The Food Intake of Iceland Cod \((Gadus \textit{morhua})\) over the Summer Season

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12 ECTS Undergraduate Research Project for Baccalaureus Scientiarum Degree in Biology

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Reykjavík, May 2012
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Declaration

I hereby declare that this paper is written by me alone, and that it has not been submitted for any higher degree, partially or wholly.

_____________________________________
Viðar Engilbertsson
Abstract

From the beginning of fish research in Iceland, great interest has been drawn to the food intake of Iceland Cod (*Gadus morhua*). The importance of dietary studies is to reveal the predator-prey relationship which can provide deeper understanding of the marine ecosystem. Stomach samples were collected on fishery trawlers from three areas around Iceland over the 2010 and 2011 summer seasons. A total of 1249 cod stomachs collected. The samples were categorized to species, counted, weighted and measured for size when possible. The hypothesis to be tested included: a) no relationship between cod size and diet and b) no difference in food composition between areas. The results showed that fish composition did vary with cod length where the proportion of fish in the diet increased as the cod increased in size. This was especially pronounced among cod greater then 60-70 cm. Also the composition of the cod’s diet differed substantially between the three geographical areas. This was likely due to difference in availability of preys among the different areas. For example, capelin was present in high numbers in area 1 but not in areas 2 and 3. The most common fish species in cod´s diet were capelin, herring, blue whiting and sandeel. Fish count for 70%-90% of cod´s dietary composition and the remaining diet consisted primarily of crustaceans.

Keywords: Cod, Food composition, Diet, Ecosystem, Stomach, relationship, Capelin, Blue whiting, Herring, Sandeel, Crustacean, Iceland.
Útdráttur

Áhugi hefur verið fyrir þekkingu á fæðunámi þorsks (Gadus morhua) allt frá upphafi fiskirannsókna á Íslandi. Mikilvægi fæðurannsókna felst í að efla vitneskjú um samband milli afræningja og bráðar sem getur gefið dýpra innsæi við rannsóknir á vistkerfi sjávar. Magasýnum var safnað um borð í ísfrystitogurum á þrem svæðum í kring um Ísland að sumarlagi árin 2010 og 2011. Alls var safnað 1249 sýnum. Sýnin voru greind til tegunda, talin, þyngdarmæld og lengdarmæld þegar við átti. Tvær tilgátur voru prófaðar sem voru a) enginn munur á milli lengdar þorsks og fæðusamsetningar og b) enginn munur á fæðusamsetningu þorsks milli svæða. Niðurstöður úr fæðugreiningu voru í samræmi við fyrri spár um að fæðusamsetning þorsks sé breytileg eftir lengd og þegar þorskur hefur náð 60-70 cm lengd þá eykst hlutfall fiska í samsetningu fæðunnar og eftir að þessari lengd er náð verða ýmsar fisktegundir helsta fæða þorsks. Einnig sýndu niðurstöður fram á breytileika í fæðusamsetningu milli svæða eins og fyrirfram var spáð. Ástæðan fyrir því er talin vera að framboð á helstu fæðugreinungum þorsks, sem eru loðna, síld, kolmunni og sandsíli, eru breytilegt milli svæða. T.d. er mikil að finna af loðnu í fæðu þorsks frá svæði 1 en finnst ekki í fæðu þorsks á svæðum 2 og 3, það er vegna þess að loðnar fer í fæðugöngur á sumrin og er þá ekki til staðar á svæðum 2 og 3. Samkvæmt niðurstöðunum eru fiskar 70% til 90% af fæðuhlutfalli þorsks en það sem eftir stendur af fæðusamsetningunni er yfirleitt krabbadýr.

Lykilorð: Þorskur, Fæðuhlutfall, Vistkerfi, Magasýni, Samband, Loðna, Kolmunni, Síld, Sandsíli, Krabbadýr, Ísland
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1 Introduction

The importance of studies on food webs and feeding behavior have been growing over the last decades (Björnsson, Höskuldur et al. 2011). As a result, the understanding of the role and importance of interrelationships between predators and preys has gained weight in the research of commercial fishery stocks in recent years. The reason is the assumption that the predator-prey relation links the whole ecosystem together, rather than focusing on each commercial fish species independently (Daan, 1973). However, research on most fishery stocks are still based on single-species models. The advantage of single-species models is that they require fewer parametric variables and the models are simpler. The main disadvantage of single-species models is that they are limited to short-term management objectives as they fail to account for interactions between fisheries and fish species, which multi-species models can on the other hand predict (Sullivan 1991). The main limitation that researchers encounter when using multi-species models is that it is often difficult to define the predator-prey interaction and its variation on a temporal and spatial scales. Multi species models also require large amount of parametric values which, in turn, can be difficult to determine. The use of multi-species modeling and ecosystem approach in fishery stocks has reached more attention over the last decades, and therefore the importance of predator-prey relation studies has gained weight lately. Food is an important factor for cod growth and migration. Therefore food research and continuous information gathering is important for cod stock control and for understanding the habitats for cod and other fish species, which often connects to food resources.

1.1 Origin of fish studies in Iceland

The first description and reference on Icelandic fish observations dates back to the 17th century to a locally well-known travel book by the Icelandic naturalists Eggert Olafsson (1726-1768) and Bjarni Pálsson (1719-1779). They traveled to the University of Copenhagen in 1746 to start their studies. Eggert focused on law, geology and philosophy while Bjarni studied medicine and published papers on botany and natural science. Bjarni was the first per-
Bjarni and Eggert were sent to Iceland by the University of Copenhagen to collect scripts and samples from the Icelandic nature (minerals, plant and animal samples). During this trip these two naturalists also achieved to be the first men to climb the volcano Hekla on 20th June 1750. After this successful trip to Iceland, the Danish scientist Niels Horrebow (1712-1760) sent Eggert and Bjarni on another survey to Iceland to collect samples from the Icelandic nature. Eggert and Bjarni spent six summers (1752-1757) in Iceland collecting samples and writing descriptions of the nature, and returned to Copenhagen in 1757 to finish their education. Bjarni finished his medical education in 1759, stopped working on the data from the Iceland travel survey and took the position of Iceland’s first surgeon general. Eggert finished working with on survey data and published his book, often referred to as travel book, in 1772. In this travel book he described 43 species of fish which had not been recorded in Iceland at that time and he was the first person to describe the spotted wolffish (A.minor). (Steinthorsson, Sigurdur 2006)

More naturalists followed in the footsteps of Eggert and Bjarni and several more descriptions of fish were published in the 17th and the beginning of 18th century in Iceland. Olafur Olavius (1741-1788) was the first to study fishery management from economic aspect, which had never been done before in Iceland. Sveinn Pálsson (1762-1840) recorded and described a few little known marine fish species. The German Frederik Faber (1795-1828) published his book Naturgeschichte der Fische Islands in 1829, this was the first book specifically about fish in Iceland. Interest in fish studies decreased in the beginning of the 18th century and no material was published on the subject until 1881-1883, when Arni Thorsteinsson published a paper about salmon and aquaculture in 1881 and he also published a paper about herring and fisheries. In the late 18th century there was an increase in fish studies and in 1884 the Danish naturalist Arthur Feddersen spent two summers in Iceland studying salmon in rivers and lakes. William Lundbeck, a Danish naturalist, spent two summers (1892-1893) off the coast of Iceland on a Danish fishery boat. In 1903 a series of surveys began with the guidance of Danish scientist Johs. Schimdt, Ove Paulsen and J.N. Nielsen on board the Danish research vessel Thor. These surveys continued from 1903-1905 and again from 1908-1909, they pro-
vided great information about marine biology around Iceland. The involvement of Icelanders in fishery studies in the beginning of 19th century was rather poor.

Iceland’s first modern ichthyologist and one of the best naturalist in the 19th century Bjarni Sæmundsson began fishery studies in 1896 when he gathered samples on board Icelandic fishery ships. Bjarni was invited to take part in the scientific surveys on board the research vessel Thor in 1903 mentioned earlier, and he collaborated extensively with Johs. Schmidt. Bjarni published a paper in Danish called Oversigt over Islands Fiske, which described fish species in Iceland waters, based on the Thor surveys. Bjarni published also many smaller papers both in Icelandic and Danish. In 1926 he published his book Fiskarnir which is the first Icelandic book about fish. In this book he described over 130 fish species around Iceland in great detail, this book is considered to be one of Iceland greatest animal book written in the 19th century. (Sæmundsson, 1926; Steinthorsson, 2006)

1.1.1 Iceland cod food intake studies

From the beginning of fish research in Iceland, great interest has been drawn to the food intake of the Iceland Cod (Gadus morhua). Iceland’s first ichthyologist Bjarni Sæmundsson described the food composition of cod in a very simple terms in his book Fiskarnir in 1926: “The cod eats everything that is eatable and even inedible also” (Sæmundsson, 1926). It is true that cod food habits vary widely and cod is highly opportunistic. Bjarni described the food habit of Icelandic cod exhaustively in his book Fiskarnir, which is the oldest food composition reference in Iceland. But although the list of prey species found in a cod stomach is long, cod favors some species over others. Other studies in the North Atlantic and North Sea regions describe similar food composition where capelin is a major part of cod’s diet. (Daan 1980; Mehl 1989; Lily 1991). Food composition in different areas and periods depend on what food resource is available at each time. Capelin is not available as a diet during some parts of the year because of capelin’s feeding migration in the Iceland Sea and adjoining areas. Capelin migrates from the North Iceland Sea to the waters southeast of Iceland over the spawning period and becomes important food resource for cod during winter. When capelin is available as a dietary source, it becomes the cod’s dominating diet (Vilhjálmsson, Hjálmar et al.2004). Therefore the food intake of cod differs between seasons (summer-winter), based on capelin’s migration trends.
Temperature is also an important environmental factor that affects the distribution of fishes. Cod’s optimal temperature is 4-7°C but it can reside at wide ranges of habitat temperature anywhere from 0-17°C (Saemundsson, 1927; Árnason, Tómas et al. 2009). The species composition varies between areas because of different ideal habitats temperature between species. Cod is one of the most widely distributed predator in the North Atlantic Ocean and its success can be attributed to its wide adaptability to habitat temperature and to the food sources it can feed from.

Cod’s diet has been well documented with respect to ontogenetic change and temporal and spatial variability (Pálsson, 1983; Jaworski and Ragnarsson, 2006; Magnussen, Eyðfinn. 2009). Most of the data collected around Iceland comes from various surveys in spring and autumn of each year, i.e. in the annual ground fish survey which is performed by the The Marine Research Institution of Iceland. The data from the annual surveys span over three decades and provide series of data which is used to gain important information about periodical changes in diet composition. However, a research of the cod diet during the summer months has not been performed previously. Such information are direly needed and results from such a study would be likely to be of a particular interest due to changes in climate change and the appearance of mackerel in Icelandic waters during the last decade (Ástþórsson, S, & Ólafur. Sigurðsson et al. 2010)

The objective of this thesis is to describe the food composition of Icelandic cod during the summer season in different areas around Iceland. Two hypotheses were tested:

I. The food intake of cod did not differ between size classes

II. The food intake of cod did not differ between areas
2 Materials and methods

2.1 Data collection

Cod stomachs were collected in June-August 2010 and May-August 2011 (see Table 1). Samples were collected on board fishing trawlers in Iceland waters. Figure 1 shows the geographical distribution of the samples and the three areas from which the samples were taken. Table 1 presents the number of stomachs sampled in each area. Total number of samples collected was 1249 stomachs. The northwest area yielded a total of 480 cod stomachs, southeast area 472 and southwest area 297 stomachs. The method of stomach collection was random sampling from 20 cods on each location. The samples were measured for size and the stomachs were frozen in plastic bags for preservation. Analyses of the stomach data was performed at a laboratory belonging to The Marine Institution of Iceland. The stomach contents were classified to food species, counted, weighted and length measured where possible.

Fig 1. Location of data collection: Data collected from three areas around Iceland in 2010-2011.
Table 1. Number of cod sampled for dietary analysis in three areas around Iceland in 2010-2011 (see Figure 1 for locations)

<table>
<thead>
<tr>
<th>Area</th>
<th>Month</th>
<th>Number of locations</th>
<th>Depth min-max (m)</th>
<th>Number of samples collected 2010 (n)</th>
<th>Number of samples collected 2011 (n)</th>
<th>Total number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Northeast</td>
<td>June-August</td>
<td>20</td>
<td>150-250</td>
<td>0</td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td>2. Southeast</td>
<td>May-July</td>
<td>33</td>
<td>120-340</td>
<td>172</td>
<td>300</td>
<td>472</td>
</tr>
<tr>
<td>3. Southwest</td>
<td>June-August</td>
<td>12</td>
<td></td>
<td>150</td>
<td>147</td>
<td>297</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1249</td>
</tr>
</tbody>
</table>

2.2 Statistical Analyses

Statistical analyses were performed with R version 2.14.1 ([www.r-project.org](http://www.r-project.org)). Food composition results were analyzed with two different methods. When comparing the food composition as displayed in Fig. 2 and 3 mean weight of prey species against total weight of stomach ingredients were used.

\[
\text{Prey rate by weight} = \frac{\sum W_s^{sp}}{\sum W_{tot}} \tag{1}
\]

\[
\text{Prey rate by frequency} = \frac{\sum S_s^{sp}}{\sum S_{tot}} \tag{2}
\]

Where \(W^{sp}\) = Species weight, \(W^{tot}\) = Total weight,

\(S^{sp}\) = Stomach frequency with species, \(S^{tot}\) = Total stomachs frequency.

In Figure 2 the above method was used to find mean food composition within each cm interval of the length distribution. In Figure 3 the prey rate was used to find the rate for each
food group (species). In Figure 4 the prey rate was obtained by dividing stomachs frequency with observed species against total frequency of stomachs. (Equation 2)

3 Results

3.1 Variation in food intake between years and areas

Food composition of cod varied between areas and time periods (Fig 2). However, despite this variation, a general trend was detected where fish followed by crustacean and krill dominated the diet in all areas and time periods. In both area 2 and 3 and both time periods, fish became increasingly a larger part of the diet as the cod increased in size. This was especially pronounced among cod > 70 cm, as when the cod reached this length, fish became the dominant diet. There was also trend in both periods that smaller cod depends more on crustaceans and as can see in Figure 2 the cod which was under 60 cm in length, depends almost entirely on crustaceans. Area 3 on the other hand varied from area 1-2. In this area, larger cod displayed greater variation in diet by consuming both krill and crustaceans and even polychetaes (see Fig 2).

Almost 75% of the samples were collected during the summer of 2011 due to better access to fishery trawlers than the previous summer (see Table 1). Another difference between the two summer seasons was the addition of Area 1 in 2011.

The studies revealed a difference between areas 2 and 3, in cod’s food composition between the two periods (2010-2011) based on weight (Equation 1). In 2010 the diet was 94% fish in area 2 and 70% in area 3 which differs from 2011 when fish diet composed 75% in area 2 and 85% in area 3(Fig 2).

Crustacean composition in area 2 also differs between periods where krill and crustacean count for about 5% in 2010 but counts for almost 25% in 2011. This was reversed in area
3 where the crustacean counted higher in 2010 where they were 28% of diet composition but decreased to 6% in 2011 (Fig 2).

### 3.2 Variation in food composition within the main food groups between years and areas

Results showed that fish was a dominating diet when food composition of cod was analyzed. All areas have in common that fish is a major part of cod’s diet which varies from 70% to 98% of dietary composition. Though all areas have in common that fish is dominating part of cod’s diet, there exists much variation which fish species cod depends on between areas. The most common fish prey in area 1 was capelin, in area 2 blue whiting and in area 3 sandeel (see Fig 3-4).

The main food group in area 1 is fish which account for 72% of average composition of the diet, and thereafter comes crustaceans with 17% and krill with 10% of average composition of the diet, based on weight (Equation 1). When prey rate is based by frequency (Equation 2) the fish’s composition in diet counts for 40%, crustaceans for 30%, krill for 15% and polychaeta and echinodermata for the last 12% (see Fig 4).

In addition: data for area 1 was collected in two surveys, one in June and the other in August. The dietary composition of capelin in the June survey was 64% fish but in August the capelin rate in diet counted only for 24%.

The fish’s composition in cod’s diet in area 1 was 53% capelin, 16% herring, 15% Norway pout, 5% sand eel and the last 10% composites from cod, haddock, lycodes and flatfish, when based on weight (see Fig 3). When pray rate is based on frequency the fish composition in cod’s diet is 51% capelin, 4% herring, 9% sandeel, 13% paralepidae, 14% unid fish (unid fish stands for unidentifiable fish) and the last 10% are flatfish, mackerel, Norway pout and other fish species (see Fig 4).

Crustacean composition in area 1 was 47% hymenodora glacialis, 38% krill, 12%
Hyperiidae and the remaining is 1% pandalus and 1% other, when based on weight (see Fig 3). When based on frequency the crustacean composition is 11% hymeodora glacialis, 33% krill, 25% hyperiidae, 8% gammeridae, 7% pandalus and 15% other (see Fig 4).

The main food groups in dietary composition for area 2 in 2010 were 94% fish, 4% crustacean, 1% krill and 1% other, based on weight (see Fig 3). Fish counted for 66% based on frequency, crustaceans for 19%, krill for 5% and the remaining 9% consists of echinodermata (4%), polychaeta(2%), mollusca (1%) and other (3%) (see Fig 4).

Fish species composition based on weight was 40% blue whiting, 32% herring, 11% mackerel, 4% great argentine, 1% Norway pout and 12% unid fish (see Fig 3). When composition based on fish species frequency is studied, blue whiting counts for 31%, herring for 23%, unid fish 26%, mackerel 5%, Norway pout for 3% and other 13%, (see Fig 4).

Crustacean dietary composition based on weight was 80% krill, 13% Norway lobster, 1% pagurus and 6% other. When composition based on frequency is studied, the krill counts for 22%, Norway lobster 25%, hyas coarctatus 8%, pagurus 5% and other 40%.

The main food groups in cod’s dietary composition for area 2 in 2011 were 75% fish, 22% krill, 2% crustacean and 1% other, based on composition by weight (see Fig 3). Fish counted for 21% of the total diet based on frequency, krill for 51%, crustacean for 18% and the remaining 10% was polychaeta (7%), echinodermata (2%), and other (1%) (see Fig 4).

Fish species composition in cod’s diet was 45% blue whiting, 37% herring, 7% mackerel and the remaining 10% is 5% redfish, 4% haddock and 1% other, based on composition by weight (see Fig 3). When composition based on frequency is studied, the blue whiting counts for 40%, herring for 38%, unid fish 10%, mackerel 3% and other 8% (see Fig 4).

Crustacean dietary composition based on weight was 93% krill, 2% Norway lobster and 5% other (see Fig 3). Composition based on frequency shows that krill counted for 74%, Gammeridae 6%, pagurus 5%, pandulus 4% and other 11% (see Fig 4). In addition data from area 2 was collected in two surveys in 2011, in May and July. Both surveys had similar sample size, or about 150 samples each. The result for dietary composition in the May survey indicates that 72% of food composition is krill and 23% fish, which differs from the results from the July survey when 98% of food composition was fish.

The main food groups in cod’s dietary composition based on weight for area 3 in 2010 were 70% fish, 28% crustacean, 1% echinodermata and 1% other (see Fig 3). When composi-
tion based on frequency Fish in cod’s diet counted for 15% based on frequency, crustaceans for 70%, mollusca for 6%, echinodermata 5% and polychaeta and krill both with 2% (see Fig 4).

Fish species dietary composition based on weight was 47% paralepidae, 34% sand eel, 18% herring and 1% flat fish and other. (see Fig 3). When composition based on frequency, the dietary rate of paralepidae counts for 29%, sand eel for 38%, herring 18% and 1% for unid fish and flatfish (see Fig 4).

Crustacean dietary composition based on weight was 24% hyas coarctatus, 9% macropipus sp, 8% munida tenuinama, 3% hyas araneus and 34% other, including 22% unid shrimp (see Fig 3). When based on frequency the dietary rate of hyas coarctatus counts for 19%, munida tenuinama for 13%, macropipus sp and hyas araneus for 4% each, unid shrimp for 15% and other 44%.

The main food groups in dietary composition by weight for area 3 in 2011 were 85% fish, 8% echinodermata, 6% crustacean and 1% other. (see Fig 3). When based on frequency fish counted for 28%, crustaceans for 34%, mollusca for 17%, echinodermata for 14%, polychaeta for 6% and krill for 1% (see Fig 4).

Fish dietary composition based on weight was 97% sand eel, 2% blue whiting and 1% other (see Fig 3). When composition based on frequency is studied the dietary rate of sand eel counts for 77%, blue whiting for 3%, flat fish for 3% and unid fish for 17% (see Fig 4).

Crustacean dietary composition based on weight was 54% pagurus, 12% hyas coarctatus, 6% pandulus and 27% other (see Fig 3). The results based on frequency show that the dietary rate of pagurus counts for 33%, hyas coarctatus for 16%, pandulus for 16% and other 35% (see Fig 4).
Fig 2. Proportion of food groups based on weight, in stomach of cod of different sizes in areas 1-3 (from top to bottom) in 2010 and 2011
Fig 3. Average weight of food groups in cod stomachs in three areas around Iceland in 2010-2011: (a) Main food groups (b) fish (c) crustacean.
<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2010</th>
<th>2011</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Fishes 60%</td>
<td>Fishes 60%</td>
<td>Fishes 21%</td>
<td>Fishes 21%</td>
<td>Kri 12%</td>
</tr>
<tr>
<td></td>
<td>Other 2%</td>
<td>Kyst 51%</td>
<td>Other 1%</td>
<td>Echinodermata 2%</td>
<td>Kri 15%</td>
</tr>
<tr>
<td></td>
<td>Echinodermata 4</td>
<td>Polychaeta 2%</td>
<td>Echinodermata 5%</td>
<td>Other 8%</td>
<td>Fishes 28</td>
</tr>
<tr>
<td></td>
<td>Polychaeta 7%</td>
<td>Mollusca 1%</td>
<td>Polycheata 2%</td>
<td>Polycheata 2%</td>
<td>Crustacea 34%</td>
</tr>
<tr>
<td></td>
<td>Crustacea 30%</td>
<td>Mollusca 2%</td>
<td>Crustacea 18%</td>
<td>Crustacea 18%</td>
<td>Echinodermata 14%</td>
</tr>
<tr>
<td>(b)</td>
<td>Capelin 51%</td>
<td>Herring 4%</td>
<td>Blue whiting 46%</td>
<td>Herring 10%</td>
<td>Sandeel 38%</td>
</tr>
<tr>
<td></td>
<td>Herring 23%</td>
<td>Blue whiting 31%</td>
<td>Herring 10%</td>
<td>Sandeel 77%</td>
<td>Blue whiting 3%</td>
</tr>
<tr>
<td></td>
<td>Sandeel 9%</td>
<td>Herring 30%</td>
<td>Herring 6%</td>
<td>Sandeel 17%</td>
<td>Flatfishes 3%</td>
</tr>
<tr>
<td></td>
<td>Herring 3%</td>
<td>Other 13%</td>
<td>Other 13%</td>
<td>Herring 9%</td>
<td>Flatfishes 5%</td>
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<td></td>
<td>Petrel 13%</td>
<td>Other 6%</td>
<td>Other 8%</td>
<td>Other 8%</td>
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<tr>
<td></td>
<td>Norway pout 1%</td>
<td>Other 6%</td>
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<td></td>
<td>Norway pout 1%</td>
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<td>Und fish 3%</td>
<td>Other 6%</td>
<td>Other 6%</td>
<td>Other 6%</td>
<td>Other 6%</td>
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<tr>
<td>(c)</td>
<td>Hyas crinites 6%</td>
<td>Kiol 15%</td>
<td>Hyas crinites 4%</td>
<td>Hyas crinites 15%</td>
<td>Hyas crinites 16%</td>
</tr>
<tr>
<td></td>
<td>Norway lobster 25%</td>
<td>Kiol 22%</td>
<td>Hyas crinites 25%</td>
<td>Hyas crinites 15%</td>
<td>Hyas crinites 8%</td>
</tr>
<tr>
<td></td>
<td>Norway lobster 25%</td>
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<td>Hyas crinites 15%</td>
<td>Hyas crinites 8%</td>
</tr>
</tbody>
</table>

Fig 4. Frequency of food group in cod stomachs in three areas around Iceland in 2010-2011: (a) Main food groups (b) fish (c) crustacean.
3.3 Statistical testing of main hypothesis

Results from a statistical test using ANOVA show that there is a relationship between cod length and fish and crustacean composition in diet but no relationship detected in other food groups. Results show that there is also a relationship between food groups composition and areas where fishes, mollusca, polychaeta and echinodermata composition in diet varies between areas (see Table 2).

It was tested whether there exists a relationship between food groups, length and areas with a two way ANOVA test. The first null hypothesis is that there is no significant difference between cod length and food composition. Significant difference is measured when p-values ≤ 0.05 by 95% confidence interval. Table 2 summarizes the p-values results from the ANOVA test. The results from the ANOVA test were that there is highly significant difference between multiply relationships in fish composition in diet (p < 0.001) and in crustaceans (p < 0.001). No relationship was detected in other food groups (krill, mollusca, polychaeta, echinodermata, other).

The second null hypothesis is that there is no significant difference between areas and food composition. The results were that there is a significant difference between areas and fish composition in diet (0.1 > p > 0.001), in mollusca (p < 0.001), in polychaeta (p < 0.001) and in echinodermata (p < 0.001). There were no significant differences in krill and crustacean between areas. Multiple relationships between food group composition in diet were tested against cod length and areas (see column size: area in Table 2). The results were that there is a significant difference between multiple relationships in fish composition in cod’s diet (p < 0.001) and in crustaceans (p < 0.001). No relationship were detected in other food groups (krill, mollusca, polychaeta, echinodermata, other).
Table 2. Results (p values) from two way ANOVA test (lm) where correlation between food groups, size and area were tested.

<table>
<thead>
<tr>
<th>Food groups</th>
<th>Fish</th>
<th>Krill</th>
<th>Crustacean</th>
<th>Mollusca</th>
<th>Polychaeta</th>
<th>Echinodermata</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>2x10^{-16} ***</td>
<td>0.480</td>
<td>0.018*</td>
<td>0.0422*</td>
<td>0.086</td>
<td>0.122</td>
<td>0.748</td>
</tr>
<tr>
<td>Area</td>
<td>1.6x10^{-4} **</td>
<td>0.063</td>
<td>0.059</td>
<td>4x10^{-4} ***</td>
<td>5.8x10^{-4} ***</td>
<td>4.7x10^{-6} ***</td>
<td>0.702</td>
</tr>
<tr>
<td>Size: Area</td>
<td>1x10^{-7} ***</td>
<td>0.325</td>
<td>5x10^{-10} ***</td>
<td>0.075</td>
<td>0.752</td>
<td>0.814</td>
<td>0.239</td>
</tr>
</tbody>
</table>

(p-values)

3.4 Variation in food intake between size groups of cod

Results show that there is a relationship between cod length and fish composition in diet for both periods in area 2 but not detected in area 1 and 3 (see Fig 5). Results show also a relationship between crustacean composition in diet and cod length in area 1 and in area 2 in 2010 (see Fig 6).

Following the ANOVA test, the relationship between cod length and food groups was tested. Fish, crustaceans and mollusca were the only food groups which counted for significant difference between length and diet, based on the results from the ANOVA test (see Table 2). The correlation between cod length and diet was tested with linear regression test for each area. Results from the regression test for each area and between the two summer seasons (2010-2011) are shown in Figure 5 and Figure 6. Fish and crustaceans were the only food groups tested because the most significant difference was in these two groups.
The results for regression test between fish weight in stomach and cod length is shown in Figure 5. There were no significant differences found in areas 1 and 3, based on 95% confidence interval. Significant differences were identified in both periods in area 2. The significant difference was established to be high in the 2010 results where $p < 0.0001$ and the coefficient of determination was $R^2=0.37$, which indicates that there is a good relation between these two variables. In 2011 there existed also some difference in area 2 where $p < 0.01$ and $R^2=0.20$.

The results for the regression test between crustacean weight in stomach and cod length is shown in Figure 6. There was no significant difference found in area 2 in 2011 and in area 3 for both periods (2010-2011), based on 95% confidence interval. Significant differences were identified in area 1 and area 2 in 2010. There was significant difference in area 1 where $p < 0.05$ and the coefficient of determination was $R^2=0.12$. For area 2 in 2010 there was also significant difference detected where $p < 0.01$ and coefficient of determinations was high, $R^2=0.40$. 
Fig 5. The relationship between length of cod and weight of fish diet in their stomachs.
Fig 5. The relationship between length of cod and weight of crustacean diet in their stomachs.
4 Discussion

The results of this study show that the food intake of cod varies between years, areas and size groups. Overall, fish was the most important part of cod’s diet and the remaining part of the diet usually is crustacean. The results show that there is a relationship between cod length and fish, crustacean and mollusca composition in cod’s diet (see Table 2). There seems to be a change in food composition when the cod reaches 70 cm in length and fish in dietary composition increases heavily when cod reached 70 cm in length and becomes the main food resource in areas 2 and 3 (see Fig 2).

The first null hypothesis is that there is no difference between fish composition in diet and cod length. This was tested with ANOVA test and the result was that there is high variance between fish diet and length, where p-value was $2 \times 10^{-16}$, this rejects the hypothesis of no difference, which supports the theory that fish composition increases with increasing cod length. A relationship between cod length and crustacean and mollusca in diet was also detected (see Table 2). The second hypothesis where tested with ANOVA test and the results where that there is different food composition between areas in fish, mollusca, polychaeta and echinodermata as predicted. The effect of cod length and area on food composition was also tested in multivariable ANOVA test and the results show significant difference in fish and crustacean composition in diet.

Food composition varies between areas and the reason is the difference in food resources for each area. Fish is a major part for dietary composition of cod and varies from 70% to 98% composition rate, the remaining is usually composed of crustacean and krill, except in area 3 in 2011, where echinodermata counts for more than crustacean when composition rate is based on weight (see Fig 3). As can be seen in Table 2 the main difference between areas and food groups was in fish species composition in cod’s diet. Fish ideal habitat temperature varies and is probably a major factor for the reason why species diversity varies between areas.
A summary of main fish species in cod’s diet follows. Capelin is a major part of cod’s food composition in area 1, but was not detected in areas 2 and 3. The reason for the difference is that capelin is not an available food source in areas 2 and 3 over the summer period because of capelin food migration in North Iceland Sea and adjoining areas. (Vilhjalmssson, Hjálmur et al.2004) Herring is also a major food source and is detected in all areas, but varies from 15% to 40% in composition based on weight. Blue whiting is a major food source for area 2, but is only a small part of cod’s diet in other areas. The reason for this could be the variance in depth because blue whiting is available food source in all areas. Sandeel is a major food source for area 3 and was also part of the food composition in area 2. Sandeel was not detected in area 3, most likely because of too low sea temperature for the species. If the most common fish species are compared for all areas (most common species is the species with highest score with the frequency based method), the results show that in area 1 capelin is the most common species, in area 2 blue whiting is the most common and in area 3 sandeel. Therefore these three areas all depend on separate fish species. (Gunnarson, Karl & Jónsson, Gunnar et.al)

Crustacean species vary between all areas and also between periods. The variance may be because of different depth and temperature, no significant difference was detected between areas and crustacean dietary composition based on results from ANOVA test (see table 2). Krill has the highest dietary composition rate based on weight in area 1 and 2, but are not detected in area 3. Other common species in composition were hymenodora glacialis, pagurus, gammerida, Norway lobster, hyas coarctatus and hyperiidae (see Fig 3).

Other studies (Björnsson, Höskuldur & Pállsson, K, Ólafur 2011) have shown similar results for cod dietary composition, and that cod heavily depends on capelin, herring, blue whiting and sandeel as a food resource. Studies from Björnsson, Höskuldur & Pállsson, K, Ólafur also support the result that food composition varies between areas and periods.

The reason that results are shown for two methods, based on weight and frequency (see chapter Material and Methods) is that both methods provide different information about the dietary composition. The advantage of the weight based method is that it provides information about food quantity in cod’s stomach, for example one herring which is 300 grams is more energy source than two capelin which are 20 grams each, so we can conclude that one herring in this example is the main energy and nutrients source for that particularly individual. The advantage with the frequency based method is that it gives good information
about how common the prey is. For example if in a sample of 10 cod stomachs there is one capelin in 9 stomachs and one herring in the 10th stomach. From this information we can see that capelin is more common food source than herring and the frequency based model would give us that 90% of food composition is capelin. If this one herring weighted let’s say 300 grams and the total weight of the nine capelin is 90 grams, the food composition based on weight would be 23% capelin. The result from this example shows that there can be much difference in composition results. In summary the frequency based model gives good information of how common each prey species is, and the weight based model gives good information of the rate of prey quantity in the diet. The outcome can be highly different between these two methods of assessing food composition. The ultimate model should be a model based on prey weight, frequency and the predator’s weight.

4.1 Next steps

Since 1995 there has been a warm period in the Iceland Sea. This warm period may have triggered the food migration of mackerel into the Iceland Sea in the last decade (Ástþórsson, S, & Ólafur, Sigurðsson et al.2010). The mackerel was detected as part of cod dietary composition and it is important to continue studies on cod dietary composition to monitor the change in cod’s diet resource. Another exciting result was the high quantity of krill in the May 2011 survey in area 2. The krill spawn migrates during May, and therefore biomass increases and climates at the end of May. (Ástþórsson, S, Ólafur & Gíslason, Ástþór. 1995) The effect of the krill pulse in dietary composition in May is exciting studying material and it is important to study for better basic understanding of annual changes in cod’s dietary composition.
References


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