Master's thesis

Marine animal entanglements in mussel aquaculture gear

Documented cases from mussel farming regions of the world including first-hand accounts from 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

Mussel aquaculture utilizes various ropes in the water column that may pose an entanglement risk to cetaceans and sea turtles. In contrast to fishing gear, however, there are far fewer documented entanglement cases in mussel aquaculture gear. With that being said, there has been little data collected on this issue to date. Due to the growing demand for aquaculture and potential expansion into offshore areas, interactions with cetaceans and sea turtles are likely to continue and even increase into the future. In Iceland, the mussel aquaculture industry is currently small and largely experimental, but there is potential for expansion. The development of a successful management plan is dependent on understanding what type and part of the gear poses the greatest entanglement risk, as well as the location and timing of events in relation to cetacean feeding and migration patterns. The objective of this thesis is to lay the foundation for future studies regarding cetacean and sea turtle entanglements in mussel aquaculture gear. Documented entanglement cases were collected from mussel farming regions of the world via media outlets, academic articles, secondary sources, and informal interviews. Primary data collection was then undertaken in Iceland using online surveys and semi-structured interviews with mussel operators. In total, seven entanglement reports were collected, including four baleen whales, one harbour porpoise, and two leatherback turtles. A majority of cases involved mussel spat collecting ropes, which suggests this part of the gear may pose the greatest entanglement risk. Two entanglement reports were from Iceland, where there is likely proximity between cetacean distributions and mussel farming sites. Summer spat collection also coincides with the highest densities of cetaceans in Icelandic waters. Management suggestions for Iceland may include the implementation of a reporting system for entanglements in aquaculture gear and studies looking into areas where spat collection can occur with low likelihood of encountering cetaceans.

Keywords: Cetaceans, entanglement, Iceland, mussel aquaculture, mussel farming, sea turtles.

This thesis is dedicated to Oliver, Lisa, Alex, and Lucy.

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1 Introduction

The protection of threatened and endangered marine species appears to be in escalating conflict with the expanding utilization of our oceans. Marine megafauna, including marine mammals, sea turtles, seabirds and sharks, are prone to interact with a variety of gear types and hazards in the marine environment; hazards to megafauna include fishing gear, aquaculture operations, marine debris, and renewable energy moorings. Interactions with aquaculture operations may occur as a result of an overlap between the spatial location of aquaculture operations and habitat space (including foraging, breeding, resting, socializing areas) and migratory routes of certain species. To date, mussel aquaculture has largely been conducted safely and sustainably throughout many regions of the world. Some mussel aquaculture operations, however, use various ropes in the water column that may pose an entanglement risk to cetaceans and sea turtles (Consortium for Wildlife Bycatch Reduction, 2014; Clement, 2013; Kemper et al., 2003). In contrast to fishing gears, there are far fewer documented cases of cetacean and sea turtle entanglements in mussel aquaculture gear. This suggests that entanglements in mussel gear are rare occurrences (Lindell & Bailey, 2015). This lack of evidence, however, does not prove that these negative interactions cannot, or do not occur, as there has been little data collection on the issue to date (D. Alves, personal communication, April 7th, 2014). It is also common for people to use the entanglement risks associated with fixed fishing gears when considering the risks associated with mussel aquaculture operations, which is not necessarily pertinent, as they differ considerably (D. Alves, personal communication, April 7th, 2014; S. Lindell, personal communication, April, 2014; Moore & Wieting, 1999).

The potential conflict between marine animals and mussel aquaculture is of a global nature. Further, due to the ongoing and growing demand for aquaculture and potential expansion into offshore areas, interactions are likely to continue and even increase into the future (Clement 2013; International Whaling Commission [IWC], 2010; Kemper et al., 2003; Würsig & Gailey, 2002; Moore & Wieting, 1999). This could be exacerbated by changing abundances and distributions of some species (Benjamins et al., 2014; Kintisch, 2006; McMahon & Hays, 2006; Stevick et al., 2003). In Iceland, there are hopes to expand the mussel farming industry, which is currently small and largely experimental

(Matvælastofnun, 2014; Þ. Gunnarsson, personal communication, September 17th, 2014; Ministry of Fisheries and Agriculture [MFA], 2008). There is also likely to be a significant spatial overlap between mussel operations and cetacean distributions in Iceland (I Erlingsson, personal communication, April 7th, 2014). Direct interactions between cetaceans and mussel farms, particularly entanglements, not only have the potential to negatively impact the animal and populations involved, but also the mussel industry by direct damage to gear and possibly decreased harvest. Therefore, there is a need for the potential issue of cetacean entanglements in Iceland to be addressed. The development of a successful management plan is dependent on understanding what type and part of the gear may pose the greatest entanglement risk, how animals may become entangled, as well as where and when these events occur (Johnson et al., 2005; Wild Whales: B.C. Cetacean Sightings Networks, n.d.). Therefore, it is necessary to put together information on entanglement cases and gear and operational procedures employed by the mussel farming industry in Iceland. It is also important to consider potential management and mitigations measures that can be taken if the need arises. This will serve to both improve the outcome for individuals and populations involved, as well as the mussel aquaculture industry itself (Groom & Coughran, 2012). Moreover, information collected in this thesis may also be beneficial to management authorities in other countries where there may be a spatial overlap between mussel aquaculture operations and distributions of threatened species.

1.1 Research

1.1.1 Objective

The objective of this thesis is to lay the foundation for future studies regarding cetacean and sea turtle entanglements in mussel aquaculture gear. This will be done by conducting a systematic literature review on the topic to collect entanglement reports, as defined by my scope. Baseline data, including both primary and secondary data, will also be collected from Iceland. Potential solutions will also be identified and discussed.

1.1.2 Research questions

1. What gear and operational procedures are currently used by mussel farming operations in Iceland?

2. Are mussel farming operations in Iceland located within the distributional range of cetacean species, as defined by aerial and shipboard surveys conducted in Icelandic waters as part of the North Atlantic Sightings Surveys (NASS) and according to cetacean sightings at mussel aquaculture sites?
3. What characterizes the cases of cetacean entanglements collected for this study in Iceland?
4. What commonalities, if any, are there between the collected cases of cetacean (and sea turtle) entanglements off the coast of Iceland and from other mussel farming regions?

1.1.3 Methods

A mixed methods approach was used to gather entanglement reports of cetaceans and sea turtles in mussel aquaculture gear. Entanglement reports from multiple mussel-producing areas utlizing longline technology (including Canada, Korea, New Zealand and Australia) were collected from various media outlets, academic articles, secondary sources, and informal interviews. Primary investigation was then undertaken in Iceland using both quantitative and qualitative methods, in the form of online surveys and semi-structured interviews, respectively. These methods were used to gather first-hand accounts of cetacean entanglements in mussel gear and information on mussel gear and operational procedures used by mussel farming operations in Iceland. The locations of mussel farming operations were also compared to the known distributions of cetacean species in Icelandic waters as defined by NASS aerial and shipboard surveys conducted in Icelandic waters as well as cetacean sightings at mussel aquaculture sites collected from the online surveys.

1.1.4 Scope

This thesis focuses on cetacean interactions with mussel aquaculture, as opposed to all marine mammals, as this group, specifically baleen whales, appears to be the most likely to become entangled in fixed lines in the water column (Benjamins et al., 2014; Knowlton, Hamilton, Marx, Pettis, & Kraus, 2012; Read, Drinker, & Northridge, 2006; Kemper et al., 2003). Additionally, most known cases of entanglement in mussel aquaculture lines to date involve baleen whales (Y-R. An, personal communication, February 23rd, 2015; E. Daníelsson, personal communication, October 19th, 2014; Clement, 2013; Groom & Coughran, 2012). Pinnipeds were excluded from the study due to the fact that they are likely at low risk of entanglement due to their small size, flexibility, high degree of streamlining, and ‘pursuit predator’ feeding mode (Benjamins et al., 2014). In addition, no direct interactions between pinnipeds and shellfish aquaculture operations have been reported to date, in contrast to finfish operations, where depredation and entanglement in anti-predator nets is common (Clement, 2013; Kemper et al., 2003). Sea turtles were included in this study, as ropes in the water column are known to pose an entanglement risk to sea turtles (e.g. James et al., 2005) and there are two known cases of leatherback turtle entanglements in mussel aquaculture gear (T. Mills, personal communication, January 27th, 2015). The inclusion of these cases would help to understand the nature of mussel gear entanglements (S. Lindell, personal communication, April, 2014). Additionally, sea turtle interactions with mussel aquaculture are likely to increase with the expanding ranges of certain species, namely the leatherback turtle (S. Lindell, personal communication, April, 2014). Due to a lack of reported entanglement cases thus far, effort was undertaken to collect reports from multiple mussel farming areas of the world utilizing longline technology, as well as primary investigation in Iceland. Entanglement in other shellfish aquaculture gear, such as pearl oyster lines, was excluded due to the fact that after a preliminary literature search and multiple enquiries, no entanglement cases were found. In addition, only farming of blue mussels is carried out in Iceland. In Iceland, effort was made to collect primary data from one stakeholder group only: the mussel growers. This was due to the fact that the main goal of this thesis with regards to data collection in Iceland was to gather information on the mussel industry, as well as any first-hand accounts of cetacean entanglements to begin to gather information on this topic for future reference.

1.2 Thesis organization

After the introductory section, a literature overview of concepts and topics related to mussel aquaculture, megafauna interactions with aquaculture, cetacean and sea turtle entanglements, collected cases of cetacean and sea turtle entanglements in mussel aquaculture ropes, and cetaceans in Icelandic waters will be discussed. Methodology regarding surveys and semi-structured interviews in Iceland with mussel operators will then be presented followed by the results, a discussion and conclusions. Potential management and mitigation measures will then be presented, as well as suggestions for future research.

2 Literature overview

2.1 Aquaculture

Global aquaculture production has grown significantly in recent years, with total food-fish production reaching 66.6 million tonnes in 2012 (Food and Agriculture Organization of the United Nations [FAO], 2012). World aquaculture production also exceeded tonnage of capture fisheries for the first time in 2013, with an estimated production of 70.5 million tonnes, and continues to grow larger than 50% of seafood production (Aquaculture North America, 2014). This growth may be due in part to significant reduction in wild fisheries and an increasing demand for seafood, that is likely to continue into the foreseeable future (Diana, 2009). Aquaculture is defined by FAO (2015b) as:

> The farming of aquatic organisms including fish, mollusks, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.

Aquaculture operations can be intensive, semi-intensive, or extensive, depending on the level of intervention in the rearing process. Intensive and semi-intensive aquaculture involve supplementary feeding, whereas extensive aquaculture relies on natural food supply, but may require intervention in the form of predator exclusion or control of competitors (Naylor et al., 2000). Although aquaculture operations are proposed to help solve food security issues with growing populations there are concerns over environmental and ecological impacts that require further research and innovation to properly manage and mitigate (Frankic & Hershner, 2003).

2.2 Mussel aquaculture

Saltwater mussels (family Mytilidae), as well as other cultured bivalve species, are filter or deposit feeders, feeding on phytoplankton or detritus in the water column; thus, mussel aquaculture is an extensive form of aquaculture that does not require supplementary feeding. Mussels also act to clean waters through this extractive nature of water filtration. Mussel aquaculture is generally considered environmentally friendly, although some adverse effects may include phytoplankton depletion, changes in species assemblages and benthic environments, spread of invasive species, and alteration in hydrodynamics (Kaiser, Laing, Utting, & Burnell, 1998).

2.2.1 Global production

A variety of saltwater mussel species are cultivated worldwide, including the blue mussel (*Mytilus edulis*) in parts of Europe, Scandinavia and North America, the Mediterranean mussel (*Mytilus galloprovincialis*) in China, Brazil, Australia, and across Europe, the Chilean mussel (*Mytilus chilensis*) in Chile, and the New Zealand green-lipped mussel (*Perna canaliculus*), in New Zealand (Stevens, Plew, Hartstein, & Fredriksson, 2008). Total mussel aquaculture production reached 1.8 million tonnes in 2012, with China, the EU, Chile, and New Zealand being the biggest producers (European Commission Fisheries, 2012; FAO, 2012).

2.2.2 Mussel aquaculture techniques and gear

The techniques and gear used for mussel farming tend to be less complex than what is required in other aquaculture operations. However, this form of aquaculture requires specific conditions such as high seawater quality, food in the form of planktonic organisms, as well as substantial space with sufficient shelter (Aypa, 1990). Due to limited availability of sheltered inshore areas, many aquaculture developments are moving offshore, which is being made possible by recent technological developments (Stevens et al., 2008).

Mussel aquaculture is believed to have originated in France in the 13th century using intertidal pole culture or 'bouchots', which is still practiced today (FAO, 2015a; Aypa, 1990). Culture techniques have been continuously developing and a multitude of techniques are used today that vary depending on the physical, hydrological and biological parameters of the farm site, as well as the equipment and materials that are available (Bonardelli, 2013; Stevens et al., 2008). Culture methods include bottom culture, intertidal and shallow water culture, and deep-water or off-bottom culture (Bonardelli 2013; Aypa, 1990). Deep-water culture techniques include raft culture and longline culture (Aypa, 1990), the later of which will be the focus of this thesis.

Mussel aquaculture: longline systems

The longline method used for mussel aquaculture was first developed in the 1970's and is now becoming the prevailing method used to produce sizable mussel crops with minimal infrastructure (FAO, 2015a; Stevens et al., 2008). These systems consist of horizontal headropes held upright by floats and held in place by semi-permanent anchors/moorings such as deadweights (e.g. concrete blocks), drag anchors, or lightweight moorings (e.g. helical or screw anchors) (FAO, 2015a; Bonardelli, 2013; Stevens et al., 2008). Longline systems may be either surface or submerged systems (Figure 1; Stevens et al., 2008). Surface systems typically consist of single or double headropes or rigs carrying multiple ropes (Bonardelli, 2013). Surface systems are only suitable for sheltered inshore areas, however, as they are vulnerable to environmental conditions at the surface such as waves, currents, and drift ice (Bonardelli, 2013).

Submerged systems are similar to surface systems, but are submerged 5–15 m below the surface, and are thus less influenced by surface conditions (Figure 1b). Submerged systems are therefore more suitable for open-ocean areas, defined by Stevens et al. (2008) as "those that are at some distance to shore and require reasonable infrastructure" or offshore areas, defined as, "being exposed to substantial oceanic conditions—mainly in the form of exposure to large waves and storms" (p. 146). Submergence also reduces visual impact (Stevens et al., 2008). Varying degrees of submergence can be achieved through controlling the buoyancy of a combination of surface and submerged floats, as well as mooring design (Bonardelli, 2013; Stevens et al., 2008). Semi-submerged systems are often found in locations where drift ice is common, as growers are able to remove the surface floats and sink the lines (Bonardelli, 2013).

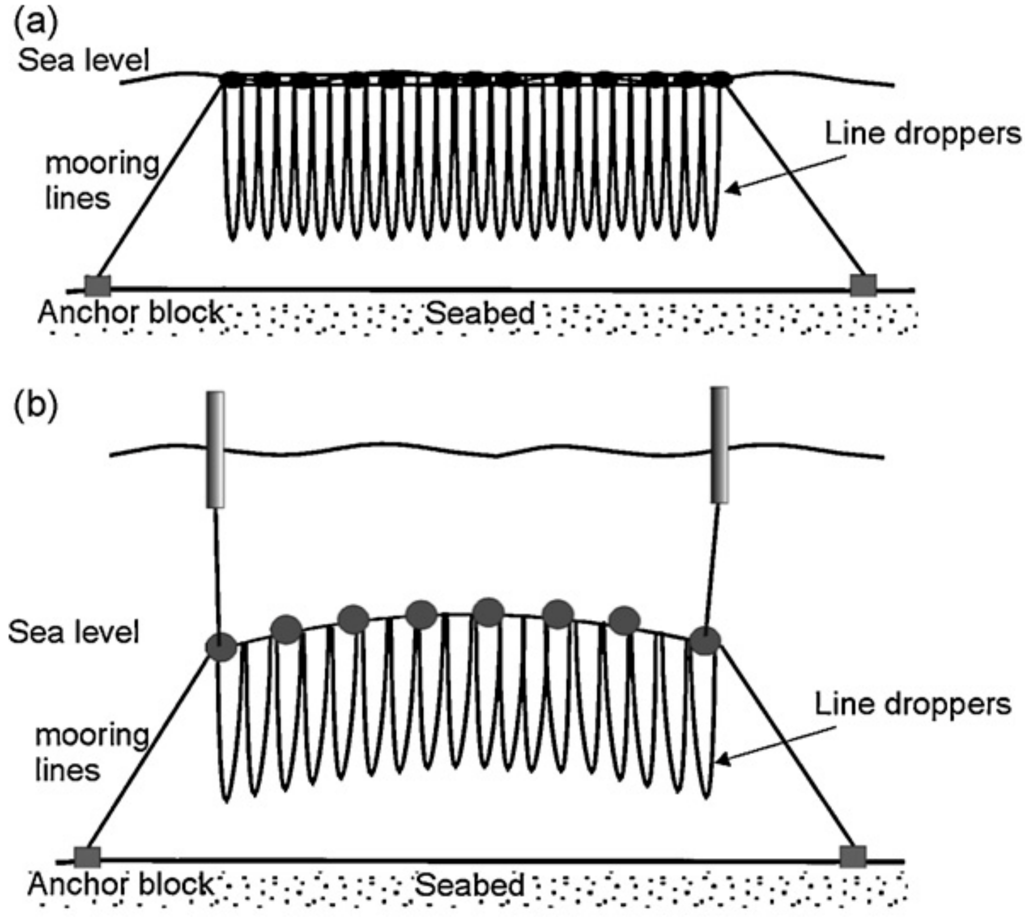

Figure 1. (a) Surface longline system (b) Submerged longline system. From Stevens et al., 2008. Copyright [2008] by Elsevier, B.V. Reprinted with permission.

Culture ropes consist of both spat collectors and grow-out ropes. In some cases, culture ropes consist of continuous droppers up to 10 m long that are looped continuously along the length of the mainline (Figure 2). The entire length of the continuously looping culture rope may be up to five kilometers long. Other systems, such as those used in eastern Canada, consist of single droppers typically three to five meters long (Stevens et al., 2008). Mussel spat is either caught on collecting ropes or collected from intertidal areas, although hatchery technology is now becoming available (FAO, 2015a). An example of a "fuzzy" New Zealand-style spat collecting rope can be seen in Figure 3. After a certain period, mussels are typically thinned and re-seeded onto grow-out ropes and secured by an over-layer of biodegradable cotton ("socks") until they naturally attach with their byssal threads (FAO, 2015a). Two types of socking are typically used. One, which is typically referred to as "Canadian socking" consists of a cotton bi-sected nylon mesh sleeve, with a weave of cotton throughout to create a temporary smaller mesh lining that initially holds the mussel seed (Figure 4). Within a few weeks, the cotton will dissolve and the mussels attach themselves to the outside of the sleeve. The second type of socking utilizes machiney to spread mussel seed onto a textured grow-out rope that is then covered by a fine cotton mesh to secure the seed. Again, after a few weeks the cotton will dissolve and the mussels will be attached to the grow-out rope (S. Lindell, personnal communication, April, 2015). Marketable size is typically 40 mm, and in most areas takes approximately 14–15 months (FAO, 2015a). An example of nearly market size product on dropper ropes can be seen below (Figure 5).

Figure 2. Continuous mussel grow-out ropes right after they have been "socked" and hung on 28 mm headrope. Image by Scott Lindell, MBL Woods Hole. Reprinted with permission.

Figure 3. New Zealand-style "fuzzy" spat collecting rope (12 mm thick core) attached to a 28 mm headrope. Image by Scott Lindell, MBL Woods Hole. Reprinted with permission.

Figure 4. Single grow-out "droppers" of Canadian-style consisting of cotton bi-sected mesh socks. Image by Scott Lindell, MBL Woods Hole. Reprinted with permission.

Figure 5. Nearly market size product on dropper ropes. Image by Scott Lindell, MBL Woods Hole. Reprinted with permission.

2.2.3 Mussel farming in Iceland

Mussel farming is a fairly new industry in Iceland, with the first experimental operations undertaken in 1973 and 1985–1987 (Þórarinsdóttir, Gunnarsson, & Theódórsson, 2007). Over the past decade, culture techniques have been constantly changing, with growers adapting the technology available for the unique environmental conditions in Icelandic waters (MFA, 2008; Gunnarsson et al., 2005). The species that is farmed is the blue mussel, which is native to Icelandic waters and found abundantly along the north, west, and east coasts of the country (Gunnarsson, n.d.). The mussel can be grown relatively easily from seed collected from the wild, and artificial food is not required (Gunnarsson, n.d.). However, it takes two to three years for market size to be reached, compared to a production cycle of one to two years in competing countries (FAO, 2015a; MFA, 2008; Þórarinsdóttir et al., 2007). Iceland offers abundant space in a very pure environment for growth of the mussel industry, which is particularly important with the limited space available in the traditional culture areas in Europe (MFA, 2008). Furthermore, the quality of Icelandic blue mussel is very high and relatively consistent throughout seasons (MFA, 2008).

As of 2014, there were 20 mussel aquaculture companies registered in Iceland (Figure 2; Þ. Gunnarsson, personal communication, September 17th, 2014). Norðurskel, located in Eyjafjörður, in Northeast Iceland, was the only company that was producing mussels on an industrial basis in 2014, but has since discontinued their operations (Þ. Gunnarsson, personal communication, September 17th, 2014). Of the remaining companies, only a few are producing mussels for the domestic market, while the rest are being run on an experimental basis, with total production only reaching a few tonnes per year (Þ. Gunnarsson, personal communication, September 17th, 2014; Matvælastofnun, 2014; MFA, 2008).

Figure 6. Map of registered mussel farming sites in Iceland in 2014. Grey symbols indicate one operation at indicated location and blue symbols indicate two operations at indicated location. Map data copyright [2015] by Google. Source: author.

Culture techniques and gear

Submerged longline systems is the only cultivation method used in Iceland (Gunnarsson, n.d.). Mussel spat collectors are deployed during the summer, usually in July, but specific deployment dates may vary between June and August, depending on location, and even then may vary from year to year (E. Daníelsson, personal communication, February 15th, 2015; H. Friðgeirsson, personal communication, February 10th, 2015; Þ. Guðmundsson, personal communication, February 10th, 2015). Mussels are either grown to market size on collectors or are "socked", by which mussel seed is stripped from collectors and loaded into mesh sleeves based on size classes (Gunnarsson, n.d.). The mussels are then grown to market size, which is approximately 50–70 mm in shell length (Gunnarsson, n.d.).

Difficult climatic conditions in Iceland mean that culture equipment must be able to withstand a significant amount of movement. Specific components of mussel farming gear vary depending on local conditions, but a generalized diagram can be seen in Figure 7. Headropes must be at least 20 mm in diameter and greater than 30 mm in more exposed locations (Gunnarsson et al., 2005). Thinner line is used to connect the surface floats to the headrope, which is suggested to be at least one meter in length in sheltered areas, and several meters in more open areas. As is the case in other mussel farming regions, culture ropes include spat collecting rope and grow-out ropes (individual sleeves [“single droppers”] or continuous cotton socks) (Figure 8a and 8b). Mussel operators are recommended to use single droppers less than 5 m long with at least 0.75 m spacing along the headrope between droppers. These lines are then connected to the headrope using a “hestahnút” or horse knot (Figure 8c). Both types of socking that were discussed above are used in Iceland (Gunnarsson et al., 2005), but in many cases, mussels may be left on spat collectors to reach market size. Collectors range between 12–14 mm. Weights may also be used on culture ropes to keep the lines vertical in the water and various bottom anchors are used, with the most common being concrete blocks, or large pieces of iron. These anchors must be at least one tonne in sheltered areas and two tonnes in more exposed locations (Gunnarsson et al., 2005). Two types of floats are also used at the surface: endfloats and surface floats. Small surface floats are generally used for the first winter during cultivation, and larger floats are added as the weight of the mussels on the lines increases (Gunnarsson et al., 2005).

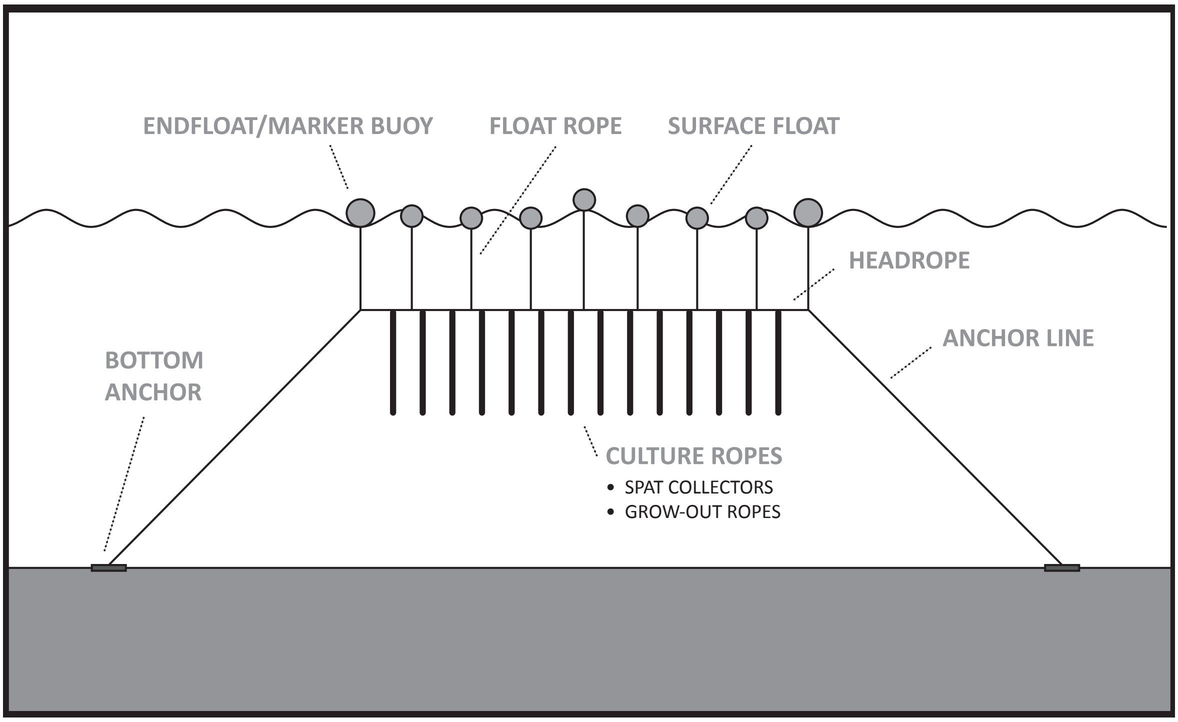

Figure 7. Generalized diagram of an Icelandic mussel farming gear. Adapted from Gunnarsson et al., 2005. Source: author.

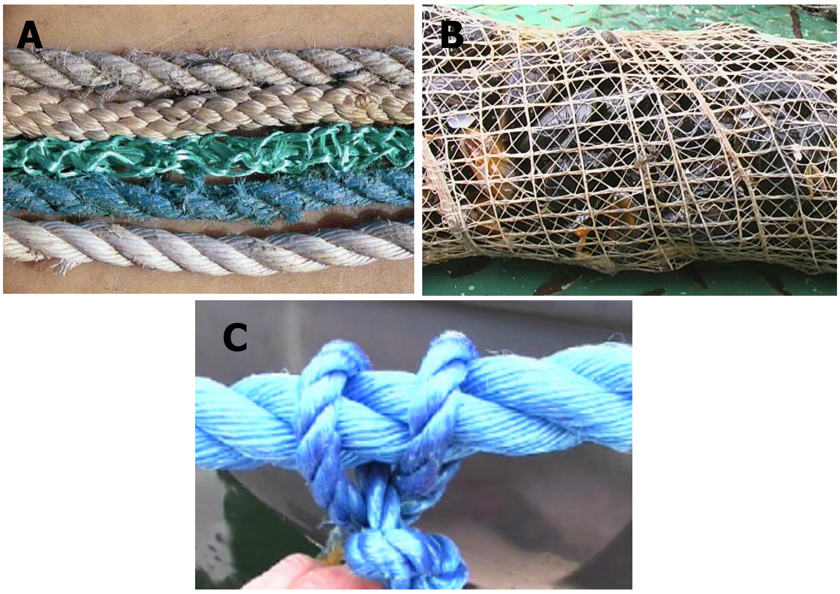

Figure 8. (a) Mussel spat collectors (b) "Sock" made of biodegradable material (c) "Hestahnútur" or horse knot used to connect the mussel culture ropes to the headrope. From Gunnarsson et al., 2005.

Legislation and licensing

Licenses are required to run all aquaculture operations in Iceland. To be granted a license, operators must first apply for a health and safety license with local authorities (MFA, 2008). After a health and safety license is granted by the Environmental and Public Health Office or The Environment Agency of Iceland, operators must then apply for an operation license with the Directorate of Fisheries. Operators who wish to obtain a license for more than 200 tonnes a year must apply to the National Planning Agency, who will then decide if there is a need for a formal environmental assessment (MFA, 2008). After a license is obtained, regular monitoring of the culture area is undertaken by the Icelandic Food and Veterinary Authority (Matvælastofnun [MAST]) in cooperation with the Marine Research Institute (MRI).

Currently, there are no policies regarding marine mammal interactions with aquaculture operations in Iceland (B. Björnsson, personal communication, May 20th, 2014). Thus, marine mammal interactions are not considered when aquaculture licenses are issued and aquaculture companies are not required to undertake mitigation measures to reduce the risk of negative interactions occurring (B. Björnsson, personal communication, May 20th, 2014). Moreover, it is mandatory for all marine mammal bycatch from commercial fishing to be reported (Gunnlaugsson, Pálsson & Ólafsdóttir, 2014); however, there are also no requirements for aquaculture companies to report any entanglement events (G. Víkingsson, personal communication, April 10th, 2014).

Potential for expansion

It has been suggested by the MFA (2008) that growth of the mussel farming industry in Iceland should be supported with actions to support infrastructure, research and increased services to the industry. The price for mussels has been rising in Europe and will likely stay high due to limited farming areas in Europe (MFA, 2008). There is abundant space in Iceland for the production of mussels and it is likely to bring economic prosperity to rural communities (MFA, 2008).

2.3 Marine megafauna interactions

Marine megafauna, including marine mammals, sea turtles, seabirds and sharks, are prone to interact with a variety of gear types in the marine environment, including fishing gears, aquaculture operations, marine debris, and renewable energy moorings (Benjamins et al., 2014). Interactions may be direct, including fatal and non-fatal entanglements, damage to gear, collisions, and depredation, in which an animal feeds on captured fish or stock from nets, and/or biological, including habitat loss or degradations and reduced wild food supply (Read, 2008; Kemper et al., 2003). This thesis will focus on direct interactions, specifically entanglements, between cetaceans and sea turtles with mussel aquaculture. However, due to the lack of research on this topic to date, interactions with other gear types, specifically entanglement in fisheries gears, will also be discussed below, as this issue is particularly prevalent in the fisheries sector.

2.3.1 Species groups discussed

Mysticetes (baleen whales)

The baleen whales include four families: the right whales, pygmy right whale (*Caperea marginata*), the grey whale (*Eschrichtius robustus*), and the rorquals, including species in the genus *Balaenoptera* (minke whale, sei whale, fin whale, blue whale, etc.) and the humpback whale (*Megaptera novaeangliae*; Shirihai & Jarret, 2006). Many baleen whales exhibit complex migratory behaviour, moving between foraging grounds in higher latitudes during the summer, and breeding and calving grounds in lower latitudes during the winter (Shirihai & Jarret, 2006). Mysticetes generally feed by engulfing large amounts of fish or crustaceans, generally in the water column or at the surface (Wilson, Batty, Daunt, & Carter, 2006). They also tend to be found alone or in small groups (Wilson et al., 2006).

Odontocetes (toothed whales and dolphins)

There are 10 different families of toothed whales and dolphins, the largest of which are the oceanic dolphins and beaked whales (Shrihai & Jarret, 2006). Other families include the porpoises, several families of river dolphins, the narwhal (*Monodon monoceros*) and beluga (*Delphinapterus leucas*) forming one family, and the sperm whale (*Physeter macrocephalus*) forming its own family (Shrihai & Jarret, 2006). Many toothed whales exhibit reduced migratory behaviour, and in some cases may be largely sedentary, or may make seasonal movements, potentially between inshore and offshore areas (Shirihai & Jarret, 2006). Many larger odontocetes occur offshore, but are known to occasionally venture into shelf, or coastal waters (Wilson et al., 2006). Some odontocetes, particularly the delphinids, are very social and tend to be found in groups and feed on a wide variety of fish and squid, mostly in the water column, but may also feed on some bottom species (Wilson et al., 2006). Odontocetes, unlike mysticetes, are also known to be able to detect objects under water using echolocation (Houser et al., 2005; Madsen, Johnson, Zimmer, & Tyack, 2005; Miller, Johnson, & Tyack, 2004; Au, Frankel, Helweg, & Cato, 2001).

Sea turtles

There are seven species of sea turtles (superfamily Chelonioidea) under two families, including the leatherback sea turtle (*Dermochelys coriacea*), the loggerhead sea turtle (*Caretta caretta*), the green sea turtle (*Chelonia mydas*), Kemp's ridley sea turtle (*Lepidochelys kempii*), hawkbill sea turtle (*Eretmochelys imbricate*), flatback sea turtle (*Natator depressus*) and olive ridely sea turtle (*Lepidochelys olivacea*). Five of these species have a circumglobal distribution, sometimes migrating great distances foraging areas and breeding grounds. The two remaining species, the Kemp's ridley sea turtle and the flatback sea turtle, have a restricted distribution in the Gulf of Mexico and waters around northern Australia and southern Papua New Guinea, respectively (World Wildlife Fund [WWF], n.d). Most species spend much of their live in continental shelf waters (WWF, n.d.).

2.3.2 Interactions with aquaculture

Marine mammals and sea turtles may interact with two types of marine aquaculture operations: intensive raising of finfish, such as salmon and sea bass, and extensive raising of shellfish, such as mussels and oysters (Würsig & Gailey, 2002). Interactions occur as a result of an overlap between the spatial location of aquaculture operations and habitat space (including foraging, breeding, resting, socializing areas) and migratory routes of marine mammals and sea turtles (Clement, 2013; Kemper et al., 2003). If a farm is physically located within the distributional range of a particular species, the type of gear used, the operational procedures employed, and their timing will then influence the probability of interactions occurring. These factors will also affect the degree of impact to an individual or population, as well as the aquaculture operation itself (Clement, 2013; Kemper et al., 2003). The species in question is also likely to influence the nature of the interaction as well as the probability of an interaction occurring. Some individuals, such as juveniles, old, diseased, or disoriented individuals may be more prone to become involved in direct interactions, such as entanglements or collisions with certain gear types (Wilson et al., 2006; Kemper et al., 2003).

With regards to finfish aquaculture in nearshore environments, the stock in holding pens and excess feed can act to attract predators, especially pinnipeds (Würsig & Gailey, 2002). Thus, most documented interactions with finfish operations involve pinnipeds, which can cause damage to gear and losses from predation (e.g. Kemper et al*.,* 2003; Nash et al., 2000). However, as interactions with finfish aquaculture operations are not the focus of this work, they will not be discussed further.

Shellfish aquaculture

In contrast to finfish aquaculture, there are far fewer documented cases of marine mammal and sea turtle interactions with shellfish aquaculture to date (Kemper et al., 2003). However, a lack of reported interactions does not mean that these interactions do not occur and an expanding industry may alter the scale of effects and prompt concerns (Clement, 2013; Lloyd, 2003). Impacts to marine mammals and sea turtles from shellfish aquaculture operations may include habitat modification and/or exclusion, and entanglements (Clement, 2013). In contrast to finfish aquaculture, shellfish operations do not require supplementary feeding and are therefore not generally an attractant to marine mammals and other marine megafauna (Würsig & Gailey, 2002). Furthermore, gear damage and loss of product from depredation are unlikely to pose a significant threat to shellfish operations in most areas as the only marine mammals to routinely feed on shellfish are sea otters (*Enhydra lutris*), river otters (*Lontra canadensis*) and walruses [1](*Odobenus rosmarus*) (Kemper et al., 2003; Würsig & Gailey, 2002; Gunnarsson, n.d.).

Compared to the more localized finfish aquaculture, shellfish aquaculture can take up substantial space in inland waterways, which may be used as breeding, resting, foraging, socializing, and travelling space for marine mammals (Ribeiro et al., 2007; Würsig & Gailey, 2002). In Admiralty Bay in New Zealand, for example, dusky dolphin habitat use has been found to overlap significantly with mussel farming operations in the area (Pearson, 2009; Markowitz, 2004). This has the potential to affect their foraging and travelling behaviour as they are known to avoid areas utilized for aquaculture, which may be largely due to the fact that it restricts their ability to efficiently aggregate their prey (Pearson, 2009; Markowitz, 2004; Würsig & Gailey, 2002). Shellfish aquaculture operations in Chile have also shown to restrict habitat use of Chilean dolphins, as is the case for bottlenose dolphins in Shark Bay, Australia (Ribeiro et al., 2007; Watson-Capps & Mann, 2005). Shellfish aquaculture that utilizes numerous ropes in the water column, such as longline mussel aquaculture, may also pose an entanglement risk to cetaceans and sea turtles (Clement, 2013; Kemper, 2003). Specific entanglement reports of cetaceans and sea turtles in mussel aquaculture gear will be discussed in the proceeding section.

2.3.3 Entanglement

There is growing international concern regarding the entanglement of cetaceans and sea turtles in materials of anthropogenic origin in the marine environment. For the purposes of this thesis, entanglement specifically refers to the wrapping of lines, netting, or other materials of anthropogenic origin around body of an animal, and may result in animals towing or being anchored by the entangling material (IWC, 2010). Entanglement differs from bycatch, which is the inadvertent capture of animals in fishing gear (IWC, 2010). Entanglement is closely related to bycatch, however, as it can occur in the nets and associated ropes and lines of many fishing gears (IWC, 2010). Benjamins et al. (2014) also note, however, that the difference between bycatch and entanglement is largely artificial as

[1] Although eider ducks and sea stars may pose a threat in Iceland (Gunnarsson, n.d.)

"both entanglement and bycatch result in animals being captured or artificially restrained to the point where injury or death occurs" (pg. 4). This phenomenon is thought to cause widespread mortality and injury of whales and sea turtles and poses a concern for conservation and population viability, as well as the welfare of affected individuals (e.g. Knowlton, et al., 2012; Cassoff et al., 2011; James et al. 2005; Read et al., 2006). Most reported cases of entanglement involve fisheries gears, with the biggest contributors being pots and gillnets (Groom & Coughran, 2012; IWC, 2010; Read et al. 2006; Johnson et al., 2005). Other gear types, such as marine debris, moorings and aquaculture can also be involved in entanglement, the later of which will be the focus of this thesis. To date there are limited records of entanglement in aquaculture gears, however this could become a greater threat with expanding industry (Clement, 2013; IWC, 2010; Kemper et al*.,* 2003; Würsig & Gailey, 2002; Moore & Wieting, 1999).

Causes of entanglement, susceptibility, and affected species

Cetaceans, specifically large baleen whales, are the most frequently reported groups of marine megafauna involved in entanglements, with humpback whales, minke whales, and North Atlantic right whales among the most commonly reported species (Benjamins, Ledwell, & Davidson, 2012; Groom & Coughran, 2012; Knowlton et al., 2012; IWC, 2010; Northridge et al., 2010). Large whale species appear to be more vulnerable to entanglement than smaller cetacean species, such as dolphins and porpoises, which are more prone to be caught as bycatch in nets due to their smaller size (Benjamins et al., 2014). With that being said, there are reported cases of entanglement involving a variety of dolphin species, most of which have occurred in ropes associated with fishing equipment (e.g. Marine tucuxis dolphin [*Sotalia guianensis*]; Azevedo et al., 2009).

Many baleen whales inhabit and migrate across coastal shelf waters, where they are likely to encounter many materials of anthropogenic origin that may pose an entanglement risk (Groom & Coughran, 2012; Cassoff et al, 2009). Although estimates are lacking on a global scale, entanglements are thought to be prevalent across many baleen whale populations and pose a significant threat to many of these populations (Read et al., 2006). In areas where this issue has been studied, a large portion of whales have been reported entangled in fishing gears, or have shown evidence of previous entanglement through scar-based analysis, including humpback whales, North Atlantic right whales, and minke whales (Benjamis et al., 2012; Knowlton et al., 2012; Song, Kim, Zhang, & Kim, 2010;

Neilson, Straley, Gabriele, & Hills, 2009; Read et al., 2006; Robbins & Mattila, 2004). Entanglements appear to be common occurrences in the North Atlantic, and have also been recorded off Alaska, Korea, Russia, Hawaii, Ecuador, and Western Australia (e.g. Benjamins et al., 2012; Groom and Coughran, 2012; Knowlton et al., 2012; Nielson, Straley, Gabriele, & Hills, 2009; Northridge et al, 2010; Song et al., 2010; Alava, Barragan, Castro, & Carvajal, 2005; Johnson et al., 2005; Mazzuca, Atkinson, & Nitta, 1998).

Any rope extending into the water column may pose an entanglement risk when overlapping with essential habitat or migratory routes of baleen whales, as well as other species of marine megafauna (Cassoff et al., 2011; Johnson et al., 2005). Nevertheless, there is some debate regarding the exact mechanism by which the process of entanglement occurs (Benjamins et al., 2014). For example, whether the entanglement occurs because the animal fails to detect the rope, if the animal does not perceive it as a threat, or due to deliberate contact with the rope (Benjamins et al., 2014). Different species may detect lines in the water column using vision, acoustics, or by detecting downstream disturbances in the water, which may be compromised in certain environmental conditions, such as low light conditions, or storms (Benjamins et al., 2014). Some species may also be able to detect certain colours better than others. For example, Kot et al. (2012) found that minke whales were able to detect and react to ropes simulating single buoy lines in the water column and were more likely to detect ropes that were white or black. Additionally, a study by Kraus, Fasick, Werner, and McFarron (2014) found that North Atlantic right whales were able to detect red and orange ropes at greater distances than ropes that were green or black. Odontocetes, such as harbour porpoises, also possess the ability to detect objects using echolocation, and have been shown to detect lines in the water column at distances of tens of metres (Nielson et al., 2012). Furthermore, it has been shown that juveniles or calves may be more likely to be involved in an entanglement than adult whales due to a lack of experience and inquisitive nature, and may act inappropriately when confronted with a hazard (Benjamins et al., 2014; Knowlton et al., 2012). Some individuals may also become distracted during feeding, leading to a higher risk of entanglement (Benjamins et al., 2014).

As mentioned above, the most common gear types involved in baleen whale entanglements are from fixed fisheries, particularly pots (e.g. lobster and crab) and gillnets, and many of these entanglements involve the buoy line and/or groundline (Figure 9). Johnson et al. (2005) found that a majority of the entanglements involving buoy line involved line made of both floating and sinking line sliced together, while a majority of the entanglements made of groundline involved floating lines. An entanglement is thought to occur when an animal collides with the gear and is unable to remove itself due to the line being caught in various parts of its body (Benjamins et al, 2012; Johnson et al., 2005; Robbins and Mattila, 2004; Knowlton & Kraus, 2001). Thus, morphology and degree of streamlining are also likely to contribute to entanglement risk (Johnson et al., 2005). For example, large appendages relative to body size, such as the pectoral fins on a humpback whale, as well as rough or rigid external features, which are also present on a humpback whale's pectoral fins, are thought to increase entanglement risk (Benjamins et al., 2014; Johnson et al., 2005). Flexibility is also another factor that may play a role, making it harder for larger whales to escape entanglement (Benjamins et al., 2014).

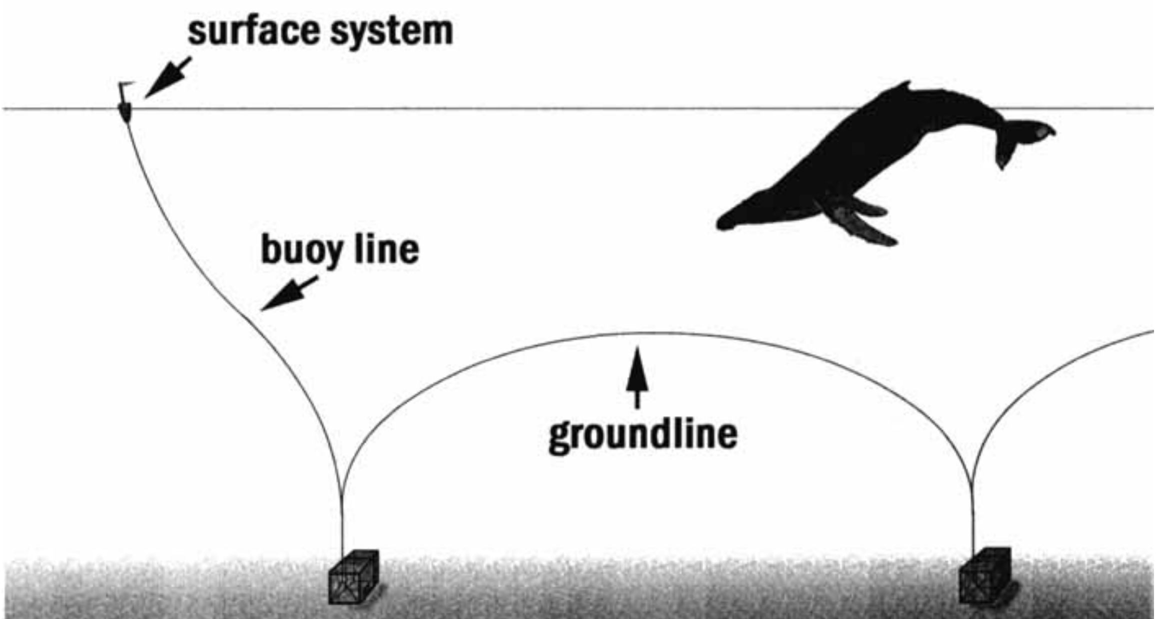

Figure 9. Generalized diagram of a pot gear and its associated parts, including groundline and buoy line. From Johnson et al., 2005. Copyright [2005] by the Society for Marine Mammalogy. Reprinted with permission.

Johnson et al. (2005) found that the most common point of attachment in entangled right whales was the mouth, while both the tail and mouth were common points of attachment for entangled humpback whales. Entanglement of baleen whales across the mouth is more likely to occur in areas where they come to forage as their filter feeding behaviour involves swimming with their mouths open, either intermittently in the form of lunge feeding, like the humpback whale, or continuously like the right whale (Cassoff et al. 2011; Johnson et al., 2005). Fewer entanglements involving the mouth are known to occur in migratory routes of baleen whales (Johnson et al., 2005). Entanglements of anchored animals are more likely to involve body wraps and multiple body parts, when compared to whales that have broken free and are towing gear (Johnson et al., 2005). Body wraps are thought to occur as a result of rolling after initial attachment, in attempt for the whale to free itself (Johnson et al., 2005). Tail wraps are thought to be an end result of an initial entanglement around the body (Johnson et al., 2005).

Ropes associated with fixed fisheries also pose a threat to sea turtles, particularly the leatherback turtle, which has a circumglobal distribution, and is listed as vulnerable by the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (James et al., 2005; López-Mendilaharsu, Rocha, Miller, Domingo, & Prosdocimi, 2009; NMFS, 2008; Zollet et al., 2009; Wallace, 2013). The leatherback turtle migrates great distances between coastal and shelf waters from tropical nesting grounds and temperate foraging grounds, leading to potentially widespread interactions with fixed fishing gear (López-Mendilaharsu et al., 2009; James et al., 2005). Exact estimates on the severity of leatherback turtle interactions with fisheries are, however, unknown (James et al., 2005). Most leatherback turtle conservation efforts have focused on interaction with pelagic fisheries; however, a study by James et al. (2005) has shown that coastal and shelf waters in northern latitudes, particularly the northeastern coast of the US and Canada, are high-use areas for leatherback turtles, where interactions with fixed fisheries pose more of a threat to the species than what has been previously recognized. James et al. (2005) collected eighty-three records of leatherback entanglements in fixed fishing gear in eastern Canada from 1997–2003, 95% of which involved entanglements of one or both front flippers in buoy lines. Furthermore, 18% were reported dead, while five turtles were found to be free-swimming, trailing ropes. James et al. (2005) also indicate that this is likely a very small fraction of total leatherback entanglements recorded in eastern Canada. Leatherback turtles have also been reported entangled in pot and trap fisheries in the US, UK and Irish waters (Zollet, 2009; NMFS, 2008b; Doyle, 2007; Pierpoint, 2000). Loggerhead turtles, have also been reported in pot and trap fisheries on the east coat of the US, and some argue they are susceptible to entanglement in these particular fisheries as they attempt to feed on bait (National Marine Fisheries Service and US Fish and Wildlife Service [NMFS and USFWS], 2008).

Extent

The full extent of entanglement of cetaceans and sea turtles is unknown as reports are vastly underestimated; however, it has been estimated that hundreds of thousands of cetaceans and other marine mammals die unintentionally in fishing gear every year (IWC, 2014; Read et al., 2006). Entanglement records are usually found within a wider range of bycatch records, which as a whole are likely to be huge underestimates (Read et al., 2006). Entanglement incidences are likely to be underreported as they are based solely on observations, and the likelihood of witnessing an incident is very small (Johnson et al, 2005). Entanglement events often occur far from shore, underwater, and larger species may be able to break free before being recorded. Chronically entangled whales may also become emaciated if unable to eat, and unlike some species of healthy whales, will sink after they die, further leading to entanglement underestimates (Kraus et al, 2005). Fishermen may also under report entanglements for fear of being reprimanded or having further restrictions placed on them (Johnson et al., 2005). Furthermore, reporting systems may not be in place, or those that are may be ineffective and inadequate (Benjamins et al., 2014; Read et al., 2006). Even in areas where there are well-established reporting and response networks, entanglements have been shown to be vastly underreported (Johnson et al., 2005). This is supported by the fact that multiple studies using scar-based analysis have found that more than half of the individuals in some large whale populations have been entangled at least once in their life, including 52–78% of humpback whales in northern Southeast Alaska (Nielson et al., 2009) and 82.9% North Atlantic right whales, with an annual rates of entanglements estimated to be 25.9% (Knowlton et al., 2012). Furthermore, an annual entanglement rate based on scar-based analysis was estimated to 12.1% for humpback whales on the east coast of the US, with an annual mortality rate due to entanglement estimated to be approximately 3% (Robbins, Landry, & Mattila, 2009). It is likely that other large whale populations are suffering from similar rates of entanglement, but data is often not available (Benjamins et al., 2014).

Outcome

Entangled animals may drown if unable to reach the surface to breathe, with the degree of entanglement and size of the animal largely affecting this outcome (Cassoff et al., 2011). Benjamins et al. (2012) found that minke whales, a small baleen whale species, were found dead more often than bigger species, such as the humpback whale. The researchers also note that minke whales may exhibit similar behaviour to smaller odontocete cetaceans, such as the harbour porpoise (*Phocoena phocoena*), which have exhibited spinning behaviour when trying to break free of a gillnet, which results in the animal becoming very tightly entangled (Benjamins et al., 2012). Even if the animal is able to break free, which is more likely for larger whales, gear may remain attached, which may affect its chance of survival. Entangled lines can cause varying degrees of tissue damage, hemorrhaging, and infection, as well as impairing foraging ability if they are in or around the mouth (Moore & Van der Hoope, 2012; Cassoff et al., 2011; Woodward et al. 2006). Entanglement events can also lead to chronic stress repsonses in affected individuals, which can contribute to the development of systemic infections (Cassoff et al., 2011). Entangled gear may also increase drag, leading to higher energy demands and reduce ability to carry out necessary life functions such as foraging, diving, and migrating (Moore & Van der Hoope, 2012). Lethal cases can lead to a very slow death, which in some cases for large baleen whales can take as long as 5–6 months to 1.5 years, leading to serious concerns for the welfare of affected individuals (Cassoff et al., 2011; Moore et al., 2006; Knowlton & Kraus, 2001).

Many species of cetaceans and sea turtles are slow growing and have low reproductive rates, and as a result are inherently vulnerable to adult mortality, and thus fatal entanglement could have a significant impact on the conservation of some species (Lewison, Crowder, Read, & Freeman, 2004). In populations with very low numbers, such as the North Atlantic right whale, which is estimated to number around 500 individuals, one fatal entanglement could severely threaten the survival of the population (S. Lindell, personal communication, April, 2014; Pettis, 2011). Furthermore, annual entanglement mortality rates as high as 3%, which have been determined for some large whale populations (e.g. Robbins et al., 2009), are likely to have a negative impact on population growth (Benjamins et al., 2014).

2.3.4 Entanglement reports of cetaceans and sea turtles in mussel gear

Some shellfish operations, such as longline mussel aquaculture, which is the focus of this thesis, use ropes in the water column that may pose an entanglement risk when overlapping with distributions of cetaceans and sea turtles (Clement, 2013; Kemper et al., 2003). Despite the few documented cases to date, some shellfish developments are venturing offshore in response to user-conflicts and space constraints, where potential conflicts, particularly cetacean entanglements, may increase if they are not properly sited or managed (Clement 2013, Moore & Wieting, 1999).

Bryde's whale, Great Barrier Island, New Zealand

In August 1996, a Bryde's whale was found dead after becoming entangled in a mussel spat collecting rope near Great Barrier Island New Zealand. This incident was first referenced in *Seafood New Zealand* in 1996 and has since been referred to in various secondary sources (e.g. Clement, 2013; Lloyd, 2003). The mussel line was found wrapped around the body and tightly lodged in the animal's mouth. An official necropsy was never performed on the carcass, which has led to some dispute over whether the whale was alive during the time of the entanglement (Clement, 2013). The Bryde's whale is listed as data deficient by the IUCN and species taxonomy has not yet been resolved, and more than one species or subspecies may exist (Reilly et al., 2008b). Therefore, uncertainty exists regarding the range distribution of Bryde's whales, although they are thought to occur in the Atlantic, Pacific, and Indian Oceans, between 40°N and 40°S (Reilly et al., 2008b). Bryde's whales are known to occur in waters of the Hauraki Gulf of New Zealand, which is bordered by Great Barrier Island, all year round, but their densities are highest during the summer (December–February in New Zealand) (Baker & Madon, 2007). The whales are known to both travel and feed in this area (Baker & Madon, 2007).

Humpback whale, Albany, Western Australia

A humpback whale calf was found entangled in mussel spat collecting rope in King George Sound, off Albany in Western Australia in August 2005 and was safely disentangled and released (Groom & Coughran, 2012). The following text is based on information collected via email from Doug Coughran from the Department of Conservation and Land Management of Western Australia (personal communication, November 17th, 2014). The humpback whale calf had initially caught the rope in its mouth and turned, leading to two wraps of the rope around its body and four wraps around the joint of its right flipper. The rope was made of black nylon and was 20 mm in diameter. The calf was struggling to remain at the surface during the disentanglement, as there was a significant amount of weight on the rope, which was anchored through an anchor line to the seabed. Therefore, four buoys had to be attached to the surface line in order to cut the anchor line to keep the calf at the surface so it could be cut free. During this time, the mother remained close to the calf and one point came as close as 50 m. The calf was cut free of its body and joint wraps, with only one piece of trailing rope left in its mouth, which was likely to have been shed when the whale opened its mouth.

Humpback whales are found in all major ocean basins and as a whole are listed as a species of least concern by the IUCN and are the most common whale species found in Western Australia waters (Reilly et al., 2015d; Groom & Coughran, 2012). They are known to make annual migrations between Antarctica to northwestern Australian calving grounds along the Western Australia coastline (Jenner, Jenner, & McCabe, 2001). Northward migrations last between June and August, and southward migrations last from August to November (Jenner et al., 2001).

North Pacific right whale, Namhae, South Korea

On February 11th, 2015, an endangered North Pacific right whale (*Eubalaena japonica*) was safely disentangled and released from mussel grow-out ropes in Namhae, Korea. The following information was provided via email by Yong-Rock An, a researcher at the Cetacean Research Institute in Korea (personal communication, February 23rd, 2015). The mussel farm in question is 50,000 m^2, located approximately 600 to 900 m from shore, at a water depth of 15 m. The farm uses a surface-buoyed longline system with single droppers. The diameter of the rope is 60 mm but much thicker with attached mussels. Four thick mussel grow-out ropes, measuring 240 mm in diameter with attached mussels, were wrapped around the caudal peduncle and fluke of the whale. The disentanglement team was able to cut three out of the four ropes but had to stop the operation at midnight due to safety precautions. The next morning, the forth rope was found at the site of the entanglement and the whale was nowhere to be found, leading researchers to conclude that the whale had freed itself of the last remaining rope. An also stated that large whales are hardly seen in the area, but there are many finless porpoises (*Neophocaena phocaenoides*) (personal communication, February 23rd, 2015).

This is the first sighting of a North Pacific Right whale in Korean waters since 1974 (Y-R. An, personal communication, February 23rd, 2015). The North Pacific Right whale population was severely depleted during commercial whaling of the 19th and 20th century; it has been estimated that as much as 26,500–37,000 animals were taken during 1839–1909, and the population was further depleted during illegal whaling activities in the 20th century (Clapham et al., 2004; Scarff, 2001). The North Pacific right whale is currently listed as endangered by the IUCN, with an estimated population of less than 500 individuals (Reilly et al., 2008c). Their distribution is also believed to be more offshore and remote compared to the more intensively studied North Atlantic right whale and little is known about their habitat use (Reilly et al., 2008c). Historical records however, reveal migrations northwards in the summer and southwards in the winter, but their exact wintering grounds and calving are unknown (Clapham et al, 2004). There are believed to be two discrete populations, the eastern North Pacific subpopulation and the western North Pacific subpopulation, with the western population occurring in Sea of Okhotsk during the summer, and moving south to the Sea of Japan, Taiwan Strait, and the Bonin Islands during the winter (Reilly et al., 2008c; Clapham et al, 2004). The eastern subpopulation is thought to occur in the southeastern Bering Sea, the Aleutian Islands, and the northern Gulf of Alaska during the summer, and occur in Baja California Sur (Mexico) during the winter (Reilly et al., 2008c; Clapham et al, 2004).

Leatherback turtles, Newfoundland, Canada

Two endangered leatherback turtle entanglements have also occurred in mussel gear in Notre Dame Bay in Newfoundland, Canada. The following information is based on information collected during informal phone interviews with Terry Mills, owner and operator of Norlantic Processors, the company in which both entanglements occurred (personal communication, January 27th, 2015 and February 22nd, 2015). Both entanglements occurred at a deep-water site called Mouse Island-Tea Arm, with a maximum water depth reaching approximately 115 m, and covering an area of approximately 430,000 m^2. The Mouse Island-Tea Arm is completely submerged down to 18 m in the winter (usually between August and June) do to arctic ice movement is the bay. However, during spat collection in the summer, the collectors are set approximately 0.3 m below the surface. Exact timing of deployment varies from year to year, but usually takes place between mid-July to Mid-August. The ropes are then submerged after the spat collection, which usually lasts six weeks.

The first entanglement occurred in summer 2010 in continuous spat collecting ropes between 2–3 m long and was fatal. During the time of this entanglement, the lines had just been submerged after spat collection, and the entanglement occurred at depth, preventing the turtle from reaching the surface. It was only discovered after it became bloated and floated to the surface. It was estimated to weigh between 300 and 360 kg, and was entangled only around once around one flipper. The second entanglement occurred in August 2013 in a rope leading from a buoy to spat collectors. The turtle was entangled around the neck as well as both flippers, but was able to reach the surface to breathe. It was discovered by recreational boaters and released.

As stated above, coastal shelf waters off the northeastern US and eastern Canada have been shown to be high-use areas for leatherback turtles, where they come to forage on various species of gelatinous zooplankton during the summer months (James et al., 2005; McMahon & Hays, 2006). Mills noted that leatherback turtles have only been coming into Notre Dame Bay for the past six years to feed on jellyfish during the summer, which are subsequently feeding on the mussel larvae (personal communication, January 27th, 2014). He also noted that humpback whales occasionally come and swim through the farm but they have never had an entanglement involving a cetacean (personal communication, January 27th, 2014).

Humpback whale, Miðfjörður, Northwest Iceland

There is also one documented entanglement case in Iceland of a humpback whale that died in an experimental mussel farm in Miðfjörður in Northwest Iceland on August 26th, 2010 (Figure 10). The following information is based on an informal interview with Eðvald Daníelsson, the owner of the mussel farm in question, conducted in person on October 19th, 2014. The humpback was reported to be 8–9 m long and the tail was four meters wide, which may indicate it was a juvenile, as adult humpback range from 12–18 m in length (National Oceanic and Atmospheric Association [NOAA], 2015). The whale was believed to have drowned and was only discovered after the bloated carcass floated to the surface after two or three days. The entanglement occurred in single dropper spat collectors that were five meters long with a weight attached to the end and attached to a 50 m headrope.

The ropes were wrapped several times around the tail. The mussel ropes were initially at 25 m depth, but were found at 40 m. This entanglement had occurred in an experimental farm, and the mussel collectors had been put in the water two weeks prior to the event. The mussel grower also noted that he had had trouble sinking the ropes, and the weather was stormy at the time of the entanglement. Humpback whales distributions in Icelandic waters will be discussed in section 2.5.

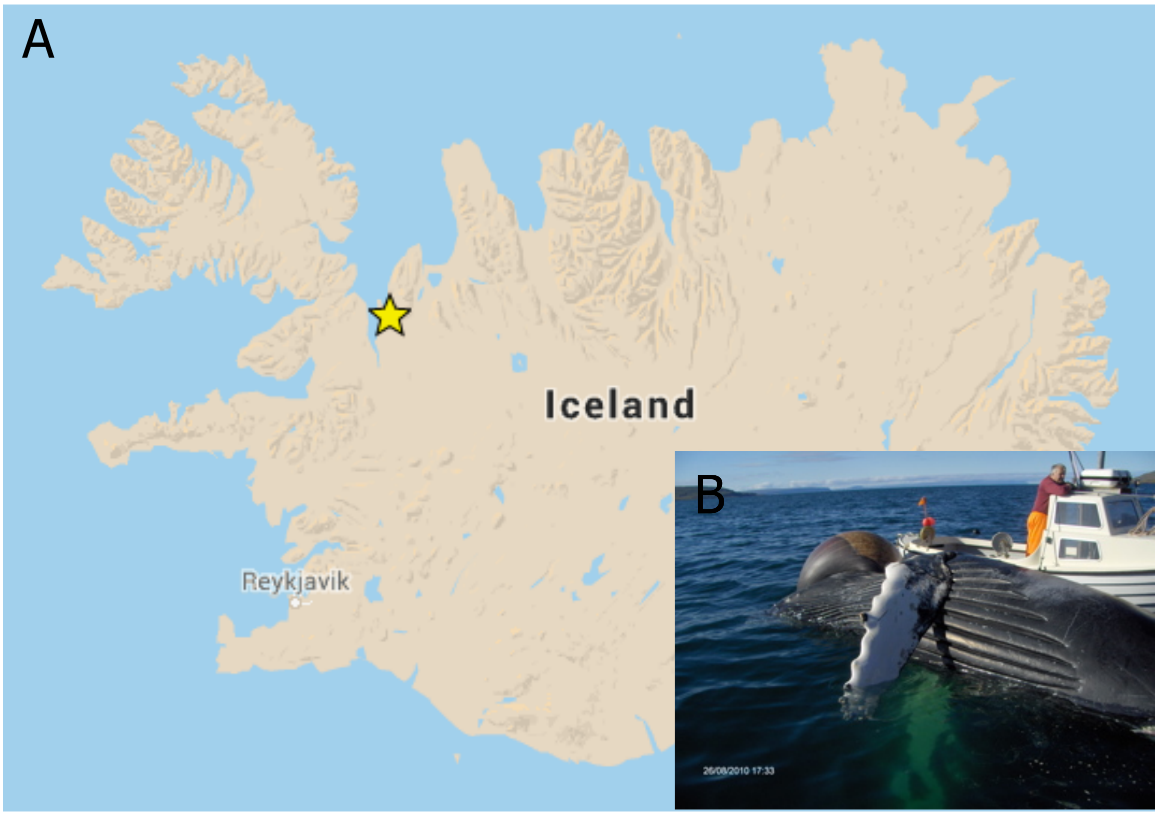

Figure 10. Fatal humpback entanglement, Miðfjörður, Northwest Iceland, August 26th, 2010. (a) Site of entanglement. Map copyright data [2015] by Google. Source: author. (b) Photograph of entanglement. Image by Eðvald Danielsson, 2010. Reprinted with permission.

2.3.5 Changing species distributions and abundances

Due to global climate change and rising sea surface temperatures, the distributions and migratory routes of some species may change as the outer limits of their range expand (Kintisch, 2006; McMahon & Hays, 2006). Therefore, species that are sensitive to changing water temperatures, such as the endangered leatherback turtle, are likely to increase in abundance in northern temperate water, where interactions with fisheries and aquaculture could increase (Doyle, 2007; McMahon & Hays, 2006). Further concerns for conservation may arise as endangered species start to appear in areas where conservation measures have not been implemented (Kintisch, 2006; McMahon & Hays, 2006).

Many populations of baleen whales were severely depleted during modern commercial whaling efforts in the 19th and 20th century and some may be slowly recovering after the ban on commercial whaling in the North Atlantic in 1955, the southern hemisphere between 1963 and 1964, and in the North Pacific in 1966 (Stevick et al., 2003). For example, North Atlantic right whale populations are slowly growing but are far from recovered and humpback whale populations are increasing across most of their range (NOAA, 2015; S. Lindell, personnal communication, March 31st, 2015). As populations begin to re-occupy pre-exploitation ranges, interactions with anthropogenic hazards are likely to increase (Benjamins et al., 2014).

2.4 Management and mitigation

Due to the continuing growth of aquaculture operations in nearshore environments and likely expansion in offshore environments, coupled with changing abundances and distributions of many species groups, direct interaction with cetaceans and sea turtles are likely to increase in the foreseeable future (Clement, 2013; IWC, 2010; Doyle, 2007; McMahon & Hays, 2006; Kemper et al*.*, 2003; Würsig & Gailey, 2002; Moore & Wieting, 1999). However, there has been little research looking into the specific entanglement risks associated with mussel aquaculture gear to cetaceans and sea turtles to date, and often fishing gear is used as a surrogate for mussel farming gear when considering entanglement risks, which is not necessarily pertinent as they differ greatly (D. Alves, personal communication, April 7th, 2014; Würsig & Gailey, 2002). Even though specific entanglement risks associated with mussel gear are unknown, it is still important to consider potential management and mitigations measures that can be taken to improve both the outcome for individuals and populations involved and the shellfish industries from economic loss due to damaged gear reduced production if a conflict does arise. The scale of impact will vary greatly depending on location and the species in question (Clement, 2013). Due to a possible wide range and scale of impacts, careful selection of farm siting is of the upmost importance (Clement, 2013). Additionally, since there has been little research looking into specific management and mitigation strategies for interactions with aquaculture operations, strategies related to entanglement in fishing gear, which in some cases could potentially be applied to aquaculture operations, will also be discussed below.

2.4.1 Fishing gear vs. aquaculture gear

As stated above, entanglement risks associated with fishing operations cannot be directly applied to mussel aquaculture operations, as they differ, both with respect to gear used and placement in the water column (Moore & Wieting, 1999). Many ropes associated with fishing gears tend to be thinner than those associated with mussel aquaculture operations, and thus may be more likely to wrap or entangle (Moore & Wieting 1999). The types of lines involved in most entanglements of baleen whales are the buoy lines and/or groundlines of pots and gillnets, which tend to measure less than 12 mm in diameter (Johnson et al., 2005). Lines associated with mussel aquaculture, on the other hand, are typically 20 mm or greater in diameter, and thus more substantial compared to those associated with fixed fisheries (Figure 11; Lindell & Bailey, 2015; Moore & Wieting, 1999). Some ropes, however, such as ropes leading to surface buoys and spat collecting ropes, are thinner (>12 mm) and may pose more of an entanglement risk in comparison to other culture ropes, such as mussel socks (>50 mm), which have not been considered much of an entanglement risk (Lindell & Bailey, 2015; Moore & Wieting, 1999). Further, mussel ropes tend to be under greater tension in the water column than those from fixed fisheries, which may make them less prone to form entangling loops in the water column (Lindell & Bailey, 2015; Moore & Wieting, 1999).

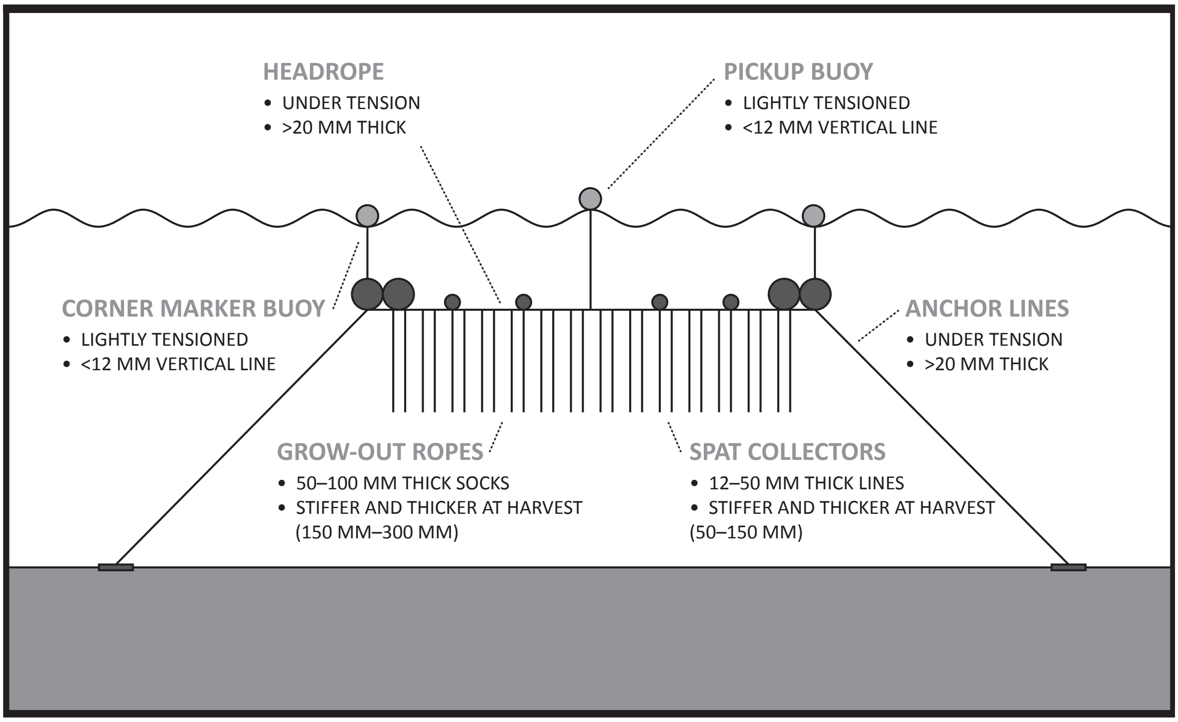

Figure 11. Longline mussel farm diagram. Adapted from Lindell and Bailey, 2015. Adapted with permission. Source: author.

2.4.2 Fixed fisheries

Entanglement of marine megafauna in fixed fisheries, particularly baleen whales, and sea turtles, is an issue that is being dealt with by marine resource management organizations in numerous parts of the world (e.g. Benjamins et al., 2012; Groom and Coughran, 2012; James et al., 2005). Groom and Coughran (2012) note that co-management with commercial fisheries is vital, and a range of management responses are available that work to reduce the number of entanglements and/or improve the outcome for the animal involved (Benjamins et al., 2012; Groom and Coughran, 2012). These include full or periodic area closures, modifications to gear, alteration of fishing practices, the presence of disentanglement organizations trained in recent and innovative disentanglement strategies, and the maintenance of a database for entanglement incidents and outcomes (Benjamins et al., 2012; Groom and Coughran, 2012).

There are several disentanglement organizations worldwide that will attempt to release entangled whales and other marine megafauna that are reported to them (Benjamins et al., 2014). The Global Whale Entanglement Response Network was also developed by the IWC, where knowledgeable leaders of established national disentanglement networks have come together to help train volunteers and extend aid to other areas where entanglements are known to occur (IWC, 2014). The success rates of these organizations depend on multiple factors including location, specifics related to each entanglement case (e.g. water depth and distance to shore) as well as financial resources (Groom & Coughran, 2005). The success rate is also dependent on disentanglement groups being trained in recent developments in disentanglement strategies (Groom & Coughran, 2005). One example is kegging, which utilizes floats to keep the whale on the surface, as well as to slow and tire it (Groom & Coughran, 2012). Some more recent advancement in large whale disentanglement strategies include satellite tagging to track a whale when a disentanglement could not be completed during one attempt, as well as sedation techniques (Mate, Mesecar, & Lagerquist, 2007; Moore, Reeb, Miller, & Smith, 2001). There are some concerns regarding sedation, however, including difficulty in estimating the size of the whale and dosage, as well as ensuring the whale does not drown during sedation (Groom & Coughran, 2012). It is also important for a relationship to be developed between the disentanglement organizations and fishermen, which will ensure that they will report entanglements without fear of being reprimanded or further restrictions being placed on them (Benjamins et al., 2012).

Various fishing gear modifications are available to reduce entanglements by either avoiding contact, or facilitating escapement or release once contact has occurred (Werner, Kraus, Read, & Zollett, 2006). Methods to avoid contact by physically excluding animals from the area of concern include acoustic pingers or acoustic deterrent devices (ADDs) to alert or scare animals away from gear posing an entanglement risk (Dawson, Northridge, Waples, & Read, 2013; Werner et al., 2006). Pingers have proven successful in significantly reducing bycatch of harbour porpoises in gillnets in the Gulf of Maine and their use has also been mandated off the Pacific coast of the US and parts of Europe (Consortium for Wildlife Bycatch Reduction, 2014). However, pingers may not be successful with all cetacean species and should only be used in circumstances where the target species has a large home range, so as not to displace them from a significant portion of critical habitat (Dawson et al., 2013). Habituation may also be an issue with some species (Cox, Read, Solow, & Tregenza, 2001). Other methods to avoid contact include methods to make lines more easily detectable in the water column. This includes the use of certain colours that are easily detected visually by certain species, such as red and orange, which have been shown to be detected at farther distances by North Atlantic right whales than green or black ropes (Kraus et al., 2014). Probably the most successful method to lower entanglement risk, however, is to reduce the number of potentially entangling lines in the water column. Acoustic releases, which are devices that would utilize an acoustic trigger to release a buoy attached to submerged pots for line retrieval, could also potentially be used to reduce then number of entangling lines in the water column when species of concern are present (Werner et al., 2006). Sinking grounline can also be used to reducing the number of potentially entangling lines (Knowlton et al., 2012; Johnson et al., 2005). Stiffening ropes and using lines under greater tension may also be used to prevent lines from bending, and thus preventing entanglement (Consortium for Wildlife Bycatch Reduction, 2014). One method to stiffen lines may be the use of “stiff lines”, which would theoretically be stiff in the water column and loose on deck, is also a possibility, although the technology is still being developed (Werner et al, 2006). Other methods include the use of rubber sections over ropes to stiffen them (McCarron, 2009). Methods facilitating escapement or release once contact has occurred include breakaway lines, or weak links, which would function normally for hauling but would enable a large whale to break free once entangled (Zollet, 2009; Werner et al., 2006).

Other changes to fisheries to reduce entanglement risks include reducing fishing effort or full or periodic area closures (Benjamins et al., 2014; Groom & Coughran, 2012). However, in order for area closures to be effective, a thorough understanding of migratory paths and essential habitat of whales and sea turtles is necessary in order to determine when and where entanglement may occur (Groom & Coughran, 2005). Reduced fishing effort and area closures also have a significant impact on the fisheries in question (Groom & Coughran, 2012).

Codes of conduct have also been produced by fishing industries in effort to reduce entanglements. An example of a detailed code of conduct was developed by the Western Australia Rock Lobster Fishery, which was released in 2006, and coincides with a reduction in reported entanglements (along with reduced fishing effort) (Groom and Coughran, 2012). This code outlines ways to reduce entanglements, including shortening pot rope lengths, avoid placing pots in clusters, and regular monitoring (Groom and Coughran, 2012). They also give instructions to fishers on what to do if they encounter an entanglement and encourage them to stand by an entangled whale until a disentanglement team arrives (Groom and Coughran, 2012). The highest amount of disentanglement success in Western Australia has been achieved when a vessel has been able to track a whale and update a disentanglement team as they prepare and travel to the operation (Groom and Coughran, 2012).

An example of a plan that has implemented many of these measures mentioned above is the Atlantic Large Whale Take Reduction Plan (ALWTRP), implemented by NOAA in the US, in order to reduce the entanglement of large whales, particularly the endangered North Atlantic right whale in fishing gear (National Marine Fisheries Service [NMFS], n.d.). The ALWTRP is composed of various components, including area closures and gear modifications, a large whale disentanglement program, research into whale populations and behaviour and gear modifications and interactions, as well as outreach programs in order to collaborate fishermen and other stakeholders (NMFS, n.d.). All marine mammals in US waters are protected under the Marine Mammal Protection Act of 1972 and all endangered or threatened species are protected under the Endangered Species Act of 1973 (ESA). North Atlantic right whales, being an endangered species, are protected under both of these acts. However, the species continues to face conservation concerns despite numerous protective measures that have been put in place; entanglement in fishing gears (specifically pot and gillnet fisheries), for example, is a major source of mortality and injury for this species (Johnson et al., 2005; Kraus et al., 2005). As mentioned above, a scar-based analysis study conducted by Knowlton et al. (2012) found that 82.9% of the population exhibited signs of at least one previous entanglement, while it was estimated that 25.9% of the population acquired entanglement wounds on an annual basis (Knowlton et al., 2012; Kraus et al., 2005). In order to protect this species from entanglements, several fishing regulations, including dynamic area closures and gear restrictions, have been implemented incrementally under the ALWTRP (Knowlton et al., 2012; NMFS, n.d.). Gear restrictions include sinking groundlines, and weak links connecting various parts of pot and gillnet gear (Knowlton et al., 2012). Despite these restrictions, several serious entanglements have been reported since, including four in 2010 and 11 in 2011 (Knowlton et al., 2012). Additionally, vertical buoy lines of fixed fishing gears have been shown to be a serious entanglement threat to large whales, which currently remain unregulated (Knowlton et al., 2012; Johnson et al., 2005). Furthermore, there are no current regulations to protect large whales from entanglement in fixed fishing gear in Canadian waters, where they are known to spend several months each year (Knowlton et al., 2012). Therefore, despite some actions taken to reduce large whale entanglements, further actions must be taken in order to effectively eliminate their occurrences (Knowlton et al., 2012). This case also underlines the importance of developing methods to monitor the effectiveness of any mitigation methods taken (Knowlton et al., 2012).

2.4.3 Shellfish aquaculture

Some management and mitigation measures that can be applied to fixed fisheries to reduce entanglements of cetaceans and sea turtles could potentially be applied to shellfish aquaculture operations, particularly with respect to timing and placement. The most important factor to consider, however, in limiting entanglement risk is the siting of aquaculture operations to minimize overlap between distributions of particular species (Clement, 2013). This requires information on abundance, distribution, and critical habitat (e.g. foraging and calving areas) of species of concern (Clement, 2013; Kemper et al, 2003). However, data of this sort is lacking for many species, and therefore ongoing research is required in many cases (Clement, 2013; Kemper et al, 2003). It is also critical to have information on both local and wider ranging knowledge of population sizes in order to determine the effect of fatal entanglements on long-term viability of a population or species (Kemper et al., 2003). Currently, only a few environmental quality standards and guidelines for aquaculture industries specific to marine mammals have been developed (Clement, 2013). In general, however, some guidelines recognize the importance of farm siting to reduce potential overlap with wildlife or critical habitats (e.g. British Columbia Shellfish Growers Association [BCSGA], 2013; NMFS, 2002). Some indicators for farm siting criteria include identification of the proximity of proposed sites to critical, sensitive, or protected habitats and species, identification and description of possible impacts to these habitats and species, description of strategies that may be employed to reduce these impacts, and adequate monitoring and assessment parameters to evaluate potential impacts (Clement, 2013; NMFS, 2002).

It is important for research to be conducted into gear modifications and design, maintenance features and operational procedures to minimize entanglement risk specific to shellfish aquaculture as the research that has been conducted with fishing gear is not always transferable due to differences between depth and gear configurations (S. Lindell, personal communication, April, 2014; Clement, 2013). An example of a research project to develop whale and sea turtle-friendly aquaculture gear, particularly oyster and mussel gear, is currently underway in Cape Cod Bay, Massachusetts (S. Lindell, personal communication, April, 2014). The ESA in the US requires that a consultation process be undertaken with the federal agencies when aquaculture projects are proposed in areas where endangered or threatened species are present, in order for conservation measures to be proposed to reduce any risks to these species (Moore & Wieting, 1999). Currently, there are proposals for vast areas of offshore shellfish farming to be undertaken in the northeastern US (Bragg, 2013). In Cape Cod Bay, for example, which is considered critical feeding and nursery habitat for the North Atlantic right whale, there is a proposal for a 50 acre shellfish farming area, including mussels, oysters, quahogs, and bay and sea scallops, that is under consideration (Bragg, 2013; Moore & Wieting, 1999). In this exact area, one North Atlantic right whale entanglement has occurred in fixed fishing gears since 2009, as well as twelve leatherback turtle entanglements since 2005 (Bragg, 2013). Currently, regional regulations applying to fixed fisheries have been applied to the area, including bans on all lines in the water column between February and April in Cape Cod Bay (when right whales may be present in the area), bans on all surface or subsurface horizontal lines, and the necessity for all vertical lines to semi-rigid (S. Lindell, personal communication, April, 2014; Nichols, Kenney, & Brown, 2008). This greatly limits the gear that can be used for shellfish farming in the area, which has led to the need for technology limiting entanglement risk to be developed (S. Lindell, personal communication, April, 2014). Research projects are now underway to develop whale and sea turtle-friendly subtidal aquaculture gear in order to minimize protected species entanglements in the area (S. Lindell, personal communication, April, 2014; Moore & Wieting, 1999). These include the use of helical screw anchors if they can prove cost effective, as they are more likely to keep a line under tension in the water column (S. Lindell, personal communication, April, 2014). Additionally, acoustic releases, which would enable bottom lines and gear to be retrieved and tended, or brought up when seasonal bans are in place, may prove practical for some aquaculture operations, if the technology can prove cost effective (S. Lindell, personal communication, April, 2014). Other possible modifications include stiffening lines with rigid or semi-rigid sleeves or replacing them with rigid poles (Lindell & Bailey, 2015; S. Lindell, personal communication, April, 2014).

2.5 Cetaceans in Icelandic waters

Eleven cetacean species are commonly seen in Icelandic waters, with minke whales (*Balaenoptera acutorostrata*), dolphins of the genus *Lagenorhynchus* (almost exclusively white-beaked dolphins [*Lagenorhynchus albirostris*]), humpback whales (*Megaptera novaeangliae*), and harbour porpoises (*Phocoena phocoena*) being among the most frequently encountered species (Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). Other species include the fin whale (*Balaenoptera physalus*), blue whale (*Balaenoptera musculus*), long-finned pilot whale (*Globicephala melas*), orca (*Orcinus orca*), sperm whale (*Physeter macrocephalus*), sei whale (*Balaenoptera borealis*), and the northern bottlenose whale (*Hyperoodon ampullatus*). Some species, including the minke and the humpback whale, are highly migratory and spend the summer months in the productive feeding grounds around Iceland, while migrating south to breeding grounds during the winter (Valtýsson, n.d). Densities of some cetaceans are therefore expected to be much higher during the feeding season that lasts from May to October (Basran, 2014). Other migratory species include the blue, sei, and fin whales, although they are found in more offshore waters, and little is known about their migratory patterns (Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). Other smaller cetaceans, such as dolphins of the genus *Lagenorhynchus* and harbour porpoises, appear to be present year round, although the exact movements are unknown (Víkingsson, Ólafsdóttir & Sigurjónsson, 2014).

Aerial sightings surveys of cetaceans in Icelandic waters were conducted in 1986, 1987, 1995, and 2001, and again in 2007, 2008, and 2009, in addition to shipboard surveys in 1987, 1989, 1995, and 2001 in June and July of each year as part of the North Atlantic Sightings Surveys (NASS), in effort to determine distributions and abundances, as well as possible trends through time (e.g. Pike, Gunnlaugsson, & Víkingsson, 2011; Pike, Gunnlaugsson, Víkingsson, Desportes, & Bloch, 2009; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009; Víkingsson, Pike, Desportes, Øien, Gunnlaugsson, & Bloch, 2009). In Iceland, fin whales were the focus of shipboard surveys, while minke whales were the focus of coastal aerial surveys, although all species encountered were recorded (Pike, Gunnlaugsson, Víkingsson, Desportes, & Bloch, 2009; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009; Víkingsson et al., 2009).

2.5.1 Species abundances and distributions

Common minke whale

The common minke whale (*Balaenoptera acutorostrata*) is listed as a species of least concern by the IUCN (Reilly et al., 2008a). Different subspecies are thought to be present in the North Atlantic, North Pacific, and Southern hemisphere (Reilly et al., 2008a). Minke whales, like most other baleen whales, are a migratory species, and will spend summer months feeding at high latitudes and winter months at breeding grounds at lower latitudes, although their migratory patterns are poorly known (Reilly et al., 2008a). In the North Atlantic, it is thought that some individuals may also winter in higher latitudes, although observation effort is not undertaken at this time (Reilly et al., 2008a). Minke whales are the most abundant cetacean species in Icelandic coastal shelf waters during the summer months, with a mean density from the aerial surveys in 1986, 1987, 1995, 1995, and 2001 reaching 0.07 animals/nm^2 (Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). The highest densities were observed in the southwest (Faxaflói Bay), southeast, and north of the country (Figure 12; Pike, Gunnlaugsson, Víkingsson, Deportes, Bloch, 2009; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). More recent aerial surveys from 2007, 2008, and 2009, reveal a similar distribution pattern, although almost no sightings were observed in the southeast (Pike, Gunnlaugsson, & Víkingsson, 2011). The results of both shipboard and aerial surveys from 1986 to 2001 indicate that the minke whale population remained stable, or slightly increasing, in Icelandic coastal waters during that time period, in addition to a relatively consistent distribution (Pike, Gunnlaugsson, Víkingsson, Deportes, Bloch, 2009; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). The surveys from 2007, 2008, and 2009, however, indicate lower numbers of minke whales in coastal shelf waters (Pike et al., 2011). It is thought that such an abrupt density decrease in coastal shelf waters is likely a result of a change in distribution to more offshore areas, following a shift in prey distributions, as opposed to a decrease in population size (Víkingsson, et al., 2014; Pike, Gunnlaugsson, & Víkingsson, 2011). However, due to a lack of data from offshore areas, a population decrease cannot be ruled out (Víkingsson et al., 2014; Pike, Gunnlaugsson, & Víkingsson, 2011).

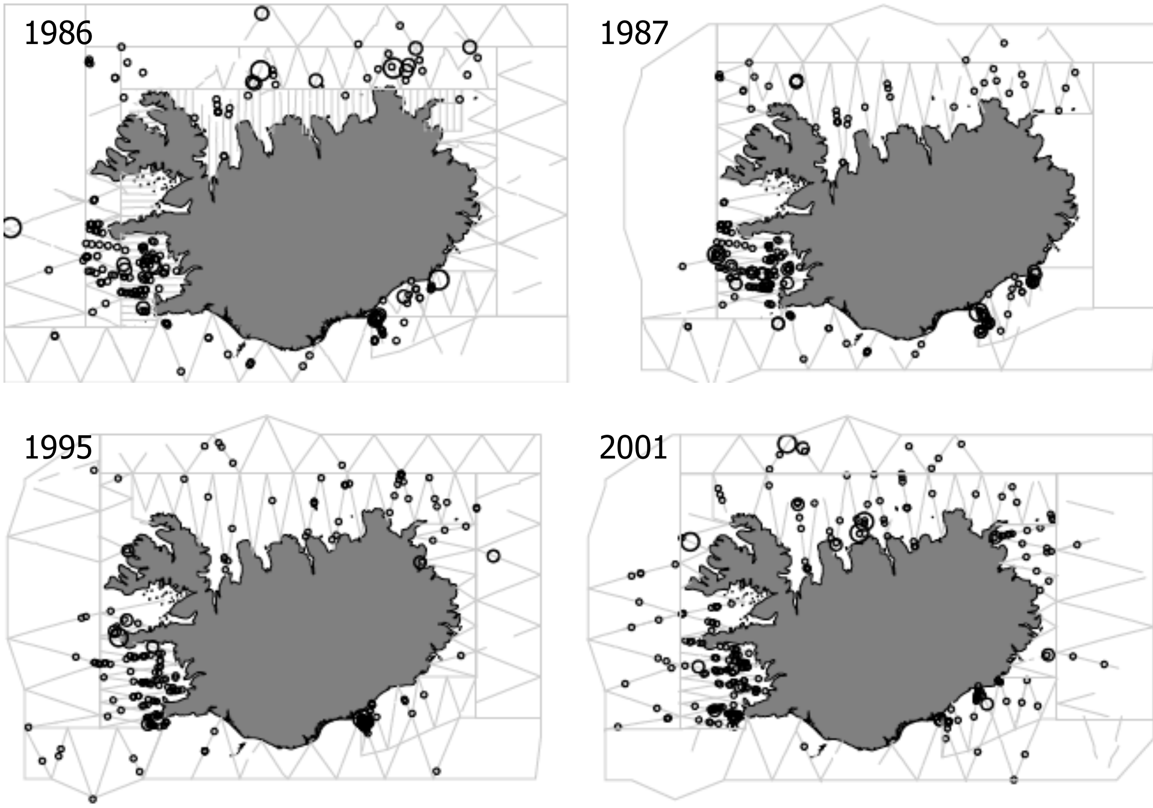

Figure 12. Sightings of minke whales from NASS aerial surveys, 1986-2001. The smallest symbol represents a group size of one, the next biggest symbol represents a group size of two, and bigger symbols represent a group of three whales or more. From Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009. Reprinted with permission.

Dolphins

Dolphins (*Lagenorhynchu*s spp.) were the second most common species group sighted in the 1986 to 2001 aerial surveys after minke whales (Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). Species identification was not always certain, but it is thought that a great majority of these sightings were white-beaked dolphins, a species of least concern according to the IUCN (*L. albirostris*) (Hammond et al., 2012; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). No apparent changes in abundance were revealed over the course of the summer aerial surveys, and were most common in the southwest, northeast, and southeast of the country, in nearshore waters (Figure 13). An abundance estimate for the 2001 aerial survey was 31,653 (95% CI 17,679–56,672) individuals in coastal waters, however, other cetacean sightings effort in the 1980's and 1990's indicate a similar distribution in nearshore water but also a continuous distribution into offshore areas, particularly into Denmark Straight between Iceland and Greenland (Gunnlaugsson, Víkingsson, & Pike, 2005). Therefore, this estimate does not apply to a unit stock (Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). Little is known about the movement patterns of dolphins in Icelandic waters, however, Magnúsdóttir (2007) found them to be present off the southwest coast of Iceland year-round (as cited in Rasmussen et al., 2013).

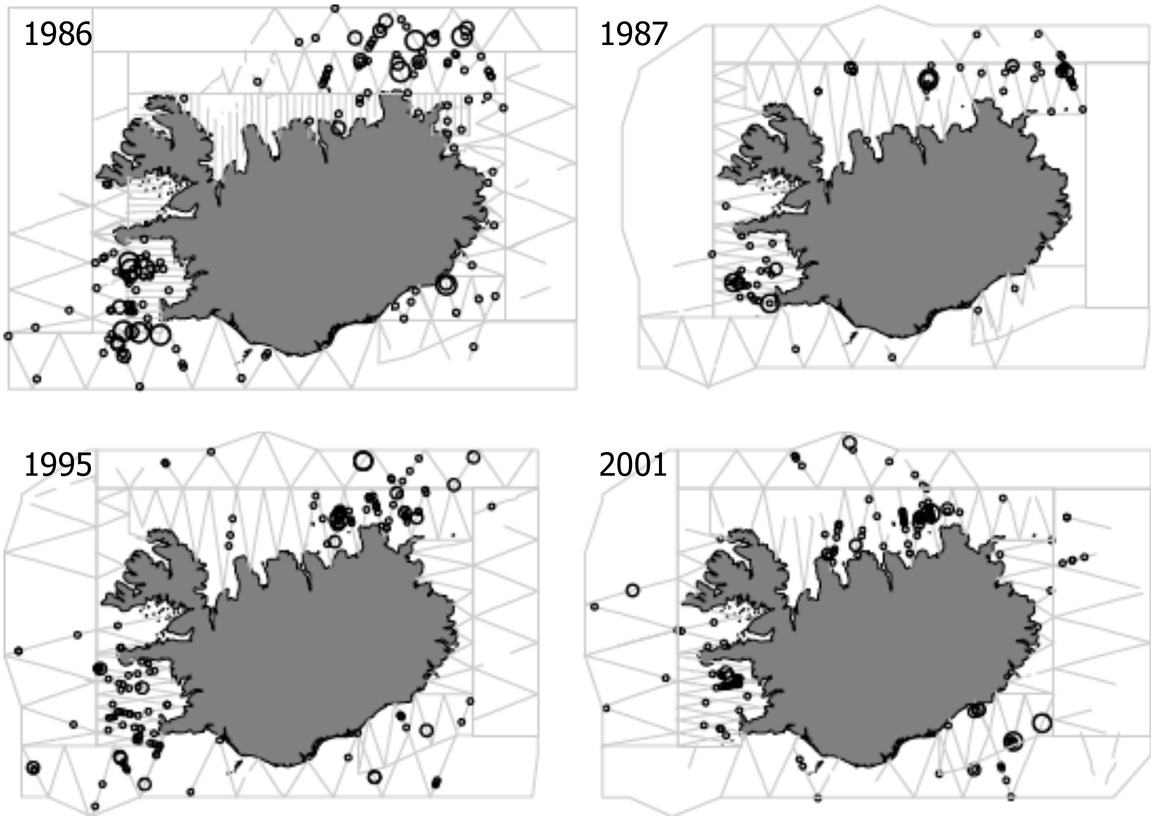

Figure 13. Sightings of dolphins of the genus Lagenorhynchus from NASS aerial surveys, 1986-2001. The smallest symbol represents a group size of 1-10, the next biggest symbol represents a group size of 11-20, and bigger symbols represent a group of 21 or more individuals. From Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009. Reprinted with permission.

Humpback whales

As stated above, humpback whales are found in all major ocean basins and as a whole are listed as a species of least concern by the IUCN (Reilly et al., 2015d). As a highly migratory species, most humpbacks will spend summer months feeding in productive waters higher latitudes and will migrate to calving grounds in lower latitudes during the winter (Reilly et al., 2015d). Feeding grounds in the North Atlantic include the Gulf of Maine in the US, eastern Canada, West Greenland, Norway, and Iceland (Center for Coastal Studies, 2014). Some individuals, however, are known to stay in Icelandic waters over the winter (Valtýsson, n.d.). Humpbacks can be found in both inshore and offshore waters around Iceland (Valtýsson, n.d.). The distribution of humpbacks in Icelandic coastal waters in June and July have remained relatively similar across years (Figure 14), with the highest densities observed off the east and west coasts of the country, and some scattered sightings in the north (Figure 15 and 16). Furthermore, both shipboard and aerial surveys have exhibited an increasing trend in sightings rates and densities in coastal waters, particularly off eastern Iceland, which may be indicative of an increase in prey species in the area (Pike, Gunnlaugsson, Víkingsson, Deportes, Bloch, 2009; Gunnlaugsson et al., 2005). Combined data from both survey types give an estimated humpback abundance over the survey area of 10,521 whales in 1995 (C.I.: 3,716–24,636), while the estimate for 2001 was 14,662 (C.I.: 9,441–29,879) (Paxton et al., 2013).

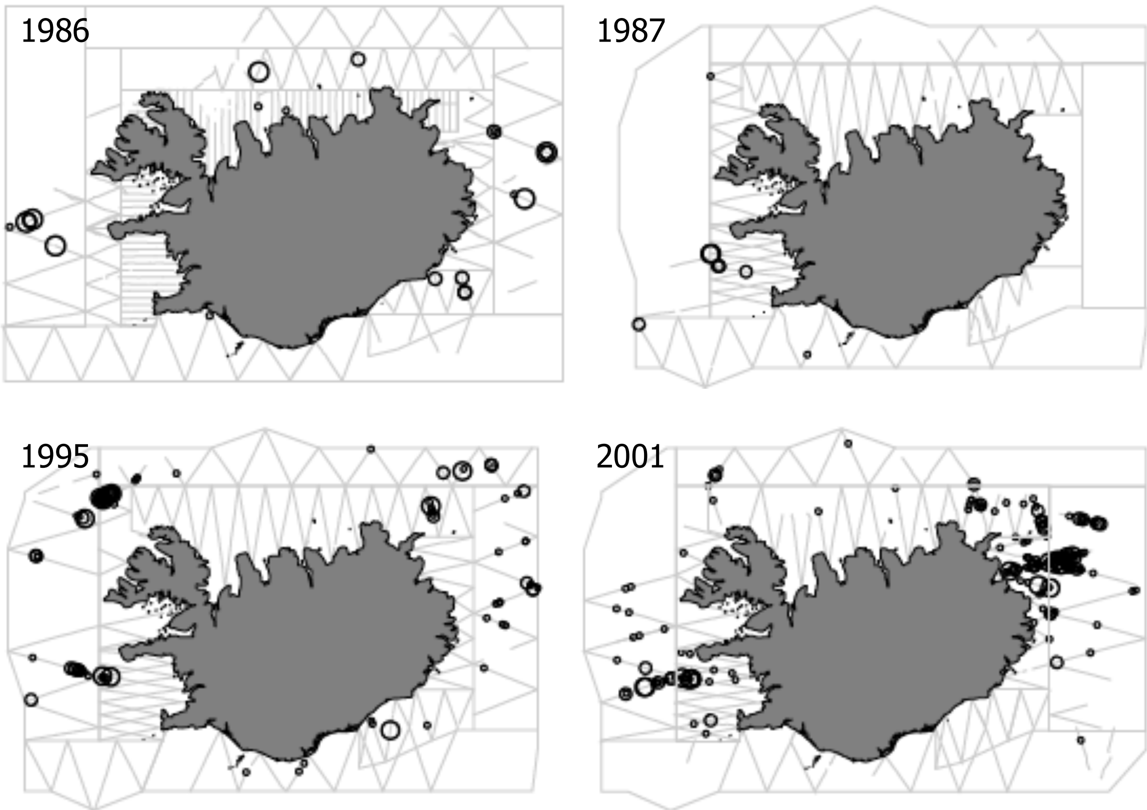

Figure 14. Sightings of humpback whales (Megaptera novaeangliae) from NASS aerial surveys, 1986-2001. The smallest symbol represents a group size of one, the next biggest symbol represents a group size of two, and bigger symbols represent a group of three whales or more. From Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009. Reprinted with permission.

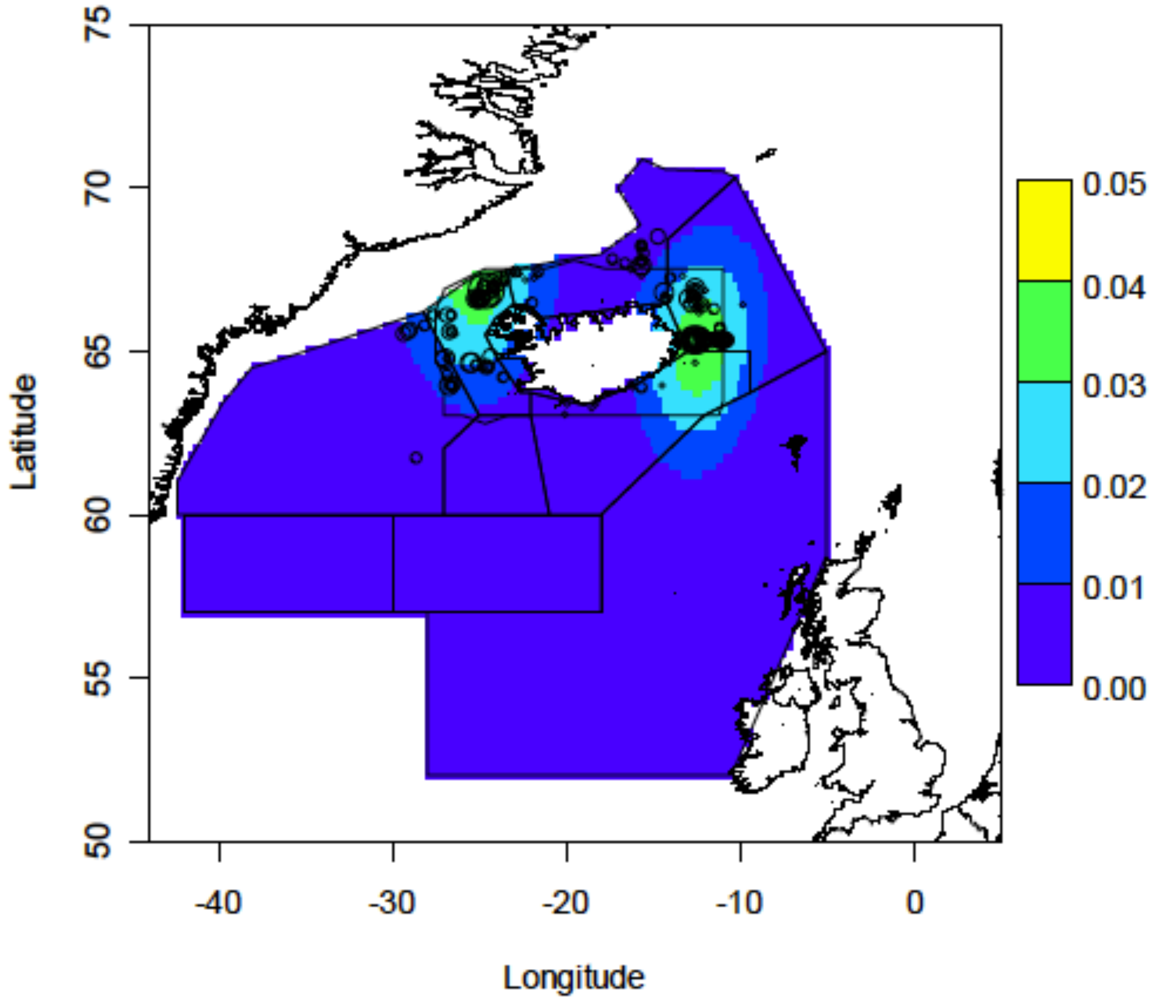

Figure 15. Estimated humpback whale density for 1995 NASS using combined data from aerial and shipboard surveys. The scale bar indicates density estimates on a scale of 0 to 0.05 whales/km². From Paxton, Burt, Hedley, Víkingsson, Gunnlaugsson, & Desportes, 2013. Reprinted with permission.

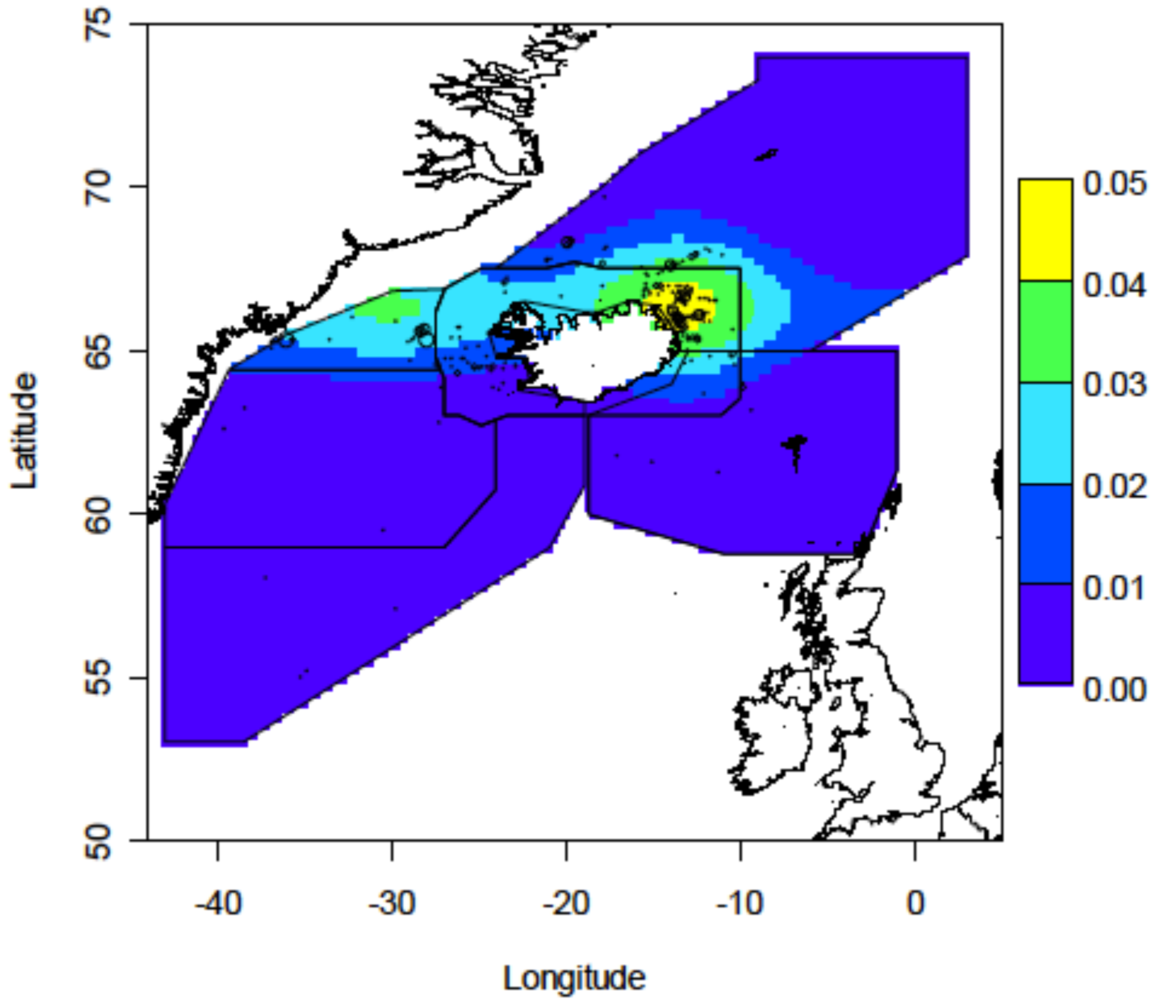

Figure 16. Estimated humpback whale density for 2001 NASS using combined data from aerial and shipboard surveys. The scale bar indicates density estimates on a scale of 0 to 0.05 whales/km². From Paxton, Burt, Hedley, Víkingsson, Gunnlaugsson, & Desportes, 2013. Reprinted with permission.

Harbour porpoises

Harbour porpoises are the smallest and among the most common cetacean species in Icelandic waters. They often exhibit elusive behaviour, making them difficult to see from ships or aircrafts (Gilles, Gunnlaugsson, Mikkelsen, Pike, & Víkingsson 2011). The harbour porpoise is also thought to be very flexible and opportunistic with regards to feeding habits and their movements are thought to change seasonally and annually, potentially as a result of prey availability (Víkingsson, et al., 2014). The distribution of harbour porpoises was mainly inshore but varied greatly between aerial surveys from 1986 to 2001, revealing significant variation in distribution, both annually and seasonally (Figure 17). A decrease in relative abundance was observed throughout the survey period, which was largely due to very low sightings in 2001 (Pike, Paxton, Gunnlaugsson, &

Víkingsson, 2009). An aerial survey conducted in 2007, however, for which the harbour porpoise was the target species, resulted in a much higher estimated abundance of 43,179 (95% C.I. 31,755–161,899) animals in Icelandic waters, with a density of 0.15 individuals/km^2 (Gilles, Gunnlaugsson, Mikkelsen, Pike, & Víkingsson, 2011). Little is known about the distribution of harbour porpoises in the winter months, but they are thought to move to open water during the winter (Víkingsson et al., 2014).

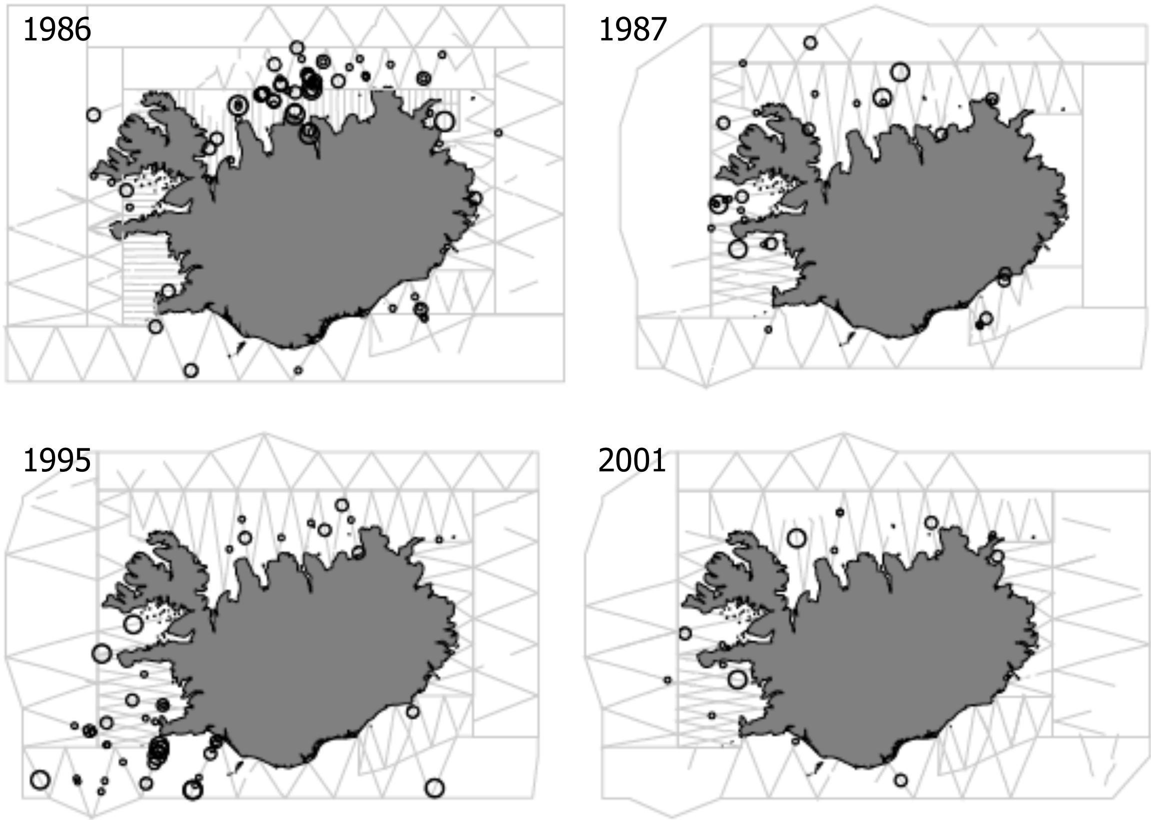

Figure 17. Sightings of harbour porpoises (Phocoena phocoena) from NASS aerial surveys, 1986-2001. The smallest symbol represents a group size of one, the next biggest symbol represents a group size of two, and bigger symbols represent a group of three whales or more. From Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009. Reprinted with permission.

Other species

Most of the other species found in Icelandic waters tend to have a deep water, offshore distribution and are not often seen in coastal shelf waters around the country. Fin whales, which are currently listed as endangered by the IUCN, were most commonly seen on the outer edge of the aerial survey area, and were the most common species sighted in offshore waters during shipboard surveys (Reilly et al., 2013; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009; Gunnlaugsson et al., 2005). Abundance estimates based on shipboard surveys from 1995 and 2001 were 19,672 (95% C.I. 12,083–28,986) and 24,887 (95% C.I. 18,186–30,214), respectively (Víkingsson et al., 2009). Abundances of fin whales were seen to increase over the survey period, which may indicate the population is recovering after significant depletion from commercial whaling in the 19th and 20th century (Víkingsson et al., 2009). During the summer months, blue whales can occasionally be seen in deep waters off of Snæfellsnes Peninsula in western Iceland (Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). Orcas have also been known to occur in coastal waters around Iceland in the fall and winter, but are rarely seen during the summer (Sigurjónsson, 1988, as cited in Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009).

2.5.2 Bycatch

Bycatch of some cetacean species is thought be quite high in Iceland, particularly with respect to harbour porpoises and dolphins in coastal gillnet fisheries (Víkingsson, 2004, as cited in Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). However, until recently there was no estimate for levels of bycaught animals (Gunnlaugsson, 2014). As stated above, it is mandatory for all marine mammal bycatch to be reported in Iceland; however, it is thought that it is still significantly underreported (Gunnlaugsson, 2014; Ólafsdóttir, 2010, as cited in Gunnlaugsson, 2014). Gunnlaugsson et al. (2014) attempted to estimate total harbour porpoise bycatch in Icelandic net fisheries using records from logbooks, the annual cod gillnet survey conducted by the MRI and data from at sea observers from the Directorate of Fisheries and the MRI (Gunnlaugsson et al., 2014). The harbour porpoise was found to be the most numerous bycaught marine mammal, with 80% occurring in cod gillnets, and 20% in lumpsucker nets (Gunnlaugsson et al., 2014). Bycatch in the cod gillnet fishery was estimated to be 7,300 animals in 2003, which dropped to about 1,600 animals from 2009–2013, which is likely due to a decrease in fishing effort using gillnets (Gunnlaugsson et al., 2014). Including an estimated 400 animals from the lumpsucker fishery, total bycatch of harbour porpoises was estimated at 2000 animals annually from 2009 (Gunnlaugsson et al., 2014). This is 1.2–6.0% of the estimated abundance from coastal aerial survey (43,179, 95% C.I. 31,755–161,899, Gilles et al. 2011; Gunnlaugsson et al., 2014). In the absence of satisfactory estimates of maximum population growth or other management targets adopted, a bycatch limit for small cetaceans has been set at 1.7% of estimated abundance levels by the International Council for the Exploration of the Sea (ICES) and any number above this, could be detrimental to the population (ICES, 2001). If the abundance estimate covered by the aerial surveys is assumed to cover the entire range of harbour porpoises in Icelandic waters, and the abundance is at the lower end of the confidence interval (less than 75,000), then the bycatch level is greater than 2.7%, which is higher than the precautionary bycatch level set by ICES (1.7%). However, if the abundance is at the higher end of the confidence interval (greater than 115,000), then the bycatch level is within the precautionary limit set by ICES (Gunnlaugsson et al., 2014). With that being said, harbour porpoises are also thought to occur in deeper waters where there has been no survey estimate; therefore the estimate based on aerial surveys is likely to be an underestimate (Gunnlaugsson et al., 2014). Due to this uncertainty, Gunnlaugsson et al. (2014) concluded that bycatch of harbour porpoises may be exceeding the precautionary limit by ICES and bycatch reporting and monitoring in Iceland requires improvement. Dolphins (mostly white-beaked dolphins) were the third most common species caught in cod gill nets, after harbour porpoises and harbour seals (Gunnlaugsson et al., 2014). There have also been occasional reports of baleen whales in fishing gears (Gunnlaugsson et al., 2014). A recent study looking into entanglement of humpback whales in fishing gear in Iceland reported six eyewitness accounts of entanglement in fishing gear, including three entanglements in capelin purse seines, and one in each of bottom trawls, cod handlines, and gillnets, respectively (Basran, 2014). This study also included a component on scar-based analysis of humpback whales in the north coast of Iceland (Basran, 2014). This study estimated that a minimum of 41.8% of the Icelandic subpopulation of humpbacks has been involved in a previous entanglement (Basran, 2014).

2.5.3 Attitudes towards cetaceans in Iceland

The public perception and image of cetaceans in the western world has changed profoundly in recent decades (Einarsson, 2009). This can largely be attributed to work by whale conservation and environmental groups, such as Greenpeace, which by anthropomorphizing whales and giving them an emotional quality, have turned them into symbols of the environmental movement (Einarsson, 2009). Fundamentally differing perceptions and images of whales remain in Iceland, which as a fishing nation, may be based on different environmental experiences relating to these animals and differences in cultural feelings towards nature and conservation (Einarsson, 2009). Iceland is a whaling nation and has had a history of controversy and conflict with environmental groups over the right to whale (Einarsson, 2009; Brydon, 2006). After an international whaling moratorium in 1982, Iceland continued with a four-year scientific whaling program before temporarily ceasing commercial whaling in 1990 (Einarsson, 2009; Brydon, 2006). For this, they came under attack by foreign national governments, environmental groups, and people opposed to whaling (Einarsson, 2009; Brydon, 2006). As a result, the government and a vast majority of the public took an extreme attitude against foreign interference with regards to how to use and manage marine resources within their 200-mile exclusive economic zone, and have questioned motives of "Grænfriðungar" or "Greenpeacers"—all those who are anti-whaling (Einarsson, 2009). Whaling and whale products today have little cultural, historic or economic significance, and little is actually consumed by modern Icelanders (Einarsson, 2009). However, the right to harvest it remains at the core of national fishing policy and more recent feelings among many have moved from "the right to hunt whale to the duty to do so, in the name of non-discriminatory sustainable use of natural resources, not excluding any animal species as less suitable for harvesting or consumption" (Einarsson, 2009, p. 130). This sentiment is particularly apparent in smaller fishing villages, where many fishermen consider whale populations a problem due to direct competition with them for valuable commercial fish stocks (Einarsson, 2009).

With that being said, however, and as noted by Basran (2014), several research projects are being conducted in Iceland involving cetacean populations, biology, management, and conservation (e.g. Víkingsson, 2011). Some of this research is being conducted though participation in the IWC (IWC, 2015), the North Atlantic Marine Mammal Commission agreement (NAMMCO, 2005), and International Council for the Exploration of the Sea (ICES, n.d.).

3 Methods

Cetacean and sea turtle entanglement reports in mussel aquaculture gear were gathered from a comprehensive review of media outlets, academic articles, and secondary sources. Additionally, various marine researchers and institutes, resource management organizations, and marine mammal disentanglement organizations were contacted from countries using mussel longline technology in effort to find any known entanglement cases (Table 1). When a case was found, the author attempted to contact any individuals via email who may have been able to provide more information on the incident in question. In one case, an informal interview was conducted over the phone with an owner of a mussel farm in Newfoundland, Canada, in order to gather more information on a leatherback turtle entanglement that was reported in an online news article (CBC News, 2013). Additionally, an informal interview was conducted in person with a mussel grower in Northwest Iceland, who reported a humpback whale entanglement to the MRI. These entanglement cases were discussed in the literature overview.

For this research both quantitative and qualitative methods were used to collect information on mussel operations, cetacean sightings near mussel operations, and potential cetacean entanglements in Iceland. This was done in the form of online surveys and semi-structured interviews with mussel operators, respectively. Additionally, point locations of farms in Iceland were mapped in order to visually compare their locations with cetacean distributions around the country. All collected entanglement cases were then compared to find any similarities with regards to gear, techniques, timing of operation and location with respect to cetacean distributions. It is important to note that due to entanglement being a seemingly rare event thus far, a statistically relevent comparison was never intended.

Table 1. Organizations and individuals contacted regarding cetacean and sea turtle entanglements in mussel aquaculture gear and their responses. Source: author.

Organizations or Individuals Contacted	Response
Gísli Víkingsson (Head of Whale Research, Marine Research Institute of Iceland [MRI])	Aware of only one humpback whale entanglement in Miðfjörður, Northwest Iceland, discussed in the literature overview
Björn Björnsson (Head of Aquaculture, MRI Iceland)	Unaware of any further entanglements in Iceland
Sarah Stewart-Clark (Dalhousie University, Assistant Professor, Shellfish Aquaculture)	Unaware of any entanglements in Canada Forwarded enquiry to scientists at Fisheries and Oceans Canada (DFO), no response
Cyr Couturier (Research Scientist, Marine Institute of Memorial University)	Aware of one leatherback turtle entanglement in Atlantic Canada (referring to the incident reported online (CBC News, 2013) Referred author to Coordinator of the Whale Rescue Center in Newfoundland, who provided contact information for Terry Mills, owner of mussel operation where the entanglement in question occurred (an informal phone interview was conducted with Terry Mills, discussed in the literature overview)
University of Prince Edward Island	No response
Dag Vongraven (Researcher, Norwegian Polar Institute)	Unaware of any entanglements, forwarded enquiry through the university system in Norway, no response
John Bonardelli (Owner of Shellfish Solutions, international advisor for shellfish growing techniques)	Unaware of any entanglements in Norway or Canada
Oliver Tully (Marine Institute of Ireland)	Unaware of any entanglements in Ireland
Tomas Doyle (National University of Ireland)	Unaware of any entanglements in Ireland
Simon Berrow (Irish Whale and Dolphin Group)	Unaware of any entanglements in Ireland
Fiona Manson (Scottish Natural Heritage)	Unaware of any entanglements in the UK
Natural Resources Wales	No response
Douglas Coughran (Senior Wildlife Officer, Marine Wildlife Operations Department of Parks and Wildlife Nature Protection Branch, Western Australia)	Aware of only one humpback entanglement in Australia, already known to the author (Groom & Coughran, 2012) as well as one North Pacific right whale entanglement in Korea, discussed in literature overview

3.1 Surveys and interviews

3.1.1 Selection of participants

Survey

Survey participants were primarily recruited through snowball sampling, where initial contact was taken with the head of the Icelandic Shellfish Association, who then provided the author with names and contact information of mussel operators in Iceland (see Heckahorn, 2011). Three contacts were also given to the author by one of the thesis supervisors. Mussel operators were then contacted via phone or email, if a phone number was not provided, and asked to participate in the survey. One survey participant was added at later stages and surveyed exclusively on general farming operations and cetacean sightings; questions regarding cetacean entanglements were excluded as this information was obtained during a preliminary interview with the participant. Out of the 11 surveys that were sent out, 10 responses were collected. At the end of the survey, mussel operators were asked if they would like to be interviewed in person about their experiences, and if so, were asked to provide contact information.

Semi-structured interviews

Seven semi-structured interviews were conducted with mussel operators in Iceland. Five interviews were conducted as a follow-up to the online surveys. These participants were chosen solely on their willingness to participate and provide further information. Additionally, one interview was conducted before the survey was completed and another was conducted with a researcher for the Icelandic aquaculture company Fjarðalax. Prior to the later interview, the author was unaware that the company was actively running experimental mussel farming operations. As a result, this interviewee did not fill out a survey, but the author gathered as much information as possible that was asked in the survey during the interview process.

3.1.2 Survey design

The online survey tool Survey Monkey was used to create and distribute surveys to all participants (www.surveymonkey.com). The survey was written in both English and Icelandic, with participants given the option to answer in either language (Appendix 1).

The author does not speak Icelandic, and therefore translated surveys enabled the author to contact and gather information from people with limited knowledge of English. The survey was originally written in English and translated into Icelandic with the help of two translators to ensure consistency between the English and Icelandic version. The front page of the survey consisted of a description of the project followed by instructions for filling out the questions. Anonymity was ensured to all participants unless their permission was given otherwise and the author's contact information was provided in the case of any questions or concerns.

The survey consisted of both open and close-ended questions (Appendix 1). The first set of questions requested information regarding the status of the mussel farming operation, farm location, layout, distance from shore, water depth, size, equipment, production, and potential plans for expansion. Anonymity was ensured by asking for farm location by region, rather than exact location (for the purposes of the survey the Capital Region and the Southern Peninsula were included in the West Iceland Region) (Figure 18). The second set of questions requested information about cetacean sightings near the mussel operation, time of year cetaceans are most commonly seen, and most commonly sighted species. Respondents were also asked if they had ever witnessed a cetacean swimming through, or very close (within 50 m) to their farm, and if so, what species, and how often it had occurred. Participants were then asked if they had ever witnessed a cetacean entangled in their mussel farming gear, and if so, how many times it had occurred. For each entanglement (up to three entanglements), the participant was asked to provide details, including what cetacean species was entangled, cetacean size, in what part of the gear the entanglement occurred, what part of the cetacean was entangled, and if the entanglement was fatal. At the end of the survey, participants were asked if they would like to be interviewed about their experiences and if they wanted to be updated about the results of the research project. Furthermore, a space was provided if the respondents had any further comments.

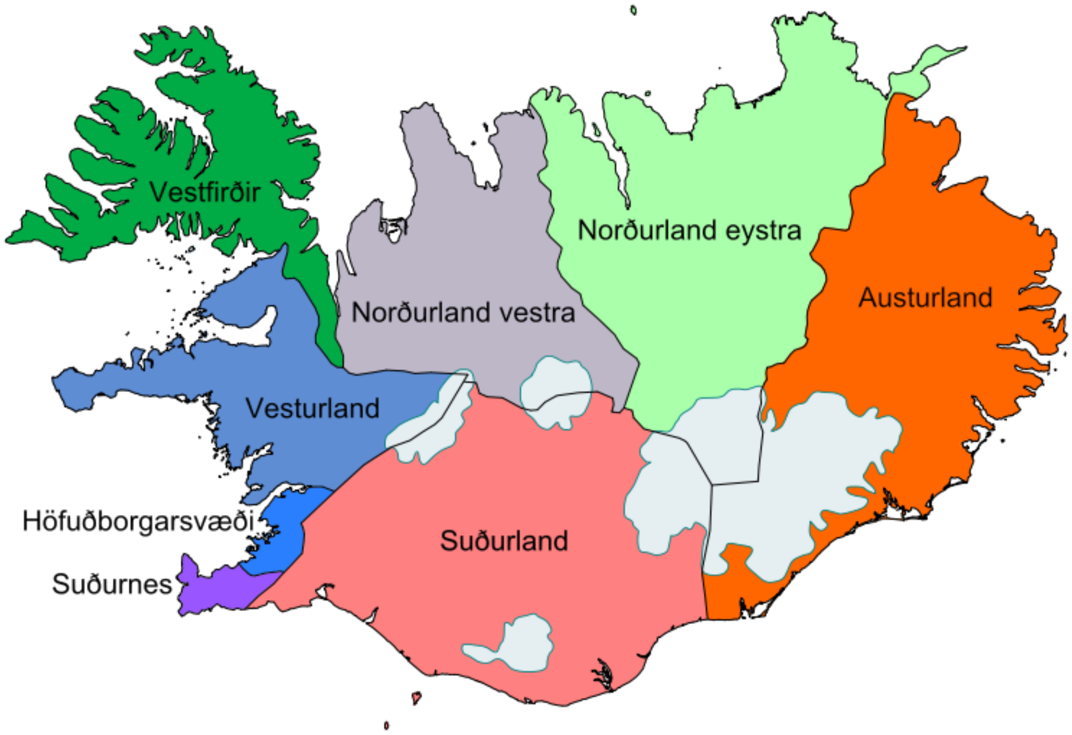

Figure 18. Regions of Iceland (Suðurnes = Southern Peninsula, Höfuðborgarsvæði = Capital Region, Vestfirðir = Westfjords, Norðurland vestra = Northwest, Norðurland eystra = Northeast, Austurland = East). Anonymous. (2008). [Online image]. Retrieved from Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Iceland_regions.svg

Before the survey was sent out, a pilot test was conducted with three people outside the mussel industry. These individuals provided comments and minor changes were made. The survey was sent out via email, and all responses except one were collected online. The author entered the answers to one survey manually after they were given verbally to the author during an interview, as he did not have time to fill out the survey. The first version of the survey was sent out via email in November 2014 and responses were collected until February 2015. If respondents did not reply within four days, a reminder email was sent, and then again a week later. If a response was still not received, the participants were called periodically and reminded to fill out the survey.

3.1.3 Survey limitations

Surveys were translated from English to Icelandic, and the answers were translated back from Icelandic to English, which may have resulted in some inconsistencies between the translations. Although, two translators were used during the survey design in attempt to minimize any discrepancies between the two versions. Additionally, question 12 and 14a had to be excluded from the survey analysis after the responses were collected, as they appeared to be overly complicated in their design or took too much time to fill out because a majority of respondents left them blank (Appendix 1). Question 12 asked respondents to order the seasons according to how many cetacean sightings there were in each season. Question 14a was a follow-up question to whether or not the respondent witnessed cetaceans swimming through or very close to their farm (within 50 m). In this question, respondents who reported having seen cetaceans swim through or very close to their mussel farm were asked to indicate from "never" to "all of the time" each species (from a list of species on the survey) was seen exhibiting this behaviour.

There were also two versions of the survey. In the first version of the survey, two questions were asked at the end of the survey that were not well received by some participants. One of these questions asked how important the respondent thought it is to protect cetaceans from man-made hazards in the sea. After the first version was sent out, however, the author was notified of an error in this question, in which there was not an appropriate range of answer choices (i.e. "not important" was accidentally not listed as an option). The other question asked participants if they would be willing to take measures to reduce the risk of cetaceans being harmed by mussel gear, if this eventually did appear to be a risk of this happening. It was brought to the author's attention that some potential participants refused to fill out the survey because of the mistake in answer choices for the first question as well as the overall sensitive nature of these questions. As a result, they were removed from the survey, as they were not essential to answering the research questions, and the remaining respondents were sent a new version of the survey. In addition, one of the thesis supervisors had to call some of the participants who had voiced concerns about the project and explain that it was not the intention of the author to pry with questions about cetacean conservation and welfare, but to gather information regarding their mussel aquaculture operations, and if any cetaceans had become entangled and subsequently damaged any gear.

3.1.4 Interview design and process

Semi-structured interviews were used primarily as a follow-up with participants of the online surveys in order to clarify any answers, to obtain answers to questions that were previously unanswered, as well as to gain additional information not asked in the survey. In this way, they allowed the author to gather more information than was possible in the surveys, which had to be limited in terms of length and detail. Interviews were conducted in a semi-structured fashion, allowing the interviewer to develop questions ahead of time, but also providing the opportunity to follow any relevant points brought up by the interviewee that were not specifically part of the interview guide (see Cohen & Crabtree, 2006). All interviews were conducted by the author between December 2014 and February 2015. Three interviews were conducted in person, while the remaining four were either conducted through the phone or Skype. All interviews were conducted in English and lasted between 10 and 60 minutes. During the interviews that were conducted in person, an interpreter was present to assist with translations when needed. No interpreters were present, however, during the phone or Skype interviews. All interviews were recorded with permission from the interviewees. Additionally, all interviewees were asked his or her preferred level of anonymity in the eventual thesis before the interview began.

During the interviews, interviewees were asked to clarify any answers from the survey that were unclear, or required more detailed information, as well as answers to questions that were left blank from the survey. The interviewee was then asked questions that were not on the survey, under such topics as the future of the mussel industry in Iceland, knowledge of whale/mussel aquaculture interactions in Iceland, and willingness to take measure to reduce entanglement risk if needed (Appendix 2). It also must be noted that some questions emphasized the risk that whales could cause the mussel industry through gear damage, in order for people to cooperate and participate in the interviews.

3.1.5 Interview limitations

Interviews for this thesis were not all conducted in the same format, which could have led to some inconsistencies between interviews. The initial interviews were conducted in person, but as the study progressed, it became necessary to conduct phone or Skype interviews due to travel costs and time limitations. A language barrier was also apparent during most, if not all, interviews. This may have prevented some interviewees from answering some questions fully or resulting in a misinterpretation of the questions. During the three interviews that were conducted in person, an interpreter was present, however, there was no interpreter present for the phone or Skype interviews. Some interviewees may also have declined to participate in a follow-up interview due to the fact that it would be conducted in English, which was the case for one of the survey participants. Additionally, one participant refused to participate in an interview after filling out the survey due to skepticism regarding the intention of the author. A fundamentally different attitude towards cetacean conservation remains in Iceland, especially among fishermen, when compared to other westernized countries (Einarsson, 2009). There is also an intense skepticism when it comes to foreign intervention with regards to how to manage marine resources in Iceland (Einarsson, 2009). This must be considered when interpreting the results, as there was skepticism among some mussel operators when considering whether to participate in this study, as well as a possible reason for biased result in this survey of cetacean entanglements in Iceland.

The author also had little to no experience with qualitative research methods prior to the onset of this study, and interview results are highly dependent on the skill and experience of the interviewer. As noted by Jansen (2013), who did a similar qualitative study in the Westfjords, the skills of the interviewer increased as the study progressed, as did their knowledge on the research topic. As a result, the interviewer was better able to gather information that was relevant to the research questions as the interview process progressed.

Overall, this research is based on a few cases collected from a variety of sources; therefore, a statistically valuable comparison is not possible. The results can only be applied hypothetically, which although interesting, is something that must be considered for the context of this study. Furthermore, the results from the data collection in Iceland may be negatively biased due to the fact that some mussel operators may not have reported cetacean entanglements in their mussel gear for fear of being reprimanded, or having restrictions placed on them, which is known to be the case for some fishing industries (Johnson et al., 2005). Skepticism from participants towards the research subject may have further led to a negatively biased result.

3.2 Site locations

The locations of all but one of the mussel farms, that were the focus of both the surveys and interviews in Iceland, were mapped using Google maps (https://www.google.com/maps/d/). It must be noted that all participants in the survey were guaranteed to remain anonymous unless their permission was given otherwise. To further protect their anonymity, participants were asked what region their farm was located in, rather than exact location. All participants that went on to participate in an interview agreed to be referred to by name, and therefore it was possible to map the exact location of their company and to have this location associated with their answers from the surveys and interviews. Before the locations of the survey participant's operations that did not participate in an interview were mapped and associated with the answers given on the survey, their permission had to be given. Two participants agreed, while one requested to remain anonymous.

4 Results

4.1 Surveys

From the 10 survey responses, six respondents reported that their mussel farming operation was active at the time of the survey, three reported that their operation was inactive, and one respondent did not specify the status of their farming operation. Out of the respondents who reported inactive operations, one respondent ceased operation in 2011, one ceased operation in 2013, and one respondent was taking up their lines during the time of the data collection (late 2014/early 2015). The earliest date a respondent began mussel farming in Iceland was 1998, while the newest operation began in 2012 (Table 2).

Table 2. Date when survey respondents began mussel farming in Iceland. Source: author.

Number of respondents	Year
1	1998
1	1999
4	2007
1	2008
2	2010
1	2012

Referring to locations of mussel farming operations in Iceland, four respondents reported having active operations in West Iceland (including the Capital Region and the Reykjanes Peninsula) and three reported having active operations in the Westfjords. One operation was reported in each of Northwest Iceland, Northeast Iceland, and East Iceland, all of which are currently inactive, while no operations were reported in South Iceland.

A range of responses were collected from respondents when asked for a description of the layout of their farm, including the number of headropes and vertical lines to the surface associated with their farm (Table 3). The highest number of headropes reported was 170 from an inactive farm in Northeast Iceland, while the smallest number of headropes reported was four, from a farm that is no longer active in Northwest Iceland. The length of headropes ranged from 200–400 m, and some respondents listed lengths of individual droppers, while others listed total length of collectors and/or socks under each headrope, or for their total operation. Distances of mussel operations to shore ranged from 20–2000 m, and water depth ranged from 0–55 m. The largest area covered by a mussel farming operation that was reported was 1,600,000 m^2, from a farm that is no longer active in Northwest Iceland. One respondent also reported that the area of their operation was negligible because the current operation only consisted of a continuous line of seven headropes. However, the practical area of this operation can be calculated as 10 m multiplied by the length of the headropes, since this is the practical width a headrope might swing with changing tides and currents. Therefore, the practical area of this operation is [230 m (length of each individual longline) x 7 x 10 m], which is equal to 16,100 m^2. Practical area was also calculated for a respondent who reported that their headropes were in a continuous 4–6 km line, but did not report a total area covered. The practical area for this operation was 40,000–60,000 m^2. This was also the case for an operation that reported a continuous line of 400 m, with a calculated practical area of 4000 m^2. An area of 8,000,000 m^2 was also reported, but this answer was for what was permitted by the operator's current license, not the actual area covered by the farm. When asked how mussels are grown from settlement to market size on their farm, two respondents stated that mussels were grown to market size on seed collectors, while five respondents reported that their mussels were "socked". The three remaining respondents chose "other", with two of these three explaining that they sometimes socked their mussels, while the other respondent explained that they dredge their mussels from the bottom of the seabed, and then sock these mussels to grow them up to market size.

Table 3. Description of mussel farming operations from survey responses. Source: author.

Region	Status of operation	Layout and gear	Method of grow-out	Distance to shore (m)	Water depth (m)	Area covered (m^2)	Production quantity (tonnes)	Plans to expand?
West Iceland	Active	6 headropes (230 m each), 1700 m of collectors on each headrope	Mussels are either "socked" or grown on spat collectors	230	30	30,000	15 currently, 300 possible in full production	Would like to, but not possible
West Iceland	Active	14 headropes	Mussels are grown on spat collectors	1000	30	–	20	Yes
West Iceland	Active	30 headropes, 1500 m of collectors on each headrope	Mussels are "socked"	150	12–30	1,000,000	200	Yes–by 1,000,000 m^2 and 5-600 tonnes
West Iceland	Active	15 headropes (250 m each)	Mussels are "socked"	150	10–40	500,000	100	No
Westfjords	Active	7 headropes (220 m each), 2000 m of socking on each (5 m long loops), and 0.5–1 m spacing	Mussel seed/small mussels are dredged and then "socked"	600–2000	0–20	8,000,000 (permitted by license)	<50 currently (200 possible with license)	No
Westfjords	–	7 continuous headropes (230 m each), 1800–2000 m of collectors on each headrope	Mussels are either "socked" or grown on spat collectors	500	35–50	16,100 (practical area calculated)	Unable to provide a precise figure	Yes–the company eventually wants to have 3 separate areas, each 500,000 to 1,000,000 m^2
Westfjords	Active	15 headropes (200 m each), a total of 30,000 m of collectors	Mussels are "socked"	500–1500	25–55	–	200	No
Northwest Iceland	Inactive	4 headropes	Mussels are grown on spat collectors	300–400	25	4000 (practical area calculated)	Experimental	No
Northeast Iceland	Inactive	170 headropes (220 m each), 5 m long collectors/socks, with 0.5 m spacing	Mussels are "socked"	50–300	6–50	1,600,000	Different from year to year	No
East Iceland	Inactive	8–12 headropes (200–400 m each), 5 m long droppers, 0.5 m spacing, submerged 5-10 m	Mussels are "socked"	20	5–15	840,000–600,000	–	Possible to start up again if conditions permit

When asked if respondents planned to expand the size of their farm, three respondents with active operations responded “yes” and three responded “no” (Table 3). The remaining respondent with an active operation responded “maybe” and explained that they wanted to expand, but the area around their current operation was allocated elsewhere. Furthermore, one of the respondents with an inactive operation explained that if circumstances permitted, it would be possible for their operation to start up again. Of the three respondents that replied “yes”, only two answered the follow-up question that asked by how many square meters and production volume.

A table of cetacean sightings near mussel operations reported in the online surveys can be see in Table 4. Three respondents reported never seeing cetaceans within sight of their farm, three reported rarely seeing cetaceans, and two reported sometimes seeing cetaceans, while two left the question unanswered. Referring to the most common and second most common species seen within sight of mussel operations, humpback whales, minke whales, and harbour porpoises were the most frequently reported species. The third most commonly sighted species reported by respondents varied greatly; long-finned pilot whales, orcas, white beaked dolphins, harbour porpoises, humpback and minke whales were all reported by separate respondents. Four respondents were aware of cetaceans swimming through or very close (within 50 m) to their mussel operation, while three respondents reported never witnessing a cetacean that close to their operation. Of the respondents that replied “no”, however, one went on to answer a part of the follow-up question that required a “yes” answer. When asked if respondents were aware of a cetacean ever becoming entangled in their mussel farming gear, two respondents replied “yes”, four replied “no”, and three left the question unanswered. The two respondents that were aware of a cetacean entanglement reported that it had happened only once. A table with details of each entanglement, including affected species, can be seen in Table 5. Lastly, when asked if participants wanted to be interviewed personally about their experiences, five respondents said they would like to be interviewed, two said they did not want to be interviewed, and three left the question unanswered.

Table 4. Cetacean sightings and interactions within mussel operations in Iceland from survey responses. Source: author.

Region	Status of operation	How often are cetaceans seen within sight of operation?	Most common species sighted	Second most common species sighted	Third most common species sighted	Do cetaceans ever *swim through* or *very close* (within 50 m) to the operation?	Has a cetacean ever become entangled?
West Iceland	Active	Sometimes	Harbour porpoise	Orca/killer whale	Long-finned pilot whale	Yes	No
West Iceland	Active	Rarely	–	–	–	Yes	Yes
West Iceland	Active	Never	–	–	–	–	–
West Iceland	Active	Never	–	–	–	–	–
Westfjords	Active	Never	–	–	–	–	–
Westfjords	–	Rarely	Minke whale	Humpback whale	Orca/killer whale	–	No
Westfjords	Active	–	Humpback whale	–	White-beaked dolphin	No	No
Northwest Iceland	Inactive	–	Humpback whale	Minke whale	Harbour porpoise	Yes	* Participant did not answer this question as it was asked during a preliminary interview
Northeast Iceland	Inactive	Rarely	Harbour porpoise	Minke	Humpback whale	Yes	No
East Iceland	Inactive	Sometimes	Humpback whale	Harbour porpoise	Minke whale	No	Yes

Table 5. Entanglement reports collected from online surveys. Source: author.

Region	Species	Length	Part of gear entangled	Part of cetacean entangled	Outcome of entanglement
West Iceland (active operation)	Minke whale	–	–	–	Non-fatal, freed itself, no gear remained attached
East Iceland (currently inactive operation)	Harbour porpoise	Approx. 2 m	Single droppers (spat collecting)	Fins	Fatal

4.2 Interviews

Additional details about mussel farming operations in Iceland obtained during follow-up interviews can be seen below in Table 6.

Table 6. Additional details about mussel farm location, layout, gear and operational procedures used by mussel growers in Iceland, gathered following participation in the survey using semi-structured interviews. Source: author.

Interviewee	Additional details about farm layout, gear, and operational procedures
Bergsveinn Reynisson (active operation in West Iceland)	• No additional details
Þórður Guðmundsson (active operation in West Iceland)	• Single dropper spat collectors, 3.5 m long, 0.4 m spacing • Only "sock" mussels if ropes get too heavy • Collectors start on the surface in the summer, and submerged 7-10 m below the surface in late August/September • Layout: 6 headropes (2 sets of 3) • Loosely anchored
Einar Magnússon (active operation in West Iceland)	• Headropes 220 m • Single dropper spat collectors, 2.5 m long, 0.4 m spacing • Ropes submerged 8 m • Layout: 14 headropes (2 sets of 2 and 2 sets of 5) • Tightly anchored
Víðir Björnsson (inactive operation in Northeast Iceland)	• Mostly single droppers, some continuous • Collectors deployed in the middle of July, initially at the surface and then submerged 5 m • "Socked" after 1 year • Tightly anchored
Elías Oddsson (active operations in the Westfjords)	• Connected/continuous system of droppers, 6 m long loops, 0.6 to 0.7 m spacing • Ropes submerged 3 m • Mussels only "socked" if ropes get too heavy • Tightly anchored • Main operation in Álftafjörður, but also test operations in Seyðisfjörður and Skötufjörður (so far all experimental operations, no product)
Halldór Logi Friðgeirsson (active operation in the Westfjords)	• Connected/continuous system of droppers, 5 m long loops • Ropes submerged 15–30 m • Loosely anchored

A semi-structured interview was also conducted with Jón Örn Pálsson, Research and Development Manager at Fjarðalax ehf., who did not complete a survey. During this interview, the author was informed that Fjarðalax began test production for mussel farming in the Westfjords in 2006. During this time, however, there has not been regular husbandry. The company has had lines in Tálknafjörður and Arnarfjörður, but more effort is being focused on Tálknafjörður, where they currently have four headropes, each 220 m long, arranged in a continuous line (practical area: 4 x 220 m x 10 m = 8,800 m^2). There are currently two headropes in Arnarfjörður. The company uses a connected or continuous system of culture ropes, with loops that are 5 m long, and separated by 1 m. The water depth in Tálknafjörður is 30 m, and the ropes are submerged 10 m below the surface, and anchored very tightly to the bottom. After 14–15 months, mussels are stripped from collectors and "socked" in continuous lines. Fjarðalax has a licensed area of approximately 500,000 m^2 in the fjord, but the current operation does not cover that. The company has been producing product for several years, but are not yet selling it, as they do not have the equipment to harvest and process the mussels. The company plans on increasing production in Tálknafjörður, but not in Arnarfjörður.

Einar Magnússon currently runs an active mussel operation in Faxaflói Bay, West Iceland, and reported on the online survey a minke whale that had been entangled in his gear. During his follow-up interview, he clarified that he had not actually seen the whale, but had assumed a whale had been entangled in both a headropes and droppers, because when he saw the ropes, they were in disarray and there was a "slime" coating them. From experience as a gillnet fishermen, the interviewee stated that this coating of slime was similar to what would be left on his gillnets after a whale had been caught. He also assumed it had been a minke whale, as there had been many minke whales around his farm during that time, in the summer of 2012. The site where the minke entanglement was thought to occur was 1000 m from shore, at a water depth of 30 m, in an area where minke whales are known to be found in high densities during the summer months (Pike, Gunnlaugsson, Víkingsson, Deportes, Bloch, 2009; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009). No other minke entanglements, however, were reported from this area.

Three out of seven interviewees were unsure about the future of mussel farming in the country, and whether or not they thought it was going expand on a larger industrial scale.

Bergsveinn Reynisson stated: “I wouldn’t say more farms coming in but I think the farms will be bigger. So if they can find money of it, it will grow. I am not one hundred percent sure it will happen”. Three interviewees were more optimistic on the subject, stating they were certain it will expand. Elías Oddsson stated: “Yes, I think it will go bigger. It might take time but the shells and the seed in the water is very good. So yes I think it will go bigger, yes”. One participant on the other hand, did not think the industry is going to expand as there used to be a lot more mussel farmers in the country and the ones that are left appear to be struggling to survive.

When asked what may prevent the Icelandic mussel industry from expanding, three out of seven interviewees cited current regulations as being a large problem for the mussel industry in Iceland, particularly the need to send samples to Ireland to test for the presence of algal toxins, as it is expensive. Three interviewees specifically mentioned the difficulty in running a small mussel business in Iceland because of the expense, and the conflicting need to start small in order to perfect the culture techniques that suit site-specific growing conditions. Bergsveinn Reynisson stated:

> No area in Iceland is the same. […] They are not even the same year after year. So if you start big, the mistake will very likely be very big on the first year. You have to, in mussel farming, you have to start slow.

Predation by Eider ducks was also mentioned by four out of seven interviewees as being a threat to the mussel industry. Difficulty associated with fitting the product to the European market was also mentioned by one participant, as well as the lack of suitable areas around the country.

All of the interviewees did not view cetacean entanglements in mussel lines as being a problem that currently needed to be addressed. Furthermore, when the six actively farming interviewees were asked about willingness to take measures to reduce the risk of whales causing damage to gear through entanglements, three stated that they would be willing to take measures, such as modifying their gear, if entanglements were to become a problem and their gear was at risk of being damaged. As noted by Bergsveinn Reynisson: “If I have to change my mussel lines to save some whales I will not do it. If I have to change my mussel lines so they will not be damaged from whales I would do it." Þórður Guðmundsson also noted:

> If the whales would start to come into the area where the mussel lines are and you can try to see or try to learn if they get stuck in somewhere, you probably try and change the equipment so it won't get stuck because you don't want it. It has no meaning to stop the whale. But shooting one whale doesn't help. So the only thing you can do is try and avoid it by changing your equipment so it fits the area.

On the other hand, two interviewees said they would not be willing to take any measures to reduce this risk, whereas one would take measures such as attempting to scare the cetaceans away.

4.3 Site locations

The locations of mussel farming operations that were the focus of both surveys and interviews, with the exception of one as the operator requested to remain anonymous, are shown in Figure 19.

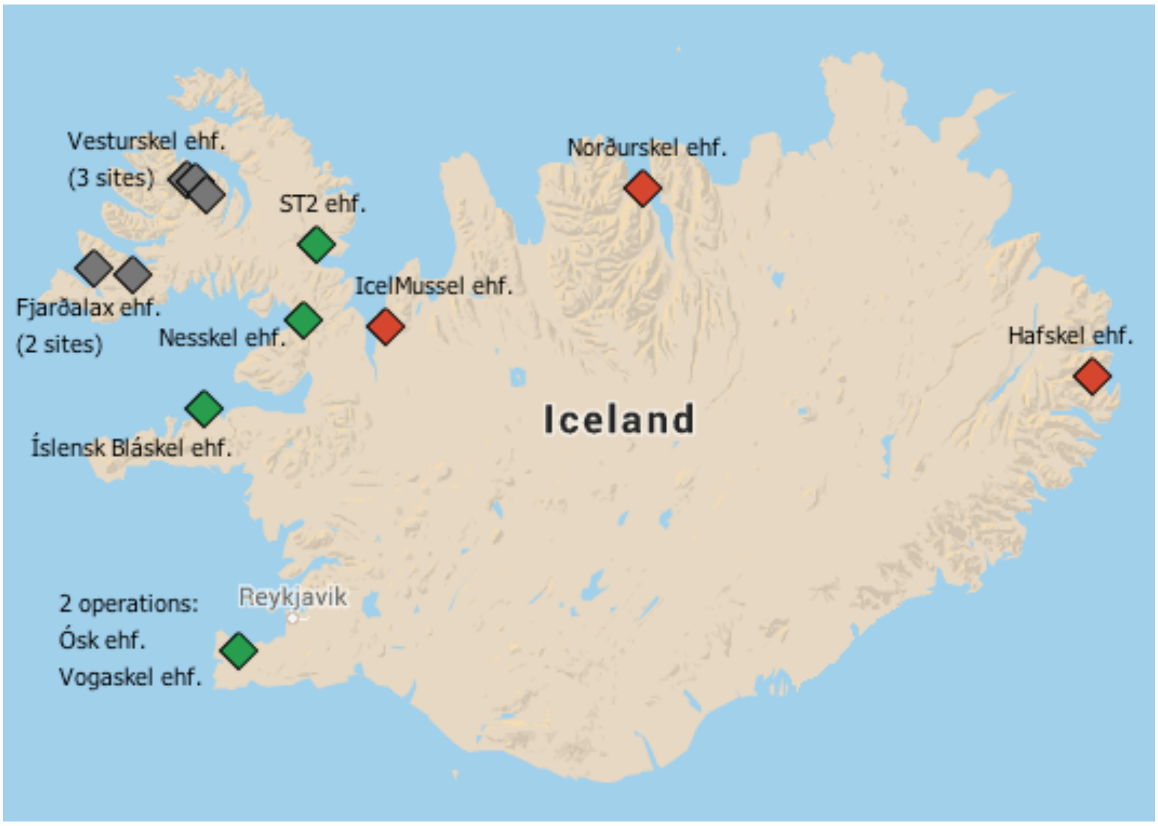

Figure 19. Locations of mussel operations from surveys and interviews. Green symbols indicate active operations, red symbols indicate inactive operations, and grey symbols indicate experimental or test sites. Map data copyright [2015] Google. Source: author.

5 Discussion

5.1 Summary of entanglement reports

A table of all collected entanglement reports can be seen below (Table 7). Of the seven documented cases, four involved baleen whales, two involved leatherback turtles, and one involved a harbour porpoise. One entanglement in Iceland was excluded as it was just speculation on the part of the mussel grower, and the whale was never seen, which makes it impossible to know if the event in question was a true entanglement. The majority of entanglements involved baleen whales, which is consistent with the fact that this group of cetaceans is believed to be at the highest risk of entanglement in fixed ropes in the water column (e.g. Benjamins et al., 2014; Knowlton et al., 2012; Read et al., 2006; Kemper et al., 2003). A majority of entanglements (6/7) involved mussel spat collectors or buoy lines connected to them. These ropes are thought to pose more of an entanglement risk when compared to other ropes used in the mussel-growing process, such as grow-out ropes, which are thicker, particularly near harvest, and more tightly anchored and tensioned (Lindell & Bailey, 2015; Moore & Wieting, 1999). Therefore, it is possible that entanglement risks may vary seasonally, if the deployment of spat collectors coincides with the presence of whales or sea turtles in the area (Lindell & Bailey, 2015). Considering sea turtle entanglements in the eastern US and Canada, no entanglements have been reported in Southern New England, where spat collection occurs in the spring and sea turtles arrive in the summer (Lindell & Bailey, 2015). However, in eastern Canada, where spat collection occurs in the summer and coincides with when leatherback turtles are in the area, there are two known entanglements, both of which involved spat collecting ropes, or buoy lines connected to them (Lindell & Bailey, 2015; T. Mills, personal communication, January 27th, 2015). This may indicate that spatial or temporal adjustments could be made to deployment of spat collecting rope to reduce overlap with the distribution of species of concern and reduce the risk of entanglements occurring (Lindell & Bailey, 2015). In some cases, spat collection may even be more successful far inshore, away from migrations of protected species (Lindell & Bailey, 2015).

All cetacean entanglements (with the possible exception of the North Pacific right whale entanglement in Korea) occurred in areas in close proximity to known distributions, feeding grounds or migratory routes of affected species (e.g. Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009; Baker, & Modon, 2007; Jenner et al., 2001). Although North Pacific right whales have not been sighted in Korean waters since 1974, they were known to be present historically in the Sea of Japan and Taiwan Straight during the winter (Y-R. An, personal communication, February 23rd, 2015; Reilly et al., 2008c; Clapham et al, 2004).

Table 7. Summary of cetacean and sea turtle entanglements in mussel aquaculture gear discussed in this thesis. Source: author.

Location	Species	Date	Size	Water depth at location (m)	Part of gear entangled	Part of cetacean entangled	Outcome of entanglement
Northwest Iceland	Humpback whale (juvenile)	August 26th, 2010	8–9 m long, 4 m wide	25	Single dropper (spat collecting)	Tail/fluke	Fatal
East Iceland	Harbour porpoise	August 1998[2]	Approx. 2 m long	5–15	Single dropper (spat collecting)	Body	Fatal
NL, Canada	Leatherback turtle	Summer 2010	300–360 kg	115	Spat collecting ropes (continuous)	Flipper	Fatal
NL, Canada	Leatherback turtle	August 2013	–	115	Buoy line to spat collecting ropes (continuous)	Neck and both front flippers	Non-fatal, freed by recreational boaters
South Korea	North Pacific right whale	February 11th, 2015	–	15	Single dropper (grow-out ropes: 240 mm in diameter with attached mussels)	Caudal peduncle and tail	Freed and no re-sighting (assumed to be non-fatal)
Western Australia	Humpback whale (calf)	August 2005	–	–	Spat collecting rope	Through mouth, 2 wraps around body, and four wraps around right flipper	Non-fatal, freed by disentanglement team
New Zealand	Bryde's whale	August 1996	–	–	Spat collecting rope	Body and tightly lodged in mouth	Fatal

5.2 Iceland

Utilizing both surveys and interviews, descriptions of 11 mussel farming operations were obtained. An amalgamated table of these descriptions, including company names, when possible, is included in the appendix (Appendix C).

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[2] Information obtained via email

Siting of aquaculture operations is the most important element to consider when discussing the potential for entanglements (Clement, 2013). Based on a visual comparision between point locations of mussel farms and the results from NASS discussed in the literature overview, farms appear to be located within the distributional range of cetacean species in Icelandic waters during the summer months, particularly the most abundant species: minke whales, dolphins, humpback whales, and harbour porpoises (Pike, et al., 2011; Pike, Gunnlaugsson, Víkingsson, Desportes, & Bloch, 2009; Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009; Víkingsson, et al., 2009). However, smaller scale data and more consistent year-round monitoring is needed to specifically determine which operations are located within or in close proximity to the distribution of each species. With that being said, several mussel operators in Iceland listed minke whales, humpback whales, and harbour porpoises as common species seen within sight of farms, which suggest that these operations are located within the range of these species. Dolphins, however, were only listed by one operator as the third most common species sighted, which could indicate that this group of cetaceans rarely ventures close to mussel farms. An exception of one operation that may not be located within the distributional range of any cetacean species in Iceland is Nesskel ehf. in the Westfjords (Figure 17). This may be due to the fact that the water depth at this location is shallow, ranging from 0–20 m, with the area completely drained during a low spring tide. The operator of this farm also confirmed that he has never seen cetaceans in the area. Two other mussel operators also reported never seeing cetaceans within site of their farms. Both sites are located in West Iceland, one of which is Íslensk Bláskel ehf., while the other respondent requested to remain anonymous. These operations were also located in shallow areas, with water depths ranging from 10–40 m and 12–30 m, respectively.

As discussed above, spat collecting ropes may pose a higher entanglement risk compared to other ropes used in mussel aquaculture (Moore & Wieting, 1999). Therefore, entanglement risks may vary seasonally, if deployment of collectors coincides with the presence of cetaceans in the area (Lindell & Bailey, 2015). In Iceland, mussel spat collectors are deployed during the summer, usually in July, but specific deployment dates may vary between June and August, depending on location, and may even vary from year to year (E. Daníelson, personal communication, February 15th, 2015; H. Friðgeirsson, personal communication, February 10th, 2015; Þ. Guðmundsson, personal communication, February 10th, 2015). Summer deployment of over a hundred kilometers of spat collectors coincides with the highest concentrations of cetaceans in Icelandic coastal shelf waters (e.g. Pike, Paxton, Gunnlaugsson, & Víkingsson, 2009; Víkingsson et al., 2014). Moreover, both of the witnessed cetacean entanglements in Iceland occurred over the summer and involved single dropper spat collecting ropes. One could conclude that the risk of cetacean entanglements may be highest during the summer and with spat collectors. Despite the limited number of incidents this pattern is seen overseas as well. It also must be noted that some Icelandic mussel farms use continuously deployed spat collecting systems (or "looped" systems) which may pose more of an entanglement risk than single drop collectors, as they are connected at the bottom. Interestingly, no entanglement reports have been received from these operations, which may indicate that these sites may not have encounters with cetaceans, have been fortunate at avoiding them, or there is under reporting.

In total, two difinitive entanglement reports were collected from Iceland; their locations can be seen in Figure 20. The two entanglements occurred in operations that are no longer active, in single dropper mussel spat collecting ropes. The harbour porpoise incident occurred at a site that was 20 m from the coastline, and at a water depth of 5–15 m. The humpback entanglement, on the other hand, was much farther from shore (300–400 m) and at a water depth of 25 m. The two entanglements occurred during the summer, when concentrations of both baleen whales and harbour porpoises are thought to occur in higher densities in coastal shelf waters around Iceland. When compared to sites where no entanglements were reported, sites with reported entanglements do not appear to be more susecptible to cetacean encounters, with the exception of Nesskel ehf., discussed above, with a shallow water depth of 0–20 m.

Figure 20. Cetacean entanglements in Iceland. *Map data copyright [2015] Google. Source: author.*

Two entanglement reports from Icelandic mussel farming operations that have been active for the last 18 years amounts to a very small number especially when compared to fisheries bycatch in Iceland. It has been estimated that bycatch of harbour porpoises in gillnet fisheries numbers around 2000 a year since 2009, and was over 7000 animals a year in 2003 (Gunnlaugsson et al., 2014). Additionally, although there is no numerical estimate for bycatch of baleen whales in Iceland, a recent scar-based analysis study estimated that a minimum of 41.8% of the Icelandic subpopulation of humpback whales has been involved in a previous entanglement (Basran, 2014). NASS abundance estimates for humpback whales in Icelandic coastal waters in June and July were 10,521 whales in 1995 (C.I.: 3,716–24,636) and 14,662 in 2001 (C.I.: 9,441–29,879) (Paxton et al., 2013).

It is possible that some respondents may not have reported cetacean entanglements in their mussel gear for fear of being reprimanded, or having restrictions placed on them, which is known to be the case for some fishing industries (Johnson et al., 2005), potentially leading to a negatively biased result. Furthermore, a fundamentally differing attitude towards cetaceans remains in Iceland when compared to other westernized countries, especially among fishermen, as well as intense skepticism when it comes to interference from foreigners with regards to how to manage marine resources (Einarsson, 2009). This became apparent during data collection from mussel farmers in Iceland, many of whom used to be fishermen, as the survey was initially met with skepticism and one participant refused to be interviewed due to fact that cetacean entanglements were the focus of the study. This must be considered when interpreting the results as this may have led to biased reports or under-reporting of cetacean entanglements in Iceland.

Iceland offers abundant space and a pure environment for growth of the mussel industry, which is particularly important with the limited space available in the traditional culture areas in Europe (MFA, 2008). Many of the current operations, however, are only producing a few tonnes per year. When considering the potential for the Icelandic mussel industry to expand, half of the operators running active operations said they planned on expanding their operations. Additionally, one of the operators who had ceased operations reported that it could be possible to start up again. Some members of the mussel industry feel that they face a number of challenges, however, including current regulations and legislation, and the expense required to run a small mussel farming business, particularly when trying to adapt to local growing conditions. Therefore, it appears that there is a potential for the mussel industry to expand in Iceland, although it will not be without its challenges. In order for mussel farming to sustainably expand and continue to have a low impact on threatened cetacean species in Iceland, various stakeholders must study the issue of potential conflicts more rigorously. Some examples of action that might be taken include better survey data of cetacean distribution seasonally, and prudent selection of sites for deployment of spat collection lines, and mandatory reporting of entanglements.

6 Conclusions

When considering the assembled entanglement reports, spat collectors were involved in a majority of cases. This includes the two witnessed entanglement cases from Iceland, where deployment of spat collectors appears to overlap with the highest densities of cetaceans in coastal waters around the country. In total, only seven (possibly eight) cetacean and sea turtle entanglement reports in mussel aquaculture gear were collected. This further exemplifies that despite thousands of kilometers of rope used in the mussel aquaculture industry each year, entanglement of cetaceans and sea turtles is currently a rare event (Lindell & Bailey, 2015). This is particularly small when compared to the hundreds of thousands of cetaceans that die unintentionally in fishing gear every year (IWC, 2014; Read et al., 2006). With that being said, however, even one fatal entanglement of a highly endangered species, such as the North Atlantic right whale, which is estimated to number less than 500 individuals, could severely threaten the survival of the species (S. Lindell, personal communication, April, 2014; Pettis, 2011). This number is also very likely to be an underestimate considering the fact that this topic has not been investigated in many countries, and in some cases, aquaculture operators may be unwilling to report entanglements. Additionally, mussel aquaculture is likely to continue to grow in nearshore environments and expand into offshore environments, which when coupled with changing abundances and distributions of many species groups, will likely mean that direct interaction between cetaceans and sea turtles are likely to increase in the foreseeable future (Clement, 2013; IWC, 2010; Doyle, 2007; McMahon & Hays, 2006; Kemper et al., 2003; Würsig & Gailey, 2002; Moore & Wieting, 1999). There is also potential for the mussel industry to expand in Iceland. It is therefore important for management authorities to begin to consider the nature of the risk and potential management or mitigation measures that could be implemented if the need arises.

7 Future research and management recommendations

Only two (possibly three) cetacean entanglement reports were collected from Iceland. As stated above, however, this may be an underestimate of the true number of entanglement cases. Further, there is hope that the Icelandic mussel industry will expand, which may increase the risk of direct interactions occurring if new farming areas overlap with cetacean distributions. From the perspective of mussel operators in Iceland that were interviewed for this thesis, the issue of cetacean entanglements in mussel farming gear is not viewed as an issue that currently needs to be addressed. However, if the frequency of entanglement events increase and begin to cause significant damage to gear, some operators may be willing to take measures, such as modifying or moving gear, to reduce the risk of this occurring. A more pressing management measure, however, may be to implement a mandatory reporting system for all entanglements of cetaceans and other marine mammals in aquaculture gear in Iceland. Currently, it is mandatory for all marine mammal bycatch from fisheries to be reported (Gunnlaugsson, 2014), but there is no such requirement for fatalities in aquaculture gear. It would also be beneficial to have a requirement for non-fatal entanglements to be reported, so as many entanglement events as possible, regardless of the outcome, could be collected for future reference. As recommended by Basran (2014), it may also be of benefit to set up an online reporting system, which would be cost effective and would enable anyone who witnesses an entanglement to submit a report. It could also be combined with an online reporting system for entanglements in fishing gear. Reporting systems would enable a database of entanglement records to be created which could be readily accessed and utilized by researchers.

Future research may involve compiling detailed observations of the presence or absence of different cetacean species in the vicinity of mussel operations and time spent under or around the gear (Clement et al., 2003; Moore & Wieting, 1999). Analysis of data of this kind would further help to determine which species may be affected, as well as when and where entanglements may occur. If the mussel industry is to expand in Iceland, it may also be necessary to consider the siting of mussel operations to reduce overlap with the distribution or critical habitat of some species (Clement, 2013; Kemper et al, 2003). However, information on critical habitats and small-scale, year-round distribution data for many cetacean species in Iceland is lacking; therefore ongoing research and more consistent monitoring is required. Information of this kind could also be used in future studies looking into potential habitat exclusion caused by mussel farms. If spat collecting lines pose the largest risk for entanglement conflicts, then a study of areas that spat collectors can be successfully established with low likelihood of encountering whales should also be considered. Nearshore and shallow environments may be better places to collect spat and avoid potential conflicts with migrating and feeding whales, and this could be tested locally (S. Lindell, personal communication, April 2015). It is also critical to have a better understanding of both local and wider ranging knowledge of cetacean population sizes in order to determine the effect of fatal entanglements on the long-term viability of a population or species, and therefore determine if measures need to be taken to reduce the risk of entanglements occurring (Kemper et al., 2003).

On the whole, mussel farming has been conducted safely and sustainably throughout many regions of the world, while also cleaning the marine environment through its extractive nature of water filtration. In a broad sense, there appears to be a very low risk of entanglements of cetaceans and sea turtles in mussel gear to date. However, there may be higher risks under certain conditions than others. It seems likely that with these management measures taken, i.e. that siting be safely considered, and that spat collectors be established in areas with low encouter risk, mussel farming should be able to continue and expand in all the appropriate regions of the world, including Iceland, with little threat to cetaceans and sea turtles. There are still many unknowns, but largely because they have not been studied. Sustainable development will require cooperation between resource managers and industry to be compliant with reporting conflicts. The issue is of a global nature, and Iceland has the potential to be at the forefront of integrating resource studies with the sustainable development of the mussel farming industry.

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Appendix A: Online survey

Icelandic mussel operator survey

Þessi könnun er hluti af meistaraverkefni við Háskólasetur Vestfjarða á Ísafirði. Meginmarkmiðið með þessu verkefni er að kanna mögulega skörun dýra af hvalaætt og kræklingaræktar, í þeim tilgangi að meta líkur á skaðlegum "árekstrum" hvala og kræklingaræktar. Aflað verður upplýsinga um þekkt tilfelli hér við land, ef einhver eru, þar sem hvalir hafa farið inn á ræktunarsvæði og í kjölfarið lagt mat á áhættu sem í því getur falist fyrir hvalina. Slíkum upplýsingum hefur ekki verið safnað á þennan hátt áður svo vitað sé, hvorki á Íslandi né erlendis. Áhættan fyrir hvali í tengslum við kræklingarækt er því oft heimfærð yfir á almenn veiðarfæri þó munurinn geti verið mikill og niðurstöðurnar ekki endilega samanburðarhæfar. Þetta verkefni er því liður í að meta beint hvort hvölum stafi hætta af kræklingarækt (eða öfugt) og þá hægt að bera niðurstöðurnar saman við þekkt tilfelli og/eða aðstæður í öðrum löndum.

This survey is being carried out as part of a master's thesis at the University Centre of the Westfjords in Ísafjörður, Iceland. The topic of the research involves the potential for cetaceans (whales, dolphins and porpoises) to interact with mussel farming operations. One objective is to gather information on any known occurrences of cetaceans interacting with mussel farming operations in Iceland in order to properly determine the risks of potentially detrimental situations, such as entanglements, occurring in the country. To date, there appears to have been no direct collection of data on this topic globally. As a result, people in other mussel producing countries often use entanglement risks associated with fishing gears when discussing mussel farming gear, which is not necessarily appropriate, as they differ significantly. This study will help to determine if there are any risks to cetaceans from mussel farming gear, or vice versa, and the results can then be compared to known cases and/or conditions in other countries.

Nöfn svarenda munu ekki koma fram eða þau notuð í verkefninu að neinu leyti nema leyfi hvers og eins fáist til þess.

All respondents will be kept anonymous, unless permission is given otherwise. No names will be associated with any responses or will appear in the final research paper unless permission is given by the respondent.

Vinsamlegast skrifið svörin við spurningunum hér að neðan eða merkið í viðeigandi kassa. Vinsamlegast svarið eftir bestu getu.

Please write your answer on the lines provided or mark the appropriate box next to your answer choice if multiple options are given. Please answer the questions to the best of your ability.

Ef þú hefur einhverjar spurningar eða athugasemdir vinsamlegast hafðu samband:

If there are any questions or concerns, the researcher's contact information is provided below:

Madeline Young

Netfang *Email*: madeline13@uwestfjords.is

Símanúmer *Phone Number*: 666 2516

1. **Hver er núverandi staða á kræklingaræktinni þinni?** *What is the current status of your mussel farming operation?*

   □ Virk *Active*
   □ Óvirk (starfsemi hætt) *Inactive (operation has ceased)*
   □ Annað (vinsamlegast útskýrið) *Other (please specify)*

Ef óvirk … *If inactive …*

   a. **Hvenær hættir þú starfseminni?** *When did you cease operations?*

Ef óvirk, vinsamlegast svaraðu þá eftirfarandi spurningum miðað við þá kræklingarækt sem þú hafðir síðast. *If inactive, please answer the following questions as if referring to your last active operation.*

2. **Hvenær byrjaðir þú að rækta krækling við Ísland?** *When did you begin mussel farming in Iceland?*

3. **Hvar á landinu er kræklingaræktin þín staðsett?** *In what region is your mussel farm located?*

   □ Norðvesturlandi *Northwest Iceland*
   □ Norðausturlandi *Northeast Iceland*
   □ Austurlandi *East Iceland*
   □ Suðurlandi *South Iceland*
   □ Vesturlandi (þar með talið Faxaflói og Reykjanesskagi) *West Iceland (including the Capital Region and the Reykjanes Peninsula)*
   □ Vestfjörðum *Westfjords*

4. **Vinsamlegast lýstu útbúnaði kræklingaræktarinnar, meðal annars hve margar láréttar (burðarlínur) og lóðréttar línur eru að jafnaði í sjó.** *Please describe the layout of your farm, including the number of horizontal longlines and vertical lines to the surface associated with your farm.*

5. **Hversu langt frá landi er kræklingaræktin (í metrum)?** *How far is your farm from shore (in m)?*

6. **Hvert er dýpið þar sem kræklingaræktin er staðsett (í metrum)?** *What is the water depth at your farm location (in m)?*

7. **Á hve stóru svæði er kræklingaræktin (í fermetrum)?** *What is the total area covered by your mussel farm (in square metres, m^2)?*

8. **Hver er áætluð framleiðslugeta á ári (í tonnum)?** *What is the size of your production per year (in tonnes)?*

9. **Hvernig fer ræktunin fram, frá lirfuásetu til markaðsstærðar?** *How are mussels grown from settlement to market size on your farm?*

□ Á lirfusöfnurum *On seed collectors*
□ Kræklingurinn er "sokkaður" *They are "socked" (i.e. juvenile or seed mussels are removed from seed collectors and loaded into mesh sleeves)*
□ Á annan hátt (vinsamlegast útskýrið) *Other (please specify)*

10. **Eru uppi áform um að stækka ræktunarsvæðið?** *Do you plan to expand the size your mussel farm?*
    □ Já *Yes*
    □ Nei *No*
    □ Kannski (vinsamlegast útskýrið) *Maybe (please explain)*

Ef svo er… *If yes…*

a. **Hve mikil yrði aukningin (í fermetrum) og framleiðslu (í tonnum)?** *By how many square metres (m^2) and production volume (in tonnes)?*

11. **Hversu oft sérðu hvali í nágrenni við kræklingaræktina þína?** *How often do you see cetaceans within sight of your mussel farm?*

    □ Aldrei (ef svo er, farið beint í spurningu 16) (*if never go directly to question 16)*
    □ Sjaldan *Rarely*
    □ Stundum *Sometimes*
    □ Oft *Often*
    □ Alltaf *All of the time*

12. **Vinsamlegast raðaðu tímabilunum frá 1-4 eftir því hve oft hvalir sjást á ræktunarsvæðinu (1 fyrir oftast og 4 fyrir sjaldnast).** *Please rank each time period from 1-4 according to how many sightings there are in each time period (1 being the most sightings and 4 being the fewest sightings).*

    □ Mars-maí *March-May*
    □ Júní-ágúst *June-August*
    □ September-nóvember *September-November*
    □ Desember-febrúar *December- February*

13. **Vinsamlegast merktu við þá tegund sem sést oftast og er algengust á svæðinu, þá tegund sem er næst algengust, og þá tegund sem er þriðja algengust.** *Please indicate which species is the most commonly sighted, which species is the second most commonly sighted, and which species is the third most commonly sighted.*

    a. **Algengasta tegundin:** *Most commonly sighted:*

       □ Hrefna *Minke Whale*
       □ Hnúfubakur *Humpback Whale*
       □ Langreyður *Fin Whale*
       □ Steypireyður *Blue Whale*
       □ Hnísa *Harbour Porpoise*
       □ Hnýðingur/Blettahnýðir *White Beaked Dolphin*
       □ Grindhvalur *Long Finned Pilot Whale*

□ Andarnefja *Northern Bottlenose Whale*
□ Háhyrningur *Orca/Killer Whale*
□ Búrhvalur *Sperm Whale*
□ Annað *Other*
□ Veit það ekki *Don't know*

b. **Næst algengasta tegundin:** *Second most commonly sighted:*

□ Hrefna *Minke Whale*
□ Hnúfubakur *Humpback Whale*
□ Langreyður *Fin Whale*
□ Steypireyður *Blue Whale*
□ Hnísa *Harbour Porpoise*
□ Hnýðingur/Blettahnýðir *White Beaked Dolphin*
□ Grindhvalur *Long Finned Pilot Whale*
□ Andarnefja *Northern Bottlenose Whale*
□ Háhyrningur *Orca/Killer Whale*
□ Búrhvalur *Sperm Whale*
□ Annað *Other*
□ Veit það ekki *Don't know*

c. **Þriðja algengasta tegundin:** *Third most commonly sighted:*

□ Hrefna *Minke Whale*
□ Hnúfubakur *Humpback Whale*
□ Langreyður *Fin Whale*
□ Steypireyður *Blue Whale*
□ Hnísa *Harbour Porpoise*
□ Hnýðingur/Blettahnýðir *White Beaked Dolphin*
□ Grindhvalur *Long Finned Pilot Whale*
□ Andarnefja *Northern Bottlenose Whale*
□ Háhyrningur *Orca/Killer Whale*
□ Búrhvalur *Sperm Whale*
□ Annað *Other*
□ Veit það ekki *Don't know*

Vinsamlegast tilgreinið tegundina hér ef "Annað" var valið í einhverju tilfelli: *If the "Other" option was chosen for any of the three options above, please indicate which species you are referring to:*

14. **Veistu til þess að dýr af hvalaætt hafi SYNT Í GEGNUM eða MJÖG NÁLÆGT (innan 50 m) kræklingaræktinni þinni?** *Are you aware of a cetacean ever SWIMMING THROUGH or swimming VERY CLOSE (within 50 m) to your mussel farm?*

□ Já *Yes*
□ Nei *No*

Ef svo er… *If yes…*

a. **Vinsamlegast tilgreinið hér fyrir neðan (frá “Aldrei” til “Alltaf”) hve oft hver tegund syndir í gegnum eða nálægt kræklingaræktinni.** *Please indicate how often (from “Never” to “All of the time”) each species swims through your mussel farm using the drop down menu next to each species name.*

Hrefna *Minke Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Hnúfubakur *Humpback Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Langreyður *Fin Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Steypireyður *Blue Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Hnísa *Harbour Porpoise*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Hnýðingur/Blettahnýðir *White Beaked Dolphin*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Grindhvalur *Long Finned Pilot Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Andarnefja *Northern Bottlenose Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Háhyrningur *Orca/Killer Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Búrhvalur *Sperm Whale*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Annað *Other*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Veit það ekki *Don't know*

Aldrei *Never* Sjaldan *Rarely* Stundum *Sometimes* Oft *Often* Alltaf *All of the time*

Vinsamlegast tilgreinið tegundina hér ef "Annað" var valið: *If the "Other" option was chosen above, please indicate what species you are referring to:*

15. **Veistu til þess að dýr af hvalaætt hafi FLÆKST Í búnaði kræklingaræktarinnar hjá þér?** *Are you aware of a cetacean ever becoming ENTANGLED in your mussel farming gear?*

□ Já *Yes*
□ Nei *No*

Ef svo er… (ef "Nei" farið beint í spurningu 16) *If yes… (If "No" go directly to question 16)*

a. ***Hve oft hefur það gerst?*** *How many times has this occurred?*

□ Einu sinni *Once*
□ Tvisvar *Twice*
□ Oftar en tvisvar, vinsamlegast tilgreinið *More than twice, please specify*

Ef oftar en einu sinni, vinsamlegast svarið 15b-h aftur fyrir hvert tilfelli aftast í könnuninni. *If more than once, please fill out questions 15b-h again for each incident, located at the end of the survey.*

b. **Hvaða tegund FLÆKTIST Í búnaðinum?** *What species was ENTANGLED?*

□ Hrefna *Minke Whale*
□ Hnúfubakur *Humpback Whale*
□ Langreyður *Fin Whale*
□ Steypireyður *Blue Whale*
□ Hnísa *Harbour Porpoise*
□ Hnýðingur/Blettahnýðir *White Beaked Dolphin*
□ Grindhvalur *Long Finned Pilot Whale*
□ Andarnefja *Northern Bottlenose Whale*
□ Háhyrningur *Orca/Killer Whale*
□ Búrhvalur *Sperm Whale*
□ Annað (vinsamlegast útskýrið) *Other (please specify)*
□ Veit það ekki *Don't know*

c. **Hversu langt var dýrið (í metrum)?** *How long was the cetacean (in m)?*

d. **Í hvaða hluta búnaðarins flæktist dýrið?** In what part of the mussel farming equipment did the entanglement occur?

e. **Hvaða hluti dýrsins flæktist?** *What part of the cetacean was entangled*?

□ Munnur/höfuð *Mouth/head*
□ Líkami *Body*
□ Bægsli *Fins*
□ Sporður Tail/fluke
□ Annað (vinsamlegast útskýrið) *Other (please specify)*

f. **Flækjan…** *The entanglement was…*

□ Leiddi til dauða dýrsins *Fatal*
□ Leiddi EKKI til dauða dýrsins *Non-fatal*
□ Veit það ekki *Don't know*

g. **Ef dýrið lifði, hvernig var það losað?** *If non-fatal, how was the cetacean freed?*

□ Dýrið losnaði sjálft *The cetacean freed itself*
□ Dýrið var leyst með hjálp mannfólks *The cetacean was freed by people*
□ Annað (vinsamlega tilgreindu) *Other (please specify)*

h. **Ef dýrið lifði af, var búnaðurinn (eða hluti hans) áfram fastur á dýrinu eftir að það var losað?** *If non-fatal, did gear remain entangled around the cetacean after it was freed?*

□ Já *Yes*
□ Nei *No*
□ Veit það ekki *Don't know*

16. **Værir þú reiðubúinn til að veita viðtal um reynslu þína af þessu viðfangsefni?** *Would you be willing to be interviewed personally about your experiences?*

□ Já *Yes*
□ Nei *No*

Ef svarið er já, vinsamlegast veittu tengiliðaupplýsingar þínar hér að neðan *If yes, please provide your contact details below:*

Nafn *Name:*
Símanúmer *Phone Number*:
Netfang *Email:*

17. **Viltu fá að fræðast um niðurstöður rannsóknarinnar þegar að því kemur?** *Would you like to be updated with the results of this research project?*

□ Já *Yes*
□ Nei *No*

Ef svarið er já, vinsamlegast veittu tengiliðaupplýsingar þínar hér að neðan (ef þær koma ekki fram hér að ofan) *If yes, please provide your contact details below (If not provided above):*

Nafn *Name:*
Símanúmer *Phone Number*:
Netfang *Email:*

Hefur þú frekari athugasemdir? *Do you have any further comments?*

Kærar þakkir fyrir að taka þátt í þessari könnun! *Thank you for participating in this survey!*

Framhald/endurtekning spurningar 15: *Continuation of question 15:*

Vinsamlegast svaraðu eftirfarandi spurningum aftur ef fleiri en eitt dýr hafa flækst í búnaði kræklingaræktarinnar hjá þér *Please answer the following questions again if you responded more than once for question 15a (ie. if you are aware of more than one entanglement)*

Tilfelli #2 þar sem dýr af hvalaætt hefur flækst í búnaði: *Second entanglement:*

a. **Hvaða tegund FLÆKTIST Í búnaðinum?** *What species was ENTANGLED?*

□ Hrefna *Minke Whale*
□ Hnúfubakur *Humpback Whale*
□ Langreyður *Fin Whale*
□ Steypireyður *Blue Whale*
□ Hnísa *Harbour Porpoise*
□ Hnýðingur/Blettahnýðir *White Beaked Dolphin*
□ Grindhvalur *Long Finned Pilot Whale*
□ Andarnefja *Northern Bottlenose Whale*
□ Háhyrningur *Orca/Killer Whale*
□ Búrhvalur *Sperm Whale*
□ Annað (vinsamlegast útskýrið) *Other (please specify)*
□ Veit það ekki *Don't know*

b. **Hversu langt var dýrið (í metrum)?** *How long was the cetacean (in m)?*

c. **Í hvaða hluta búnaðarins flæktist dýrið?** In what part of the mussel farming equipment did the entanglement occur?

d. **Hvaða hluti dýrsins flæktist?** *What part of the cetacean was entangled*?

□ Munnur/höfuð *Mouth/head*
□ Líkami *Body*
□ Bægsli *Fins*
□ Sporður Tail/fluke
□ Annað (vinsamlegast útskýrið) *Other (please specify)*

e. **Flækjan…** *The entanglement was…*

□ Leiddi til dauða dýrsins *Fatal*
□ Leiddi EKKI til dauða dýrsins *Non-fatal*
□ Veit það ekki *Don't know*

f. **Ef dýrið lifði, hvernig var það losað?** *If non-fatal, how was the cetacean freed?*

□ Dýrið losnaði sjálft *The cetacean freed itself*
□ Dýrið var leyst með hjálp mannfólks *The cetacean was freed by people*
□ Annað (vinsamlega tilgreindu) *Other (please specify)*

g. **Ef dýrið lifði af, var búnaðurinn (eða hluti hans) áfram fastur á dýrinu eftir að það var losað?** *If non-fatal, did gear remain entangled around the cetacean after it was freed?*

□ Já *Yes*
□ Nei *No*
□ Veit það ekki *Don't know*

Tilfelli #3 þar sem dýr af hvalaætt hefur flækst í búnaði: *Third entanglement:*

a. **Hvaða tegund FLÆKTIST Í búnaðinum?** *What species was ENTANGLED?*

□ Hrefna *Minke Whale*
□ Hnúfubakur *Humpback Whale*
□ Langreyður *Fin Whale*
□ Steypireyður *Blue Whale*
□ Hnísa *Harbour Porpoise*
□ Hnýðingur/Blettahnýðir *White Beaked Dolphin*
□ Grindhvalur *Long Finned Pilot Whale*
□ Andarnefja *Northern Bottlenose Whale*
□ Háhyrningur *Orca/Killer Whale*
□ Búrhvalur *Sperm Whale*
□ Annað (vinsamlegast útskýrið) *Other (please specify)*
□ Veit það ekki *Don't know*

b. **Hversu langt var dýrið (í metrum)?** *How long was the cetacean (in m)?*

c. **Í hvaða hluta búnaðarins flæktist dýrið?** In what part of the mussel farming equipment did the entanglement occur?

d. **Hvaða hluti dýrsins flæktist?** *What part of the cetacean was entangled*?

□ Munnur/höfuð *Mouth/head*
□ Líkami *Body*
□ Bægsli *Fins*
□ Sporður Tail/fluke
□ Annað (vinsamlegast útskýrið) *Other (please specify)*

e. **Flækjan…** *The entanglement was…*

□ Leiddi til dauða dýrsins *Fatal*
□ Leiddi EKKI til dauða dýrsins *Non-fatal*
□ Veit það ekki *Don't know*

f. **Ef dýrið lifði, hvernig var það losað?** *If non-fatal, how was the cetacean freed?*

□ Dýrið losnaði sjálft *The cetacean freed itself*
□ Dýrið var leyst með hjálp mannfólks *The cetacean was freed by people*
□ Annað (vinsamlega tilgreindu) *Other (please specify)*

g. **Ef dýrið lifði af, var búnaðurinn (eða hluti hans) áfram fastur á dýrinu eftir að það var losað?** *If non-fatal, did gear remain entangled around the cetacean after it was freed?*

□ Já *Yes*
□ Nei *No*
□ Veit það ekki *Don't know*

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Appendix B: Interview guides

Icelandic mussel grower surveys

Before starting

- Thank interviewee for filling out the survey and agreeing to do the interview
- Ask for permission to record the interview
- Ask the interviewee about their preferred level of anonymity in the eventual thesis
- Ask if there are any questions before beginning the interview

Survey- follow-up questions

1. Clarify any answers on the survey that are confusing or unanswered.
2. Ask for more specifics about farm layout, mussel culture techniques and gear used (if not addressed in the survey).
   a) How long are your longlines?
   b) Are your mussel culture lines single droppers (hang straight down in single lines), or do they form a connected system (looped)?
   c) How long are your culture lines?
   d) What is the spacing between your culture lines?
   e) Are your lines submerged?
      - If so, how far?
   f) Are your lines anchored tightly in the water or are they more loosely flowing?

Further questions

3. How do you see the future of mussel farming in Iceland?
   a) Prompt: Do you see if expanding on a larger scale (both with regards to the number of farms or their size)?
4. Is there anything that could prevent mussel farming from expanding?
   a) Prompt: Is the industry facing any challenges?
      - Market?
      - Export fees?
      - Testing for toxins?

- Predation?

5. From your experience as a mussel farmer, do you see the potential for whales damaging mussel gear (by becoming entangled in the gear or by colliding with it) as being a problem for the mussel industry in Iceland?

   Prompt: What if the industry were to expand (become larger than it is today)?

6. And if there did appear to be a risk of mussel gear being damaged through *contact with whales here in Iceland* would you be willing to take measures to reduce this risk?
   a) Prompts:
      - Modifying your gear
      - Relocating the operation
      - Or something else?
   b) What about other farmers here in Iceland?

Appendix C: Mussel operations in Iceland

Description of mussel farming operations in Iceland that were the focus of both surveys and interviews. Source: author *(continued on the next page).*

Region and company	Status of operation	Layout, gear, techniques	Method of mussel grow-out	Distance to shore (m)	Water depth (m)	Area covered (m^2)	Production quantity (tonnes)	Plans to expand?
West Iceland (Vogaskel ehf.)	Active	- 6 headropes (230 m each, 2 sets of 3) - 1700 m of single dropper collectors on each headrope (each 3.5 m long, 0.4 m spacing) - Collectors on the surface in the summer and submerged 7–10 m in late August/early September after spat is collected - Loosely anchored	Mussels typically grown on spat collectors but may be "socked" if lines become to heavy	230	30	30,000	15 currently, 300 possible in full production	Would like to, but not possible
West Iceland (Ósk ehf.)	Active	- 14 headropes (220 m each, 2 sets of 2 and 2 sets of 3) - Single dropper collectors (2.5 m long, 0.4 m spacing) - Ropes submerged 8 m after spat collection - Tightly anchored	Mussels are grown on spat collectors	1000	30	–	20	Yes
West Iceland	Active	30 headropes, 1500 m of collectors on each headrope	Mussels are "socked"	150	12–30	1,000,000	200	Yes– by 1,000,000 m^2 and an additional 5–600 tonnes
West Iceland (Íslensk Bláskel ehf.)	Active	15 headropes (250 m each)	Mussels are "socked"	150	10–40	500,000	100	No
Westfjords (Nesskel ehf.)	Active	7 headropes (220 m each), 2000 m of socking on each (5 m long loops), 0.5–1 m spacing	Mussel seed/small mussels are dredged and then "socked"	600–2000	0–20	8,000,000 (licensed area)	<50 currently (200 possible with license)	No
Westfjords (Vesturskel ehf.)	Active (experimental)	- 7 headropes (230 m each, continuous line) - 1800–2000 m of collectors on each headropes (connected system, 6 m long loops, 0.6 m spacing) - Ropes submerged 3 m - Tightly anchored	Mussels typically grown on spat collectors but may be "socked" if lines become to heavy	500	35–50	16,100 (practical area)	Unable to provide a precise figure	Yes– the company eventually wants to have 3 separate areas, each 500,000 to 1,000,000 m^2

Region and company	Status of operation	Layout, gear, techniques	Method of mussel grow-out	Distance to shore (m)	Water depth (m)	Area covered (m^2)	Production quantity (tonnes)	Plans to expand?
Westfjords (ST2 ehf)	Active	- 15 headropes (200 m each), total of 30,000 m of collectors (connected system, 5 m long loops) - Ropes submerged 10–15 m - Loosely anchored	Mussels are "socked"	500–1500	25–55	–	200	No
Westfjords (Fjarðalax ehf.)	Active	- 4 headropes (220 m each, continuous line) -Connected system of droppers (5 long loops, 1 m spacing) - Ropes submerged 10 m - Tightly anchored	Mussels are socked after 14–15 months	–	30	8,800 (practical area, 500,000 licensed area)	Experimental	Yes
Northwest Iceland (IcelMussel ehf.)	Inactive	4 headropes (50 m long each), 5 m long single dropper collectors	Mussels were grown on spat collectors	300–400	25	4000 (practical area calculated)	Experimental	No
Northeast Iceland (Norðurskel ehf.)	Inactive	- 170 headropes (220 m each) - Mostly single dropper collectors/socks (some looped; 5 m long, 0.5 m spacing) - Tightly anchored	Mussels were "socked" after 1 year	50–300	6–50	1,600,000	Different from year to year	No
East Iceland (Hafskel ehf.)	Inactive	8–12 headropes (200–400 m each), 5 m long droppers, 0.5 m spacing, submerged 5-10 m	Mussels were "socked"	20	5–15	840,000–600,000	–	Possible to start up again if conditions permit

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