Master's thesis

Putting the Eggs in Different Baskets:

Potential Marketing Strategies for Icelandic Lumpfish *(Cyclopterus lumpus)* Roe

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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.

John H. Burrows

Abstract

The Lumpfish (*Cyclopterus lumpus*) has been caught in Iceland for centuries. In recent decades the primary value of the lumpfish fishery in Iceland has been from the use of the roe in the creation of imitation caviar. Historically, the fishery responsible for this catch has been largely comprised of boats from rural, low-density population areas. This study looked to identify new ways to use lumpfish roe to increase their value and bring additional revenue to these smaller communities in Iceland. Due to growing consumer awareness of the benefits of long-chain n-3 polyunsaturated fatty acids (n-3 LC-PUFA's), especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), this study looked to quantify whether these acids were a marketable feature. Lumpfish roe fatty acids as percent of fatty acid methyl ester (FAME) and phospholipids (PL) as percent of total lipids (TL) were studied using gas chromatography and compared with n-3 fish/krill oil supplements currently available to consumers as well as roe of other species. Nutritional supplement data was gathered in December 2017 both online and in-person. Nutritional data were obtained from product tests and supplement labels. Lumpfish roe rated highly in n-3 content against krill oils and products made in Iceland and had a more larger proportion of n-3 than roe from other species. Compared to most finished consumer products the lumpfish roe was higher in DHA but had comparable EPA levels. Compared with roe of other species lumpfish roe was average in DHA but higher in EPA. EPA+DHA also comprised a larger percentage of n-3 than most consumer n-3 supplements of all types. Strategies to increase the value include market separation via indication of the n-3/DHA/EPA and phospholipid content and tying the product more closely with its origin with labelling. Applications which may benefit include alternative preparations, functional foods, and supplements. The nutritional properties of lumpfish roe studied herein indicate potential exists to drive the market globally and thus grow incomes in communities in Iceland which collect the lumpfish.

Útdráttur

Hrogn gráleppunnar (*Cyclopterus lumpus*) hafa verið nýtt á Íslandi um langa hríð. Undanfarna áratugi hafa helstu verðmæti tegundarinnar skapast vegna framleiðslu á grásleppukavíar sem hefur er ætlaður sem staðkvæmdarvara styrjuhrogna. Verkefni þessu er ætlað að finna ný tækifæri til nýtingar á grásleppuhrognum með aðmarkmiði að auka hagsæld og tekjumöguleika í hinum dreyfðu byggðum á Íslandi. Fitusýruinnihald grásleppuhrogna var rannsakað með gasgreini til þess að meta hlutfall fosfórlípíða og metílestera af heildarfituhlutfalli hrognanna. Þær niðurstöður voru bornar saman af n-3 vörum og við niðurstöður hrogna annarra fisktegunda. Í desember 2017 var upplýsingum safnað varðandi innlendar vörur sem eru seldar á netinu ásamt því að skoða vörur í verslunum og apótekum á Norðurlandi vestra. Hlutfall n-3 fitusýra, EPA og DHA í grásleppuhrognum kom vel út í samanburði við sambærilegar vörur framleiddar á Íslandi og hrognin innihalda almennt hærra hlutfall n-3 fitusýra en hrogn annarra fisktegunda. Samanburður á vörum sýndi jafnframt sambærilegt hlutfall EPA og í flestum tilfellum hærra hlutfall DHA. Tillögur verkefnisins er snúa að auknu aflaverðmæti felast í því að skapa hrognunum sérstöðu á markaði með því að draga fram hlutfall fjölómettaðra fitusýra/DHA/EPA og fosfórlípíða. Einnig er lagt til að leggja mikið upp úr upprunamerkingu vörunnar. Einnig var lagt til að horft yrði til frekari útvinnslu í átt til heilsufæðis og fæðubótarefna.

Dedicated to the memory of Charles Burrows who passed away during the creation of this study.

Table of Contents

List of Figures

List of Tables

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1 Executive Summary

1.1 Background

The Lumpfish (*Cyclopterus lumpus*) gillnet fishery in Iceland operates seasonally and primarily targets the roes of spawning females due to their use in the creation of imitation caviar. The boats fishing this catch are in general out of more rural locations, comprised of 1-3-person operations and functioning outside of the Icelandic quota system. At present, the caviar products are the sole output of the actual roes, and it was only very recently that the spawning females themselves have seen larger use via export to China: a practice which was primarily resulting from a desire to eliminate the common practice of gutting for roes at sea and throwing back the fish itself. This practice enhanced the value of the fishery, but it did little to enhance the value of the roes themselves.

In 2017, the fishery lost its Marine Stewardship Council Certification, losing what may have been an important market separator, and adding to the urgency to establish additional methods of marketing and/or using the roes. Even prior to this, the trend had been one of lost value, as the roes in 2016 were only valued at 120 ISK per kg. This study looked to identify new strategies and bring additional revenue to the smaller communities in Iceland. In the seafood industry, growing trends in the marketing of the health benefits and the country of origin made it prudent to investigate these perspectives as they relate to lumpfish roe. Due to growing consumer awareness of the benefits of long-chain omega-3 polyunsaturated fatty acids (n-3 LC-PUFA's), especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), this study looked to quantify whether these acids were a marketable feature to either separate the Icelandic lumpfish from competing caviar products, or to mark the lumpfish roe as a candidate as a raw material in new product designs such as functional foods or nutraceuticals.

1.2 Methods

Lumpfish roe fatty acid and phospholipid composition was determined using samples from the 2017 Icelandic lumpfish catch, and in turn compared with omega-3 fish and krill oil supplement products currently available to consumers. This was done in order to not only set a high standard of omega-3 composition against which to measure the lumpfish roe, but also to determine the general market of high performing omega-3 products and supplements. The omega-3 and phospholipids were also compared to the roe of other species, to determine whether the roes of the lumpfish were in any way exceptional among these comparable raw materials. Nutritional supplement data was gathered in December 2017 both online and in-person and were obtained from product tests and supplement labels. From the composition determination of the roes and the nutritional supplement data gathered, many additional calculations were done in order to determine proportional compositions, prices and of the active compounds, and potential value of the catch with new product derivation.

1.3 Findings

Lumpfish roe possessed 5% lipids, and rated highly in comparative omega-3 content against krill oils and fish oil products which were made in Iceland and rated close to the middle-range of best-selling fish oils in the US. The lumpfish roe also showed a more larger proportion of omega-3 than the roe from other species, including some which are commonly used in fish oil creation. The lumpfish roe was higher in terms of relative DHA levels than most of finished consumer supplements. Compared with roe of other species, lumpfish roe was above average in DHA content (25% of fatty acids for lumpfish, compared to 15% on average) but among the highest in EPA levels (18% for lumpfish, compared to 7% on average) . EPA and DHA together also comprised a larger percentage of n-3 than most consumer n-3 supplements of all types (91%). While phospholipids were not elevated in the lumpfish roe (22%), phospholipids were still present at levels which fell within the range of best-selling krill oil products (the only omega-3 supplements which feature phospholipids, and claim their presence enhances bioavailability of the n-3 present).

Based on these results, strategies to increase the value of the catch include market separation via indication of the omega-3/DHA/EPA and phospholipid content and tying the product more closely to its national origin with labelling. Labelling strategies based on these marketing leverages could be used in either the already existing lumpfish caviars, or in new applications. Applications which may benefit include alternative preparations, (i.e., new preparation methods of fresh roe or caviar), functional foods, and nutraceutical supplements.

Among raw materials for an omega-3 fish oil supplement or additive for functional food, the lumpfish roe's roughly 3:2 ratio of DHA to EPA, in fatty acids which are nearly 50% omega-3, may be a niche composition among omega-3 products because of the elevated DHA levels and analogous EPA levels when compared to current industry standards. Lumpfish roe fatty acids, rated exactly at 18:25 EPA to DHA, double the DHA in the 18/12 triglyceride (TG) formulation of fish oil and the inverse of the 30:20 types. Even in an unprocessed form, the roe fatty acids were still nearly 50% omega-3, just below the 55% that 18/12TG fish oil attained after being molecularly distilled into ethyl esters. As knowledge of the functions and benefits of EPA and DHA both together and in isolation continues to grow, more niche formulations of omega-3 supplements and foods may be required. It is possible that avenues available in this industry may allow additional products to be developed from lumpfish roe. Based on pricing data of supplements alone, the lumpfish catch could potentially earn as much as 14 million k ISK in a year, while the maximum earned in the past decade was 2.3 million k ISK. In the course of investigating other roes, it was also noted that cod and haddock roe also possessed very high levels of omega-3, and higher levels of phospholipids. As these species are landed in far greater amounts in Iceland, these species may also be suitable for further exploration.

Given current trends in the market, as well as recent developments in Icelandic fish oils, it appears that country of origin may be another easy way to add value to the stock. While not quantified by the research, it is the strategy that major entities in Icelandic fish oils appear to be attempting in foreign markets. Based on Iceland's positive association with seafood and marine products, and the small-scale state of the wild caught fishery, eco-labels which highlight this may also be valuable.

It is recommended that labelling strategies denoting high omega-3 content and the roe's country of origin be explored. Any new preparations utilizing lumpfish roe as an ingredient should likewise explore this market differentiation tool. Additionally, new projects to attempt to create both supplements and functional foods from lumpfish roe should be undertaken. These strategies show great promise for further developing the market for Icelandic Lumpfish and thereby improving incomes in the nation's fishing communities

2 Introduction

2.1 The Female Lumpfish Fishery

2.1.1 History

The lumpfish (*Cyclopterus lumpus*) is a semi-pelagic species with a wide distribution across the North Atlantic (Kennedy, Jónsson, Ólafsson, & Kasper, 2016), which has been caught in Icelandic waters for centuries (Kristjánsson, 1985). Though there have been several utilizations, the fishery primarily targets the spawning females (*grásleppa*) during the spring and summer to collect the roe, a commodity which is used in the creation of an imitation caviar (Bledsoe, Bledsoe, & Rasco, 2003). Prior to the development of the commercial fishery in the 1920's, the Icelandic lumpfish (*hrognkelsi*) saw a more varied usage (Chambers, 2017). The males of the species (*rauðmagi*) are considered a local delicacy, and are still caught in a separate fishery ("lumpfish_tech_rep221.pdf," n.d.). The females themselves are rarely consumed in Iceland, and but those that are hung to dry due to their flesh being considered overly gelatinous (Kristjánsson, 1985). Iceland's commercial catch of the roe is thought to have grown substantially during the 1970's, though it has remained a small piece of the Icelandic commercial fishing. The implementation of the Individual Transferrable Quota (ITQ) system following from the Icelandic Fisheries Management Act of 1990 led to a consolidation of quota to fewer and larger fishing entities and ships, and accelerated a shift away from the less population dense regions of Iceland (Chambers & Carothers, 2017). However, the female lumpfish fishery was never included in the ITQ system, and such a consolidation of efforts did not occur.

2.1.2 Today

Instead of governance under the ITQ, the fishery is instead primarily limited through effort restrictions. There is a set number of permits for the female, i.e. roe-targeted fishery, a total of 458 for the year 2016 ("lumpfish_tech_rep221.pdf," n.d.). These permits never expire, but require a yearly license to be obtained in order to become active for the year (Chambers, 2017). New permits are not created, but rather must be transferred via sale to a new vessel (Magnusson, 2016). For licensing, the fishery divides the Icelandic coast into seven regions, lettered A-G, arranged clockwise and starting from the capital region. The largest density of both landings and vessels occurs in area E (Northcentral and Northeast coast) but the entire Northern coast has activity, with nearly no vessels operating on the Southern coast (Area G) ("lumpfish_tech_rep221.pdf," n.d.). Approximately 60% of the permits held are registered in communities of less than 500 inhabitants (Chambers, 2017). When activating an annual license, the vessel must select one of the seven regions for operation, and may only fish in that region for the season ("lumpfish_tech_rep221.pdf," n.d.). Once the license is activated and a region selected, the vessel is given a number of allowed fishing days (36 in 2016 and 46 in 2017) out of the typical 2-3 months that the regions are open for fishing ("lumpfish_tech_rep221.pdf," n.d.). The number of days allotted per vessel is determined by the Minister of Fisheries and Agriculture based on a suggested total annual catch (TAC) provided by the Marine and Freshwater Institute (Hafrannsóknastofnun) and an open dialogue with the Small Boat Owner's Association (Landssamband smábátaeigenda).

There is nothing which prevents all permit holders from obtaining a license in the same year, but in 2016 and 2015 there were only 239 and 316 licenses active, respectively ("Hrognkelsi," n.d.). The number of active licenses tends to correlate strongly with the price per kilo of lumpfish roe, which fluctuates annually and is set prior to each season. The most recent price per kilo (120 ISK/kg) is well below recent levels, and is the lowest since the 2007 season set at 220 ISK/kg, a time during which the price ranged from 220 ISK/kg (2007) to 1050 ISK/kg (Chambers, 2017). Landings are also highly varied annually, fluctuating generally from 2k-6k tonnes between 1990 and 2017 (Hafrannsóknastofnun, n.d.). Most recently in 2016, a total of 5480 tonnes of female lumpfish were landed (Hafrannsóknastofnun, n.d.). Roe on average comprises 30% of the female bodyweight, indicating a rough estimate of total roe to be roughly 1644 tonnes for the 2016 season.

Prior to 2011, much of the tonnage of the catch was without value, as the females were gutted and the roes were removed at sea, with the remaining 70% of the volume comprised of the head and tail thrown back (Johannesson, 2006). This changed when the Ministry of Fisheries and Agriculture established regulations requiring landing and full usage of the catch beyond just the roe. The Ministry then worked with an export entity (Triton Ltd.) to identify a market for frozen lumpfish. They succeeded in China, resulting in an annual export valued at around 3 million USD (Saulnier, 2012). As a result, China and frozen lumpfish have become a substantial portion of the tonnage and value of lumpfish exports (Figure 1). In 2016, of the 5480 tonnes landed, 3445 were exported and were valued at approximately 1,195,175 k ISK

("Lumpfish catch 1992-2016," 2017). Of that, the Chinese frozen fish export comprised 2631 tonnes and contributed 494,363 k ISK in value ("Lumpfish catch 1992-2016," 2017). However, options for selling and marketing the roes remain limited, with only two substantial usages and deference to the pre-determined pricing available.

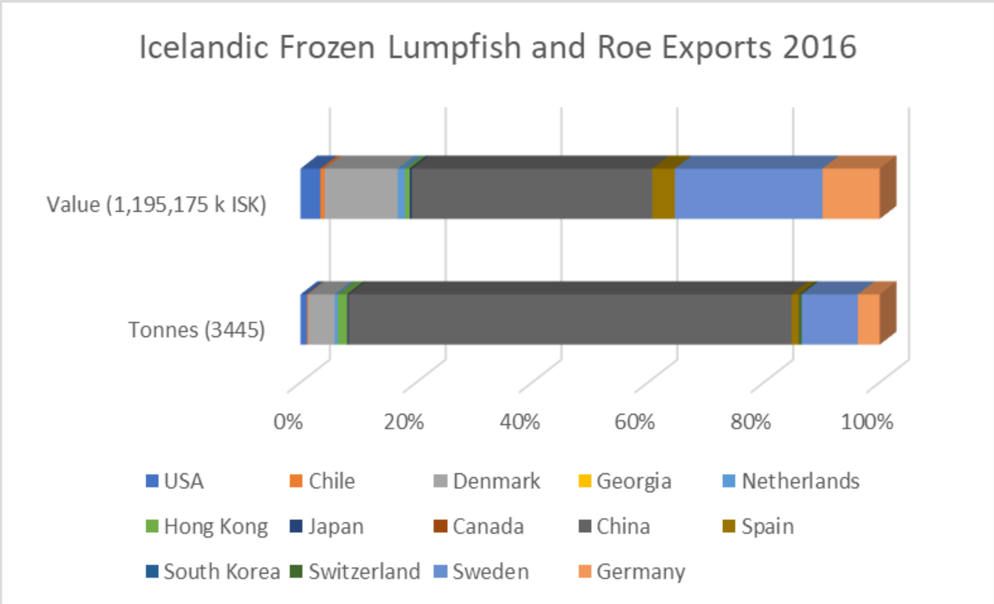

Figure 1: Volume and value of exports from the female lumpfish fishery by destination for the year 2016 courtesy Statistics Iceland.

The female fishery was also the first lumpfish fishery to be awarded a sustainability certificate by the Marine Stewardship Council (MSC) in 2013(Gascoigne et al., 2014), and was sponsored by Vignir G. Jónsson hf., a subsidiary company of HB Grandi Ltd, a major Icelandic seafood entity. Vignir was bought in 2013 from private ownership, and is now the purveyor of roe for HB Grandi ("HB Grandi | Vignir," n.d.). Also in 2013, Vignir became the client responsible for submission of the female lumpfish fishery for certification with the MSC, which was approved in 2014 (Gascoigne et al., 2014) However, as of the third annual assessment, the certification was suspended due to detection of additional bycatch of the harbour porpoise (*Phocoena phocoena*) and black guillemot (*Cepphus grille*) not previously detected (Gascoigne, Daníelsson, Jagielo, le Roux, & Guðmundsdóttir, 2017). In being suspended, products originating from lumpfish roe are prohibited from carrying the MSC certification eco-label, losing a tool for market differentiation.

2.1.3 Processing

Boat to Barrel

Roes are collected in the spring and summer by small boats crewed by 1 to 3 persons. Lumpfish are caught with specially chosen gillnets with meshes 267 to 286 mm stretched, to specifically target the females, whom are larger in general than the males which are fished and managed separately ("lumpfish_tech_rep221.pdf," n.d.). While still inside the females, the roes are essentially sterile, but it is still considered best practices for catch and initial processing to occur on the same day (Johannesson, 2006). When returned to shore, the fish are brought to a processing center to remove the roes. There the fish are gutted with care being taken to isolate the roe sack intact to prevent cross contamination, with the remainder of the fish being utilized for either air drying and local consumption (Kristjánsson, 1985) or export to China (Þórðarson, Pálmason, & Reykdal, 2013). Roes are then screened to separate the eggs themselves out from the sac and any clinging connective tissue (Johannesson, 2006).

Following this, the eggs are washed with water and then salted (12-20% of total weight of a barrel is salt). This is done with a blend of salt and preservative (typically sodium benzoate, 200 g per barrel) mixed separately and then later added to the roes in order to achieve particular ratios of each (Johannesson, 2006). This mixture is stirred carefully to avoid breaking of the individual eggs and then loaded into plastic barrels (Basby, 1997). The barrels are sealed with a pressure ring, and left upright overnight (Johannesson, 2006). Over the first few days after sealing, the barrels are either rolled or flipped to prevent clumping of the eggs which often occurs as a result of the salting process if left unperturbed (Basby, 1997).

Barrels to Caviar

After barreling, the eggs are shipped to caviar processing/manufacturing centers. Upon arrival (which typically is in either spring or summer) the barrels are opened and checked for temperature, salt levels, leaking, and presence of foreign material (Johannesson, 2006). 5% of the shipment is also selected randomly and tested for bacterial presence (Basby, 1997). If accepted, brine is added to the barrels and they are then re-sealed and stored for several months to a year, with most processing being done in late fall (Johannesson, 2006). As processing begins, the barrels are re-assessed based on sensory input, primarily smell. This is done by cutting a large hole into the center of the barrels and setting aside any which seem to smell off. Even when all steps are handled properly, it is still possible for barrels to become unviable during storage (Johannesson, 2006). These potentially unusable barrels have their pH levels tested and their bacterial levels checked, and even if only a section of the barrel is confirmed as off, the entire container is removed from processing due to risk of contamination for the entire batch (Basby, 1997).

Next the roes are de-salted by blending with water in a large stirring container, often a dairy churn, in order to dilute the salt content down from the heavy dose of salt and preservatives applied at initial processing and then allowed to set for a half hour (Johannesson, 2006). Dye, either red or black, is added either at this point or along with other ingredients later (Basby, 1997). This dye (a blend of synthetic colors including tartrazine) is used to standardize the color of the product because lumpfish eggs vary widely in color and in toughness, with darker colors being firmer than lighter/clear eggs (Dagbjartsson, 1972). The brine in the mixture is then sucked away and replaced with lightly salinized water several times (varies by plant/company) until the desired salt levels are achieved (Johannesson, 2006). Stabilizers/emulsifiers, preservatives (again typically sodium benzoate), dyes if not added during de-salting, and optional ingredients such as flavorings, spices or various pH lowering measures such as food acids are added and mixed. (Johannesson, 2006). From there, the final step is placement in glass jars with extreme precision regarding volume (typically 100g) in order to avoid profit loss from overfill and market fraud from underfill, and then are vacuum sealed (Basby, 1997).

2.2 Potential Marketing Tools

With the loss of the MSC certification, it has become even more imperative to investigate new opportunities for the roe of the lumpfish. While the relatively new export of frozen fish to China has been successful in generating new income levels, the 2016 price per kilo of roe was still the lowest it has been in a decade (Chambers, 2017). Though the MSC label is no longer permitted on Icelandic lumpfish products, other attributes of the roe or its production/fishery may be able to be used to garner additional value for the products, or perhaps even new applications for the roe outside of caviar.

2.2.1 Marketing Health Aspects (Omega-3)

Consumer awareness in seafood and seafood products has been evolving, allowing fishermen and purveyors new avenues with which to create product differentiation (Olsen, Toppe, & Karunasagar, 2014). Among the most accepted among consumers is the benefit seafoods and marine products can offer in the form of long-chain omega-3 polyunsaturated fatty acids (n-3 LC-PUFA's, omega-3, n-3) (Clough, 2008). Of the various n-3 fatty acids, eicosapentaenoic acid (EPA, 20:5n3, meaning it contains 20 carbons in the chain, and has 5 double bonds, the first of which occurs on the third carbon), and docosahexaenoic acid (DHA, 22:6n3 i.e. 22 carbons, 6 double bonds, first of which occurs on the third carbon), have been shown to be exceptionally effective in reducing inflammation, lowering oxidative stress and damage, promotion of healthy brain function and memory, immune system support, improving body composition, regulation of healthy heart rhythm, promotion of effective metabolizing of dietary fats and cholesterol, reducing mortality events associated with numerous conditions, and especially in warding off Alzheimer's disease (Alexander, Miller, Elswyk, Kuratko, & Bylsma, 2017). While these benefits speak to conjoined intake of both EPA and DHA, the two fatty acids are utilized and absorbed differently in the body. While the benefits in combination are well studied, the understanding of DHA and EPA in isolation is more recent, with much of the research directed at neurological and cardiovascular outcomes. In terms of cardiovascular effects, both have shown an impact in dropping the level of blood triglycerides (Harris, 1997), with DHA causing a larger reduction (Wei & Jacobson, 2011). Where differences are most notable is in interaction with cholesterol types, high-density lipoproteins (HDL) and low-density lipoproteins (LDL). DHA appears to raise both types of cholesterol (though it raises LDL more) while EPA reduces LDL (Allaire et al., 2016).

Neurological effects also differ. DHA in isolation is particularly important for foetal brain and eye development, continued brain and central nervous system development in infants, maintenance of healthy brain function in adults, is associated with improved or optimized learning capabilities, and lowers resting heart rate (Horrocks & Yeo, 1999) It may also play a role in protecting against cognitive decline (Swanson, Block, & Mousa, 2012). In contrast, EPA seems to be more effective in reduction of immunity issues and may be alleviating factor in certain types of depression (Martins, 2009).

Due to the wide body of research existing regarding the benefits of n-3, its acceptance into public awareness has been rapid and pervasive with the an entire industry, the growing fish oil sector, being built on their benefits (Alexander et al., 2017). While there are now entire sections in supermarkets and pharmacies dealing in these products, additionally n-3 is one of the most accepted additives in functional or enhanced foods (Lopez-Huertas, 2010) and is often used as a quality identifier on labels. According to Basby (1997) lumpfish roe from the Danish fishery had a high level of n-3, with EPA and DHA comprising a large percentage of the fatty acids. This study looked to likewise examine the fatty acids present in lumpfish roe, to identify if this acceptance and public knowledge may be a beneficial tool to enhance the profitability of lumpfish roe.

2.2.2 Country of Origin

The MSC certification of sustainability, when active, allows the product derived from the certified fishery to display the MSC certified logo on labels and marketing materials. This means that the MSC certification is primarily an eco-label. Eco-labels when used by the government are most frequently utilized to promote the growth of environmentally friendly products, especially in sectors wherein a shift in consumer choice could potentially positively benefit environmental outcomes(Teisl, Rubin, & Noblet, 2008). Amongst product creators, it is often used as a method of separation from competition (Brécard, Hlaimi, Lucas, Perraudeau, & Salladarré, 2009). Also, according to Brécard et al. (2009), the most recognized eco-label types among seafood consumers are those which identify a product as being caught from wild stock rather than farmed, and those which designate an origin from a location with which the consumer has a positive perception.

While lumpfish farms do exist in Iceland, these fish are primarily used as an anti-mite defense by farms of other species (Eliasen, Danielsen, Johannesen, Joensen, & Patursson, 2018). The roe fishery is itself entirely from wild-caught sources. In addition, in the past decade, Iceland as a whole has seen explosive growth in terms of international recognition, with economic boosts and increasingly favorable outside perception being seen (Pálsdóttir, 2016). While this has obvious benefit to sectors such as the tourism industry, products originating from a location with a favorable association to a particular product can also see a advantage, due to a concept referred to as Country of Origin, or COO (Adina, Gabriela, & Roxana-Denisa, 2015). This is often especially true for marketing techniques which underscore the health benefits of a product or ingredient, due to an overlap of audiences concerned with health and sustainability (Dobrenova, Grabner-Kräuter, & Terlutter, 2015). While the tourism sector continues to grow, Iceland is still most associated with the fish and fishing of all sectors making this the sector which may stand to benefit most from inclusion of COO labeling strategies (Björnsson, 2015).

2.3 Fish Oil

Due to the work of Basby et al. (1997), the fatty acids (particularly total n-3, EPA, and DHA) of the lumpfish roe were chosen as the feature of analysis for this study. Fish oils, which operate as a supplementary source of these acids for many, are thus a reasonable measuring stick for determining the value of products looking to highlight them as a market separation tool.

2.3.1 History

The positive impact on human wellness of oils derived from fish, both in the dietary sense (fatty fish such as mackerel and salmon) and in isolation as a supplement, have been touted well before the scientific method was ever able to quantify them (Rice & Ismail, 2016). General knowledge, or at least perception, of the beneficial health effects of fish oil intake is noted to have occurred at latest between 700 and 1100 AD, notably among Northern European populations, especially Norwegians and later those who immigrated from Norway to Iceland (Møller & Heyerdahl, 1895). Fish oils saw more general use during the industrial revolution, wherein oils of all kind were utilized for various burgeoning industries (Møller & Heyerdahl, 1895). The first scientific inquiries into fish oil's effect on human health began as early as 1845 (Jongh, Dunglison, Carey, & Stanton A. Friedberg, 1849), but the trickle into widespread public awareness was first begun in the 1970's with a series of studies comparing the diet of Inuit populations in Greenland with those of Danes and Inuit groups in Denmark (Dyerberg, Bang, & Hjorne, 1975), (Bang, Dyerberg, & Hjøorne, 1976). These studies made the first connections between cold-water fatty fish and decreased risk of heart disease, leading to the more comprehensive research that exists today.

During this same period (c. 1960-1990) fish oil was primarily hydrogenated and used in butter-alternatives in human consumption, with fractions of the global amount being used for industry and aquaculture (Shepherd & Jackson, 2013). As aquaculture became a more accepted practice during this time, fish oils became the primary fat source for farmed fish, and is still the largest sector in terms of percentage of utilization("Fish Oil Market Size & Share | Industry Report, 2022," n.d.). However, ongoing scientific interest in human benefits also spiked rapidly, and today fish oils and its inherent compounds are one of the most published topics in scientific literature, with substantial jumps in understanding of the various functions of the most beneficial compounds, both together and in isolation, being a relatively recent development (Jump, Depner, & Tripathy, 2012). This increased focus in the scientific community bled into public knowledge, leading to surging growth in the market for n-3 products.

2.3.2 Market

The fish oil market has experienced expansive growth in recent years, especially within the direct human consumption and aquaculture markets, both of which are expected to continue based on independent industry research ("Fish Oil Market Size & Share | Industry Report, 2022," n.d.). In 2016, the value of the industry was approximately 2.2 billion USD ("Fish Oil Market, Size, Share, Growth And Forecast To 2025," n.d.), and estimates predict this to grow to 2.6 billion USD by 2020 ("Fish Oil Market By Source Species (Anchovy, Mackerel, Sardines, Cod, Herring, Menhaden), Application (Aquaculture, Salmon & Trout, Marine fish, Crustaceans, Tilapias, Eels, Cyprinids, Animal Nutrition & Pet food, Pharmaceuticals, Supplements & Functional food) - Global Opportunity Analysis and Industry Forecast, 2014 - 2020," n.d.) and 3.69 billion USD by 2025 ("Global Fish Oil Market 2018," 2018).

Key drivers in this growth are expected to be the continuing expansion of aquaculture practices, especially those in China and India, as well as the increased awareness of the benefits of n-3 intake ("Fish Oil Market Size & Share | Industry Report, 2022," n.d.). Future estimates put the expected compound annual growth rate at around 6%, with aquaculture feeds and human consumption being the largest sectors, a small but rapidly growing use in pharmaceuticals, and the smallest usage going to functional foods ("Fish Oil Market, Size, Share, Growth And Forecast To 2025," n.d.).

Krill, Phospholipids, and Bioavailability

A newer factor in the equation is the expanding krill (*Euphausia superba*) oil market, which through widespread marketing campaigns has rapidly become a part of the supplement lexicon (Kwantes & Grundmann, 2015). Built upon claims of higher bioavailability, better sustainability, and the presence of the antioxidant astaxanthin, there is thus far a relatively limited amount of research regarding the effectiveness of these products, at least in relation to general fish oil (Ramprasath, Eyal, Zchut, Shafat, & Jones, 2015). This claim of bioavailability (essentially, that the n-3's found in krill oil are in a state more readily available to the body) is largely based on the inclusion of phospholipids in krill oil products(Burri, Hoem, Banni, & Berge, 2012). However, to date, the term bioavailability is not particularly well defined by the supplements utilizing it for separation of krill oils from fish oils (Ghasemifard, Turchini, & Sinclair, 2014). Still, the goal of market separation has been largely successful, as evidenced by its evolution into a separate industry from fish oil, but one which still competes against fish oil products(Kwantes & Grundmann, 2015). Reports from as recently as 2015 have the krill oil market valued at over $200 million USD (Kwantes & Grundmann, 2015).

The notion of bioavailability is largely derived from the high phospholipid content of many krill oils (Burri et al., 2012). Phospholipids are lipid molecules which contain a glycerol backbone with two fatty acids and one phosphate group attached to it, as well as a headgroup (Ramprasath et al., 2015). In krill oil, the fatty acids attached in phospholipids are n-3's. By contrast, most traditional fish oil n-3's are bound in triglycerides, in which there are three fatty acids attached to the glycerol, and no phosphate group (Rossmeisl et al., 2012). While phospholipids play a vital role in cellular function, when ingested phospholipids assist in breaking down fats and may assist in allowing more of the lipids attached be absorbed (Bjørndal et al., 2014). In addition, the krill oils in the market today are also rich in astaxanthin, a carotenoid with claimed health benefits, and which lends a reddish hue to the oils. This also has been used as a market separator from fish oils, though numerous fish oils manufacturers are beginning to add astaxanthin to fish oil products. While krill oils are an excellent source of n-3, they are also almost exclusively collected from Antarctic waters, and are not the only source of n-3 phospholipids. A drawback that krill oils have faced is those allergic to shellfish often have negative reactions to these products, solvents such as ethanol being heavily relied on in their creation, and the removal of the bottom layer of the food web, which krill comprise a large part of in their habitat (Hallaraker, Remmereit, & Berger, 2017).

Fish roes are considered an especially dense form or phospholipids containing n-3's (Burri et al., 2012). Though it varies by species, lipids of fish roes have been rated as highly 75%

phospholipids(Bledsoe et al., 2003). Due to this, lumpfish roes were also evaluated for their phospholipid content as a part of this study, as a means to determine the viability of a marketing strategy of bioavailability via phospholipids, much like current krill oil products.

2.3.3 Processing

Traditional fish oils are typically classified as either fish body oils or fish liver oils based on the raw material utilized (Kolanowski, 2010). Currently, there are several methods in which fish oil is created and purified for human-grade products. The first and most conventional technique is based on concentration (Ciriminna, Meneguzzo, Delisi, & Pagliaro, 2017). In this method, the raw material is first cooked and then pressed, producing a mixture of oil, water, and protein. The proteins are sifted out and utilized as fishmeal, leaving an oil and water mixture (Shepherd & Jackson, 2013). The water is removed from this mixture using a centrifuge, and then undergoes neutralization (removes free fatty acids, lowers pH), bleaching (remove contaminants), winterization, and deodorization via steaming (Ciriminna et al., 2017). Generally, the fish oil using this process produces an oil which is 18% EPA and 12% DHA, and is referred to as 18/12TG, wherein the TG refers to triglycerides(Ciriminna et al., 2017).

This 18:12 ratio was once considered the standard that any fish oil product for human consumption was held to, though other classifications (60-70% n-3 total but undefined EPA or DHA) were also common (Clough, 2008). However, techniques have grown more advanced in recent years. The 18/12TG oil, as the ratio might suggest, yields only 30% n-3. When 18/12TG oil is put through a molecular distillation process, in which the n-3 are converted to ethyl esters, the resulting oil becomes 55% n-3, and today most consumer products are made using oils which are refined in this manner (Ciriminna et al., 2017). An even more recent development is the further processing of this 55% product by converting the ethyl esters to free fatty acids, which are then esterified as a triglyceride (Neubronner et al., 2011).

Krill oils are primarily extracted using solvents such as ethanol or an ethanol/acetone combination (though hexane use is growing as well,), comprised of 0.5-3.6% lipids (Xie et al., 2018). The use of these solvents has been an issue of concern amongst both environmentalists and health advocates, whom have speculated that solvent usage at an industrial level will contaminate the areas of processing, and that filtration techniques to remove solvent are insufficient to remove them totally from the final consumer product (Sun & Mao, 2016). Non-solvent methods of krill oil extraction are being developed, but are not yet the norm in the industry (Kwantes & Grundmann, 2015).

While not a common product, “roe oils,” n-3 products made from fish roe, do already exist. The MOPL™30 (Marine Omega-3 Phospholipid) process a patented method which results in a high DHA to EPA ratio product of 3:1, was designed with fish roes in mind as a raw material source (Burri et al., 2012). The process has primarily been utilized with herring roe, but any single species’ roe or roe blend , mature or otherwise, is expected to generate an acceptable roe oil albeit with variations based on the roes used (Hallaraker et al., 2017). This process primarily generates a solid polar lipid, which can then be blended with a carrier oil, which can be any ingestible oil type (fish, krill, vegetable, etc.) and very little of which is needed (Hallaraker, 2017). The resulting oils vary in terms of DHA, EPA, and total n-3, and can be used as a variety of supplements, foods, animal feeds, or drug delivery systems depending on the species input and the chosen carrier oil (Hallaraker et al, 2017).

2.4 Application Potentials

Products marketing the benefits of n-3 typically fall under the scope of nutraceutical products: foods or orally administered food-based compounds which provide a specific and targeted benefit(s) (Chauhan, Kumar, Kalam, & Ansari, 2013). Nutraceuticals as a classification often straddle the legal line between medicinal products and foodstuffs, and thus their regulation varies geographically. In the EU, governance falls primarily under the European Food and Safety Authority with the majority of regulation focusing on safety and labeling restrictions based upon proven efficacy via scientific method (Coppens, da Silva, & Pettman, 2006). In the US, products one might consider to be a nutraceutical are treated as foods, food additives, supplements, or pharmaceuticals largely depending on product specifics (Noonan & Patrick Noonan, 2006).

Nutraceuticals containing n-3 can typically be classified into two groups: supplements and functional foods (Clough, 2008). Supplements, as defined by the US National Institute of Health, are orally administered products which contain one or more dietary ingredients, for contribution of additional sources of a desired compound or to compensate for that compound’s absence in diet (“Office of Dietary Supplements - Dietary Supplement Health and Education Act of 1994," n.d.). In broadest terms, fish oils in capsules or liquid form would generally fall under this category. Conversely, functional foods are whole food items which contribute to a particular benefit generally because of a higher than normal concentration of a health-positive component, either through naturally occurring characteristics or fortification (Bech-Larsen & Scholderer, 2007). Fish oils have been utilized as additives for contribution of n-3's to other food sources, such as eggs with added DHA and EPA (Siró, Kápolna, Kápolna, & Lugasi, 2008). However, both product classifications begin with fish oils, and thus the supplement products which feature fish oil were chosen as a point of examination.

Roe as a functional food could take many forms, from the existing caviar replacement, to unflavoured nutrient dense garnish, to hydrolysed protein powders (Rajabzadeh, Pourashouri, Shabanpour, & Alishahi, 2017). These foods could be utilized by individuals seeking to add any or all of these components to their diet for the associated health benefits. As an additive this same approach can be applied, in which roe or an extracted element of roe is utilized as an ingredient/additive to foods consisting of a wider array of ingredients, such as bars, pastas, etc. which aim to bring a diverse nutritional content into a single food item (Olsen et al., 2014), and lipids from seafood in isolation have been utilized to make extruded snack foods (Dileep, 2005). Animal feeds in particular may see a rise in need of new sources of n-3, and as seen with the aquaculture industry, demand may exceed supply as aquaculture practices become more widespread (Bimbo, 2007). Determining which, if any, of these options lumpfish would be most suited to is largely dependent of the findings regarding the qualities of the lumpfish roe. While numerous nutritive qualities may be necessary considerations for several potential food products, this study primarily investigates the suitability of the roe in n-3 applications, wherein the DHA, EPA, and total n-3 would be an asset.

2.5 Research Questions, Design, and Hypotheses

This study looked to analyze whether the Icelandic lumpfish roe fishery could potentially enhance the value of the annual catch by marketing the n-3 content of the roes, and to identify market separation tactics which could benefit n-3 heavy products derived from the roe. Thus, the following questions guided the design of the study:

- Is the fatty acid profile of lumpfish roes a marketable feature?
- How do the lumpfish roe lipids and fatty acids compare with the current market landscape of fish oil supplements?
- What income or revenue streams could be generated from a lumpfish roe supplement?
- What, if any, marketing leverage can be generated from the positive qualities of the fatty acids?

To answer these, a literature regarding the past and present of roe use and the fishery, the health impacts of n-3, composition of roes and n-3 products, the market of roes and n-3 products, the value of country of origin, and alternative roe products was performed to inform the work and is presented in the literature overview.

In the study itself, lumpfish roes were analyzed for their phospholipid and fatty acid content. Data was then gathered regarding the content, composition, and pricing of best-selling fish and krill oils from the American and Icelandic markets, both online and in-person. These consisted of the 54 best-selling products in the United States, bulk fish oils produced in Iceland, consumer fish and krill oils produced in Iceland, and best-selling krill oils. Additionally, the lipids and fatty acids of the roe of other species was collected. The data from the lumpfish roe, the consumer products, and the roe from literature was then compared. Additionally, pricing data was used to generate rough estimates of potential values of the n-3 in lumpfish roe.

Based on the fatty acid analysis performed by Basby (1997) and the concept that consumer fish/krill products are specifically marketed to possess high levels of n-3 fatty acids, it was hypothesized that the n-3 levels of lumpfish roe fatty acids will be below those present in consumer products but will higher than most roe. Based again on Basby (1997) as well as additional fatty acid analyses for roe of other species, it was also thought that DHA would make up a larger proportion of the n-3 content than most consumer products, but that it would have a lower EPA content. Finally, it was hypothesized the EPA and DHA could comprise a lower proportion of total n-3 than the products, but that it would be at a comparable level to many roe types.

3 Theoretical Overview

3.1 Definitions

Caviar-marine animal eggs cured with salt and preservatives after being isolated from connective tissues; in the US only sturgeon eggs are classified as caviar (Bledsoe et al., 2003)

Lumpfish caviar- lumpfish eggs which have been cured with salt/preservatives and dyed (Johannesson, 2006)

Long Chain Omega-3 Polyunsaturated Fatty Acid (n-3 LC-PUFA, Omega-3, n-3)-subgroup of polyunsaturated fatty acids which are abundant in cold water fish and some plant types (Ghasemifard et al., 2014), and confer a variety of health benefits to humans (Alexander et al., 2017).

Eicosapentaenoic Acid (EPA, C20:5n3) and Docosahexaenoic Acid (DHA, C22:6n3)-types of n-3 fatty acids most commonly found in marine animals and which are the primary active ingredients in fish oil, offering various health benefits both together and in isolation (Mozaffarian & Wu, 2012).

Lipids: fats, biological compounds that are insoluble in water but soluble in organic solvents.

> Phospholipids: lipid molecules which contain a glycerol backbone with two fatty acids and one phosphate group attached to it, as well as a headgroup (Ramprasath et al., 2015).
>
> Triglycerides-lipid molecules in which there are three fatty acids attached to the a glycerol backbone (Rossmeisl et al., 2012).

Nutraceutical: foods or orally administered food-based compounds which provide a specific and targeted benefit(s) (Chauhan et al., 2013)

> Supplement: orally administered nutraceutical product which contain one or more dietary ingredients, for contribution of additional sources of a desired compound or to compensate for that compound's absence in diet ("Office of Dietary Supplements - Dietary Supplement Health and Education Act of 1994," n.d.).

Functional Food: whole food items which contribute to a particular benefit with elevated levels of a specific health-positive component, either through naturally occurring characteristics or fortification (Bech-Larsen & Scholderer, 2007)

Eco-label: labeling of a product to distinguish its particular sustainability, purity, environmental benefit. Often used by governments or NGO's to promote the growth of environmentally friendly products, especially in sectors wherein a shift in consumer choice could potentially positively benefit environmental outcomes(Teisl et al., 2008). They are also often used as a method of separation from competition among products (Brécard et al., 2009).

Fish Oil: a PUFA (especially n-3) rich liquid compound derived from the body or liver of fish, often ingested as a supplement capsule or directly as liquid, supplement and used as an additive in some foods (Ciriminna et al., 2017).

Krill Oil: a fish oil-like product pressed from krill rather than fish and which contains a far higher percentage of phospholipids than fish oils, as well as the antioxidant astaxanthin (Kwantes & Grundmann, 2015).

Country of Origin-the notion of a product's geographic source being a positive attribute in market separation, dependent on if the origin is strongly associated with the product in question (Adina et al., 2015).

3.2 Literature Review

3.2.1 Roe History and Processes

The broadest and most encompassing work, Bledsoe et al., (2003), articulates the various terminology and designations for products, and demonstrates the nature and trends related to their respective markets. Each species from which a roe product had been created on an industrial scale prior to the publication date is discussed, albeit briefly for most species. A rather comprehensive chemical composition section, with the ranges of various materials present being the primary focus, is an excellent tool for comparison of new or alternative roes. It is notable that lumpfish roe is not included as a part of the chemical analysis, despite its presence in other sections, such as the product descriptions and market summary. The market discussion encompasses a wide swath of the products available in varying detail, including that of lumpfish roe. While the chemical results are unlikely to be obsolete, simple population increase and evolution of markets may mean that the market data may is out of date. Primarily, Bledsoe et al. (2003) serves as the foundational status quo of the larger cumulative industry which this study is seeking to potentially influence.

In contrast to this broad overview, Johannesson (2006) is the definitive work focusing narrowly on the complete process of the history, fisheries, processing, production, and sale of lumpfish roes. This study makes lumpfish roe the central focus, rather than being only a subsection as it is in Bledsoe et. al., (2003). It concurs with the work of Bledsoe in asserting that at present the only source of revenue being derived from lumpfish roes is its contribution to caviar alternative. This work essentially captures a snapshot of the entirety of the lumpfish industry, as its name implies. The market discussion here largely establishes the same status quo as that put forward by Bledsoe et al (2003), except for its claim that Icelandic lumpfish are underfished (Johannesson, 2006). Another differing note is the presence of a discussion on potential future products, including non-salted permutations of the end-product and potential considerations for moving the roe into new markets.

A more contemporary work, by Chambers & Carothers (2017) effectively illustrates the current landscape of the place of small-boat fishing within the current quota system governing the fisheries of Iceland. Notable is the discussion of the lumpfish fishery as being outside of the Individual Transferable Quota system currently in use in Iceland, leading to its current status as typically a supplemental income for fisherman in rural communities and its intended use as a gate-of-entry to the fishing profession (Chambers & Carothers, 2017). The social importance of lumpfish is also conferred, with the fisheries non-monetary and recreational value being intrinsic to smaller communities (Chambers & Carothers, 2017). This study allows greater insight into the niche which the lumpfish fishery finds itself within the Icelandic fishing industry and focuses more on the fishermen than their products.

3.2.2 Health Impacts

The history of research and investigative study on n-3 PUFA’s is expansive and venerable. The various health effects possess fluctuating levels of study, but because of the quantity of research conducted, consensus is available in many cases. The potential benefits offered by lumpfish roe and its subsequent n-3 PUFA’s can be quantified using this existing data.

Due to the breadth of study regarding the effects of n-3 PUFA's on preventing and minimizing the risks of various maladies, the cumulative literature evaluation on the subject, Alexander et al., (2017) perhaps best exemplifies the current knowledge of one of the most publicized benefits derived from these compounds. This catalog features analyses of trials performed from 1947-2015, containing projects of differing methodologies and demographics. The review concludes that increased EPA and DHA intake may reduce risk of incidence of heart disease, with the most substantial benefits belonging to at-risk demographics (Alexander et al., 2017). Their research indicated that a strong correlation between elevated triglycerides and incidence of coronary heart disease (CHD) exists, and reduction of these levels to normal ranges is the easily achievable with DHA and EPA supplementation (Alexander et al., 2017). They did acknowledge however that no perceived changes were present in triglyceride levels of those falling into normal ranges prior to supplementation.

A study which informed Alexander et al (2017) is the work of Kris-Etherton, Harris, & Appel, (2003), which likewise found that n-3 fatty acids have a strong preventative effect against heart disease, especially in at-risk individuals. This study was also a cumulative review, examining a less extensive but broader range of randomized controlled trials as well as epidemiological studies. Rather than solely focusing on DHA and EPA, the study also included alpha-linolenic acid (ALA). While the majority of the studies they analyzed did indeed find inverse relation between n-3 PUFA intake and CHD (Kris-Etherton et al., 2013) as well as a decrease in both cardiac events and all-cause mortality for those who had suffered myocardial infarction (MI), they also found several dissenting works. In these studies, several potential variables were identified which may have caused their going against consensus, such as small population, lack of uniformity in determining intake levels, etc. (Kris-Etherton et al., 2003). It was noted even in these studies however, that the high-risk subjects identified did have reduced CHD mortality.

An outlier study included in Kris-Etherton et al. (2003), which disagreed with the consensus is Marchioli et al. (2002) in which no cardiac or fatality protection was witnessed for patients who had suffered an MI. The study's authors concluded that this result may have resulted from the use of Norwegian populations as the demographic, due to their previously existing diets already consisting of high n-3 intake, and thus receiving no additional benefits from supplementation (Marchioli et al., 2002). This would seem to align strongly with later findings of Alexander et al. (2017) in that no benefits were to be gained in elevation of DHA and EPA beyond a certain threshold.

Another cumulative discussion, the work of Wang et al. (2006) also reviewed a cumulative set of studies regarding cardiovascular disease events and risks, focusing on human trial prospective cohort (PC) studies, retrospective cohort (RC) studies and RCT's from 1966 through June 2005. The findings suggested that ingestion of long chain PUFA's from fish or fish oil led to reduced rates of general mortality events, sudden death, cardiac arrest, and stroke (Wang et. al, 2006). They further concluded that the data collected strongly suggests the existence of benefits for secondary prevention, but that the evidence and research is lacking for primary prevention (Wang et al., 2006). This concurs with both meta-data analysis referenced in the writing of Wang et al., as well as the studies of Kris -Etherton et al. (2003) and Alexander et al. (2017).

An additional literature evaluation which examined n-3 PUFA's and effect on heart disease was the work by Jump et al., (2012). This study took a slightly different tact however, in that it aimed to examine if plant-based sources could provide the same set of benefits to cardiovascular health as is provided by fish and fish oil, meaning that it examined ALA rather than DHA and EPA. It was found that the most important compound in the benefits of n-3 was DHA, in that elevated levels of DHA in blood serums and ingestion correlated to improved heart health and reduction of health events (Jump et al., 2012). This was deemed to be due to a variety of physiological processes which result in the direct circulation of DHA in blood and portioned conversion of DHA to EPA (Jump et al., 2012). Similar patterns were not seen with ingestion of ALA or EPA, and it was concluded that while EPA and ALA intake do possess benefits, such as lowering of inflammation levels in the case of EPA, the ingested compound of greatest importance to cardiovascular function was DHA (Jump et al., 2012).

The value of DHA as a compound was expanded upon beyond heart health by a study performed by Muldoon et al., (2010). This study examines the relationships of PUFA types and their role in healthy cognitive function. The study found the highest correlation of high function to presence of DHA in middle-aged adults, through testing of function of several pre-determined markers and measuring of the n-3 PUFA's present. High DHA presence in phospholipid serum was associated with elevated scores on 4 sectors of cognitive function tested (working memory, mental flexibility, reasoning, vocabulary) whereas high EPA was only associated with one sector (working memory) (Muldoon et al., 2010). High ALA was not associated with elevation of any sector (Muldoon et al., 2010).

A study preceding Muldoon et al. (2010) and Jump et al. (2012) was that performed by Horrocks & Yeo (1999), which attempted to quantify the mechanisms behind DHA in isolation and across various phases of the human lifespan through data and literature analysis. They found that while the cardiovascular benefits possessed the largest body of literature behind it, the ingestion of DHA was also a reducing factor in blood triglycerides, inflammation, thrombosis, and related maladies such as DVT, cancerous mass growth, and allergic reactions, prevention of Alzheimer's, and dementia, (Horrocks and Yeo, 1999). There was additional marked benefit to the nervous system when ingested by infants, notably leading to improved cerebral development, learning capabilities, and eyesight later in life (Horrocks and Yeo, 1999). Importantly, the benefits of DHA were most noted when in certain ratios with EPA, and then again when n-3 PUFA's were in certain ratios to n-6 PUFA's (Horrocks and Yeo, 1999).

Comparison of roes with fully processed fish oils was discussed in the work of Shirai, Higuchi, & Suzuki (2008). This study compared the effects of kazunoko (a dried herring roe product) and fish oil. While the fish oil scored better in terms of blood glucose, it was noted that they scored similarly in effect on resistin levels (Shirai et al., 2008). The herring roe oils pressed from a pre-processed ingredient in this case did not match the benefits offered by the fish oil supplement, though benefits were still present in the reduction of incidence heart disease and diabetes and related risk factors (Shirai et al., 2008).

Another study which pressed oil from herring roes, Bjørndal et al. (2014), displayed benefits to non-at-risk populations. This study was aimed at analyzing the effects of herring roe oil supplementation on adults aged 22-26 and who met certain fitness criteria (Bjørndal et al., 2014). Despite the overall health of the participants, the supplementation still showed improvements in both blood glucose tolerance and lipid profile of those tested (Bjørndal et al., 2014). This is notable in that it still concurs with previous data which showed greatest benefit to at-risk individuals, in that those findings were regarding coronary issues. This identifies a potential knowledge gap in identification of differing impacts on those with healthy blood glucose and lipids compared with more dangerous glucose levels and lipid profiles. This study possesses no control however and utilized a population which may have already exhibited a high intake of DHA and EPA.

An additional study which focused on fresh herring roe oils as a product was Moriya et al. (2007). This study made a direct comparison between roe oil extracted from herring and salmon with that of commercially available fish oils already on the market, primarily those comprised from sardine and tuna and based in triglycerides. It was found that the roe oils were more oxidatively stable and inferred that the phospholipids present were the source of this (Moriya et al., 2007). In addition, a secondary analysis was performed to determine the nutritional impact of ingestion of the roe oils. It was noted that no increase in cholesterol was observed in blood plasma of the specimens given the roe oil in relation to the fish oil, despite the roe oil possessing roughly 33% greater cholesterol by volume (Moriya et al., 2007).

3.2.3 Bioavailability and Phospholipids

A concept of interest within the studies of n-3 PUFA's is the potential greater bioavailability of n-3 PUFA's bound in phospholipids Burri et al. (2012) focuses on the various biological effects had by marine phospholipids, independent of any comparative analysis with other dissolutions. This was in response to the generation of alternative forms of PUFA, such as krill oil and fish roe oil, which are bound in phospholipids rather than triglycerides or ethyl-esters like most traditional fish oil (Burri et al., 2012). The authors fixated primarily on phospholipid-bound n-3 PUFA's, which is the suspension of PUFA's in both krill oil and fish roe oil (Burri et al., 2012). The study examines the differences in both chemical makeup and the differing paths to digestion, distribution, and absorption by the body. The study collectively compares recent studies on the issue and synthesizes them to conclude that PUFA's bound in phospholipids may possess substantial advantages when compared to that of PUFA's bound in triglycerides (Burri et al., 2012).

The work of Dyerberg, Madsen, Møller, Aardestrup, & Schmidt, (2010) was one of the informing studies for Burri et al. (2012). This work was comprised of an analysis of three n-3 suspension form concentrations (ethyl-ester, triglyceride, and free form) and then measurement against fish body oil, fish liver oil, and a placebo in an additional single-blind assessment. It was determined that of these forms, the triglycerides provided the greatest bioavailability due to superior presence of DHA and EPA in fasted states of those tested (utilizing triglycerides, cholesterol ester, and phospholipid measurements from the volunteers) (Dyerberg et al., 2010). Relevant to the comparison to other formulations is the study by Vaisman et al. (2008). This was a double-blind study comparing phospholipid-based fish oil, triglyceride-based fish oil, and a placebo to measure effects on attention markers for children with an attention disorder. The triglyceride-based oil and phospholipid-based oil groups both correlated with improvements to overall attention measurements, while the placebo did not (Vaisman et al., 2008). In addition, both oil groups performed similarly in presence of PUFA's, but only the phospholipid group showed improvements in their blood lipid profiles (Vaisman et al., 2008).

Similarly, the work of Rossmeisl et al. (2012) directly compares the effects of triglyceride-based fish oils and phospholipid-based fish oils in instances of obesity. It was found that the phospholipid-based oil was superior in maintenance of metabolic regulation, anti-inflammatory effects, and glucose tolerance (Rossmeisl et al., 2012). This will add credence to claims of bioavailability, but of additional interest in this study is that the more substantial effects were attributed not only to bioavailability but also to better cadence of white adipose tissue endocannabinoid systems (Rossmeisl et al., 2012).

The high bioavailability of phospholipids has not been limited to dietary examination however, as a non-food or nutraceutical was suggested by Li et al. (2015), which instead examined bioavailability of phospholipids but with a pharmaceutical application in mind; one in which they are proposed as an improved method of drug delivery for therapeutic compounds. Going further into additional food applications, Balaswamy, Prabhakara Rao, Narsing Rao, Rao, & Jyothirmayi (2009) speculates on new food based utility for freshwater fish roes This study used the lipid, protein, and micronutrient contents to assess feasibility of additional use. This study resulted in the creation of various roe preparations, pastas, sausages, cakes, and protein isolates for use in energy bars/crackers all derived from fish roe, often as a replacement to whey hydrolysate or eggs. Many of the products generated were not only acceptable but deemed highly palatable by testers (Balaswamy et al., 2009).

Despite these studies, bioavailability remains a topic of controversy, as the work of Ghasemifard et al. (2014) shows. This study attempted to sort through the assorted comparative studies done which measured the various forms of n-3 PUFA's for bioavailability and found that there were too few sound studies which illustrated differences in bioavailability (Ghasemifard et al., 2014). Much of this is due to the loose definition of the term, and problems in methodology which did not take considerations such as lack of dosing differences based on subject, choice of effectiveness indicator, lack of standardized protocols, etc. (Ghasemifard et al., 2014). It was determined that the cumulative knowledge that in animal trials, phospholipids were indeed absorbed far differently by the body, though not necessarily superior and human trials were not yet sufficient to make any claim on phospholipid superiority.

3.2.4 Composition

The study of perhaps greatest relevance to the project is the work of Basby (1997), a dissertation which accounts in detail the chemical makeup of lumpfish roe and suggests that the lipids of the roe are highest in both DHA and EPA, a result which earmarks it as ideal for development into a supplement or as ingestion as part of an n-3 rich diet. (Basby, 1997.) Basby also compared the fresh roe profile against the caviar and found that the salting and dyeing process did not affect the profile of the roe (Basby, 1997).

A similar processed v. unprocessed analysis was performed in Garaffo et al., (2011).This study entailed the extraction and comparative evaluation of blue fin tuna roe and its eventual salted consumer product sold under the name Bottarga and compared the n-3 PUFA content of raw roes with that of the salted and dried end product. While obviously pertaining to an entirely different species, it concurred with Basby (1997) that the salting/drying process had no measurable effect on the types or amounts of n-3 PUFA’s available (Garaffo et al., 2011).

A comparable study, Balaswamy, Rao, Rao, & Jyothirmayi (2010), took a closer look at the impact that different processing strategies had upon the makeup and composition of the roes before additional processing in the form of pickling. Comparisons were made with fresh roes, pasteurized roes, blanched roes (salted) and unsalted non-fresh roes. It was noted in sensory testing that the pasteurized product was deemed so foul as to not merit further study for use. However, the measurements of protein content were still taken, with pasteurized roe losing far more protein than the untreated and blanched roe, which scored similarly, suggesting that in addition to not affecting lipid profile as shown by Basby (1997) and Garaffo et al. (2011), salt treatment also does not influence protein content.

A study which chose to focus on salted products was the work of Shirai, Higuchi, & Suzuki (2006) which examined the Japanese roe landscape. The Asian marketplace and Asian populations in Western markets have extended use of fish roes in cuisine extending beyond caviar use (Shirai et al., 2006), and have been identified as a potential area of expansion for current lumpfish roe sales. This study focuses on the various types of salted roe found commonly throughout traditional Japanese culinary arts and compares their lipid profiles. The foods examined include Ikura, Tarako, Tobiko, and Kazunoko. The findings were widely varied across species, but all species measured possessed high levels of n-3 PUFA's and phospholipids after processing and preparation (Shirai et al, 2006).

Another species to species analysis was performed in Mol & Turan (2008), a baseline contrast of the amino acids, proteins, lipids, and micronutrients of several types of fish roes. Notable inclusion is the ratio of essential vs. non-essential amino acids in the profiles, as well as the various levels of each type of fatty acid. The study concludes that the nutritional profile of roes is substantical in contents of amino acids, proteins, and fatty acids, and bears further study for utilization as a health food, functional food, larger inclusion in overall diet, and use in supplementation (Mol and Turan, 2008).

Chemical analysis has also been utilized in generation of potential uses for roe, as discussed in a study by Rajabzadeh et al. (2017), which resulted from the generation of fish roe protein hydrolysate as a potential food additive or functional food. The resulting hydrolysate possessed a remarkable amino acid profile and a wide variety of antioxidants, with authors suggesting it may be suitable as a nutraceutical (Rajabzadeh et al., 2017).

3.2.5 Market

The starting point for any discussion regarding the current roe markets is the work of Monfort & others (2002). This study of fish roe utilization across sectors in Europe is still the definitive piece, remaining most comprehensive study focusing on the market rather than as a piece of a wider overview of either seafood or roe production. The work shows that roes are still an under-utilized commodity across much of the EU market, and possess the potential for further expansion both in geographic regions served and in new uses (Monfort et al., 2002)

Moving to the pursuit of new applications in an economically feasible manner, Watters, Edmonds, Rosner, Sloss, & Leung, (2012) provides a comparison of the various sources of DHA and EPA with a focus on increasing the number of products available to the public in order to maximize its availability. Fish oils, specifically pelagic fish oil, were found to be the most cost-effective method (Watters et al., 2012). However, improved food fortification and ingestion of seafood was also deemed an action of value (Watters et al., 2012).

Building upon this Olsen et al. (2014) details the many pitfalls that may exist in creating products from all by-products of seafood and aquaculture. The study provides an in-depth discussion of the many identified costs and existing products. The authors found that it is primarily low-cost products (i.e., selling heads of fish caught for fillets, etc.) which are most feasible due to production costs associated with high-value products (Olsen et al., 2014). Though products such as the hydrolysate created by Rajabzadeh et al. (2017) are discussed, they are largely waved as being too costly to produce. The study quantifies one exception, that of nutraceuticals with n-3 PUFA's due to the high demand, low production cost and elevated cost at consumer level (Olsen et al., 2014).

This concept is explored further in Clough (2008), which examines the various marketing strategies employed by n-3 products and vehicles (foods) across geographic regions. The study examines media reports which are communicated to large populations and which cite peer-reviewed studies, but which are not peer-reviewed publications themselves. This was done in order to understand the state of public knowledge regarding n-3 products in order to predict success of various n-3 products. Of note is the discussion of the n-3 market, which even in 2008 was rated as a rapidly expanding global industry worth approximately $700 million USD (Clough, 2008). Clough notes that a product's success was not dependent on the nutritive source, but rather its ability to meet the often-rigorous quality standards across various government mandates (Clough, 2008). It was noted that several categories exist, which subdivide products based on EPA to DHA ratio, and that products typically either are marketed directly to consumers as functional foods/supplements or to other businesses which use them as an ingredient in multi-sourced end products (Clough, 2008).

In terms of functional foods, a great deal of research has been performed on the trends of consumer habits and opinions. In Kaur & Singh (2017), the authors found through close examination of the cumulative literature that consumer purchases for several decades have been trending toward products which offered health benefits, and often the single most important factor in a functional food's success was the awareness of the perceived benefit of the food/nutritive quality in of the material in question (Kaur & Singh, 2017). It was found that among functional foods and ingredients, the n-3 fatty acids possessed among the most widespread consumer awareness and acceptance, though its addition as an additive was perceived as a promotional ploy (Kaur & Singh, 2017). Sensory markers were important for repeat buyers, and non-sensory markers such as quality and brand led to higher trust and price commitment (Kaur & Singh, 2017).

A study which similarly compared research on consumer data was the work of Siró et al. (2008) which found that consumer tendency to purchase based on health benefit rather than satiation and sensory perception was an escalating trend which provides opportunity for new functional food products. It was noted that the factor of greatest importance was consumer knowledge of functional benefits of the additive or food (Siró et al, 2008). Beyond this, the "carrier" food, the product in which the additive is included, also influenced consumer acceptance. However, it was also seen that in some cases functional advertising adversely affected a product's sales capability (Siró et al, 2008), especially in products deemed more frivolous (candy, etc.) (Siró et al, 2008).

A study which focused in particular on the European market for functional foods is Bech-Larsen & Scholderer (2007). The study discusses the various issues legally which can occur for companies wishing to market a functional food in the EU, especially in comparison to other major markets. This is largely due to restriction of product labeling to benefits which are proven via scientific method and omitting holistic claims and general wellness (Bech-Larsen and Scholderer, 2007). The research into successful and failing products found that the most vital marker for success was the creation of products of elevated quality, though some high-quality products failed due to lack of distribution and/or poor packaging (Bech-Larsen and Scholderer, 2007). The study also found that consumers generally responded best to products with most holistic appeal, and that products which had a highly specific function often failed, speculating that insufficient personal knowledge may have factored into this (Bech-Larsen and Scholderer, 2007).

3.2.6 Country of Origin

In discussion of any product originating in Iceland and considering export, it is prudent to discuss the national “branding” as this may provide an inherent advantage. The concept of country of origin, or COO, has long been discussed in terms of marketing utility (Björnsson, 2015). The concept and markers of the strength of a national brand are discussed at length in Fetscherin, (2010). In this analysis, it was found that the perception of several purpose-based tools which measured strength of national brand were based on subjective evidence alone. The study designed a tool which used data analysis instead. The creation of this tool led to some differences in rankings in that the use of the data rather than subjective input led to differences in the actuality of numbers vs the perceived reality of subjective analysis, though it is acknowledged that in the case of branding the perception is more important than the reality. Some markers for a country’s strength of brand were in its export agencies and tying of product to homeland, prevalence of tourism, and governmental climate (Fetscherin, 2010). It was also found that a country’s level of development was a key correlation to a positively perceived COO (Fetscherin, 2010.)

The concept of COO usage in marketing is a well-known one, as demonstrated in Verlegh & Steenkamp (1999). This study effectively outlines the cumulative history of the research prior to more contemporary findings. This review found that COO was a cue for quality for most consumers but not a key for choosing to purchase or not (Verlegh & Steenkamp, 1999). They found that COO was rather a more effective gauge in selection amongst products, and interestingly that industrial scale buyers behaved similarly to those at the consumer level (Verlegh & Steenkamp, 1999).

A study which sought to connect brand names to country of origin is Adina et al. (2015). It was examined how COO plays a role in product development and niche location and found that COO was often a vital tool for new products from new companies whom do not yet have a foothold in the market to ensure conveyance of quality to the consumer (Adina et al., 2015). The various and interwoven cognitive mechanisms which are influenced by COO are discussed, with a summation that a brand or products’ ties back to a country which have a strong link to the product, overall good perception internationally, ability to appeal to lifestyle choices (such as “clean, green” etc.) or high likelihood of connecting to a consumer’s personal experience, stand to benefit greatly from inclusion of a COO as a marketing tool.

A more in-depth study of the impact of COO on foods was performed in Dobrenova et al., (2015). This research found that if the product was linked to a geographic location, then a COO in that location was a marketable feature (Dobrenova et al., 2015). It was found that this was likely a mitigating factor of consumer doubt, which may be more ubiquitous in health food products due to the prevalence of greater buyer discretion (Dobrenova et al., 2015). Like other studies however, it was still found that products were more successful based on consumer knowledge of functional benefits and benefits derived from COO were dependent on this factor having already been satisfied (Dobrenova et al., 2015). The work of Costa, Carneiro, & Goldszmidt, (2016) similarly found that COO was a buying factor only when things such as quality and product effect were already trusted. This study agreed with Verlegh and Steenkamp (1999) that while not influencing whether to purchase a product type, it may be a factor in decisions between products of a similar classification (Costa et al., 2016).

Another study which examined the effect of COO on buying tendency was Loureiro & Umberger, (2007). It was found that the COO was only a beneficial inclusion for a product if the country was associated with the product and known for quality (Loureiro & Umberger, 2015). While this study dealt with beef sold in the US, it was still notable that product COO and traceability were considered important factors in determining premium level quality among buyers seeking it (Loureiro & Umberger, 2015).

Speaking on Iceland’s national brand, Pálsdóttir, (2016) provides narrative discussion of the events which led to the formation of the current state of Iceland as a brand, and what continues to impact marketing efforts. The history of the nation’s international appeal, especially in the past decade, is discussed at length, as is the vision for the future. It is argued that while nature is the main draw, a shift to the appeal of the country should be undertaken so that the culture, economy, and people are themselves an equal share of the brand (Pálsdottir, 2016). While the tourism sector has boomed, all sectors are inexorably linked and may build upon this growth (Pálsdottir, 2016). It is argued that the food and creative industries possess possibly the highest potential of capitalizing on the brand success, and expanding upon it (Pálsdottir, 2016).

3.2.7 Alternative Roe Products

Caviar and caviar products remain the dominant use of most fish roe products presently available today. Though alternative uses and preparations have been and are being investigated, the breadth of published peer-reviewed material regarding this subject is limited. Due to this, some repetition of sources was necessary in order to demonstrate the current status of roe use investigation.

Early discussions of new applications are seen in Bledsoe et al. (2003), wherein Bledsoe discusses several alternative processing methodologies which had met with success or at least acceptance. Most notable is the examination of roe processing differences occurring in Japan, where there has been a movement towards minimally processed and non-treated salmon roe products which are only flavored and/or marinated (Bledsoe et. al., 2003). These products fall outside of traditional classifications amongst the Japanese culinary field (sujiko, ikura) but have become an additional possible ingredient in many dishes (Bledsoe et al., 2003). Common preparations include brief soaking of the roes in soy sauce, wine vinegar, sugars, spices, garlic, or some combination of these (Bledsoe et al., 2003).

An investigation into additional applications outside of caviars was performed in Balaswamy et al. (2009). In this study, fish roe of rohu (*Labeo rohita*) was used in replacement of chicken eggs as an ingredient in cakes and pastas and measured against a control group of traditionally prepared products (Balaswamy et al., 2009). The roe-based foods performed well in sensory testing though a fishy odor was found to remain in pastas, which was deemed likely due to PUFA content (Balaswamy et al., 2009). It was also noted that the products had a large (12-16%) increase in protein content compared to the control group (Balaswamy et al., 2009).

An extension of this study was performed in the connected work, Balaswamy et al. (2010). In this work, pickling of roes was assessed for viability as a food product. Roes were both blanched and pasteurized to determine which was most suitable for pickling, but the pasteurized product was deemed too unpleasant in terms of sensory testing to merit use (Balaswamy et al., 2010). However, the blanched roes yielded a pickled roe which rated well among sensory testers and was found to be stable and safe for long term storage (Balaswamy et al., 2010). Previous tests, including long term freezing of fresh roes, and creation of ready-to-eat roe cutlets are also discussed, as are Indian culinary traditions with roe-based foods, such as deep-frying of fresh roes (Balaswamy et al., 2010).

A final set of potential applications is found in Rajabzadeh et al. (2017). This work identified roe as an excellent source for protein due to the high protein content and an excellent amino acid profile (Rajabzadeh et al., 2017). As a part of this study, it was also determined that the roe hydrolysates resulting from the study had emulsifying properties and antioxidant activity (Rajabzadeh et al., 2017). It was deemed feasible that hydrolysates and emulsions from roes were suitable as food additives and emulsifiers, among other applications (Rajabzadeh et al., 2017).

4 Methodology

4.1 Fatty Acid Analysis

Two lumpfish roe samples were landed in Raufarhöfn, (roughly 250 km Northeast of Akureyri on May 29thf 2017. The roe was washed thoroughly and then packed and frozen. The roe was stored at the University of Akureyri until October. In October, the roe was transferred to BioPol ehf. in Skagaströnd, Iceland, where it was frozen until October. Fat extraction was performed via Bligh and Dyer (1959) methodology at Biopol ehf. by Karin Zech, noting analysis such as moisture content and total lipids via wet row, and lipid classification. Of these analyses, only total lipids were used in this study. For the fat extraction, the roe was homogenized in a blender along with a chloroform and methanol, in a 1:1:2 ratio for two minutes (Bligh & Dyer, 1959). Next, an additional 1-part of chloroform and blended again for another 30 seconds, followed by 1-part distilled water and blended again for 30 seconds. The mixture was then filtered through filtration paper and a Buchner funnel. After filtration, the mixture was placed in a graduated cylinder and allowed to separate. Volume of the chloroform layer was noted, the alcohol layer was allowed to aspire, and a small amount of the chloroform layer was removed to ensure the total removal of the alcohol layer, leaving the chloroform layer which contains the isolated lipid. Lipid content was determined by portioned evaporation via nitrogen stream, and the resulting lipid residue was weighed. The residue was then dried over phosphoric anhydride in a vacuum desiccator and the weight of the dried residue was determined. Chloroform was added to detect insoluble material (non-lipids). The dry weight of the residue was then subtracted from the total starting weight (Bligh & Dyer, 1959).

The same amples were sent to Matís ohf. in Reykjavik, Iceland for fatty acid analysis. At Matís, two samples were analyzed via gas chromatography as percentage of fatty acid methyl esters (FAME) on November 10, 2017 and a fatty acid analysis was returned to Biopol ehf. electronically. According to Ingibjörg Rósa Þorvaldsdóttir of Matís, this was performed with the following methods:

> Separation of FAME on a Varian 3900 gas chromatographer with a fused silica capillary column, split injector split injector and flame ionisation detector fitted with Galaxie Chromatography Data System, Version 1.9.3.2 software. The oven is programmed as follows: 100°C for 4 min, then raised to 240°C at 3°C/min and held

at this temperature for 15 min. Injector and detector temperature are 225°C and 285°C, respectively. Helium is used as a carrier gas at the column flow 0.8 mL/min; split ratio, 200:1. The programme is based on AOAC 996.06. (Þorvaldsdóttir, 2018).

In addition to these tests, the phospholipid (phosphatidylcholine) content was determined using spectrophotometric method, as a direct estimation of phospholipids (Stewart, 1980). The results provided by Matís included:

- Saturated Fatty Acid% (SFA)
- Monounsaturated Fatty Acid% (MUFA)
- Trans Fatty Acids% (TFA)
- Unknown/Unidentifiable %
- Polyunsaturated Fatty Acids % (PUFA)
- EPA%
- DHA%
- EPA+DHA%
- n-3 %
- Phospholipid%
- Percentages for all additional individual fatty acids

These figures were set as a percentage of fatty acid methyl esters (FAME). These were the basis for calculation of additional data performed by the author, as seen in Table 1, in order to compare the lumpfish roe fatty acids with other products/other roes in later sections.

Table 1: Data which were calculated from the fatty acid analysis profile provided by Matís.

Lumpfish Roe Fatty Acid Calculations	
Data	**Formula**
n-3% of PUFA	n-3% / PUFA%
EPA% of PUFA	EPA% / PUFA%
EPA% of n-3	EPA% / n-3%
DHA% of PUFA	DHA% / PUFA%
DHA% of n-3	DHA% / Omega-3%
EPA+DHA% of PUFA	EPA+DHA% / PUFA%
EPA+DHA% n-3	EPA+DHA% / n-3%
DHA to EPA%	DHA% / EPA%

The data from Table 1 which were used in comparison in later sections varied based on the available data for each section, but all subsequent comparisons were limited to those which were expressed in percentage (%) due to the lack of total amounts in mg or g in the Matís data set.

4.1.1 Catch Totals of Fatty Acids and Potential Valuations

Rough catch data calculations were performed by the author to determine the total amounts of n-3, EPA, and DHA in the annual roe catch in Iceland. The percentage of female bodyweight taken up by roe was gathered from Basby (1997) and confirmed internally within BioPol in unpublished data (“Biopol,” n.d.). The total lipids determined via Bligh and Dyer (59) was utilized with catch data, as well as the catch data from Hafrannsóknastofnun between 2008 and 2016 to calculate the data below in table 2:

Table 2: Calculations made for annual catch minimums and maximums of fatty acids if FAME are assumed as equal to Total Lipids.

Fatty Acid Annual Catch Totals (Assuming FAME=Total Lipids)	
Data	**Formula**
Roe lipid % of catch (minimum)	Roe % bodyweight (minimum)*total lipid %
Roe lipid % of catch (maximum)	Roe % bodyweight (maximum)*total lipid %
Roe lipid totals in catch (min)	Roe Lipid % of Catch (min) * minimum total catch
Roe Lipid Totals in Catch (max)	Roe Lipid % of Catch (max) * maximum total catch
EPA	
n-3 catch (min)	Roe lipid totals in catch (min)*n-3%
n-3 catch (max)	Roe lipid totals in catch (max)*n-3%
EPA catch (min)	Roe lipid totals in catch (min)*EPA%
EPA catch (max)	Roe lipid totals in catch (max)*EPA%
DHA catch (min)	Roe lipid totals in catch (min)*DHA%
DHA catch (max)	Roe lipid totals in catch (max)*DHA%
EPA+DHA catch (min)	EPA catch (min) + DHA catch (min)
EPA+DHA catch (max)	EPA catch (max) + DHA catch (max)

These findings are presented as ranges for ease of interpretation and it is acknowledged that FAME is likely not 100% of total lipids. These tonnage numbers were combined with pricing data from later sections to later determine proximate possible values for the for the available market. These catch totals were multiplied by the average price per gram of n-3 and price per gram of EPA+DHA of the consumer products (US best-selling fish oils, Icelandic consumer fish oils, and best-selling krill oils) determined in later sections to determine proximate value potential for the lumpfish roe n-3.

4.2 Analysis of US Best Selling Fish Oils

Full and detailed data on the 54 best-selling fish oil products in the US was accessed via labdoor.com. Each of the 54 product tests was individually accessed and the relevant data was extracted and accumulated by the author. The data itself was generated by Labdoor, Inc., an independent consumer quality assurance entity which accepts no funding from any manufacturers. Labdoor bought each of the products listed and sent them to laboratories recognized by the Federal Department of Agriculture for independent testing. The test series which resulted is openly available to the public in more specificity than commonly available via nutrition labels. The data cache provided detailed and extensive product information that is used here by express permission of Labdoor, Inc. The data cache was accessed mid-December 2017 and included:

- Serving size
- Price (USD)
- Total n-3
- EPA mg per serving
- DHA mg per serving
- EPA + DHA % (omitted for some, calculated if needed)
- n-3% (omitted for some, calculated if needed)
- Mercury parts per billion
- Capsules per container
- Servings per purchase

Using the above figures, additional figures were calculated by the author using simple formulas, depicted in Table 3. These data were chosen based on their ability to be generated given the figures provided, their potential usefulness in determining the relative content of the n-3, DHA, and EPA of each product, and in determining the pricing for the relative amounts of these compounds.

Table 3: Data which were calculated using Labdoor, Inc independent lab tests ("Top 10 Fish Oil Supplements," n.d.) for best-selling fish oils.

Calculations for US Best Selling Fish Oil Comparison	
Data	**Formula**
Serving (g)	100*(n-3mg/n-3%)
EPA+DHA% of O-3	EPA+DHA% / n-3%
EPA + DHA mg	DHA mg + EPA mg
EPA % of n-3	EPA% / n-3 %
EPA % of total	EPA mg / Serving mg
DHA % of n-3	DHA% / n-3%
DHA % of total	DHA mg / Serving mg
DHA to EPA %	DHA mg / EPA mg
Cost per Serving	Price / Servings per purchase
Price per g n-3	1000*(Price/((Capsules/Serving Size)*n-3 mg))
Price per g EPA + DHA	1000*(Price/ ((Capsules/Serving Size)*EPA+DHA mg))

The data provided by Labdoor and the data calculated were both used in comparison to the fatty acid profile of the lumpfish roe. Due to the sum of the lumpfish data being in percentage (%) of the fatty acid methyl esters, only percentages were directly compared. For the following data, medians and averages were calculated for the 54 products, and then compared in-turn with the same data for the lumpfish roes:

- n 3%
- EPA + DHA %
- EPA + DHA % of n-3
- EPA% of n-3
- EPA% of total
- DHA% of n-3
- DHA% of total
- DHA to EPA %

In data that were not directly provided by Matís for the lumpfish roe, they were calculated by the author using the same formulas as defined in Tables 1 and 3.

4.3 Icelandic Bulk Items

Creators of fish oils based in Iceland were identified via domestic availability in grocery stores, pharmacies, .is webstores, and online availability. Of these entities, those that produced items for bulk wholesale to other companies were identified using listings on each company homepage. Only two brand entities were able to be confirmed to be creating and selling bulk fish oil products in this way, Lýsi ("Bulk Products - LYSI Iceland," n.d.) and Margildi ("margildi – Refined fish oils with high stearin content," n.d.). Data were provided on each bulk oil but these were less detailed than those on end products for direct consumer sale. In total, 10 bulk sale oil types were noted, and the data provided by the company creating the oil were recorded. These included:

- Minimum PUFA%
- Minimum EPA%
- EPA mg per g of oil (provided for only 2 products, calculated for others)
- Minimum DHA %
- DHA mg per g of oil (provided for only 2 products, calculated for others)
- n-3% (Only provided for 4 products)
- n-3 mg per g of oil (Only provided for 1 product, calculated for 3 additional which had provided n-3%)

Using the above figures, additional data were calculated by the author using simple formulas, depicted in Table 4. These data points were chosen based on their ability to be generated given the figures provided, their potential usefulness in determining the relative content of the n-3, DHA, and EPA of each product, and in determining the pricing for the relative amounts of these compounds. It was noted that several products provided only a minimum for values of EPA and DHA percentages, but the minimum was the only available data. These minimums were also used alongside products which provided definitive percentages in order to keep the data comparable. In addition, EPA mg per g (mg/g) of oil, DHA mg/g, and n-3 mg/g were determined via conversion of the percentage of each fatty acid to mg for the products that did not provide this information directly. It was noted that for the products which did provide those figures initially, the amounts they presented were less mg/g than the minimum average would imply via conversion, but the direct conversion rate was maintained for the other products due to lack of standardization of the variance between the minimum percentage and the mg/g content. Finally, since n-3 as a whole was only an available figure for 4 products, calculations requiring an n-3 input were also limited to 4 products.

Table 4: Data which were calculated for all domestic bulk products featured.

Calculations for Icelandic Bulk Fish Oil Comparison	
Data	**Formula**
n-3 mg/g	10(n-3%)
EPA+DHA mg/g	EPA mg/g + DHA mg/g
EPA+DHA%	EPA% + DHA% /
EPA+DHA% of n-3	EPA% + DHA% / n-3%
EPA mg/g	10(EPA%)
EPA % of n-3	EPA% / n-3 %
DHA mg/g	10(DHA%)
DHA % of n-3	DHA%/n-3%

The data provided by the websites and the data calculated were both used in comparison to the fatty acid profile of the lumpfish roe. Due to the sum of the lumpfish data being in percentage (%) of fatty acid methyl esters, only percentages were directly compared. For the following data, averages were calculated for the 10 products, and then compared in-turn with the same data for the lumpfish roes:

- n-3%
- EPA+DHA%
- EPA+DHA% of n-3

- DHA to EPA % (calculations also done sans one outlier)
- EPA%
- EPA% of n-3
- DHA%
- DHA% of n-3

In data that were not directly provided by Matís for the lumpfish roes, they were calculated by the author using the same formulas as defined in Tables 1 and 4.

4.4 Icelandic Brands

Domestic brands producing fish oil products were identified during the same identification of bulk products made in Iceland. Companies were found via grocery stores, pharmacies, .is webstores, and online availability. Much like other lists, this was not meant as an exhaustive categorization of products, but as a snapshot of popular on-shelf commodities. Because no best sellers list was available as it was in other sections, all brands which could be traced to being based in Iceland in this method were used, and their full product lines included. It is possible that other brands exist, but they were not readily discoverable using the methods available to the average online shopper. Product labels were the basis for the data provided and were observed either in person or online using packaging images. In person observation was performed at grocery stores and pharmacies in Sauðarkrókur, Blönduós, and Skagaströnd in December 2017.

Due to some variance in the detail provided amongst the products, a small number of products which provided more extensive figures were separated to allow more detailed comparison in isolation against the lumpfish roes. However, these products were also included in the analysis of products which provided more simple figures, with their comparable data being utilized. Thus, those products which appear in the detailed label analysis also appear in the simple label analysis.

4.4.1 Simple Labels

Data of a total of 22 products were collected, and figures recorded were on a per serving basis. The labels directly gave the following data:

- n-3 mg
- EPA mg

- DHA mg
- Price
- Capsules per purchase
- Serving Size
- Servings per purchase

Using the above data, additional data were calculated by the author using simple formulas, depicted in Table 5. These data were chosen based on their ability to be generated given the figures provided above, their potential usefulness in determining the relative content of the n-3, DHA, and EPA of each product, and in determining the pricing for the relative amounts of these compounds.

Table 5: Data which were calculated for all domestic products featured.

Calculations for Icelandic Fish Oil Consumer Product Comparison (Simple Labels)	
Data	**Formula**
EPA % of n-3	EPA mg / n-3 mg
DHA % of n-3	DHA mg /n-3 mg
EPA + DHA mg	DHA mg + EPA mg
EPA + DHA % n-3	EPA + DHA mg / n-3 mg
DHA to EPA %	DHA mg / EPA mg
Price per Serving	Price / # of servings per package
Price per g n-3	1000*(Price/((Capsules/Serving-Size)*n-3 mg))
Price per g DHA + EPA	1000*(Price/((Capsules/Serving Size)*EPA+DHA mg))

The data provided by product labels and the data calculated were both used in comparison to the fatty acid profile of the lumpfish roe. Due to the sum of the lumpfish data being in percentage (%) of fatty acid methyl esters, only percentages were directly compared. For the following data, medians and averages were calculated for the 22 products, and then compared in-turn with the same data for the lumpfish roes:

- EPA % of n-3
- DHA % of n-3
- EPA+DHA % of n-3
- DHA to EPA %

In data that were not directly provided by Matís for the lumpfish roes, they were calculated by the author using the same formulas as defined in Tables 1 and 5.

4.4.2 Detailed Labels

Of the 22 products identified from Icelandic brands, 7 provided greater detail regarding content than commonly provided. It is noted that all but 2 of these seven products were in liquid form, alluding to a possibility of differing regulatory protocols in content reports than those governing the more typical capsule-based products. These 7 products were still analyzed as a part of the analysis of simple labels but were also isolated for their own comparison against the lumpfish roes. It is also noted that these more detailed products belonged to only two brands, namely Lýsi and Dropi.

The following data were provided either by labels or via online product information:

- Ml per container (if applicable, liquid products only)
- G per container (if applicable, liquid products only)
- Ml per serving (if applicable, liquid products only)
- MUFA g per serving
- PUFA g per serving
- n-3 g per serving
- EPA g per serving
- DHA g per serving

Using the above data, additional data were calculated by the author using simple formulas, depicted in Table 6. These data were chosen based on their ability to be generated given the figures provided above, their potential usefulness in determining the relative content of the n-3, DHA, and EPA of each product, and in determining the pricing for the relative amounts of these compounds. Due to many of the products being liquid, additional calculations were necessary to derive any meaningful numbers. This was due to servings being denoted in ml while compounds were described in g. Thus, conversion factors were needed to obtain percentages of the compounds. Due to these products also being included in the simple labels comparison, pricing data was not calculated. Several data which were calculated due to their use for generating additional data are not discussed in analysis due to their already being a part of the simple labels data, which contained a wider field. Likewise, those which are merely conversion factors, such as the EPA g per serving figure, is not analyzed beyond its use for generation of additional formulas due to the analysis of EPA mg per serving in the simple labels.

Table 6: Data which were calculated for domestic products which included more detailed product information.

Calculations for Icelandic Fish Oil Consumer Product Comparison (Detailed Labels)	
Data	**Formula**
Volume to weight conversion rate (v/w)	Ml per container / g per container
Serving in g	Serving ml*v/w
EPA + DHA mg	DHA mg + EPA mg
MUFA % of total	MUFA g / Serving g
PUFA %n of total	PUFA g / Serving g
n-3 % of PUFA	n-3 g / PUFA g
n-3 % of total	n-3 g / Serving g
EPA % of PUFA	EPA g / PUFA g
EPA% of n-3	EPA g / n-3 g
EPA % of total	EPA g / Serving g
DHA % of PUFA	DHA g / PUFA g
DHA % of n-3	DHA g / n-3 g
DHA % of total	DHA g / Serving g
EPA+DHA g per Serving	EPA g + DHA g
EPA+DHA % of PUFA	(EPA+DHA g) / (PUFA g)
EPA+DHA % of total	(EPA+DHA g) / (Serving g)
EPA+DHA % of n-3	(EPA+DHA g) / (n-3 g)
DHA to EPA	DHA g / EPA g

The data provided by product labels and the figures calculated were both used in comparison to the fatty acid profile of the lumpfish roe. Due to the sum of the lumpfish data being in percentage (%) of fatty acid methyl esters, only percentages were directly compared. For the following data, medians and averages were calculated for the 7 products, and then compared in-turn with the same data for the lumpfish roes:

- MUFA %
- PUFA%
- n-3 % of PUFA
- EPA % of PUFA
- EPA % of n-3
- EPA % of total
- DHA % of PUFA
- DHA % of n-3
- DHA % of total
- EPA+DHA % of PUFA
- EPA+DHA % of n-3
- EPA+DHA % of total
- DHA to EPA

In data that were not directly provided by Matís for the lumpfish roes, they were calculated by the author using the same formulas as defined in Tables 1 and 6.

4.5 Krill Oils

Comparison to best-sellers in the emerging krill oil market was also performed, due to its potential greater relevance to any roe-derived n-3 oils due to phospholipid content. Products were identified using amazon.com (USA site) ("Amazon Best Sellers: Best Krill Oil Nutritional Supplements," n.d.), specifically the best seller function. This function updates hourly to show the 20 products selling most frequently. The function was utilized 3 times, with each being 72 hours apart during early January of 2018. All products which appeared on the list once or more were included. Repeated products, such as different serving counts of the same product, were not included, with a total of 5 such products being omitted. A total of 17 unique products were featured over the span of the 3 uses of the best seller function. The pricing data utilized was the cheapest option available for a one-time purchase, e.g., not the discounted monthly subscription rate. Due to standardization of imagery on Amazon, label information on product packaging was utilized for much of the data collection. Some additional figures were also gathered from infographics provided for certain products.

The following data were gathered directly from product labels or by supplemental material provided in product information:

- Krill oil mg per serving
- n-3 mg per serving
- EPA mg per serving
- DHA mg per serving
- Phospholipid mg per serving
- Price
- Capsules per purchase
- Serving size
- Servings per purchase

Using the above data, additional data were calculated by the author using simple formulas, depicted in Table 7. These data were chosen based on their ability to be generated given the figures provided above, their potential usefulness in determining the relative content of the n-3, DHA, and EPA of each product, and in determining the pricing for the relative amounts of these compounds.

Table 7: Data which were calculated using product labels for best-selling krill oils.

Calculations for Krill Oil Product Comparisons	
Data	**Formula**
n-3% of total	n-3 mg / Krill oil mg
EPA% of n-3	EPA mg / n-3 mg
EPA % of total	EPA mg / Krill oil mg
DHA % of n-3	DHA mg / n-3 mg
DHA % of total	DHA mg/ Krill oil mg
EPA+DHA mg	DHA mg + EPA mg
EPA+DHA % of n-3	(DHA+EPA mg) / (n-3 mg)
EPA+DHA% of total	(DHA+EPA mg) / (Krill oil mg)
DHA to EPA%	DHA mg / EPA mg
Phospholipid % total	Phospholipid mg / krill oil mg
Price per Serving	Price / Servings per purchase
Price per g of n-3	1000*(Price/((Capsules/Serving Size)*n-3 mg))
Price per g EPA+DHA	1000*(Price/((Capsules/Serving Size)*EPA+DHA mg))

The data provided by product labels and the figures calculated were both used in comparison to the fatty acid profile of the lumpfish roe. Due to the sum of the lumpfish data being in percentage (%) of fatty acid methyl esters, only percentages were directly compared. For the following data, medians and averages were calculated for the 18 products, and then compared in-turn with the same data for the lumpfish roes:

- n-3 %
- EPA% of n-3
- EPA% of total
- DHA% of n-3
- DHA% of total
- EPA+DHA% of n-3
- EPA+DHA% of total
- DHA to EPA%

In data that were not directly provided by Matís for the lumpfish roes, they were calculated by the author using the same formulas as defined in Tables 1 and 7.

4.6 Literature Comparisons

In addition to comparison with shelf-ready consumer products, lipid profiles for the roes and roe products of additional species was also gathered from literature for comparison to lumpfish roes. This was done to attempt to quantify any exceptional qualities the lumpfish roes may possess and develop a better understanding of the lipid tendencies in roes across the species spectrum. Studies which isolated the lipid profile of fish roes, caviars, or similar products were identified from October 2017 through January of 2018, and publications which utilized gas-liquid chromatography were prioritized for standardization of results, though it is acknowledged that this method can be variable. In all, 6 publications were utilized, and 5 of these provided data similar enough for group consideration.

4.6.1 n-3 and Phospholipids

One of the six publications utilized, Bledsoe et al. (2003), applied an amalgamation of various other lipid profile reports and standardized the results for simplicity of interpretation. Bledsoe isolated and compared the percentages for n-3 fatty acids, phospholipids, cholesterol, triglycerides, free fatty acids, and n-6 fatty acids, amongst others.

n-3 fatty acids and phospholipids were the data for focus of comparison with lumpfish roes. 25 roe/caviar types were compared in the analysis, with 23 separate species. One species was represented twice due to inclusion of both farmed and wild specimens. Of the 24 types, 20 reported values for n-3 percentage of fatty acid methyl esters, and 20 reported a percentage of phospholipids. Of those, 4 n-3 percentages and 15 phospholipid percentages were reported as a range rather than definitive value. Averages of those ranges were utilized in order to be included with the other types in analysis. An average and median were then determined for the n-3 % and phospholipid % and compared with that of the lumpfish roes. Due to n-3 percentage being a category of comparison for the remaining publications, the values for this were included in analysis against standardized literature to broaden the field. Phospholipid percentage is also included with the rest of the figures, but it is acknowledged that these are numbers solely from Bledsoe et al. (2003). In addition to n-3 percentage and phospholipid percentage, triglyceride percentage was similarly noted, but no test for determining this for lumpfish was performed.

4.6.2 Standardized Literature

The remaining 5 publications reported the lipid profiles of various types of fish roes and fish roe products in comparable data. Studies which were used included (Mol & Turan, 2008), (Shirai et al., 2006), (Saliu, Leoni, & Della Pergola, 2017), (Intarasirisawat, Benjakul, &

Visessanguan, 2011), and (Czesny, Dabrowski, Christensen, Van Eenennaam, & Doroshov, 2000). These studies used gas liquid chromatography to extract and determine the lipid profiles of 18 roe and roe products. Of these 18, 3 were representative of various lifestyle statuses (e.g., farmed, wild, domestic) from a single species, meaning 15 species were represented. One study, Saliu et al (2017), presented 4 samples of the same roes, and the averages of the four sample results were used for that study. 4 of the 5 studies expressed the fatty acids as percentage of fatty acid methyl esters, while one (Shirai et al, 2004) expressed as percentage of total lipids. data which were presented in the studies were comparable, with one deviation existing wherein Mol And Turan (2008) did not disclose EPA content. The following data were gathered via direct reporting in the publications, most often in tables but occasionally in textual description:

- PUFA% of total
- n-3% of total
- EPA% of total
- DHA% of total
- Phospholipid %

Using the above data, additional data were calculated by the author using simple formulas, as shown in Table 8. These data were chosen based on their ability to be generated given the figures provided above, their potential usefulness in determining the relative content of the n-3, DHA, and EPA of each roe type, and in determining where lumpfish roe fits in the spectrum of existing roe fatty acids for these compounds.

Table 8: Calculations made using data from similar lipid tests from literature.

Calculations for Comparison of Roe by Species	
Data	**Formula**
n-3% of PUFA	n-3 % / PUFA %
EPA% of PUFA	EPA % / PUFA%
EPA % of n-3	EPA % / n-3%
DHA % of PUFA	DHA %/ PUFA%
DHA % n-3	DHA % / n-3 %
EPA+DHA% of total	EPA% + DHA% of total
EPA+DHA % of PUFA	EPA+DHA% / PUFA%
EPA+DHA % of n-3	EPA+DH % / n-3 %
DHA to EPA%	DHA % / EPA %

The data provided by the literature and the figures calculated were both used in comparison to the fatty acid profile of the lumpfish roe. All figures, both pulled directly and calculated, were in percentage (%) so data was directly comparable. For the following data, medians and averages were calculated for the 18 roes/roe products, and then compared in-turn with the same data for the lumpfish roes:

- PUFA%
- n-3%
- n-3% of PUFA
- EPA% of total
- EPA% of PUFA
- EPA% of n-3
- DHA% of total
- DHA% of PUFA
- DHA% of n-3
- EPA+DHA% of total
- EPA+DHA% of PUFA
- EPA+DHA% n-3
- DHA to EPA%

In data that were not directly provided by Matís for the lumpfish roes, they were calculated by the author using the same formulas as defined in Tables 1 and 8.

5 Results

5.1 Fatty Acid Analysis

The roe was determined to be 5% lipids via wet roe, with the primary lipids being phospholipids and triglycerides during the tests performed at BioPol. The lipid profiles performed by Matís on the two samples of lumpfish roe (Figure 2), show that the highest proportional fatty acid types are n-3's, especially EPA and DHA. The full original report is viewable in Appendix A.

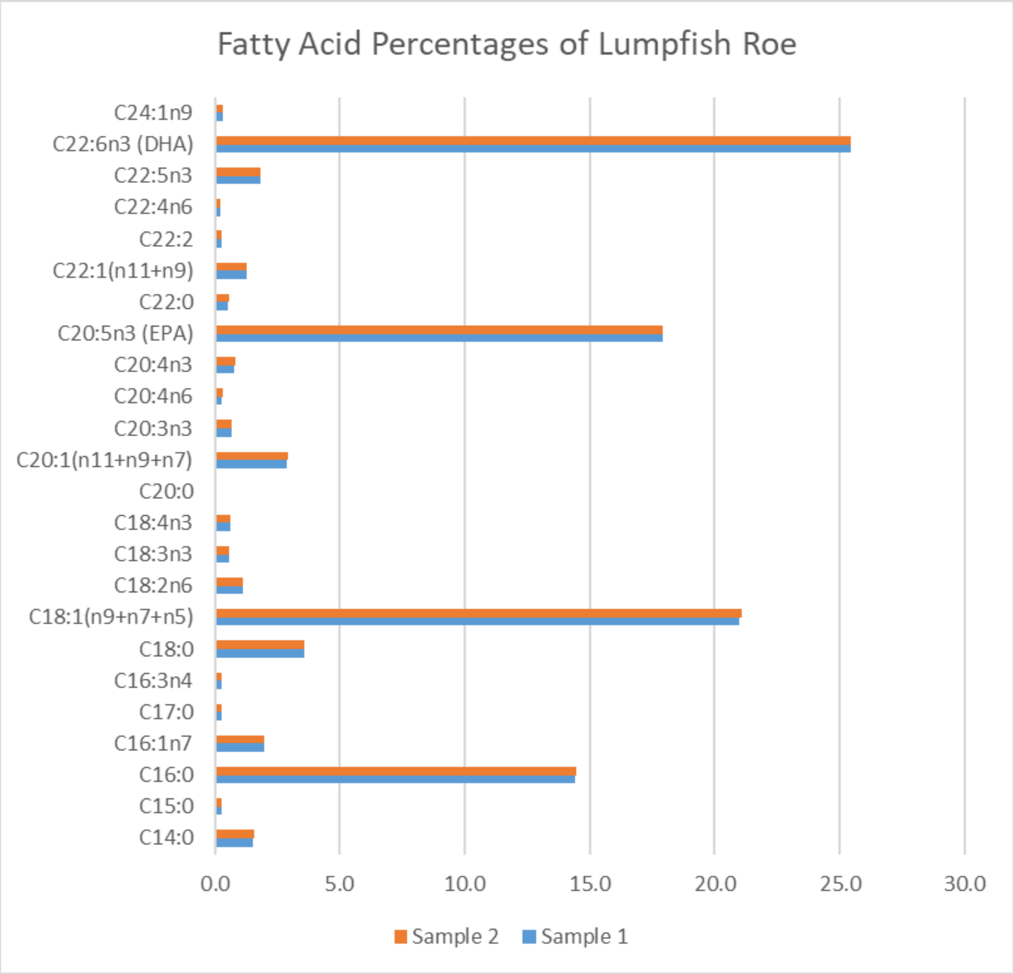

Figure 2: Percentages of individual fatty acids as determined by gas chromatography performed by Matís ohf.

Figure 2 represents the totals of all fatty acids present in the samples provided. Results are in keeping with ranges previously reported by Basby (1997). Results for each respective fatty acid group between the two samples are consistent, with differences being ≤0.2% for both given and calculated values (Table 9). The only exceptions to that are the unknowns (0.6%) and DHA to EPA% (0.4%). The averages of the two samples were used in comparisons of later sections if differences occurred between results for samples 1 and 2.

Table 9: Data results of lumpfish fatty acid group content expressed as % of fatty acid methyl esters, and calculations made based on them.

Lumpfish Roe Fatty Acid Content via Gas Chromatography		
Given Data (%FAME)	**Sample 1**	**Sample 2**
SFA%	20.7	20.9
MUFA%	27.4	27.6
PUFA%	49.9	50.1
TFA%	0	0
Unknown%	2.0	1.4
EPA+DHA %	43.3	43.4
EPA%	17.9	17.9
DHA%	25.4	25.4
Total n-3%	47.8	47.9
Calculated Data (% FAME)		
n-3% of PUFA	95.7	95.6
EPA% of PUFA	35.8	35.8
EPA% of n-3	37.4	37.5
DHA% of PUFA	50.9	50.8
DHA% of n-3	53.2	53.1
EPA+DHA% of PUFA	86.8	86.6
EPA+DHA% of n-3	90.7	90.6
DHA to EPA%	142.2	141.8

Table 9 presents the measured data, both given calculated for the samples provided that were used in the subsequent comparisons. Per the phospholipid test by Matís, the phospholipids rated at 21.5%.

5.1.1 Catch Totals of Fatty Acids and Potential Value

A calculation of the total amount of n-3 which is landed annually is required to gauge potential value of the catch in the nutraceutical market. There is typically between 4500 and 6500 tonnes of total catch in a given year for female lumpfish (Hafrannsóknastofnun, n.d.). Thus, there would be between 58.5 tonnes (1.3% of 4500) and 110.5 tonnes (1.7% of 6500) of total lipids from lumpfish roes. Using the percentages generated by Matís, this would translate to the below in terms of the EPA, DHA, and n-3:

- n-3: 27.99-52.87 tonnes
- EPA: 10.47-19.78 tonnes

- DHA: 14.89-28.07 tonnes
- EPA+DHA: 25.36-47.85 tonnes

In addition, the average price per gram of omega 3 and per gram of EPA+DHA was determined to be the following:

- US best-sellers: ppg n- =73 ISK; ppg EPA+DHA=86 ISK
- Icelandic Consumer Oils: ppg n-3=148 ISK; ppg EPA+DHA=163.9 ISK
- Krill Oils: ppg n-3=244 ISK; ppg EPA+DHA=305 ISK.

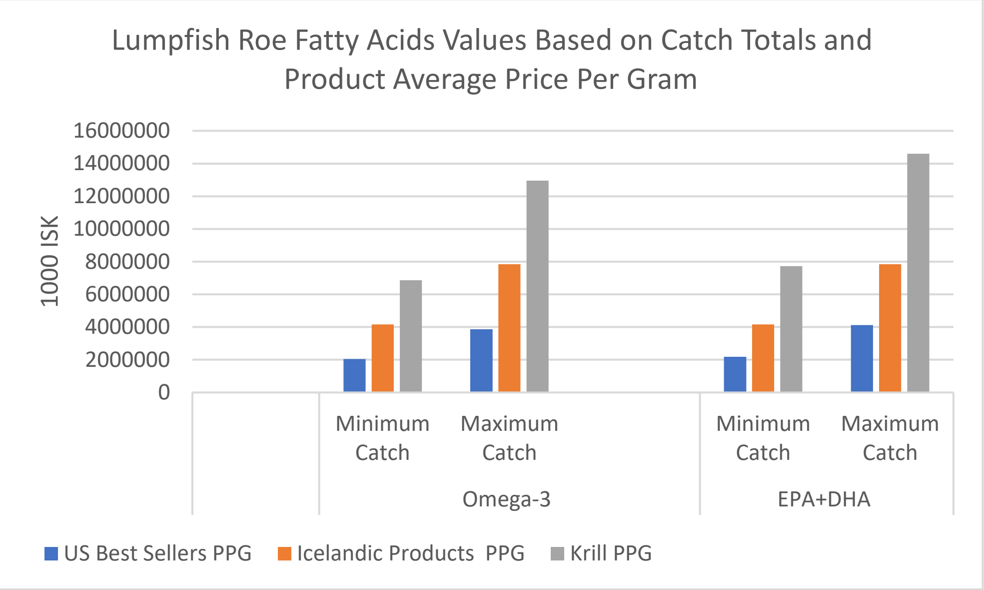

Figure 3: Estimated value of the fatty acids in the annual lumpfish roe fishery, based on ppg from consumer products in later sections.

Based on these averages, value estimates can be determined (Figure 3). The catch totals may be valued at between 2,043,270 k ISK and 3,859,510 k ISK per year if priced according to US best-sellers' ppg n-3, and between 2,180,960 k ISK and 4,115,100 k ISK per year if priced according to US best-sellers' average ppg of EPA+DHA. If using the Icelandic consumer products' average pricing, the catch totals may be valued between 4,153,716 k ISK and 7,845,908 k ISK per year if using ppg n-3 and between 4,156,504 k ISK and 7,842,615 k ISK if using ppg of EPA+DHA. Finally, the krill oils pricing provides estimated valuation between 6,857,550 k ISK and 12,953,150 k ISK per year if using the ppg of n-3, and between 7,734,800 k ISK and 14,594,250 k ISK per year if using the ppg of EPA+DHA. It is acknowledged that these pricing estimates are based on averages and the assumption that FAME is equal to total lipids, which is not likely in practice. The incomes from a fully processed consumer supplement would likely vary.

5.2 Analysis of US Best Sellers v. Lumpfish Roes

The values for the data, both given and calculated, were determined in various metrics (Table 10) with values in mg, mg per serving, USD ($), or percentage. The percentage data (%) for the fish oils are in percentage of serving, while the lumpfish roe fatty acids are in percentage of fatty acid methyl esters. The original spreadsheet for data collection and calculation is viewable in Appendix B.

Table 10: Data results for best-selling US fish oils and comparison to lumpfish roes for relevant figures.

US Best Sellers (Labdoor) v. Lumpfish Roe			
Data (Non%)	**Median**	**Average ±Standard Deviation(n=54)**	**Lumpfish Roe**
Serving mg	1353	1664.6±1193.1	--
n-3 mg/serving	840	861.5±477.5	--
EPA+DHA mg/serving	735	764.3±456.2	--
EPA mg/serving	425	507.1±332.3	--
DHA mg/serving	243	257.3±144.7	--
Price USD	18.95	23.04±12.06	--
Price per serving (USD)	.27	.34±.25	--
Price per g n-3 (USD)	.30	.73±1.22	--
Price per g EPA+DHA (USD)	.35	.86±1.45	--
Percentage (% Serving for Products, %FAME for Roe			
n-3%	63	57±26	47.9
EPA+DHA% of	56	50±25	43.4
EPA+DHA% of n-3	89	87±9	90.7
DHA to EPA%	56	59±23	142
EPA% of total	34	34±19	17.9
EPA% of n-3	56	56±11	37.5
DHA% of total	17	17±8	25.4
DHA% of n-3	32	31±6	53.2

5.2.1 Servings and General Pricing

The majority of products (40 of 54) contained servings that were 900 mg -2000 mg. The range was between 369 mg (Schiff MegaRed Krill Oil) and 8500 mg (Nordic Naturals Fishies), but this upper outlier was nearly 4000 mg above the next closest product. The third largest serving size, at nearly 3700 mg, was nearly 1400mg above the fourth highest dosage. The average serving size was determined to be 1665 mg. Price per serving ranged from $.04 (Kirkland Signature) to $.99 (Nordic Naturals Fishies) with an average of $.34 (Figure 5). Of the 44 priced products, 10 were rated at more than $.50 per serving, with only 5 being priced under $.10 per serving.

General price of products ranged from $8.39 (Puritan's Pride Premium) to $56.78 (Nutrigold Triple Strength) with an average price of $23.04. Of the 54 products, 11 were without prices due to unavailability. 4 products were priced at under $10 and 5 are over $40. For these prices, servings per purchase ranged between 15 and 240, and all products provided serving sizes of 1 or 2 capsules, barring one liquid product which provided 2 ml as a serving size with a 60 fl. oz total per purchase, and one product which uses a gummy food-based delivery.

5.2.2 n-3

The average content of n-3 per serving was 862 mg (Figure 3), with a range of 96 mg to 1960 mg. The same product, which was the lowest in serving size, Schiff's MegaRed Krill Oil, was also the lowest in n-3 content per serving, with Viva Natural's Triple Strength providing the maximum figure in the range. The standard recommended by the European Food Safety Authority of 250 mg ("EFSA assesses safety of long-chain omega-3 fatty acids | European Food Safety Authority," n.d.) is met by all but 4 products. 24 items, just under half, rated an n-3 content above 900 mg.

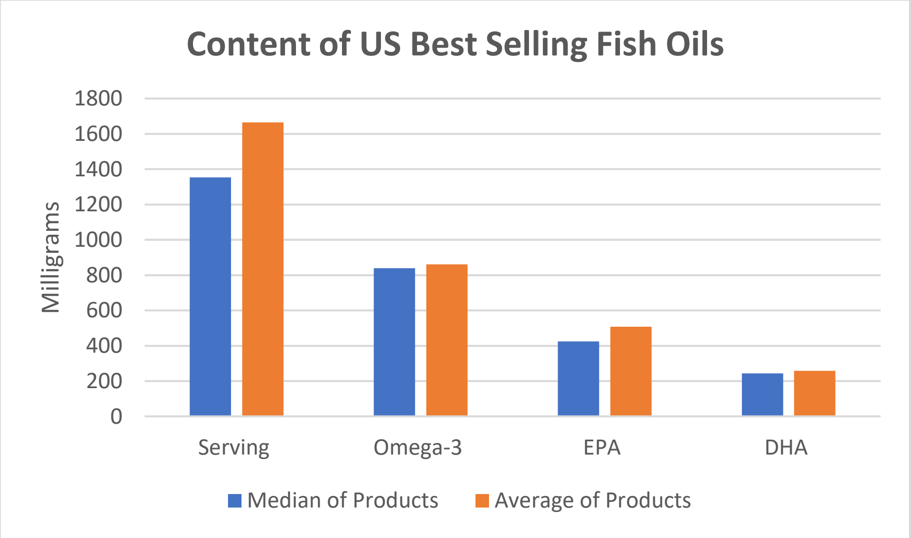

Figure 4: Serving size, total n-3, EPA, and DHA mg in best-selling US fish oil products

On average, a serving of one of the 54 products studied was comprised of 57% n-3 (Figure 3). The range was from 2% (Nordic Naturals Fishies) to 93% (NOW Foods Ultra). Amongst the various products, 16 had a percentage exceeding 80%, and 30 were over 50%. 22 products contained less than 40 percent n-3, with 10 products containing less than 30%, and only 2 at less than 20 percent. The lumpfish roe fatty acids were 48% n-3, nearly 10% below the average and 15% below the median (63%). If accounted for amongst the products, the roe fatty acids would be 31st out of 55 by this metric. The price per g of n-3 ranges from $.09 (Natrol) to $5.80 (Nordic Naturals Fishies) with an average of $.73, or 73 ISK at the time of writing (Figure 5). If applied to lumpfish roe, this would value the lumpfish roe n-3 at between 2,043,270 k ISK and 3,859,510 k ISK per year. Only 5 products are priced at over $1.00 per g of n-3, with 2 products pricing above $5.00 per g (the aforementioned Nordic Naturals Fishies, and Schiff MegaRed Krill Oil). 12 were priced below $.20 per g of n-3, and only one product priced lower than $.10 per g (Natrol).

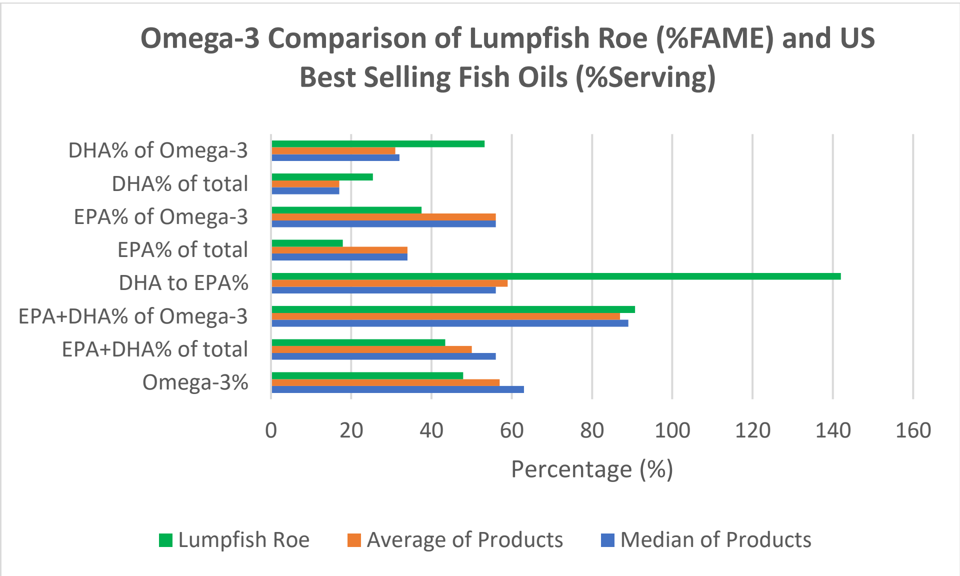

Figure 5:Comparison of n-3 in lumpfish roe fatty acids compared with the dose percentages of best-selling US fish oils

5.2.3 EPA and DHA

EPA+DHA

In combination (EPA+DHA mg), the average was 764mg per serving, but products ranged from 81 mg (Schiff MegaRed Krill Oil) to 1829.7mg (Viva Naturals Triple Strength). Of the 54 products, 18 provided more than 1000mg EPA+DHA, and 19 provided less than 500mg. EPA and DHA comprised 50% of a product’s dose on average (Figure 4), with a range between 2% (Nordic Naturals Fishies) and 89% (Nutrigold Triple Strength). 20 products were comprised of 70% or more of DHA+EPA, and 17 were less the 30%, with only 5 falling under 20%. Lumpfish roe fatty acids rated at 43% EPA+DHA, putting it 7% below average and 13% below median. Measured against the field, the fatty acids were 30th of 55. EPA and DHA also made up 87% of the n-3 content on average (Figure 4), with a range of 43% (Top Secret Fish + CLA) to 98% (WHC UnoCardio). While only 4 products had n-3 comprised of over 95% EPA+DHA, only 10 were below 80%, and only one was below 70%. In terms of price per g of EPA+DHA, the range was $.12 per g (Natrol) to $6.60 (Nordic Naturals Fishies) with an average of $.86, or 86 ISK at the time of writing (Figure 5). If applied to lumpfish roe, this would value the lumpfish roe EPA and DHA at between 2,180,960 k ISK and 4,115,100 k ISK per year. By this metric, 6 products crossed the $1.00 per g threshold, but only 11 of the 43 priced products were priced at over $.70 per g EPA+DHA, while 28 were priced at or below $.50 per g. Of those 28, 9 priced at or below $.20 per gram. On average, there is 59% as much DHA as there is EPA in the 54 products (Figure 4), with a range from 24% (Omax3 Ultra-Pure) to 133% (Pure Alaska Salmon Oil). The vast majority, 50 of 54, possessed more EPA than DHA (<100%), with 35 having at least half as much DHA as EPA (<50%). Lumpfish roe fatty acids possessed 42% more DHA than EPA, putting it 1st of 55 when measured against the field, and more than doubling the average.

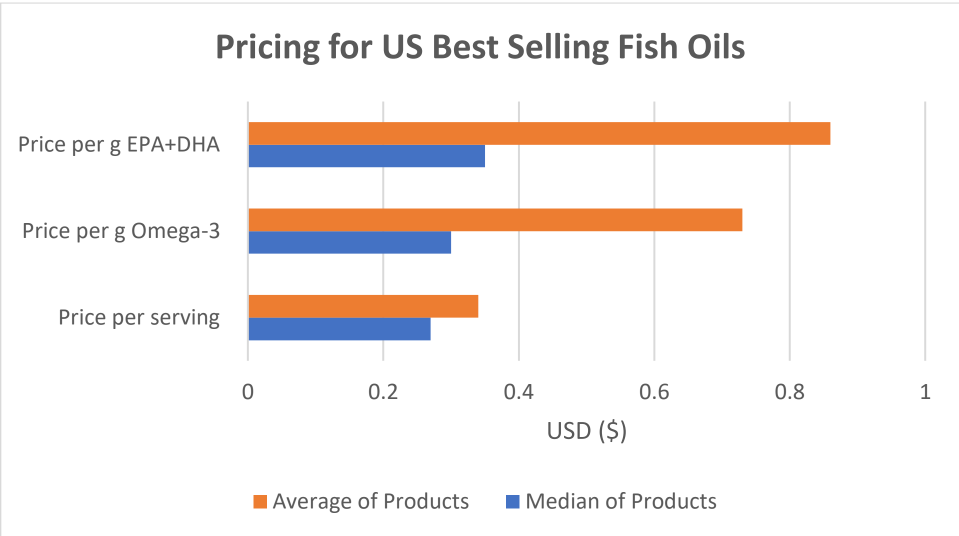

Figure 6: Determinate pricing of ppg of serving, total n-3, and DHA+EPA for best-selling US fish oils

EPA

The average EPA mg per serving was 507 mg (Figure 3), with a range from 50 mg (Nature Made Cod Liver Oil) to 1351 mg (Viva Naturals Triple Strength). Only 11 products contained in excess of 800 mg of EPA, and of those, 8 met or exceeded 900 mg. 16 products contained 200 mg or less, and 4 contained 100 mg or less. EPA comprised 34% of products on average but ranged from .01% (Nordic Naturals Fishies) to 71% (Omax3 Ultra-Pure). In this range, 20 products were between 40% and 60% EPA, 21 products were less than 20% EPA, and 6 were less than 10%. Lumpfish fatty acids rated at 18% EPA, just under half of the average and median, putting the fatty acids 39th out of 55 if taken as a field. EPA also made up an average of 56% of the total n-3 content for the 54 products measured, with a range from 24% (Top Secret Fish + CLA) to 78% (Omax3 Ultra-Pure). Only 3 products had n-3 comprised of over 70% EPA, and 5 had under 40%. However, a total of 23 products possess n-3 consisting of between 50% and 60% EPA. The n-3 of the lumpfish fatty acids was 38% EPA, putting it at nearly 20% below both average and median, and ranking it 51st of 55 if measured against the field.

DHA

The average DHA content per serving was 257 mg (Figure 3) with a range from 29 mg (Schiff MegaRed Krill Oil) to 600 mg (Dr. Tobias Optimum). 16 products contained 300 mg of DHA or more, of those only 7 exceeded 400 mg. Conversely, only 8 products fell at or below 100 mg, with 4 at or below 50 mg. DHA comprised 17% of products on average but ranged from .01% (Nordic Naturals Fishies) to 38% (WHC UnoCardio). In this range, 38 products were at 20% or below, and 25 products were less than 15% DHA. Only 4 products were comprised of over 30% DHA. Lumpfish fatty acids rated at 25% DHA, a full standard deviation above the average and median and putting the fatty acids 10th out of 55 if taken as a field. DHA also made up an average of 31% of the total n-3 content for the 54 products measured, with a range from 13% (Top Secret Fish + CLA) to 44% (WHC UnoCardio). Only 4 products had n-3 comprised over 40% DHA, and only 2 had under 20%. However, a total of 32 products possessed n-3 comprised of between 25% and 35% DHA. The n-3 of the lumpfish fatty acids was 53% DHA, putting it over 20% greater than the average and median, and ranking it 1st of 55 if measured against the field.

5.3 Analysis of Icelandic Bulk Items v. Lumpfish Roes

The values for the data, both given and calculated (Table 11) were determined in either milligram per gram (mg/g) or percentage. The percentage data (%) for the fish oil products were on the percentage of oil, while the percentage of lumpfish roes was in percentage of fatty acid methyl esters. The original spreadsheet for data collection and calculation is viewable in Appendix C.

Table 11: Data results for bulk domestic fish oils and comparison to lumpfish roe fatty acids.

Bulk Icelandic Oils Comparison with Lumpfish Roe Fatty Acids		
Data (mg/g)	**Average ±Standard Deviation (n=10)**	**Lumpfish**
EPA mg/g	113±71.4	--
DHA mg/g	97.7±40.3	--
EPA+DHA mg/g	217.8±110.7	--
n-3 mg/g	212.5±69.1	--
Percentage (% of oil for Products, %FAME for Roe)		
EPA% (minimum)	12±8	17.9
DHA% (minimum)	12±6	25.4
EPA% of n-3	44±10	37.5
DHA% of n-3	37±2	53.2
EPA+DHA%	24±13	43.4
DHA+EPA% of n-3	79±7	90.7
DHA to EPA%	132±125	142
n-3 %	23±9	47.9

PUFA% was provided by two items, but this was deemed too small a sample size as that metric was not determinable via alternative calculation. Both products listing the figure rated 20% PUFA, while the lumpfish roe fatty acids were 50% PUFA.

5.3.1 n-3

The average content of n-3 for one of the 4 products for which n-3 mg/g and % was determinable was 213 mg/g with a range of 110 mg/g (Margildi Capelin Oil) to 300 mg/g (Lýsi Omega-3 Fish-API Grade). On average, the oils were comprised of 23% n-3 (Figure 6), with a range from 11% (Margildi Capelin Oil) to 35% (Lýsi Omega-3 Fish-API Grade). The lumpfish roe fatty acids were 48% n-3, more than double the average, and ranking 1st of five if measured against the field, though this was only 4 products.

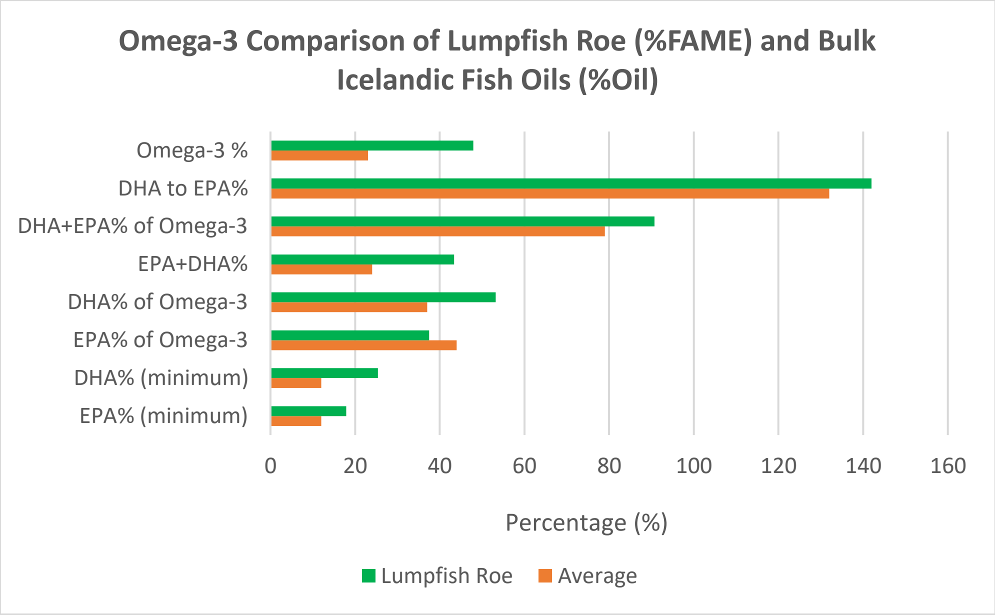

Figure 7:Comparison of n-3 fatty acids of Lumpfish Roe as % of fatty acid methyl esters with bulk Icelandic fish oils as % of 100g

5.3.2 EPA and DHA

EPA+DHA

In combination, the average amount of DHA and EPA together was 226 mg/g, but products ranged from 100 mg/g (Margildi Capelin Oil) to 485mg/g (Lýsi Omega-3 Ethyl Esters 33/22). Of the 10 bulk items, 6 contained less than 200 mg/g of EPA+DHA. EPA and DHA comprised 24% of oil content on average (Figure 6), with a range between 10% (Lýsi Tuna Fish Oil) and 55% (Lýsi Omega-3 Ethyl Esters 33/22). Of the 10 bulk oils, 6 were less than 20% EPA+DHA and 3 were 30% exactly. Lumpfish roe fatty acids rated at 43% EPA+DHA, putting it 19% above average and the fatty acids were 2nd of 11 against the field.

EPA and DHA also made up 79% of the n-3 content on average (Figure 6), with a range of 71% (Margildi Mackerel Oil) to 86% (Margildi Capelin Oil). On average, there was 132% as much DHA as there was EPA in the 10 products (Figure 6), with a range from 58% (Margildi Mackerel Oil) to 500% (Lýsi Tuna Fish Oil). It was noted that the Tuna Oil was an outlier (Over 4x the second highest percentage and nearly three standard deviations above average), so the average sans this outlier was calculated as 92%. Other than the 500% DHA to EPA tuna oil, all other products fell between either 58%-67%, or 112-114%. Lumpfish roe fatty acids possessed 42% more DHA than EPA, putting it 2nd of 11 and 10% above average, if the outlier was included, and 1st of 10 and 50% above average if it was excluded.

EPA

The average EPA content was 113 mg/g, with a range from 50 mg/g (Lýsi Tuna Fish Oil) to 290 mg (Lýsi Omega-3 Ethyl Esters 33/22). 4 products contained 160 mg/g or more, and 7 contained 80 mg/g or less. EPA comprised 12% of products on average (Figure 6) but ranged from 5% (Lýsi Tuna Fish Oil) to 33% (Lýsi Omega-3 Ethyl Esters 33/22). In this range, 7 products were less than 10% EPA, and 2 were exactly 18%. Lumpfish fatty acids rated at 18% EPA, 6% above average, putting the fatty acids at a tie for 2nd out of 11 if taken as a field. EPA also makes up an average of 44% of the total n-3 content for the 4 products for which this was determinable, with a range from 33% (Margildi Mackerel Oil) to 55% (Margildi Capelin Oil). The n-3 of the lumpfish fatty acids was 38% EPA, putting it 7% below average and ranking it 3rd of 5 if measured against the field.

DHA

The average DHA content per serving was 113 mg/g with a range from 40 mg/g (Margildi Capelin Oil) to 250mg/g (Lýsi Tuna Oil). 6 of 10 products contained 100mg/g or less of DHA. DHA comprised 12% of products on average (Figure 6) but ranges from 4% (Margildi Capelin Oil) to 25% (Lýsi Tuna Oil), in keeping with the mg/g determinations. Lumpfish fatty acids rated at 25% DHA (Figure 6), double the average and tying for first of 11 if taken as a field. DHA also makes up an average of 38% of the total n-3 content for the 4 products for which this was determinable. The n-3 of the lumpfish fatty acids was 53% DHA, putting it 16% and 8 standard deviations greater than the average, and ranking 1st of 5 if measured against the field.

5.4 Analysis of Icelandic Consumer Products (Simple Labels) v. Lumpfish Roes

The values for the data, both given and calculated, were determined in various metrics (Table 11). Non-percentage numbers were in either mg per serving or ISK value. The percentage data (%) for the fish oil products were on the percentage of serving, while the percentage of lumpfish roes was in percentage of fatty acid methyl esters. The original spreadsheet for data collection and calculation is viewable in Appendix D.

Table 12:Data results for domestically produced consumer fish oils and comparison to lumpfish roe fatty acids for relevant figures

Comparison of Icelandic Consumer Fish Oils (Simple Labels) with Lumpfish Roe Fatty Acids			
Data (Non%)	**Median**	**Average ±Standard Deviation (n=22)**	**Lumpfish Roe**
n-3 mg/serving	399	562.8±458.8	--
EPA+DHA mg/serving	350	563.9±494.9	--
EPA mg/serving	212	294±216.7	--
DHA mg	138	269.8±300.5	--
Price ISK	1075	1639.5±1354.6	--
Price per serving (ISK)	26.7	39.7±32.1	--
Price per g n-3 (ISK)	71.1	148.4±171.1	--
Price per g EPA+DHA (ISK)	50.6	112.6±139.6	--
Percentage (%Serving for Products, %FAME for Roe)			
EPA+DHA% of n-3	78	74±12	90.7
DHA to EPA%	65	84±44	142
EPA% of n-3	48	42±10	37.5
DHA% of n-3	30	31±8	53.2

5.4.1 Servings and General Pricing

General price of products ranged from 454 ISK (Lýsi Health Duet) to 5300 ISK (Dropi Liquid) with an average price of 1640 ISK. Of the 22 products, 6 were without prices due to unavailability. 7 products were priced at under 1000 ISK and 3 were over 3500 ISK. It was also notable that no products were priced between 2000 and 3500 ISK. For these prices, servings per purchase ranged between 8 and 120 ISK. Products differed in delivery method as either liquid (7 products) or capsules (15 products). Price per serving ranged from 14 ISK (Lýsi Health Duet) to 131 ISK (Hafkalk Krill) with an average of 27 ISK (Figure 9). Of the 16 priced products, 7 were rated at more than 30 ISK per serving, with only 4 being priced under 20 ISK per serving.

5.4.2 n-3

The average content of n-3 per serving was 563 mg (Figure 7), with a range of 118 mg (Hafkalk Krill) to 2160 (Lýsi Liquid Cod Liver). The standard recommended by the European Food Safety Authority of 250 mg ("EFSA assesses safety of long-chain omega-3 fatty acids | European Food Safety Authority," n.d.) was met by all but 3 products. The price per g of n-3 ranged from 14 ISK (Lýsi Liquid Cod Liver) to 597 ISK (Hafkalk Krill) with an average of 148 ISK (Figure 9). If applied to lumpfish roe, this would value the lumpfish roe n-3 at between 4,153,716 k ISK and 7,845,908 k ISK per year. Of the 15 products for which price per gram of n-3 was determinable, only 3 products were priced at over 100 ISK, with none but the minimum in the range pricing below 40 ISK per g.

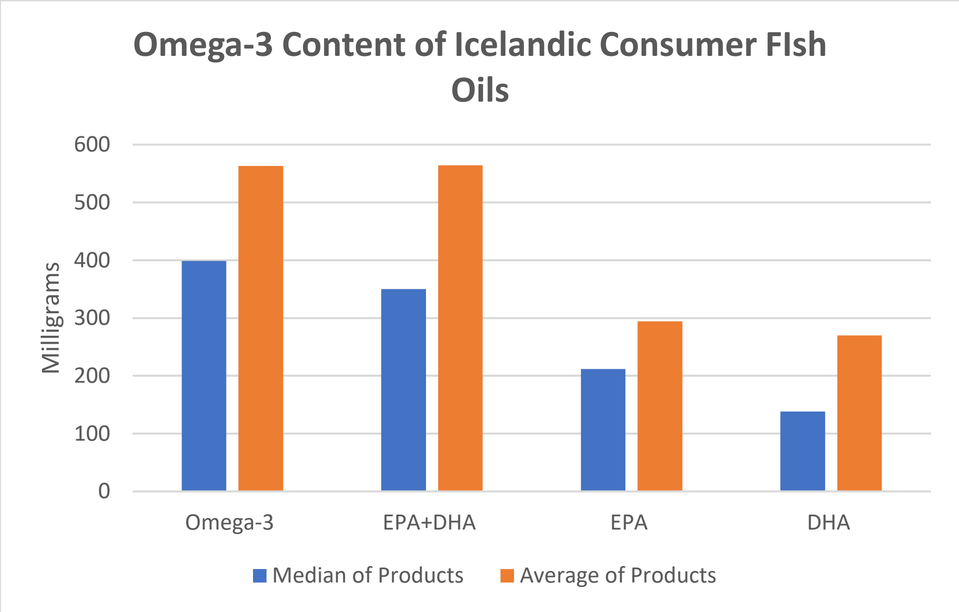

Figure 8: n-3 content and type in domestically produced fish oil products

5.4.3 EPA and DHA

EPA+DHA

In combination (EPA+DHA mg), the average was 564 mg per serving, but products ranged from 43 mg (Lýsi Cod Liver Capsules) to 2000 mg (Lýsi Children's Cod Liver). Of the 22 products, 4 provided more than 1000 mg EPA+DHA, and 11 provided less than 350 mg. EPA and DHA also made up 74% of the n-3 content on average (Figure 8), with a range of 36% (Lýsi Cod Liver Capsules) to 83% (Lýsi Omega-3 Forte, Lýsi Omega-3 HYAL-Joint, Lýsi Sport Trio Energy, and Lýsi Sport Trio Joints). Of the 18 products for which it was determinable, DHA and EPA comprised between 70% and 80% of n-3 content for 11 products, and less than 50% for only 2.

Price per g of EPA+DHA was determinable for 15 products, which had a range of 12.5 ISK (Lýsi n-3 Fish Oil Liquid) to 746.4 ISK (Hafkalk Krill) with an average of 163.9 ISK (Figure

9). If applied to lumpfish roe, this would value the lumpfish roe EPA and DHA at between 4,156,504 k ISK and 7,842,615 k ISK per year. By this metric, 6 products crossed the 100 ISK per g threshold, and of those, 3 were 400 ISK or greater. 4 products were priced below 20 ISK per g of EPA+DHA. On average, there was 84% as much DHA as there was EPA in the 22 products, with a range from 13% (Lýsi Cod Liver Capsules) to 198% (KeyNatura Asta Lýsi). Roughly 2/3 of products possessed between 63% and 67% as much DHA as EPA, and all but 6 had less DHA than EPA (<100%), with all but 2 having at least half as much DHA as EPA (<50%) Notably, all but 1 of the products which had more DHA than EPA (>100%) were in liquid form, but not all liquids possess more DHA than EPA. Lumpfish roe fatty acids possessed 42% more DHA than EPA, putting it 3rd of 23 when measured against the field, and nearly 60% above average.

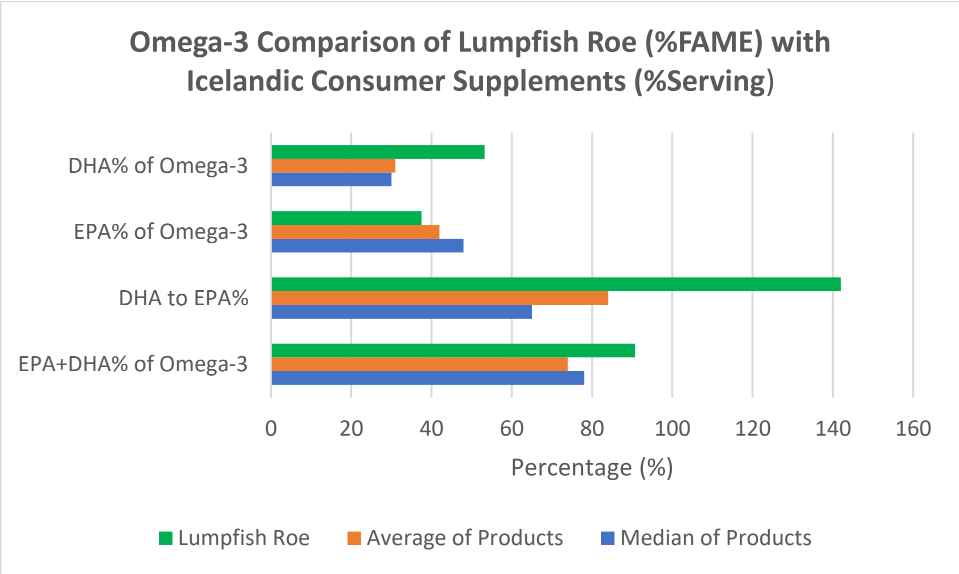

Figure 9: Comparison of n-3 composition between domestically produced fish oils and lumpfish roe fatty acids

EPA

The average EPA mg per serving was 294 mg (Figure 7), with a range from 38 mg (Lýsi Cod Liver Capsules) to 736 mg (Lýsi Omega-3 Fish Oil and Lýsi Omega-3 Fish Oil + Vitamin D). Only 4 products contained in excess of 350 mg of EPA, and of those, all possess at least 690 mg. All other products (18) possessed 315 mg or lower of EPA and 10 contained 200 mg or less. EPA also made up an average of 42% of the total n-3 content for the 18 products for which this figure was determinable (Figure 8), with a range from 15% (KeyNatura AstaOmega) to 55% (Hafkalk Krill). Only 3 products had n-3 comprised of 30%

EPA or lower. 12 of the products possessed n-3 consisting of between 45% and 55% EPA, with 11 of those being either 48% or 55%. The n-3 of the lumpfish fatty acids was 38% EPA, putting it at around a ½ standard deviation below average and ranking it 13th of 19 if measured against the field.

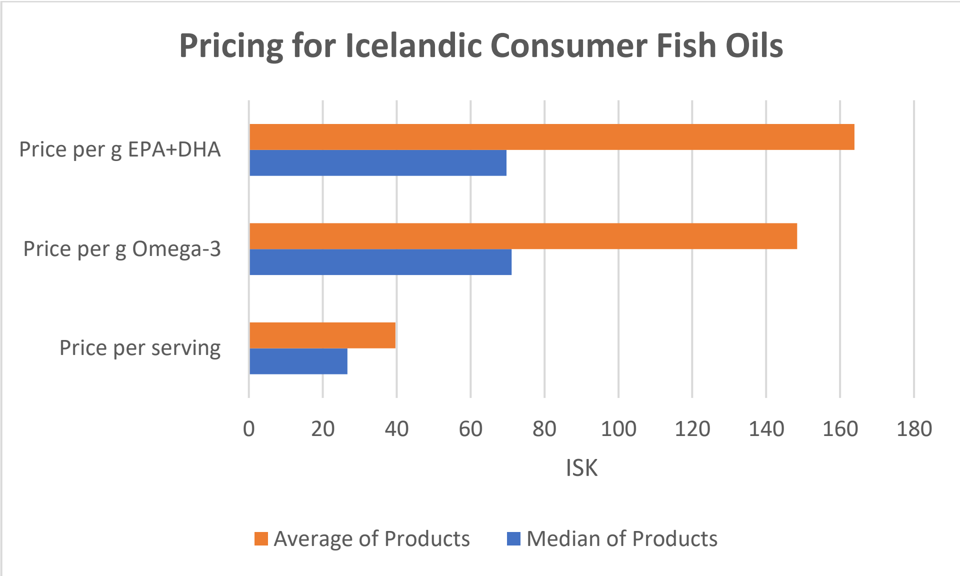

Figure 10:Determinate pricing of ppg of serving, total n-3, and DHA+EPA for domestic fish oils

DHA

The average DHA content per serving was 270 mg (Figure 7) with a range from 5 mg (Lýsi Cod Liver Capsules) to 1300 mg (Lýsi Children's Cod Liver). All but 2 products possessed under 500 mg of DHA, and both of those were above 900 mg. Of the remaining 19, 16 possessed less than 300 mg of DHA, and 3 of those possessed less than 100 mg. DHA also made up an average of 31% of the total n-3 content for the 18 products for which this was determinable, with a range from 4% (Lýsi Cod Liver Capsules) to 43% (Lýsi Liquid Cod Liver). Only 2 products had n-3 comprised of under 30% DHA, with the minimum 4% being 21% lower than the next lowest product. However, 15 products possessed n-3 comprised of between 30% and 40% DHA, with all but two of those being either 30% or 33%. The n-3 of the lumpfish fatty acids was 53% DHA, putting it over 20% greater than the average and median, and ranking it 1st of 19 if measured against the field.

5.4.4 Detailed Labels

The values for the data, both given and calculated, were determined in various metrics (Table 13). Non-percentage numbers were in g per serving. The percentage data (%) for the fish oil products were on the percentage of serving, while the percentage of lumpfish roes was in percentage of fatty acid methyl esters. The original spreadsheet for data collection and calculation are viewable in Appendix E. Data or conversion analogues already appearing in Table 12 were not included.

Table 13: Supplemental data results for domestically produced consumer fish oils with more detailed labels, and their comparison to lumpfish roes for relevant figures.

Comparison of Icelandic Consumer Fish Oils (Simple Labels) with Lumpfish Roe Fatty Acids		
Data (Non%)	**Average ±Standard Deviation (n=7)**	**Lumpfish Roe**
Serving in g	5.51±3.19	--
MUFA g per serving	2.14±1.57	--
PUFA g per serving	2.21±1.13	--
Percentage (% Serving for products, % FAME for Roe)		
MUFA%	37.3±9.9	27.5
PUFA%	40.8±7.9	50
n-3% of total	23.9±0.8	47.9
n-3% of PUFA	66.2±10.2	96
EPA+DHA% of total	20.8±4	43.3
EPA+DHA% of PUFA	51.9±7.4	86.6
EPA%	10.3±3.9	17.9
EPA% of PUFA	24.9±6.2	35.8
DHA%	10.5±1.6	25.4
DHA% of PUFA	26.9±6.7	50.9

Servings

There were 4 serving sizes for the products, 2 for each delivery method (capsules or liquid). There were two of each serving sizes for liquids (5ml or 10 ml, adjusted to roughly 4.6 g or 9.12 g) and one of each for capsules (.5 g or 1 g).

MUFA and PUFA

The average MUFA g per serving for the 7 products was 2.14, with a range from .25 (Lýsi Cod Liver Capsules) to 4.6 (Lýsi Liquid Cod Liver). MUFA made up an average of 40% of each product (Figure 10), ranging from 26% (Lýsi Omega-3 Fish Oil Liquid and Lýsi

Omega-3 + Vitamin D Liquid) to 50% (Lýsi Cod Liver Capsules). Lumpfish fatty acids were 27.5% MUFA, putting them nearly 10% and 1 standard deviation below average, and ranking 6th of 8 in this metric if measured against the field.

The average PUFA g per serving was 2.22, with a range from .17 (Lýsi Cod Liver Capsules) to 3.3 (Lýsi Children's Cod Liver). PUFA made up an average of 41% of each product (Figure 10), with a range of 33% (Lýsi Liquid Cod Liver) to 50% (Dropi Liquid Oil). The lumpfish fatty acids were 50% PUFA, putting them 9% and more than a standard deviation above average, and tying them for 1st of 8 if compared amongst the products.

n-3

n-3 makes up an average of 23% of the four products for which this information was determinable (Figure 10). All products were between 23% and 25% n-3. The lumpfish roe fatty acids were comprised of 48% n-3, putting them at double the average, and nearly double every product, for 1st in an otherwise standardized field. n-3 also comprised 66% of the PUFA of the 4 measurable products on average, though this ranged from 50% to 77%. The lumpfish roe lipid PUFA's were 96% n-3, 30% and 3 standard deviations above average, making it 1st of 5 if measured against the field.

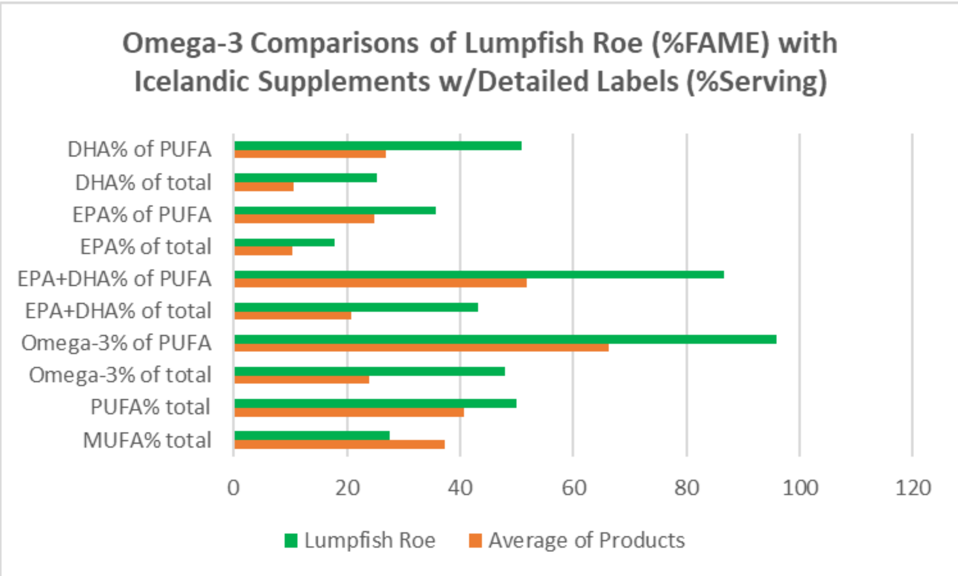

Figure 11: Comparison of n-3 composition between domestically produced fish oils with more detailed labels and lumpfish roe fatty acids.

EPA+DHA

EPA+DHA together comprised an average of 21% of the 7 products (Figure 10), with a range between 16% (Dropi Capsules) and 26% (Lýsi Omega-3 Fish Oil Liquid and Lýsi Omega-3 Fish Oil Liquid +Vitamin D). Lumpfish roe fatty acids were 43% EPA and DHA, more than doubling the average and putting them 1st of 8 if measured against the products. EPA and DHA together also comprised 52% of PUFA on average for the products, with a range from 35% (Dropi Liquid Oil) to 61% (Lýsi Children's Cod Liver Oil). EPA and DHA comprised 86.6% of lumpfish roe PUFA content, nearly 35% and 5 standard deviations above average, placing them 1st of 8 if compared directly.

EPA

EPA made up an average of 10% of each product (Figure 10), with a range of 7% (Dropi Capsules) to 16% (Lýsi Omega-3 Fish Oil Liquid and Lýsi Omega-3 Fish Oil Liquid+Vitamin D), with all within extremes of that range being 8%. Lumpfish roe fatty acids were 18% EPA, 8% and 2 standard deviations above average, and place them 1st of 8 if measured against the field. EPA also comprised an average of 25% of the PUFA content for the products, with a range from 15% (Dropi Capsules) and 33% (Lýsi Omega-3 Fish Oil Liquid and Lýsi Omega-3 Fish Oil Liquid+Vitamin D). The 4 products not at the maximum or minimum of this range all had PUFA content that was between 21% and 23% EPA. Lumpfish roe fatty acids had PUFA that was nearly 39% EPA, over 10% above average and putting them 1st of 8 if measured against the products.

DHA

DHA comprised an average of 11% of the products (Figure 10), with a range from 9% (Dropi Capsules) to 14% (Children's Cod Liver Oil). The 5 products within the extremes were all between 10% DHA. Lumpfish roe fatty acids were 25% DHA, putting them 14% and 7 deviations above average and placing them 1st of 8 if measured against the field. DHA also made up an average of 27% of PUFA, with a range between 21% (Lýsi Omega-3 Fish Oil Liquid and Lýsi Omega-3 Fish Oil Liquid+Vitamin D) and 39% (Children's Cod Liver Oil). PUFA in lumpfish roes were 51% DHA, 23% above average and putting them 1st of 8 if measured against the field.

5.5 Analysis of Best-Selling Krill Oil Products v. Lumpfish Roes

The values for the data, both given and calculated, were determined in various metrics (Table 14). Non-percentage numbers were in either mg per serving or USD value. Non-percentages were in either mg per serving or USD. The percentage data (%) for the krill oil products were on the percentage of serving, while the percentage of lumpfish roes was in percentage of fatty acid methyl esters. The original spreadsheet for data collection and calculation are viewable in Appendix F.

Table 14:Data results for best-selling krill oils in US and comparison to lumpfish roes for relevant figures.

Comparison of Icelandic Best-Selling Krill Oils with Lumpfish Roe Fatty Acids			
Data (Non%)	**Median**	**Average ±Standard Deviation (n=17)**	**Lumpfish Roe**
Serving (krill oil) mg	1000	982.4±274.3	--
n-3 mg/serving	230	273.8±139.8	--
EPA+DHA mg per serving	190	230.2±126.7	--
EPA mg per serving	120	146.6±81.1	--
DHA mg per serving	60	81.3±51.7	--
Phospholipid mg per serving	400	397.4±158.1	--
Price USD	21.99	26.66±15.09	--
Price per serving (USD)	.50	.55±.27	--
Price per g n-3 (USD)	2.17	2.44±1.29	--
Price per g EPA+DHA (USD)	2.67	3.05±1.70	--
Percentage (%Serving for Krill Oils, %FAME for Roe			
n-3%	23	28.3±14.5	47.9
EPA+DHA% of total	19	25.4±15.1	43.4
EPA+DHA% of n-3	81.7	83±8.2	90.7
DHA to EPA%	55	53.4±8.1	142
EPA% of total	12.8	14.8±7.6	17.9
EPA% of n-3	55	54±3.7	37.5
DHA% of total	6	8.2±5.1	25.4
DHA% of n-3	26.9	28.5±5.4	53.2
PL%	40	38.2±9.3	21.5

5.5.1 Servings and General Pricing

The average serving contains an average of 982 mg of total krill oil, with a range between 500 mg (3 products) and 1500 mg (Natrogix Antarctic). Of the 17 products, 8 had 1000 mg, 4 had 1200-1250, and 3 had 500 mg. Price per serving ranged from $.26 (MAVNutrition) to $.1.36 (Schiff MegaRed Ultra Strength) with an average of $.55 (Figure 13). General price of products ranged from $7.88 (MAVNutrition) to $78.97 (Dr. Mercola Antarctic) with an average price of $26.66. 2 products were priced at under $15 and 2 were over $40. For these prices, servings per purchase range between 30 and 100, and 16 products provided serving sizes of 1 or 2 capsules.

5.5.2 n-3

The average content of n-3 per serving was 275 mg (Figure 11), with a range of 115 mg (MegaRed Extra Strength) to 603 mg (NewRhythym). The standard recommended by the European Food Safety Authority of 250 mg ("EFSA assesses safety of long-chain n-3 fatty acids | European Food Safety Authority," n.d.) was met by only 4 products, and only 3 products possess over 350 mg of n-3.

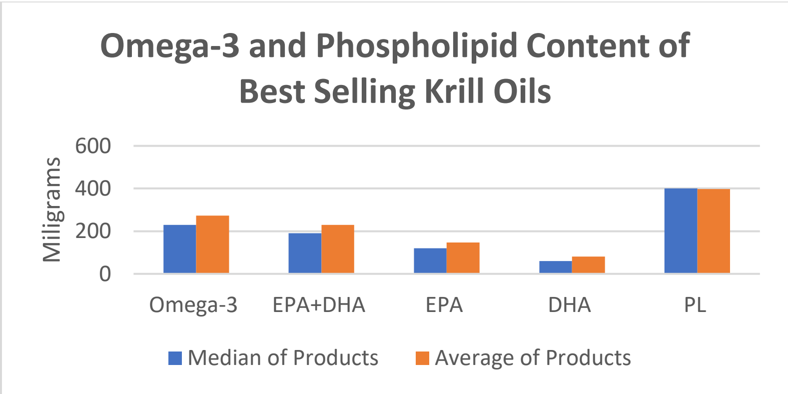

Figure 12: n-3 content+type and phospholipids in best-selling krill oil products.

On average, a serving of one of the 17 products analyzed was comprised of 28% n-3 (Figure 12). The range was from 8% (Natrogix) to 68% (Schiff MegaRed Advanced 4 in 1, though this product was a blend of krill and fish oil). Amongst the 15 products for which it was determinable, only 3 were more than 25% n-3, and 10 were between 20% and 24% n-3. The lumpfish roe fatty acids were 48% n-3, 20% above the average. If accounted for amongst the products, the roe fatty acids would be 4th out of 16 by this metric. The price per g of n-3 ranges from $.78 (NewRhythym) to $5.90 (Schiff MegaRed Ultra Strength) with an average of $2.44, or 244 ISK at the time of writing (Figure 13). If applied to lumpfish roe, this would value the lumpfish roe n-3 at between 6,857,550 k ISK and 12,953,150 k ISK per year. All but 1 product was priced at over $1.00 per g of n-3, with 5 products pricing above $3.00 per g. 8 products were between $1.50 and $2.50 per g of n-3.

5.5.3 EPA and DHA

EPA+DHA

In combination (EPA+DHA mg), the average was 230 mg per serving (Figure 11), but products ranged from 79 mg (Natrogix) to 545 mg (NewRhythym). Of the 17 products, 12 provided between 150 and 270 mg of EPA+DHA. EPA and DHA comprised 25% of a product's dose on average (Figure 12) with a range between 5% (Natrogix) and 63% (Schiff MegaRed Advanced 4 in 1, though this was a blend of krill and fish oils). Only 4 products were comprised of 40% or more of DHA+EPA, and 10 were 20% or lower. Lumpfish roe fatty acids rated at 43% EPA+DHA, putting it 17% above average. Measured against the field, the fatty acids were 5th of 18.

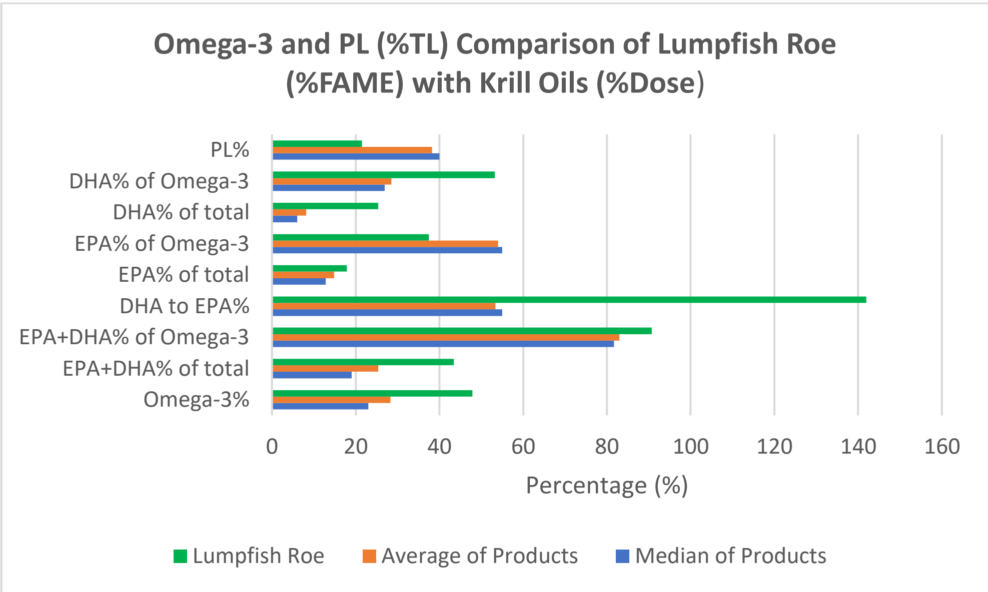

Figure 13:Comparison of n-3 composition and phospholipids between krill oil products and lumpfish roe fatty acids

EPA and DHA also made up 83% of the n-3 content on average (Figure 12), with a range of 73% (Jarrow Formulas) to 100% (Bronson Antarctic). 4 products had n-3 comprised of over 90% EPA+DHA, and only 2 possessed levels below 80% of total n-3 content. In terms of price per g of EPA+DHA, the range was $.86 per g (NewRhythym) to $7.22 (Schiff

MegaRed Ultra Strength) with an average of $3.05, or 305 ISK at the time of writing (Figure 13). If applied to lumpfish roe, this would value the lumpfish roe EPA and DHA at between 7,734,800 k ISK and 14,594,250 k ISK per year. By this metric, all but 2 products crossed the $1.00 per g threshold, all but 4 were at least $2.00 per g of EPA+DHA, and 3 products were priced at over $5.00 per g EPA+DHA. On average, there was 53% as much DHA as there was EPA in the 15 products for which DHA to EPA percentage was determinable, with a range from 46% (Onnit) to 67% (Pure Alaska Salmon Oil). All possessed more EPA than DHA (<100%). Lumpfish roe fatty acids possessed 42% more DHA than EPA, putting it 1st of 16 when measured against the field, and nearly 90% above average.

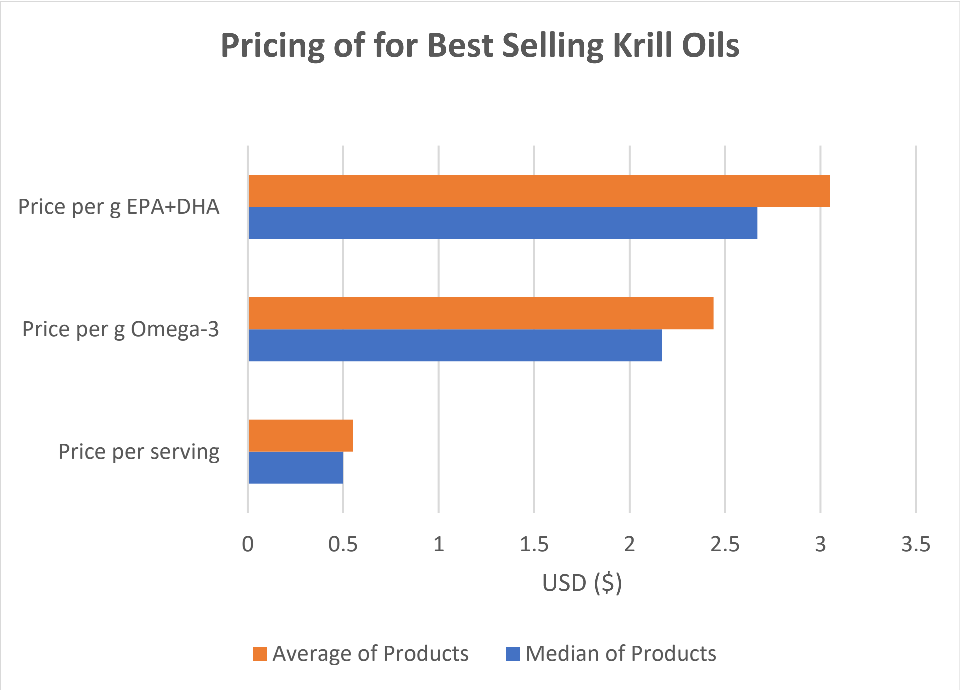

Figure 14:Determinate pricing of ppg of serving, total n-3, and DHA+EPA for best-selling krill oils

EPA

The average EPA mg per serving was 147 mg (Figure 11), with a range from 58 mg (Natrogix Antarctic) to 67 mg (NewRhythym). All but 2 products contained less than 200 mg of EPA, and all but 2 exceeded 100 mg. EPA comprised 15% of products on average for the 15 products for which this was determinable (Figure 12), but the percentages ranged from 4% (Natrogix Antarctic) to 33% (MAVNutrition). In this range, 11 products were between 10% and 13% EPA, three were above 20%, and only one was below 10% EPA. Lumpfish fatty acids rated at 18% EPA, 3% above average, and putting the fatty acids 4th out of 16 if taken as a field. EPA also made up an average of 54% of the total n-3 content for the 14 products for which this was determinable, with a range from 46% (Jarrow Formulas) to 60% (Bronson Antarctic). Only 2 products have n-3 comprised of under 50% EPA. Other than the maximum value (60%) all other products' n-3 was between 52% and 57% DHA. The n-3 of the lumpfish fatty acids was 38% EPA, putting it 16% below both average, and ranking it 16th of 16 if measured against the field.

DHA

The average DHA content per serving was 81 mg (Figure 11) with a range from 21 mg (Natrogix Antarctic) to 203 mg (NewRhythym). Only 3 products contained more than 100 mg of DHA and only 2 contain at least 200 mg. 2 products contain 30 mg or less, with all others being at least 50 mg. 8 products contain between 50 and 60 mg. DHA comprised 8% of products on average for the 15 for which this was determinable (Figure 12) but ranged from 1% (Natrogix Antarctic) to 21% (MAVNutrition). In this range, 11 products were between 5% and 7%. Lumpfish fatty acids rated at 25% DHA, over 300% of the average and putting the fatty acids 1st of 10 if taken as a field. DHA also made up an average of 28% of the total n-3 content for the 14 products for which this was determinable, with a range from 17% (Natrogix Antarctic) to 40% (Bronson Antarctic). Only 4 products had n-3 comprised of over 30% DHA, 7 have n-3 that was between 25% and 30% DHA. The n-3 of the lumpfish fatty acids was 53% DHA, putting it 25% greater than the average and ranking it 1st of 15 if measured against the field.

5.5.4 Phospholipids

The products contain an average of 38% phospholipids (Figure 12) for the 15 for which it was determinable, with a range from 20% (MAVNutrition and Bronson Antarctic) to 54% (Jarrow Formulas). Only 3 products were more than 40% phospholipids, and 10 were between 30% and 40%. Lumpfish roes were 22% phospholipids, 16% below average and ranking them 14th of 16 if measured against the field.

5.6 Analysis of Roe Data from Literature vs Lumpfish Roes

The values for the data, both given and calculated were determined in percentage of fatty acid methyl esters, with the exception of phospholipids which is in percent of total lipids

(Table 15). The original spreadsheet for data collection and calculation were viewable in Appendix G. The percentage data (%) all roes and caviars were in percentage of fatty acid methyl esters or in percentage of total fatty acids. The original spreadsheet for data collection and calculation are viewable in Appendix G.

Table 15:Data results for roe fatty acid analysis from literature compared with lumpfish roes. Data was drawn from: Bledsoe et al., 2003, Mol & Turan, 2008, Shirai et al., (2006), (Saliu et al., 2017), (Intarasirisawat et al., 2011), and (Czesny et al., 2000)

Comparison of Lumpfish Roe Fatty Acids with Roe of Other Species			
Data (%FAME)	**Median**	**Average ±Standard Deviation (n=18)**	**Lumpfish Roe**
PUFA%	33	31±10.6	50
n-3% (n=43)	22	25.2±11.7	47.9
n-3% of PUFA	82.7	80.5±9.5	95.7
EPA+DHA%	26.2	24.7±10.5	43.3
EPA+DHA% of PUFA	74.7	68.9±15.2	86.7
EPA+DHA% of n-3	89.2	83.9±11.2	90.7
EPA%	5.1	7.4±5.1	17.9
EPA% PUFA	15.6	20±9.5	35.8
EPA % of n-3	21.9	24.2±9.4	37.5
DHA%	12.0	14.8±7.1	25.4
DHA% of PUFA	46.9	47.8±11.6	50.9
DHA% of n-3	57.6	59.3±12.2	53.2
DHA to EPA %	240.8	299.4±162.5	142
PL% Total Lipids (n=25)	31	26.8±11.8	21.5

5.6.1 PUFA and n-3

The average PUFA content was 31% (Figure 14) of fatty acids for the roe/caviars, with a range from 16% (Beluga, *Huso huso)* to 48% (tarako, i.e. pollock, *Gadus chalcogrammus*). Of the 17 literature roe and caviars for which this was determinable, there were 3 which were only 5 which were less than 25% PUFA, and 3 of these were lower than 20%. 9 were more than 30% PUFA, and 4 of these were over 40%. Lumpfish fatty acids were 50% PUFA, nearly 20% above average and ranking them 1st of 18 if measured against the field.

On average, the literature roe and caviar fatty acids were 25% n-3 (Figure 14), but ranged from 3% (hake, *Merluccius hubbsi*) to 44% (tarako i.e. pollock and vendace, *Coregonus albula*). Of the 37 roes and caviars for which this information was available, 10 were less than 15% n-3, of which only 3 were less than 10%. 17 were over 30%, and of those, 5 were over 40% n-3. Lumpfish roe fatty acids were 48% n-3, 23% and over two standard deviations above average, putting them at first of 38 if measured against the field. n-3 also constituted an average 81% of the PUFA content for those roes and caviars for which this was determinable (Figure 14), with a range from 54% (domesticated white sturgeon, *Acipenser transmontanus*) to 94% (kazunoko, i.e., pacific herring, *Clupea pallasii*). Only 2 roes/caviars contained PUFA that was less than 70% n-3, and only 3 contained PUFA which was over 90% n-3. Lumpfish roe PUFA's were 96% n-3, 15% above average and ranking them 1st of 18 among the roes and caviars.

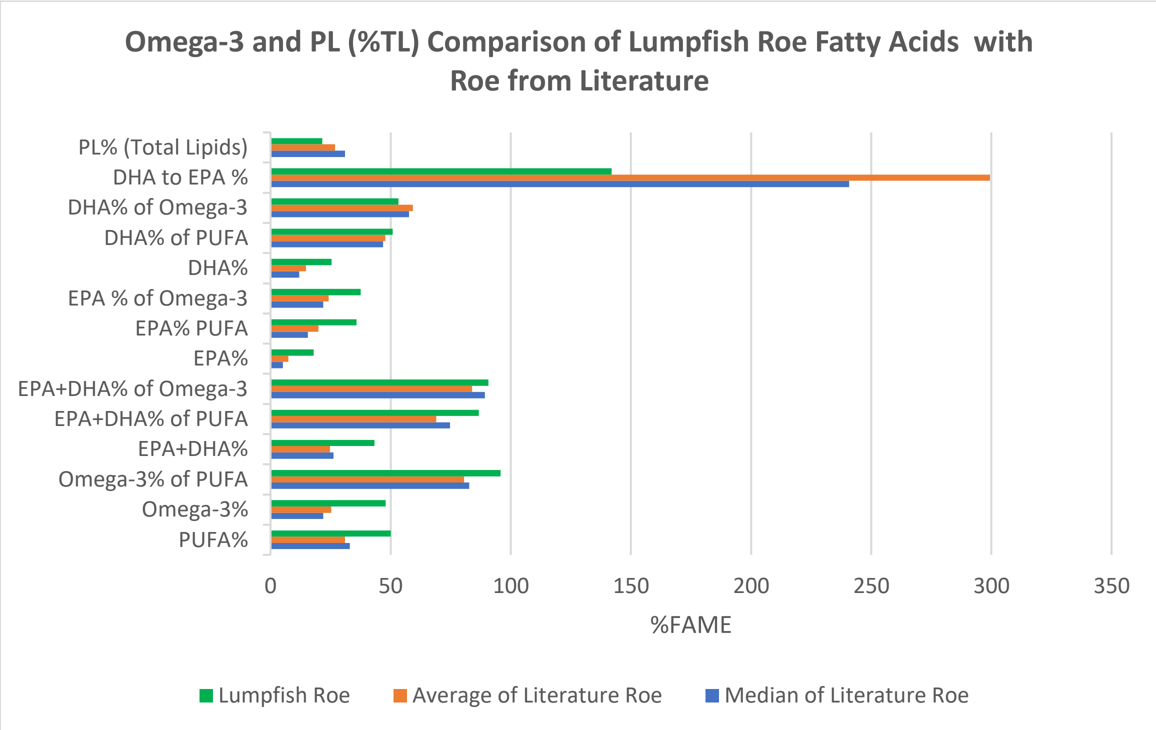

Figure 15:Comparison of n-3 composition and phospholipids between lumpfish roe fatty acids and the fatty acids of the roe of other species from literature. Bledsoe et al., 2003, Mol & Turan, 2008, Shirai et al., (2006), Saliu et al, (2017), Intarasirisawat et al. (2011), and (Czesny et al., 2000).

5.6.2 EPA and DHA

On average, EPA and DHA together comprised an average of 25% of the fatty acids in the 12 roes/caviars for which this was determinable (Figure 14). These ranged from 7% (lake sturgeon, *Acipenser fulvescens*) to 41% (tarako, i.e. pollock). 5 roe/caviars possessed over 30% EPA and DHA, and 4 contained under 20%. Lumpfish roe fatty acids were 43% EPA+DHA, 18% above average, putting them first of 13 if measured against the field. EPA and DHA combined to make up 69% of PUFA content for the roe/caviars from literature on average (Figure 14). The 12 for which this was determinable ranged from 39% (lake sturgeon, *Acipenser fulvescens*) to 88% (kazunoko, i.e., pacific herring) 3 roe/caviars from literature possessed PUFA that was 60% or less EPA and DHA, and 3 possessed PUFA that was over 80% EPA and DHA. Lumpfish roe fatty acids were 87% EPA and DHA, putting them 18% above average and 2nd of 13 if measured against the field.

EPA and DHA also made up an average of 84% of n-3 content for the 12 literature roe/caviars for which this was determinable (Figure 14), ranging from 58% (lake sturgeon) to 97% (European catfish, *Silurus glanis*). 4 of the roe/caviars from literature had n-3 content which was between 70% and 80% EPA and DHA, and of those only one was below 75%. 5 products had n-3 that was over 90% EPA and DHA. Lumpfish roe fatty acid n-3 was comprised of 91% EPA and DHA, 7% above average and ranking them 6th of 13 amongst the roes/caviars.

On average, there was nearly 3 times as much DHA as EPA in the roe/caviars from literature (Figure14), with a range from 20% more DHA than EPA (tarako, i.e. pollock, *Gadus chalcogrammus*) to over 6 times as much (skipjack, *Katsuwonus pelamis*). All 12 roe and caviars for which it was determinable had more DHA than EPA. Of these, 6 had between 1.2 and 2.5 times as much DHA and EPA. Lumpfish roe fatty acids contained 42% more DHA than EPA, less than half of average, but within less than a standard deviation, and ranking them 11th of 13 if measure against the field.

5.6.3 EPA

EPA made up an average of 7% of the fatty acids in the roe/caviars from literature (Figure 14), with a range from 2% (lake sturgeon, *Acipenser fulvescens*) to 19% (tarako, i.e. pollock). Of the 12 roes/caviars for which EPA% was given, 9 were less than 10% EPA, and of those, 7 were less than 5%. Only 3 were above 10% EPA, and of those only were 15% or more. Lumpfish fatty acids were 18% EPA, over 10% and roughly 2 standard deviations above average, and ranking them 2nd of 13 if measured against the field. EPA also made up an average of 20% of PUFA content for the roe/caviars (Figure 14), with a range from 11% (skipjack) to 40% (tarako i.e. pollock). Of the 12 roes/caviars for which this was determinable, 8 possessed PUFA comprised of 20% EPA or less, and of those 5 were less than 15%. Only 3 roes/caviars possessed PUFA comprised of over 30% EPA. Lumpfish roe PUFA was 36% EPA, 16% above average, and putting them at 2nd of 13 if measured against the field. EPA also made up an average of 24% of n-3 content for the roe/caviars (Figure 14), with a range from 13% (skipjack) to 43% (tarako, i.e. pollock). Of the 12 roe/caviars for which this was determinable, 6 have n-3 content which was below 20% EPA, but of those only 2 were below 15%. Only 3 roes/caviars possessed EPA which was over 30% EPA. Lumpfish roe n-3's were 38% EPA, 14% above average and ranking them 2nd of 13 if measured against the field.

5.6.4 DHA

DHA comprised an average of 15% of the fatty acids in the roe/caviars (Figure 14), with a range between 5% (lake sturgeon) and 28% (tobiko i.e. flyingfish, *Cheilopogon agoo*). Of the 18 roes/caviars for which DHA% was given, 7 were less than 10% DHA, and 6 were over 20%. Lumpfish roe fatty acids were 25% DHA, 10% above average and 2nd of 19 if measured against the field. DHA comprised an average of 48% of PUFA content for the 17 roe/caviars for which this was determinable (Figure 14), with a range from 27% (domesticated white sturgeon) to 66% (skipjack). 7 roe/caviars possessed PUFA content that was over 50% DHA, and of those 4 were over 60%. 5 roes/caviars possess PUFA of 40% DHA or less, and of those 2 were under 30%. Lumpfish roe fatty acids were 51% DHA, 3% above average and placing them 8th of 17 if measured amongst the caviars/roe. DHA also makes up and average of 59% of the n-3 content of the roe/caviars (Figure 14), with a range from 40% (red salmon, *Oncorhynchus nerka*) to 80% (skipjack). Of the 17 roe/caviars for which it was determinable, 8 possessed n-3 which was over 60% DHA, and of those 4 were over 70%. 5 roes/caviars contain n-3 that is less than 50% DHA. Lumpfish roe fatty acids were 53% DHA, 6% below average, and putting them at 11th of 18 if measured against the field.

5.6.5 Phospholipids

Phospholipids made up an average of 40% of the lipids for the 20 roe for which this information was available (Figure 14), with a range from 13% (vendace) to 79% (roach, *Rutilus rutilus*). 6 roe were over 60% phospholipids, and of these 2 were over 70%. 8 roes were less than 30% phospholipids, and of those 3 were less than 20%. Lumpfish roe lipids were 22% phospholipids, 18% below average and ranking them 17th of 21 if measured against the field.

6 Discussion

This study has sought to evaluate whether the fatty acid profile of lumpfish roe is a marketable feature, how lumpfish roe lipids/fatty acids compare with the current landscape of n-3 supplements, what income or revenue streams could be generated from a lumpfish roe n-3 supplement, and what marketing leverage can be generated from the positive qualities of the fatty acids. Using the data generated in this study, a dialogue on each of these evaluations is now possible.

6.1 Marketing Leverages

6.1.1 Fatty Acids

Based on the comparisons, lumpfish roes seem to possess a fatty acid profile which could be utilized in any marketing of products or foods using them. It is acknowledged that the percentages of FAME for the roes being compared with the percentage of dose in the fish/krill oils is not ideal, as the lumpfish roe lipids are a raw material, and the fish oils are finished consumer products. It is possible that a consumer nutraceutical derived from lumpfish roe may possess a fatty acid profile which compares more favourably.

n-3

Lumpfish roe fatty acids are below the fish oil n-3 content categories (60% and 70%) set forward by Clough (2008) and the more recent 55% benchmark set by Ciriminna et al. (2017). It is noted that not only is the roe not in a processed, consumer-ready state, but a sizable portion of the consumer products examined also fall below these thresholds. Though the n-3 content of the lumpfish roe is below the averages and medians of the US best sellers, it is still within the range of best-selling products. Lumpfish roe fatty acids had a higher proportional level of n-3 than any of the products originating from Iceland. This would not necessarily mean Icelandic brands are less dense in n-3 content than those which are best sellers in the US. Few of Icelandic provided n-3 percentage data, and those that did were almost all either liquid consumer products (a delivery method which was not prevalent in the US best sellers), or were meant for bulk sale, which may be used outside of direct consumer ingestion.

The krill oil products had a far lower percentage of n-3 content on average than the US bestselling fish oils, and lumpfish roe fatty acids are at a comparable percentage to two of the top 3 products, which were higher by <1%. This falls in line with expectations set in literature which stated that percentage of the krill oil product which is comprised of n-3 is often less important in krill oil products (Kwantes & Grundmann, 2015). In terms of comparisons to other roes according to literature, lumpfish roes score exceptionally well, with no other roe exceeding their n-3 percentage of total or n-3 percentage of PUFA, including common fish oil species like herring (*Clupea harengus* and *Clupea pallasi*), mackerel (*Scomber australasicus*), and various tunas. It was also noted however, that cod (*Gadus morhua*) and haddock (*Melanogramus aeglefinus*), two large stocks in Iceland, also possess roes with a high proportion of n-3, 31% and 44% respectively (Bledsoe et al., 2003).

As a marketing device, n-3 may be a valuable tool in any product that may be produced from lumpfish roes and which maintains a reasonable amount of the fatty acids in the final product. n-3 percentages exceeded expectations in their surpassing of totals of roes from literature, and in placing favorably amongst fully processed end products. Based on the data and results, it would not be irrational to pursue interests in a labeling strategy which denotes the n-3 content of the product.

EPA and DHA

The EPA and DHA content across the various products was less standardized than the impression given by literature such as Clough (2008) and Watters (2012). As hypothesized, lumpfish roe fatty acids in general surpass the consumer level products in categories which took DHA into account. Surprisingly, EPA was not present in a lower percentage than most fish/krill oils. Rather, the presence of EPA in the lumpfish roe as a percentage of FAME compared least favourably against US best-selling fish oils, where it was just below average. It compared most favourably against domestic Icelandic consumer products, finishing with higher EPA levels than all products in that category. Where a drop off did occur was in EPA as a percentage of n-3. This would seem logical due to the higher DHA levels commanding a larger proportion of the n-3 content. Interestingly, lumpfish possess the second highest level of EPA among the roes.

The DHA to EPA percentage is an interesting data for the lumpfish roes, in that it is higher than most products, including several products which tailored their labels towards the benefits of DHA, but lower than others, notably the cod liver oils, and was among the lowest in other roes. Still, it was higher than an overwhelming majority of products. The fact that EPA as a percentage was still comparable to other fish oils is of interest in that it seems to imply an extra presence of DHA, without the trade-off seen in several of the higher DHA products wherein often EPA percentage is diminished. This was also true in the higher roes in this category: the higher DHA to EPA percentage roes, logically, had very low percentages of EPA. The roes from literature possessed much larger proportions of DHA than EPA, often 2 or 3 times as much, and EPA% in the single digits. Lumpfish roes possess just shy of 50% more DHA than EPA, while maintaining a comparable EPA% to much of the fish/krill oil field, and the two fatty acids together make up a higher level of the n-3 than most available products.

The higher EPA levels present in lumpfish roe in comparison the majority of roe from other species, and higher DHA levels than the majority of fish/krill oil products, may provide the lumpfish roe marketing leverage. The lack of dominance of either DHA or EPA, but presence of both, means that marketing would not have to be skewed toward one or the other. This could mean that a food/supplement product derived from lumpfish roes could tout the benefits of either depending on the targeted demographic. As an example, high DHA content would mark it as an ideal product to be marketed towards parents of developing children, due to various benefits (Horrocks & Yeo, 1999). But since the EPA levels are still at levels comparable to many fish/krill oil products, rather than reduced as is often the case, the benefits of EPA and n-3's in general could still be utilized as marketing tools as well.

6.1.2 Phospholipids

Phospholipids as a percentage of total lipids are lower in lumpfish roe than nearly all the krill oils measured (% of dose) and roes listed in Bledsoe et al. (2003). It is noted that the measuring techniques for phospholipids in Bledsoe (2003) may have differed, as this was not directly stated. However, the roe of herring (*Clupea harengus*), the species utilized most in the MOPL30 process currently (Bjørndal et al., 2014), has a phospholipid percentage of around 69%, compared to the lumpfish's 21.5 %. This may mean that the MOPL30 process may be unsuitable for the roes, but further investigation is warranted. It is noted that several krill oils of 20% phospholipids are indeed present on the list of best-selling krill oils, however. As the other primary lipid which was detected is triglycerides, the usual lipid in fish oils, it may be that a marketing avenue exists in which the bioavailability touted by krill oils and the public awareness and depth of literature regarding traditional triglyceride n-3's could be used in tandem for any product derived from lumpfish roes.

6.1.3 Country of Origin

Use of the country of origin and that the lumpfish roe catch is from wild stock may be additional factors in market separation as health foods and supplements continue to expand as industries. During in-person observations performed in Icelandic stores, it was noted that nearly all n-3 supplements on display were from one of the identified Icelandic brands, with wide varieties of Lýsi products dominating the shelf space (Figure 15) with the only noted exceptions being products from NOW Foods, which had products represented in most supplement and food categories seen. It is perhaps assumed, correctly, that the products of Icelandic make generally are comprised of raw material from Icelandic fish stocks. The majority of products in this vein, which in Icelandic stores also possess labels written in Icelandic, make no mention of the fish oils being domestically produced. Local eating may be quite important to the Icelandic market. However, the market is also quite small, and all major producers are known. It is therefore also assumed that products are produced locally, unless stated otherwise.

Figure 16: Picture taken of Icelandic fish oil products for sale in Skagaströnd, Iceland on January 24th, 2018

Interestingly, the only krill oil product seen on shelves from an Icelandic brand (Hafkalk), is the only product whose label told the source of the product's raw materials. Due to most krill oil originating in Antarctica (Kwantes & Grundmann, 2015), it would stand to reason that an assumption of local origin would be unfounded. Thus, disclosure and use of the origin site as a marketing tool, as Hafkalk does, is still a viable strategy in Iceland.

According to Clough (2008), the raw material and species of utilization matters very little in the determination of a fish oil´s success. However, as the marketplace evolves, consumer awareness grows, and the number of products available expands, product differentiation may become increasingly important. A proof of this concept is easily viewed in recent Icelandic news regarding Margildi fish oil beginning to market products in the United States(“Lýsi now marketed in the US,” n.d.). This is due to a contract between Margildi ehf and Icelandic Trademark Holding, whom owns the rights to the “Icelandic Seafoods” brand name. The labels, depicting images of locals wearing wool sweaters and standing in fjords, leave little question as to whether Margildi is attempting to utilize the increasing awareness of Iceland to the benefit of its product (Figure 16) (“MARGILDI SIGNS A MILESTONE CONTRACT WITH ICELANDIC – margildi,” n.d.).

The use of the people and landscapes of Iceland as a marketing strategy, an established phenomenae (Pálsdóttir, 2016) may be of benefit to any lumpfish roes in a similar way. In a break with many products and previous trends (Clough, 2008), the species from which the oil is derived is also displayed on the label of the new Margildi packaging. Even without the MSC certification, the small scale of the fishery itself could be easily utilized in marketing the lumpfish fishery and the fisherman who operate it, aimed towards a similar separation via additional product transparency and purchase confidence, wherein the smaller catch amount could become an asset rather than a hindrance for a niche product.

As an example, it is concievable that given the relatively small scale of the lumpfish fleet, a small survey and photography operation could easily document each vessel and crew. From these, together Small Boat Owner‘s Association, the most marketable could be selected as brand representatives, with pictures and bit of information on each label of lumpfish roe products. This type of pseudo farm-to-table strategy which gives the buyer a direct line to the land and people from which the products originate may be able to build a niche for lumpfish roe products in addition to imiatation caviar. The marketing for either nutraceuticals derived from lumpfish roe or for lumpfish caviar would be strengthened by imagery depicting the ships and people of the fishing fleet. This concept is easily transferable to other markets and industries.

Figure 17: Picture of new branding for Margildi products for export to the USA. Photo courtesy mbl.is ("Lýsi now marketed in the US," n.d.)

6.2 Fiscal Potentials

The potential leverages discussed would be most useful to either a supplement or food item, functional or otherwise. Both of these options possess some degree of overlapping issues with implementation, notably the currently inconsistent and comparatively low catch totals (Hafrannsóknastofnun, n.d.), unknowns surrounding the potential differences which may exist in lumpfish roe fatty acids at different stages in the season (Basby, 1997), and the lumpfish being unscaled (i.e., outside of halal restrictions). It was also thought at the study's outset that a pharmaceutical usage of lumpfish roe may exist in the form of phospholipids, but due to the low amount compared with other species it is likely that this option is unlikely unless a roe emulsion much like that resulting in the MOPL30 process is easily attained, which cannot be known at this point.

6.2.1 Supplements

Though the focus of this study has been on fish/krill oils, it is possible that lumpfish roes could be utilized in supplements outside of this, such as hydrolyzed protein powders as developed alongside the MOPL30 process (Hallaraker et al., 2017) and as created for other species (Rajabzadeh et al., 2017). A similar study to this one, which examines proximate protein content, amino acid profile, and cost effectiveness may be useful for examining this option, as suggested by Balaswamy et al. (2009). Additional items may be feasible, or even created as a by-product from a roe oil extraction process (Bjørndal et al., 2014), and further research into the possibilities should be explored.

In terms of a fish/krill oil-like n-3 supplement being derived from lumpfish roe, it is possible that there may be merit in pursuit of a method to isolate or concentrate the n-3's of the roe as supplement. Although the total n-3 percentage of FAME falls outside of the guidelines of 60% n-3 set by Clough (2008) and the 55% or higher set by Ciriminna et al., (2017), it must be remembered that this was a less sophisticated extraction than even the cruder fish oil concentrations, rather than a fully processed consumer product. Considering that the totals of n-3 for lumpfish roe are near half of the FAME, it may be that a fully completed roe oil, developed with the MOPL30 (Hallaraker et al., 2017) or some other process, would meet or exceed the standards set in Clough (2008) or Ciriminna et al. (2017). Even as is, 479 mg of n-3 per 1g serving as indicated in % FAME seems to be well within industry standards based on the current products in circulation. That the lumpfish roe has the highest percentage of n-3 when measured against a literature which included herring (*Clupea harengus*), the same species currently most used in the MOPL30 process, is especially interesting.

Of the several types of fish oil compositions the 18:12 and 30:20 ratios of EPA to DHA are those which may be most relevant for lumpfish roe (Clough, 2008). Lumpfish roe fatty acids are 18% EPA and 25% DHA, and though this is not directly comparable, the presence of additional DHA which is not at the expense of the EPA percentage of total may not be a drawback. The idea that DHA content is just over double the DHA percentage for the 18:12 category, and an inverse of the 30:20 could conceivably be a feature rather than a flaw, given the rarity of fish oils which have DHA which exceed EPA.

Based on the FAME, a fully processed roe oil liquid or capsule derived from lumpfish may provide a high quality and unique product, one which offers phospholipid and triglycerides, an EPA percentage in keeping with industry standards, and an elevated level of DHA. As currently a prototype n-3 oil from lumpfish roes is not available, speculation into its properties and the classification it might find itself in is simply that, speculation. However, it is recommended that future studies which attempt to isolate roe fatty acids as a supplement, and a comparison of various potential methodologies and species may be warranted. Given their high n-3 content and their prominence in the Icelandic fish stock, the haddock (*Melanogramus aeglefinus*) and cod *(Gadus morhua*) may be prime species for inclusion. Lending even further credence to this is that their phospholipids surpass that of herring (Bledsoe et al., 2003), meaning they may be even better suited to the current MOPL30 process than the herring roes currently utilized. To the best of the author's knowledge, current utilization of fish roe in Icelandic stocks outside of lumpfish is limited to a very few uses.

If enough roes are found suitable, there may an opportunity to compete with a classification of oils derived from fish roes, which possesses the phospholipid bioavailability of krill oil. This marketable trait could be an interesting additional method of market separation. As seen with the new AstaLýsi products ("AstaLýsi - lýsi og astaxanthin," n.d.), qualities and marketing strategies of krill oils are already being mimicked in their fish oil counterparts. While added astaxanthin content answers one challenge put forth by krill oil, it may be possible that use of roe oils (blended or solitary) could be an answer to the bioavailability claim of krill. This would also allow for the possibility of a domestically sourced phospholipid-containing fish oil, which like Icelandic fish oils, could use national branding. This may be ideal given the elevated price of krill oil per gram of n-3 and EPA+DHA (Figure 17). If competing directly with krill oil, the strength of the Icelandic "brand" may be a key differentiating tool both domestically and in export.

The limiting factor with any supplement product, particularly when derived from lumpfish would be cost effectiveness, amount, and processing. While in general, fish oils are considered a rare by-product in that is cost-effective to produce (Olsen et al., 2014), it remains to be seen just how expensive the process of extraction of n-3 from lumpfish roes would be. Though the methods for the MOPL30 process are established, initial readings of the patent (Hallaraker, 2017) indicate that it is likely more expensive than conventional sourcing, and additional studies regarding fatty acid composition through spawning/fishing season is needed for establishment of whether stability in content is possible. This in turn must be weighed against the opportunity cost of diversion of roes from other enterprises.

In addition, it is very likely that the current processing methods of lumpfish roes may require alteration to separate roes for utilization if supplements were to be introduced as a possibility. It is most likely that the salting stage would be the point of divergence between eggs which are to be processed into caviar and other uses, due to this likely being an unnecessary stage for the completion of a supplement. While this may prove a challenge, changes to processing were successfully implemented previously in the mandate of on-shore gutting (Þórðarson et al., 2013).

While the ultimate composition and process cannot be finalized at this point, the results for average price per gram of n-3 and price per gram of EPA+DHA may provide some rough estimates as to the potential return on investments in processing when applied to the tonnage of lumpfish landings (Figure 3). The fatty acid values, with the highest possible value (price per gram of EPA and DHA, when using krill pricing, at 6500 tonnes catch) being over 14 million k ISK, and lowest being over 2 million k ISK (price per gram of n-3, using US best sellers pricing, at 4500 tonnes catch). It must also be remembered that such figures are based on averages, and assume the FAME as equal to total lipids, which is likely not the case. The actual income available from a final product, processed and ready for consumers may be different, but even this non-definitive suggestion of value, based solely from lumpfish, is indicative of merit for further study and warrants an attempt to identify a method best suited to creation of a high n-3 supplement. This is further bolstered when one again recognizes that the maximum value of the catch achieved in the previous 15 years was 2.3 million k ISK. (Chambers, 2017). If workable in small scale, but only cost effective with larger product, such a project still may find merit in inclusion of other species.

6.2.2 Foods and Functional Foods

In certain strategies, food items would require far less additional work to benefit from the marketing leverages offered. As it stands now, it would not be impossible to place a "high in n-3's" label on lumpfish caviars, given that the salt processing has little impact on the content of fatty acids, and those that do occur were only for heavily salted products and linked to temperature control (Basby, 1997).

Given the total lipids and percentage FAME which is n-3, a 50g serving of lumpfish roe will almost certainly have over 500 mg of n-3, and possibly over 1 g, 90% of which is likely to be either EPA or DHA. This could be a useful denotation upon any whole food item as a marketing tool, as has been seen with tuna products for market differentiation ("Omega-3 Prime Fillet® Solid White Albacore Tuna | Bumble Bee Tuna & Seafood Products," n.d.). Initial steps in investigating this would be research into the various n-3 label markers available to food products, and what barriers (applications, legalities, etc.) to use may need to be addressed to label the caviar or roe-based food products accordingly. Additionally, third-party organizations which certify the products for n-3 content and/or heart health (much like how the Marine Stewardship Council certifies for sustainability) should be identified.

The use of an n-3/EPA+DHA label on the existing lumpfish roes may be able to assist lumpfish caviars in boosting sales among caviars, but the COO or n-3 would likely be only a factor in deciding which product to buy, rather than whether or not to buy a product(Dobrenova et al., 2015). A more likely minimal option which could still make use of the n-3, would be finding of new markets for the product as is. This effort may be aided by use of fatty acid and COO labelling and marketing, but further study would be needed to quantify the extent of the impact this might have. Relevant research is clearly ongoing already within Iceland, given the strategies of exporting under the "Icelandic" brand name and increasing strategy to denote the source of products originating in Iceland. Any further research could be well-served through outreach to and coordination with Matís ohf, Margildi ehf., and/or Icelandic Group ehf.

Simple expansion to other markets was explored extensively during the process of investigation which culminated in the fish themselves being exported to China for consumption (Þórðarson et al., 2013). However, given the increasing trends of preference for source transparency and awareness of n-3 benefits, a re-visit with these new variables in consideration may also be warranted. This may simply be a re-assessment with different labelling, and the ideal starting point for this work would be the reports performed in assessing the potential for exports of the fish themselves (Þórðarson et al., 2013).

Several potential uses of the roe as an ingredient exist, per Balaswamy et al. (2009), such as pastas, sausages, and baked goods which utilize the n-3 and protein content as functional additives, and the n-3 of lumpfish roes being as rich in the fatty acids as they are would seem to indicate the potential of a fit to this use. Though protein analyses were not conducted as a part of this study, they were performed in Basby (1997), which indicated a high level of protein was present. A protein study of the roe is warranted to re-examine and confirm these findings. The products created in the Balaswamy et al. (2009) study yielded promising results in terms of sensory testing, and a similar set of products should be created from lumpfish roe to test the possibilities of each individual application based on nutrition. Any product successfully created in this manner would stand to benefit from the same marketing leverages of COO and n-3 content (assuming the latter is left intact for the product type).

Finally, explorations into new ways to prepare/package/process roes could also feasibly benefit from the fatty acids and COO, in the same way as suggested for labelling and marketing the caviar with n-3 and ties to Iceland. Like the caviars, and unlike the supplements, these new outputs would benefit from the full nutritional profile of the roe and could be marketed accordingly as a health-conscious choice dependent on what exactly a new preparation entails. The identification of which new preparation methods are most acceptable in a sensory sense is paramount, as is tailoring of preparation to potential untouched markets which may be receptive. New food combinations, cooking techniques, marinade styles, and reception from various demographics could widely expand the reach of lumpfish roes, and additional experimentation focusing on sensory feedback should be undertaken. At the time of writing, it is the author's understanding that there are several such tests ongoing, in which various cooking methods and marinade styles are being evaluated for feasibility, with a focus on fresh roes, much like the shifting of salmon roe preferences in Japan as described in Bledsoe (2003). Whichever of these options which would be deemed most successful, the fatty acids and connection to Iceland will be beneficial regardless.

7 Conclusions

This study has set out to attempt to quantify whether the n-3 content of Icelandic lumpfish roe is a workable asset in attempting to bring additional value to the catch. This aspect was chosen because of the growing consumer awareness of the benefits of n-3 fatty acids as well as the expanding market for foods and supplements which feature n-3's (Clough, 2008). By comparing the n-3 fatty acids of the lumpfish roe to a multitude of various n-3 fish and krill oil products, it has been determined that the n-3 content is a valuable quality and could be utilized by any lumpfish roe products that do not remove fats. This has been supported based on the lumpfish roe fatty acids n-3 percentage of FAME exceeding the n-3 percentage of product of all current domestically produced fish oils found (bulk and consumer), all best-selling krill oils, and all other roes from literature, including herring.

The specific EPA and DHA contents have also been found to be an interesting possible sub-asset of the n-3 content. Based on data gathered from literature, it was thought that the lumpfish n-3's would be higher proportionally in DHA and lower in EPA than the majority of consumer and bulk fish/krill oils. While it has held that DHA levels are indeed proportionally higher, EPA levels were not proportionally lower. The roughly 3:2 ratio of DHA to EPA, in fatty acids which are nearly 50% n-3, may be a niche composition. According to Clough (2008) and Ciriminna et al. (2017), the 18/12TG oil is most commonly produced for fish oils. There is also a set of products that present this same proportion, but in larger proportional presence of n-3 (i.e., 30:20 EPA to DHA) (Clough, 2008). The use of a product which is 18:25 EPA to DHA, merely doubling the DHA in 18/12TG or the inverse of the 30:20 types, may be an interesting raw material as the knowledge of EPA and DHA in isolation continues to grow and various ratios are explored more thoroughly (Mozaffarian & Wu, 2012). Potential value of the roe's n-3 content was also determined, with the n-3 of the catch being worth between 2 million k ISK and 14 million k ISK.

It has been found that phospholipid content of the lumpfish roe is likely not a substantial asset, based upon their presence being lower than most krill oils and roe of other species. While this still could be of use in terms of future applications, it is not a comparatively high source.

Based on observations and trends in the market, as well as recent developments in Icelandic fish oils, it has been observed that country of origin may be an easy way to add value to the stock. While not quantified by the research, it is the strategy that major entities in Icelandic fish oils appear to be attempting in foreign markets ("MARGILDI SIGNS A MILESTONE CONTRACT WITH ICELANDIC – margildi," n.d.). Based on Iceland's positive association with seafood and marine products, and the small-scale state of the wild caught fishery, eco-labels which highlight this may also be valuable (Brécard et al., 2009).

7.1 Limitations

The study results are limited by the more simplistic processing of the roe in comparison to the supplements collected. While it does not appear to handicap the roe as a comparative, the results are likely less favourable to lumpfish roe than they could otherwise be. In addition, supplement data other than US best sellers (those provided by Labdoor's independent testing), was based upon data found on the nutritional label. It would have been preferable to attain the same details across the spectrum of various products. Additionally, the author was living in Iceland for the duration of the time this study was completed. It was initially hoped that a period would be spent in the United States in order to perform a more thorough quantification of the potential benefits of seafoods using Icelandic origin as a value multiplier in exports.

7.2 Value and Future Research

The value of the research performed is primarily that it allows a rapid way to counteract the loss of the MSC label. A denotation of n-3 fatty acid content and label connecting the product more strongly with Iceland and the fishermen themselves may be able to add value to the product in both a short-term stop-gap and a long-term value multiplier. It also may set a precedent with which to more thoroughly examine the roe as a source of n-3. Unintentionally, the research has created a detailed comparison tool for any fish or krill oil product seeking to enter the market and requiring a snapshot of the products and pricing available.

In terms of future research, there are several recommendations. It is recommended that creation of a lumpfish roe oil is attempted using either or both the MOPL30 process and traditional methods utilized to make/refine krill and fish oils. Ideally, oils should be created using multiple processes, and evaluated for content of n-3. This could also be done for haddock and cod roes, due to their larger footprint in the Icelandic stocks, high n-3 content, and high phospholipid content. Ideally, these oils should also be tested for efficacy, against one another and existing oils.

Though not explored in this study, aquaculture applications should also be considered. Lumpfish are already utilized in aquaculture against sea lice, so an integrative measure in which roe as an n-3 source for fish feed is cultivated along with the anti-lice lumpfish could be explored. In order to better quantify the value of an n-3 label on food, the importance of health factors among caviar buyers could be examined in a survey study. Similarly, the study of country of origin labels connecting seafood products to Iceland should be studied via survey of seafood and fish oil consumers. Ideally, this should be performed both within and outside of Iceland, in an attempt to quantify the actual value this may offer. A sea-to-table project, connecting Icelandic seafood products to the fishermen who catch them via labelling and Icelandic imagery should also be undertaken. Finally, kitchen and food creation studies should be undertaken to develop foods or food preparation methods which may extend lumpfish roe into untapped areas. These should be tailored to speculated markets, with sensory testing performed by both locals and those from the targeted markets.

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Appendix A

Matís fatty acid analyis.

Biopol Sjávarlíftæknisetur		**Reykjavík 7.11.2017**
Fattyacid analysis as % FAME, fatty acid methyl esters		
Starlims no		
Merking	**Biopol 1**	**Biopol 2**
	Sample 1	**Sample 2**
C14:0	1.5	1.6
C15:0	0.3	0.3
C16:0	14.4	14.5
C16:1n7	2.0	2.0
C17:0	0.3	0.3
C16:3n4	0.3	0.3
C18:0	3.6	3.6
C18:1(n9+n7+n5)	21.0	21.1
C18:2n6	1.1	1.1
C18:3n3	0.6	0.6
C18:4n3	0.6	0.6
C20:0	0.1	0.1
C20:1(n11+n9+n7)	2.9	2.9
C20:3n3	0.7	0.7
C20:4n6	0.3	0.3
C20:4n3	0.8	0.8
C20:5n3 (EPA)	17.9	17.9
C22:0	0.5	0.6
C22:1(n11+n9)	1.3	1.3
C22:2	0.3	0.3
C22:4n6	0.2	0.2
C22:5n3	1.8	1.8
C22:6n3 (DHA)	25.4	25.4
C24:1n9	0.3	0.3
SFA	20.7	20.9
MUFA	27.4	27.6
PUFA	49.9	50.1
TFA	0	0
unknown	2.0	1.4
EPA + DHA	43.3	43.4
Total omega 3	47.8	47.9

SFA = saturated fatty acids (mettaðar fitusýrur); MUFA = monounsaturated fatty acids (einómettaðar fitusýrur); PUFA = polyunsaturated fatty acids (fjölómettaðar fitusýrur); TFA = trans fatty acids (transfitusýrur); EPA = eicosapentaenoic acid (C20:5n-3); DPA = docosapentaenoic acid (C22:5n-3); DHA = docosahexaenoic acid (C22:6n-3)

Ingibjörg R. Þorvaldsd.

Ingibjörg R.Þorvaldsdóttir
Research Scientist

Appendix B

US Best-Selling fish oil data and calculations. Initial data courtesy of Labdoor Inc.

Product	Serving	Omega-3 %	Omega-3 tot	IOM Rec Y/N	DHA+EPA %	DHA+EPA % O-3	DHA+EPA tot	EPA total (mg	EPA % of O-3	EPA % of prod	DHA total (m	DHA % of O-3	DHA % of prod	DHA to EPA	Mercury (P	Price (US	Capsule	Serving S	Price Per Serving	Price per g O-3	Price per g EPA+DHA
WHC UnoCardio*	1225.529412	85%	1041.7	N	77%	90.6%	950.5	556.5	0.534222905	0.454089469	394	0.378227897	0.321493712	0.707996406	<4	43.95	60	1	0.7325	0.703177498	0.770647028
Viva Naturals Triple Strength	2305.647059	85%	1959.8	Y	79%	92.9%	1829.7	1351.4	0.689560159	0.586126135	478.3	0.244055516	0.207447188	0.353929259	<10	37.86	180	2	0.420666667	0.214647753	0.229910186
WHC UnoCardio (Reformulated)	1360.623557	87%	1178.3	Y	85%	98.2%	1160	642.2	0.54502249	0.471989476	517.8	0.43944666	0.380560808	0.806290875	<1.4	44.95	60	1	0.749166667	0.635802993	0.645833333
OmegaVia	1307.692308	91%	1190	Y	86%	94.5%	1130	870	0.731092437	0.665294118	260	0.218487395	0.198823529	0.298850575	1	34.22	60	1	0.570333333	0.479271709	0.504719764
WHC UnoCardio Triglyceride	975.1764706	85%	828.9	N	78%	91.8%	755.9	405	0.488599349	0.415309446	350.9	0.423332127	0.359832308	0.866419753	11		60	1			
Nutrigold Triple Strength	1271.73913	92%	1170	Y	89%	96.7%	1140	900	0.769230769	0.707692308	240	0.205128205	0.188717949	0.266666667	3	56.78	180	2	0.630888889	0.539221273	0.553411306
Omax3 Ultra-Pure	1648.351648	91%	1500	Y	89%	97.8%	1458	1178	0.785333333	0.714653333	280	0.186666667	0.169866667	0.237691002	4	39.95	60	2	0.665833333	0.887777778	0.913351623
Vitamin Shoppe*	1236.842105	85%	1050	N	76%	89.5%	940	680	0.647619048	0.549787234	260	0.247619048	0.210212766	0.382352941	1	19.55	60	1	0.325833333	0.31031746	0.346631206
Ocean Blue Professional	2353.658537	82%	1930	Y	74%	90.2%	1740	1260	0.652849741	0.535336788	480	0.248704663	0.203937824	0.380952381	1	19.55	60	2	0.651666667	0.337651123	0.374521073
InnovixLabs Triple Strength	1249.941793	86%	1073.7	N	76%	87.9%	944.8	613.1	0.571016113	0.490502841	331.7	0.308931731	0.265372357	0.541021041	<9	29.99	200	1	0.14995	0.13965726	0.158710838
Controlled Labs OxiMega	1924.050633	79%	1520	Y	75%	94.9%	1440	980	0.644736842	0.509342105	460	0.302631579	0.239078947	0.469387755	1	16.38	120	2	0.273	0.179605263	0.189583333
Sam's Club Simply Right	1397.435897	78%	1090	N	66%	84.6%	925	679	0.62293578	0.485889908	246	0.225688073	0.176036697	0.362297496	1	23.62	150	1	0.157466667	0.144464832	0.170234234
Nordic Naturals Ultimate	2140.625	64%	1370	Y	58%	90.6%	1240	770	0.562043796	0.359708029	470	0.343065693	0.219562044	0.61038961	3	24.61	60	2	0.820333333	0.598783455	0.66155914
NOW Foods Ultra	1093.023256	93%	1020	N	86%	92.2%	940	650	0.637254902	0.594680851	290	0.284313725	0.265319149	0.446153846	2	11.98	90	1	0.133111111	0.130501089	0.141607565
Life&Food Supreme	1345.238095	84%	1130	Y	78%	92.9%	1092	734	0.649557522	0.545628319	358	0.316814159	0.266123894	0.48773842	2		180	1			
MRM Smart Blend**	1733.333333	45%	780	N	34%	75.6%	590	370	0.474358974	0.213461538	220	0.282051282	0.126923077	0.594594595	2	25.89	240	1	0.21575	0.276602564	0.365677966
Spring Valley Triple Strength	1527.777778	72%	1100	Y	67%	93.1%	1027	744	0.676363636	0.486981818	283	0.257272727	0.185236364	0.380376344	10	18.69	60	1	0.3115	0.283181818	0.303310613
Dr. Tobias Optimum	1942.528736	87%	1690	Y	78%	89.7%	1520	920	0.544378698	0.473609467	600	0.355029586	0.30887574	0.652173913	2	29.97	180	2	0.333	0.19704142	0.219078947
Axis Labs Citrus	1898.734177	79%	1500	Y	70%	88.6%	1330	900	0.6	0.474	430	0.286666667	0.226466667	0.477777778	2	18.95	120	2	0.315833333	0.210555556	0.237468672
GNC Triple Strength	1445.783133	83%	1200	Y	73%	88.0%	1050	670	0.558333333	0.463416667	380	0.316666667	0.262833333	0.567164179	1	44.99	60	1	0.749833333	0.624861111	0.714126984
Trader Joe's	1257.575758	66%	830	N	59%	89.4%	750	520	0.626506024	0.413493976	230	0.277108434	0.182891566	0.442307692	1	9.99	90	1	0.111	0.13373494	0.148
GNC Ultra Triple Strength 1560	1465.116279	86%	1260	N	78%	90.7%	1150	890	0.706349206	0.607460317	260	0.206349206	0.177460317	0.292134831	3		60	1			
Nutrigold Double Strength	1307.692308	65%	850	N	63%	96.9%	817	564	0.663529412	0.431294118	253	0.297647059	0.193470588	0.44858156	1	15.64	60	1	0.260666667	0.306666667	0.319053448
Bausch+Lomb Ocuvite**	660.3773585	53%	350	N	42%	79.2%	280	180	0.514285714	0.272571429	100	0.285714286	0.151428571	0.555555556	2	9.78	30	1	0.326	0.931428571	1.164285714
GNC Triple Strength + Krill	1448.717949	78%	1130	N	73%	93.6%	1060	770	0.681415929	0.531504425	290	0.256637168	0.200176991	0.376623377	2		30	1			
MusclePharm	976.4705882	85%	830	N	74%	87.1%	720	430	0.518072289	0.440361446	290	0.34939759	0.296987952	0.674418605	4	11.02	90	1	0.122444444	0.147523427	0.170061728
Schiff MegaRed Extra Strength Krill	396.5517241	29%	115	N	28%	96.6%	112	73	0.634782609	0.184086957	39	0.339130435	0.098347826	0.534246575	1	19.62	80	1	0.24525	2.132608696	2.189732143
Twinlab	950	60%	570	N	56%	93.3%	530	330	0.578947368	0.347368421	200	0.350877193	0.210526316	0.606060606	1	14.7	100	1	0.147	0.257894737	0.277358491
Nordic Naturals Baby DHA	3695.652174	23%	850	N	16%	69.6%	600	270	0.317647059	0.073058824	330	0.388235294	0.089294118	1.222222222	4	13.56	2ml	60floz			
Sundown Triple Strength	1413.333333	75%	1060	N	70%	93.3%	984	730	0.688679245	0.516509434	254	0.239622642	0.179716981	0.347945205	3		60	1			
Schiff MegaRed Krill	369.2307692	26%	96	N	22%	84.6%	81	52	0.541666667	0.140833333	29	0.302083333	0.078541667	0.557692308	2	29.35	60	1	0.489166667	5.095486111	6.03909465
GNC Triple Cod Liver	1057.142857	35%	370	N	31%	88.6%	320	200	0.540540541	0.189189189	120	0.324324324	0.113513514	0.6	2	9.39	90	1	0.104333333	0.281981982	0.326041667
Nature's Bounty	2272.727273	66%	1500	Y	59%	89.4%	1350	870	0.58	0.3828	480	0.32	0.2112	0.551724138	5	12.47	90	2	0.277111111	0.184740741	0.20526749
Life Extension Super	2442.622951	61%	1490	Y	56%	91.8%	1380	830	0.55704698	0.339798658	550	0.369127517	0.225167785	0.662650602	1	18	120	2	0.3	0.201342282	0.217391304
Country Life	969.6969697	33%	320	N	29%	87.9%	280	170	0.53125	0.1753125	110	0.34375	0.1134375	0.647058824	1	17.54	200	1	0.0877	0.2740625	0.313214286
Solgar	1914.285714	35%	670	N	30%	85.7%	570	350	0.52238806	0.182835821	220	0.328358209	0.114925373	0.628571429	1	12.16	120	2	0.202666667	0.302487562	0.355555556
Bodybuilding.com Foundation	1242.424242	33%	410	N	26%	78.8%	320	190	0.463414634	0.152926829	130	0.317073171	0.104634146	0.684210526	3		100	1			
Nordic Naturals Purified	2031.25	32%	650	N	28%	87.5%	570	360	0.553846154	0.177230769	210	0.323076923	0.103384615	0.583333333	4	36.93	180	1	0.410333333	0.631282051	0.719883041
Natrol	2000	44%	880	N	33%	75.0%	660	420	0.477272727	0.21	240	0.272727273	0.12	0.571428571	6	11.73	150	1	0.0782	0.088863636	0.118484848
MET-Rx Fish Oil+D	1088.235294	34%	370	N	29%	85.3%	320	200	0.540540541	0.183783784	120	0.324324324	0.11027027	0.6	3		90	1			
New Chapter Wholemega	1962.962963	27%	530	N	19%	70.4%	370	170	0.320754717	0.086603774	200	0.377358491	0.101886792	1.176470588	2	11.19	30	1	0.746	1.40754717	2.016216216
GNC 1000	942.8571429	35%	330	N	30%	85.7%	284	210	0.636363636	0.222727273	74	0.224242424	0.078484848	0.352380952	3		360	1			
Nature Made Cod Liver	541.6666667	24%	130	N	19%	79.2%	100	50	0.384615385	0.092307692	50	0.384615385	0.092307692	1	6	49.18	100	1	0.4918	3.783076923	4.918
Nature Made Fish Oil	2387.096774	31%	740	N	26%	83.9%	620	380	0.513513514	0.159189189	240	0.324324324	0.100540541	0.631578947	2	13.25	180	2	0.147222222	0.198948949	0.237455197
Carlson Labs	1121.212121	33%	370	N	30%	90.9%	340	220	0.594594595	0.196216216	120	0.324324324	0.107027027	0.545454545	3	32.18	240	1	0.134083333	0.362387387	0.394362745
Top Secret Fish+ CLA**	1000	73%	730	N	31%	42.5%	305	180	0.246575342	0.18	125	0.171232877	0.125	0.694444444	3		10	1			
Pure Alaska Salmon Oil	1964.285714	28%	550	N	21%	75.0%	420	180	0.327272727	0.091636364	240	0.436363636	0.122181818	1.333333333	1	16.35	180	2	0.181666667	0.33030303	0.432539683
Kirkland Signature	974.3589744	39%	380	N	33%	84.6%	320	240	0.631578947	0.246315789	80	0.210526316	0.082105263	0.333333333	1	17.71	400	1	0.044275	0.116513158	0.138359375
Nature's Answer Liquid	4689.655172	29%	1360	Y	26%	89.7%	1210	740	0.544117647	0.157794118	470	0.345588235	0.100220588	0.635135135	2	21.76					
Optimum Nutrition	1000	32%	320	N	28%	87.5%	280	160	0.5	0.16	120	0.375	0.12	0.75	2	12.22	200	1	0.0611	0.1909375	0.218214286
Spring Valley Fish Oil	969.6969697	33%	320	N	27%	81.8%	260	140	0.4375	0.144375	120	0.375	0.12375	0.857142857	1	24.75	100	1	0.2475	0.7734375	0.951923077
Met-Rx Triple Omega	2285.714286	14%	320	N	11%	78.6%	260	140	0.4375	0.06125	120	0.375	0.0525	0.857142857	4	16.72	240	2	0.139333333	0.435416667	0.535897436
Puritan's Pride Premium	1206.896552	29%	350	N	25%	86.2%	300	200	0.571428571	0.165714286	100	0.285714286	0.082857143	0.5	1	8.39	100	1	0.0839	0.239714286	0.279666667
Nordic Naturals Fishies	8500	2%	170	N	2%	88.2%	150	100	0.588235294	0.011764706	50	0.294117647	0.005882353	0.5	1	29.71	30	1	0.990333333	5.825490196	6.602222222
Median	1352.93	63%	840		56%	89%	735	425	56%	34%	243	32%	17%	56%		18.95			0.273	0.302487562	0.346631206
Standard Deviation	1193.06	26%	477.49		25%	9%	456.24	332.37	11%	19%	144.70	6%	8%	23%		12.062953			0.245346233	1.221308002	1.446845317
Average	1664.62	57%	861.54		50%	87%	764.37	507.08	56%	34%	257.29	31%	17%	59%		23.048222			0.340366344	0.733186015	0.855550351
Lumpfish Roe		47.85%			43.40%	90.7%			37.4%	17.90%		53%	25.40%	142%							

Appendix C

Data and Calculations for domestic bulk fish oils.

Bulk Items													
Product	PUFA% (min)	EPA% (min)	EPA mg/g	EPA% O-3	DHA% (min)	DHA mg/g	DHA% Omega-3	DHA+EPA %	DHA +EPA% O-3	EPA+DHA mg/g	DHA to EPA	O-3%	O-3 mg/g
LYSI													
Cod Oil	20%	8%	80		7%	70		15%		150	114%	NG	NG
Cod Liver Oil	20%	8%	80		9%	90		17%		170	112.5%	NG	NG
Cod Liver-API Grade	NG	8%	80		9%	90		17%		170	112.5%	NG	NG
Omega-3 Fish	NG	18%	180		12%	120		30%		300	66.7%	NG	NG
Omega-3 Fish-API Grade	NG	18%	160	0.533333333	12%	105	0.35	30%	85.7%	265	66%	35%	300
Omega-3 Ethyl Esters 33/22	NG	33%	290		22%	195		55%		485	67%	NG	NG
Tuna Fish Oil	NG	5%	50		25%	250		30%		300	500%	NG	NG
Margildi													
Herring Oil	NG	7%	70	0.35	8%	80	0.4	15%	75.0%	150	114.3%	20%	200
Mackerel Oil	NG	8%	80	0.333333333	9%	90	0.375	17%	70.8%	170	112.5%	24%	240
Capelin Oil	NG	6%	60	0.545454545	4%	40	0.363636364	10%	86.4%	100	58.3%	11%	110
Average		**12%**	**113.00**	**44%**	**12%**	**113.00**	**37%**	**24%**	**79%**	**226.00**	**132%**	**23%**	**212.50**
SD		**8%**	**71.42**	**10%**	**6%**	**59.55**	**2%**	**13%**	**7%**	**107.88**	**125%**	**9%**	**69.06**
Lumpfish Roe	**50%**	**17.9%**		**37.45%**	**25.4%**		**53.20%**	**43%**	**90%**		**142%**	**47.85%**	
											92%		
											^Avg sans outlier		
											24%		
											^SD sans outlier		

Appendix D

Data and calculations for domestic consumer fish oils with simple labels.

Brand	Product	Omega-3 (mg)	DHA+EPA mg	DHA+EPA% O-3	DHA to EPA	EPA mg	EPA%O-3	DHA mg	DHA % O-3	Price ISK	Capsules	Serving Size	Price Per Serving	Price g 0-3	Price g DHA + EPA
LYSI	Omega-3 Forte	620	515	83%	66%	310	50%	205	33%	1528	32	1	25.46666667	77.01612903	92.7184466
LYSI	Cod Liver Capsules	118	43	36%	13%	38	32%	5	4%	1062	120	2	17.7	150	411.627907
LYSI	Children's Cod Liver		2000		186%	700		1300		912	240	10	38		19
LYSI	Liquid Cod Liver	2160	1610	75%	133%	690	32%	920	43%	736	240	10	30.66666667	14.19753086	19.04761905
LYSI	Omega-3 Fish Oil Liquid		1196		63%	736		460		719	240	5	14.97916667		12.52438685
LYSI	Omega-3+D Liquid		1196		63%	736		460		939	240	5	19.5625		16.35660535
LYSI	Health Duet*	335	260	78%	63%	160	48%	100	30%	454	32	1	14.1875	42.35074627	54.56730769
LYSI	Omega-3 + D	335	260	78%	63%	160	48%	100	30%	1088	120	2	18.13333333	54.12935323	69.74358974
LYSI	Omega-3 Calcium + D*	335	260	78%	63%	160	48%	100	30%	1208	30	1	40.26666667	120.199005	154.8717949
LYSI	Omega-3 HYAL-Joint*	620	515	83%	66%	310	50%	205	33%		12	1			
LYSI	Sport Trio Energy*	620	515	83%	66%	310	50%	205	33%	549.3333333	16	1	34.33333333	55.37634409	66.66666667
LYSI	Omega-3 Capsules	335	260	78%	63%	160	48%	100	30%		120	1			
LYSI	Omega-3 Eyes*	400	310	78%	63%	190	48%	120	30%		64	1			
LYSI	Omega-3 Chewables	400	310	78%	63%	190	48%	120	30%	802	60	2	26.73333333	66.83333333	86.23655914
LYSI	Sport Trio Joints *	620	515	83%	66%	310	50%	205	33%		8	1			
LYSI	Omega-3 Glucosamine and	335	260	78%	63%	160	48%	100	30%		12	1			
Dropi	Liquid	1150	800	70%	129%	350	30%	450	39%	3599	220	5	74.97916667	71.12648221	102.2443182
Dropi	Capsules	230	160	70%	129%	70	30%	90	39%	5300	120	2	88.33333333	384.057971	552.0833333
Guli Miðin	Mega Omega		390		67%	234		156		1715	80	1	21.4375		54.96794872
KeyNatura	AstaLysi	900	675	75%	114%	315	35%	360	40%	1680		5ml			
KeyNatura	AstaOmega	398	179	45%	198%	60	15%	119	30%						
Hafkalk	Krill (400 mg PL's)	220	176	80%	47%	120	55%	56	25%	3941	60	2	131.3666667	597.1212121	746.4015152
Median		399	350	78%	65%	212	48%	138	30%	1075			26.7	71.1	69.7
Average		562.8333333	563.8636364	74%	84%	294.045455	42%	269.8182	31%	1639.5			39.7	148.4	163.9
SD		458.7657657	494.859695	12%	44%	216.662384	10%	300.5085	8%	1354.6			32.1	171.1	215.3
Lumpfish				91%	142%		37.5%		53%						

Appendix E

Data and calculations for domestic consumer fish oils with detailed labels.

Brand	Product	ml	g	v/w	Serving ml	Serving g	MUFA g	MUFA %	PUFA g	PUFA %	0-3 Total g	0-3 % PUFA	0-3% total	EPA g	EPA% PUFA	EPA% 0-3	EPA % Product	DHA g	DHA% PUFA	DHA% 0-3	DHA% Product	EPA+DHA g	EPA+DHA% PUFA	EPA+DHA% Product	DHA+EPA% 0-3	DHA to EPA
LYSI																										
	Cod Liver Capsules					0.5	0.25	50%	0.17	34%	0.118	69%	24%	0.038	22%	32%	8%	0.05	29%	42%	10%	0.088	52%	18%	75%	132%
	Children's Cod Liver Oil	240	220	0.916667	10	9.16666667	3.9	43%	3.3	36%				0.7	21%		8%	1.3	39%		14%	2	61%	22%		186%
	Liquid Cod Liver	240	220	0.916667	10	9.16666667	4.6	50%	3	33%	2.16	72%	24%	0.69	23%	32%	8%	0.92	31%	43%	10%	1.61	54%	18%	75%	133%
	Omega-3 Fish Oil Liquid	240	220	0.916667	5	4.583	1.2	26%	2.2	48%				0.736	33%		16%	0.46	21%		10%	1.196	54%	26%		63%
	Omega-3 + D Liquid	240	220	0.916667	5	4.583	1.2	26%	2.2	48%				0.736	33%		16%	0.46	21%		10%	1.196	54%	26%		63%
Dropi																										
	Liquid Oil	240	220	0.916667	5	4.58333333	1.5	33%	2.3	50%	1.15	50%	25%	0.35	15%	30%	8%	0.45	20%	39%	10%	0.8	35%	17%	70%	129%
	Capsules					1	0.46	46%	0.3	30%	0.23	77%	23%	0.07	23%	30%	7%	0.09	30%	39%	9%	0.16	53%	16%	70%	129%
	Average	240	220	0.916667	7	5.51388889	2.143333	37.3%	2.216667	40.8%	1.18	66.2%	23.9%	0.547	24.9%	31%	10.3%	0.613333333	26.9%	40%	10.5%	1.16033333	51.9%	20.8%	71%	117%
	SD					3.18940991	1.568482	9.9%	1.13759	7.9%	0.82305574	10.2%	0.8%	0.293673	6.2%	1%	3.9%	0.411468252	6.7%	2%	1.6%	0.65747557	7.4%	4%	2%	40%
	Lumpfish							27.5%		50%		96%	47.9%		35.8%	37.5%	17.9%		50.9%	53.2%	25.4%		86.6%	43.30%	90.7%	142%

Appendix F

Data and calculations for best-selling krill oils.

	Krill Oil mg	O-3 mg	O-3%	DHA + EPA mg	DHA + EPA% O-3	DHA +EPA % Total	DHA to EPA	EPA mg	EPA % O-3	EPA % Total	DHA mg	DHA% O-3	DHA % Total	PL mg	PL % Total	Price (USD)	Capsules	Serving Size (capsules)	Price Per Serving	Price per g O-3	Price per g EPA + DHA
Viva Naturals	1250	300	0.24	260	0.866666667	0.208	0.575757576	165	0.55	0.132	95	0.316667	0.076	500	0.4	27.95	60	2	0.931666667	3.105555556	3.583333333
Sports Research Antarctic Krill	1000	230	0.23	188	0.817391304	0.188	0.46875	128	0.5565217	0.128	60	0.26087	0.06	400	0.4	29.95	60	1	0.499166667	2.170289855	2.655141844
MegaRed Advanced 4 in 1*	500	339	0.678	314	0.926253687	0.628	NG	NG	NG	NG	NG	NG	NG	NG	NG	20.89	40	1	0.52225	1.540560472	1.663216561
Jarrow Formulas Krill Oil	1200	260	0.216667	190	0.730769231	0.158333333	0.583333333	120	0.4615385	0.1	70	0.269231	0.058333333	650	0.541667	15.2	60	2	0.506666667	1.948717949	2.666666667
Natrogix Antarctic Krill Oil	1500	123.5	0.082333	79	0.639676113	0.052666667	0.362068966	58	0.4696356	0.03866667	21	0.17004	0.014	730	0.486667	24.99	180	3	0.4165	3.372469636	5.272151899
Bronson Antarctic Krill Oil	1000	200	0.2	200	1	0.2	0.666666667	120	0.6	0.12	80	0.4	0.08	200	0.2	18.99	120	2	0.3165	1.5825	1.5825
NatureMyst Professional SuperiorRed	1250	601	0.4808	541	0.900166389	0.4328	0.595870206	339	0.5640599	0.2712	202	0.336106	0.1616	450	0.36	14.39	60	2	0.479666667	0.798114254	0.886629698
Onnit Krill Oil	1000	240	0.24	190	0.791666667	0.19	0.461538462	130	0.5416667	0.13	60	0.25	0.06	400	0.4	29.95	60	2	0.499166667	4.159722222	5.254385965
MegaRed Extra Strength	500	115	0.23	94	0.817391304	0.188	0.46875	64	0.5565217	0.128	30	0.26087	0.06	167	0.334	21.99	80	1	0.274875	2.390217391	2.924202128
NOW Neptune Krill	1000	230	0.23	190	0.826086957	0.19	0.583333333	120	0.5217391	0.12	70	0.304348	0.07	390	0.39	27.3	60	1	0.455	1.97826087	2.394736842
MegaRed Ultra Concentration	750	225	0.3	180	0.8	0.24	NG	NG	NG	NG	NG	NG	NG	390	0.52	19.89	40	1	0.49725	2.21	2.7625
MAVNutrition Krill Oil	500	NG	NG	270	NG	0.54	0.636363636	165	NG	0.33	105	NG	0.21	100	0.2	7.88	30	1	0.262666667		
NewRhythym Krill Oil	1250	603	0.4824	545	0.903814262	0.436	0.593567251	342	0.5671642	0.2736	203	0.33665	0.1624	450	0.36	21.19	90	2	0.470888889	0.780910263	0.86401631
Renew Naturals Krill Oil	1000	220	0.22	174	0.790909091	0.174	0.45	120	0.5454545	0.12	54	0.245455	0.054	400	0.4	19.95	60	2	0.665	3.022727273	3.82183908
aSquared Nutrtition	1000	190	0.19	155	0.815789474	0.155	0.55	100	0.5263158	0.1	55	0.289474	0.055	NG	NG	32.99	200	2	0.3299	1.736315789	2.128387097
Dr. Mercola Antarctic	1000	NG	NG	155	NG	0.155	0.55	100	NG	0.1	55	NG	0.055	400	0.4	78.97	180	2	0.877444444		
MegaRed Ultra Strength	1000	230	0.23	188	0.817391304	0.188	0.46875	128	0.5565217	0.128	60	0.26087	0.06	334	0.334	40.71	30	1	1.357	5.9	7.218085106
Median	**1000**	**230**	**23.0%**	**190**	**81.7%**	**19.0%**	**55.0%**	**120**	**55.0%**	**12.8%**	**60**	**26.9%**	**6.0%**	**400**	**40.0%**	**21.99**			**0.50**	**2.17**	**2.67**
SD	**274.9**	**139.8**	**14.5%**	**126.7**	**8.2%**	**15.1%**	**8.1%**	**81.1**	**3.7%**	**7.6%**	**51.7**	**5.4%**	**5.1%**	**158.1**	**9.3%**	**15.09**			**0.27**	**1.28**	**1.70**
Average	**982.4**	**273.8**	**28.3%**	**230.2**	**83.0%**	**25.4%**	**53.4%**	**146.6**	**54.0%**	**14.8%**	**81.3**	**28.5%**	**8.2%**	**397.4**	**38.2%**	**26.66**			**0.55**	**2.45**	**3.05**
Lumpfish			**47.90%**		**90.7%**	**43.4%**	**142%**		**37.5%**	**17.90%**		**53.2%**	**25.40%**		**21.50%**						

Appendix G

Data and calculations for roe from literature.

Source	Product	PUFA%	O-3%	O-3% PUFA	EPA	EPA % PUFA	EPA% O-3	DHA	DHA % PUFA	DHA% O-3	EPA + DHA%	EPA +DHA% PUFA	EPA+DHA % O-3	DHA % EPA	PL%
Mol and Turan, 2008	Caviar														
Mol and Turan	Beluga (Huso huso)	16	12.1	0.75625				8.45	0.528125	0.698347107					
Mol and Turan	Imperial (Huso huso)	21.04	16.46	0.782319				10.5	0.49904943	0.637910085					
Mol and Turan	Osetra (Huso huso)	17.93	12.9	0.719465				7.79	0.434467373	0.603875969					
Mol and Turan	Red Salmon Roe (Oncorhynchus nerka)	36.73	32.68	0.889736				13.21	0.359651511	0.404222766					
Mol and Turan	Waxed Mullet Roe (Mugil cephalus)	20.95	16.26	0.776134				9.36	0.446778043	0.575645756					
Mol and Turan	Channel Catfish Roe (Ictalurus punctatus)	NG	NG					8.04							
Shirai et al 2004															
Shirai et al	Ikura (Salmon, Oncorhynchus keta)	44.6	40.3	0.90	13.6	0.30493274	0.33747	17.4	0.390134529	0.431761787	31	0.695067265	0.769230769	1.27941176	
Shirai et al	Tarako (Pollock, Gadus chalcogrammus)	47.5	43.8	0.92	18.8	0.39578947	0.42922	22.2	0.467368421	0.506849315	41	0.863157895	0.936073059	1.18085106	
Shirai et al	Tobiko (Flyingfish, Cheilopogon agoo)	45.5	39.3	0.86	7	0.15384615	0.17812	27.9	0.613186813	0.709923664	34.9	0.767032967	0.888040712	3.98571429	
Shirai et al	Kazunoko (Herring, Clupea pallasii)	42.7	40.1	0.94	15	0.35128806	0.37406	22.6	0.529274005	0.563591022	37.6	0.880562061	0.93765586	1.50666667	
Saliu et al, 2017,															
Saliu et al	European Catfish (Silurus glanis)	27.55	21.05	0.764065	6.2	0.22504537	0.294536817	14.2	0.515426497	0.674584323	20.4	0.740471869	0.96912114	2.29032258	
Intarasirisawat et al. 2010															
Intarasirisawat et al	Skipjack (Katsuwonus pelamis)	35.34	29.47	0.833899	3.8	0.10752688	0.12894469	23.46	0.663837012	0.796063794	27.26	0.771363894	0.925008483	6.17368421	
Intarasirisawat et al	Tongol (Thunnus tonggol)	39.68	33.54	0.845262	4.62	0.11643145	0.137745975	26.19	0.660030242	0.780858676	30.81	0.776461694	0.918604651	5.66883117	
Intarasirisawat et al	Bonito (Sarda sarda)	33.38	28.09	0.841522	4.62	0.13840623	0.164471342	20.53	0.615038945	0.730865077	25.15	0.753445177	0.895336419	4.44372294	
S. Czesny et al, 2000	Sturgeon Roe Origin														
S. Czesny et al	White Sturgeon Sea Farm (Acipenser transmontanus)	27	21.4	0.792593	5.5	0.2037037	0.257009346	10.7	0.396296296	0.5	16.2	0.6	0.757009346	1.94545455	
S. Czesny et al	White Sturgeon Domestic (Acipenser transmontanus)	33.9	18.6	0.548673	4.6	0.13569322	0.247311828	9	0.265486726	0.483870968	13.6	0.401179941	0.731182796	1.95652174	
S. Czesny et al	White Sturgeon Wild (Acipenser transmontanus)	19.6	16.2	0.826531	3.1	0.15816327	0.191358025	9.2	0.469387755	0.567901235	12.3	0.62755102	0.759259259	2.96774194	
S. Czesny et al	Lake Sturgeon Wild (Acipenser fulvescens)	17.1	11.5	0.672515	1.9	0.11111111	0.165217391	4.8	0.280701754	0.417391304	6.7	0.391812865	0.582608696	2.52631579	
Bledsoe et al., 2003															
Bledsoe et al.	Trout (Oncorhyncus mykiss)		37												52%
Bledsoe et al.	Chum Salmon (O. Keta)		NG												30%
Bledsoe et al.	SeaTrout (O. mykiss)		8												30%
Bledsoe et al.	Whitefish/Vendace (Coregonus albula)		44												33%
Bledsoe et al.	Burbot (Lota lota)		37												13%
Bledsoe et al.	Baltic Herring (Clupea harengus)		31												68.50%
Bledsoe et al.	Roach (Rutilus rutilus)		NG												79%
Bledsoe et al.	Perch (Perca fluviatilis)		NG												14%
Bledsoe et al.	Cod (Gadus morhua)		31												74%
Bledsoe et al.	Mullet (Mugil cephalus)		NG												NG
Bledsoe et al.	Hake (Merluccius hubbsi)		2.6												14%
Bledsoe et al.	Channel Catfish (Ictalurus punctatus)		12												NG
Bledsoe et al.	Orange Roughy (Hoplostethus antlanticus)		21.5												20.70%
Bledsoe et al.	Blue Mackerel (Scomber australasicus)		32												27%
Bledsoe et al.	Kahawai (Arripis trutta)		22												29%
Bledsoe et al.	Hoki (Macruronis novaezelandiae)		21												22%
Bledsoe et al.	Red Cod (Pseudophycis bacchus)		17												31%
Bledsoe et al.	Haddock (Melanogramus aeglefinus)		44												66%
Bledsoe et al.	Saithe (Pollachius virens)		31												67%
Bledsoe et al.	Whiting (Merlangus merlangus)		4												61%
Bledsoe et al.	Sand Eel (Ammodytes lancea)		38												24%
Bledsoe et al.	Capelin (Mallotu vilosus)		33												51%
Bledsoe et al.	Gulf Sturgeon (Cultured) (Acipenser oxyrinchus desotoi)		22												NG
Bledsoe et al.	Gulf Sturgeon (Wild)		12												NG
	Median	33.4%	22.0%	82.7%	5.1%	15.6%	21.9%	12.0%	46.9%	57.6%	26.2%	74.7%	89.2%	240.8%	31%
	Average	31.0%	25.2%	80.5%	7.4%	20.0%	24.2%	14.8%	47.8%	59.3%	24.7%	68.9%	83.9%	299.4%	26.8%
	Standard Deviation	10.6%	11.7%	9.5%	5.1%	9.5%	9.4%	7.1%	11.6%	12.2%	10.5%	15.2%	11.2%	162.5%	11.8%
	Lumpfish	**50%**	**47.90%**	**95.7%**	**17.90%**	**35.8%**	**37.5%**	**25.40%**	**51%**	**53.2%**	**43.30%**	**86.6%**	**90.7%**	**142%**	**21.5%**

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