alaska (Neilson et al., 2009), and recently in Ecuador (Alva et al., 2012), but there are still other populations that have not yet been assessed. Since entanglement is likely an issue anywhere in the world where there are cetacean populations and fishing fleets, the International Whaling Commission (IWC) has recommended guidelines to improve data collection on this issue. One of the main guidelines created in order to compile a global monitoring and reporting system for entanglements is “collection of standardized data on entanglement and health of the individual, with survival studies in areas not presently studied" (Leaper et al., 2011).

There is an estimated population of approximately 11,500 North Atlantic humpback whales which spend the spring and summer months (April – September) distributed in sub-groups from eastern North America to Norway (NOAA, 2013a). They spend these months feeding before migrating south to their breeding grounds in the Caribbean and off of the west coast of Africa (Figure 1). A significant number of these humpback whales frequent the north coast of Iceland, with over 300 individuals identified in the Húsavík Whale Museum humpback whale catalogues. Iceland has a large commercial fishing fleet, consisting of 1690 ships in 2012 (Statistics Iceland, 2013) with the main fishing methods being trawling, long-lining, and gillnetting (Ministry of Fisheries, 2011a). Of all these fishing vessels, 46% are classified as decked vessels which use handline, Danish seine, and gillnet methods (Statistic Iceland, 2013; Ministry of Fisheries, 2011a). Both gillnetting and longlining are used all around Iceland (Ministry of Fisheries, 2011b, 2011c) and are known to pose serious entanglement risk. In 2011 there was high gillnetting effort mainly in the south and east of Iceland, but also occurring in the known humpback feeding grounds in the north (though no further explanation of the effort from Hafro Marine Research Institute was available) (Figure 2). There were up to 100-200+ thousand longline hooks per square mile per year used in the most active longline fishing areas, with an estimated 10-50 thousand hooks per square mile per year used in the known humpback feeding grounds in the North (E. Hreinsson, December 5, 2013, personal communication) (Figure 3). These numbers show significant fishing effort in all Icelandic waters for these two methods, suggesting that the potential entanglement risk is high. Since gillnets have been found to pose one of the most significant entanglement threats (Read, 2008), and longlines have also been determined to be involved in humpback entanglements (NOAA, 2013a), this makes the possible interactions between the North Atlantic humpback and the fisheries in Iceland likely, particularly during the summer feeding season.

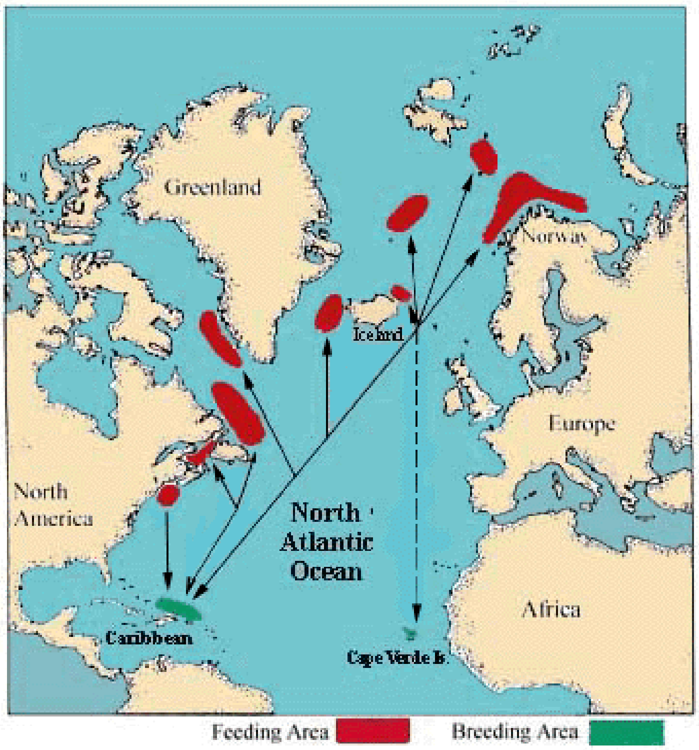


Figure 1. Map showing North Atlantic humpback whale feeding and breeding areas, with two main feeding areas around the coasts of Iceland (© YoNAH, 2012).

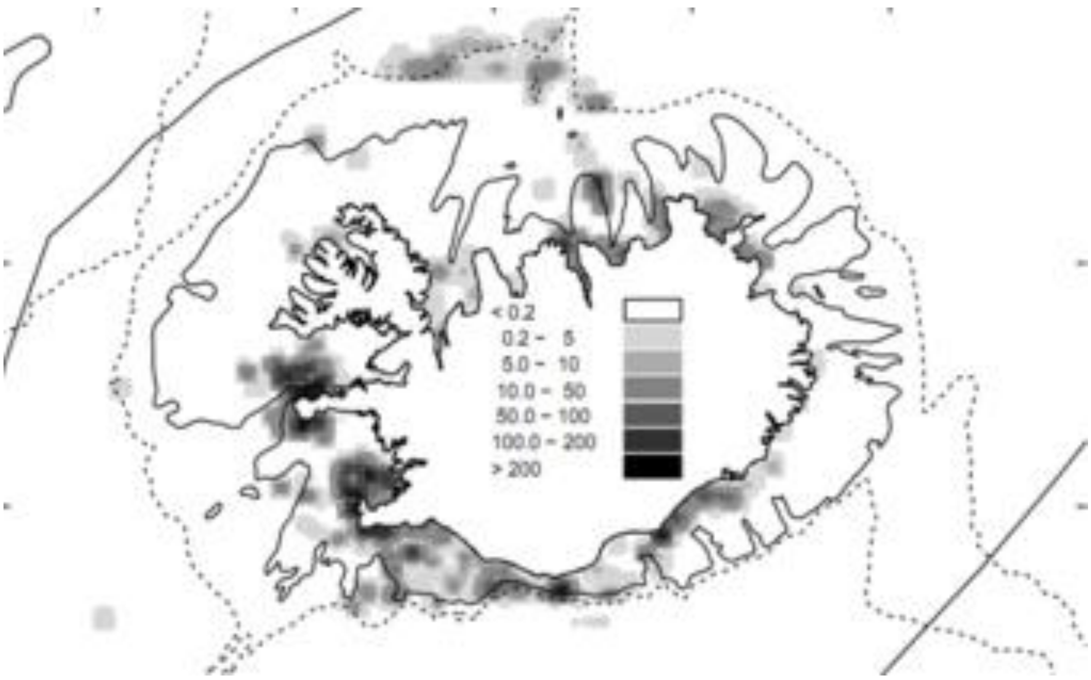


Figure 2. Gillnetting effort around Iceland in 2011 (Ministry of Fisheries, 2013).

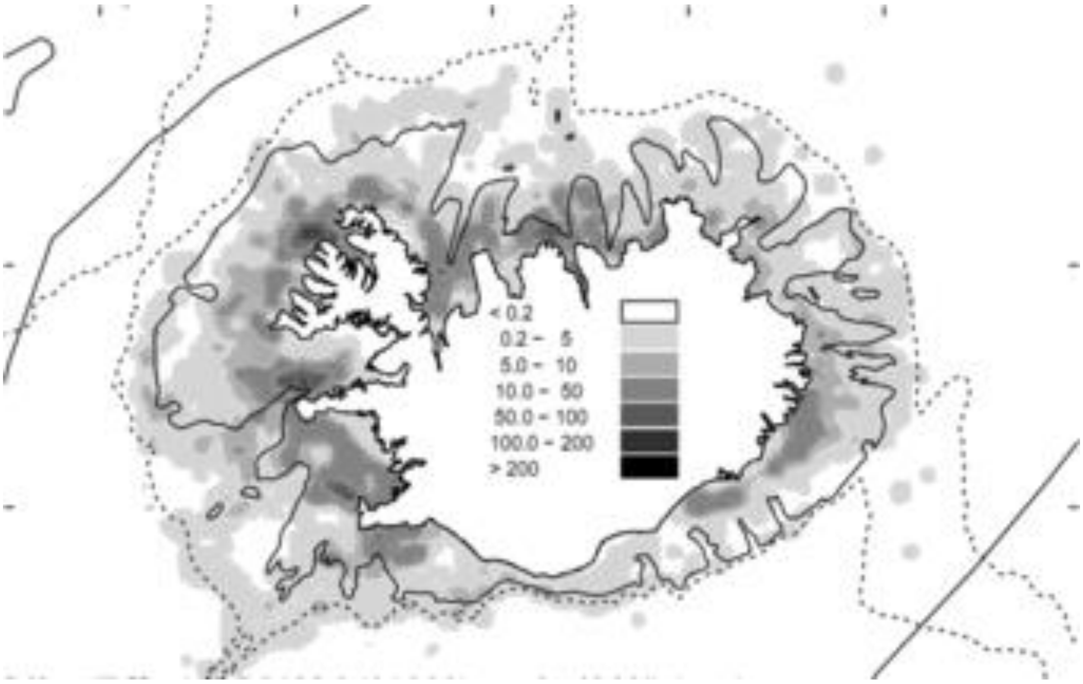


*Figure 3. Location and effort of long-line fishing in Iceland in 2011 with the scale indicating x * 1000 hooks/sqr mile/year. (Ministry of Fisheries, 2013).*

Scar-based photograph analysis is often used to study non-lethal entanglements of cetaceans. When conducting this research on humpback whales in particular, entanglement-related injuries are often seen around the flukes and peduncle (the tail, and where the tail attaches to the body), and photographs of this area can be analyzed for notches and scarring that have been attributed to a prior entanglement (Robbins and Mattila, 2004). Prior to 1991, the only studies done regarding interactions between fisheries and marine mammals in the Northeast Atlantic region were conducted on grey seals (FAO, 1991), and entanglement scar analysis has just recently begun in Iceland (C. Bertulli, February, 2013, personal communication). The Arctic waters surrounding Iceland are important cetacean feeding grounds, and one of the major feeding grounds for Icelandic North Atlantic humpback whales is in Skjálfandi Bay, off of the town of Húsavík on the north coast of Iceland (Hoyt, 2011; Cecchetti, 2006). Since many North Atlantic humpbacks feeding in Iceland frequent Skjálfandi Bay, and this area is also used as a commercial fishing ground, this would appear to be an ideal area in Iceland to conduct studies on the interactions between the whales and the fishing industry.

This study will use the methods of scar-based analysis developed by Robbins and Mattila (2001) to suggest whether entanglement is an issue for North Atlantic humpbacks in Iceland. It will provide an estimate, based on observations collected during the summer and early fall of 2013, of the percent of the population of humpback whales which frequent Skjálfandi Bay that are likely to have been entangled in fishing gear at least once at some point in their lives. In addition to providing insights into the potential scope and magnitude of entanglement in Iceland, this information can be used to suggest any possible fisheries management measures that can be taken to prevent future entanglements from occurring. The scar-based analysis can be supplemented with information from any eye-witness accounts from fishermen of entanglements, which can provide valuable information about how the event occurred and what type of fishing gear was involved (Knowlton et al., 2005 and Johnson et al., 2005). Therefore, a survey was developed for this study and was distributed to people working on commercial fishing boats around the north of Iceland to attempt to obtain any eye-witness entanglement account information that might be available.

The following sections provide a theoretical overview of the study, an in-depth explanation of the methods used to conduct the research, and the results of the study. The results are then discussed and compared to findings from similar studies around the world. Recommendations regarding potential fisheries management responses are also provided based on the findings. Areas of further research on this topic are discussed, and any sources of error or bias in the study are explained.

2 Theoretical Overview

2.1 Detrimental Impacts on Cetaceans

Entanglement has been determined to have a number of potentially detrimental effects on cetacean species (Figure 4). Perhaps the most obvious of these would be the potential of drowning. Especially in the smaller of the cetaceans such as porpoises and dolphins, entanglements often lead to drowning of the animal. Entanglements are associated with drowning either when the animal is found still entangled in the gear, or when rope impressions or lacerations are found on a drowned animal (Moore and van der Hoop, 2012). Drowning can also occur in much larger species as well, particularly if the whale is entangled at multiple body parts, such as around the fluke and flippers (Cassoff et al., 2011). Many cetaceans, particularly those which are prone to entanglement of the head region due to skim-feeding, a common feeding behaviour observed in right whales, may starve due to a decreased ability to feed properly if the whale was not able to shed all of the gear in which it was entangled. The gear may disrupt the flow of water and food through the baleen plates, or restrict movement of the mouth or tongue which can directly impact the animal's ability to feed (Moore and van der Hoop, 2012; Cassoff et al., 2011). Increased buoyancy due to some gear types could also prevent a whale from having the energy to dive to depths where preferred prey may be found, further increasing the threat of emaciation (van der Hoop et al. 2013). Starvation due to entanglement can lead to death at a much later date. Cassoff et al. (2011) found in their study that an entangled right whale died 320 days after becoming entangled. Furthermore, animals that were not able to shed all the gear in which they became entangled will have increased drag while swimming. This increased drag causes changes in the energy budget of the whale, and could result in behavioural changes such as less time spent foraging, which could impact the whale's health (Moore and van der Hoop, 2012, van der Hoop et al., 2013). Further impacts of entanglement include rope laceration injuries, which cause the animal to be at a high risk of infection that could potentially become fatal. Entanglement injuries are often also causes of tissue damage which may induce fatal haemorrhaging (Cassoff et al., 2011). Cassoff et al (2011) found that whales could have relatively superficial wounds from an entanglement, but if these wounds covered a large area, the risk of infection may still be high enough to lead to fatality. Many of these impacts are believed to cause the animals involved pain and suffering for months, and have therefore been regarded as an animal welfare issue in recent years (Moore and van der Hoop, 2012, Cassoff et al., 2011). Newly discovered feeding behaviour of humpbacks, called bottom side-roll feeding, is believed to put them at even greater risk of entanglements and resulting injuries in gillnet fisheries than previously believed because the whales are feeding directly adjacent to the seabed and are performing body rolls from 80-121 degrees on average (Ware et al. 2013).

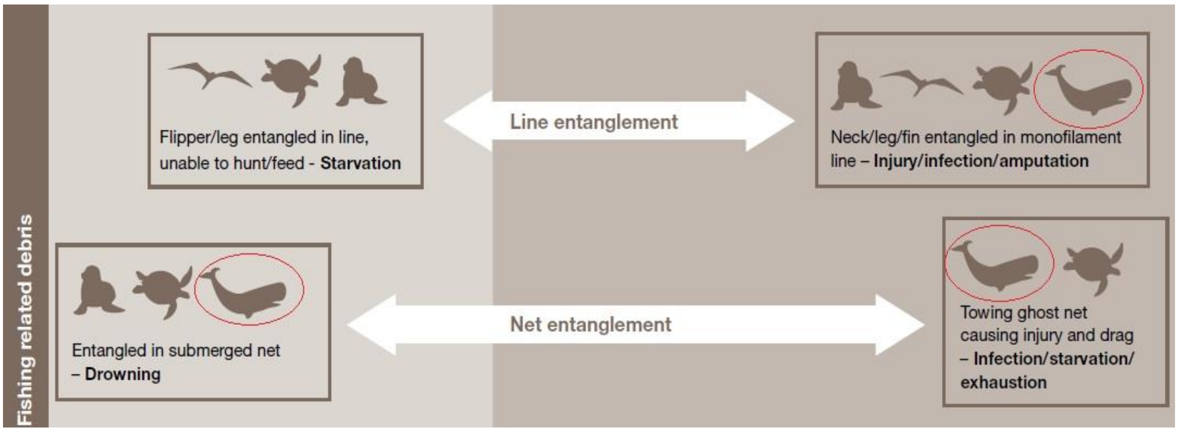


Figure 4. Examples of detrimental effects of entanglement on marine mammals, with red circles highlighting where cetaceans are included (Butterworth et al. 2012).

What has been more difficult to determine is the impact an entanglement event has on an animal that was able to seemingly recover from the event by shedding the gear and having any injuries heal, rather than it being fatal. Entanglement causes high stress on the animal and often elicits both a behavioural and physiological response (Cassoff et al., 2011; Moore et al., 2012). Persistent tissue damage due to an animal carrying entangling gear is known to cause the suppression of lymphocytes and can compromise the animal's immune system, though this effect should be reversible if the gear is removed before illness or infection occurs (Cole et al., 2006). The stress response may also be determined by factors such as how tightly the gear is attached (Cole et al., 2006). Research conducted by St. Aubin (2002a) investigated the physiological response of spotted dolphins to chase and encirclement in tuna seine nets. Blood samples from the dolphins taken after chase and encirclement showed much higher than average levels of cortisol, which is an indicator of an acute stress response. The samples also showed that high levels of cortisol and adrenocorticotropic hormone (another stress hormone indicator) did not diminish with time as expected when the stressful event had ended compared to available baseline data from other odontocetes, suggesting that some cetaceans may continue to have a stress response hours after an entanglement event. Some of these dolphins were recaptured after one or two days and already showed signs that they had not fed after the first entanglement event, and blood samples showed that they had low iron-binding proteins which can lead to higher risk of microbial infection. Fecal samples can also be tested for corticoid levels, and in right whales it was found that a severely entangled individual had very high corticoid levels indicating stress, while an individual who was not severely entangled and was believed to have eventually shed the gear it was carrying had normal corticoid levels (Hunt et al., 2006). Stress responses and increased corticoid levels can cause low white-blood cell counts and compromise the immune system, as well as may have negative effects on reproductive success (St. Aubin, 2002b).

Some countries have specialized teams which are trained in tagging, sedating, and removing gear to disentangle cetaceans in attempt to rescue them. Through the International Whaling Commission, a Global Whale Entanglement Response Network was developed so that leaders in the field could assist in the development and training of disentanglement teams world-wide (International Whaling Commission, 2013). The availability of a trained team to disentangle a whale provides the opportunity to gain valuable information about the effects of entanglement and of the disentanglement procedures. Moore et al. (2012) documented a North Atlantic right whale which had been entangled, causing severe lacerations and disruption to the whale's feeding abilities. Disentanglement of the whale required the use of some invasive techniques including the use of spring-loaded knives to cut gear, sedation of the animal, and the attachment of a tracking tag. It was found that any measures taken during disentanglement could be life-saving, but also can potentially cause more damage to the animal leading to its eventual death. Moore et al. 2012, concluded that the focus should primarily remain on mitigation measures within the fishing industry that prevents entanglements of cetaceans from occurring. Further research was done on an entangled right whale in order to determine behavioural changes and energy costs before and after disentanglement (van der Hoop et al. 2013). It was found that dive duration and depth significantly increased after the whale was disentangled, likely due to the fact that the increased energy needed to dive while towing entangling gear causes oxygen to deplete more quickly. It was also reported that the normalized dive area was significantly less while the whale was still entangled (van der Hoop et al. 2013). Furthermore, the study also found that increases in the drag coefficient of the whale caused by the attached gear can lead to a 60-164% increase in locomotory energy output, and this increased energy output would cause a whale to deplete its migratory energy budget after traveling 71-78% of the distance to its destination (van der Hoop et al. 2013).

Modelling the ways in which different line types and tensions cause injuries to a whale can provide more in-depth information on how serious entanglement injuries are occurring and aid in developing better mitigation measures. In an experiment conducted by Woodward et al. (2006), new and old float lines and sink lines were used to test the resulting injuries on a right whale fluke. The results showed that the old lines were more abrasive than the new lines and caused measurable furrows in the skin, with the old sink line determined to be the most abrasive (Woodward et al. 2006). It was also found that marks left by the float lines and sink lines were distinguishably different from one another. The length of time that the rope was rubbed on the skin also affected the resulting injury, with the 24-hour experiment resulting in a longer furrow with a greater overall depth than that produced by the 12-hour experiment. Further experimental injury modelling was conducted by Winn et al. (2008), using a right whale calf flipper, a right whale fluke, and a humpback whale fluke. Results suggested that the three specimens differed in their resistance to abrasion, with the calf flipper having the least resistance and the right whale fluke having the most. It was also determined that line diameter had a greater effect on abrasion than line type, with preliminary testing of float lines suggesting that the smaller diameter lines consistently created deeper cuts (Winn et al., 2008). For the humpback whale in particular, it was found that the injury resulting from a long draw length (7.6 cm) created a cut that was 8.5 times deeper than that created by a short draw length (2.5cm). This suggests that loosely wrapped entangling gear may cause more serious injuries than those caused by tightly wrapped that is not loose enough to move across the skin surface. Though the humpback and right whale flukes had similar skin thickness, they differed in the resistance to abrasion, suggesting that the humpback whale may be more prone to serious entanglement injuries than some other species (Winn et al., 2008).

All of these studies provide evidence that entanglement can have serious consequences for many marine mammal species, and may effect different species and even different individuals in contrasting ways. Gathering information on the impact that entanglements can have on cetaceans provides important insight that can inform how these effects might be mitigated in the future.

2.2 Bycatch Research

Studying bycatch reports can lend valuable information on entanglement events, from how these events could impact an entire population, to what species of marine mammals are being most often entangled in what type of fishing gear. Bycatch of all marine mammals is estimated to be hundreds of thousands of animals globally each year (Read et al., 2006), and it can be assumed that all places around the globe that have marine mammal populations and a commercial fishing fleet, particularly using gillnets, have issues with marine mammal bycatch even if it goes unreported (Read et al., 2006). Determining estimates of bycatch can often be difficult since the principle way to obtain such estimates is to have observers on fishing or whale watching vessels to document events and then extrapolate the results using a measurement of fishing effort to determine bycatch rates of different species in an area. Out of 90 countries for which bycatch rates were available for gillnet fisheries, baleen whales (including humpbacks) were reported being caught in gill-nets in at least 28 countries, and there are probably more countries than this that have not been identified due to unreported entanglement incidents (Reeves et al., 2013). Entanglements have become more of an issue in recent years as fishing gear technology has changed. In contrast to earlier decades of fishing where cotton ropes were used, many nets are now made with polypropylene ropes which are much stronger and cause many more entrapments and injuries during an entanglement event (Volgenau et al., 1995). Different gear types being used around the world affect separate populations and could also potentially affect the same populations at different times of the year, as could be the case with the humpbacks who make long seasonal migrations covering thousands of kilometers (Volgenau et al., 1995). Using archival entanglement and bycatch data over a 25 year period, an increase in entanglements in natural and synthetic fibre could be seen from 1992-1996 in Hawaii (Mazzuca et al., 1998). Of all the bycatch reports in Hawaii over the 25 years, over half of the lethally entangled humpbacks were identified as calves according to body length measurements. This can be explained by the fact that calves are less likely to be strong enough to free themselves (Mazzuca et al., 1998). In the United States, dolphins and porpoises have been found to make up most of the bycatch of cetaceans, and the majority of all reported marine mammal entanglements occurred in gillnet fisheries (Read et al., 2006). Baleen whales are one group that is not only caught in the gillnets like most marine mammals, but also become entangled in other gear using vertical lines such as traps and pots (Read et al., 2006). For these larger cetaceans, such as the humpback whale, entanglement is considered to be a rare event to witness in the United States, but entanglement rates are probably greatly underestimated due to the fact that these animals can carry some of the gear away with them (Read et al., 2006). Since entanglement is an event that is rarely observed, this is an issue that has proven complicated to address and prevent, largely due to the fact that it can be difficult to convince the fishing industries that this is an important issue that should require mitigation measures (Read, 2008).

Detrimental effects of entanglement can most easily be recognized at the individual level, but also small, localized populations or sub-populations can be more vulnerable to population decline due to entanglement than it may seem when looking at the issue at a larger scale (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004; Read, 2008). Cole et al. (2006) looked at serious injuries to baleen whales caused by entanglement on the eastern seaboard of the United States from 2000-2004. They found that humpback whales in particular were most often observed entangled, and had the highest number of serious injuries. A deeper understanding of large whale entanglements can be acquired by looking at the temporal and spatial overlaps of the whale populations and the fisheries activity. Citta et al. (2013) reported that there was some spatial overlap but no apparent temporal overlap between the bowhead whale population and pot fisheries in the Bering Sea, though whales were still being found entangled in this gear. The area potentially has a high rate of lost gear because of sea-ice can and frequent, severe storms, and suggests that if the whales are becoming entangled in this area, at least some of the whales may be entangled in this lost gear, which would require additional targeted research (Citta et al., 2013). In the Bay of Fundy area, Angelia et al. (2011) determined that there was spatial and temporal overlap of right whales with the hook and line fishery, but not with the pot fishery. It was also found that the probability of observing a right whale was very high only in critical habitat zones, therefore these critical habitat zones need special management attention since they are areas where right whales have a potentially higher probability of interacting with fishing gear (Angelia et al., 2011).

Changes in prey abundance and population size of cetaceans can impact the amount of entanglement that occurs each year, as well as changes in the fishing industry such as alterations in effort or fishing area (Hofman, 1990). For North Atlantic humpbacks in Newfoundland and Labrador, Canada, the majority of entanglements from 1979-1992 were found to be associated with cod traps from. This has since changed due to the collapse of the cod stock (Volgenau et al., 1995). Overall, it was determined that humpback whales made up 50-95% of the reported entanglements from the years 1979 until 2008 in this area (Benjamins et al. 2012). After the cod moratorium was put in place, the number of humpback whale entanglements decreased overall, but fishing effort shifted and entanglements in pot fishing gear in offshore waters has increased in recent years (Benjamins et al., 2012). Of all the reported entanglements used for the study conducted by Benjamins et al. (2012), approximately 69% involved bottom gillnets. Humpbacks were only found dead in 16% of reported cases, since they were often disentangled or freed themselves from the gear. Similar results were also found by Hofman (1990), determining that approximately 78% of humpbacks that become entangled in Newfoundland, Canada manage to escape or are released alive. For North Atlantic humpbacks frequenting the Gulf of Maine from 1975 to 1990, the majority of entanglements could also be associated with gillnets. Volgenau et al. (1995) found in their study that entanglements causing death could potentially impact the subpopulations in Canada and the Gulf of Maine based on the natural birth and mortality rates for these groups. At the very least, this can slow these subpopulations from recovering from the commercial whaling pressures they were put under in the past. Fatal entanglements also have a cumulative impact on whale populations when occurring along with ship strikes, which are considered to be the other major cause of human-induced cetacean mortality (NOAA, 2013a). Even potential non-lethal consequences of entanglement could impact sub-populations of humpbacks, particularly if reproductive success is negatively impacted as suggested by Robbins and Mattila (2001), or if energetic costs effect migration to feeding or breeding grounds as determined by van der Hoop et al. (2013).

Johnson et al. (2005) further investigated what specific gear types were involved in entanglements of right and humpback whales in the North Atlantic. The study found that in total 89% of the gear that could be identified was from pot or gillnet fisheries. Reviewing cases where specific parts of the gear could be identified, it was found that buoy line and ground line were involved in 49% of the entanglements. The majority of the humpback entanglement cases in particular involved sink gillnets. It was also determined that for humpback whales, 53% of the documented entanglements involved the tail as a point of attachment. All of the documented lethal entanglements involved Danish seines, pots, or gillnets, with both float line (from the top edge of the net) and buoy line (attaching the net to the buoys) reported on dead humpbacks. Entanglement in gillnets appeared to be the biggest issue along the mid-Atlantic coast, where 86% of identifiable gear from humpback entanglements was gillnet gear. Similar results were found in the study conducted by Hofman (1990), where it was determined that the seemingly greatest potential entanglement risk to cetaceans is posed by inshore set-net and offshore drift-net gillnet fisheries, and by Meyer et al. (2011) who found that based on 93 whale entanglements in South Africa, the majority of all the entanglements involved static, bottom gear including trap, anchor, and buoy lines, longlines, and gillnets.

Studies of humpback entanglement have been most often conducted at the feeding grounds of the whales, as is the case in the present study, but much less is known about what is occurring at some of the breeding grounds. Since humpback breeding grounds are around countries with less developed fishing industries, which are mainly artisanal, the characteristics of the entanglement events and entanglement rates may differ from feeding ground areas (Felix et al., 2006). It has been found, that each year humpbacks are entangled, particularly in gillnets from the artisanal fisheries, in Ecuador (Felix et al., 2006). It has been estimated that approximately 33 individuals are entangled in fishing gear every year in Ecuador breeding grounds, and an increasing trend in bycatch can be seen from 2000 to 2009 as production in the artisanal fisheries increased (Alva et al., 2012). The Southeastern Pacific humpback population in the Ecuadorian breeding ground was found to already have naturally low birth and survival rates, which could be seen further decreasing over the years as bycatch increased. Alva et al. (2012) suggested that the observed trend of decreasing birth and survival rates make zoning management, fishing permits, and gear modification restrictions important issues to address in this area to mitigate entanglement impacts on the population.

Along with the risk of fishing gear in migration routes and both feeding and breeding grounds, in places such as South Africa, large-mesh gillnets, used to protect highly populated beaches from sharks, also pose an entanglement threat to large cetaceans. The shark nets that have been often used in the past have a mesh size of 51cm (stretched) and entangle sharks as well as other bycatch such as cetaceans (Shark Spotter, 2012). Meyer et al. (2011), determined that of all the cetaceans that became entangled in these shark nets, humpback whales accounted for 61% of entanglements over the past decade, and the rate of increase of humpback entanglements rose significantly from 1990 to 2009. Entanglements of humpbacks in the shark nets was found to correlate with both the winter breeding migration and the summer feeding migration. There has been an increase in the humpback whale population migrating in this area, which could be an explanation for the increasing number of entanglements that was seen over the study. There are recent proposals to switch to exclusion nets in South Africa, which have a mesh size of only 6cm (stretched) and claim to pose a much smaller entanglement risk due to this very small mesh size (Shark Spotter, 2012). Similar shark nets are also used to protect beaches in Australia. The Queensland Shark Control Program database reports 9 humpback whale entanglements from 1962-1995 in which 6 were disentangled and 3 were found dead (Gribble et al., 1998). There are likely other entanglements that go unwitnessed in these nets since humpbacks can be strong enough to free themselves. There is concern of these nets interfering with migration routes, and with the number of entanglements increasing as the humpback population in this area increases. Due to these concerns mitigation measures such as “whale alarm” pingers have been fitted to nets along the Gold and Sunshine coasts (Gribble et al., 1998). Entanglement concerns in Australia have been cause for controversy in 2013. With the fifth humpback becoming entangled in shark nets in Queensland in October of this year, the Humane Society has pushed for the removal of the nets and further research into mitigation measures of both shark attacks and whale entanglement (Colvin and Ogilvie, 2013, October 2).

Due to overfishing, changing climate, and high demand for fish, aquaculture has been introduced to supplement many fisheries-based economies, including that of Iceland. There is potential that aquaculture could also cause entanglements of humpback whales and many other cetaceans though there are currently few documented cases of this occurring. In the Johnson (2005) study of fishing gear involved in entanglements, it was determined that one right whale was entangled in identifiable aquaculture gear. In New Zealand, mussel farming lines are considered to be an entanglement threat to baleen whales and there are two reported cases of Bryde’s whales becoming entangled in these lines and dying (Du

Fresne, 2008). As studies of whale entanglements continue in the future, aquaculture practices as well as different fishing techniques will have to be considered, since it is very likely that any type of aquaculture using vertical lines and/or netting will pose an entanglement risk to all types of marine mammals (S. Landry, October 29, 2013, personal communication).

2.3 Scar-based Analysis Research

Scar-based analysis was developed as a way to determine relative entanglement frequencies and entanglement rates from year to year for non-lethal entanglement events, or events that are potentially lethal at a later date (Robbins and Mattila, 2001). These studies have been carried out on various baleen whale populations around to the world in order to identify areas of high risk and improve fisheries management strategies.

Anthropogenic scarring was analysed in the critically endangered population of western gray whales in Russia (Bradford et al., 2009). This research reported that from 1994-2005, approximately 18.7% of the identified whales had entanglement scarring, and 39.3% of these whales were three years of age or younger when the entanglement occurred, further supporting that calves are entangled more frequently than adults. Although the entanglement frequency of this population seems quite low in comparison with some other areas, even low numbers of entanglements can have serious impacts on such a small population of whales since there are so few of them that can aid in the recovery of the species. A similar long term study was conducted for North Atlantic right whales from 1980-2002 by Knowlton et al. (2005). This study found that 75.6% of the identified whales had been entangled at least once, with one whale being entangled an estimated 6 times in its life. It was also determined from comparing scars on the same individuals from one year to the next that the annual entanglement rate ranged anywhere from 14-39% from 1993/94 onwards (Knowlton et al., 2005). Similar to previously mentioned studies for different cetacean species by Mazzuca et al. (1998) and Bradford et al. (2009), Knowlton et al. (2005) also reported that there was a higher than average number of juvenile North Atlantic right whales which showed entanglement scar evidence.

For humpback whales in particular, studies have been conducted in both the Pacific and Atlantic humpback populations. Preliminary results of research being done in the North Pacific found that southeast Alaska had the highest entanglement frequency, with approximately 50% of the population displaying entanglement evidence, while the northern British Columbia, the Bering Sea, and the north Gulf of Alaska populations ranged from 29.2-33.3% of the population being previously entangled (Robbins et al., 2007; Robbins, 2009). Further research on the southeast Alaska population conducted by Neilson et al. (2009) found that the minimal entanglement scarring percentage for the humpback population was 52% while the maximum was 78%, and the entanglement rate from 2003 to 2004 was 8%, based on 26 individuals that were photographed in consecutive years. One of the most in-depth scar analysis studies has been an ongoing study of the North Atlantic humpback whales in the Gulf of Maine. In 1999, it was determined that at least 65% of this humpback population had scars indicating a high probability of previous entanglement, and from 1997-1999 the scar acquisition rate was 31% (Robbins and Mattila, 2001). This study also showed examples of how very short entanglements (i.e. carrying gear for one day) could produce high probability scarring (i.e. scarring that is considered very characteristic of a prior entanglement event), and also how scars on a whale with a known entanglement could heal beyond the point of recognition as high probability scars. These differences in scarring potentially contribute to the variation in scar analysis results and suggests that calculated entanglement estimates will be conservative. There was also evidence of entanglements negatively impacting reproduction rates in this population, based on the number of lactating females with entanglement scars versus those without (Robbins and Mattila, 2001). As research continued on this population, it was determined that from 2000-2002, 48-57% of the population had been entangled and the annual scar acquisition rate was 8-10.4% per year (Robbins and Mattila, 2004). From the images used in 2002, it was determined that 68% of the entangled sample had diagnostic scarring on the leading edges of the fluke, 58% at the dorsal peduncle, and 44% at the ventral peduncle, confirming that these were the coding areas of greatest importance for entanglement scar analysis of humpback whales (Robbins and Mattila, 2004). This study continued from 2003-2006, and found that 64.9% of the humpbacks whales which entered the study for the first time had entanglement scarring evidence, and the average acquisition rate for these three years was 12.1% (Robbins, 2009). Again in 2008-2009, the entanglement scar acquisition rate from one year to the next was 12.5% (Robbins, 2011). After a decade of observing this population, the scar acquisition rate had changed very little, which suggests that whales are still being consistently entangled in this area. Changes in fishing effort and distribution need to be considered to determine if current management measures are widespread enough and properly implemented in order to be having any effect on entanglement rates. Data over the years of this study, and output from statistical models also showed the high probability entanglement injuries were more frequent in juvenile humpback whales than other age classes (Robbins, 2011), supporting a more general trend in observations supported by the previously mentioned studies for western gray and North Atlantic right whales. This long-term study also shed light on the effectiveness of the entanglement reporting system. Though the Gulf of Maine area has a well-developed reporting and disentanglement system, the reporting rate for entanglements remained very low, ranging from 3-5.7%.

All of these studies provide examples of how scar-based entanglement analysis can provide valuable information about whale interactions with the fishing industry. By monitoring entanglement scarring and reports throughout the years, areas with high entanglement risk can be determined, impacts on a population can be monitored, and management practices can be recommended and their success measured.

2.4 Impacts on the Fishing Industry

Very little research has been conducted on the potential impacts and losses that entanglements of cetaceans can have on the fishing industry, though it can be presumed that entanglements are not only detrimental for the whale, but also for the fishermen who have gear damaged or lose catches. Some research on this was conducted in the late 1970s and early 1980s in Newfoundland, Canada by Lien et al. (1979, 1982). For the report based on data collected in 1979, 328 whale interactions with gear were reported causing a reported gear-loss cost equivalent to $929,208 (CAD[1]*) and an estimated down-time loss of somewhere between $3,716,834 to $4,646,043 (CAD*) (Lien, 1979). In the 1981 report, there was a total of 183 whale-gear interactions were reported through a card system and telephone system, with a total gear-loss estimation of $149,064 (CAD*) (Lien and Aldrich, 1982). For this report, the under-reporting estimate was calculated to be approximately 14%, which would bring the gear-loss estimate to approximately $238,372 (CAD*) (when damages from sharks are included). Down-time from damages had been found to average approximately four times that of the gear-loss, bringing the combined losses from whale and shark collisions to approximately $1,191,860 (CAD*) in 1981 (Lien and Aldrich, 1982).

In the study area, it was estimated that humpback whale-gear interactions made up 80-90% of the total number.

Though there is little information on monetary losses for the fishing industry caused by marine mammal interactions with gear, it is evident that this could have a significant impact on some fishermen. Based on this, considering the implication of these potential economic losses in the industry, development of management strategies to mitigate these impacts is likely warranted.

[1]CAD* - All Canadian dollars converted to values for 2013 using Bank of Canada inflation calculator (©1995-2013, Bank of Canada).

2.5 Entanglement Management

There are several different management strategies that have been proposed to try to mitigate whale entanglement. The first step in developing an appropriate management plan is to gather enough baseline data to properly assess the problem, which could be enhanced through public awareness and participation. Many areas in the United States and Canada have entanglement reporting systems or protocols put in place so that any witnessed entanglements can be documented and acted upon if necessary. The National Oceanic and Atmospheric Administration (NOAA) in the United States has a fisheries entanglement hotline for witnesses to call, and produces brochures for the public explaining what type of information would be useful, including location of the sighting, species of whale, and nature of distress (NOAA, n.d. b). These hotlines, and response teams to follow-up on reports, exist for different coastal states. A similar reporting and response program is set up for five different coastal regions of Canada through the Department of Fisheries and Oceans (2011), and for seven states/territories in Australia (Australian Government Department of the Environment, 2013). All of these countries have trained response teams that disentangle large whales that are reported. It takes years to properly train a disentanglement team and training done through apprenticeships (S. Landry, October 29th, 2013, personal communication) making this strategy challenging to implement. Though disentanglement could save an entangled whale, it can be a costly and dangerous procedure which is not mitigating the entanglement issue, but rather trying to manage the problem once it has already occurred.

There are many suggestions for fishing gear modifications that are designed in an attempt to reduce the risk of potential entanglements. Pingers have been developed to attach to gillnets, as well as other gear types, to try to warn cetaceans of the presence of a net and prevent them from coming close enough for entanglement to occur (Consortium for Wildlife Bycatch Reduction, n.d.). A pinger emits sounds of a certain determined frequency that should be audible to the target cetacean species that they are trying to deter (Erbe and McPherson, 2012). Such pingers have been made mandatory in the European Union for vessels 12m or bigger for determined fishing areas (Europa, 2010) and in the United States, particularly under the harbour porpoise take reduction plan, requiring a pinger on each end and between each net in a string of gillnets (NOAA, 2010). For specific areas in the United States, it is even required that vessels carry certification that operators have received pinger training so the devices are installed and used correctly on gillnet gear (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004). Many of these pingers have been designed to deter animals with good high-frequency hearing such as porpoises and dolphins, but there have also been lower-frequency versions developed to reduce humpback whale entanglement in particular. In Australia, these lower-frequency pingers are being used on shark protection nets around beaches during the humpback migration seasons (Erbe and McPherson, 2012). Through modelling, it can be determined how many pingers are required per length of net to ensure the entire net should be detectable by any humpback within a few meters. The use of pingers can have potential issues and negative side-effects. One of the main issues is that the pingers are adding to noise pollution in the ocean which cumulatively can potentially effect the communication and/or hearing of some species. Since pingers are set to certain frequencies and sound levels based on the target species of marine mammal they aim to deter, there is potential that they could damage the hearing of non-target species who are more sensitive to the settings (Franse, 2005). There is also potential that effective pingers will exclude marine mammals from previously used habitat that could be of importance to the species (Gordon and Northridge, 2002). The other major issue with the use of pingers is the possibility of habituation. If the devices are in the water for long periods of time, emitting the same sound, the target marine mammal species may eventually get used to the noise and ignore it, rendering the pingers ineffective after a certain amount of time (Franse, 2005).

Entanglement mitigation measures and management plans for hook and line fisheries are being developed. In the Gerry E. Studds Stellwagen Bank National Marine Sanctuary (2013) in the United States, tuna fishermen will troll through active humpback feeding grounds and incidentally hook the whales. In the area, letters and posters are issued to tackle shops to display, reminding fishermen that hooking a whale is in violation of the Marine Mammal Protection Act and they should maintain a safe trolling distance. Whale-safe hooks have also been developed to avoid entanglement if a whale does come in contact with hook and line gear. The hooks are designed to straighten out under the great force of a whale pulling on them while still being strong enough to effectively catch target fish species. These hooks are currently being tested for use in the United States long-line fisheries (Consortium for Wildlife Bycatch Reduction, n.d.).

Some experts are of the opinion that the best way, and possibly the only certain way, to reduce entanglements is by reducing the amount of rope in the water or at least making ropes associated with fishing gear less lethal or damaging to cetaceans (S. Landry, October 29, 2013, personal communication). Therefore, there have been many different gear modifications focusing on the use of ropes. Two methods which are still undergoing consideration and testing are stiff ropes and glow ropes. Stiff ropes are made less flexible by placing rubber sections over the rope and have higher tension than regular ropes, intended to reduce the physical ability of a rope to wrap around and entangle an animal (McCarron, 2009; Consortium for Wildlife Bycatch Reduction, n.d.). There is concern that the rubber sections on stiff rope could get stuck in a whale's baleen plates and disrupt its ability to feed. Glow ropes are ropes that have been chemically treated so that they glow under the water, with the intention that this would make the gear more visible to marine mammals and result in less collisions. Glow ropes were tested in the Gulf of Maine and there were issues with the ropes losing their luminescence and chafing, but there has been no research conducted on marine mammal response to the ropes (McCarron, 2009). Winn et al. (2008) suggested in their study that the development of stretchy lines would potentially reduce the severity of injuries to entangled cetaceans. It is hypothesized that these stretchy lines could reduce the sliding of the ropes against a whale's skin which causes cuts, but this has not yet been tested. There has also been development of weak rope sink lines, rope made of polypropylene but with barium sulfate incorporated, to change the breaking strength (Consortium for Wildlife Bycatch Reduction, n.d.). The inclusion of different kinds of weak links has been one of the main focuses of gear modification and this is mandatory for compliance to the NOAA Atlantic Large Whale Take Reduction Plan (ALWTRP) in the United States, which focuses on entanglement as one of the major issues to mitigate (NOAA, n.d. c). These weak links create a point in the ropes attached to buoys/flotation and weighted portions of the gear that will break under a certain amount of force, which can be exerted by a whale but not the target fish species. Modifications to incorporate these weak links include inserting off-the-shelf weak links or inserting a piece of rope of appropriate breaking strength (NOAA, n.d. c). The other important focus was on the use of sinking groundline which would lie at the sea bottom rather than be in the water column where they are posing the highest entanglement risk (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004). The ALWTRP made it mandatory for all trap/pot fishermen to use sinking groundline on the east coast of the United States (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004). Regulations in the European Union also requires the ropes between buoys and passive gear, such as gillnets, be submersible or weighted down (European Union, 2005).

Area closures has been another proposed management solution to reducing entanglement particularly in areas of high whale population density, or of high biological importance such as feeding and breeding grounds. Area closures can be in the form of overall no-fishing zones, seasonal area management zones, and dynamic management zones. In an attempt to find balance between the fishing industry and marine mammal conservation, dynamic and seasonal area management zones may be preferred management tools, particularly by fishermen, compared to the stringency of no-fishing zones. Dynamic area management zones are designed particularly for endangered and fragile whale populations. In the eastern United States waters, a dynamic area management zone is put in place when a qualified person determines that there is an aggregation of endangered North Atlantic right whales (three or more whales within 75 square nautical miles) in certain areas (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004). Once this zone has been determined, fishing can be closed in the area and gear must be removed, or more stringent gear modifications must be put in place in order to continue to fish in the area. Seasonal area management zones are determined areas with predictable high densities of whales, where restrictions apply only during certain times such as during migration, breeding, or feeding seasons. Gear modifications are often much more stringent at this time including weaker breaking strengths, and under the ALWTRP fishing methods used in these areas must be considered to use Low Risk Gear for which death or serious injury to a whale is considered to be highly unlikely (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004). The rules and regulations to protect marine mammals have to be adaptive, and change over time as new science and technology develop, and as whale populations and fishing efforts change. For example, the ALWTRP has proposed rule changes for 2013 which must go through public and stakeholder review, and finally federal review, before they can be put in place. Examples of rule changes include expansion for seasonal area management zones based on more recent research conducted in areas where the whales are commonly sighted, and expanding on gear marking requirements (NOAA, 2013b).

Gear marking regulations can help researchers learn about what specific gear portions pose the greatest entanglement risk, from which areas entangling gear is coming, and also help to monitor how well gear modification and entanglement mitigation measures are working. European Union regulations require that all passive gear, such as gillnets, be properly labelled with the vessels identification number (European Union, 2005). The ALWTRP also requires that gear be marked with vessel identification numbers, and additionally, requires that buoy lines for trap/pot gear have a red, black, or orange marking depending on the area , and buoy lines for gillnet gear have green, blue, or yellow depending on the area (Higgins and Salvador, 2010). This colour coding system provides information about from which type of gear the line originated (Trap/pot or gillnet), and from which fishing area. Further expansion of gear marking systems could allow for the identification of different portions of gear by having the different types of lines marked differently. Though specific line marking would give the most information about whale entanglements, there has been strong opposition to this idea in the United States from fishermen concerned with being found at fault or in violation with the law (B. Barr, November 25, 2013, personal communication).

Wet storage of fishing gear, particularly trap and pot gear, is another issue that poses an entanglement risk. Wet storage is when the gear is left in the water for long periods of time when it is not actively being fished, rather than hauling the gear out of the water (NOAA, 1997). Under the ALWTRP, wet-storage of gear is prohibited and all traps and pots must be hauled out of the water every 30 days (Higgins and Salvador, 2010).

Another issue that further complicates entanglement issues is lost or abandoned fishing gear. Lost and abandoned gear in the water can increase the entanglement risk of all marine mammals by adding more gear to an area than is being considered by just monitoring active fishing gear activity. Once a whale has become entangled in gear, it is often very hard to tell whether it was lost or active gear at the time of the entanglement (S. Landry, October 29th, 2013, personal communication). Causes for lost gear include bad weather, marine traffic, operator mistakes, and gear conflicts, or the gear may be abandoned intentionally (Macfadyen et al., 2009). In places where lost gear, or “ghost-nets”, is considered to be a serious issue, different management strategies are used to try to encourage the collection of previously lost gear and discourage abandonment of any gear in the future. Gear marking guidelines are a way to discourage abandonment of gear since it could later be traced back to the owner, and is implemented/suggested in such places as the United States, Canada, Korea, EU states, and Antarctica (Macfadyen et al., 2009). A reporting system for any gear that is accidently lost is also an option so that areas can monitor how much gear is in the water. Studies and reporting systems have been used in places such as Malaysia, Latvia, and the United States (Macfadyen et al., 2009). Harbours and ports are recommended to have proper disposal areas for old gear, eliminating any incentive to discard of the gear in the ocean (Macfadyen et al., 2009). Further increasing the incentive to discard of old gear responsibly is the establishment of gear buy-back programs such as the one established by Ministry of Maritime Affairs and Fisheries in Korea. The program purchases old fishing gear brought ashore, not only discouraging the disposal of gear into the ocean, but also encouraging the removal of gear that may be discovered in the water (Macfadyen et al., 2009). Voluntary ocean clean-up programs have also been established in the North Sea where boats voluntarily bring ashore any litter and marine debris caught in trawling nets, and gear retrieval programs, where a creeper is used to snag ghost-nets, have been established in places such as Sweden, Poland, Norway, Australia, and different areas around the United States (Macfadyen et al., 2009). In Cordell Bank Marine Sanctuary on the west coast of the United States, a remotely operated vehicle (ROV) has been fitted with arm attachments deigned for cutting lines and grabbing gear in order to locate and remove lost gear from the water without having to rely on other fishing gear (NOAA, 2008).

Different countries have legislation, conventions, and agreements put in place to protect marine mammals, some of which directly address injuries caused by fishing activities. Internationally, the United Nations banned all driftnets in the high seas over 2.5 km long in 1991, which were of serious concern for marine mammal bycatch (FAO, 2013). European

Union legislation addresses protecting cetaceans against incidental catch by regulating gillnet use in specific areas and requiring the use of acoustic pingers. The regulations also require fishing vessels to use a monitoring system and report bycatch of cetacean species (Europa, 2010).

The Marine Mammal Protection Act in the United States, states that one of the immediate goals is to lower the number of marine mammal incidental injuries or mortalities caused by fishing operations to an insignificant level (NOAA, 2012). The act also requires that an annual list of commercial fisheries is compiled and classified into categories corresponding with the level of marine mammal injuries and/or mortalities the fishery causes, which can then be used to put in place management strategies for specific areas. The U.S. Endangered Species Act lists humpback whales as endangered and therefore it is illegal to cause any harm to them (NOAA, 2013c). This act requires conservation management measures to be implemented for the listed species. The Marine Mammal Protection Act 1978 in New Zealand requires that a maximum level of fisheries related mortality be determined for each species of marine mammal in order to determine a level in which each population is not being reduced or having its reproductive capacity affected. In Australia, entanglement of vertebrate marine animals in marine debris is listed as a key threatening process under the Environmental Protection and Biodiversity Conservation Act 1999 (Australian Government Department of the Environment, 2009). Though this does not cover actively fished gear, it does focus on mitigating some sources of entanglement of marine mammals.

In Iceland there are agreements in place for protection of cetacean species. The country signed the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR convention) for protection of the Northeast Atlantic marine environment which requires signatories to identify marine species that are in need of protection (Hoyt, 2011). Through this convention, Iceland has been involved in decision making for the creation of marine protected areas in the high seas, but not specifically in Icelandic waters. Iceland also signed the Convention on Migratory Species to offer protection to migratory species such as the humpback whale (UNEP/CMS, 2004). Ongoing research about cetacean populations, management, and conservation are conducted by the Icelandic Marine Research Institute and other organizations through participation in the North Atlantic Marine Mammal Commission agreement (NAMMCO, 2005), the International Whaling Commission, and through the International Council for the Exploration of the Sea

(ICES, n.d.). Though there is ongoing research into marine species protection, there are currently no laws or regulations specifically addressing entanglement of any cetacean species regarding fishing activity rules or restrictions in Iceland, other than that Icelandic law requires that bycatch of any species must be reported (Icelandic Fisheries, 2007).

3 Methods

3.1 Study Area

Skjálfandi Bay, off of the town of Húsavík on the north coast of Iceland (66°4'60" N and 17°33'0" E) was the principle focus area for this research (Figure 5). The bay is fed by two rivers and influenced by two major currents making it very nutrient rich and productive at times, but also causing food availability to change rapidly (Cecchetti, 2006). This area is very well known for the number cetaceans that come there to feed during the summer months, making it renowned for both whale-watching and research opportunities (Hoyt, 2011). Whale-watching has been ongoing in the bay since 1995, and currently three whale-watching companies operate out of the bay running a total of 31 trips a day at the peak of the season in July. North Sailing whale-watching company works in collaboration with the Húsavík Research Center, and the Húsavík Whale Museum and together these organizations conduct studies on stock sizes, distribution, individual identification, and more recently entanglement, of the different cetacean species that frequent the bay. The bay is also a favourable place to study humpbacks and be able to extrapolate results to the entire population in Iceland since there is no set population that returns to the bay. The Húsavík Humpback Whale Catalogue 2004-2011 shows humpbacks that have been identified in Skjálfandi Bay have also been identified in other parts of Iceland, lending support to the idea that these whales are utilizing multiple sites around country’s coastal waters. In the bay, trawling, long-lining, and gillnetting, all of the three main fishing methods used in Iceland.

Figure 5. Map of the northeast of Iceland showing the study site Skjálfandi Bay (©2013 Google).

3.2 Humpback Photographs and Photograph Analysis

Humpback whale photographs were obtained for the months of April through October of 2013, either taken by the author or provided by Marianne Rasmussen and Chiara Bertulli, and her assistants, working with the University of Iceland. All the photographs were taken in Skjálfandi Bay, Húsavík, on the northern coast of Iceland while on board North Sailing whale watching boat tours. Photographs were taken using Nikon DSLR cameras equipped with a Nikon 55-300mm zoom lens or a Nikon 70-300mm zoom lens, and were taken as the whale took a terminal dive where it lifted its fluke, a characteristic behaviour of humpback whales (Robbins and Mattila, 2001). Photographs were taken every day unless weather conditions did not permit the whale watching boats to operate. The photographs were first analyzed to determine which were of suitable quality to see the necessary detail, and also only chosen where at least two of the scar-analysis coding areas were visible in attempt to ensure a scarring pattern could be observed across coding areas. As per the scar-analysis protocol developed by Robbins and Mattila (2001), the six coding areas used for analysis were right and left flank, right and left leading edge of fluke, dorsal peduncle, and ventral peduncle (Figure 6). Photographs needed to be taken parallel to, or slightly in front of the whale as it took a dive in order to properly see the coding areas. Photographs were taken regardless of whether scarring appeared to be present or not to eliminate bias. Usable photographs of humpbacks from each day were identified to determine each individual whale used in the study, using the Húsavík Whale Museum humpback whale catalogues.

Identification of the individual was accomplished by matching pictures taken of the underside of the fluke and dorsal fin with images contained in the whale catalogues. The versions of the catalogue used for this study were the Humpback Whale Catalogue 2011 (September 2013 version) and the Humpback Whale Catalogue 2012-2013 (October 2013 version). The selected photos were then analyzed for the presence of "wrapping scars" and notches which are considered evidence of entanglement events (Figure 7; Figure 8). If the whale had entanglement scar evidence in two or more of the coding areas, it was categorized as "high probability" of entanglement. If the whale only had entanglement scarring in one coding area it was categorized as "uncertain", and if it had no clear entanglement scar evidence it was categorized as "low probability" of entanglement, as per the protocol developed by Robbins and Mattila (2001).

Once all the usable photographs were analyzed for entanglement scars and categorized accordingly, they were used to determine the estimated percent of the Icelandic North Atlantic humpback whale population that has been entangled in fishing gear at least once prior to arriving in Iceland for the spring and summer of 2013, closely following the methodology of Robbins and Mattila (2004). The percent of the sample categorized as "high probability" of entanglement is considered the minimum entanglement estimate. This was calculated using the formula: ("high")/("high" + "uncertain"+ "low"). The maximum entanglement estimate was calculated using the formula: ("high" + "uncertain")/("high" + "uncertain"+ "low"). The 95% confidence intervals were calculated using the following formula.

CI = $1.96\sqrt{p * (100 - p)/n}$ (Where p = percent of the sample represented by a category, n = total number of individuals).

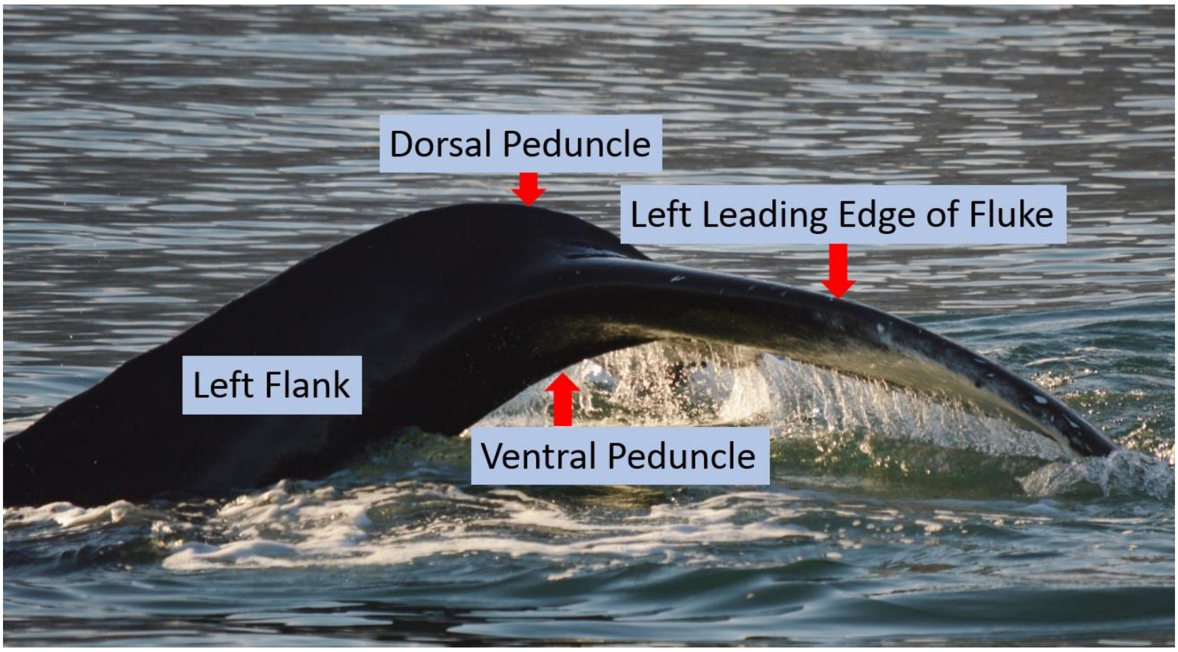


Figure 6. Photo of a humpback whale showing four of the six coding areas used for analysis.

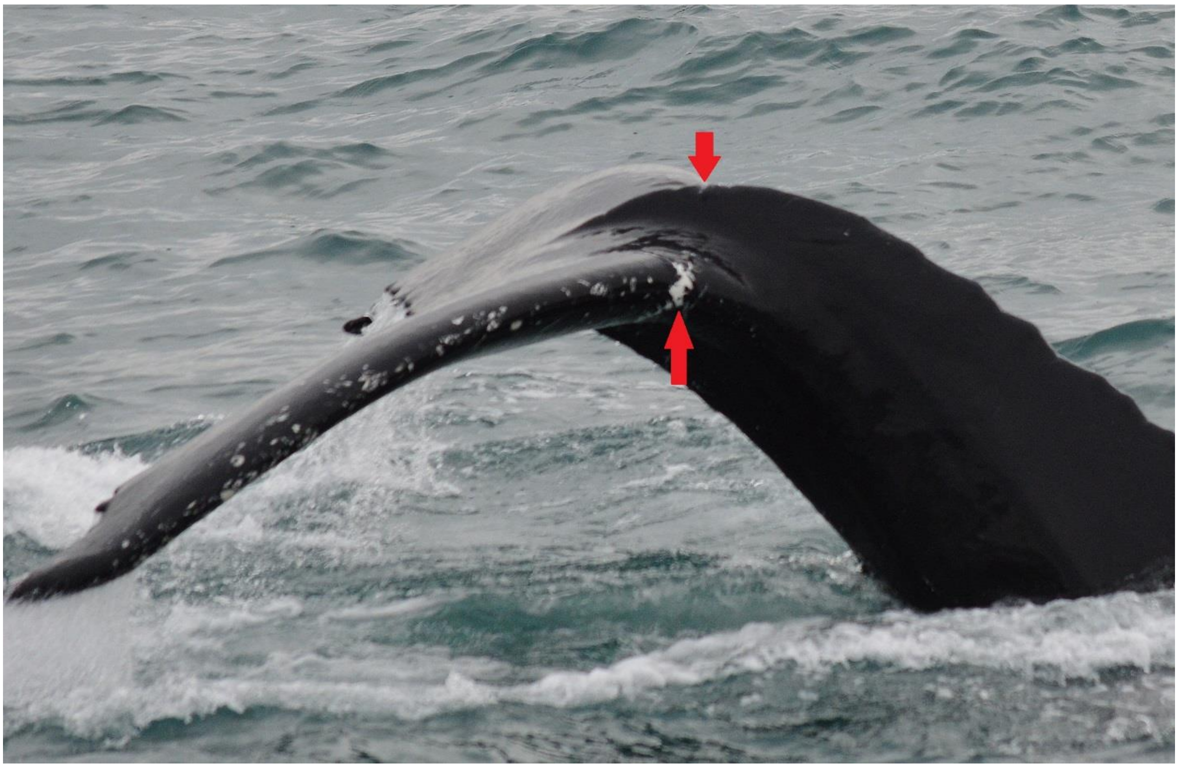


Figure 7. Photo of a humpback whale showing examples of wrapping scars and notches consistent with an entanglement event.

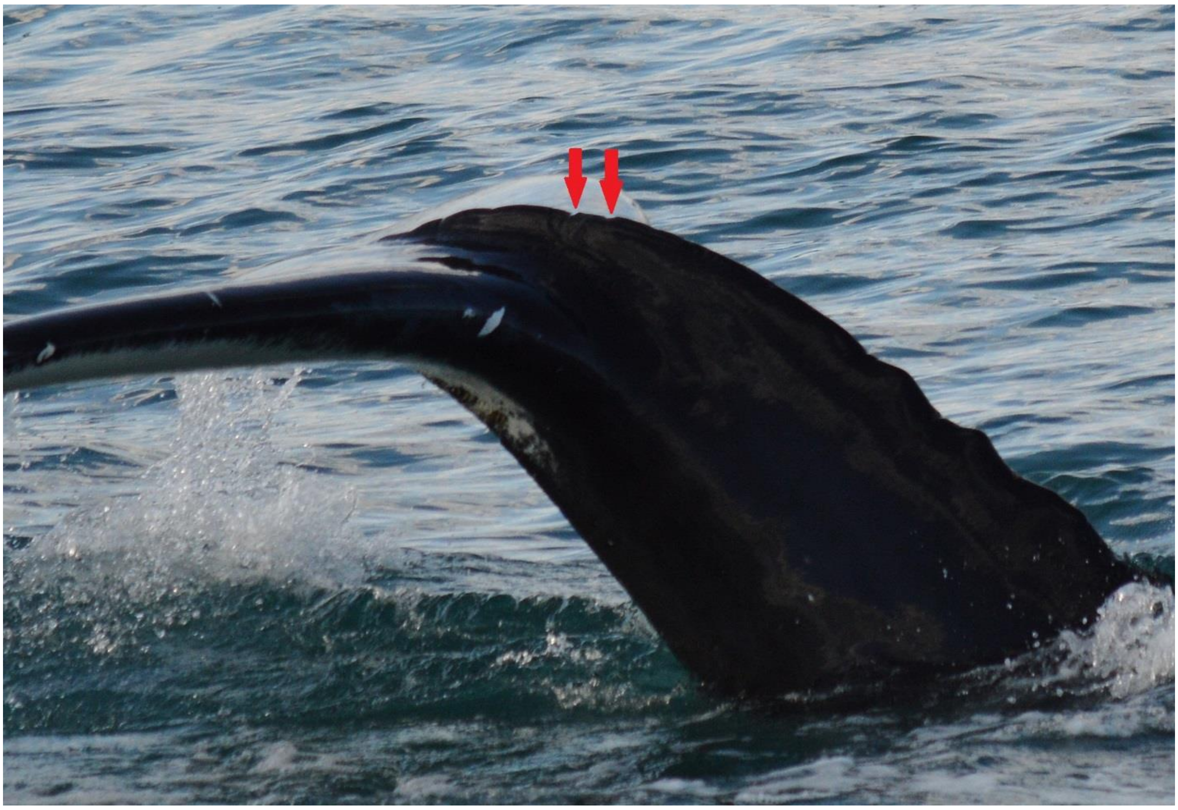


Figure 8. Photo of a humpback whale showing multiple notches consistent with a possible entanglement event.

3.3 Survey of Fishermen

As a second part to this study, a short survey was developed and distributed to fishermen working on commercial fishing boats in the northwest and northeast of Iceland, where humpback whales have known feeding grounds. This survey is intended to gain some insight into marine mammal sightings during commercial fishing operations in Icelandic waters, and whether humpbacks have been witnessed interacting with or becoming entangled in their fishing gear (Appendix 1). The survey was distributed as either a paper or electronic version through email, personal contact, and the help of businesses based in fishing ports (a café, the Ísafjörður harbour office, and a fish processing plant) to fishermen based primarily in the Westfjords, Akureyri, and Húsavík from July through November of 2013. The surveys were in Icelandic and responses were translated back into English after they were returned. There were 23 surveys completed and analyzed mainly to determine if there were any eye-witness accounts of humpback whales interacting with commercial fishing gear, and to gain some qualitative insight on the occurrence of spatial and temporal overlap between marine mammals and commercial fishing in Iceland. Reporting of where entanglement events occurred was achieved by asking fishermen to mark where they were fishing during the event from a coded map of Icelandic waters. The surveys also provided some qualitative information regarding the types of gear being used during eye-witness entanglement accounts, what the target species being fished for was at that time, and where the fishing was taking place.

4 Results

4.1 Photograph Analysis

A total of 283 pictures were considered usable for analysis after removing all poor quality photos and any same-day duplicates of the same individual. There was a total of 67 different individual humpback whales that had usable scar-analysis photographs taken of them from April to October 2013 in Skjálfandi Bay (Appendix 2). Of these 67 individuals, 26 were categorized as "high probability" of a prior entanglement, giving a minimum estimate of entanglement of 38.8% (n=67, 95% CI: 27.1-50.5%) for the Icelandic North Atlantic humpback whale subpopulation. There were 2 individuals that had clear entanglement scarring evidence outside of the six coding areas typically used for humpback scar analysis. If these two individuals are considered "high probability", the minimum entanglement estimate is 41.8% (n=67, 95% CI: 30.0-53.6%). There were 11 individuals in the "uncertain" category since they only had evidence of a prior entanglement in one coding area. A maximum estimate of entanglement was calculated to be 58.2% (n=67, 95% CI: 46.4-70.0%) by adding together the "high probability" and "uncertain" individuals (Table 1.). The actual percentage of the Icelandic humpback subpopulation that has been entangled is likely somewhere between the minimum and maximum estimates, but the minimum estimate (including the two whales with entanglement evidence outside of the coding areas) will be used for further discussion of the results. There were 28 individuals categorized as "low probability" of a prior entanglement because they either had no scarring, or had scarring that could not necessarily be attributed to an entanglement event.

Table 1. Table showing number of individuals, percents of sample, and confidence intervals. (High includes 2 individuals with scarring outside of coding areas; High* + Uncertain = maximum entanglement estimate).*

	Number of Individuals	Percent	Confidence Interval (+/-)
High*	28	41.8	11.8
Uncertain	11	16.4	8.9
Low	28	41.8	11.8
High* + Uncertain	39	58.2	11.8

4.2 Survey Eyewitness Accounts

A total of 23 responses to the survey were returned from fishermen in the northwest and northeast of Iceland out of approximately 45 surveys that were emailed to companies, distributed in-person, or handed out by businesses in fishing ports. There were 20 respondents who reported seeing whales while fishing either sometimes, often, or frequently, and 17 who reported seeing specifically humpback whales. There were 7 respondents who reported having seen whales entangled in fishing gear at least one time. The species of whale that were reported to have been seen entangled were humpback whales (*Megaptera novaeangliae*), minke whales (*Balaenoptera acutorostrata*), and killer whales (*Orcinus orca*). There were 5 eye-witness accounts of humpback whale entanglement that were explained in the responses. The chart of area codes for Icelandic waters and sites corresponding with eye-witness accounts can be seen in Figure 9.

1. The first account is from December of 1979. The humpback was caught in a purse seine while the crew was fishing for capelin north of Kolbein Island (area 669B). The net was not damaged, but was lowered and opened so that the humpback could swim out.
2. The second account is from July/August of 1995. The humpback was caught in a purse seine while the crew was fishing for capelin southeast of Scoresby Sund on the east coast of Greenland (not shown in Figure 9). The net was not damaged because it was opened by the crew so that the humpback could free itself.
3. The third account is from May of 2010. A humpback was seen briefly caught in a gillnet outside of Kopasker, Iceland (near area 616/666). The humpback was able to free itself from the gear and was seemingly unharmed.
4. The fourth account is from June/July of 2012-2013. The fisherman was using handlines to fish for cod in Skjálfandi Bay (areas 617C and 667B). When the humpback was hooked, the line would break according to the account provided.
5. The fifth account does not have a date. The crew was using a bottom trawl to catch cod in area 674B when a humpback was reported to have been caught in the trawl. It was further reported in this account that the gear was found to be undamaged. No other information was provided.
6. A sixth account was obtained from the Iceland Review newspaper issued December 16th, 2012. In the article, crews working for the HB Grandi company in Iceland

report humpbacks being caught multiple times in their seine nets while fishing for capelin north of the Westfjords, Iceland. The interviewee explains that the nets were torn while the humpbacks were trying to get free, and a lot of time had to go into repairing the damage (Iceland Review, December 16, 2012).

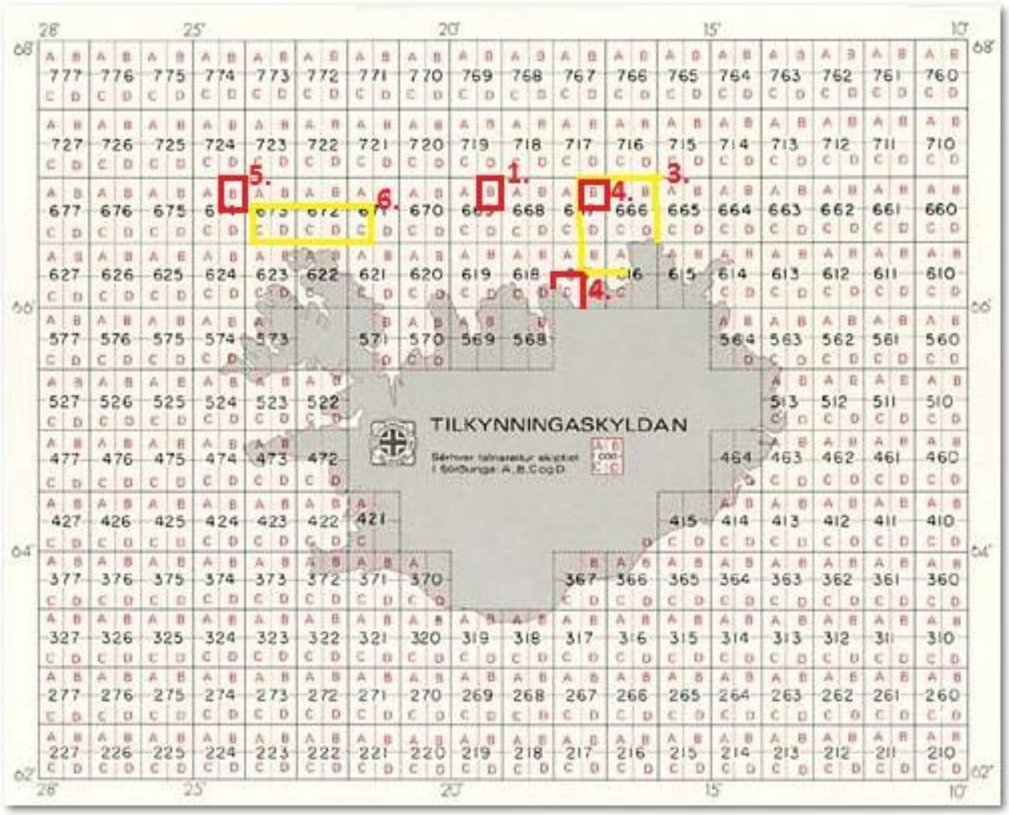


Figure 9. Map showing coding system of Icelandic waters used by Icelandic fishing vessels with red boxes indicating reported sites of eye-witness accounts and yellow boxes indicating estimated sites of eye-witness accounts.

5 Discussion

5.1 Photograph Analysis

The minimum estimate of entanglement for North Atlantic humpback whales in Iceland in this study was determined to be 41.8% (n=67, 95% CI: 30.0-53.6%). When taking into consideration the 95% confidence intervals, this is most comparable to that of humpbacks in Southeast Alaska, where the minimum estimate was 53% (n=137, 95% CI: 45-61%) in 2004 (Neilson, 2009) (Figure 10.). Based on results presented by Robbins (2009), comparing minimum humpback entanglement estimates from areas in the North Pacific, results from this study were slightly higher than the Bearing Sea and the northern Gulf of Alaska (approximately 20% and 35% respectively), but lower than northern British Columbia (approximately 50%). Results of this study are also lower than those for the other North Atlantic subpopulation of humpbacks in the Gulf of Maine. Single-year data for 1999 estimated a minimum entanglement of 65% (n=93, 95% CI: 55.3-74.7%) (Figure 10) and throughout the course of the study determined that approximately half of the humpback population sample (48-57%) each year showed high probability evidence of a prior entanglement (Robbins and Mattila, 2004).

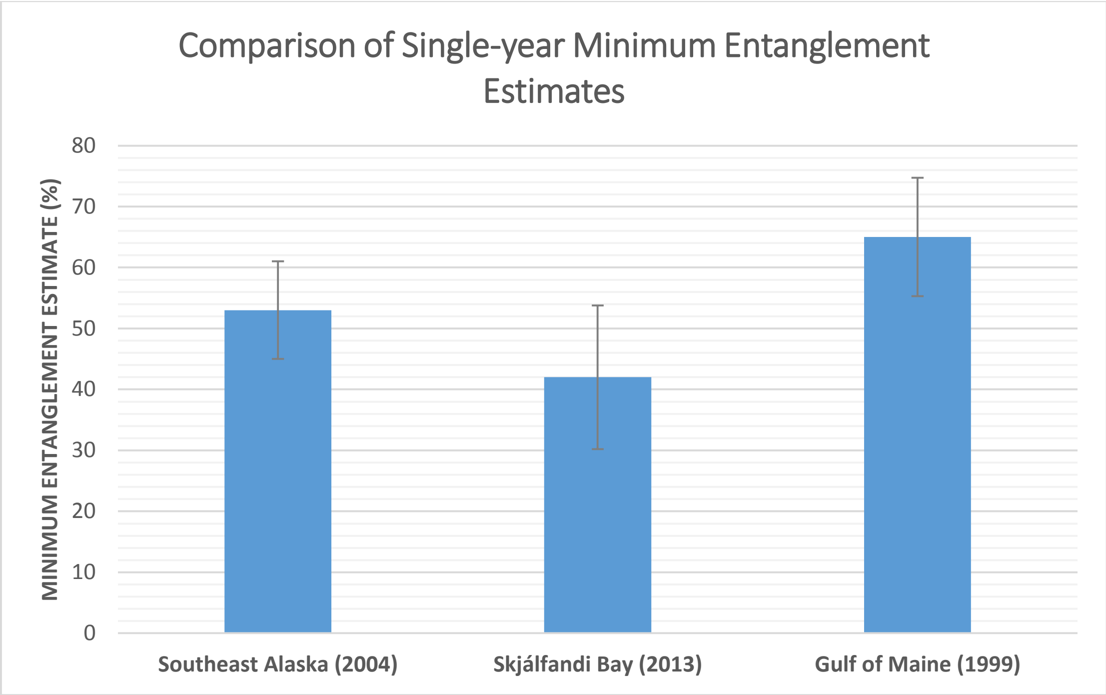


Figure 10. Chart showing the minimum entanglement estimates for three humpback subpopulations with 95% confidence interval error bars.

There are differences in the fishing practices between the Gulf of Maine and Skjálfandi Bay (and Iceland in general) that could partially explain the differences in the percent of the North Atlantic humpback subpopulations that have previously been entangled. In the Gulf of Maine region trawling is extensively used for groundfish species, a fishing method which is considered to be less of an entanglement threat to large whales (based on review of available literature) as well as gillnetting and more recently lobster potting, which both are considered to pose high entanglement risks (Read, 2008; Johnson, 2005). Trawling and gillnetting methods are also extensively used in the Icelandic fisheries, but there is no lobster fishery in Icelandic waters, creating a major difference between the two areas. Lobsters are caught with pot-gear which uses rope connecting all of the traps to one another, and to buoys floating at the surface, making this method a potentially serious entanglement threat to large whales. Depending on the fishing zone, inshore pot-gear configurations have vertical lines with an average length of anywhere from 10-40 fathoms (approximately 18-23m) and buoy lines of 10 fathoms (McCarron and Tetreault, 2012). Offshore pot-gear configurations have vertical lines with an average length of anywhere from 40-120 fathoms (approximately 73-219m) and buoy lines between 8-10 fathoms (15-

18m). Johnson et al. (2005) found that in the western North Atlantic 53% of entanglements with identifiable gear in the study involved pot-gear, most often from lobster pots. This suggests that areas such as the Gulf of Maine, where there is a high reliance on pot-gear fishing in addition to the other fishing methods such as gillnetting, are potentially higher risk areas for entanglement. There is some interest in creating a cod-trapping industry in Iceland. Where ongoing research on cod trapping is being conducted, there are experimental traps being tested (E. Hreinsson, December 5, 2013, personal communication), suggesting that there is potential for entanglement in the vertical lines used to connect traps and buoys to be an issue in Iceland in the future if this method expands into commercial use. The entanglement risk posed by cod trapping in Iceland would depend on what trap configurations are developed and the amount of vertical and bottom line they use.

Overall, minimum entanglement estimates for humpback subpopulations in different areas can vary, with close subpopulations sometimes showing greater differences to each other than to completely separate populations (as is suggested to be the case with Skjálfandi Bay, the Gulf of Maine, and Southeast Alaska). Apart from differences in fishing practices, these differences may also be attributed to scar healing and changing over time, which can also cause an underestimation of the number of “high probability” whales that are observed. Robbins and Mattila (2004) found that scars at the leading edges of the fluke caused by a serious injury are often consistently visible from one year to the next, but this was not necessarily the case for the other coding areas. Wrapping scar and notches on the dorsal and ventral peduncle were found to often heal until the white scar tissue was gone and only the notch(es) remained (Robbins and Mattila, 2004). The same was found for wrapping scars on the flanks of the whale, which often returned to their natural colour over time, making them much harder to detect in photographs.

The age and sex distribution of the different populations may also impact the numbers of entanglements. There have been instances where it was determined that male humpback whales were more likely to show signs of a prior entanglement than females (Robbins and Mattila, 2001; Neilson et al., 2009), but further studies of the Gulf of Maine population could not find evidence or an explanation for those results (Robbins and Mattila, 2004). Though this may be attributed partially to a bias towards more male photographs than female (Neilson et al., 2009), if there are differences in behaviours such as feeding strategies used by males and females or particular areas being utilized by each sex, some of which may have more fishing activity than others, then this could potentially lead to observed differences in the likelihood of each of the sexes being entangled. These potential differences between males and females have not been determined so far (Robbins and Mattila, 2001; Robbins, 2011).

The age class of the whale seems to have a more significant impact on the likelihood of entanglement. It has been found that the juvenile age class (whales known to be less than 5 years old) is entangled more frequently than the mature age class (Robbins, 2011). If there are more juvenile whales spending the summer in the feeding grounds in the Gulf of Maine than there are in Iceland, and Skjálfandi Bay in particular, then this could partially explain the lower percent of the population exhibiting high probability scarring in the Icelandic sub-population. No research has yet been conducted on aging or sexing of the Icelandic sub-population of humpbacks (M. Rassmusen, November 28, 2013, personal communication), and could be pursued in the future to determine if these factors could have an effect on entanglement estimates.

Since the different sub-populations also follow different migration routes to and from their winter breeding grounds there could be differences between the amounts of entanglement threat they face depending on how many active fishing grounds they are passing through. The Year of the North Atlantic Humpback project (YoNAH) studied all the known feeding grounds of North Atlantic humpbacks, as well as the breeding ground in the Dominican Republic. The project determined that at least part of the Icelandic humpback subpopulation migrates to the West Indies, particularly to the Dominican Republic, along with many of the other subpopulations which can then interbreed (Martin et al., 1984). It has also been confirmed that part of the Icelandic subpopulation is migrating to the Cape Verde Islands on the West Coast of Africa. The first identified individual confirming this was photographed in 1982 west of Iceland and later in 1999 near the Cape Verde Islands (Jann et al., 2003). Migration to the Cape Verde Islands has never been confirmed for subpopulations on the eastern coasts of the United States and Canada. Stevick et al. (2003) found that there was a relationship between the proportion of sightings of North Atlantic humpbacks in the West Indies and longitude, which suggested that the further east the humpback feeding ground was, the less likely those humpbacks were to migrate to the West Indies breeding grounds. Off of the coasts of the Dominican Republic, fisheries from the artisanal to industrial scale operate using traps, gillnets, longlines, and other methods

(Herrera et al., 2011). Some of these fisheries operate year-round with little or no restrictions making the possibility of humpback whale entanglements seemingly high. In Cape Verde, there are fisheries agreements put in place in collaboration with the European Union allowing European seiners and longliners to fish in Cape Verde waters (European Commission, 2013). Cape Verde also has its own fishing industry ranging from the artisanal to industrial scale, with the artisanal fisheries mainly using seining methods, and the industrial fisheries primarily using longlining and some lobster traps (Fonseca, 2000). Though longlines have been found to pose an entanglement threat to humpback whales, there is little to no gillnetting reported in this area, which could make the entanglement risk much lower than in other breeding areas such as the Dominican Republic. In order to determine the exact migration route and how many fishing grounds North Atlantic humpbacks pass through, tracking of individuals during migration would have to be performed.

There are several possible explanations for why entanglement estimates differ in separate areas, which could suggest why the estimates from this study are slightly lower than those for the other North Atlantic humpback subpopulations. Further research needs to be conducted to determine the actual causes for the differing entanglement estimates. It is likely that the differences in the fisheries in Iceland compared to those in the Gulf of Maine account for a large portion of difference in entanglement estimates for the two North Atlantic subpopulations. Although North Atlantic humpback whale entanglement seems to be slightly lower in the Icelandic subpopulation than in the other well-studied populations, results of this study suggest that there is still a significant amount of entanglement that could warrant management and mitigation recommendations. It was previously determined that the humpback whale population in Iceland and surrounding waters was increasing at a mean annual rate of 10.8% from 1986 to 2001, creating potential for more entanglements as the fishing industry and the whale population grow and overlap (Pike et al., 2009). Further investigation into the whale population suggested that between 2001 and 2007 there was little-to-no growth in population size, and therefore the population may have plateaued at an estimated 15,000 animals (Pike et al., 2010). Protocols developed by Robbins and Mattila (2001) were closely followed for this study, and therefore this first estimate of humpback entanglement in Iceland should be a fairly accurate representation of entanglement in this subpopulation.

5.2 Surveys

It has been recommended in scientific articles by Knowlton et al. (2005) and Johnson et al. (2005) that surveys like the one conducted for this study be performed in order to gain insight of the specifics of whale entanglements. Such surveys can increase the understanding of these events and inform, and ultimately improve, management strategies. Based on review of published literature, this is the first attempt at such a survey accompanying entanglement scar analysis. Well over half of the respondents reported seeing humpback whales at least sometimes while they were fishing, offering some evidence to suggest that there is potentially a spatial and temporal overlap between the North Atlantic humpbacks and the Icelandic commercial fishing in the areas where respondents were fishing. There were 7 respondents that reported having seen whale entanglements while they were fishing, not only of humpbacks, but of minke and killer whales as well, suggesting that there are more species than just the humpbacks that are being entangled in fishing gear in Iceland.

The eye-witness accounts from this survey and the newspaper article provided some valuable information. Humpbacks were reported having been seen entangled in four different types of gear in the six eyewitness accounts: Purse seines, gillnets, handlines, and a bottom trawl. Though the sample size is small, this does seem to suggest that in Iceland, North Atlantic humpback whales are interacting with, and potentially becoming entangled in, more than one type of fishing gear. One of the most important things to note was the prominence of humpbacks interacting with capelin purse seines. There were 3 accounts of this occurring (including the Iceland Review article), suggesting that this may be one of the more significant issues in Iceland. Johnson et al. (2005) did not identify any seine fishing gear on humpback whales in their study of gear identified on entangled whales, but this does not necessarily mean that the whales did not interact with this gear. For the purpose of this study, humpback interactions with purse seines are being considered as an entanglement event though they can sometimes be released without damage to the animal or net. It was reported in the Iceland Review article that the seine nets tear while the humpback is inside, allowing it to free itself from the gear, which differed from the other two accounts from the survey where the net was opened so that the humpback could swim free. Since the humpbacks are not carrying the seine gear with them, entanglement studies may not be including interactions with seine nets even though this could still have detrimental consequences for the whale. Although these interactions may not result in identifiable injuries or scarring on the entangled cetacean, other physiological responses that entanglements potentially produce may have an impact on the immune system and feeding as suggested by Aubin (2002a, 2002b). In Iceland, it has been determined that approximately 60% of the humpbacks diet consists of fish, and the humpbacks are consuming 6-9% of the total cetacean fish consumption estimate (Sigurjónsson and Víkingsson, 1997) supporting the potential for high overlap between fishing activities and whale feeding. Capelin is one of the major prey species of the North Atlantic humpback, and the whales are known to congregate where prey abundance is high (Johnson and Wolman, 1984), which suggests that there could be a higher probability of humpbacks being incidentally caught in capelin seine nets while they are feeding in Icelandic waters in areas with significant fishing activity.

One eye-witness account reported hooking humpbacks in hook-and-line gear. Johnson et al (2005) did find one humpback whale entangled in tuna handline in their study confirming that this does occur in other fisheries besides in Iceland. The account from the survey for this study reported that the humpbacks were getting caught in cod handlines and breaking the lines. There is also photographic evidence of this occurring in Skjálfandi Bay from June 2013, showing a hook caught in the humpback's skin and part of a line trailing behind (Figure 10). The hook may be from hook-and-line gear or longline gear, of which both potentially create similar entanglements (but there was no eye-witness accounts involving longline gear in this study). Although this doesn't appear to be causing any serious injuries or impediment to this whale, any open wound caused by the hook could be at risk for infection. Humpbacks in Stellwagen Bank National Marine Sanctuary are observed hooked by and entangled in tuna fishing hooks and line, and currently mitigation measures are being developed to address this issue and the negative publicity the fleet receives due to it (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2013).

Figure 11. Photograph of MN240 (Black Ribbon) taken on June 9th, 2013 in Skjálfandi Bay showing a fishing hook with line attached to the right anterior flank.

Trawling gear is generally not considered to be an entanglement risk to humpbacks, and was not considered in the Johnson et al. (2005) entangling gear study, though one of the accounts from the survey for this study reports catching a humpback in a bottom trawl while fishing for cod. It is possible that this was just a very rare event in which case the whale was potentially already sick or injured, or possibly it was incorrectly identified as a humpback. No previous reports of humpback whale entanglement in a trawling net could be found to support this claim.

It was surprising to only have one account of a humpback being entangled in gillnet gear, since this gear is considered to pose one of the greatest entanglement risks (Read, 2008). The account from the survey for this study reported that the whale freed itself from the net and appeared to be fine, although this does not necessarily mean that it was uninjured. Eye-witness accounts of humpbacks caught in gillnets in Iceland could be harder to obtain than for some of the other fishing methods due to the amount of time the nets are left in the water. For the lumpfish fishery, gillnets are in the water for 2-4 days (E. Hreinsson, November 25, 2013, personal communication), giving ample time for a humpback to interact with the gear unobserved, while cod gillnets are hauled out of the water once a day. If a humpback whale is not carrying part of the gillnet with it, it could be more difficult to gather accounts of gillnet entanglement in Iceland. In the recent report from 2010, there was a bycatch report of a humpback whale having died from entanglement in cod gillnet gear, further supporting that this is occurring in Iceland (Víkingsson, 2011). It is possible that there is under-reporting of gillnet entanglements, but an increase in survey sample size is required to further investigate this.

It was interesting to find that none of the gear from the accounts obtained through the survey was reported to have been damaged other than the handlines breaking, while the account obtained from the news article reported significant damage to purse seines, resulting in multiple time-consuming repairs. Attempts were made to follow-up with the company about this report, but were unsuccessful. The reporting card system that Lien and Aldrich (1982) developed for their study suggested that gear is quite often damaged in entanglement events resulting in monetary losses to fishermen through gear loss, repairs, and downtime. A separate survey aimed to better address these damages and losses would need to be developed to further investigate whether this is an issue for the Icelandic fishing industry or not. Currently there is not a standard reporting system for gear loss or damage in Iceland, and this is something that could be useful to investigate entanglement impacts in the future.

All of the eye-witness accounts of humpback entanglement from the survey and article occurred along the north coast of Iceland. This is where the study intended to focus on since this is where the North Atlantic humpbacks are seen in the greatest numbers and are known to have specific feeding grounds. Additional surveys would need to be conducted in other parts of Iceland to determine if there are eye-witness entanglement accounts from other areas in Icelandic waters. Even with a low sample size, the survey was able to suggest that humpback entanglement is occurring in Icelandic waters, and has been occurring throughout the years, with the earliest account being in 1979 and latest being from 2012/2013. The survey was also able to suggest that the whales appear to be interacting with a variety of fishing gear types in Icelandic waters.

6 Conclusions and Recommendations

Results from this study suggest that North Atlantic humpback whale entanglement in fishing gear is a potential issue for the conservation and management of the Icelandic subpopulation, giving a minimum estimate of 41.8% of the population being previously entangled. The survey conducted for this study also suggested that entanglement is occurring in Icelandic waters and involves a variety of fishing methods and gear, reporting a total of 6 eye-witness accounts from Icelandic fishing vessels. This is an issue that should be addressed in Iceland for several reasons. The first is the fact that the humpback whale is a protected species which is recovering from severe over-exploitation from the whaling era in the 1800s to the early 1900s (Smith et al., 1999), and the many detrimental effects of an entanglement event, such as risk of infection and reduced reproductive success, could be slowing down the species' recovery. Iceland is one of few countries in the world that still practices whaling, which may give the country a unique interest in the health of the population. Currently there is a protective ban on whaling of humpbacks in Iceland (The Húsavík Whale Museum, n.d.), but there were reports this year that the Minke Whalers' Association may apply for a permit to hunt the humpback whales for scientific purposes and consultancy on whaling in the future (Bjornsdottír, August 1, 2013). In order to do this, the health and threats to the humpback population need to be addressed.

The whale-watching industry in Iceland has become a large and valuable addition to the tourism sector in recent years. It is reported that in 2010, approximately 50,000 people went on whale-watching tours in Skjálfandi Bay alone (Martin, 2012), and in 2012 34% of all tourists who visited Iceland in the summer went whale-watching somewhere in the country (Óladóttir, 2013). Since thousands of tourists go whale-watching in Iceland every year, the health of the humpback population and concern with the impacts seeing entangled whales could have on the tourist industry should be of particular interest in the country. The negative connotation and publicity that may come along with many people seeing a whale entangled in fishing gear could also lead to pressure being put on the fishing industry to change their practices to reduce this impact. This is mentioned in the letter sent to tackle shops near the Stellwagen Bank Marine Sanctuary, reminding tuna fishermen about the bad publicity they receive when whale watchers see a whale entangled in their gear (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2013). Another reason to address entanglement issues from the perspective of the fishermen is damage to and loss of gear and loss of catch associated with entanglements. As Lein (1979) found in his study, hundreds of thousands of dollars can be lost annually due to entanglements.

The first step to addressing entanglement issues in Iceland is to continue to collect standardized data about entanglement rates and the health of the subpopulation, as is recommended by the IWC guidelines (Leaper et al. 2011). Scar-based photograph analysis will be performed for photographs taken in Iceland since 2001, in order to get a deeper understanding of how serious humpback whale entanglement is in Iceland and if the issue has been changing over the years (C. Bertulli, October 22, 2013, personal communication). The development of an entanglement reporting system could be used to aid in future research in Iceland. In places such as Canada and the United States, the reporting system is often associated with disentanglement efforts, but in Iceland where a disentanglement team may not be cost effective or necessary, the reporting system could still be a valuable tool. Currently bycatch of any cetacean species is required to be reported and findings are published in cetacean research progress reports, for example the findings of the 2010-2011 report showed bycatch of two humpback whales in the cod gillnet and mussel fisheries (Víkingsson, 2011). To improve upon this bycatch reporting, a reporting system could be set up online, giving the opportunity for anyone who saw an entangled whale while in Iceland to fill out a simple form and also submit any pictures they may have taken. This reporting database could be accessible by researchers in Iceland working on entanglement issues to lend more information to research efforts, and would be a relatively low cost system. A system could also be developed in a similar manner for gear loss and damage reporting, which could also improve entanglement estimates as well as create an estimate for how much lost fishing gear may be in Icelandic waters.

Education and regulations could be a powerful tool to reducing interactions between whales and the fishing industry. Having fishermen aware of the issues including damage to the whale population, damage and loss of their fishing gear, and potential negative effects on other industries such as tourism should be incorporated into any management plan that is created. Determining a mandatory distance that must be kept from areas where whales are visible while vessels are fishing may be a small step towards less interactions. This could be most effective for hook-and-line fishing and purse seining where areas in which whales are already present could be most easily avoided. Regulations for gear modifications and whale habitat management could also be effective for other fishing methods such as gillnetting.

Some of the gear modifications that are mandatory in the Atlantic Large Whale Take Reduction Plan in the United States could be applied to gear in Iceland. The incorporation of weak links, either through purchased weak-link devices or by the use of ropes of appropriate breaking strength, could be incorporated into buoy lines and float lines for gill-nets to minimize the entanglement risk that they pose. These weak links can also be placed on the up and down lines on each end of the net as required in the ALWTRP (Figure 11). The use of whale-safe hooks, which would straighten under the force exerted by hooking a whale, is also an option to test in Icelandic waters for longline and hook-and-line fishing methods. There are costs associated with switching to whale-safe fishing gear. In the Gulf of Maine, a gear exchange program was designed and funded so that lobster fishermen would switch their ropes to sinking groundline. It has been estimated that the use of whale-safe rope leads to a three-fold increase in annual rope costs for lobstermen since the rope only last approximately half the time (Schreiber, April, 2006). Since Iceland does not currently have a trap/pot fishery, the costs for making some whale-safe modifications should be much less. Break-away weak links for lines and swivels for buoys can be purchased in the United States for $1.75-$3.39 USD (New England Marine and Industrial, 2009), or approximately 210-405 ISK each. Following the ALWTRP configurations in Figure 11, the cost for weak links per gillnet panel would be approximately 1050 ISK plus approximately 405 ISK for each buoy. Since gillnets pose one of the greatest cetacean entanglement threats, it is assumed that all gillnet fisheries face similar entanglement issues. Accounts from this study could not confirm how large of a role gillnets play in entanglements of humpbacks in Iceland, and further research into this is necessary to determine whether these gear modifications could have a significant positive effect in the Icelandic gillnet fishery.

Making these changes to whale safe gear has potential to add market value to fisheries. There is increasing pressure in consumer markets for fish products to be sustainably caught without damaging fish stocks or other marine life. A poll conducted in the United States found that 53% of respondents believe purchasing sustainably caught seafood was "important" or "very important" (Truven Health Analytics, 2013), and this suggests that "whale-safe fisheries" could become another eco-label of importance.

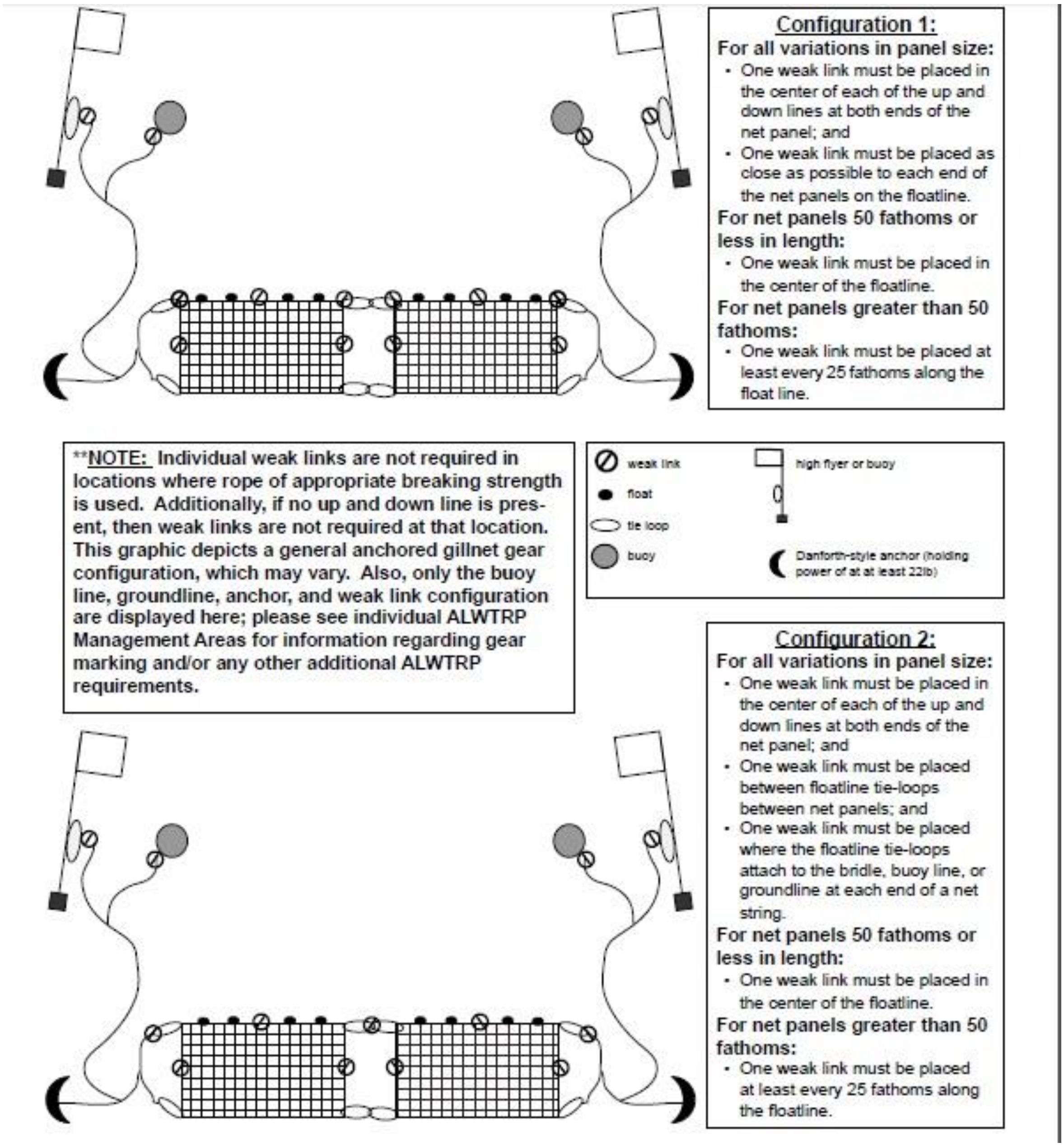


Figure 12. Gillnet configurations with weak link modifications complying with the Atlantic Large Whale Take Reduction Plan (Higgins and Salvador, 2010).

Currently in Iceland, there is a recycling fee imposed on fishing gear made out of synthetic fibres (Icelandic Recycling Fund, n.d.). It is already possible for the Icelandic Recycling Fund and fishing companies in Iceland to make agreements regarding fees for the recycling of old fishing gear. A free recycling program can be used to not only discourage the abandonment of old gear which would pose and entanglement threat, but could also be an incentive for the use of whale-safe gear. Agreements could be made between the Icelandic Recycling Fund and fishing companies in which companies who have made modifications to gear to reduce entanglement could have their old gear recycled for free.

With further research of the humpback subpopulation in Iceland, critical habitat that is used by the whales for feeding can be determined. These critical areas could be managed separately rather than having only blanket rules for the entire Icelandic fishing grounds. For example, in these areas stricter gear restrictions or modifications can be required to offer greater protection to the whales where they are most likely to congregate. These areas may also be considered for seasonal area management zones. Since the majority of the humpback subpopulation is in Iceland from May until October for the feeding season, seasonal restrictions and modifications for only these months of the year could be applied. Currently the only seasonal area management zones in Europe have been developed for bottlenose dolphins and harbor porpoises, but they have potential to be effective for other cetacean species (Hoyt, 2011). There are difficulties implementing these types of management areas that have to be considered. First of all, determining the boundaries of these areas will take significant research of the humpback population, of which relatively little has be done to date in Iceland. This type of research also requires funding which may not be available in Iceland. Implementing these types of management areas will also require some changes to an already well-developed fishing industry. If these zones were to be designed, education of fishermen would be key to their success. It would be important to emphasize that these zones are not designed to discourage fishing but minimize impacts on the humpback population as well as those faced by the fishermen. There is potential that these zones will impose some costs on fishermen. If the vessels are not equipped with gear complying with the regulations of the management zone, they may have to fish elsewhere. Depending on where other fishing grounds exist, fuel costs could increase to travel to further grounds, and catch could be decreased if the areas outside the management zone have less fish than within the zones.

Some form of enforcement would need to be put in place in management zones to ensure that the regulations and gear modification requirements are being followed. Though all the fishing activity cannot be monitored all of the time, fines for non-compliance to regulations, restrictions or modifications in management areas can be proposed to discourage fishermen from ignoring any management changes that are made. The

Directorate of Fisheries in Iceland is responsible for monitoring fisheries management and activities, and is the authority which enforces laws and regulations (Fiskistofa, n.d.). This authority would be responsible for checking for compliance to gear modification regulations. The Icelandic Coast Guard could also be trained on all new regulations and would be able to check vessels for compliance while fishing activity was ongoing if necessary.

In conclusion, despite some limitations this study closely follows scar-based analysis protocols developed by Robbins and Mattila (2001) and provides a reliable first estimation of entanglement of Icelandic North Atlantic humpback whales. Further research needs to be conducted on this subpopulation to continue to investigate the extent of entanglement and the impacts this issue is having on both the whale population and the fishermen. In recent years, there has been little political backing for suggestions of developing management strategies to protect Icelandic cetaceans and their habitat, but results from this study suggest that entanglement is an issue in this humpback subpopulation, and is in fact occurring in Icelandic waters through interactions with Icelandic fishing fleets. The development of a reporting system in Iceland for entangled whale sightings and fishing gear damage could assist in further humpback whale research efforts. There are also entanglement management strategies that could be utilized in Iceland. Creating regulations for distances that must be kept between fishing activities and whales when they are present could reduce entanglement events and damage to fishing gear such as hook-and-lines and purse seines. The implementation of weak links in gillnet gear, and potentially of whale safe hooks for longline and other hook-and-line gear, could also reduce the number of entanglements and the damage to gear.

7 Limitations

There are some limitations to both components of this study that have to be considered when interpreting the results. The first is the inexperience of the author in scar and entanglement evidence identification. Though measures were taken to compare photographs from this study to scar identification photographs from experts in this field, ultimately the identification of entanglement scarring is learned through years of experience and opportunities to observe entangled animals in consecutive years to understand how scars form and change. The other major limitation to the photo analysis in this study is the unusable photographs and the differences in the usable photographs. There were photographs taken of more individuals than could be used in this study due to poor quality, angle, distance, or lighting of the photographs, which lowered the sample size. Also, some individuals were seen and photographed many times over the course of study while others were only photographed once. Since it is known that the angle and lighting of each photograph can affect the results (Robbins and Mattila, 2004), even between photographs that have all been deemed usable, the whales with more photographic coverage may have a more accurate diagnosis of the coding areas than the whales with less photographic coverage, in which case something could be missed. The relatively short time for conducting fieldwork likely also had an effect on the entanglement estimates. Similar studies are conducted over many consecutive years, which will be attempted in Iceland in the future.

The main limitation to the survey component of this study is the accuracy of the eye-witness account information. Since the survey was addressing topics asking someone to admit they had interacted with, and potentially even injured, a humpback whale through fishing activities, the subject can be considered a sensitive one. Though there are no regulations making fishermen at fault for any interactions with the whales in Iceland, some potential respondents questioned how the information would be used. Even for those who did fill out a survey, it is not possible to know if all the information given was accurate, both in the sense of whether the details of accounts are true and if whale species could be correctly identified. Also, many surveys ended up being filled out by the captain of a fishing vessel on behalf of his whole boat, rather than each crew member filling it out individually, which significantly lowered the sample size and the possibility to obtain more eye-witness entanglement accounts. To obtain a clearer idea about eye-witness entanglement events in Iceland, a survey would need to be distributed over a larger geographical range since humpbacks can be spotted in other areas than just the northwest and northeast.

References

Alva, J.J., Barragan, M.J., and Denkinger, J. (2012). Assessing the impact of bycatch on Ecuadorian humpback whale breeding stock: A review with management recommendations. *Ocean & Coastal Management, 57*, 34-43

An, Y.R., Choi, S.G., and Moon, D.Y. (2010). *A review on the status of bycatch minke whales in Korean waters*. (Document SC/62/NPM19). Available from Secretariat, International Whaling Commission, Cambridge, UK

Angelia, S.M., Vanderlaan, R., Smedbol, K., and Taggart, C.T. (2011). Fishing-gear threat to right whales (*Eubalaena glacialis*) in Canadian waters and the risk of lethal entanglement. *Canadian Journal of Fisheries and Aquatic Science, 68*, 2174-2193

Australian Government Department of the Environment. (2013*). Australian Marine Mammal Centre – Report an entanglement*. Retrieved from http://data. marinemammals .gov.au/portal/entry/index.cfm?type=entanglement

Australian Government Department of the Environment. (2009). *Listed Key Threatening Processes.* Retrieved from http://www.environment.gov.au/cgibin/sprat/public/publicgetkeythreats.pl

Benjamins, S., Ledwell, W., and Davidson, A.R. (2012). Assessing changes in numbers and distribution of large whale entanglements in Newfoundland and Labrador, Canada. *Marine Mammal Science, 28*(3), 579-601

Bjornsdottír, I.R. (2013, August 1). Want To Hunt Humpbacks Too. *Reykjavik Grapevine*. Retrieved from http://grapevine.is/News/ReadArticle/Want-To-Hunt-Humpbacks-Too

Bradford, A.L., Weller, D.W., Ivashchenko, Y.V., Burdin, A.M., and Brownwell Jr., R.L. (2009). Anthropogenic scarring of western gray whales (*Eschrichtius robustus). Marine Mammal Science, 25*(1), 161-175

Butterworth, A., Clegg, I., and Bass, C. (2012). *Untangled – Marine debris: a global picture of the impact on animal welfare and of animal-focused solutions*. London: World Society for the Protection of Animals

Cassoff, R.M., Moore, K.M., McLellan, W.A., Barco, S.G., Rotstein, D.S., and Moore, M.J. (2011). Lethal entanglement in baleen whales. *Diseases of Aquatic Organisms, 96*, 175-185

Citta, J.J., Burns, J.J., Quakebush, L.T., Vanek, V., George, J.C., Small, R.J., Heide-Jorgensen, M.P., and Brower, H. (2013). Potential for bowhead whale entanglement in cod and crap pot gear in the Bering Sea. *Marine Mammal Science, n.v.*

Clapham, P. (2009). *N. Atlantic humpback whales: MONAH/YONAH*. In Calambokidis, P. Symposium on the results of the SPLASH humpback whale study – Final Report and Recommendations, Quebec City, Canada.

Cole, T., Hartley, D., and Garron, M. (2006). *Mortality and Serious Injury Determinations for Baleen Whale Stocks along the Eastern Seaboard of the United States, 2000-2004*. U.S. Department of Commerce: NOAA National Marine Fisheries Service.

Colvin, M., and Ogilvie, F. (2013, October 2). Humane Society calls for shark nets to be removed after whale caught. *ABC News Australia.* Retrieved from http://www.abc.net.au/pm/content/2013/s3860951.htm

Consortium for Wildlife Bycatch Reduction. (n.d.). *Fishing Technique Modifications*. Retrieved from http://www.bycatch.org/research/consortium/fishing-gear-modi–fications

Department of Fisheries and Oceans Canada. (2011). *Report a Sighting or Incident*. Retrieved from http://www.dfo-mpo.gc.ca/fm-gp/mammals-mammiferes/observation-eng.htm

Du Fresne, S. (2008). *Evaluation of the Impacts of Finfish Farming on Marine Mammals in the Firth of Thames.* (Document 1318922). Prepared for Environment Waikato.

Erbe, C., and McPherson, C. (2012). Acoustic characterisation of bycatch mitigation pingers on shark control nets in Queensland, Australia. *Endangered Species Research, 19*, 109-121.

Europa. (2010). Summaries if EU legislation: *Protecting cetaceans against incidental catch* (Council regulation (EC) No 812/2004). Retrieved from http://europa.eu/legislation_summaries/environment/nature_and_biodiversity/l66024_en.htm

European Commission. (2013). *Cape Verde – Fisheries partnership agreement*. Retrieved from http://ec.europa.eu/fisheries/cfp/international/agreements/cape_verde/index_en.htm

European Union. (2005). *Official Journal of the European Union: Commission Regualtion (EC) No 356/2005 of 1 March 2005 – laying down detailed rules for the marking and identification of passive fishing gear and beam trawls*. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32005R0356:en:NOT

FAO - Fisheries and Aquaculture Department. (2013). *Fishing Gear Types – Driftnets – Characteristics*. Retrieved from http://www.fao.org/fishery/geartype/220/en

FAO - Fisheries and Aquaculture Department. (1991). *An updated world review of interactions between marine mammals and fisheries*. Retrieved from http://www.fao.org/docrep/003/t0452e/T0452E01.htm

Felix, F., Munoz, M., and Haase, B. (2006). *Bycatch of humpback whales in artisanal fishing gear in Ecuador during 2005*. (Document SC/A06/HW14). IWC Workshop on Comprehensive Assessment of Southern Hemisphere Humpback Whales, Hobart, Tasmania: 3-7 April 2006

Fiskistofa – Directorate of Fisheries. (n.d.). Retrieved from http://en.fiskistofa.is/

Fonseca, B.D'O. (2000). *Expansion of Pelagic Fisheries in Cape Verde – A Feasibility Study* (Unpublished master's thesis). University of Akureyri, Iceland.

Franse, R. (2005). *Effectiveness of Acoustic Deterrent Devices (pingers)*. (Unpublished master's thesis). Center for Environmental Sciences, University Leiden, the Netherlands.

Gerry E. Studds Stellwagen Bank National Marine Sanctuary. (2013). *Resource Protection: Protecting Whale from Tuna Gear*. National Ocean Service. Retrieved from http://stellwagen.noaa.gov/protect/whaletuna.html

Gerry E. Studds Stellwagen Bank National Marine Sanctuary (2004). *Marine Mammal Entanglement Working Group Action Plan*. Retrieved from http://stellwagen.noaa.gov/management/workinggroups/entanglewg.html

Gordon, J., and Northridge, S. (2002) *Potential impacts of Acoustic Deterrent Devices on Scottish Marine Wildlife*. (Report No. F01AA404). Scottish Natural Heritage Commissioned Report.

Gribble, N.A., McPherson, G., and Lane, B. (1998). Effect of the Queensland Shark Control Program on non-target species: whale, dugong, turtle and dolphin: a review. *Marine and Freshwater Research, 49*, 645-651

Herrera, A., Betancourt, L., Silva, M., Lamelas, P. and Melo, A. (2011). Coastal fisheries of
the Dominican Republic. In S. Salas, R. Chuenpagdee, A. Charles and J.C. Seijo (eds). *Coastal Fisheries of Latin America and the Caribbean.* (pp 175-217). FAO Fisheries and Aquaculture Technical Paper.No. 544. Rome.

Higgins, J., and Salvador, G. (2010*). Guide to the Atlantic Large Whale Take Reduction Plan*. Retrieved from http://www.nero.noaa.gov/Protected/whaletrp/

Hofman, R.J. (1990). Cetacean entanglement in fishing gear. *Mammal Review, 20*(1), 53-64

Hoyt, E. (2011). *Marine Protected Areas for Whales, Dolphins, and Porpoises: A World Handbook for Cetacean Habitat Conservation and Planning* (2nd ed.). New York, NY: Earthscan

Hunt, K.E., Rolland, R.M., Kraue, S.D., and Wasser, S.K. (2006). Analysis of fecal glucocorticoids in the North Atlantic right whale (*Eubalaena glacialis*). *General and Comparative Endocrinology, 148*, 260-272

Icelandic Fisheries. (2007). *Statement on Responsible Fisheries in Iceland.* Retrieved from http://www.fisheries.is/management/government-policy/responsible-fisheries/

Icelandic Recycling Fund – Úrvinnslusjóður. (n.d.). *Products subject to the recycling fee*. Retrieved from http://www.urvinnslusjodur.is/english/products-subject/

Iceland Review Online. (December, 16th, 2012). *Humpback Whales Tear Nets in Iceland Fishing Grounds*. Retrieved from http://www.icelandreview.com/icelandreview/–search/news/Default.asp?ew_0_a_id=396200

ICES. (n.d.). *The International Council for the Exploration of the Sea (ICES) – a global organization for enhanced ocean sustainability*. Retrieved from http://www.ices.dk/explore-us/who-we-are/Pages/Who-we-are.aspx

International Whaling Commission. (2013). *The IWC Global Whale Entanglement Response Network.* Retrieved from http://iwc.int/entanglement-response-network

Jann, B., Allen, J., Carrillo, M., Hanquet, S., Katona, S.K., Martin, A.R., Reeves, R.R., Seton, R., Stevick, P.T., and Wenzel, F. W. (2003). Migration of a humpback whale (*Megaptera novaeangliae*) between the Cape Verde Islands and Iceland. *Journal of Cetacean Research and Management, 5*(2), 125-130

Johnson, A., Salvador, G., Kenney, J., Robbins, J., Kraus, S., Landry, S., and Clapham, P. (2005). Fishing gear involved in entanglements of right and humpback whales. *Marine Mammal Science*, *21*(4), 635-645

Johnson, J.H., and Wolman, A.A. (1984). The Humpback Whale*, Megaptera novaeangliae. Marine Fisheries Review, 46*(4), 30-37

Knowlton, A.R., Marx, M.K., Pettis, H.M., Hamilton, P.K., and Krause, S.D. (2005). Analysis of scarring on North Atlantic right whales (Eubalaena glacialis): Monitoring rates of entanglement interaction: 1980-2002. *Final Report to: National Marine Fisheries Service*

Leaper, Donovan, Panigata, Ritter, and Weinrich. (2011). Report on the Working Group on Estimation of Bycatch and Other Human-Induced Mortality. *Journal of Cetacean Research and Management; April 2011 Supplement, 12*, 230.

Lien, J. (1979). *A study of entrapment in fishing gear: Causes and Prevention*. Progress Report March 1, 1979

Lien, J., and Aldrich, D. (1982). *Damage to the inshore fishing gear in Newfoundland and Labrador by whales and sharks during 1981*. CAFSAC Marine Mammal Committee Meetings, St. John's NFL, May 18-19, 1982

McCarron, P. (2009). *Maine Lobster Industry Field Testing of Experimental Vertical and Groundlines*. Presentations for the Consortium for Wildlife Bycatch Reduction and the Maine Lobstermen's Association. Retrieved from www.bycatch.org/research/consortium/fishing-gear-modifications

McCarron P., and Tetreault, H. (2012). *Lobster Pot Gear Configurations in the Gulf of Maine*. Report for the Consortium for Wildlife Bycatch Reduction and the Maine Lobstermen's Association. Retrieved from www.mainelobstermen.org/Lobster_Gear_Report.pdf

Macfadyen, G., Huntinton, T., and Cappell, R. (2009). *Abandoned, lost or otherwise discarded fishing gear.* UNEP Regional Seas Reports and Studies, and FAO Fisheries and Aquaculture Technical Paper. Retrieved from http://www.fao.org/docrep/011/i0620e/i0620e00.HTM

Marine Mammals Protection Act 1978. (New Zealand). Retrieved from http://www.legislation.govt.nz/act/public/1978/0080/latest/DLM25111.html

Martin, S.M. (2012). *Whale Watching in Iceland: An Assessment of Whale Watching Activities on Skjalfandi Bay*. (Unpublished master's thesis). University of Akureyri, Iceland.

Martin, A.R., Katona, S.K., Matilla, D., Hembree, D., & Waters, T.D. (1984). Migration of humpback whales between the Caribbean and Iceland. *Journal of mammalogy*, *65*(2), 330-333

Mazzuca, L., Atkinson, S., and Nitta, E. (1998). Deaths and Entanglements of Humpback Whales, *Megaptera novaeangliae*, in the Main Hawaiian Islands, 1972-1996. *Pacific Science, 52*(1). 1-13

Meyer, M.A., Best, P.B., Anderson-Reade, M.D., Cliff, G., Dudley, S.F.J., and Kirkman, S.P. (2011). Trends and interventions in large whale entanglement along the South African coast. *African Journal of Marine Science, 33*(3), 429-439

Ministry of Fisheries (2011a). *Fishing gear*. Retrieved from http://www.fisheries.is/fisheries/fishing-gear/

Ministry of Fisheries (2011b). *Longline*. Retrieved from http://www.fisheries.is/fisheries/fishing-gear/longline/

Ministry of Fisheries (2011c). *Gillnets*. Retrieved from http://www.fisheries.is/fisheries/fishing-gear/gillnets/

Moore, M.J., and van der Hoop, J.M. (2012). The Painful Side of Trap and Fixed Net Fisheries: Chronic Entanglement of Large Whales. *Journal of Marine Biology, 2012*, 1-4

NAMMCO. (2005). *Welcome to North Atlantic Marine Mammal Commission*. Retrieved from http://www.nammco.no/

Neilson, J.L., Straley, J.M., Gabriele, C.M., and Hills, S. (2009). Non-lethal entanglement of humpback whales (*Megaptera novaeangliae*) in fishing gear in northern Southeast Alaska. *Journal of Biogeography, 36*, 452-464

New England Marine and Industrial. (2009). Retrieved from http://newenglandmarine.com/?s=break+away

NOAA - National Marine Fisheries Service: Alaska Regional Office. (n.d. a). *Marine Mammal Entanglement: Large Whale Entanglement*. Retrieved from http://alaskafisheries.noaa.gov/protectedresources/entanglement/whales.htm

NOAA. (n.d. b). *Report Entangled Whales* brochure. Retrieved from www.nmfs.**noaa**.gov/pr/pdfs/health/northwest/**soswhale**_brochure.pdf

NOAA. (n.d. c). *Gear Modification Techniques for Complying with the Atlantic Large Whale Take Reduction Plan (ALWTRP)*. Retrieved from http://www.nmfs.noaa.gov/pr/laws/mmpa/text.htm

NOAA - Fisheries Office of Protected Resources (2013a). *Humpback Whale (Megaptera novaeangliae)*. Retrieved from http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/humpbackwhale.htm

NOAA - Department of Commerce. (2013b). Taking of Marine Mammals Incidental to Commercial Fishing Operations; Atlantic Large Whale Take Reduction Plan Regulations; Proposed Rule. *Federal Register, 78*(136), 42653-42675

NOAA - Fisheries. (2013c). *Endangered Species Act (ESA)*. Retrieved from http://www.nmfs.noaa.gov/pr/laws/esa/

NOAA - National Marine Fisheries Service. (2012). *Protected Resources Management – Process for Distinguishing Serious from Non-Serious Injury of Marine Mammals*. (Directive PD 02-038) National Marine Fisheries Service Policy. Retrieved from http://www.nmfs.noaa.gov/directive

NOAA - National Marine Sanctuaries: Hawaiian Island Humpback Whale National Marine Sanctuary. (2011). *Resource Protection: Large Whale Entanglements*. Retrieved from http://hawaiihumpbackwhale.noaa.gov/res/impact.html

NOAA – Fisheries Service: Protected Resources Division. (2010). Harbor Porpoise Take Reduction Plan. Retrieved from: http://www.nero.noaa.gov/prot_res/porptrp/ptci.html

NOAA - National Marine Sanctuaries. (2008). *Sanctuary Innovations: Testing Fishing Gear Removal Techniques at Cordell Bank: About Remote Operated Vehicles*. Retrieved from http://sanctuaries.noaa.gov/missions/2008cordellbank/essay.html

NOAA. (1997). *Federal Plan Announced to Reduce Large Whale Entanglements in Atlantic Lobster and Gillnet Gear*. (Document 97-R149). Retrieved from www.publicaffairs.noaa.gov/pr97/jul97/noaa97-r149.html

Óladóttir, O. Þ. (2013). *Tourism in Iceland in Figures, April 2013.* Icelandic Tourist Board. Retrieved from www.ferdamalastofa.is/tourism-in-iceland-in-figures-april-2013.pdf

Pike D., Paxton C., Gunnlaugsson T., and Víkingsson G.A. (2009). Trends in the distribution and abundance of cetaceans from aerial surveys in Icelandic coastal waters, 1986-2001. *NAMMCO Scientific Publication, 7,* 117–142

Pike, D.G., Gunnlaugsson, T., Víkingsson, G.A., Desportes, G., and Mikkelsen, B. (2010) *Estimates of the abundance of humpback whales (Megaptera novaeangliae) from the T-NASS Icelandic and Faroese ship surveys conducted in 2007*. (Document 15pp. IWC SC/62/O13)

Read, A.J., (2008). The looming crisis: Interactions between marine mammals and fisheries. *Journal of Mammalogy, 89*(3), 541-548

Read, A.J., Drinker, P., and Northridge, S. (2006). Bycatch of Marine Mammals in U.S. and Global Fisheries. *Conservation Biology, 20*(1), 163-169

Reeves, R.R., McClellan, K., and Werner, T.B. (2013). Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. *Endangered Species Research, 20*, 71-97

Robbins, J. (2011). *Scar-Based Inference into Gulf of Maine Humpback Whale Entanglement: 2009*. Report to the Northeast Fisheries Service

Robbins, J. (2009). *Entanglement Scarring on North Pacific Humpback Whales*. In Calambokidis, J. (2009). Symposium on the results of the SPLASH humpback whale study – Final Report and Recommendations, Quebec City, Canada.

Robbins, J., Barlow, J., Burdin, A.M., Calambokidis, J., Clapham, P.J., Ford, J.K.B., Gabriele, C.M., LeDuc, R., Mattila, D., Quinn II, T.J., Rojas-Bracho, L., Straley, J.M., Urban, J., Wade, P., Weller, D., Witteveen, B.H., Wynne, K., and Yamaguchi, M. (2007). *Preliminary minimum estimates of humpback whale entanglement frequency in the North Pacific Ocean based on scar evidence.* (Unpublished document SC/59/BC15).

Robbins, J., and Mattila, D. (2004). *Estimating humpback whale (Megaptera novaaeangliae) entanglement rates on the basis of scar evidence*. Report to the Northeast Fisheries Science Center National Marine Fisheries Service

Robbins, J., and Mattila, D.K. (2001). *Monitoring entanglements of humpback whales (Megaptera novaeangliae) in the Gulf of Maine on the basis of caudal peduncle scarring*. (Document SC/53/NAH25). Unpublished report to the 53rd Scientific Committee Meeting of the International Whaling Commission. Hammersmith, London.

Schreiber, L. (2006, April). Groundline Exchange Scheduled for Maine. *Fishermen's Voice*. Retrieved from http://www.fishermensvoice.com/archives/0406groundlineexchange.html

Shark Spotters. (2012). *Shark Nets vs Exclusion Nets*. Retrieved from http://sharkspotters.org.za/shark-nets-vs-exculsion-nets

Sigurjónsson J., and Víkingsson G.A. (1997). Seasonal abundance of and estimated food consumption by cetaceans in Icelandic and adjacent waters. *Journal of Northwest Atlantic Fish Science, 22*, 271–287

Smith, T. D., Allen, J., Clapham, P. J., Hammond, P. S., Katona, S., Larsen, F., Lien, J., Mattila, D., Palsboll, Sigurjónsson J., Stevick, P.T., and Øien, N. (1999). An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Megaptera novaeangliae*). *Marine Mammal Science*, *15*(1), 1-32

Song, K-J. (2010). Fishing gears involved in entanglements of minke whales (*Balaenoptera acutorostrata*) in the East Sea of Korea. *Marine Mammal Science, 26*(2), 282-295

Statistics Iceland. (2013). *Fishing vessels*. Retrieved from http://www.statice.is/Statistics/Fisheries-and-agriculture/Fishing-vessels

St. Aubin, D.J. (2002a). *Hematological and serum chemical constituents in pantropical spotted dolphins (Stenella attenuate) following chase and encirclement.* Report for the Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA

St. Aubin, D.J. (2002b). *Further assessment of the potential for the fishery-induced stress on dolphins in the eastern tropical Pacific*. Report for the Southwest Fisheries Science Center, National Marine Fisheries Service, NOAA

Stevick, P.T., Allen, J., Berube. M., Clapham, P.J., and Katona, S.K. (2003). Segregation of migration by feeding ground origin in North Atlantic humpback whales (*Megaptera novaeangliae*). *Journal of Zoology, London*, *259*, 231-237

The Húsavík Whale Museum. (n.d.). *History of Whaling*. Retrieved from http://www.whalemuseum.is/whaling-in-iceland/history-of-whaling/

Truven Health Analytics, and NPR. (2013). *Health Poll: Sustainable Fishing*. Retrieved from http://www.npr.org/blogs/thesalt/2013/02/11/171743185/most-americans-eager-to-buy-seafood-thats-sustainable

van der Hoop, J., Moore, M., Fahlman, A., Bocconcelli, A., George, C., Jackson, K., Miller, C., Morin, D., Pitchford, T., Rowles, T., Smith, J., and Zoodsma, B. (2013). Behavioral impacts of disentanglement of a right whale under sedation and the energetic costs of entanglement. *Marine Mammal Science, n.v.*

Víkingsson, G.A. 2011. *Iceland. Progress report on cetacean research, May 2010 to April 2011, with statistical data for the calendar year 2010*. International Whaling Commission (IWC). (Document SC/63/ProgRep Iceland 6 pp). Retrieved from iwc.int/document_1303.download

Volgenau, L., Kraus, S.D., and Lien, J. (1995). The impact of entanglements on two substocks of the western North Atlantic humpback whale, *Megaptera novaeangliae*. *Canadian Journal of Zoology, 73,* 1689-1698

Ware, C., Wiley, D.N., Friedlaender, A.S., Weinrich, M., Hazen, E.L., Bocconcelli, A., Parks, S.E., Stimpert, A.K., Thompson, M.A., and Abernathy, K. (2013). Bottom side-roll feeding by humpback whales (Megaptera novaeangliae) in the southern Gulf of Maine, U.S.A. *Marine Mammal Science, n.v.*

Winn, J.P., Woodward, B.L., Moore, M.J., Peterson, M.L., and Riley, J.G. (2008). Modeling whale entanglement injuries: An experimental study of tissue compliance, line tension, and draw-length. *Marine Mammal Science*, *24*(2), 326-340

Woodward, B.L., Winn, J.P., Moore, M.J., and Peterson, M.L. (2006). Experimental modeling of large whale entanglement injuries. *Marine Mammal Science, 22*(2), 299-310

Appendix 1

English version of the survey distributed to fishermen for this study.

This short survey is being conducted for a Coastal and Marine Management master's thesis at the University Center of the Westfjords in Isafjordur focusing on humpback whale entanglement in fishing gear. Thank you for your participation!

Any further questions can be sent to:

Charla Basran

cj_basran@hotmail.com

Name ___________________________________

Company_________________________________

1. How often do you see marine mammals when you are fishing?
   - Whales Never Occasionally Often Frequently
   - Dolphins or Porpoises Never Occasionally Often Frequently
   - Seals Never Occasionally Often Frequently
   - Other ________________ Never Occasionally Often Frequently

2. How often have you seen **humpback whales** in the area where you were fishing?
   Never Occasionally Often Frequently

3. Have you ever witnessed marine mammals entangled in fishing gear (*Identify species if possible*)?
   - Whales (Species_________________) Never Once More than once
   - Dolphins or Porpoises (Species_________________) Never Once More than once
   - Seals (Species_________________) Never Once More than once
   - Other ________________ Never Once More than once

4. Have you ever witnessed **humpback whales** entangled in your fishing gear? YES NO
   (*If yes, please fill out the following questions*)

When did this occur? Month__________________ Year___________________

What type of fishing gear were you using?

____

What type of fish were you fishing for?

____

What area were you fishing in (*Please use the reference chart below)?*

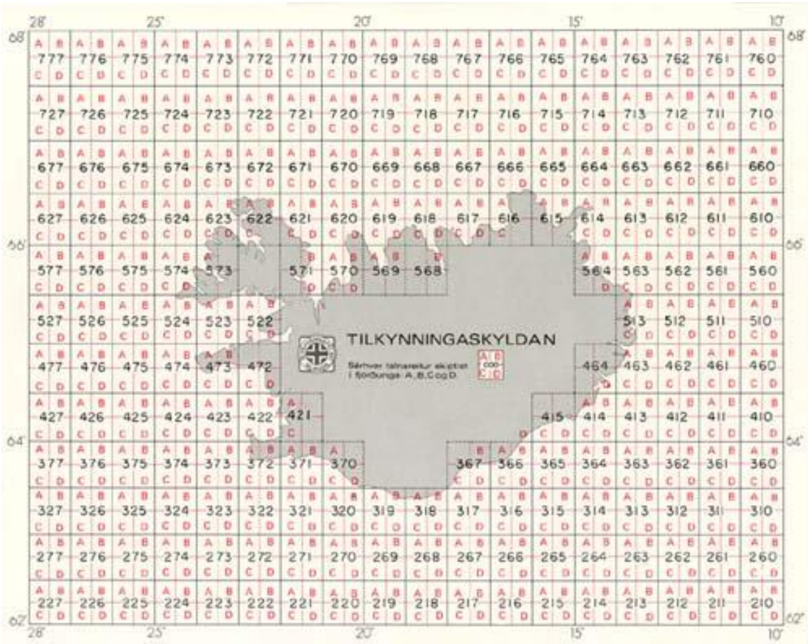
____

Was the gear damaged? In what way?

____

Comments?

____



Appendix 2

Scar analysis and probability category of each individual North Atlantic humpback whale identified in this study.

WHALE ID	*AREA*	*RIGHT FLANK*	*LEFT FLANK*	*LEFT EDGE*	*RIGHT EDGE*	*DORSAL PEDUNCLE*	*VENTRAL PEDUNCLE*	*ENTANGLEMENT PROBABILITY*
MN217 (JAW SCAR)	SB	NA	N	N	N	N	N	LOW
MN269 (NO FACE)	SB	N	NA	NA	N	N	NA	LOW
MN271 (PAC-MAN)	SB	Y	NA	NA	NA	NA	NA	HIGH**
MN262 (KODAMA)	SB	N	Y	N	Y	Y	N	HIGH
MN177	SB	NA	NA	NA	Y	Y	N	HIGH
MN254 (CHESHIRE)	SB	NA	N	N	NA	Y	N	UNCERTAIN
MN249 (BLACK SPOTS)	SB	N	N	N	N	N	N	LOW
MN230 (CURVY SCAR)	SB	N	N	N	N	N	N	LOW
MN209 (BLACK DOT)	SB	NA	NA	Y	N	Y	N	HIGH
MN 228 (LUIGI)	SB	NA	NA	NA	N	N	NA	LOW
MN223 (PUNTO CROCE)	SB	NA	Y	Y	Y	Y	Y	HIGH
MN222 (MISSING SCOOP FROM TIP)	SB	NA	NA	NA	N	N	NA	LOW
MN267 (MR BLACK)	SB	N	N	N	N	N	N	LOW
MN270 (ORIEN)	SB	N	N	N	N	N	N	LOW
MN279 (SHEN XUI)	SB	NA	NA	Y	Y	NA	Y	HIGH
MN240 (BLACK RIBBON)	SB	Y	N	N	Y	N	Y	HIGH
MN255 (CHIP)	SB	N	N	N	N	Y	N	UNCERTAIN

MN232 (WHITE CAP)	SB	N	N	N	N	N	N	LOW
MN268 (NAUGHTS AND CROSSES)	SB	NA	N	N	N	N	NA	LOW
MN200 (SNOW WHITE)	SB	N	N	N	N	Y	Y	HIGH
MN195 (MACULA)	SB	N	NA	Y	Y	Y	Y	HIGH
MN286 (WINNIE THE POOH)	SB	N	N	N	N	Y	N	UNCERTAIN
MN264 (MARU)	SB	N	NA	Y	N	N	N	UNCERTAIN
MN280 (TRIANGLE)	SB	N	N	Y	Y	Y	N	HIGH
MN266 (MONTEREY)	SB	N	NA	N	N	N	N	LOW
MN248 (BABY TEETH)	SB	NA	NA	N	NA	Y	Y	HIGH
MN277 (SALT AND PEPPER)	SB	NA	NA	NA	N	Y	N	UNCERTAIN
MN281 (TRIBBLE)	SB	NA	NA	NA	Y	Y	Y	HIGH
MN258 (DAEMON)	SB	NA	NA	N	NA	N	NA	LOW
MN176 (ENGLEBERT)	SB	NA	NA	NA	N	N	NA	LOW
MN227 (PEPPINO)	SB	N	NA	NA	N	N	N	LOW
MN274 (PUSHEEN)	SB	NA	N	N	NA	N	N	LOW
MN293 (FELIX)	SB	NA	N	N	N	N	N	LOW
MN203 (WHITE TOP DORSAL)	SB	N	NA	N	N	Y	Y	HIGH
MN210 (19)	SB	NA	NA	Y	NA	N	N	UNCERTAIN
MN298 (PORPOISE)	SB	N	N	N	Y	Y	N	HIGH
MN291 (CHOPSTICKS)	SB	NA	Y	NA	N	Y	NA	HIGH
MN303 (SPOT)	SB	NA	NA	N	NA	N	NA	LOW
MN232 (WHITE CAP)	SB	N	N	N	N	Y	N	UNCERTAIN
MN305 (WHITE TIP)	SB	NA	NA	N	N	Y	N	UNCERTAIN

MN304 (SPRAY GUN)	SB	NA	NA	NA	N	N	N	LOW
MN289 (BLACK SURF)	SB	N	NA	NA	N	N	N	LOW
MN201 (BOLD BLACKS)	SB	NA	NA	NA	Y	Y	NA	HIGH
MN290 (BLOSSOM)	SB	N	NA	N	N	N	N	LOW
MN233 (SMACK)	SB	NA	N	N	N	Y	N	UNCERTAIN
MN294 (GRAFFITI)	SB	NA	Y	Y	NA	Y	NA	HIGH
MN173	SB	NA	NA	NA	N	N	N	LOW
MN300 (RYU)	SB	NA	NA	Y	NA	Y	N	HIGH
MN292 (DASH-DOT)	SB	N	NA	NA	N	Y	NA	UNCERTAIN
MN147 (KUTI)	SB	N	NA	Y	Y	Y	N	HIGH
MN245 (48 - CROOKED GRIN)	SB	N	N	Y	Y	N	N	HIGH
MN265 (MESSY)	SB	N	Y	N	N	N	N	HIGH**
MN307 (MONG)	SB	Y	Y	Y	Y	Y	Y	HIGH
MN309 (SLEEPING BEAUTY)	SB	N	NA	N	N	Y	Y	HIGH
MN310 (SMACK'S TWIN)	SB	N	NA	NA	N	N	NA	LOW
MN204 (CUT OFF GREY)	SB	NA	NA	NA	N	N	N	LOW
MN306 (LITTLE AYAX)	SB	N	Y	N	Y	N	N	HIGH
MN312 (WILLIAM)	SB	N	N	N	N	N	N	LOW
MN308 (POCK)	SB	N	N	N	N	N	N	LOW
MN162 (THE BIG ONE)	SB	N	N	Y	Y	Y	N	HIGH
MN65 (LIQUORICE)	SB	NA	NA	NA	N	N	Y	UNCERTAIN
MN237 (GOBBA)	SB	NA	NA	N	Y	N	NA	UNCERTAN
NO ID (NUCK)	SB	N	NA	Y	Y	Y	N	HIGH
NO ID	SB	N	N	N	N	N	N	LOW

(EXCLAMATION)								
NO ID (LINDEN)	SB	N	NA	NA	N	N	NA	LOW
NO ID (KOOTS)	SB	NA	N	Y	NA	N	Y	HIGH
NO ID (SHEEMA)	SB	NA	Y	Y	NA	N	NA	HIGH