Master's thesis

The consumption of commercially valuable fish by pinnipeds in Northwest Icelandic waters

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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

Fisheries are one of the most valuable exports for Iceland. In order to protect valuable fish stocks, it is necessary to understand their ecological context. Interspecific competition between humans and pinnipeds for commercially valuable fish requires consideration when managing fisheries and marine resources. The foundation for the study of interspecific competition lies in the analysis of the overlap in prey consumption between competing predators. This requires an understanding of the consumption of prey by predatory species of interest. While information regarding the fisheries is widely available, the knowledge of seal diets in Iceland is limited. This study uses the identification of fish otoliths and other hard parts, invertebrate carapaces, and squid beaks to assess the diets of the native common seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*), as well as the winter-visiting harp seals (*Pagophilus groenlandicus*). Seals were collected by fishers and hunters, either as by-catch in gill nets or shot, during the months of March to September 2010. Sixty-four common seal, 19 grey seal and 13 harp seal stomachs were analyzed for prey contents. Common seal stomachs contained Atlantic cod (*Gadus morhua*) and Atlantic wolffish (*Anarhichas lupus*) in the highest quantities of estimated wet weight (60.7% and 20.8%, respectively), while grey seal stomach contents contained Atlantic wolffish (67.9%) and Atlantic cod (23.9%) and harp seal samples contained haddock (*Melanogrammus aeglefinus*) (36.0%), Atlantic cod (33.2%) and capelin (*Mallotus villosus*) (17.5%). Analysis of the overlap with fisheries determined that of the 17 fish species of economic value that are targeted by commercial fisheries, nine were found in the stomachs of common seals, seven in the stomachs of grey seals, and six in the stomachs of harp seals. Harp seals were the only seal species analyzed in this study found to consume a by-catch species of economic value to the Icelandic fishery; the dab, (*Limanda limanda*). Although the overlap with fisheries indicates the occurrence of interspecific competition for several commercially valuable species, further analysis is required to fully understand the extent of the relationship and assist in the management of these commercially valuable fish stocks.

Table of Contents

Abstract……………………………………………………………………………v

Table of Contents…………………………………………………………………vii

List of Figures……………………………………………………………………ix

List of Tables……………………………………………………………………xi

Acknowledgements………………………………………………………………xiii

1.0 Introduction……………………………………………………………………15

2.0 Theoretical Overview…………………………………………………………17
2.1 Icelandic Fisheries……………………………………………………………17
2.2 Ecosystem Based Management………………………………………………17
2.3 Seals in Iceland…………………………………………………………………18
2.4 Interactions with Fisheries……………………………………………………18
2.4.1 Operational Interactions……………………………………………………18
2.4.2 Biological Interactions………………………………………………………19
2.4.2.1 Transmission of Parasites………………………………………………19
2.4.2.2 Trophic Interactions………………………………………………………19
2.5 Diet Studies………………………………………………………………………21
2.5.1 Methods of Diet Analysis……………………………………………………21
2.5.2 Diet Studies in Iceland………………………………………………………24
2.6 Management Implications………………………………………………………24

3.0 Ethics……………………………………………………………………………27

4.0 Research Methods………………………………………………………………29

5.0 Results……………………………………………………………………………31
5.1 Common Seals……………………………………………………………………31
5.2 Grey Seals…………………………………………………………………………31
5.3 Harp Seals…………………………………………………………………………32
5.4 Diet/Fisheries Overlap…………………………………………………………32
5.4.1 Common Seals………………………………………………………………32
5.4.2 Grey Seals……………………………………………………………………33
5.4.3 Harp Seals……………………………………………………………………33

6.0 Discussion………………………………………………………………………35
6.1 Seal Diets…………………………………………………………………………35
6.1.1 Common Seals………………………………………………………………35
6.1.2 Grey Seals……………………………………………………………………36
6.1.3 Harp Seals……………………………………………………………………36
6.2 Diet/Fisheries Overlap…………………………………………………………37

6.3 Methods, Biases and Sources of Error………………………………………. 37
6.3.1 Method of Analysis………………………………………………… 37
6.3.2 Identification Errors…………………………………………………38
6.3.3 Otoliths and Correction Methods…………………………………….38
6.3.4 Underrepresented Species……………………………………………39
6.3.5 Sampling……………………………………………………………..... 40
6.4 Management Strategies……………………………………………………… 41
6.5 Future Studies………………………………………………………………..42

7.0 Conclusion……………………………………………………………………43

8.0 Summary……………………………………………………………………..45

9.0 Figures………………………………………………………………………..47

10.0 Tables……………………………………………………………………… 57

11.0 Literature Cited…………………………………………………………….65

List of Figures

Figure 1:Incomplete food web for the Northwest Atlantic……………………………… 47
Figure 2: Potential indirect and direct trophic interactions………………………………. 48
Figure 3: The inner ear of a teleost fish………………………………………………….. 49
Figure 4: Map of Iceland depicting sampling area……………………………………….. 50
Figure 5: Diet composition of common seals (*Phoca vitulina*)…………………………... 51
Figure 6: Diet composition of grey seals (*Halichoerus grypus*)…………………………..52
Figure 7: Diet composition of harp seals (*Pagophilus groenlandicus*)……………………53
Figure 8: The percentage of the diet composed of commercially
valuable target and by-catch species in 2009……………………………………54
Figure 9: Map of sampling divisions in Hauksson and Bogason 1997…………………… 55

List of Tables

Table 1: Advantages and disadvantages of different diet analysis methods……………… 57
Table 2: Total stomachs analyzed for each seal species and capture method……………..58
Table 3: Morphological features defining the degree of digestion of otoliths…………….59
Table 4: Regression equations………………………………………………………… 60
Table 5: Number of stomach samples based on month of capture……………………….. 61
Table 6: Commercially targeted and bycatch species……………………………………. 62
Table 7: Comparison of total seal stomachs analyzed…………………………………… 63

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1.0Introduction

Knowledge about species interactions is important for the current shift in fisheries management from single-species focus towards ecosystem-based approaches. Ecosystem or multi-species approach to management attempts to view a single species as part of an ecosystem, rather than a separate entity. An ecosystem is the combined unit of both an ecological community and its surrounding environment (Link, 2002). Through gaining an understanding of the roles that species play in an ecosystem, one can attempt to predict how perturbations in the ecosystem (i.e. the removal of individuals, the extinction of a species, habitat changes, etc.) will affect the complex processes taking place.

Pinniped species are abundant, potentially significant, consumers of marine prey species worldwide (Bowen et al., 1993). Specifically, common seals, *Phoca vitulina,* grey seals, *Halichoerus grypus* and harp seals, *Pagophilus groenlandicus,* are known to consume a wide variety of prey species including species that are targeted by both commercial and recreational fisheries (Bax, 1998; Brown and Pierce, 1997 Lundström et al., 2010; Tollit and Thompson, 1996; Trites et al., 1997). Due to their large populations in many coastal and marine regions and their consumption of prey that are valuable to fisheries, they are often assumed to be significant competitors with fisheries by reducing fisheries' yields (Bowen, 1997). Therefore, it is necessary to understand the interactions between humans and seals to assess the presence and extent of interspecific competition, to allow for the implementation of appropriate management schemes to maintain the resilience of the ecosystem.

The foundation for determining interspecific competition arises from the analysis of shared resource use. While data regarding fisheries catches in Iceland is widely available, there is limited data on the consumption of common, grey and harps seals in Icelandic waters and a lack of studies focusing on competition between seals and Icelandic fisheries. Considering the importance of commercial fisheries to Iceland, it is therefore prudent to gain an understanding of the ecosystem processes occurring, including interspecific competition, that potentially affect important fish stocks. To determine the occurrence of interspecific competition between fisheries and pinnipeds, this study evaluates the consumption of commercially valuable fish in Northwest Iceland through the dietary analysis of the stomach contents of common, grey and harp seals in comparison to the commercially targeted and economically valuable by-catch species.

2.0 Theoretical Overview

2.1 Icelandic Fisheries

The significance of fisheries to Iceland cannot be understated (Arason, 2003). The island nation's marine resources form the foundation of exports for the country, especially Atlantic cod (Valtýsson, 2002). The ground fish fisheries are considered the most important fishing sector, targeting Atlantic cod, haddock, redfish (*Sebastes marinus*) and saithe (*Pollachius virens*), as well as other species (Eythórsson, 2002; Valtýsson and Pauly, 2003). Historically, the pelagic fisheries concentrated on herring (*Clupea harengus*), but after a significant collapse in the stock in the 1960´s it expanded to include capelin and blue whiting (*Micromesistius poutassou*) (Valtýsson and Pauly, 2003).

Icelandic fisheries are managed by an individual transferable quota system (ITQ) which is supported by gear restrictions, spatial and temporal limitations and restrictions on fishing undersized fish (Valtýsson, 2002). The total allowable catch (TAC) is decided by the Minister of Fisheries and Agriculture based on advice given by the Icelandic Marine Research Institute (MRI) and the International Council for the Exploration of the Sea (ICES). The TAC is then divided into quotas attached to individual fishing vessels. (Ministry of Fisheries and Agriculture, 2010a).

2.2 Ecosystem Approach to Fisheries

Unsustainable fishing practices have resulted in major shifts in the composition of species throughout the world's marine ecosystems, ultimatelyaffecting productivity and economic yield (Bax, 1998; Hannesson, 2002). The mechanisms that drive these shifts are complex interactions between species and their environments, making them difficult to manage (Bax, 1998). Current management views attempt to embrace this complexity by approachingmanagement of marine ecosystems more holistically and more effectively, evolving from a suite of single-species approaches to a multi-species or ecosystem approach (Bax, 1998; Link, 2002; Pikitch et al., 2004; Read, 2008; Víkingsson et al., 2003; Yodzis, 2001).

The main objective of approaching fisheries management from an ecosystem perspective is to sustain the health of marine ecosystems and their supporting fisheries (Pikitch et al., 2004; Jennings et al., 2001). One of the main goals proposed is the generation of a knowledge base of ecosystem processes in order to comprehend the consequences of human actions (Pikitch et al., 2004). As fisheries play a significant role in marine and freshwater ecosystems, it is essential to study ecosystem dynamics to understand past interactions and to better predict and manage future interactions between fisheries and the ecosystems that support them.

2.3 Seals in Iceland

Seven species of pinniped are found in Iceland: common seal, grey seal, harp seal, ringed seal (*Phoca hispida*), hooded seal (*Cystophora cristata*) and bearded seal (*Erignathus barbatus*), and the walruses (*Odobenus rosmarus*) (Ministry of Fisheries and Agriculture, 2010b). Common and grey seals are native to Icelandic waters, found year round along the coast, while harp, ringed and hooded seals are frequent winter visitors. A visitor is a seal species that travels to an area to feed, but does not mate or moult within the area (Hauksson and Bogason, 1997). Bearded seals and walruses are the rarest of all pinnipeds sighted in Icelandic waters. According to a surveys conducted in 2005 and 2006, the grey and common seal populations were estimated at 6,000 and 12,000 individuals respectively (Ministry of Fisheries and Agriculture, 2010b).

2.4 Interactions with Fisheries

The majority of marine mammal species interact with fisheries and these interactions mainly fall under two categories: operational and biological (Bjørge et al., 2002; Bowen, 1997; Northridge and Hofman, 1999). Operational interactions involve the direct interference of marine mammals and the actual fishing operation, whereas biological interactions take a more indirect form (Matthiopoulos et al., 2008; Northridge and Hofman, 1999).

2.4.1 Operational Interactions

Operational interactions have a direct impact on the fishery by reducing fisheries yields or by damaging fishing gear. Such interactions include the removal of fish from nets or lines, also known as depredation, entanglement in fishing gear, damaging fishing gear, or disturbance of the fishing activity (Matthiopoulos et al., 2008; Northridge and Hofman, 1999). In Icelandic waters, one way seals affect the operation of the fishing industry is by becoming entangled in fishing gear. In the 2009 fishing year, the reported number of seals hunted or caught as by-catch was 154 harbour seals, 74 grey seals, 57 harp seals, one bearded seal, and 35 unidentified seals (Marine Research Institute, 2010).

2.4.2 Biological Interactions

Unlike operational interactions, biological interactions arise from a common link in a chain of events that ultimately affects the fishery or the marine mammal population. These interactions include: the transmission of parasites and trophic interactions. Trophic interactions include the competition for the same prey species and the competition for similar prey between a marine mammal and a species targeted by a fishery (Matthiopoulos et al., 2008; Northridge and Hofman, 1999).

2.4.2.1 Transmission of Parasites

While seals do play a role in the transmission of parasites around the coast of Iceland, most notably the sealworm (*Pseudoterranova decipiens*), which is a common and abundant parasite found in commercial fish species (Ólafsdóttir, 2001), the main focus of this study is on the trophic interactions between marine mammals and fisheries.

2.4.2.2 Trophic Interactions

Trophic interactions are the feeding relationships between species in an ecosystem resulting in the acquisition or loss of energy and nutrients. These interactions play a profound role in shaping an ecosystem's community, affecting the population dynamics, coexistence of species, and, even, the entire organization of communities (Holt and Loreau, 2001).

Marine mammals are predators of marine organisms from all trophic levels, including primary production, predatory fish, and even other marine mammals (Bax, 1998; Bowen, 1997). Pinnipeds are catholic feeders, eating a wide variety of prey species, often taking advantage of the high encounter rate with locally and seasonally abundant prey (Brown and Pierce, 1997; Lundström et al., 2010; Trites et al., 1997). Among the prey consumed are fish targeted by commercial and recreational fisheries, which often leads to the assumption that pinnipeds are competing with human for marine resources, the subsequent need for research and often a cull of the competing marine mammals (Bax, 1998; Brown and Pierce, 1997; Lundström et al., 2010; Tollit and Thompson, 1996).

Interspecific competition is the reduction in the ability of individuals of one species to reproduce, grow or survive due a reduction in available resources as a result of another species' exploitation (Begon et al., 1996). The current literature lacks any studies that specifically focus on determining the presence and extent of interspecific competition between seals and fisheries in Icelandic waters, however interspecific competition is the central focus of research conducted on marine mammals, including seals, in other regions (Andersen et al., 2007; Bjørge et al., 2002; Furness, 2002; Kaschner et al., 2001; Trites et al., 1997).

Simply speaking, humans and marine mammals can be seen as predators using and perhaps competing for the same resource. In reality, interspecific predatory interactions are more complicated, often involving intricate food web connections across many trophic levels (Northridge and Hofman, 1999). An incomplete foodweb of the Northwest Atlantic, illustrates that food web connections are complex and involve many different trophic interactions within a given ecosystem (Figure 1). The variability and complexity of these connections allows for many pathways for interspecific competition between humans and marine mammals to occur (Figure 2). These complexities make the occurrence of direct or indirect competition between fisheries and marine mammals difficult to determine.

Several methods, relying on the comparison between aspects of the consumption of marine organisms by pinnipeds and information regarding catches from the fishing industry, are used to determine interspecific competition, including: (1) the degree of overlap between pinniped prey selection and fisheries catches, also known as diet/fisheries overlap (Trites et al., 1997; Kaschner et al., 2001); (2) running fisheries management simulations on pinniped predation models (Cornick et al., 2006); and (3) mapping the overlap of pinniped feedingareas with fishing areas (Kaschner et.al., 2001).

While the diet/fisheries overlap method alone may not be proof of competition as stated by Lavigne (1996), Szteren et al., (2004) indicate that it can be used to assess the presence of biological interactions, including a broad indication of interspecific competition. Information presented in this manner may be misleading, however, as the assessment provides a static view of the current state of the system. A static view provides general information regarding interspecific competition, but cannot answer fundamental questions concerning how changes in the abundance and availability of the shared resource will affect the competitors (Matthiopoulos et al., 2008). In the Pacific Ocean, the use of the diet/fisheries overlap method determined that of all marine mammals, pinnipeds have the greatest overlap (60%) with fisheries as measured by prey selection (Trites et al., 1997). Assessment of competition between the commercial ground fishery in Alaska and the Stellar sea lions determined that changes in fisheries management regimes within the model had little to no effect on the energy available to Steller sea lions and therefore lacked any evidence of competition (Cornick et al., 2006).

Using map overlays to assess and illustrate the areas of overlap between marine mammal consumption and fisheries catches in the North Atlantic found that the area of overlap was the highest within pinniped species. This means that pinnipeds, in relation to other marine mammal groups, tend to feed to a higher extent in areas that are also used by the fishing industry, especially around the British Isles and Newfoundland and within the Bay of Fundy and the Gulf of Maine (Kaschner et al., 2001). Whichever method chosen, ultimately, each one stems from the need for knowledge of pinniped feeding habits.

2.5 Diet Studies

Dietary studies provide important information regarding the ecological role of a species, including prey selection and interspecific competition (Lundström et al., 2010). Understanding the ecological role of a species can enable the quantification of interspecific interactions (Pierce and Boyle, 1991).

2.5.1 Methods of Diet Analysis

There are several different methods of analyzing prey consumption in seals. Some rely on the analysis of stomach contents for determining seal diets, whether through stomach lavage as used by Antonelis Jr. et. Al, (1987) in which a tube is inserted through the mouth to allow for stomach contents to be pumped out, or through evisceration (Bowen et al., 1993; Hauksson and Bogason, 1997; Lundström et al., 2007 and 2010; Nilssen et al., 1995; Víkingsson et al., 2003; and Weslawski et al., 1994). Others have taken a less intrusive method, relying on the identification of food remains in the faecal material left behind on haul out sites (Bjørge et al., 2002; Brown and Pierce, 1997 and 1998; Cottrell and Trites, 2002; Cottrell et al., 1996; Mecenero et al., 2007; Szteren et al., 2004; Tollit and Thompson, 1996). While Anderson et al., (2007) and Hammill and Stenson, (2000) rely on both stomach evisceration and faecal samples and one study, by Carter et al. (2001), relies on observational data alone for seal diet.

Each analysis method has different impacts/interactions with the animals being studied and provide results of varying accuracy. A study of which method to choose when determining the diet composition of sea lions outlines the advantages and disadvantages each method. The study focuses on the relative impact on individual seals and overall group health, along with the parameters and accuracy required to acquire dietary information (Tollit et al., 2006) (Table 1). With these aspects as key factors in method selection, the method with the lowest overall impact on seals and seal populations is direct observation. However, this method limits the data collected to accessible areas for observation and to only prey that are seen in the mouths of seals at the surface. At the other extreme, when stomach contents are obtained through evisceration, the impact on the individual is extreme, as the seal must die. The impact on the group is moderate-high, due to the loss of individuals and perhaps physical disturbances, depending on the collection method. Information collected in this method provides a static view of the diet before death and sample sizes can be reduced due to empty stomachs (Tollit et al., 2006).

Prey remains are identified using hard parts found in stomach, vomit or faecal remains that digest at a slow rate. These include invertebrate carapaces, squid beaks, and fish bones, teeth, and otoliths (Granadeiro and Silva, 2000). Otoliths are made of calcium carbonate and are found in three pairs within the inner ear of teleost (bony) fish: the sagitta, the asteriscus and the lapillus (Figure 3) (Cottrell and Trites, 2002; Popper and Lu, 2000). The sagitta, being the largest, is recognized as one of the most useful and widely used fish hard parts to analyze when identifying fish (Campana, 2005; Granadeiro and Silva, 2000; Pierce and Boyle, 1991).

Relying solely on otoliths for the indication of prey species in a diet, however, could result in the omission of some prey types from the analysis (Cottrell and Trites, 2002). Despite being approximately three times denser than the rest of the fish, otoliths are damaged, both mechanically and chemically, throughout the digestive process, limiting their identifying properties (Granadeiro and Silva 2000; Popper and Lu, 2000). Otoliths are often broken, digested beyond recognition or not ingested at all if the fish head is not consumed (Cottrell and Trites, 2002). These limitations have resulted in an increase in the use of alternative fish hard parts (i.e. bones and teeth) to validate and supplement the identification information obtained using otoliths in the analysis of the diet of piscivorous predators (Granadeiro and Silva 2000).

Otolith, vertebrae and premaxillae (upper jaw) measurements are used to extrapolate the length and wet weight of the fish. These relationships are useful in diet analysis that estimate the biomass of fish consumed, along with studies that estimate the length and weight of fish consumed. The chemical and mechanical damage that otoliths endure in their passage through the digestive tract can affect the estimates obtained through these relationships. Digestion reduces the size of otoliths at highly variable and often unpredictable rates (Tollit et al., 1997). A feeding experiment by Tollit et. al, (1997) shows, in congruence with similar earlier studies, that the amount of reduction due to digestion, though related to the original size and species of the fish, appears to depend upon variable single-meal factors. These factors include the time an otolith spends in and the gastrointestinal mechanisms of the digestive tract. Pinniped gastronintestinal mechanisms, which move prey and digested material through the alimentary canal are poorly understood. Murie and Lavigne (1985b), cited in Pierce and Boyle (1991), determined that after three hours, with a meal of six kg of herring, stomach contents lack any significant evidence of digestion. Flesh and bones become fragmented after six hours and after 18 hours, the stomach is empty of hard parts. Ultimately, the literature illustrates that some method of correction should be utilized to deal with the variable reduction in otolith size when attempting to extrapolate length and weight information.

Stomach contents can be analyzed in different ways. (Cortés, 1997; Pierce and Boyle, 1991). The most common presentation methods are: (1) abundance (Anderson et al., 2007; Bowen et. al, 1993; Brown and Pierce, 1997 and 1998; Szteren et. al, 2004; Tollit and Thompson, 1996; Víkingsson et al., 2003); (2) frequency of occurrence (Bowen et. al, 1993; Brown and Pierce, 1997; Lilliendahl, 2009; Lundström et al., 2007 and 2010; Nilssen et al., 1995; Víkingsson et al., 2003); (3) estimated volume or weight of prey items consumed (Anderson et al., 2007; Bowen et al., 1993; Brown and Pierce, 1997 and 1998;

Hammill and Stenson, 2000; Hauksson and Bogason, 1997; Lawson et. al, 1994; Lilliendahl, 2009; Mecernero, n.d.; Tollit and Thompson, 1996; Trites et al., 1997; Víkingsson et al., 2003); (4) estimated length classes consumed (Brown and Pierce, 1997 and 1998; Víkingsson et al., 2003); (5) estimated calorific values (Bowen et al., 1993; Hammill and Stenson, 2000); and (6) other compound indices that incorporate one or more of the aforementioned measurements (Cortés, 1997). The decision of which method to use is subjective and dependent on the questions being asked (Cortés, 1997; Pierce and Boyle, 1991). Cortés, (1997), determined from the study of previous literature, that the numerical abundance is appropriate for determining feeding behaviour, estimated volume or weight of prey can be used to assess dietary value, and frequency of occurrence should be used for inferring the feeding habits of populations. Additionally, Pierce and Boyle, (1991), state that volume or weight measurements are one of the most appropriate methods of presenting diet information when assessing competition with fisheries.

2.5.2 Diet and Interspecific Competition Studies in Iceland

One study, completed by Hauksson and Bogason in 1997, extensively examined the diet of grey and common seals and, to a lesser extent, the diet of hooded and harp seals, in Iceland. The sampling period occurred between 1990 and 1993 for grey seals, 1992 and 1993 for common seals, 1990 and 1994 for both hooded and harp seals. According to the authors, the most common prey species were determined based on the percentage weight of the total estimated weight of species consumed. For grey seals, the most common prey are Atlantic cod, sandeels (the lesser sandeel, *Ammodytes marinus,* the small sandeel, *Ammodytes tobianus* and the greater sandeel *Hyperoplus lanceolatus*) Atlantic wolffish, saithe, and lumpsucker (*Cyclopterus lumpus*) and for common seals are Atlantic cod, redfish, sandeels (the lesser sandeel, the small sandeel, and the greater sandeel), saithe, herring, wolffish and capelin. The main species targeted by harp seal include sandeels (the lesser sandeel, the small sandeel, and the greater sandeel), herring, bull rout (*Myoxocephalus scorpius*) and Atlantic cod.

2.6 Management Implications

One of the main management strategies used to address losses to fisheries in several areas of the world, where interspecific competition between humans and seals occurs or is thought to occur, is to cull the marine mammal to reduce their numbers in an attempt to increase fishery yields (Bax, 1998; Lavigne, 1996; Northridge and Hofman, 1999; DeMaster et al., 2001). Yet removing this one source of mortality on a stock does not necessarily predict an increase in fisheries yields, as illustrated in Punt and Butterworth, 1995. The authors modeled the trophic interactions between two species of Cape hake, *Merluccius capensis* and *M. paradoxus* (shallow- and deep-water, respectively) and the Cape fur seals in the Benguela ecosystem off the western coast of Africa. With the inclusion of mortality from other predatory fish, the authors determined that overall a cull would not result in a significant increase in Cape hake catches (Punt and Butterworth 1995). A reduction in Cape fur seals, which predominantly consume the young shallow-water hake, would result in an increase in adult shallow-water hake. Adult shallow-water hake prey on the young of deep-water hake, and subsequently would reduce the population of deep-water hake (Butterworth and Punt, 2002). As well, a recent report by Chassot et al., (2009) states that, based on modeling, the recovery of the Northern Gulf of St. Lawrence Atlantic cod stock could be significantly impacted by the predation of harp seals. Yet, the authors conclude that managing the seals with the objective of reducing impacts on the Atlantic cod stocks may not result in the desired goal of higher Atlantic cod populations due to interactions with other components of the ecosystem.

Non-lethal management methods used include: acoustic deterrents, tactile harassment, and vessel chase. Acoustic deterrents are devices that attempt to make marine mammals aware of and deter them from interacting with fishing gear. This includes underwater firecrackers, acoustic harassment devices (AHDs), and acoustic deterrent devices (ADDs), which are modified AHDs. The effectiveness of these methods is questionable, as seals become used to the underwater firecrackers and are often drawn in by the AHDs and ADDs (Marine and Marine Industries Council, 2002). Tactile harassment includes the firing of rubber bullets or beanbags at marine mammals close to fishing operations. The use of rubber bullets as a deterrent has had mixed results in terms of effectiveness and beanbags, which can be shot from an ordinary shotgun, raise environmental concerns as they consist of lead shot in a nylon bag (Marine and Marine Industries Council, 2002). Lastly, vessel chase is the use of boats to chase, scare and harass seals. This method is likely to be most effective if used intermittently when interactions are high (Marine and Marine Industries Council, 2002).

In the current study, the stomach contents of three seal species from the Northwestern region of Iceland, common seal, the grey seal and the harp seal will be analyzed through otolith and hard part identification. The dietary information gathered will be analyzed, in terms of abundance and estimated weight, in conjunction with fisheries catches to determine the dietary overlap with fisheries. It is hypothesized that commercially valuable fish make up a large proportion of the diets of common seals, grey seals and harp seals.

3.0 Ethics

Working with marine mammals can be controversial, especially when they are harmed when collecting samples. No seals were intentionally harmed for the purpose of this study. Seals were either caught as by-catch in the gill nets of the Icelandic lumpsucker or cod fisheries or shot and subsequently obtained from local fishers and hunters. By-catch is the incidental capture of species that are not the intended target of the fishery.

4.0 Research Methods

Stomachs were collected from 75 common seals, 20 grey seals and 13 harp seals caught in the gill nets of local fishers in the lumpsucker and cod fisheries or shot in Northwest Iceland between the months of March and September 2010 and frozen until processed (Table 2). Food remains were isolated by cutting the seal stomach open, and washing the contents over sieves of varying mesh sizes, the smallest being 0.5 millimetres (mm). The stomach contents were sorted to isolate fish bones and otoliths, invertebrate carapaces and shells, and squid beaks. Otoliths and other hard remains were identified to lowest possible taxonomic level through comparison to a reference collection and the use of reference guides and books (Campana, 2004; Härkönen, 1986; Svetocheva et al., 2007; Watt et al., 1997).

Otoliths were paired and measured lengthwise, from rostrum to the posterior edge, or widthwise, at widest point, using a digital caliper to 0.01 mm. Otoliths were then assessed for state of degradation based on the gradient scale outlined (Table 3). From the measured lengths and widths, estimates of the wet weight of individual fish were made using regression equations relating otolith size and fish wet weight (Table 4). Whenever possible, equations specific to Icelandic waters were used to estimate fish wet weight.

The biomass represented by broken or grade 3 otoliths and hard parts unassociated with otoliths was calculated based on the assumption that the original otoliths were the same size as the mean length of uneroded otolith of the species consumed by that particular pinniped species during the relevant month. If there were less than five of a species for a specific month, a seasonal mean was used (late winter: March, spring: April and May, summer: June, July and August, early fall: September).

Otoliths identified to family (Gadidae and Pleuronectidae) but not to species were used to identify the original weight of prey by proration. The otoliths for each family were prorated according to the proportion of known otoliths of each prey species per fish family in the stomach samples of individual pinniped species per sample month. The otoliths were then treated in a similar manner to the broken grade 3 and unassociated hard parts.

The Atlantic wolffish was indicated in the diet almost exclusively by hard parts. To provide estimated wet weights of individuals, previous data of otolith length, collected by Hauksson and Bogason (1997), were used to estimate the mean wet weight.

The total wet weight biomass of individual species contained in the stomach samples was determined by totaling the estimated wet weights of all individual fish of a given species. Estimates for the total wet weight of sandeels, however, represented the all three species of sandeel: the lesser sandeel, the small sandeel and the greater sandeel.

5.0 Results

5.1 Common Seals

Of the 75 common seal stomachs collected, the contents of 64 were analyzed. Fifty of the 64 stomachs contained fish remains, 47 of which contained identifed fish hard parts (Table 2). The 47 common seal stomach samples contained three whole fish, 619 identifiable and four unidentified otoliths or otolith pairs, and 29 individual fish identified using hard remains or skin alone. One pair of identified otoliths, Atlantic hook-ear sculpin (*Artediellus atlanticus*), does not have a regression equation to estimate wet weight. One seal contained the beak of an unidentified cephalopod. Four common seal stomachs contained krill, two of which contained only krill. Thirteen samples contained remnants of crab carapaces and two seals contained shells from shellfish.

The 64 common seals examined contained an estimated total of 655 individual fish from 14 different species, including the four unidentified fish. Of the identified species, the most common prey, in terms of abundance, are Atlantic cod (454), whiting (*Merlangius merlangus*) (79), haddock (41) and redfish (37) (Figure 5a).

The species that contribute the most to the common seals estimated diet by weight are Atlantic cod (60.7%) and Atlantic wolffish (20.8%) (Figure 5b). The total estimated weight of all identified species of fish in the common seal stomach samples was 143.32 kg.

5.2 Grey Seals

Thirteen of the 19 grey seal stomach samples contained fish remains (Table 2). Of the 13 stomachs with food remains, eight contained identified fish hard parts. Grey seal stomachs contained 11 identified otoliths or otolith pairs. Twelve individual fish were identified based on hard parts alone. There were no unidentified otoliths and the one stomach containing krill contained no other prey species.

A total of 23 identified fish representing seven species were found in the grey seal stomachs. In terms of abundance, the majority of fish are Atlantic cod (8), haddock (5), and lumpsucker (4) (Figure 6a).

Based on weight, the grey seal stomachs contained an estimated total of 7.73 kg of fish. Atlantic wolffish made up 67.9% of the estimated total wet weight, (three individuals), followed by Atlantic cod, making up 23.9% (Figure 6b).

5.3 Harp Seals

Thirteen harp seal stomachs were analyzed, of which 69.2%, or nine, contained fish remains (Table 2). Of those containing fish remains, approximately 89.0%, or eight stomachs, contained identified fish otoliths and hard parts. Harp seal stomachs contained 145 identified and two unidentified otoliths, with one individual fish identified by hard remains. One species consumed by harp seals, the snake blenny (*Lumpenus lumpretaeformis*), which is the second most numerous prey species, had no regression equation for the estimation of wet weight.

The harp seals consumed an estimated 146 identified fish representing 10 species, at an estimated total weight of 3.78 kg of fish. The highest numbered prey species within the diet are capelin (91), snake blenny (24) and Atlantic cod (9) (Figure 7a). Of the 91 capelin consumed by harp seals analyzed, 54.6% were found in the stomach of the same seal. With the absence of the snake blenny in the estimated overall biomass, the most significant contributions to the harp seal diet were haddock (36.0%), Atlantic cod (33.2%) and capelin (17.5%) (Figure 7b).

5.4 Diet/Fisheries Overlap

Note: See Table 6 for a list of species currently targeted by or caught as bycatch by the Icelandic fisheries.

5.4.1 Common Seals

The common seal stomach samples contained nine of the 17 species targeted by the fishing industry (Atlantic cod, haddock, redfish, saithe, Atlantic wolfish, herring, capelin, whiting, and lumpsucker) and none of the five species of economic value caught as by-catch (Figure 8). Of the prey species consumed by common seals, 74.7%, based on estimated total biomass, are individuals of the top five commercially valuable fish species targeted by the Icelandic fishery (Figure 5b).

5.4.2 Grey Seals

The grey seal stomach samples contained 35.3%, or six, of the 17 species currently targeted by the fishing industry (Atlantic cod, haddock, Atlantic wolfish, herring, whiting and lumpsucker) and none of the five species of value that are caught as by-catch. 29.9 percent of the fish species identified in the stomachs of grey seals sampled, based on estimated wet weights, are individuals from the top five commercially valuable fish species targeted by the Icelandic fishery (Figure 8).

5.4.3 Harp Seals

The harp seal stomach samples contained six of the 17 species targeted by the fishing industry (Atlantic cod, haddock, redfish, herring and capelin) and one of the five species of value that are caught as by-catch (dab). 73.4 percent of the fish species consumed by the harp seals sampled, based on estimated total biomass, are individuals from the top five commercially valuable fish species targeted by the Icelandic fishery (Figure 8)

6.0 Discussion

6.1 Seal Diets

In total, 96 seal stomachs were examined for otoliths and other identifiable food remains. While only the seal stomachs were taken, it is possible that further evidence of prey species could have been located in other parts of the digestive tract. Analyzing the rest of the digestive tract would have potentially increased the accuracy of the dietary data. Overall, however, the seals were found to contain 826 fish, of which 820 were identified to at least the family.

6.1.1 Common Seals

The prey species consumed by common seals in this study are similar to the species consumed by common seals around the coast of Iceland in 1992-1993, as analyzed by Hauksson and Bogason (1997). In terms of relative importance, Atlantic cod continues to play a dominant role in the diets of common seals in Northwest Icelandic waters (43.2% along the West Coast, 62.2% in the West-fjords and 48.6% along the Northwest Coast in the spring/summer seasons of 1992-1993 (Figure 9) compared to 60.69% in 2010). Herring and capelin, while still present in the diet are lower in relative importance based on wet weight in comparison to those sampled in 1992 and 1993 (1.7%, 5.5%, and 0.3% in the West Coast, West-fjords, and Northwest Coast regions, respectively, in the spring/summer seasons of 1992-1993 for herring, compared to 0.07% in 2010; 0.3%, 0.8%, and 3.4% for capelin, compared to 0.01% in 2010).

Differences between the two datasets could, however, be a result of sample size and sampling period. Hauksson and Bogason (1997) had substantially larger sample sizes, (Table 7), and longer sampling periods (1992-1993 for common and grey seals and 1990-1994 for harp seals, compared to the sampling period of March-September 2010 in the current study) for all seal species analyzed. While the data collected between 1992-1993 was comprised of samples from all around the coast of Iceland and all throughout the year, the division of the results into regions and seasons made it possible to compare with the current results.

6.1.2 Grey Seals

Grey seal stomach contents are presented in this study, however caution should be taken in interpretation as the stomachs analyzed provide a limited representation of the diets of grey seals, with only 23 individual fish representing seven different species identified as prey. The small number of fish identified in grey seal stomachs could be a result of a couple of different scenarios. It is possible that these seals may not have consumed fish within the hours before being captured. While breeding can sometimes explain empty stomachs in diet analysis studies, the breeding period, taken to be from October to December in Icelandic waters, does not overlap with the sampling period for grey seals in the current study (May to August) (Hauksson and Bogason, 1997).

6.1.3 Harp Seals

In the years 1990-1994, sandeels, herring, bull rout, and Atlantic cod made up over 80% of the estimated wet weight of the prey of harp seals around Iceland, with sandeels comprising more than 50%. In the current study, these species made up a total of 34.8% of the weight of prey species with sandeels comprising 0.1%. However, it should be noted that these percentages represent the percentage weight of the estimated total biomass in the absence of estimates for the snake blenny, which was prominent in abundance but was not estimated for weight analysis due to the lack of a regression equation. Overall, harp seal stomachs analyzed in this study showed little evidence of sandeels and herring (1.5%). There was also no evidence of bull rout, which given their previous importance suggests either sampling error, analysis error, a decline in the availability of these species for consumption, or a change of preferred prey choice. For sandeels, the reduction in the diet is most likely explained by the decline in the availability of the lesser sandeel since 2005 (Hansen, 2009). No information was found regarding the availability of bull rout or herring. Reduction in these main species in the diet has allowed for the increase in relative importance of haddock (36.03% of estimated total consumed wet weight), Atlantic cod (33.24%) and capelin (17.49%).

Differences between these two studies could be attributed to those outlined for common seals; mainly the sample size and sampling period. Only 13 harp seal stomachs were analyzed and the sampling period was considerably smaller than the sampling period between the years 1990-1994. The majority of the harp seal samples were collected during April of 2010, and one empty stomach sample occurring in May.

6.2 Diet/Fisheries Overlap

The diet/fisheries overlap indicates that several commercially valuable species (Atlantic cod, haddock, redfish, saithe, atlantic wolfish, herring, capelin and whiting) make up a significant portion of the diets of common, grey and harp seals. Grey seals, while found to consume commercially valuable fish, require further dietary analysis to determine the relative importance of each species to the diet. The preliminary data, while not indicative of the extent of interspecific competition, clearly illustrates the importance of these commercial species to the diets of common, grey and harp seals. To determine the extent of interspecific competition requires further research into the dynamics of seal demographics in relation to fisheries and changing stock abundances.

6.3 Methods, Biases and Sources of Error

6.3.1 Method of Analysis

Abundance and estimated weight measurements were both allow for two views of the dataset. Both methods of analysis indicate the variety of prey species within the diet, however abundances provide the ability to assess the presence of species that are difficult to quantify into estimated weights due to the lack of regression equations or otoliths in the diet, including the lumpsucker, the Atlantic hook-ear sculpin and the snake blenny. Abundances, while important in illustrating the diet, presented alone, limit the data analysis, as they do not indicate the relative dietary importance. Weight estimations provide a much more useful measurement for the indication of relative dietary importance. This can be illustrated by the consumption of whiting in common seals. According to abundance estimates, 79 whiting were consumed, placing the whiting as second in importance. While the whiting is the fifth important species to the diet of common seals when considering the percentage of the estimated total weight of prey consumed (Figure 5). As stated previously considering only weights would omit the aforementioned species from the diet completely, abundance estimates were included to illustrate the maximum variability in the diet, while weights allowed for the comparison of common, grey and harp seal diets with Icelandic fisheries.

6.3.2 Identification Errors

Identification errors, of both seal species and prey species, result in a misrepresentation of the prey species. In a few cases, a seal species was identified incorrectly initially, but a closer look at the teeth of the seal allowed for corrections to be made for some misidentified seals. However, not all seal mandibles were analyzed prior to the completion of this study so the potential that individual seals were included in the dietary analysis of another seal species. Identification errors of prey species within the analysis are harder to assess as a single analyst reviewed prey otoliths and hard parts from each individual seal. To confirm prey identification and reduce the potential impact of identification errors on the dataset, a secondary reviewer should have been used to corroborate or amend the identification of otoliths and other fish hard parts.

6.3.3 Otoliths and Correction Methods

Otoliths undergo variable levels of mechanical and chemical damage as they pass through varying parts of the digestive tract (i.e. chewing and stomach acid), as outlined previously. The otoliths and hard parts analyzed did not make their entire way through the digestive tract, passing through the mouth and oesophagus and into the stomach, before being removed. Neither the oesophagi nor the intestinal tracts were examined for food remains. This method was chosen to maintain congruency with samples from previous years. It is likely, that due to the nature of digestion, food remains would also be found in other areas of the digestive tract. Ultimately any mechanical or chemical damage noted in this study occurred in the mouth, oesophagus or the stomach of the seal, and may have continued to occur during storage.

Approximately 35.8% of the food remains identified were broken or grade 3 otoliths and hard parts unassociated with otoliths (Table 3). Excluding this source of data from the dataset would underestimate the significance of certain prey items in the diet samples. Often, feeding experiments with captive seals are used to determine correction factors to apply to the digested otoliths of several fish species when estimating length or wet weight and to determine the recovery rates of otoliths (Bowen, 2000; Cottrell and

Trites, 2002; Grellier and Hammond, 2005; Tollit et al., 1997). Correction factors are a species specific constant used to improve the accuracy of wet weight estimations by accounting for the erosion of otoliths due to chemical damage within the digestive tract. As correction factors were not available for species in Icelandic waters, methods, as outlined in 9.0 Research Methods, were adopted from Hauksson and Bogason (1997) and Bowen and Harrison (1994) to account for this source of error. However, not all sources of bias and error associated with dietary analysis used in this study can be accounted for.

First, there is always the possibility of error in identification of species when analyzing otoliths. Some species, especially those of the same family, i.e. Gadidae, have otoliths that are similar in appearance. Mechanical and chemical damage can both increase the chance of identification error, as identifying features can be lost. Second, some fish, lampreys, skates, dogfish sharks and shellfish that are known to be consumed by seals do not have sagittal otoliths (Pierce and Boyle, 1991). Their presence and relative importance in the diet, unless consumed recently before evisceration, would be difficult to determine. Lastly, remains within the digestive tract of a seal may not have been consumed directly by the predator, but may be present because of secondary consumption. Secondary consumption refers to the ingestion of prey, which itself has recently ingested prey. For example, sandeels are an important prey for many fish species that are important prey for seals, including Gadidae species (Pierce and Boyle 1991).

6.3.4 Underrepresented Species

It was not possible to determine the total biomass represented by invertebrates, lumpsuckers, the snake blenny and the Atlantic hook-ear sculpin. Invertebrates identified in the samples included krill, crabs, shellfish and one cephalopod. Krill were in both the stomachs of common and grey seals, while crabs and shellfish were only found in the stomachs of common seals. The squid beak found in the stomach of a common seal was not used for estimates as it was not possible to be identified to species. The lumpsucker was the only bony fish species indicated in the diet exclusively by hard parts other than otoliths and skin. With no otoliths for measurements, estimates of biomass were not completed. The snake blenny was identified in the stomachs of harp seals by otoliths and a single pair of Atlantic hook-ear sculpin otoliths was found in the stomach contents of a common seal. However, no regression equation was available for either species to estimate individual wet weight. Therefore, these species are not present in the assessment of the percentage weight of prey species consumed by the seals.

6.3.5 Sampling

Other possible sources of error come from the sampling strategy. Random sampling, when researching marine mammals is rarely, if ever, achieved (Lundström et al., 2010). While many methods are available, as indicated in Section 7.5.1 Methods of Diet Analysis, the majority of individuals for this study were collected from fishing gear (Table 2). These fishing gears were set by fishers in specific areas optimal for catching a targeted species. It is suggested that collecting seals in this method leads to an overrepresentation of the prey being sought after by the fishery in the diet, in this case, the lumpsucker and Atlantic cod (Söderberg, 1972 as cited in Lundström et al., 2010). If this method of collection impacted the results, one would assume that the lumpsucker and Atlantic cod would be found in higher numbers within the samples, as the nets in which the seals became entangled were targeting these species.

The stomach samples of common and harp seals contained evidence of lumpsuckers in relatively low numbers, based on abundance (common seals = 5; and harp seals = 1). For grey seals, while lumpsuckers were the second most abundant species (four individuals), the entire grey seal sample contained only 23 individual fish. The low number of lumpsuckers in samples could be a result of the preferential selection of other species of prey by seals, as well as the digestibility of lumpsuckers. If easily digestible, lumpsucker remains would be less likely to be recovered. The relatively low abundance of this species in the diet does not, however, eliminate the potential that lumpsucker were overrepresented in the diet.

Unlike lumpsuckers, Atlantic cod were relatively important in the diets of all seal species, based on abundance (common seals = 454, grey seals = 8, and harp seals = 9) and on percentage weight of total estimated biomass (common seals = 33.2%, grey seals = 23.9%, and harp seals = 33.2%). However, of all seals sampled, only three harp seals were caught in the gill nets of the Atlantic cod fishery. Two of these harp seals contained the remains of four Atlantic cod, which represent 44% of the total abundance of Atlantic cod in the harp seal diet. There is no way to know, from the current study, whether the method of capture of these seals resulted in an overrepresentation of Atlantic cod in the diet of harp seals.

Relying on samples from gill nets reduces the ability to control the sample size and temporal distribution. The sample size of common, grey and harp seals could be indicative of the natural population size of seals in the area sampled in Northwest Iceland or it could just be chance that more common seals are caught than grey seals (Table 2). Harp seals, which are visitors to Icelandic waters travel to Icelandic waters to feed, with no record of mating or moulting. As such, harp seals are not likely to be found in high numbers in Iceland and therefore low catch is expected (Hauksson and Bogason, 1997). The temporal distribution (Table 5), along with the sample size have the potential to be highly influenced by the fishers and hunters who choose to turn seals into Biopol ehf., and who relay the information regarding catch location and date.

Some seals turned in by fishers and hunters were not analyzed during this study due to time constraints. At least 50% of the samples for each capture month were analyzed in an attempt to increase the balance of the dataset. Despite this attempt, the sample distribution remained insufficient enough to divide into separate months or seasons (Table 5).

6.4 Management Strategies

Based on the evidence from the modeled impact of lethal management strategies, i.e. culling, for controlling the predation on commercially valuable stocks, no lethal management strategies are deemed to be necessary. As previously indicated, in the cases of the Cape hake in the Benguela ecosystem and the Atlantic cod in the Northwest Atlantic, the culling of seals does not often have the desired effect on a fish stock (Chassot et al., 2009; Punt and Butterworth, 1995). Fishermen concerned with depredation and entanglement could consider acoustic deterrents, however, their effectiveness is questionable, often drawing seals in rather than deterring them from coming close (Marine and Marine Industries Council, 2002). Tactile harassment and vessel chase would only be effective during times when fishermen and seals meet at the fishing site, and while non-lethal, could be considered animal cruelty and raise concerns amoung the community.

Currently, management strategies should continue to focus foremost on monitoring the seal population for dietary analysis and demographics. With a database of monitoring information it would be easy to see trends and identify appropriate and apply adaptive management strategies should they be required. Monitoring information would also assist the determination of total allowable catch, as up-to-date information on mortality from seal predation can help to predict stock size.

6.5 Future Studies

Knowledge of ecosystem interactions, especially concerning species of commercial value is important when conducting stock assessments and further analysis will determine the extent to which interspecific competition between humans and seals in Icelandic waters is occurring. This includes future studies of spatial overlap of feeding and fishing areas, long term feeding trends, along with analysis of the long-term demographics of the competing species. These studies would be instrumental in determining any necessary changes to current or the need for new management techniques in this dynamic environment.

7.0 Conclusion

In conclusion, the data indicates that a large proportion of common, grey and harp seal diets consist of commercially valuable fish. This does not signify that interspecific competition is or is not taking place, however, as competition implies that one species demographic parameters are limited or suffering due to resource exploitation of another. Grey seals, while found to contain commercially valuable species, require further diet analysis due to low recovery of prey remains. Considering the results, management strategies should continue with monitoring of seal diets and demographics, in order to identify the need for and to appropriately apply management strategies as necessary.

8.0 Summary

The consumption of commercially valuable fish in Icelandic waters by common, grey and harp seals was estimated through the analysis of the stomach contents of seals caught in lumpsucker or Atlantic cod gill nets or hunted over the period of March to September 2010. Stomach samples were frozen until analysis, upon which they were thawed and contents were cleaned using a series of sieves. Collected food remains, including hard parts from fish, invertebrates and other prey were then identified to the lowest taxonomic level. The most commonly identified remain was the sagitta; the largest ear bone, also known as an otolith, in the teleost fishes. The fish remains were than used to reconstruct a representation of the wet weight of individual prey items in the diets of common, grey and harp seals in the diet using otolith length/width to fish wet weight relationships.

The dietary analysis determined that 64 common seals consumed a total of 651 fish from 14 different species. Of the species identified in the stomachs of common seals the most abundant species were Atlantic cod (454), whiting (79), haddock (41), and redfish (37). In terms of estimated wet weight, Atlantic cod and Atlantic wolffish were found to represent 60.7% and 20.8% of the diet. The 19 grey seals examined contained 23 individual fish from seven different species. Of the identified species the most abundant were Atlantic cod (8), haddock (5) and lumpsucker (4). In the diet of grey seals, Atlantic wolffish (67.9%) and Atlantic cod (23.9%) represented the highest proportions of the total estimated wet weight of prey. Thirteen harp seal stomach samples contained 147 individual identified fish of 10 different species, with capelin (91), snake blenny (24), and Atlantic cod (9) as the most abundant species. Haddock, Atlantic cod and capelin made up 86.7% of the total estimated wet weight of prey in the diet of harp seals (specifically, 36.0%, 33.2% and 17.5% respectively).

Atlantic cod remained relatively important in the diet of common seals, in comparison to data from Hauksson and Bogason 1997 who studied the diets of common, grey, harp and hooded seals around the coast of Iceland. Herring and capelin, however, represented less, in terms of percentage of estimated total wet weight than in the 1997 report. Twenty-three individual fish were identified in the grey seal stomach samples making comparison with previous data difficult. Making up over 80% of the diet of harp seals around Iceland in the sampling period of 1990-1994 were sandeels, herring, bull rout and Atlantic cod. In the current study, these species represented only 34.8% of the total estimated wet weight of identified prey. Sandeels and herring, which were the most prominent species in the diet from 1990-1994 made up only 1.5% of the diet of harp seals in the spring and summer of 2010 and bull rout was not identified in any harp seal stomachs. The differences between the current study and the previous study could be due to the sampling period and sample sizes during analysis, as the previous dietary study covered a longer period of time and a larger number of samples.

From the dietary analysis, it was determined that common seals consumed nine of the 17 commercially targeted fish in Icelandic waters, while harp seals consumed six. The top five commercially valuable fish, in terms of economic value, made up 74.7% of estimated wet weight of prey in common seal samples and 73.4% in harp seal diets. Due to low recovery of identified prey remains, the analysis of grey seals diets may not be representative of the true diet of grey seals. However, the results indicated that grey seals consumed six of the 17 species of commercially targeted fish and 29.9% of estimated wet weight of prey in grey seal samples was made up of the top five commercially valuable fish.

The data indicates that commercially valuable species make up a large proportion of the diets of common, grey and harp seals. The overlap of diet with fisheries does not signify that interspecific competition is occurring. Further studies, including the spatial overlap of feeding and fishing areas, long term feeding trends, along with long term demographics of the competing species, would provide insight into the occurrence and extent of interspecific competition.

Overall, the knowledge of ecosystem interactions, especially concerning species of commercial value is important when conducting stock assessments and further analysis would be instrumental in determining necessary changes to current or the need for new management techniques.

9.0 Figures

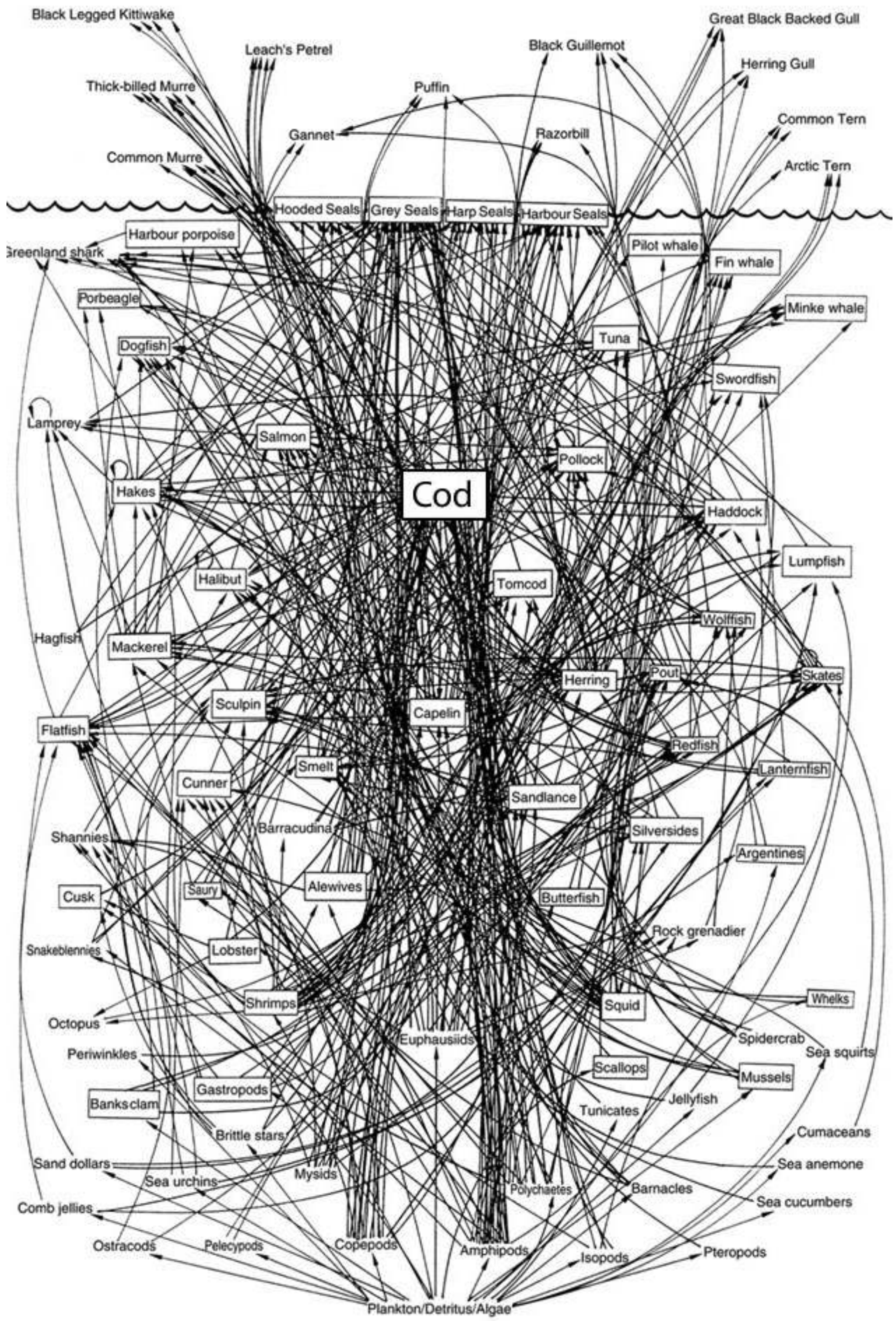


Figure 1: Incomplete food web for the Northwest Atlantic (not all feeding habits are illustrated) (Lavigne, 1996).

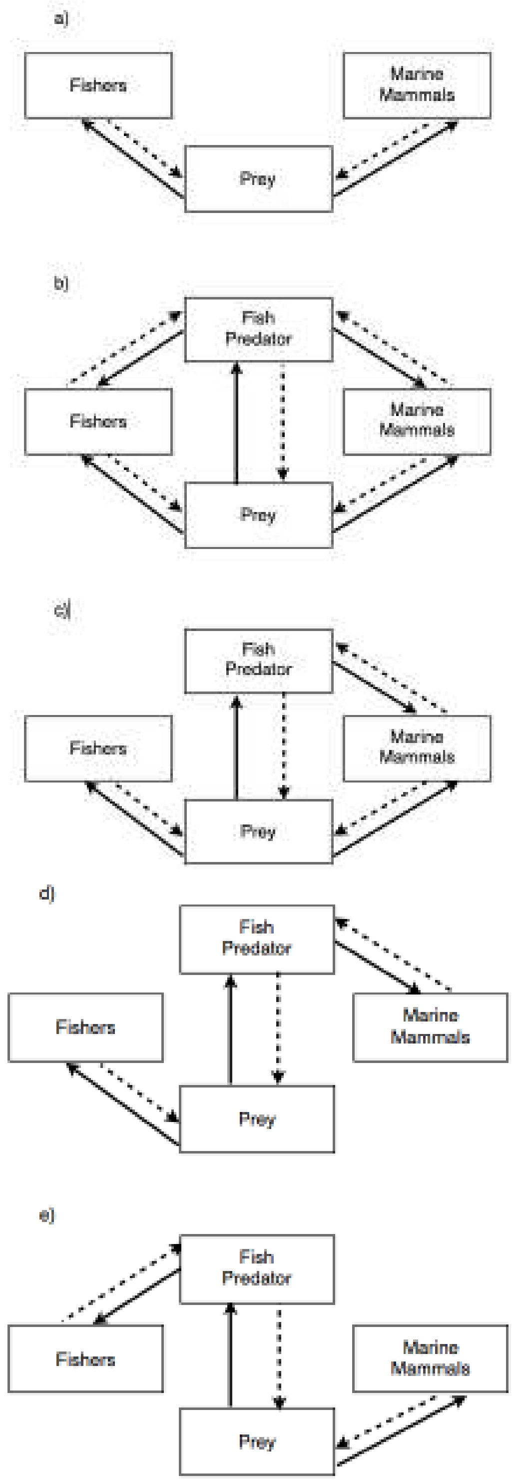


Figure 2: Potential indirect and direct trophic interactions between fisheries, marine mammals and their prey. Broken and continuous lines indicate predation and energy flow, respectively (Jennings et al., 2001).

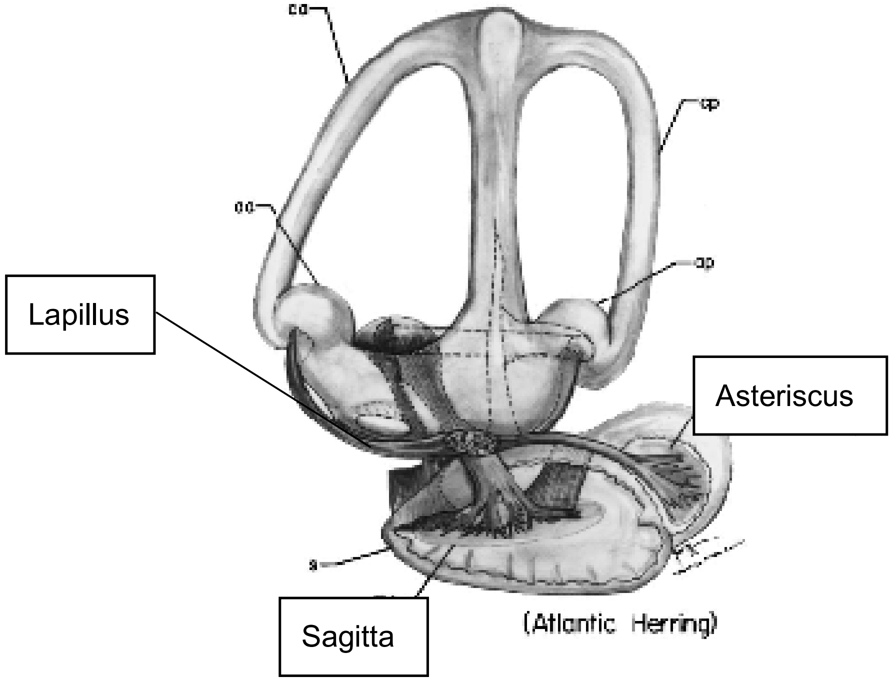


Figure 3: The inner ear of a teleost fish, Atlantic herring (*Clupea harengus*). The anterior of the fish is to the left and the dorsal is to the top. Adopted from (Popper and Lu, 2000).

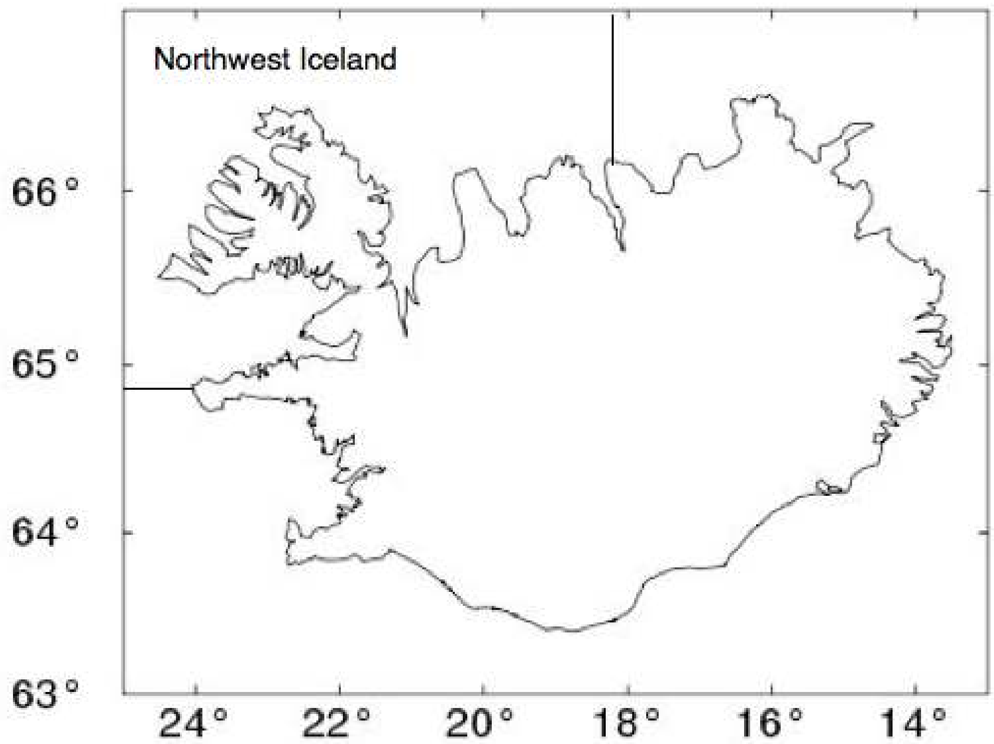
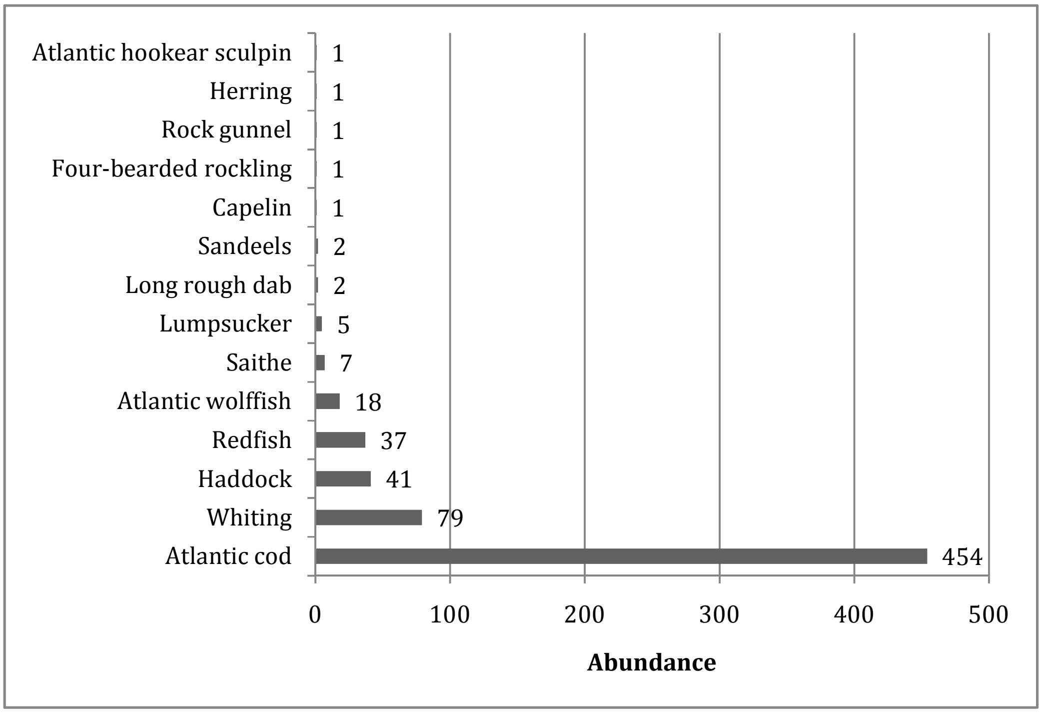


Figure 4: Map of Iceland depicting the sampling area.

a)



b)

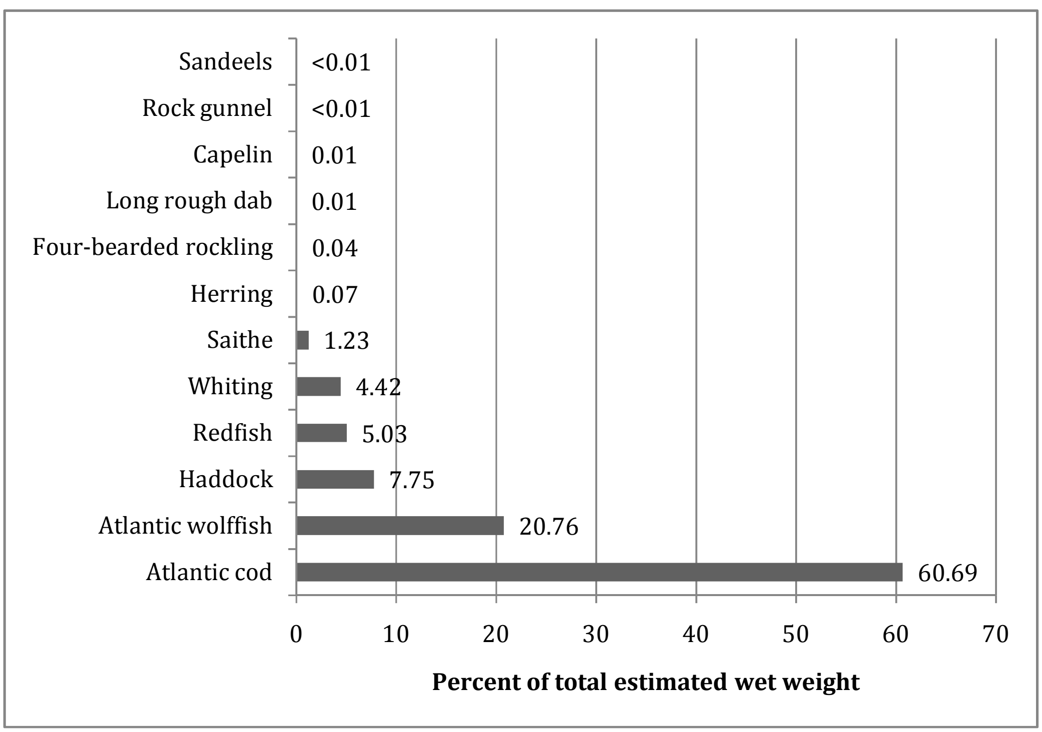
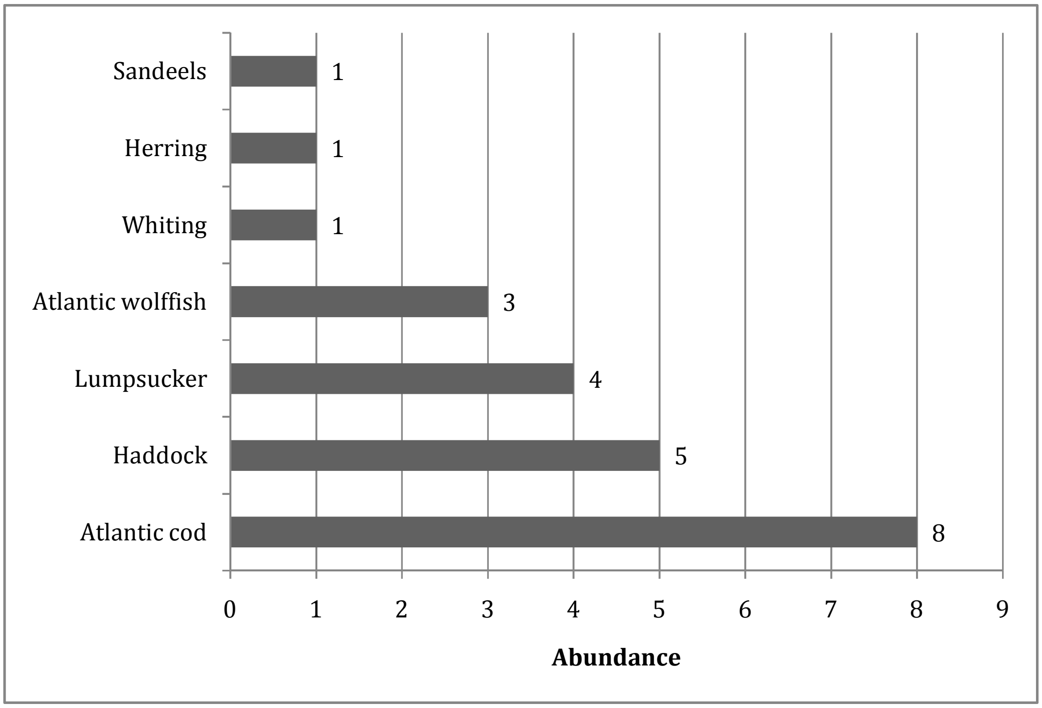


Figure 5: Diet composition of common seals (*P. vitulina*) from March-September 2010 in Northwest Icelandic waters in terms of a) abundance and b) percentage of total estimated weight. Total estimated wet weight = 143.3 kg.

a)



b)

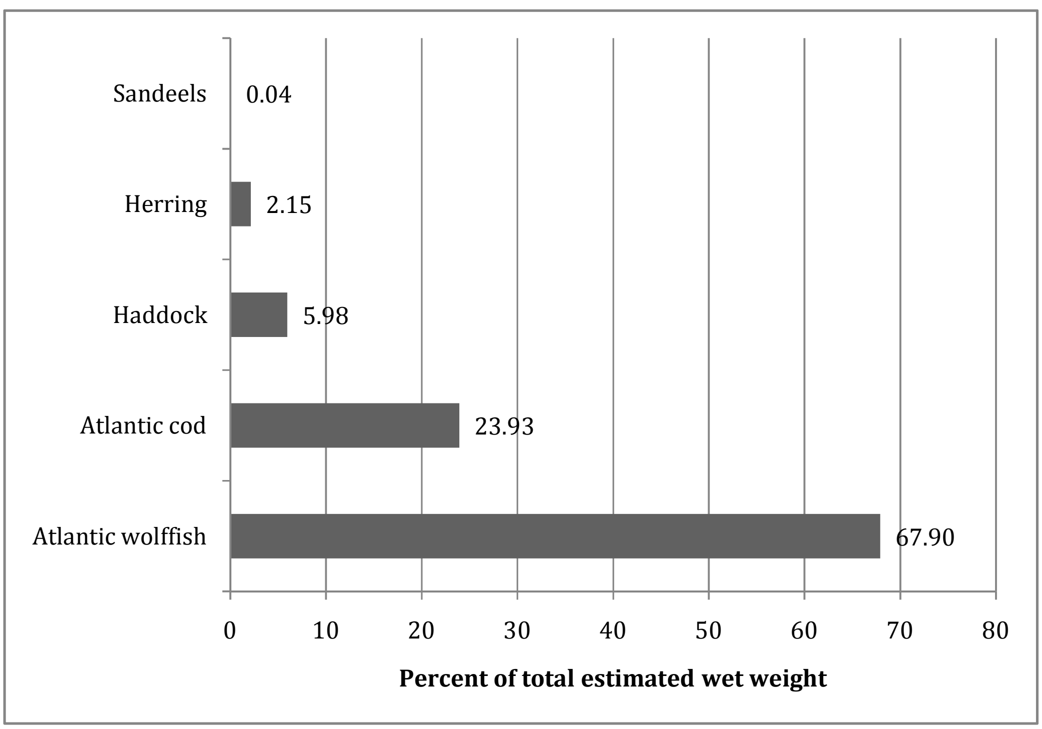
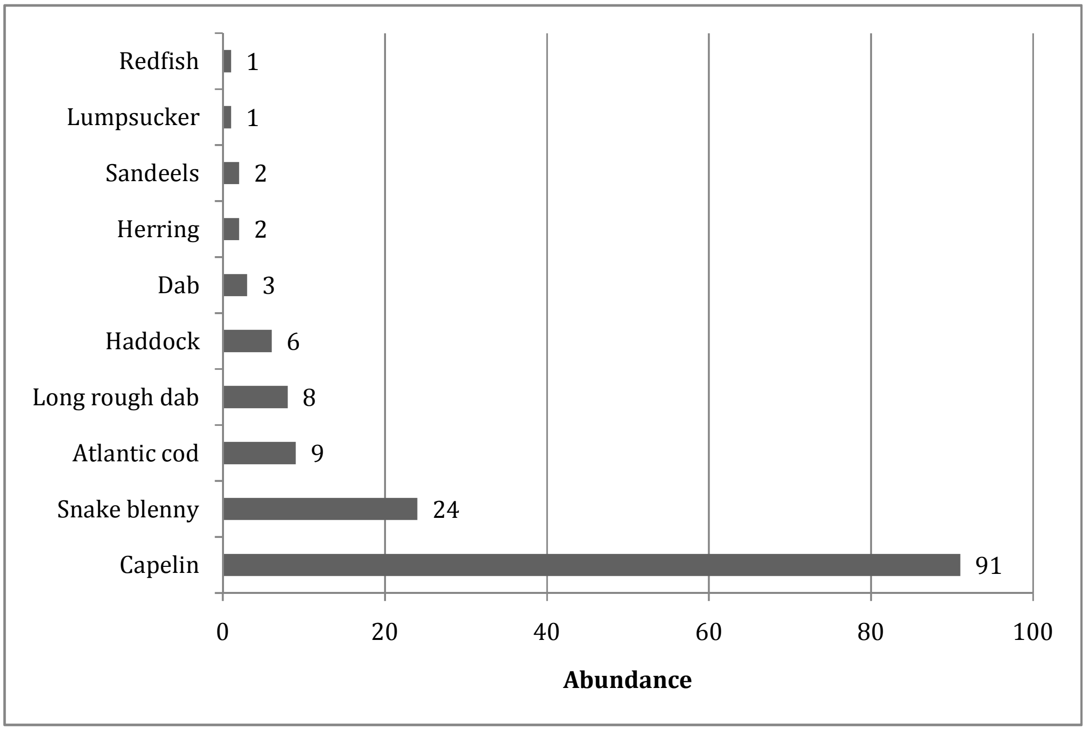


Figure 6: Diet composition of grey seals (*H. grypus*) from May to August 2010 from Northwest Icelandic waters in terms of a) abundance and b) percentage of total estimated weight. Total estimated wet weight = 7.7 kg.

a)



b)

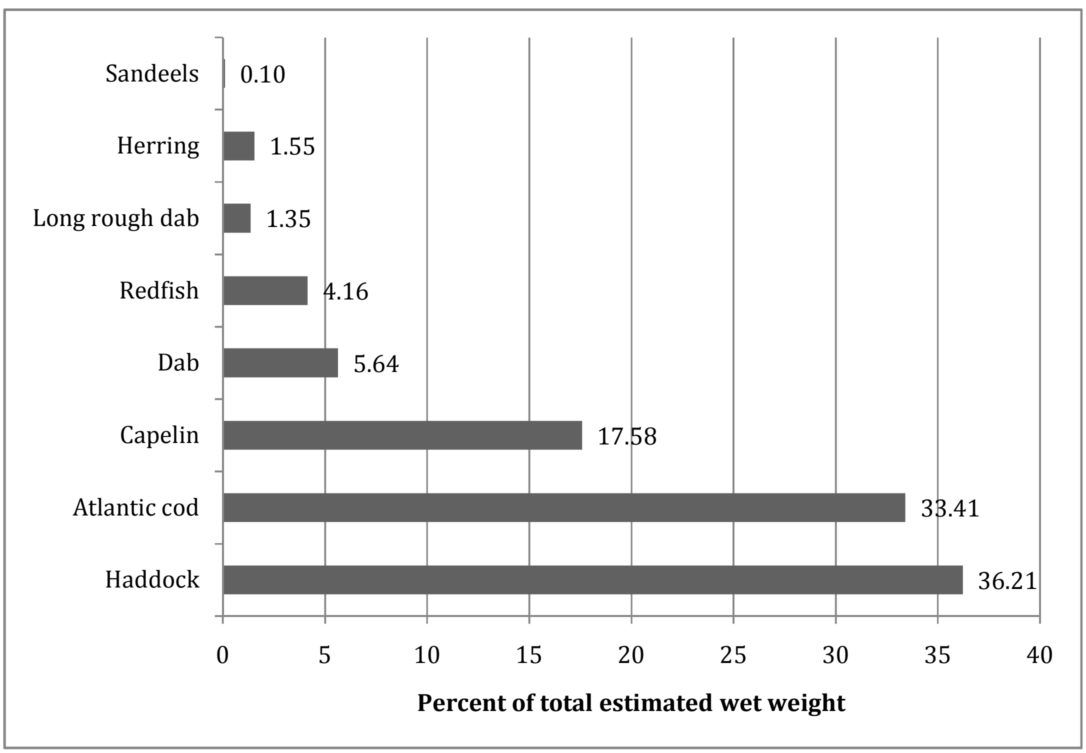


Figure 7: Diet composition of harp seals (*P. groenlandica*) from April and May 2010 in Northwest Icelandic waters in terms of a) abundance and b) percentage of total estimated weight. Total estimated wet weights = 3.8 kg.

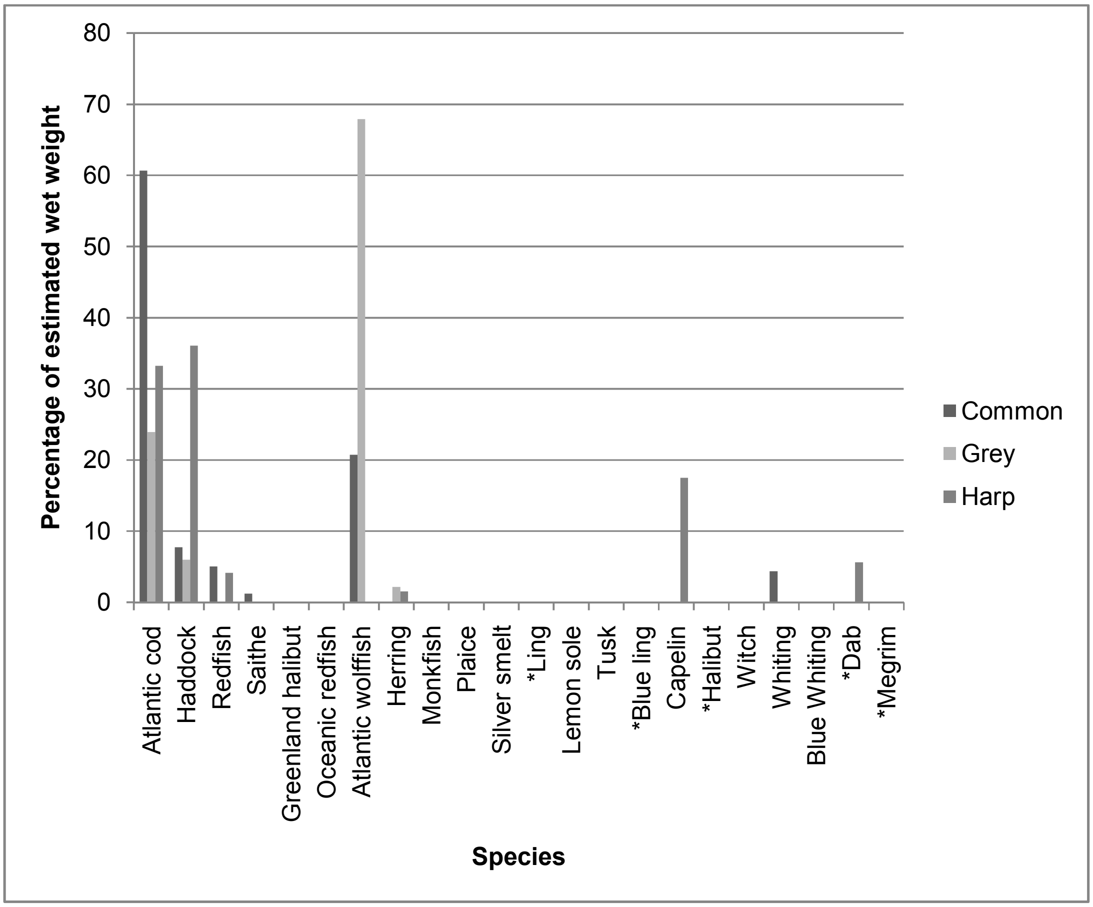


Figure 8: The percentage of estimated wet weight of the diet of common (*P. vitulina*), grey (*H. grypus*) and harp seals (*P. groenlandica*), based on weight, of commercially valuable species, descending in economic value towards the right of the histogram.

* Species caught, for the most part, as by-catch in recent years (Marine Research Institute, 2010).

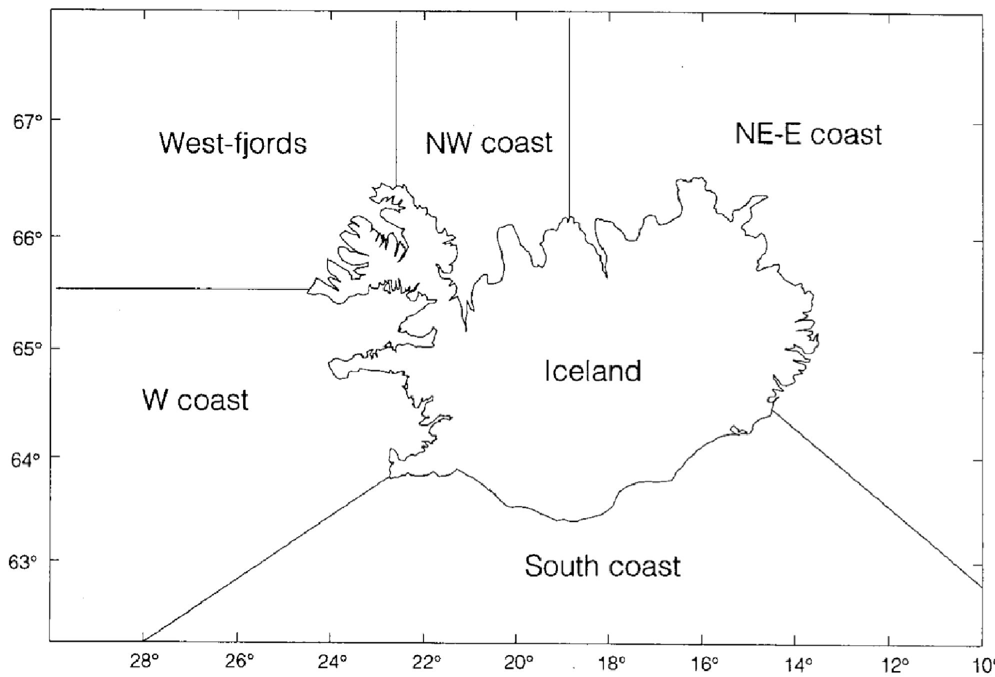


Figure 9: Map of sampling divisions in Hauksson and Bogason 1997.

10.0 Tables

Method to estimate diet	Impact on individual	Impact on group	Dietary time period	Prey size estimate	Additional limitations
Scats, hard remains	No	Moderate	Short	Yes	Differential prey digestion and retention. Requires presence of prey hard parts. Special identification skills often required.
Spews, hard remains	No	Moderate	Short	Yes	Differential prey digestion and retention. Requires presence of prey hard parts. Special identification skills often required.
Scats, DNA remains	No	Moderate	Short	No	New technique, relatively untested. Lack of genetic data for many prey.
Lavage (enema)	Moderate (low)	Low-moderate	Short	Yes	Capture and sample size issues. Empty stomachs (colons) reduce sample size.
Stomach samples	Extreme	Moderate-high	Short	Yes	Differential prey digestion and retention. Empty stomachs reduce sample size.
Stable isotopes	Moderate	Low-moderate	Moderate-long	No	Capture and sample size issues. Only trophic quantification.
Fatty acid signatures	Moderate	Low-moderate	Moderate-long	No	Capture and sample size issues. New technique, relatively untested. Current prey library required.
Head camera	Moderate	Low-moderate	Short	Possible	Capture and sample size issues. High cost and unit recovery required. Low number of feeding events captured.
Direct Observations	No	Low	Immediate	Possible	Limited to prey brought to surface. Limited mainly to nearshore interactions.

Table 1: Advantages and disadvantages of different diet analysis methods. Adopted from Tollit et. al., (2006).

Species	Method of capture	Total Number of stomachs	Number of stomachs with fish remains	Number of stomachs with only krill	Number of empty stomachs
Common seal	Lumpsucker Gill net	63	50	2	12
	Hunted	1	0	0	1
Grey seal	Lumpsucker Gill net	11	6	1	5
	Hunted	8	2	0	6
Harp seal	Lumpsucker Gill net	10	10	0	3
	Atlantic cod Gill net	3	3	0	0
	Hunted	0	0	0	0

Table 2: Review of the total number of stomachs analyzed and a breakdown of the contents for each seal species caught as by-catch in gill nets in the Icelandic lumpsucker or Atlantic cod fishery or hunted.

Grade (degree of digestion)	Morphological features
1 (low)	Sulcus visible Well defined ridges
2 (medium)	Smoothed ridges Sulcus still visible but not as prominent
3 (high)	Sulcus no longer visible Ridges no longer visible
4 (broken)	Broken, affecting accurate measurement

Table 3: Morphological features defining the analysis of the degree of digestion of otoliths in the stomachs of pinnipeds.

Species	Regression	Range	Source
Atlantic Wolffish, *Anarhichas lupus*	1.653*OL^5.070 R^2 = 0.946	1-5.5mm	Hauksson and Bogason, unpubl. data
Atlantic Cod, *Gadus morhua*	0.049*OL^3.780 R^2 = 0.943 0.0010576*OL^5.1824 R^2 = 0.93	<15 mm >15 mm	Hauksson and Bogason, unpubl. data
Capelin, *Mallotus villosus*	1.163*OL^2.742 R^2 = 0.853	no recorded range	Víkingsson et al., 2003
Dab, *Limanda limanda*	1.381*OL^2.765 R^2 = 0.497	no recorded range	Hauksson and Bogason, unpubl. data
Haddock, *Melanogrammus aeglefinus*	0.0042*OL^4.321 R^2 = 0.928	7mm-23mm	Hauksson and Bogason, unpubl. data
Halibut, *Hippoglossus hippoglossus*	18.422*OL^2.011 R^2 = 0.422	no recorded range	Hauksson and Bogason, unpubl. data
Herring, *Clupea harengus*	8.871*OL^2.217 R^2 = 0.856	2-5mm	Hauksson and Bogason, unpubl. data
Long Rough Dab, *Hippoglossoides platessoides*	0.166*OL^3.535 R^2 = 0.966	no recorded range	Härkönen, 1986
Redfish, *Sebastes marinus*	0.373*OL^2.887 R^2 = 0.723	no recorded range	Hauksson and Bogason, unpubl. data
Rock Gunnel/Butterfish, *Pholis gunnelus*	06.110*OW^1.421 R^2 = 0.938	no recorded range	Härkönen, 1986
Saithe, *Pollachius virens*	0.0077*OL^4.530 R^2 = 0.913	5-21mm	Hauksson and Bogason, unpubl. data
Sandeels, *Ammodytes marinus, Ammodytes tobianus, Hyperoplus lanceolatus*	0.275*OL^3.944 R^2 = 0.92 0.171*OL^3.916 R^2 = 0.885	0.9-3.8mm June-Dec. 1.4-3.5mm Jan.-May	Hauksson and Bogason, unpubl. data
Whiting, *Merlangius merlangus*	0.012692*OL^3.535 R^2 = 0.976	no recorded range	Härkönen, 1986

Table 4: Regression equations relating otolith length (OL) or otolith width (OW) to fish wet weight, along with their respective coefficient of determination (R^2). The range, if given, is the recorded otolith length range for which the equation is useful for estimation.

Species	March	April	May	June	July	August	September
Common seal	32	7	11	1	10	0	3
Grey seal	0	0	11	1	2	5	0
Harp seal	0	12	1	0	0	0	0

Table 5: The number of stomach samples analyzed based on month of capture in a gill net of the Icelandic lumpsucker or Atlantic cod fishery or hunted.

Commercially Targeted	Bycatch
Atlantic cod	Ling
Haddock	Blue ling
Redfish	Halibut
Saithe	Dab
Greenland Halibut	Megrim
Oceanic redfish	
Atlantic wolffish	
Herring	
Monkfish	
Plaice	
Silver smelt	
Lemon Sole	
Tusk	
Capelin	
Witch	
Whiting	
Blue whiting	
Lumpsucker*	

Table 6: List of the commercially targeted and bycatch species of the Icelandic fisheries in descending order of total catch value (Marine Research Institute, 2010; Statistics Iceland, n.d.). Grey highlights the top five commercially valuable species.

*Not included in descending order of total catch value.

Species	Current Study	Hauksson and Bogason (1997)
Common seal	64	799
Grey seal	19	1059
Harp seal	13	72

Table 7: A comparison of the total number of common, grey and harp seal stomach samples analyzed during the current study and a previous study by Hauksson and Bogason (1997).

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