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MFA of omega-3 fatty acids EPA & DHA from a Norwegian resource perspective

Implications for future growth in fisheries and aquaculture toward 2050

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Abbreviations

DKNVS – Det Kongelige Norske Videnskabers Selskab

EFA - Essential fatty acid

EPA - Eicosapentaenoic acid

ESD – Efficiency of substance delivery

D,HA - Docosahexaenoic acid

FLC - Foreign landed catch

FM&O - Fish meal and oil

FPC - Fish protein concentrate

FPH - Fish protein hydrolysate

GHG - Greenhouse gas

IPCC - Intergovernmental Panel on Climate Change

IUPAC - International Union of Pure and Applied Chemistry

LCA - Life cycle assessment

MFA - Material flow analysis

NLC – Norwegian landed catch

PUFA - Polyunsaturated fatty acids

SFA - Substance flow analysis

TL - Total lipids

W'avg - Weighted average

WW - Wet weight

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Background

Recent archeological evidence suggests that humans have enjoyed seafood since paleolithic times (O'connor et al., 2011; Henshilwood & Sealy, 1997). Technology has advanced from bone hooks and woven sea grass to modern fishing fleets equipped with GPS and sonar guided harvesting equipment, onboard processing and even workout equipment to keep fishermen busy between shifts. Industrialized fishing techniques, mismanagement and population growth are threatening fish stocks to the brink of extinction in many parts of the world (Myers & Worm, 2003), yet demand is expected to rise with increased development (York & Gossard, 2003; Cole & McCoskey, 2013). Projections from TEEB (2010) expect capture fisheries to supply 60 Mt toward a seafood demand of 227 Mt in 2050. Aquaculture is expected to cover the remaining demand at a long-term growth rate of 3% (TEEB, 2010), which is reasonable compared to an average growth rate of 8,8% since 1970 (FAO, 2012).

The prospect of increased growth in aquaculture could help relieve pressure on wild fish stocks while also benefitting the envrionment. The energy demand required by fish for physiological homeostasis is lower than terrestrial animals (Brummet, 2007). Fish therefore use 1/5 of the feed required to produce one kilo of cattle and half as much as chickens; presently the most efficiently produced warm-blooded animal (Brown, 2003; Ytrestøyl et al., 2011; Brummet, 2007). A 2010 review of life cycle analyses suggest that farmed Atlantic salmon outperfrom land based animals in land use, fresh water consumption and GHG emissions.

Despite these positive results, the reality is that intensive aquaculture presents environmental challenges along with opportunities. Unless properly managed, environmental impacts from aquaculture could negatively impact aquatic ecosystems through impact pathways including: disease, escapes, exotic species, sea lice, particulate deposition and the use of chemicals such as anti-louse treatments, disinfectants, antibiotics and anaesthetics (FHL, 2012; Hall et al., 2011; Burridge et al., 2011).

In contrast to catastrophic events such as escapes or disease outbreaks, the indirect effects of aquaculture growth continue to grow modestly with production. The main driver of indirect impacts in aquaculture is feed production. Carniverous fish species such as salmon require marine ingredients that match the nutritional profile of wild prey. This requirement has been met by the addition of fish meal and oil from forage fish, some of which are historically or currently overexploited (Naylor et al., 2000; Tacon & Metian, 2008). Due to a shortage of fish meal and oil, the aquaculture industry in Norway responded by reducing the percentage of marine ingredients from 64,8% in 2000 to 31,3% in 2012 (Cermaq, 2012) with 68% vegetable ingredients contributing to the remainder (Ytrestøyl, 2014). The rapidly changing requirements of aquaculture require new tools and analyses to determine whether these changes represent progress or problem shifting. This thesis will introduce material flow analysis to the aquaculture discourse by modelling the resource requirements of the Norwegian fisheries and aquaculture industries for the year 2012. The goal of this thesis is not to provide concrete answers, but rather to bring attention to the importance of a holistic approach when assessing the sustainability of food production systems.

Introduction

The World's Foremost Seafood Nation

Norway is a global leader in fisheries and aquaculture. In 2011, Norwegian fish farmers produced 187 tonnes (live weight) per inhabitant, compared with 29,6 in the EU and 3,6 globally (FAO, 2012). The wild capture fleet harvested 2,135 Mt of fish and shellfish in 2012. Combined with aquaculture, Norway produced an amount equal to 60% of combined EU capture fisheries and aquaculture production in 2012 (SSB, 2013; Eurostat, 2013). The continued growth of the fisheries and aquaculture sectors is of high national priority in Norway. On March 22, 2013 a white paper (Meld.St.22) entitled "Verdens fremste sjømatnasjon," (World's Foremost Seafood Nation) was submitted to the Norwegian Storting.

The report advocates for future growth and presents ambitions for improvement in the following areas: marine knowledge, new marine growth, foreign markets, the home market, safe and healthy seafood, seafood/processing industry, fishing fleet and aquaculture. Contributors to the works cited in Meld.St.22 are some of Norway's most respected research institutions, including Sintef, Det Kongelige Norske Vitenskabers Selskap (DKNVS), Hav21 and Norges Tekniske Vitenskapsakademi (NTVA). Among the ambitions summarized in the report, the following were chosen as being measurable and especially interesting from a sustainability perspective. The Norwegian government has ambitions to:

1. Develop a seafood industry that utilizes the entire fish
2. Build the seafood industry on Norwegian raw materials of high quality
3. Achieve continued growth in production capacity and value creation in the aquaculture sector within the bounds of environmental sustainability

Growth

The growth rates presented in Meld.St.22 come from another influential report, "Verdiskaping basert på produktive hav i 2050," (Value Created from Productive Oceans in 2050). This report suggests that aquaculture production in Norway will grow at 4% per year until 2050, a 500% increase from 2010 levels (Olafsen et al., 2012). The same report also predicts that the marine ingredients industry could grow at 7% per year. Since publication in 2012, these growth rates (see Table 1) have been trumpeted by industry and government representatives as the goal for future growth in aquaculture.

Table 1: Predictions from "Value created from productive oceans"

	2010	2050	Annual growth (%)
Wild fish landed (Mt)	2,7	4	0,99 %
Salmon and trout production (Mt)	1	5	4,11 %
Marine ingredients industry (bNOK)	5	70	6,82 %
By-products from fisheries and aquaculture (Mt)	0,9	4,4	4,05 %
Aquaculture feed production (Mt)	1,2	6	4,11 %

Material/Substance Flow Analysis (MFA/SFA)

Material flow analysis (MFA) is a physical environmental accounting approach that follows materials or substances through socio-economic systems. Materials / substances are tracked as flows of goods between processes organized to mimic the chosen socio-industrial complex within a system boundary. An MFA system is a picture of the physical economy linked to parameters that can be altered to model different scenarios. Analyses of MFA systems can be used to measure environmental impacts, resource scarcity, land management, substitution potentials, tradeoffs, or in general provide new ways to think about the current and future material supply and demand of society (Haberl & Weisz, 2007).

MFA methodology has been increasingly used to analyze the long term effects of resource depletion, material criticality and supply chain management for metals (Liu & Müller, 2013), housing (Bergsdal et al., 2007), and electronic waste (Hischier et al., 2005). Another form of MFA is when a homogenous chemical substance is used instead of a material. Substance flow analysis can be used to evaluate flows of environmental toxins, precious metals or macronutrients depending on the aim of a study (Brunner & Rechberger, 2004; Haberl & Weisz, 2007).

The diagram below provides a simplified example of a MFA system with a single process and three flows. The system boundary is represented by a dashed line, which is the absolute border for the system. The system models input and output interactions between the system and the external environment and follows these flows within the system from process to process. MFA studies with the goal of linking to the System of National Accounts (SNA) have necessarily strict guidelines for national MFA methodology (Eurostat, 2001). MFA studies performed for strategic decision making are much more flexible to stakeholder demands. By changing system boundaries, an MFA could model socio-industrial processes at various scales, i.e. factory, town, municipality, ecosystem, country or region. System boundaries can be set for many reasons, such as goal and scope, data availability, uncertainty and time constraints. For inputs and output between the system and the external environment, 0 is commonly used to denote "outside of system boundaries." In the example below, an "a" is added to the bottom flow to identify it as separate from 0,1. The balance of the system or for an individual process is Inputs - Outputs = Change in Stock (Brunner & Rechberger, 2004). The stock of an individual process is the amount of material, substance or energy that is left over after an MFA "transaction," where transaction is defined as the inputs and outputs that occur during the period of evaluation.

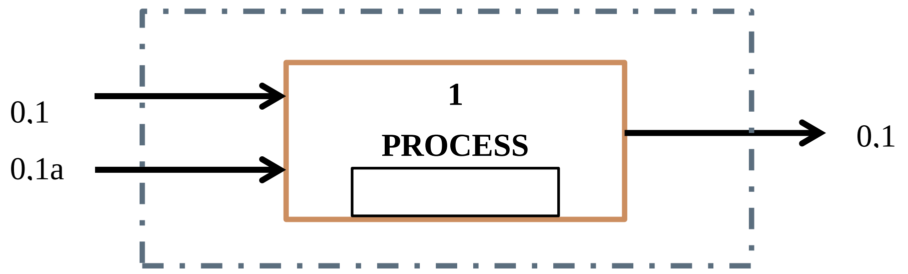

Figure 1: MFA system example

Stock has different interpretations depending on the system. Market processes represent the exchange of goods and do not usually have tangible stocks of mass or energy (Brunner & Rechberger, 2004). Other processes represent transformative conversions where mass or energy is converted from one form to another (Brunner & Rechberger, 2004). Transformative processes can have tangible stock accumulation during the study period, such as steel in the process "infrastructure" or have negligible stock accumulation if the process has a high throughput of materials i.e. "steel construction." For the system modeled in this paper, stocks are not considered due to the quick turnover of products in the fisheries and aquaculture sectors.

SFA - Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA)

The substance chosen for the SFA layer is the sum of the fatty acids EPA and DHA. The unit is tonnes or kilotonnes of EPA + DHA. These fatty acids originate from marine microalgae and move up trophic levels. EPA and DHA are essential for fish health (Turchini et al., 2009), human health (Flock et al., 2013) and increasingly important from a consumer perspective (Martinsdottir, 2012). The structure of

EPA and DHA is shown in Figure 2. The COOH end is considered the starting point of the molecule and therefore the alpha (α) end. The last position of the molecule is the omega (ω or N) end (CH_3). The nomenclature for distinguishing types of fatty acids starts from the omega end of the molecule and counts the number of carbon atoms in the chain (IUPAC, 1997). The distinction between omega-3 and omega-6 relates to the location of the first double bond. The first double bond in omega-3 fatty acids is at the third carbon atom from the methyl group and the 6th for omega-6. To complete the naming nomenclature, the number of double bonds follows the total number of carbons in the chain. For EPA, the nomenclature is therefore: 20 carbons: 5 double bonds N-3 also known as 20:5, n-3.

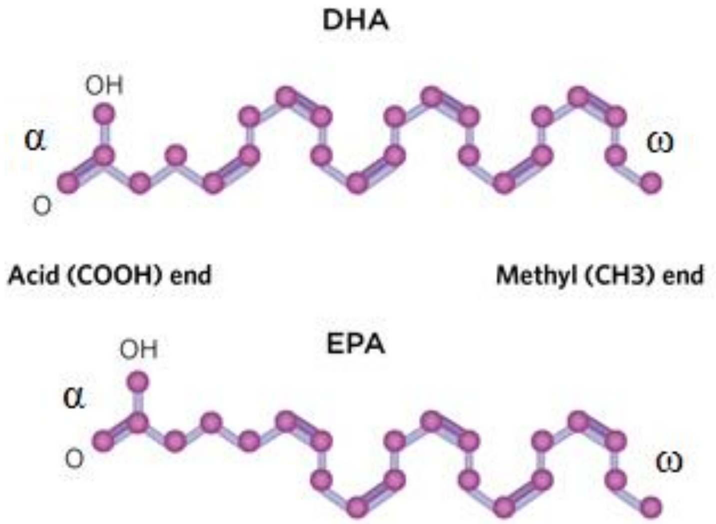

Figure 2: Chemical structure of EPA + DHA (modified from Andersen & Taylor, 2012)

EPA + DHA in Fish Health

The EPA and DHA content of carniverous fish species like salmon depends on which marine organisms comprise the majority of their prey in the wild. Feeding patterns tend to suggest that wild Atlantic salmon select prey based on net energy gain, preferring high-fat prey such as Arctic copepods, capelin and herring when available (Mikhaev, 1984; Andreassen et al., 2001; Hansen et al., 2012). This corroborates with data showing that farmed Atlantic salmon prefer to produce energy from lipids (Turchini et al., 2009).

However, a diet rich in arctic lipids is also rich in EPA + DHA (Lambertsen, 1978). Atlantic salmon thus evolved in an EPA and DHA rich environment, possibly explaining why Atlantic salmon display a higher dependency on dietary EPA + DHA than other fish species (Sargent et al., 1999; Sargent et al., 2002; Turchini et al., 2009). Although minimum levels of EPA + DHA in feed have yet to be established, a recent review by Torstensen et al. (2013) showed that farmed Atlantic salmon fed low EPA + DHA diets developed symptoms similar to many human lifestyle diseases, i.e. bone deformities, fat deposition around vital organs (liver, heart, abdomen), altered immune response, cataracts, inflammation, stress response and an overall increase in death rates. In response to industry concerns about the long-term effects of low EPA + DHA feeds on fish health, a follow-up field study is currently ongoing (FHF, 2013-2015).

EPA + DHA in Human Health

From studies on vegans and vegetarians, it is clear that humans, like fish (Sargent et al., 1999; Sargent et al., 2002; Turchini et al., 2009) have the ability to convert shorter chain omega-3s into EPA and DHA (Pawlosky et al., 2001). The general process of conversion described by Williams & Burdge (2006) occurs via a series of enzymatically catalyzed desaturation and elongation reactions. Despite individual variation, the conversion efficiency of this process is typically just a few percent for the average person (Pawlosky et al., 2001), which means that most humans, like salmon, have to consume EPA + DHA through diet.

Interest in the dietary essentiality of EPA + DHA has never been higher. Recently, the WHO, European Food Safety Agency and USDA have set daily recommended intakes of EPA + DHA at 250mg/day (Flock et al., 2013). These recommendations are based on a body of evidence suggesting that EPA + DHA supplementation improves the cognitive development of children (Bloomer et al., 2009; Rauch et al., 2010; Judge et al., 2007), reduces the incidence of heart disease (Danaei et al., 2009) and reduces the risk of developing neurological diseases such as Alzheimer's disease and dementia (Schaefer et al., 2006).

Simopolous (2002) also reviewed the importance of EPA + DHA consumption, but expanded the discourse by introducing the omega-6 to omega-3 ratio. Typical "Western" diets average omega-6/omega-3 ratios appoximately 15-16 times higher than modern day or Paleolithic hunter gatherers. A review of clinical intervention studies on the EFA omega-6/omega-3 balance found that a ratio of greater than 4 was associated with a higher risk of inflammation, cardiovascular diseases, cancer and death rates. The current omega-6/omega-3 ratio of 15-16 represents a 400% increase from the highest ratio known to preserve human health (4:1); Simopolous suggests that 99,95% of human genes evolved with a ratio of approximately 1:1.

With this in mind, it is not unsurprising that the "Western" diet is associated with human disease. Interestingly, farmed Atlantic salmon fed a diet with above average EPA + DHA for 2012 feed had an omega-6/omega-3 ratio of 0,44, an increase of 550% compared to wild Atlantic salmon in the same study (Jensen et al., 2012). The conclusions presented by Simopolous (2002) and Torstensen et al. (2013) suggest that humans and salmon share common disease pathology when diets are deficient in EPA + DHA and/or high in omega-6 PUFA relative to omega-3.

EPA + DHA from a consumer perspective

It is clear that EPA and DHA are important to fish and human health. Recent surveys into seafood consumption habits suggest that consumers have taken notice. A survey of seafood consumption knowledge in Europe revealed that 95% of consumers know that fish are a good source of omega-3 fatty acids (Vanhonacker et al., 2011). Another study found that Nordic consumers ranked omega-3 highest among the perceived healthiness of seafood products (Martinsdottir, 2012). The Vanhonacker et al. (2011) survey provides especially interesting insights into seafood consumption habits and awareness.

The study included cross-sectional data from 1 319 seafood consumers in Belgium, Spain and Norway. The scope of the study included a knowledge survey with results shown in Table 2. All consumers showed a near unanimous understanding that fish is a good source of omega-3 fatty acids. However, scores for other questions showed a remarkable knowledge gap between consumer perception and reality. A very important takeaway from these results is that less than 45% of Norwegians know that Atlantic salmon is almost exclusively farmed. Results from this study suggest that consumers are vulnerable to changes in the fisheries and aquaculture sector. This realization places extra responsibility on the fisheries and aquaculture sectors to provide products that live up to consumer perceptions, especially in terms of omega-3.

Table 2: Percentage of correct answers by seafood consumers to knowledge questions in Belgium, Norway and Spain (modified from Vanhonacker et al., 2011)

	Belgium	Norway	Spain
More than half of the fish we can buy is farmed fish (false)	32,7	31,9	31,4
The use of antibiotics in fish farming has significantly decreased in recent years (true)	57,5	65,4	61,1
Farming of fish is a new activity (false)	77,7	88,5	75,5
Salmon is almost exclusively farmed (true)	63,2	44,8	52,2
Farmed fish contain more mercury than wild fish (false)	80,9	65,4	68,9
Only slightly more than 1 kg of feed fish is needed to produce 1 kg of farmed Atlantic salmon (true)	36,6	29,4	41,0
Cod is a fatty fish (false)	73,2	81,0	78,0
Fish is a source of Omega-3 fatty acids (true)	92,0	99,3	95,7
Salmon is a fatty fish (true)	75,5	83,0	76,4

Research Questions

Three research questions were derived from Meld.St.22 for this thesis. Question one focuses on how well the fisheries and aquaculture industries utilize by-products. By-product utilization is estimated for fisheries and aquaculture separately and also aggregated to represent Norway as a whole. Question two examines the level of import reliance for fisheries and aquaculture goods in 2012. Question three attempts to contribute to the advancement of holistic sustainability analysis in fisheries and aquaculture in contrast to common industry based approaches.

Ambitions from Meld.St.22

1. Develop a seafood industry that utilizes the entire fish
2. Build the seafood industry on Norwegian raw materials of high quality
3. Achieve continued growth in production capacity and value creation in the aquaculture sector within the bounds of environmental sustainability

Research questions

1. How well does the industry utilize by-products in 2012? What are the implications for growth to 2050?
2. To what degree is the Norwegian seafood industry built on access to Norwegian ingredients in 2012? What are the implications for growth to 2050?
3. Can this growth be achieved within the bounds of sustainability and consumer acceptance?

Methods

System Definition

The physical system boundary is the Norwegian EEZ, encompassing Norwegian land borders and extending to 200 nautical miles from the mean low water mark of the territorial sea. Figure 3 shows the various types of maritime boundaries that comprise Norwegian waters. The red outlined area represents the physical system boundary for the system. The EEZ was chosen because resources from this zone are exclusively Norwegian. Norwegian and foreign catch are not treated as "Norwegian landed" until they enter this zone.

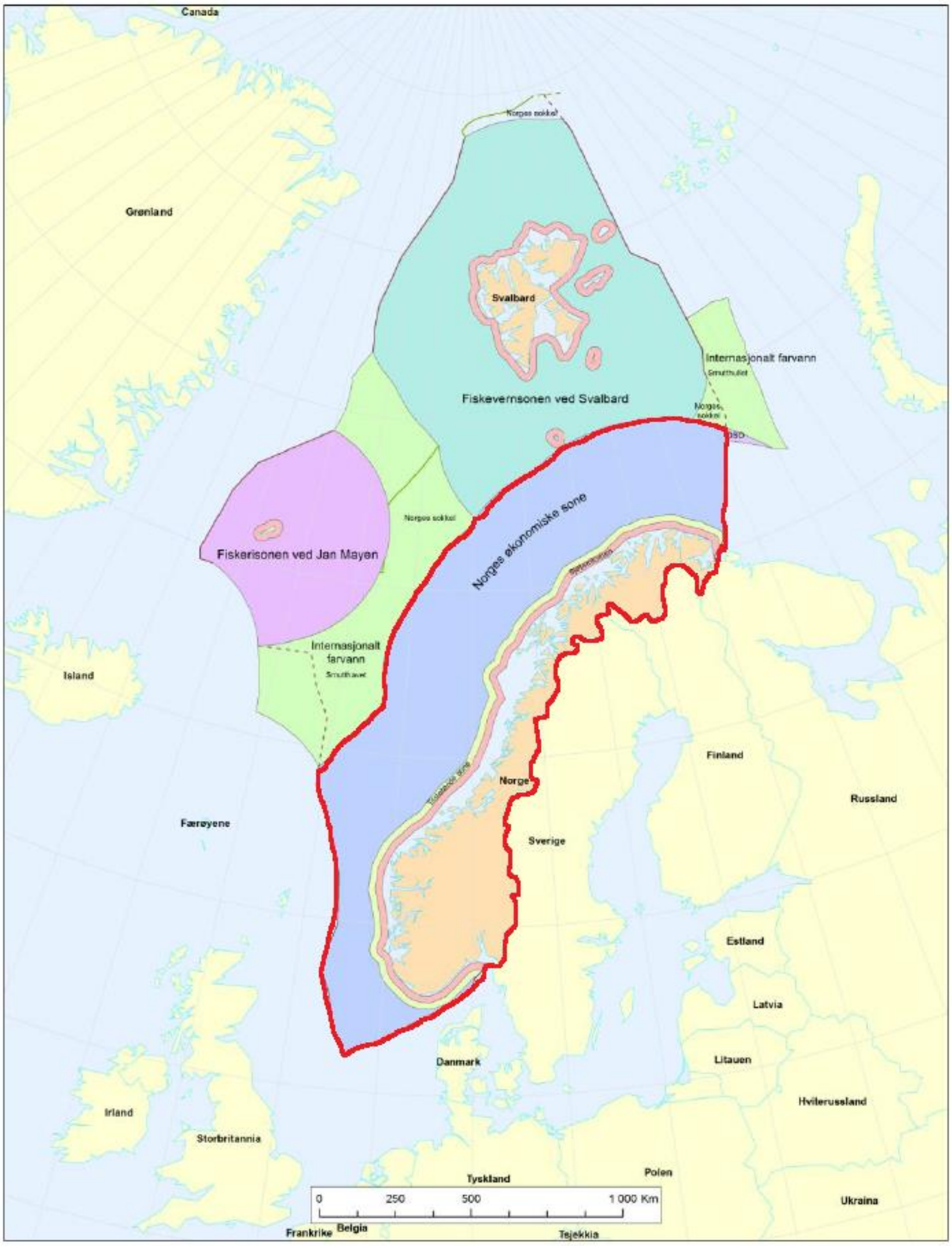

Figure 3: Norwegian EEZ and system boundary (modified from Kartverket, 2014)

Flows and Processes

Following is a general account of steps taken to determine which processes and flows to include in the model.

1. Literature review of previous efforts to map the fisheries and aquaculture value chain.
2. Selected the most relevant literature for a deeper review of methodology and key findings.
3. Created a map of key industry actors in cooperation with Biomar Norway.
4. Initiated contact with key industry actors to gain access to critical information.
5. Cross-referenced key findings from the literature with key findings from industry actors.
6. Periodically checked in with contacts when new questions arose concerning certain processes and flows.

Among the processes and flows identified as important, selection for inclusion in the system was based on strength of data. As noted by Olafsen et al. (2013), publicly available data on material flows in the fisheries and aquaculture sectors is insufficient for a high degree of resolution. Data from industry actors improves the resolution of the system, but also adds a higher degree of uncertainty due to the difficulty of verification. A description of the processes chosen for inclusion in the system is presented in Table 3; excluded processes and reasons for exclusion are found in Table 4.

Table 3: Overview of processes chosen for system definition

ID	Process	Description
1	Fisheries landing and processing	Harvesting, landing and processing of primary product from marine animal (ww) to seafood product
2	Marine by-products market	The collection and sale of marine by-products for feed, industrial and human consumption
3	Zooplankton processing	Thermochemical/enzymatic/mechanical extraction of lipids from zooplankton
4	Macroalgae processing	Thermochemical/enzymatic/mechanical extraction of products from fresh kelp (round weight)
5	Fish meal and oil processing	Thermal and mechanical conversion of fish into a protein fraction (meal) and lipid fraction (oil)
6	Fresh oils by-product processing	Enzymatic and mechanical conversion of fish scrap into a protein fraction (hydrolysate) and lipids (oil)
7	Silage by-product processing	Thermochemical and mechanical conversion of acid hydrolyzed by-products
8	New marine ingredients market	The purchase and sale of trending or future oriented ingredients/goods
9	Traditional marine ingredients market	The purchase and sale of traditional marine ingredients/goods
10	Aquaculture feed production	The purchase of feed ingredients and the physical transformation into feed (mostly salmon type feed)
11	Refined omega-3 oils	Physical transformation of crude oils into marine oils for human consumption, often omega-3 products
12	Aquaculture and processing	Rearing and processing marine animals (mainly salmon) slaughtered or lost in 2012
13	Market for human consumption	The purchase and sale of goods for human consumption
14	Marine mammals processing	The act of processing Minke Whale and Seal for meat, oils and furs

Processes and flows that were deemed too uncertain for inclusion within the system were left out. The selective exclusion of processes is most evident in the flows exiting the process *Market for Traditional Ingredients*. With a higher resolution of data, all major purchasers of ingredients from this market would have been included within the system. Table 4 shows potential processes that were not included for various reasons.

Table 4: Processes selectively excluded from system and grounds for exclusion

Potential Process	Reason for Exclusion
Pet food	High uncertainty, data from industry actors
Animal husbandry feed	Uncertainty in percent of exports/domestic
Fur industry feed (mink, fox, etc)	Uncertainty in percent of exports/domestic
Mediterranean fish feed (sea bream)	High uncertainty, data from industry actors
Specialty pharmaceuticals	Limited data availability
Specialty nutraceuticals	Limited data availability
Secondary seafood processing	Time constraints
Intensive mariculture (microalgae)	Limited data availability

Constructing the Model

The product weight layer is expressed in mass units (t or kt) and represents the actual weight (wet weight) of the product/ingredient represented in a flow. The varying dry matter composition of products means that production processes will not be mass balance consistent as water weight will often be lost. A product weight layer in dry mass would have been interesting, however wet weight was chosen for ease of comparison with contributing literature (Olafsen et al., 2013; Richardsen, 2011) and industry data. The EPA + DHA layer (SFA) is derived from the product weight layer by using EPA + DHA coefficients expressed as a percentage of product weight. Both layers provide interesting, but different insights into the research questions.

Assumptions & key definitions

1. The words “ingredient” and “product” are used interchangeably. Both are defined as flows of goods with “product” often used from the perspective of the producing process and “ingredient” from the perspective of the recipient process.

2. Market processes represent the collection and distribution of goods without a physical transformation of goods. Mass balance consistency in the product layer is therefore possible for market processes. The EPA + DHA layer is expressed in tonnes of EPA + DHA and therefore does not account for water weight. Mass balance consistency is therefore meaningful for processes in the EPA + DHA layer.

3. All processes not explicitly stated as being a market process are production processes. Ingredients enter a production process where they are physically transformed, exiting the process as products. Efficiency losses from production processes are not taken into account.

4. The terms “fish meal equivalent,” “fish oil equivalent,” and “fish meal and oil equivalent,” are all used to create a common unit for marine ingredients with similar functional characteristics. Fish meal, fish protein concentrate and fish protein hydrolysate are different products, but all contain protein for feed purposes. Similary fish oil from silage and enzymatic processing is functionally similar to fish oil from the traditional FM&O pressing technique. This assumption simplifies the calculations.

5. The general method for building flows in an MFA/SFA system is through a common set of parameters linking all flows (Brunner & Rechberger, 2004). By linking all flows to a single set of parameters, a change in one parameter will adjust every flow in the system sharing that parameter. Example 1 shows how the flow “Pelagic type fish meal from scrap” is calculated.

Parameter “Pelagic FLC” (t) + Parameter “Pelagic NLC” (t)
*
Parameter “Pelagic landed for fillet” (%)
*
Parameter “Pelagic fillet by-product rate” (%)
*
Parameter “Pelagic scrap utilization rate” (%)
*
Parameter “Pelagic scrap to fish meal and oil” (%)
*
Parameter “Fish meal reduction efficiency” (%)
=
Pelagic type fish meal from scrap

The system in this thesis is built the same way (see Appendices 6.1 and 6.2 for the complete list of parameters and system flows) with the exception of four flows that are calculated from mass balance. Flows calculated from mass balance have a higher uncertainty than flows calculated from parameters derived from literature (Brunner & Rechberger, 2004). The product layer system distinguishes these flows with a heavier weighted arrow easy identification. In addition to the four mass flows wholly calculated from mass balance, there are two multi-species (aggregated) flows that are partially calculated from mass balance. These are the two outflows from the process *Silage Processing*. These flows contain three single species flows and one mass balance flow called “non-hydrolyzed fraction”. The flow “non-hydrolyzed fraction” represents 59% of the salmon by-product protein fraction not further processed into FPH after oil extraction in *Fresh Processing* (Olafsen et al., 2013). The leftover non-hydrolyzed proteinaceous matter (mass balance) consisting mainly of oil press cake is sent to silage processing. See the appendices for the calculation “Mixed silage oil for feed,” one of the two flows containing “non-hydrolyzed fraction.”

Selection of EPA + DHA parameters

Food databases and marine ingredients publications typically express EPA and DHA content as the sum of EPA + DHA, while academic research publications typically express EPA and DHA separately. In this thesis EPA + DHA is used for the convenience of constructing one layer instead of two. Single EPA and single DHA values from academic literature were added together. The EPA + DHA layer is therefore a mirror of the product weight system, but expressed in units of EPA + DHA (t or kt) instead of product weight.

Wild Fisheries

Efforts by the aquaculture industry to reduce dependency on marine ingredients have led to widespread substitution with vegetable protein meals and oils. Although results for fish health are questionable (Torstensen et al., 2013), vegetable ingredients have allowed the industry to continue growing in the face of limited marine protein and lipid sources. Wild fisheries contribute 30% of the ingredients in fish feed by product weight and 100% of the EPA + DHA. EPA and DHA first enter the marine ecosystem through synthesis by marine autotrophic microalgae. The chemical composition of microalgae is very sensitive to changes in environmental variables such as nutrient levels, salinity, temperature, acidity and light (Yongmanitchai & Ward, 1991). Fatty acid variance is transferred from primary producers to higher trophic levels through predator-prey relationships. Each species has a unique fatty acid signature that fluctuates seasonally over the geographic range of their preferred prey (Budge et al., 2011).

Commercially important species are landed in Norwegian ports at all times of the year from different marine ecosystems. The practical challenge of estimating average EPA + DHA values for marine species is finding multiple measurements over several years and geographic areas for each species. In this thesis, mean EPA + DHA values were estimated using data representative of the spatial and temporal reality of Norwegian fisheries to the extent possible. Landed catch data for marine fish, zooplankton and macroalgae was obtained from national statistics (NO. MoF, 2014; SSBa, 2014). Data for the harvest of marine mammals was collected from Statistics Norway (SSBe, 2014).

Table 5 presents the total landed catch contributed by Norwegian and foreign vessels, including the mean EPA + DHA values for each species. The catch from foreign vessels is not presented as individual species by the Ministry of Fisheries, but rather as an aggregated category of species. In order to reconcile the foreign catch data, the Norwegian landed catch was aggregated into the same categories. The Ministry of Fisheries defines landed catch as all marine organisms landed in Norway by Norwegian or foreign registered vessels and direct landings in foreign countries by Norwegian registered vessels. Marine catches landed by hobby fishermen are included.

Table 5: EPA + DHA weighted mean values of individual species and aggregated categories for Norwegian landed catch (WW)

	Landed catch round weight[1]		EPA + DHA Parameters			
	Norwegian vessels (t)	Foreign vessels (t)	EPA + DHA % of ww	Catch weight factor	EPA + DHA factor	Category sum (t)
Lodde - Capelin - *Mallotus villosus*[4]	$2{,}69 \cdot 10^{5}$	--	1,80 %	21,58 %	0,39 %	--
Øyepål - Norway Pout - *Trisopterus esmarkii*[2]	$4{,}60 \cdot 10^{3}$	--	2,23 %	0,37 %	0,01 %	--
Kolmule - Blue Whiting - *Micromesistius poutassou*[2]	$1{,}18 \cdot 10^{5}$	--	1,14 %	9,47 %	0,11 %	--
Tobisfisker - Sand Lance - *Ammodytidae*[4]	$4{,}25 \cdot 10^{4}$	--	1,72 %	3,41 %	0,06 %	--
Taggmakrell - Horse Mackerel - *Trachurus trachurus*[3]	$3{,}38 \cdot 10^{3}$	--	1,98 %	0,27 %	0,01 %	--
Makrell - Mackerel - *Scomber scombrus*[3]	$1{,}76 \cdot 10^{5}$	--	4,31 %	14,12 %	0,61 %	--
Sild - Atlantic Herring - *Clupea harengus*[3]	$6{,}11 \cdot 10^{5}$	--	2,61 %	48,96 %	1,28 %	--
Brisling - Sprat - *Sprattus sprattus*[2]	$1{,}04 \cdot 10^{4}$	--	2,46 %	0,83 %	0,02 %	--
Strøm- og vassild - Silver Smelt - *Argentina silus*[4]	$1{,}24 \cdot 10^{4}$	--	0,89 %	0,99 %	0,01 %	--
PELAGIC	$1{,}25 \cdot 10^{6}$	$1{,}47 \cdot 10^{5}$	--	100,00 %	2,49 %	$3{,}46 \cdot 10^{4}$
Torsk - Atlantic Cod - *Gadus morhua*[13]	$3{,}58 \cdot 10^{5}$	--	1,56 %	49,07 %	0,76 %	--
Hyse - Haddock - *Melanogrammus aeglefinus*[13]	$1{,}61 \cdot 10^{5}$	--	1,56 %	22,07 %	0,34 %	--
Sei - Saithe/Coalfish - *Pollachius virens*[13]	$1{,}76 \cdot 10^{5}$	--	1,56 %	24,19 %	0,38 %	--
Brosme - Cusk - *Brosme brosme*[13]	$1{,}34 \cdot 10^{4}$	--	1,56 %	1,84 %	0,03 %	--
Lange - Ling - *Molva molva*[13]	$1{,}57 \cdot 10^{4}$	--	1,56 %	2,16 %	0,03 %	--
Blålange - Blue Ling - *Molva dypterygia*[13]	$3{,}25 \cdot 10^{4}$	--	1,56 %	0,04 %	0,00 %	--
Lyr - European Pollock - *Pollachius pollachius*[13]	$1{,}45 \cdot 10^{3}$	--	1,56 %	0,20 %	0,00 %	--
Lysing - European Hake - *Merluccius merluccius*[13]	$2{,}90 \cdot 10^{3}$	--	1,56 %	0,40 %	0,01 %	--
Hvitting - Whiting - *Merlangius merlangus*[13]	$1{,}73 \cdot 10^{3}$	--	1,56 %	0,02 %	0,00 %	--
CODFISH	$7{,}29 \cdot 10^{5}$	$1{,}30 \cdot 10^{5}$	--	100,00 %	1,56 %	$1{,}34 \cdot 10^{4}$
Blåkveite - Greenland Halibut - *Reinhardtius hippoglossoides*[5]	$1{,}27 \cdot 10^{4}$	--	1,64 %	29,01 %	0,48 %	--
Kveite - Atlantic Halibut - *Hippoglossus hippoglossus*[13]	$2{,}18 \cdot 10^{3}$	--	0,85 %	4,98 %	0,04 %	--
Rødspette - European Plaice - *Pleuronectes platessa*[13]	$1{,}56 \cdot 10^{3}$	--	0,85 %	3,56 %	0,03 %	--
Tunge - Common Sole - *Solea vulgaris*[13]	$8{,}79 \cdot 10^{0}$	--	0,85 %	0,02 %	0,00 %	--
Smørflyndre - Butter Sole - *Glyptoceophalus cynoglossus*[13]	$5{,}12 \cdot 10^{1}$	--	0,85 %	0,12 %	0,00 %	--
Sandflyndre - Sand Dab - *Limanda limanda*[13]	$5{,}37 \cdot 10^{1}$	--	0,85 %	0,12 %	0,00 %	--
Lomre - Lemon Sole - *Microstomus kitt*[13]	$7{,}56 \cdot 10^{1}$	--	0,85 %	0,17 %	0,00 %	--
Slettvar - Turbot - *Scophthalmus rhombus*[13]	$2{,}26 \cdot 10^{1}$	--	0,85 %	0,05 %	0,00 %	--

Piggvar - Turbot - *Psetta maxima*[13]	$4,99 *10^{1}$	--	0,85 %	0,11 %	0,00 %	--
Other flatfish [13]	$1,67 *10^{1}$	--	0,85 %	0,04 %	0,00 %	--
Ål - Eel mixed species - *Anguilliformes*[6]	$3,03 *10^{-2}$	--	3,06 %	0,00 %	0,00 %	--
Uer - Rose Fish/ Atlantic redfish - *Sebastes norvegicus*[7]	$1,03 *10^{4}$	--	0,97 %	23,44 %	0,23 %	--
Steinbiter - Wolf Fish - *Anarhichadidae*[8]	$8,22 *10^{3}$	--	0,62 %	18,75 %	0,12 %	--
Breiflabb - Monkfish - *Lophius piscatorius*[2]	$4,38 *10^{3}$	--	0,26 %	9,98 %	0,03 %	--
Rognkjeks - Lumpfish - *Cyclopterus lumpus*[6]	$1,04 *10^{3}$	--	2,09 %	2,37 %	0,05 %	--
Other deepwater/misc/unspecified fish[13]	$3,19 *10^{3}$	--	1,31 %	7,27 %	0,10 %	--
FLATFISH AND BOTTOMFISH	$4,38 *10^{4}$	$6,47 * 10^{3}$	--	100,00 %	1,07 %	$5,39 *10^{2}$
Krabbe - Brown Crab - *Cancer pagurus*[6]	$5,01 *10^{3}$	--	1,31 %	19,00 %	0,02 %	--
Kongekrabbe - King Crab - *Paralithodes camtschaticus*[6]	$1,44 *10^{3}$	--	1,31 %	5,45 %	0,02 %	--
Hummer - Lobster - *Homarus gammarus*[9]	$6,21 *10^{1}$	--	0,38 %	0,24 %	0,00 %	--
Sjøkreps - Norway Lobster - *Nephrops norvegicus*[8]	$2,43 *10^{2}$	--	0,37 %	0,92 %	0,00 %	--
Reke - Shrimp - *Caridea*[6]	$1,87 *10^{4}$	--	0,44 %	70,99 %	0,00 %	--
Skjell - Mollusc species - *Mollusca*[10]	$6,80 *10^{2}$	--	0,10 %	2,58 %	0,00 %	--
Other shellfish and crustaceans [11]	$2,19 *10^{2}$	--	2,63 %	0,83 %	0,07 %	--
SHELLFISH AND CRUSTACEANS	$2,64 *10^{4}$	$4,95 * 10^{3}$	--	100,00 %	0,11 %	$3,39 *10^{1}$
Antarktisk krill - Antarctic Krill - *Euphausia superba*[2]	$9,30 *10^{4}$	--	2,63 %	--	--	$2,45 *10^{3}$
Grisetare - Knotted kelp - *Ascophyllum nodosum*[12]	$2,00 *10^{4}$	--	0,03 %	--	--	$5,69 *10^{0}$
Stortare - Brown kelp - *Laminaria hyperborea*[12]	$1,50 *10^{5}$	--	0,09 %	--	--	$1,29 *10^{2}$
Vågehval - Minke Whale - *Balaenoptera acutorostrata*[13]	$5,89 *10^{2}$	--	2,46 %	--	--	$1,45 *10^{1}$
Grønlandssel - Harp Seal - *Pagophilus groenlandicus*[13]	$6,60 *10^{1}$	--	4,17 %	--	--	$2,76 *10^{0}$

1 Norwegian Ministry of Fisheries (2014)
2 Lambertsen (1978)
3 Average of Nifes (2014); Lambertsen (1978)
4 Average of Budge et al (2002); Lambertsen (1978); Sigurgisladóttir & Pálmadóttir (1993)
5 Average of Budge et al (2002); Nifes; Sigurgisladóttir & Pálmadóttir (1993)
6 Food. D (2009)
7 Average of Ackman (1988); Budge et al (2002); Sigurgisladóttir & Pálmadóttir (1993)
8 Nifes (2014)
9 Ackman (1988)
10 USDA (2014)
11 Lambertsen Antarctic krill (1978) - Assumed to be Calanus finmarchicus
12 Van Ginneken et al. (2011)
13 Estimated = See appendices

North Atlantic fish meal

North Atlantic type fish meal is the fishery industry label for fish meal produced in Norway or other countries harvesting North Atlantic species. The EPA + DHA content of fish meal and oil are important parameters in the system and vary by species. Fish meal from Peruvian Anchoveta or South African Pilchard may have an EPA + DHA content as high as 32% of TL. The species composition of Norwegian fish meal varies with catch quotas, but primarily consists of capelin, sand lance, blue whiting and sprat (Sørensen et al., 2011). The composition of different North Atlantic fish meals can be found in the scientific literature, but it is uncertain whether these meals originated in Norway or included scrap (Opstvedt, 1985). Rather than utilizing a potentially unrepresentative fish meal from literature, the EPA + DHA concentration of the 2012 North Atlantic type whole fish meal from Norway was estimated as shown in table 6. A Norwegian representative North Atlantic scrap meal EPA + DHA percentage was also derived in addition to fish oil values for both scrap and whole fish. See the appendices for parameters and system flows for further details.

Table 6: EPA + DHA content of forage fish in North Atlantic type fish meal in 2012

Species	Weight of catch[1] to fish meal	Total Lipids (%)	EPA + DHA (% TL)	EPA + DHA factor (%)
Capelin[4]	60,70 %	13,47 %	15,70 %	1,28 %
Sprat[4]	18,50 %	11,75 %	19,10 %	0,42 %
Sand Eel[3]	9,00 %	10,70 %	29,20 %	0,28 %
Blue Whiting[4]	6,50 %	4,87 %	23,50 %	0,07 %
Remaining fish[2]	5,30 %	12,70 %	15,00 %	0,10 %
Weighted AVG	100,00 %	12,30 %	18,01 %	2,16 %

[1] SSBa
[2] Mass balance - EPA + DHA derived from Lambertsen (1978)
[3] Values are averages of Sørensen et al. (2011) and Lambertsen (1978)
[4] Lambertsen (1978)

Wild fish for human consumption

The flow from *Wild Fisheries Landing and Processing* to *Products for Human Consumption Market* includes all processing from round weight to dinner plate. Round weight landed catch statistics are first multiplied by the transfer coefficient to human consumption. This is especially important for pelagic species, as 18% of landed catch goes to reduction for feed. Next, the post-processing weight is calculated by subtracting the total by-products from all landed catch for human consumption (Olafsen et al., 2013). High value by-products such as liver and roe are often retained for sale as seafood and do not formally enter the *By-products Market*. By-products harvested and sold as seafood for human consumption are therefore added back to the post-processing weight.

An imporant point for tracking EPA + DHA through the processing value chain is that EPA + DHA tends to follow the by-products due to the higher lipid content and preferable stroage by gadiform fishes in the liver. Necessarily, the EPA + DHA content of 1 kilo of "whitefish" or "pelagic" product depends on which part of the fish is represented. This requires explicit knowledge of whether a fish was filleted, butterflied, j-cut, headed and gutted or frozen whole in order to accurately estimate the amount of EPA + DHA in the seafood. Table 7 presents pelagic fish for human consumption and their respective EPA + DHA values. Note that the EPA + DHA content for all species depends on the level of processing (fillet or whole).

Table 7: EPA + DHA concentration of pelagic fish for human consumption in 2012

Species and grouping[5]	Tonnes landed[1]	Catch weighting	EPA + DHA[2] (% of ww)
Capelin[3]	1,21 * 10^5	12,17 %	1,07 %
Herring[3]	5,94 * 10^5	59,61 %	2,43 %
Blue Whiting[3]	1,02 * 10^5	10,20 %	0,29 %
Horse Mackerel[4]	3,26 * 10^3	0,33 %	1,80 %
Mackerel[4]	1,74 * 10^5	17,50 %	4,31 %
Sardine[4]	2,05 * 10^3	0,21 %	2,46 %
Weighted AVG	9,97 * 10^5	100,00 %	2,37 %

[1] NO.Ministry of Fisheries (2014)
[2] EPA + DHA values from Nifes (2014)
[3] Fillet
[4] Whole
[5] Fillet or whole Olafsen et al. (2013)

The species and state of processing for most seafood products can be estimated with reasonable certainty from SSB (2014d) and Olafsen et al. (2013). Accurately estimating the composition of by-products is more challenging. By-product flows not specifically for human consumption are typically aggregated into “whitefish” and “pelagic” categories each representing five or more species (Rubin, 2011; Olafsen et al., 2013). However, reasonable assumptions about species composition can be made by utilizing processing details from Olafsen et al. (2013). For example, Olafsen et al. (2013) estimated that 70% of Atlantic herring are filleted. Multiplying the total landed catch of Atlantic herring (NO. MoF, 2014; SSBa, 2014) for human consumption by 70% and again by the by-product percentage from fillet processing (Olafsen et al., 2013) equals a volume corresponding to the published pelagic by-product total. We therefore make the assumption that all pelagic by-products can be modelled using the EPA + DHA content of Atlantic herring by-products.

Gadiform fishes (saithe, cod, haddock, cusk, etc) present a unique challenge to determing EPA + DHA transfer coefficients between seafood and by-products due to large fat deposits in the liver. For adult Atlantic cod, total body weight consists of approximatley 43% by-products (Olafsen et al., 2013) which contain 80% of the EPA + DHA in the whole fish (Falck et al., 2006); 65% in the liver alone. The weight of cod liver during the winter/spring spawning season increases to 16% of the total weight of cod by-products (Olafsen et al., 2013). A large percentage of the Norwegian whitefish harvest occurs during the winter/spring season. The assumption of a 16% liver percentage was therefore used as a proxy for all gadiform by-products with data unavailable for other species.

The unequal distribution of lipids and EPA + DHA in gadiform liver has created niche markets for liver such as Norwegian cod oil or canned/smoked cod liver. The market preference for liver over other by-products means that the EPA + DHA content of flows following liver consuming processes is lower than the initial value. To account for these changes, a gadiform liver account balance was created to keep track of the amount of liver used in the manufacture of cod liver oil. Table 8 shows the liver account balance methodology used to generate gadiform by-product parameters presented in Tables 9 and 10. Gadiform liver for human consumption is estimated by multiplying the volume of gadiform by-products to human consumption by the liver composition of by-products (7,6%) after the cod liver oil process. The 7,6% liver ratio was applied for human consumption ahead of the feed markets to represent the superior buying power of the seafood markets in purchasing gadiform liver. The 3,13% gadiform by-product parameter was used for all flows in which gadiform by-products were processed into feed ingredients.

Table 8: Gadiform liver account balance for EPA + DHA estimates of by-products

	Initial value[1] (t)	Cod liver oil (t)	Seafood (t)	Residual (t)	Residual (%)
Liver in landed catch	$6{,}24 * 10^4$	--	--	$6{,}24 * 10^4$	100,00 %
Liver in dumped catch	$4{,}46 * 10^4$	--	--	$1{,}78 * 10^4$	28,58 %
Liver to marine by-products market	$1{,}78 * 10^4$	$1{,}01 * 10^4$	--	$7{,}75 * 10^3$	7,64 %
After cod liver oil processing	$7{,}75 * 10^3$	--	$5{,}69 * 10^3$	$2{,}06 * 10^3$	3,13 %

[1] Based on 16% liver of total by-products, which constitute 43% of round weight (Olafsen et al. (2013)

Table 9: Gadiform by-product EPA + DHA concentration 16% liver

By-product	By-product weighting[1]	Total lipids[2] (%)	EPA + DHA[2] (% TL)	EPA + DHA factor (%)
Heads	36,00 %	0,30 %	26,20 %	0,03 %
Guts	18,00 %	1,20 %	33,30 %	0,07 %
Liver[3]	16,00 %	60,00 %	18,00 %	1,73 %
Cuts	19,00 %	0,40 %	40,90 %	0,03 %
Milt	6,00 %	1,75 %	40,60 %	0,04 %
Roe	5,00 %	0,80 %	43,10 %	0,02 %
Weighted AVG	100,00 %	10,15 %	30,67 %	1,92 %

Table 10: Gadiform by-product EPA + DHA concentration 7,6% and 3,13%

By-product	By-product weighting[1]	Total lipids[2] (%)	EPA + DHA[2] (% TL)	EPA + DHA factor (%)
Heads	38,00 %	0,30 %	26,20 %	0,03 %
Guts	20,00 %	1,20 %	33,30 %	0,08 %
Liver[3]	7,64 %	60,00 %	18,00 %	0,83 %
Cuts	21,00 %	0,40 %	40,90 %	0,03 %
Milt	8,00 %	1,75 %	40,60 %	0,06 %
Roe	5,36 %	0,80 %	43,10 %	0,02 %
Weighted AVG	100,00 %	5,20 %	32,14 %	1,04 %

By-product	By-product weighting[1]	Total lipids[2] (%)	EPA + DHA[2] (% TL)	EPA + DHA factor (%)
Heads	39,00 %	0,30 %	26,20 %	0,03 %
Guts	22,00 %	1,20 %	33,30 %	0,09 %
Liver[3]	3,13 %	60,00 %	18,00 %	0,34 %
Cuts	22,51 %	0,40 %	40,90 %	0,04 %
Milt	8,00 %	1,75 %	40,60 %	0,06 %
Roe	5,36 %	0,80 %	43,10 %	0,02 %
Weighted AVG	100,00 %	2,53 %	32,87 %	0,57 %

[1] Olafsen et al. - Adjusted for even weighting
[2] Lambertsen
[3] EPA + DHA data from Nifes

Aggregation of Species Categories into Whitefish, Pelagic and Shellfish

The groupings from Table 5 were further aggregated in the model by combining the two species categories "Flatfish and bottomfish" and "Gadiforms," into the species category "Whitefish." This aggregation was performed to make the system compatible with processing coefficients identified in Olafsen et al. (2013 where the species are grouped into "Whitefish, Pelagic and Shellfish". After aggregation, the two data sets are comparable, albeit with a few important differences. The system in this thesis includes by-products from foreign vessels; treating them the same as Norwegian caught fish under the assumption that if primary seafood products can be landed in Norway, then by-products should be landed as well. Another difference is that the system definition in this model includes all marine organisms commercially harvested in Norway in 2012, while Olafsen et al. (2013) focuses on the most commercially important species.

Imports and Exports

Import and export data provide the basis for estimating MFA inflows and outflows at the country level. In 2012, Norwegian fish feed producers required1,4 Mt of imported ingredients to produce 1,6 Mt of feed; including over one Mt of vegetable ingredients (SLF, 2013; SSB, 2014a). With only 5 million inhabitants, Norwegian aquaculture producers turned 1,6 Mt of feed into 187 tonnes of farmed fish and shellfish (live weight) per inhabitant, compared with 29.6 in the EU and 3.6 globally (FAO, 2012). The wild capture fleet harvested 2 135 million tonnes of fish and shellfish in 2012 (SSB, 2013). Norway's combined production of seafood from capture fisheries plus aquaculture is equal to nearly 60% of production in the EU, of which 95% is exported (Eurostat, 2014; Meld.St.22). It is obvious that Norway is an efficient seafood producing nation, but appears to be heavily reliant on imports for raw materials.

Research question two is revisited:

2. To what degree is the Norwegian seafood industry built on Norwegian raw materials of high quality in 2012? What are the implications for growth to 2050?

The methodology for answering this question requires a very clear picture of Norway's dependency on foreign trade in 2012. Statistics Norway (SSB) is Norway's foremost collector and publisher of statistics, organized under the Ministry of Finance. Import and export data is organized under the "external economy" section of the website (SSBd). Under this section lies the category "external trade in goods." The function "create own graphs and tables" allows the user to sort through time series data for imports and exports using harmonized system codes (HS). Under "external trade in goods" harmonized system codes (HS) were data mined for production chosen for Norway in 2012 (SSB – Grouping 08801). The time series grouping 08801 was manually data mined for product categories (HS) containing marine animal commodities. HS commodity categories containing similar types of marine species were grouped according to their perceived use (see the appendices for examples). When species contributions to HS categories were uncertain, representatives in the fisheries and aquaculture industries were contacted for comment and clarification, which were altered to reflect their contributions. An import/export example is presented in the appendices.

Uncertainty

The methodology used for the development of parameters relied heavily on assumptions. The assumptions made in this report reflect the highest attempt at academic integrity allowed within the time allowed. The author acknowledges that statistical quantification of uncertainty is always desirable. The data used to derive system parameters relies heavily on publications which do not quantify uncertainty (Olafsen et al., 2013; Richardsen, 2011). Uncertainty in individual processes is also difficult to quantify due to the amount of confidential personal communication required to achieve the desired resolution. As a general rule, processes heavily influenced by the wild catch sector are more uncertain than for aquaculture. Aquaculture operations are heavily regulated and localities are more easily monitored than fishing vessels. In addition, a recent investigation into the fishing industry found alleged cheating in the counting of landed catch at approximately 20% (NRK, 2014). With this in mind, even a 25% uncertainty for parameters linked to wild catch is insufficient. The author recommends therefore an uncertainty of 35% for all flows linked to wild landed catch and 25% for all other flows.

Quantification of the System in Results

Results for the quantification of the system are displayed using two different methods. The product weight and EPA + DHA layers are both displayed using common MFA methodology with boxed processes, a dotted line for the system boundary and flows between processes. Color coded boxes main display the flow value and the predominant species in the flow. Flows are represented by either red or dashed black arrows. Dashed black arrows were used for contrast when flows crossed over in the diagram. A Sankey diagram was created for better resolution of the EPA + DHA system. In Sankey diagrams, the width of the flow is related to the magnitude relative to other flows. The Sankey was created using e!Sankey Pro (2013) software from IFU Hamburg version 3.2.0.466.

Results

Presentation of results will follow the initial layout of the research questions reviewed below. The results section will start by introducing the product weight layer in Figure 4, followed by insights into questions one and two from a product weight perspective. The EPA + DHA layer is first introduced in the same format as the product weight layer in Figure 6. The Sankey representation of the EPA + DHA layer is presented in Figure 7. Both layers provide interesting results to the research questions, but results related to question three rely more on the substance layer due to the importance of EPA + DHA to sustainability.

1. How well does the industry utilize by-products in 2012? What are the implications for growth to 2050?

2. To what degree is the Norwegian seafood industry built on access to Norwegian ingredients in 2012? What are the implications for growth to 2050?

3. Can this growth be achieved within the bounds of sustainability and consumer acceptance?

Alternatively, question two focuses on the product weight layer to assess the high degree of imported vegetables ingredients. An assessment of the impacts of vegetable ingredients would be meaningless in the EPA + DHA layer because vegetables do not contain EPA + DHA. The results section concludes with a forecast of supply and demand for EPA + DHA until 2050. The forecast starts with an estimation of system requirements in the base year (2012) and extends the analysis to 2050 at annual growth rates of 4% for aquaculture and 7% for marine ingredients. A scenario representing the best case for increasing existing EPA + DHA resources was created. This scenario represents a ban on by-product dumping fully enforced in 2030, combined with a 50% increase in wild landed catch. Inclusion of scenarios for alternative sources of EPA + DHA were evaluated, but not included in the forecast due to high uncertainties. Alternative sources of EPA + DHA are included in the system with negligible values to represent future contributions.

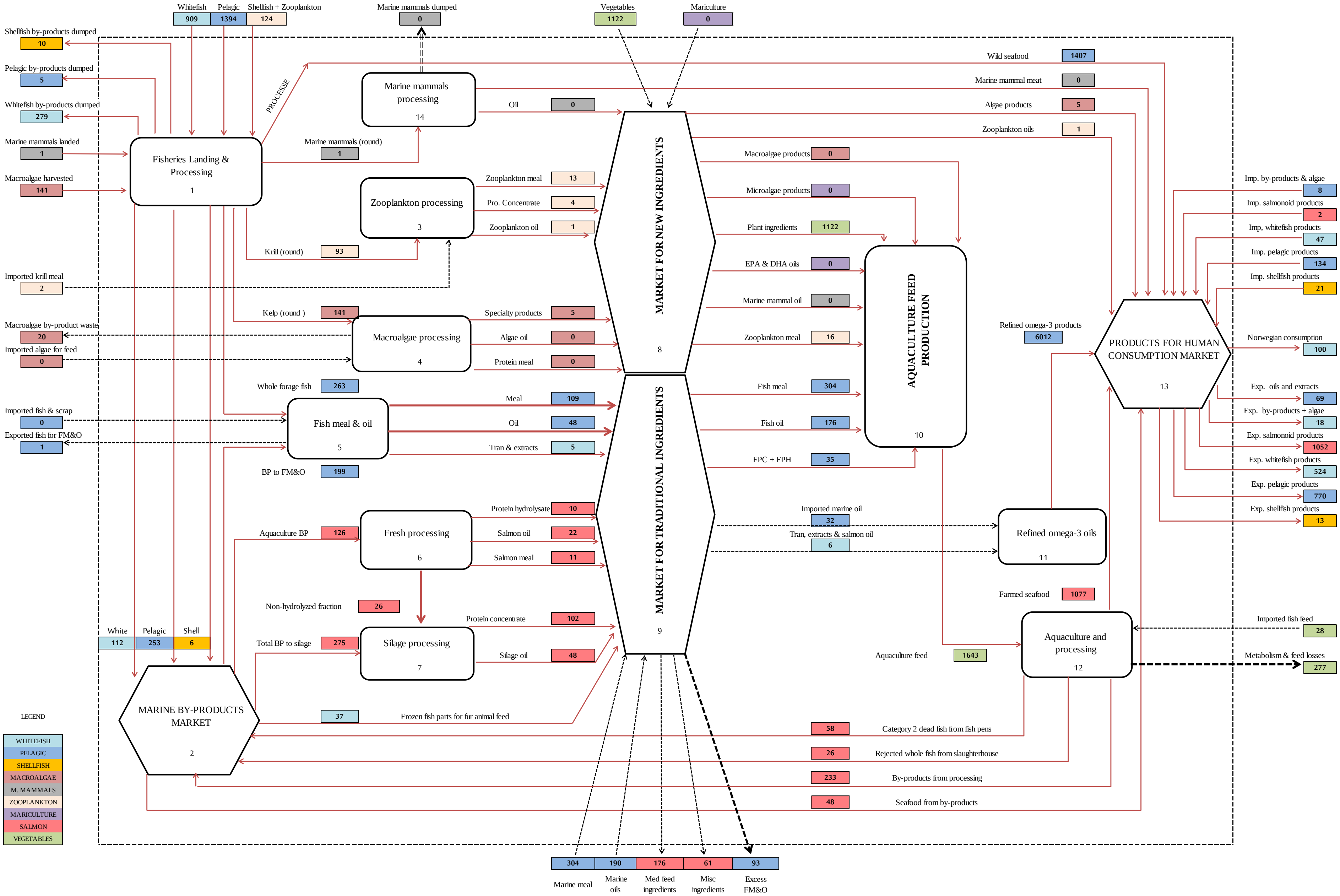

Figure 4: Product weight layer in kilotonnes

Product Weight Layer

To what degree is the industry based on Norwegian ingredients?

The marine ingredients industry is represented by production processes separating the two large ingredient markets from *Fisheries Landing and Processing* and *Marine By-products Market*. These production processes are *Fish Meal & Oil (FM&O), Macroalgae Processing, Silage Processing, Fresh Processing and Zooplankton Processing*. These processes and their products demonstrate clearly the level of exchange between wild fisheries and aquaculture. The aquaculture sector was assumed to utilize all of the 221 kt of Norwegian FM&O equivalents (FM&O, FPH, FPC) and an additional 336 kt of imported FM&O for a total of 557 kt overall. The total amount of imported FM&O in 2012 was 434 kt. This leaves a surplus of imported FM&O of approximately 100 kt, which was assumed to be inventory. In Table 11, the import percentage for FM&O was 60% without inventory and 66% if the surplus FM&O is taken into account.

Table 11: Overview of fish meal and oil consumed for aquaculture in kilotonnes

	Fish meal[1]	Fish oil	Total FM&O	Vegetable ingredients	Total ingredients
Domestic 2012	161	61	221	--	221
Imports used in feed 2012	219	116	335	1122	1458
Imports unaccounted for (inventory)	56	43	99	--	99
Total 2012	380	177	557	1122	1679
Total 2012 + inventory	436	219	656	1122	1778
Percent imports 2012	58 %	66 %	60 %	--	87 %
Percent imports 2012 + inventory	63 %	72 %	66 %	--	88 %

[1] Includes fish meal, FPC and FPH from whitefish, pelagic and zooplankton, and macroalgae

Vegetable ingredients were by far the largest single contributor to aquaculture feed composition in Norway in 2012. Approximately 1 122 Mt of vegetable ingredients were consumed. Rapeseed oil and soybean concentrate each contributed approximately 335 kt to the total (Ytrestøyl, 2014). Without taking additives into account, the production of one kilo of aquaculture feed in 2012 would require approximately 870 to 880 grams of imported ingredients.

How well does the industry utilize by-products?

The fisheries and aquaculture industries produced approximately 1 Mt of potential by-products from 3,66 Mt (ww) marine animals and macroalgae. The relative efficiency of converting potential by-products into actual by-products varies across industries. The aquaculture industry converts approximately 100% of potential by-products into new products. The pelagic fishing fleet is equally efficient at converting their available scrap into fish meal, oil and protein concentrate. The whitefish, shellfish, macroalgae and marine mammal harvesting industries are less efficient. Marine mammals had to be excluded from Figure 5 due to a very low harvest. However, conversations with industry representatives suggest that the by-product utilization rate for marine mammals and macroalgae is negligible. The overall by-product utilization rate for Norway expressed as (by-product utilized/total potential by-products) with all industries taken into account is approximately 62%.

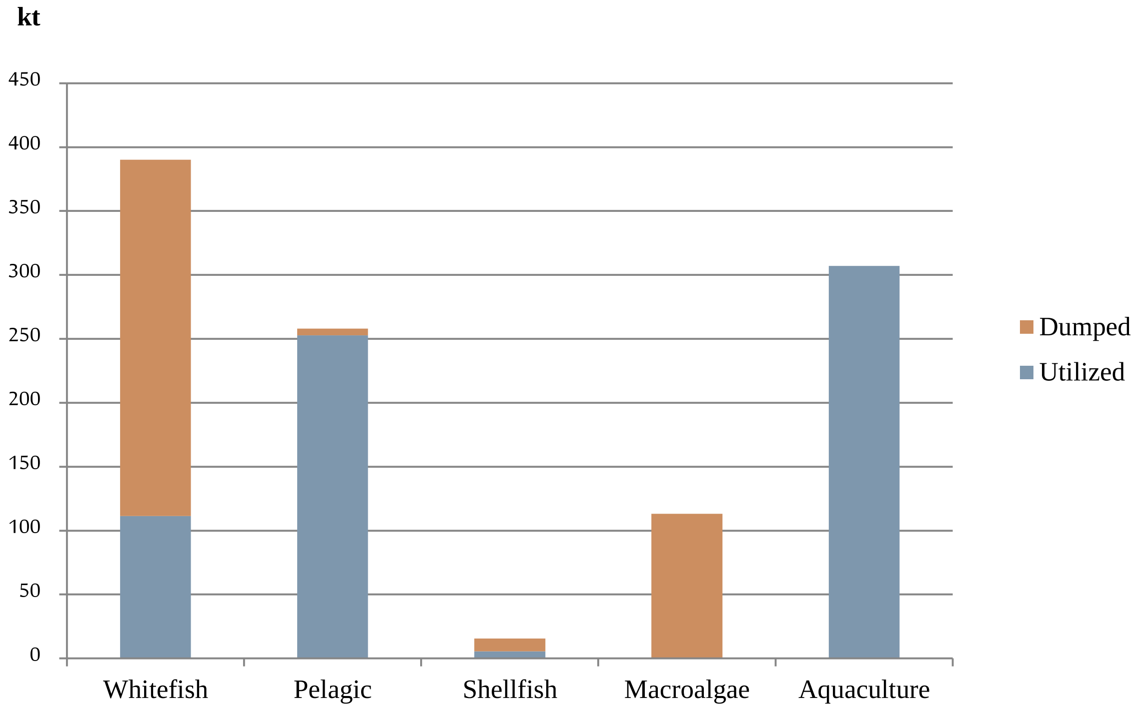

Figure 5: By-product utilization across industries in kilotonnes

All scrap collected from non-salmon species was assumed to be converted into aquaculture feed. Based on FM&O composition data from Ytrestøyl (2014), Norway imported 71 kt of FM&O from North Atlantic scrap. Norwegian scrap contributed 112 kt of marine ingredients to aquaculture feed. Assuming that all imported North Atlantic type FM&O goes to feed and not inventory (Table 12), scrap accounted for approximately 33% (183/557) of marine ingredients in aquaculture feed in 2012.

Table 12: Overview of fish meal equivalents and oil production from fish scrap in kilotonnes

	Meal	Oils	Total
Domestic pelagic scrap	37	19	56
Domestic whitefish type scrap + cod liver oil presscake	10	1	11
Domestic pelagic and whitefish scrap from *Silage Processing*	35	12	47
Imported North Atlantic type[1]	50	21	71
Total	131	52	183

EPA + DHA Layer

The change from product weight to EPA + DHA elicits immediate changes in the magnitude and composition of system flows. The biggest immediate change is the disappearance of the imported vegetable ingredients flow. Vegetable ingredients are suitable replacements for protein and other lipids, but do not contain EPA or DHA. The reduction in magnitude of flows containing salmon reflect the low EPA + DHA composition of salmon by-products relative to the higher EPA + DHA composition of wild fish. The flow "misc. ingredients," an outflow from process *Market for Traditional Ingredients (9)* changes color from pink to green to reflect the higher EPA + DHA content of the whitefish by-products contained in the aggregated flow. The feed related flows interacting with *Aquaculture and Processing (12)* change color from green to blue. This is a result of the large vegetable ingredient product weight flow zeroing out.

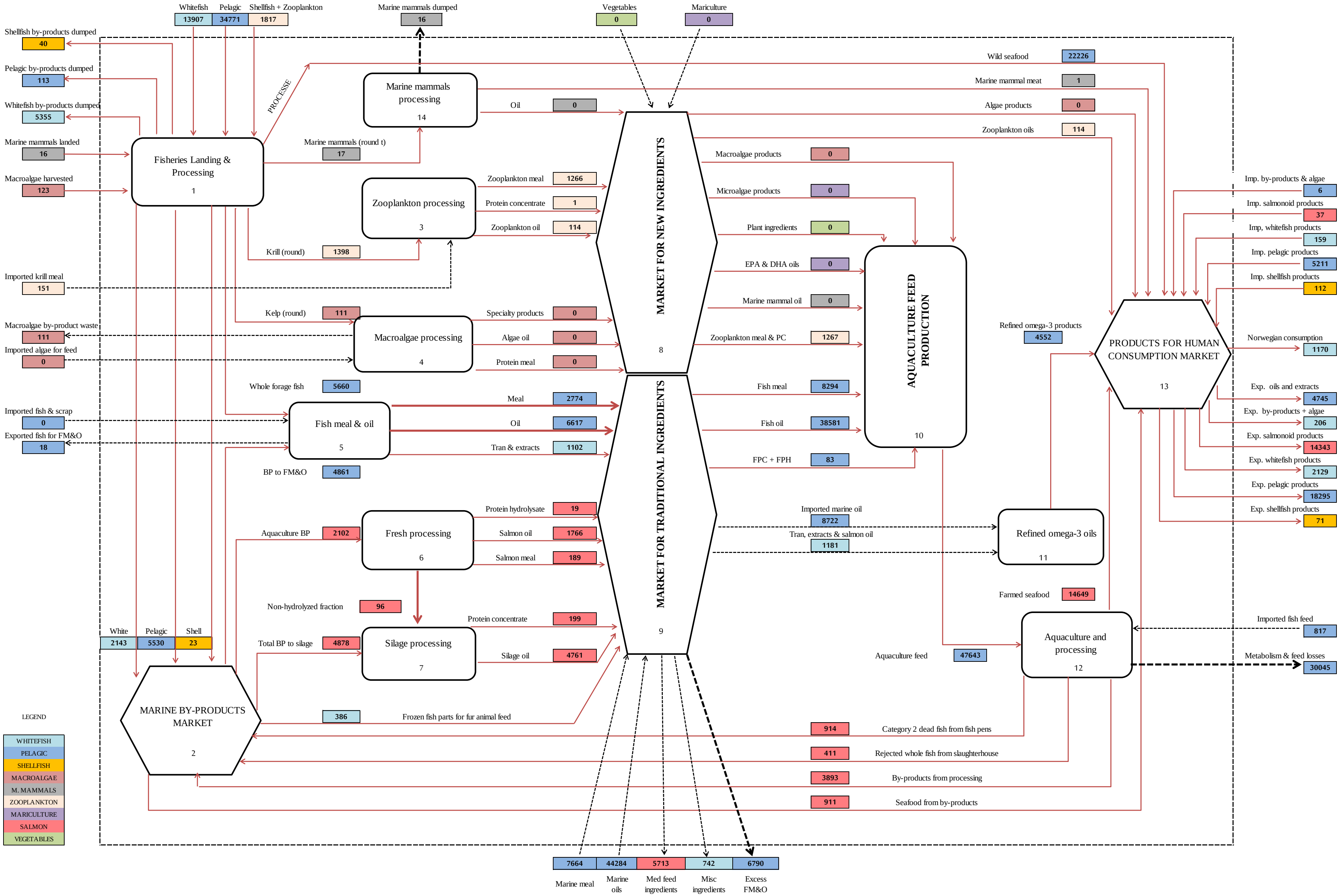

Figure 6: EPA + DHA layer in tonnes

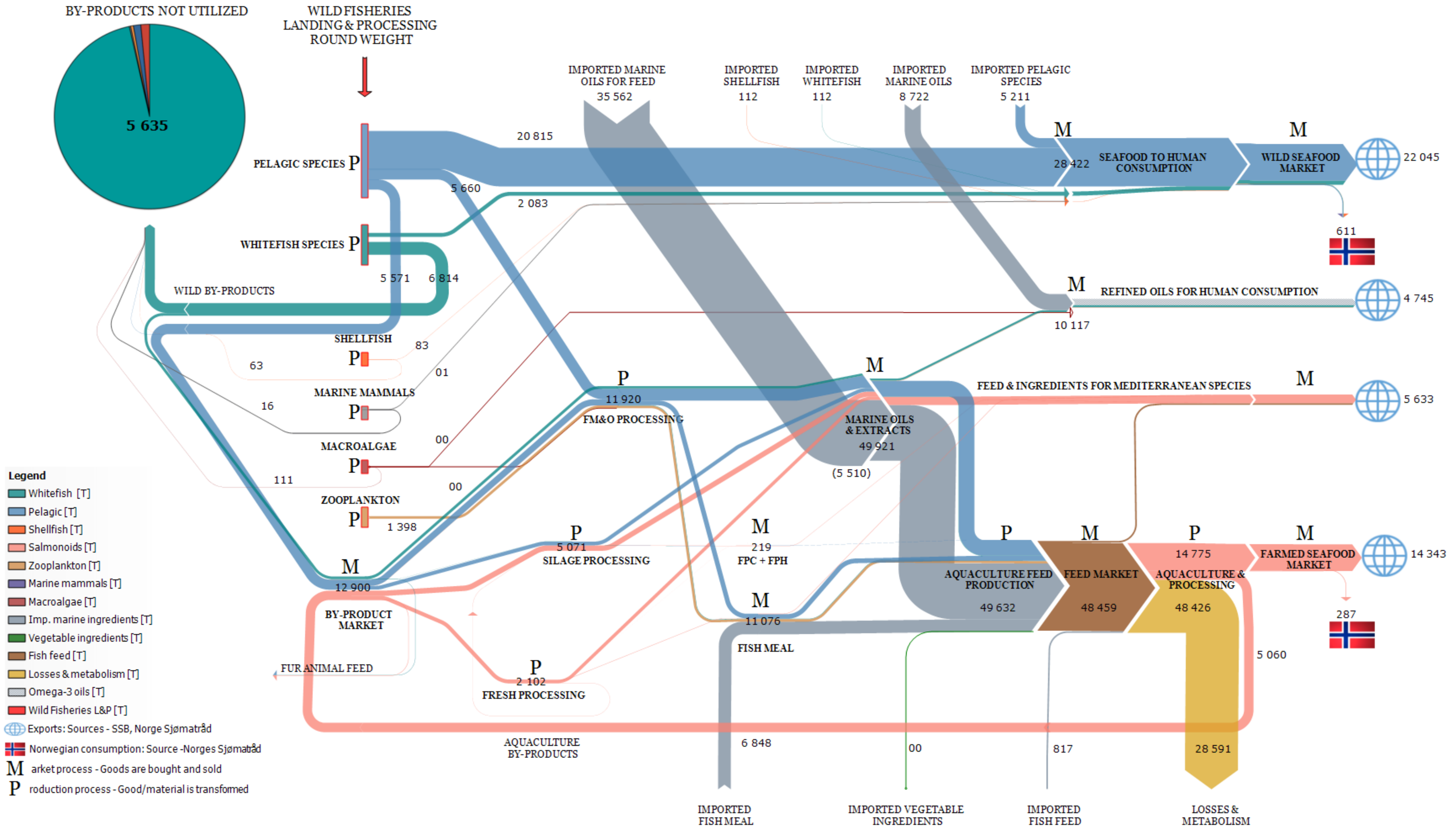

Figure 7: Sankey representation of the EPA + DHA layer in tonnes

The Sankey diagram in Figure 7 illustrats the volume of imported EPA + DHA required to sustain the aquaculture feed industry. The gray flows are imports of pelagic fish meal and oil from Peruvian Anchoveta. The magnitude of flows containing pelagic species is especially clear in the Sankey, reflecting the fact that pelagic species are richer in EPA + DHA than whitefish or salmon. The distribution of whitefish flows suggests that consumers are gaining access to only a fraction of the available EPA + DHA.

To what degree is the industry based on Norwegian ingredients?

The overall percentage of imported ingredients for Norwegian aquaculture feed in 2012 was 79% for the EPA + DHA layer. The marine ingredients industry was reliant on imports for 54% of raw materials. Table 13 shows the contribution of individual products to product categories in the marine ingredients industry.

Table 13: EPA + DHA distribution of products in the marine ingredients sector in tonnes

	Refined oils[3] and extracts	Salmon[2] products	Fur industry feed	Total
Whitefish liver oil (tran) - *FM&O processing*	1 102	--	--	--
Zooplankton oil - *Zooplankton processing*	114	--	--	--
Salmon oil - *Fresh processing*	80	--	--	--
Macroalgae alginat - *Macroalgae processing*	0	--	--	--
Imported pelagic oil for omega-3 industry	8 722	--	--	--
Salmon oil - *Fresh* and *Silage processing*	--	4 455	--	--
Salmon FPC + hydrolysate - *Fresh and Silage processing*	--	135	--	--
Salmon meal - *Fresh processing*	--	189	--	--
Mediterranean species fish feed[1]	--	865	--	--
Whitefish by-products (frozen)	--	--	127	--
Pelagic by-products (frozen)	--	--	55	--
Salmon by-products (frozen)	--	--	204	--
Total marine ingredients	--	--	--	16 048
Percent imported	--	--	--	54,35 %

[1] SSB reported 29 476 tonnes of exported fish feed in 2012. Assumed Mediterranean type fish feed with salmon ingredients from personal communication with industry representative and allocated the system standard 2,90% EPA + DHA percentage

[2] Most of the these products are exported for the production of Mediterranean type fish feed

[3] For human consumption

Sustainability

The economic feed conversion ratio (eFCR) is a common sustainability metric reported by the aquaculture industry. This metric represents the efficiency of coversion of raw material to final delivery and is measured as the feed input/ready to slaughter fish in wet weight (Ytrestøyl et al., 2011). In order to allow for comparison with wild fisheries, the eFCR was modified into a new metric called the efficiency of substance delivery (ESD). The ESD is calculated as total inflows of EPA + DHA to the product system / total EPA + DHA delivered to consumers as seafood. "Seafood" includes all primary and secondary products sold as seafood, but does not include marine oils or powdered protein products. A comparison between the wild and aquaculture industries will reflect production losses, losses from fish metabolism for aquaculture and processing tendencies between the industries, as well as the consumption of by-products as seafood. The goal of the ESDA is to quantify compare major inflows and losses against the shared operational goal of delivering high quality seafood to consumers. Figure 8 shows the results; note that wild landed catch does not contain imported seafood.

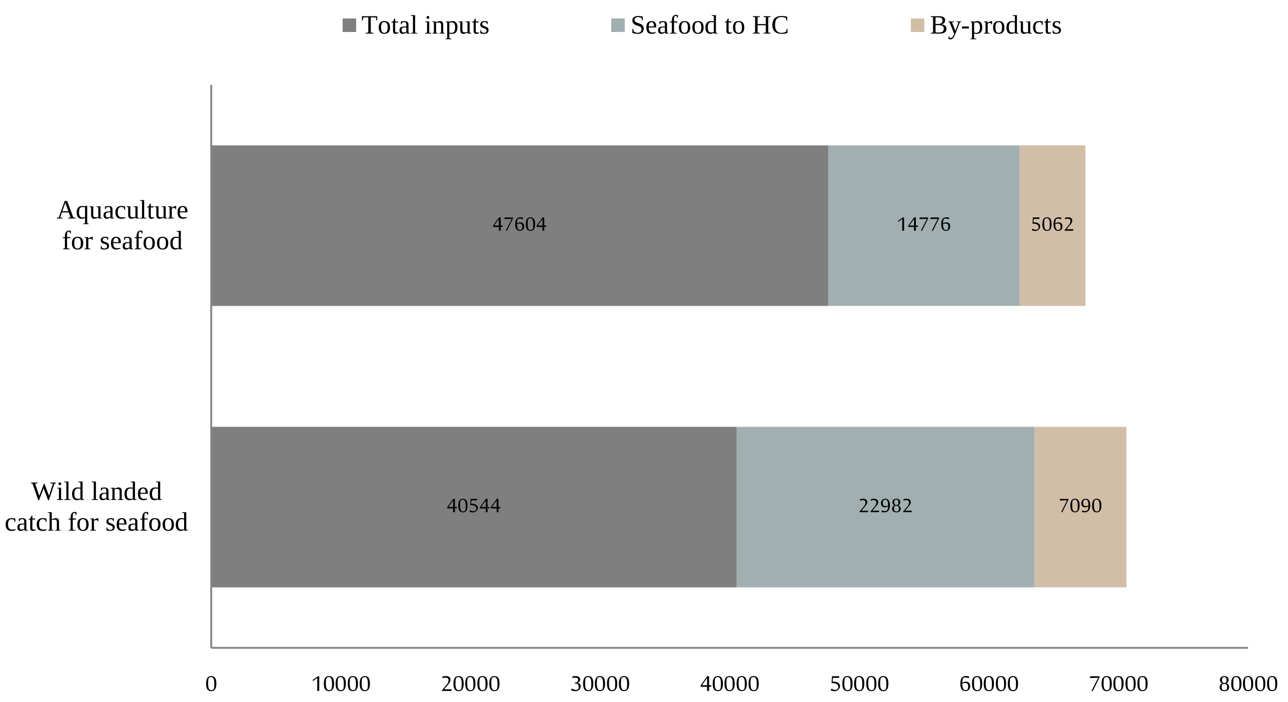

Figure 8: Efficiency of substance delivery in tonnes of EPA + DHA

The total inputs to wild caught seafood are the round weight marine animals landed for human consumption, totaling 40 544 tonnes of EPA + DHA. The wild seafood industry contributed 22 982 tonnes of EPA + DHA in seafood products to human consumption. The total inputs to the aquaculture sector is represented by the 47 604 tonnes of EPA + DHA in feed consumed (domestic + imported). The aquaculture sector delivered 14 630 tonnes of EPA + DHA as seafood to consumers. The aquaculture sector utilizes more by-products as a percentage than the wild fisheries sector, but wild landed catch has the higher absolute value. The overall results were an ESD_aqua of 3,22 tonnes of EPA + DHA per tonne of seafood delivered to consumers, compared with an ESD_wild of 1,76 for the catch based industry.

Supply and demand forecast – Insights into sustainability and growth

Wild fish stocks are not expected to increase dramatically in the future, suggesting that supply of EPA + DHA may have already reached a global maximum. A forecast of future EPA + DHA supply and demand was performed. This forecast was created to determine whether the fisheries and aquaculture industries can realistically continue high annual growth.

Assumptions

4% growth in aquaculture from 2012 – 2050

7% growth in marine ingredients industry from 2012 – 2050

Imports to the system remain unchanged from 2012 levels

The EPA + DHA content in marine ingredients and feed remains unchanged from 2012 levels

Total feed = domestially produced feed + imported feed

2012 is the base year. Aquaculture feed starts with a product mass of 1,67 Mt and an EPA + DHA value of 48 500 tonnes. Marine ingredients starts with a product mass of 25 600 tonnes and an EPA + DHA value of 16 000 tonnes.

No dumping + wild fishery increase of 50% is based on assumptions made in "World's Foremost Seafood Nation." The forecast was modelled using a simple exponential growth function to simulate slow adoption of the dumping ban between 2012 and 2020. By-product utilization increases from 2020 to 2030, wth total utilization reached in 2030.

Results for the forecast show that demand begins to outstrip supply by 2014. By 2020, an EPA + DHA shortage defined as 1 – (demand/supply) of 35% is a reality. By 2050, demand tops 400 000 tonnes, an increase of 620% from the base year. The best case scenario for increasing future supply without alternative sources of EPA + DHA covers approximately 3% of the gap between supply and demand in 2050.

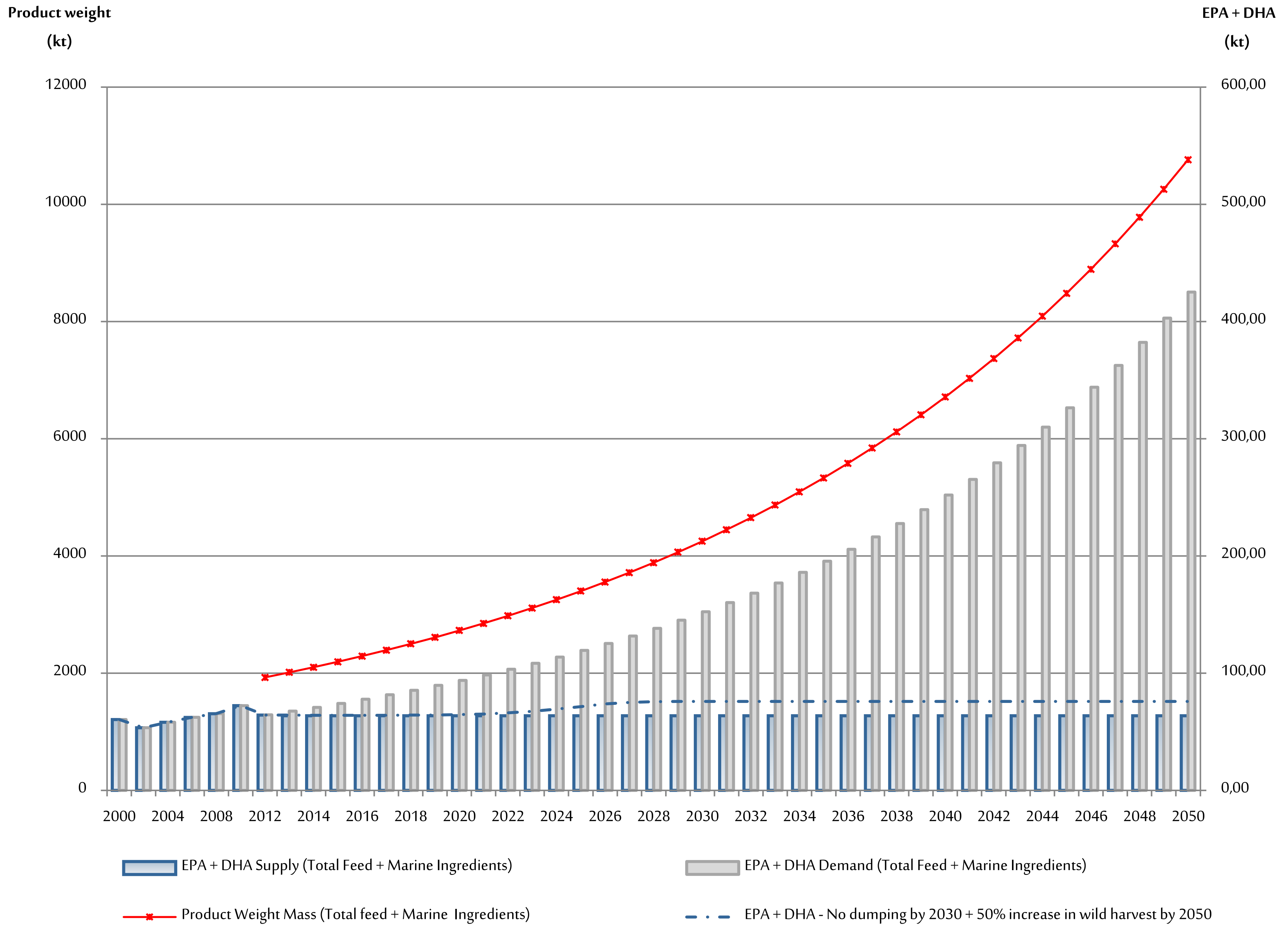

Figure 9: **S**upply and demand forecast for EPA + DHA from 2012 to 2050

Discussion

Assessment of the Explanatory Power of the Model

The fisheries and aquaculture system modelled in this thesis cannot be seen as an exact representation of reality in 2012. However, the explanatory power of the model can be tested against measured indicators to lend credibility. The Norwegian Institute of Nutrition and Seafood Research (NIFES) publishes an annual feed monitoring report including the EPA + DHA concentration of Norwegian salmon feed. NIFES calculated the mean EPA + DHA concentration of aquaculture feed in 2012 to be 3,12%. The EPA + DHA content of "average" fish feed can also be estimated by dividing the EPA + DHA layer value for aquaculture feed produced by the product weight layer value. The system estimated the EPA + DHA content of feed to be approximately 2,94%. This value matches up well with the "average" feed measured by NIFES.

To What Degree is the Industry Based on Norwegian Ingredients?

The aquaculture industry imports 88% of feed ingredients in the product weight layer and approximately 75% in the EPA + DHA layer. The marine ingredients industry relies less on imports than the feed industry, but still imported 55% of the EPA + DHA required for operations in 2012. The high import percentage for 2012 suggests that Norway does not have an industry built on Norwegian ingredients. The explanation for the high import percentage for feed ingredients is multifaceted. Marine ingredients are expensive (add price stuff here). The Norwegian situation is an example of the growing interdependence between fisheries, aquaculture and agriculture. In 1995, aquafeeds in Norway contained approximately 50% marine ingredients. Aquafeeds in 2020 are expected to contain up to 10 times less fish meal than in 1995; already in 2008/2009 world production of soybean meal topped 150 million tonnes, 25 times the annual production of fish meal.

The collapse of the Peruvian anchoveta stock due to an El Niño event in 1998 is a classic example of the danger of relying too heavily on imports for critical ingredients. Peruvian anchoveta represented approximately 50% of the EPA + DHA in Norwegian aquaculture feed and 55% for marine ingredients in 2012. The recently released IPCC 5th Assessment (AR5) report on climate change suggests that the ocean has been warming and will continue to warm towards 2050 (Pörtner et al., 2014). The report suggests that pelagic fish stocks like sardines and anchovies have been migrating away from traditional fishing grounds due to warming ocean currents. The direction of migration of anchovies and sardines has trended toward cooler waters in the Sea of Japan in the Pacific and the North Sea in the Atlantic. While future pelagic migration patterns are uncertain, the current reliance on imported pelagic species should be met with caution in light of the findings in IPCC AR5.

Vegetable ingredients

Vegetable ingredients made up 68% of the product weight in aquaculture feed in 2012. The contribution of domestic vegetables to the Norwegian fish feed industry is assumed to be zero (SLF, 2012). Sources of imported vegetable protein are soybean protein concentrate, wheat gluten, sunflower meal, corn gluten, fava bean meal and pea meal. Binders for increased technical pellet quality are derived from wheat and peas. The largest dietary energy source for salmon in 2012 is rapeseed oil, contributing approximately twice as much as fish oil (Ytrestøyl, 2014).

The sustainability of a largely imported vegetarian diet for salmon has many variables for consideration. Ziegler et al. (2013) performed a carbon footprint analysis for Norwegian seafood that evaluated the GHG emissions of salmon aquaculture using several future feed types. Included in the study was a feed high in marine ingredients and one with a higher percentage of vegetable ingredients than today. Results of the study were inconclusive, showing little difference in GHG emissions for the various feed types. The study did note that vegetable ingredients had lower GHG emissions than marine ingredients on average (kg/kg); however the GHG emissions from Brazilian soybean concentrate were higher than most marine ingredients per unit weight.

Vegetable ingredients and impact assessment

The goal of this thesis is not to determine all of the environmental impacts from fisheries and aquaculture, but rather to display the utility of a systems approach to resource management. Material flow analysis helped to identify the large flow of vegetable ingredients into the Norwegian system. After identifying this flow as interesting from a sustainability standpoint, more pointed methodologies like LCA can be implemented to gain a higher degree of resolution about the impacts. We continue the example of Brazilian soybean production to further illustrate this point.

Brazil is the second largest producer of soybeans in the world with a growth rate twice the world average (FAO, 2012). Stimulating this growth is an increasing demand for soy protein for the animal feed industry in Europe. It is estimated that 70 % of Brazil's soybean exports end up in European ports (Cavalett et al., 2009). Soybean plantation areas have grown from roughly 1 million hectares in 1970 to 23 million hectares in 2010 (Garrett et al., 2012), with 50% of the production in the Amazon and Central West regions. For comparative purposes, the area of Norway is about 32 million hectares.

Da Silva et al. (2010) performed a life cycle analysis to evaluate the environmental impacts of intensive soybean production in Brazil. Results suggest that soybean farming is a resource intensive industry with high process inputs of energy and fertilizers. Land use impacts stemming from the occupation and transformation of tropical rainforest and cerrado to cropland were included in the study, but losses in biodiverity were not quantified. It terms of environmental impact assessment, biodiversity hotspots like the Amazon are of immeasurable importance. LCA, despite improvements in spatially explicit modelling, (Koellner et al., 2013a;b) cannot accurately assess local land use impacts alone. This is an important argument for holistic approaches to resource management. In this example, MFA has not quantified the impact of Brazilian soybean concentrate in Norwegian salmon feed, but by identifying the flow, has initiated the process.

How Well Does the Industry Utilize By-products?

The status of marine by-products has increased dramatically in the last two decades. Previously considered a problem, marine by-products have been the subject of considerable attention due in part to unique functional properties, but also increasing demand for marine products (Rubin, 2011; Arason et al., 2009). Marine by-products have contributed significantly to the rapid growth in the marine ingredients industry. Some of the most profitable companies in the fisheries and aquaculture industries focus specifically on by-product processing (Richardsen, 2011). When the Norwegian government published the "World's Foremost Seafood Nation," it envisioned a total utilization of fish. This report has extended that vision to all wild landed catch. This group includes marine mammals, zooplankton and macroalgae.

Results for the utilization rates of potential by-products showed that salmon and the pelagic industry achieved nearly total utilization of potential by-products in 2012. The whitefish industry had a utilization rate of 34%, followed by utilization rates of nearly zero for macroalgae and marine mammals. For zooplankton, it was assumed that no by-products were created from the catching and milling of krill into meal and oil.

Pelagic by-products

By-products from the pelagic fleet are an important domestic contribution of EPA + DHA to the marine ingredients industry and aquaculture feed industry. Historically Norway has been a major exporter of fish meal and oil from reduction fisheries. In 1980, Norway exported 548 044 tonnes of fish meal and oil. Domestic consumption from Norwegian aquaculture, marine ingredients and domestic seafood production have combined to reduce this amount to 33 872 (FAO FishStat Plus, 2013). Norwegian reduction fisheries still provide the majority of EPA + DHA for aquaculture feed and marine ingredients, while by-products from pelagic scrap account for approximately 60%. Scrap utilization from pelagic seafood fisheries is nearly 100%. Future increases in supply depend on catch increases or changes in processing techniques.

Salmon by-products

Salmon by-products are characterized by three types: processing scrap, dead fish from net pens and whole fish rejected by the processor. Of the three, only processing scrap is used for human consumption. Salmon by-products cannot be used in salmon feed and the vast majority of salmon by-products are processed for the export-oriented marine ingredients industry. From personal communication with the industry, the largest markets for salmon by-products are Mediterranean aquaculture companies raising marine species such as sea bream. Salmon by-products can be used in aquaculture feeds for non-salmon species. Salmon by-products are also used in pet feed and agricultural feeds for pigs and chickens. The nearly 100% utilization of by-products in the aquaculture industry in Norway is a major contributor of scarce marine lipids to these markets, thus reducing the burden on wild fish stocks. This is a positive development from a sustainability perspective.

Whitefish by-products

The fleet fishing for whitefish species has unique challenges in processing by-products. There are two main fleets in Norway categorized by vessel length; the coastal fleet and the ocean fleet (Olafsen et al., 2013). The coastal fleet has the advantage of operating closer to land based processing facilities, while the ocean fleet could be operating days away from the nearest port. This discrepancy led to the coastal fleet processing 58% of its by-products while the ocean fleet managed less than 9%. Whitefish by-products are especially valuable due to the large amount of EPA + DHA in the liver and viscera. Calculating the actual EPA + DHA composition of whitefish by-products is complicated by the increased size of the liver and gonads during the spring spawning season. A more realistic measure of the EPA + DHA value of by-products in this report would have assigned EPA + DHA values to specific harvest zones to reflect whether the whitefish species harvested was spawning or not. Nevertheless, the EPA + DHA contribution of whitefish by-products to the system was important to the marine ingredients sector in 2012. Cod liver oil production accounted for approximately 7% of the EPA + DHA requirement in marine ingredients.

Marine mammal by-products

Interest in EPA and DHA increased in relation to marine mammals with the discovery by Bang et al. (1976) of the “Greenland paradox” in the 1970’s. The authors studied the plasma lipids of three groups: Greenland Eskimos living in Greenland, Danes, and Greenland Eskimos living in Denmark. The diet of the Eskimos in their native Greenland consisted of marine mammals rich in fat and protein, supplemented with kelp and berries/vegetables during the summer, while the other two groups consumed a standard Danish diet. The prevailing research at the time suggested that a diet high in fiber and low in fat was the key to avoiding heart disease. Results from the study showed that heart disease was practically unheard of among Greenland Eskimos despite consuming a diet of 60% – 80% marine animal fat for most of the year. This study and subsequent studies determined that the blood lipids of Greenland Eskimos showed EPA and DHA levels significantly higher than cohorts on Western diets (Bang et al., 1971; 1975). A key finding from the report was that essential vitamins and minerals that most Western diets obtain from vegetables were found only in marine mammal by-products, which were consumed along with the meat and blubber.

A persistent effort was made during the course of this project to establish contact with the processors of marine mammals in Norway. Marine mammal processors were the only actors to provide zero information to this report. Instead, system modelling was accomplished by utilizing data compiled in SSB (2013) and SSBe (2014), in addition to assumptions based on Norway’s marine mammal politics

(Meld.St.27, 2003-2004). Norway has harvested seal and whale for centuries. In recent years, Norwegian whaling vessels have harvested around 600 minke whales for human consumption.

In accordance with “World’s Foremost Seafood Nation,” Meld.St.27 (2003-2004) also presents a vision of total utilization of whale and seal by-products. SSBe (2014) and SSB (2013) provides data on primary product weight and number of whole animals harvested, but zero by-product data. A mass balance approach was used to derive potential by-product volumes and their EPA + DHA content by utilizing literature on the body composition of marine mammals (Brunborg et al., 2006; Olsen et al., 2003; Shahidi et al., 1994). For Minke whales, by-products included every part of the animal besides the meat. For Harp Seals, the by-products consisted of seal meat and seal blubber, minus the seal blubber used to produce 66 tonnes of seal oil in 2012 (SSBe, 2014). By-product data for marine mammals thus has a high degree of uncertainty, but is considered reasonable based on the available information. Although the volume of dumped by-products is low compared to more common catches, the high value of EPA + DHA in marine mammal by-products deserves further attention.

Macroalgae

There are two firms that process significant amounts of macroalgae in Norway. One of them focuses solely on the production of alginate from *Laminaria hyperborea* and the other produces a host of wellness and feed ingredients from *Ascophyllum nodosum*. Both companies export most of their product weight and do not recycle potential by-products. Potential by-products from alginate production could include bioethanol, macroalgae meal and macroalgae oils among others. The total EPA + DHA value of by-products from macroalgae processing was not high in 2012 (111 tonnes), but still would have contributed about as much EPA + DHA as oil from whitefish scrap (116 tonnes) if fully utilized.

Can the Industry Grow Within the Bounds of Sustainability?

Life cycle studies consistently show that feed production has the largest share of environmental impacts in aquaculture production (Ziegler et al., 2013; Pelletier et al., 2009). The efficient conversion of feed into seafood is therefore an important part of mitigating impacts. The economic feed converstion ratio (eFCR) is often used as an indicator of efficiency in animal cultivation systems (Ytrestøyl et al., 2011). Variables captured by the eFCR indicator include fish metabolism, digestibility, feed losses and production losses.

The eFCR is usually expressed as the ratio (kg of pellets/kg of fish), in round weight. The eFCR is calculated in this manner to enable comparison between different farmed animals, but the comparative value of the eFCR is biased due to varying energy densities of animal feeds. Salmon metabolisms have evolved to utilize protein and fat for energy while terrestrial animals have evolved with a higher carbohydrate requirement. Adding to the problem is the water disparity between pellets at 93% dry weight (Sanden et al., 2013) and round weight fish at 35% dry weight (Kjos, 1997). Substance flow analysis takes water out of the equation by using EPA + DHA, allowing for a different efficiency indicator.

The new measure, here introduced as the efficiency of substance delivery (ESD), seeks to provide an unbiased measure of efficiency for comparing animal production systems. We applied the ESD to the wild fishery and aquaculture value chain and compared results. The common argument for the sustainability of using forage fish in aquaculture feed is that seafood markets view these species as undesirable (Tacon and Metian, 2008). The point made here and illustrated by the ESD is that farmed seafood requires an average of 3,22 units of EPA + DHA per unit delivered to the consumer, nearly twice the amount for wild fishery products.

EPA + DHA Supply and Demand Forecast

EWOS is one of the world's largest producers of fish feed, producing 1/3 of the world's salmon and trout feed (EWOS, 2014). The most recent edition (7) of EWOS spotlight (2013) evaluated the supply and demand forecast for marine oils. EWOS assumed 3% growth per year from 2014 for aquaculture and 10% for the omega-3 market. An average EPA + DHA content of 20% was assumed for marine oils. The dietary inclusion rate of total oils (plant and marine) was 31% of feed. Figure 11 shows the expected shortage of EPA + DHA for three different feed profiles, expressed as percentages of EPA + DHA in the total oils (31% of feed). A constant 7,5% EPA + DHA percentage of dietary feed oils will lead to a shortage of approximately 32% by 2020.

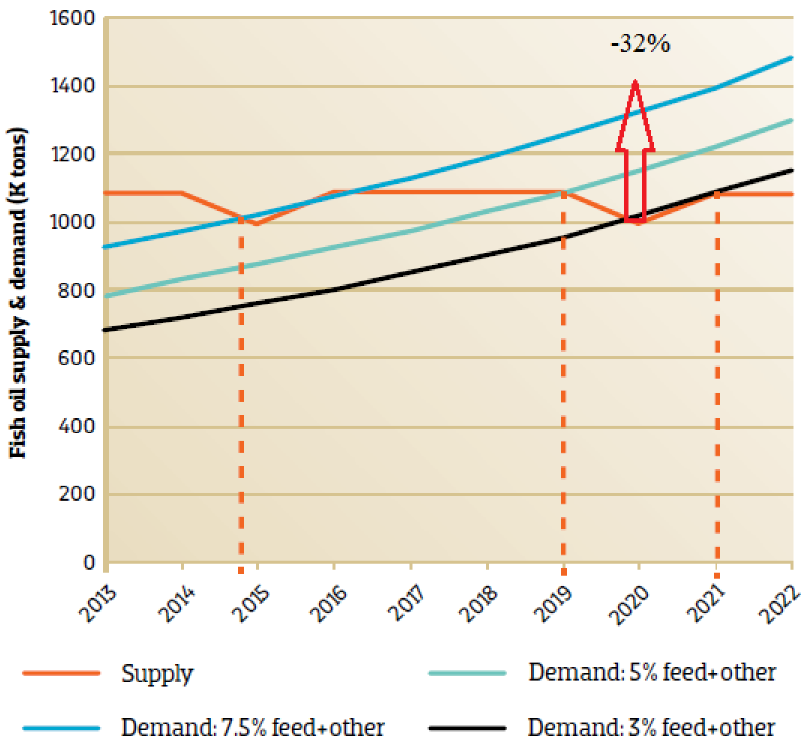

Figure 10: EWOS estimated global fish oil demand for salmonid feed and omega-3 capsules exceeds supply in 2014-2015 at 7,5%, 2019 at 5% and 2021 at 3% EPA + DHA inclusion levels in the marine oil added to salmonid feed (modified from EWOS, 2013)

The 7,5% inclusion level corresponds with an EPA + DHA contribution of 2,35% of the EPA + DHA in feed (31% total oils * 7,5% EPA + DHA = 2,35%). Results from this model suggest that fish meal provides a contribution of EPA + DHA to fish feed at approximately 21% of fish oil. For 2013, this means that fish meal contributed 0,49% of the EPA + DHA in feed (0,21 * 2,35% = 0,49%). Adding the contributions of fish meal and fish oil together give an estimate of the overall EPA + DHA content of fish feed in 2013. The EWOS feed estimate at the 7,5% inclusion level for 2013 (2,84% EPA + DHA) is very close to the 2012 estimate (2,94% EPA + DHA) produced in this model. Results from the EWOS forecast show that demand exceeds supply in all three scenarios within 7 years. Assuming that the 7,5% inclusion scenario was representative for 2013, the report suggests that demand will exceed supply in two years unless EPA + DHA levels are further reduced.

The assumptions and conclusions made in this thesis are very similar to those made by EWOS. Table 14 shows a comparison of important assumptions and main findings. An important difference between the two forecasts is the definition of marine ingredients. This thesis defined marine ingredients as all products of marine origin not consumed by the Norwegian aquaculture feed sector or as seafood. This definition encompasses the omega-3 market, fur industry feed and most salmon by-products. The inclusion of flows beyond the omega-3 market will lead to a higher overall demand for EPA + DHA in our forecast and could explain the difference in the absolute deficit by 2020. The overall takeaway from either forecast is that a shortage of EPA + DHA will limit growth in both the aquaculture and marine ingredients markets in the very near future.

Table 14: Comparison of two independent forecasts of EPA + DHA supply and demand

	EWOS spotlight	Gracey 2014
Yearly growth in aquaculture	3 %	4 %
Yearly growth in marine ingredients[2]	10 %	7 %
Scope	Global	Norway
EPA + DHA percentage of feed in base year[1]	2,84 %	2,94 %
EPA + DHA content of average marine oil for salmon feed	20 %	23 %
Time to EPA + DHA shortage	2 years	2 years
Absolute deficit by 2020 (Demand/Supply/100)	~ 32%	~ 35%

[1] Assumed that 7,5% EPA + DHA inclusion represents the average for 2013
[2] EWOS spotlight considered only the omega-3 market

EPA + DHA – Consumer Perspective

The study by Vanhonacker et al. (2011) suggests that consumers are vulnerable to sudden changes in the composition of seafood due to knowledge gaps. This thesis has identified that the composition of salmon feed ingredients has shifted from feed based on marine ingredients to a vegetable based feed. Previous studies have found that substituting vegetable oil for fish oil reduced the amount of EPA + DHA in the salmon fillet by 67% and changed the omega-6/omega-3 ratio from 0,192 for fish oil to 0,94 for vegetable oil – an increase of 492% (Torstensen et al., 2005). Jensen et al., (2012) found that farmed Atlantic salmon had an omega-6/omega-3 ratio of 0,44 in 2012, whereas the omega-6/omega-3 for wild salmon was 0,08.

The Jensen et al. study found that farmed salmon had a lower EPA + DHA content expressed as a percentage of fatty acids, but delivered more EPA + DHA to consumers (g/100g) than wild salmon due to higher overall lipid content. It should be noted that the EPA + DHA composition of the feed in the Jensen et al. study was 5,8%, nearly double the EPA + DHA content of Norwegian standard feed in 2012. Despite using a comparatively superior feed, the study suggests that the aquaculture industry has made significant progress in maintaining a high EPA + DHA content in salmon flesh while reducing dietary EPA + DHA levels. Much of this success can be attributed to the strategy of using “finishing feeds” with high EPA + DHA content just before slaughter. This strategy takes advantage of the findings by Stubhaug et al. (2007) and Mørkøre et al. (2013) that EPA + DHA retention rates can be manipulated through seasonal feeding and dietary restriction. These findings suggest that the lipid profile of farmed Atlantic salmon flesh has suffered a reduction in quality due to vegetable ingredient substitution, but confirms that salmon are still a good source of EPA + DHA for consumers.

Mitigation Strategies for Continued Growth

There is a general agreement in the aquaculture community that novel alternatives to fish meal and oil are needed (Turchini et al., 2009; Naylor et al., 2009; FHL 2013; Sørensen et al., 2011). Alternative sources of EPA + DHA from underutilized marine biomass include mesopelagic fish (EWOS, 2014) and lower trophic level species such as krill and other zooplankton (Naylor et al., 2009). Terrestrial sources for lipid and protein replacement are already highly utilized by the industry, but a replacement for EPA + DHA will require the genetic modification of crops. EWOS (2014) reports that BASF/Cargill, Dupont and DOW/DSM among others, have initiated research projects to develop genetically modified vegetables containing EPA + DHA. Fish feed producers have received concessions for the use of 19 GM plant ingredients from the Norwegian Food Safety Authority since 2005 (Mattilsynet, 2013), but have not exercised them for fear of consumer backlash.

Marine microalgae grown in land based mariculture systems may be the most promising solution for the future EPA + DHA shortage (Ryckebosch et al., 2014). Most research on microalgae systems have focused on the production of biofuels (Brennan & Owende, 2010), but the shortage of EPA + DHA has stimulated new interest in the production of marine lipids (Sørensen et al., 2011; Naylor et al. 2009). A recent study by Ryckebosch et al. (2014) tested 9 different marine microalgae against fish oil to test microalgal lipids against the status quo. The total lipid content as a percent of dry weight was above 10% for 8 out of the 9 species, with 5 of the 9 species reaching levels of 20% or more in total lipids. The researchers found that *Nannochloropsis gaditana*, *Nannochloropsis oculata*, *Phaeodactylum tricornutum* and *Pavlova lutheri* produced EPA contents similar to the fish oil control. None of the algal strains produced enough DHA to replace the fish oil. *Pavlova lutheri* was the only strain to produce high quantities of both EPA and DHA, reaching a combined EPA + DHA content of 13,3% of the oil sample. While not as high as the fish oil control used in the study, 13,3% is similar to the EPA + DHA content of oils made from herring and capelin in Norway.

Another alternative is to increase the level of fish processing in Norway. A higher degree of processing in Norway will increase the amount of by-products available for feed production and marine ingredients. Using the methodology of Olafsen et al. (2013), it was estimated that approximately 42% of the pelagic fish landed for human consumption in Norway are filleted. Nearly all of the mackerel and sardines are sold round frozen. It would be unrealistic to suggest that all pelagic fish landed for human consumption should be filleted because some of these fish (sardines, anchovies) are sometimes served whole. Mackerel however are rarely served whole and if not filleted, could be partially processed (head on gutted, or headed and gutted) in Norway. A low degree of processing is also the trend for whitefish and salmon, which are often processed cheaper outside of the country (Henriksen, 2013). St.Meld.22 (2012-2013) addresses the need to increase processing capabilities in Norway and it will be interesting to see how the industry responds.

Conclusion

This thesis has focused on the prospects of achieving growth using the goals presented in the DKNVS report “Value Created from Productive Oceans,” and the Norwegian government white paper Meld.St.22 “World’s Foremost Seafood Nation.” The definition of growth according to the DKNVS report is 4% annual growth in aquaculture and 7% for marine ingredients from 2012 to 2050. Many of the arguments for the vision in Meld.St.22 were based on principals of sustainability. The increasing shortage of food and especially marine protein and lipids was presented as an argument for Norway to more efficiently utilize its robust marine resources. Meld.St.22 presented strategies and ambitions for how Norway could improve its position as a seafood nation. Ambitions were presented for growth based on Norwegian raw materials, the total utilization of by-products and within the bounds of sustainability. These ambitions were modified into research questions to frame an assessment of whether the marine ingredients and aquaculture industries could obtain 7% and 4% growth rates from 2012 to 2050.

Results using material/substance flow analysis (product weight and EPA + DHA) suggest that Norway's degree of self sufficiency is low for both aquaculture and marine ingredients. Norway is 88% reliant on imports (product weight) for aquaculture and 55% for marine ingredients (EPA + DHA). Of the 88% of imported ingredients in feed, 68% were imported vegetable ingredients. Soybean concentrate and rapeseed oil comprised the largest share of ingredients in Norwegian fish feed in 2012.

Norway is not operating with a total utilization of by-products. The aquaculture industry and pelagic wild catch industry were most efficient. Both utilize nearly 100% of by-products with pelagic scrap contributing approximately 35% of domestically produced fish meal and oil. Salmon by-products are primarily exported as feed ingredients for Mediterranean finfish. The whitefish fleet has the lowest utilization rate (34%) among the three major categories of commercial species. The potential contribution of whitefish by-products is high due to gadiform fishes storing most of total body EPA + DHA in the liver. Macroalgae and marine mammals were assumed to have negligible by-product utilization rates, which combined with poor performance by whitefish, lowers the Norwegian by-product utilization rate to 62% overall (product weight).

Sustainability from an industry perspective was evaluated using a supply and demand forecast for EPA + DHA. The forecast utilized system-estimated supply and demand in 2012 as the base year. Growth rates of 4% for aquaculture and 7% for marine ingredients were used as annual growth parameters. Results suggest a shortage of EPA + DHA within two years and a 35% deficit in demand by 2020. The future EPA + DHA shortage was independently confirmed by a study performed by EWOS using similar parameters and assumptions. The EWOS study showed a 32% deficit in demand by 2020, but only considered the omega-3 industry, in contrast to the marine ingredients industry used in this thesis, which also includes fur industry feed and salmon by-products.

This thesis also addressed aspects of sustainability from the perspective of consumers and the environment in general. The efficiency of delivering one unit of EPA + DHA to consumers was quantified by using the novel indicator "efficiency of substance delivery" (ESD). The ESD was applied to the wild fishery and aquaculture systems for comparison. The aquaculture industry was found to require 3,22 kg of EPA + DHA per kg of EPA + DHA delivered to consumers as seafood, while the wild fishery sector required 1,76/kg. Vegetable ingredients were found to negatively affect the relative EPA + DHA content of farmed Atlantic salmon fillet and the omega-6/omega-3 ratio.

Final Thoughts

Advancements in fish nutrition and improvements in by-product utilization have allowed the aquaculture industry to continue growing despite historically low levels of EPA + DHA in feed. Further reductions in the EPA + DHA content of feed may provide a few more years of growth, but should not come at the expense of consumer expecations and fish welfare. The mitigation section in the discussion introduced some of the best candidates for alternative sources of EPA + DHA to replace fish meal and oil. Out of the discussed alternatives, intensive mariculture of microorganisms is the most likely long-term solution to the EPA + DHA shortage. It is recommended that industry actors engage in a collective effort to invest in the future and perhaps reevalulate the concept of growth towards 2050.

Appendices

System Parameters

Table 15: Table of system parameters

Parameter	Source	Units	Value
Norwegian landed catch Pelagic	NO.Ministry of Fisheries (2014)	Tonnes	1,25E+06
Norwegian landed catch Gadiforms	NO.Ministry of Fisheries (2014)	Tonnes	7,29E+05
Norwegian landed catch Bottomfish/Flatfish	NO.Ministry of Fisheries (2014)	Tonnes	4,38E+04
Norwegian landed catch Shellfish and Crustaceans	NO.Ministry of Fisheries (2014)	Tonnes	2,62E+04
Norwegian landed catch Antarctic krill	NO.Ministry of Fisheries (2014)	Tonnes	9,32E+04
Norwegian landed catch landed Minke whales	SSBe. (2014)	Tonnes	5,89E+02
Norwegian landed catch landed Seals	SSBe. (2014)	Tonnes	6,60E+01
Laminaria hyperborea harvest	NO.Ministry of Fisheries (2014), Pers. comm.	Tonnes	1,24E+05
Ascophyllum nodosum harvest	NO.Ministry of Fisheries (2014), Pers. comm.	Tonnes	1,66E+04
Foreign landed catch Pelagic	NO.Ministry of Fisheries (2014)	Tonnes	1,47E+05
Foreign landed catch Gadiforms	NO.Ministry of Fisheries (2014)	Tonnes	1,30E+05
Foreign landed catch Bottomfish/Flatfish	NO.Ministry of Fisheries (2014)	Tonnes	6,47E+03
Foreign landed catch Shellfish and Crustaceans	NO.Ministry of Fisheries (2014)	Tonnes	4,95E+03
Aquaculture production (All species)	FHL (2012)	Tonnes	1,35E+06
Aquaculture feed produced in Norway	NIFES (2014)	Tonnes	1,64E+06
Total fish meal for feed	Ytrestøyl (2014)	Tonnes	3,04E+05
Total fish oil for feed	Ytrestøyl (2014)	Tonnes	1,82E+05
Imported seafood by-products + algae products for HC	SSBd. (2014)	Tonnes	8,03E+03
Imported salmon products	SSBd. (2014)	Tonnes	2,44E+03
Imported whitefish products	SSBd. (2014)	Tonnes	4,68E+04
Imported pelagic products	SSBd. (2014)	Tonnes	1,34E+05
Imported shellfish	SSBd. (2014)	Tonnes	2,09E+04
Imported zooplankton meal for human consumption	SSBd. (2014)	Tonnes	1,51E+03
Imported algae for feed	SSBd. (2014)	Tonnes	1,52E+01
Imported fish for feed	SSBd. (2014)	Tonnes	1,70E+01

Imported fish oil for feed	SSBd. (2014)	Tonnes	1,59E+05
Imported fish meal and dried fish products for feed	SSBd. (2014)	Tonnes	2,51E+05
Imported fish feed	SSBd. (2014)	Tonnes	2,82E+04
Imported FPC or other marine products for feed or industrial use	SSBd. (2014)	Tonnes	2,50E+04
Imported marine oils of various grade for human consumption	SSBd. (2014)	Tonnes	3,17E+04
Exported oils of various grade for human consumption	SSBd. (2014)	Tonnes	6,86E+04
Exported upconcentrated omega-3 oils	SSBd. (2014)	Tonnes	6,09E+02
Exported seafood by-products + algae products	SSBd. (2014)	Tonnes	1,76E+04
Exported salmon products	SSBd. (2014)	Tonnes	1,05E+06
Exported whitefish products	SSBd. (2014)	Tonnes	5,24E+05
Exported pelagic products	SSBd. (2014)	Tonnes	7,70E+05
Exported shellfish products	SSBd. (2014)	Tonnes	1,32E+04
Exported zooplankton meal for human consumption	SSBd. (2014)	Tonnes	1,22E+03
Exported algae for feed	SSBd. (2014)	Tonnes	5,62E+02
Exported fish for feed	SSBd. (2014)	Tonnes	7,25E+02
Exported fish oil for feed	SSBd. (2014)	Tonnes	3,13E+03
Exported fish meal and dried fish products for feed	SSBd. (2014)	Tonnes	2,35E+04
Exported fish feed	SSBd. (2014)	Tonnes	2,95E+04
Exported FPC or other marine products for-feed or industrial use	SSBd. (2014)	Tonnes	8,01E+04
Sale of *Ascophyllum nodosum* meal for feed	Personal communication	Tonnes	2,06E+02
By-products (salmon) processed into hydrolysate protein	Olafsen et al. (2013)	Tonnes	9,00E+03
By-products FPC production from silage in 2012	Olafsen et al. (2013)	Tonnes	1,13E+05
By-products to cod liver oil and specialty oils processing	Olafsen et al. (2013)	Tonnes	1,78E+04
By-products cod liver oil and specialty oils yield	Olafsen et al. (2013)	Tonnes	5,00E+03
By-products to agriculture	Olafsen et al. (2013)	Tonnes	6,00E+04
Salmon oil to human consumption	Richardsen (2011)	Tonnes	1,00E+03
Marine mammal oil imported 2012	SSBd. (2014)	Tonnes	2,87E+02
Marine mammal oil exported 2012	SSBd. (2014)	Tonnes	2,74E+02
Minke Whale meat sold in Norway in 2012	Personal communication	Tonnes	7,93E+02
Minke Whale blubber sold in Norway in 2012	Personal communication	Tonnes	8,50E+00
Fish meal to Norwegian animal husbandry	No. A.A. (2012)	Tonnes	7,99E+03
Fish silage to Norwegian animal husbandry	No. A.A. (2012)	Tonnes	3,75E+03
Norwegian home consumption of seafood	Rørtveit & Nerland (2012).	Tonnes	1,00E+05

Total salmon as seafood to HC	Rørtveit & Nerland (2012).	Tonnes	1,08E+06
Whole sprat EPA and DHA ratio	Lambertsen (1978)	% of TL	19,10 %
Whole capelin EPA + DHA ratio	Sørensen et al. (2011)	% of TL	15,00 %
Peruvian Anchovy oil EPA + DHA ratio	FHL (2013)	% of TL	27,50 %
Herring oil EPA + DHA ratio	FHL (2013)	% of TL	16,00 %
Capelin oil EPA + DHA ratio	FHL (2013)	% of TL	13,00 %
Menhaden oil EPA + DHA ratio	FHL (2013)	% of TL	22,50 %
Peruvian Anchovy type meal EPA + DHA ratio	Opstvedt (1985)	% of TL	32,00 %
Herring type meal EPA + DHA ratio	Opstvedt (1985)	% of TL	25,50 %
Whitefish type meal EPA + DHA ratio	Opstvedt (1985)	% of TL	31,20 %
Farmed salmon EPA + DHA content in salmon fillet	Jensen et al. (2012)	% of TL	13,90 %
Wild salmon EPA + DHA content wild fillet	Jensen et al. (2012)	% of TL	19,00 %
Total lipids of whole sprat	Lambertsen (1978)	% round	12,90 %
Total lipids of whole capelin	Sørensen et al. (2011)	% round	14,60 %
Total lipids of Peruvian Anchovy	Personal communication	% round	6,00 %
Toal lipids of wild salmon fillet 2012	Jensen et al. (2012)	% round	6,30 %
Total lipids of farmed salmon fillet 2012	Jensen et al. (2012)	% round	12,30 %
Total lipids of 7,6% liver wild gadiform offal	Calculated, see table 10	% round	5,20 %
Total lipids of 3,13% liver wild gadiform offal	Calculated, see table 10	% round	2,50 %
Total fatty acids of farmed salmon fillet 2012	Jensen et al. (2012)	% round	7,40 %
Total fatty acids of wild salmon fillet 2012	Jensen et al. (2012)	% round	4,00 %
EPA + DHA Wavg. Atlantic type fish in fish meal 2012	Calculated, see table 6	% round	2,16 %
EPA + DHA content of whole Peruvian anchovies	Sørensen et al. (2011), calculated	% round	1,92 %
EPA + DHA content of whole farmed fish W'avg	Ytrestøyl (2014)	% round	1,58 %
EPA + DHA content of whole Pelagic fish W'avg	Calculated, see table 5	% round	2,49 %
EPA + DHA content of whole whitefish W'avg	Aggregated from table 5	% round	1,56 %
EPA + DHA content of 7,6% liver weight Gadiform by-products	Calculated, see table 10	% round	1,04 %
EPA + DHA content of 3,13% liver weight Gadiform by-products	Calculated, see table 10	% round	0,57 %
EPA + DHA content of whole Bottomfish/Flatfish W'avg	Calculated, see table 5	% round	1,07 %
EPA + DHA content of Shellfish and Crustaceans (w/o krill) W'avg	Calculated, see table 5	% round	0,54 %
EPA + DHA content of shrimp offal	Lambertson (1978)	% round	0,41 %
EPA + DHA content of herring by-products	Østvik et at. (2009)	% round	2,19 %
EPA + DHA Minke Whale	Calculated, see table 5	% round	2,46 %
EPA + DHA of Harp Seal	Calculated, see table 5	% round	4,17 %

EPA + DHA of whale flesh	MATIS (2014)	% round	0,40 %
EPA + DHA content of unknown fish W'avg	Lambertson (1978) – AVG (fat, med, low)	% round	1,31 %
EPA + DHA content of 16% liver wild gadiform offal	Calculated, see table 9	% round	1,92 %
EPA + DHA content of gadiform flesh	NIFES (2014)	% round	0,27 %
EPA + DHA content of pelagic to human consumption	Calculated, see table 8	% round	2,37 %
EPA + DHA content of salmonoid flesh	Ytrestøyl (2014)	% round	1,36 %
EPA + DHA content of salmon oil	Personal communication	% round	7,00 %
EPA + DHA content of salmon scrap	Ytrestøyl (2014); Sørensen et al. (2011)	% round	1,67 %
EPA + DHA content of wild cod liver	Falck et al. (2006)	% round	13,00 %
EPA + DHA content of salmon feed 2012	Sanden et al. (2013)	% round	3,20 %
Total lipids of wild cod liver	Falck (2006)	% round	59,00 %
Marine mammals blubber percentage	Shahidi & Wanasundara (1994)	% round	29,00 %
Marine mammals meat percentage	Shahidi & Wanasundara (1994)	% round	44,00 %
Farmed salmon protein percentage of bodyweight	Ytrestøyl (2014)	% round	17,50 %
Pelagic to human consumption	SSBd. (2014)	%	81,16 %
Pelagic for fillet landed	Olafsen et al. (2013)	%	48,96 %
Percent filleted of landed for fillet	Olafsen et al. (2013)	%	70,00 %
Scrap from fillet process	Olafsen et al. (2013)	%	54,00 %
Pelagic to FM&O	SSBa. (2014)	%	18,84 %
Amount of by-products after "average" processing	Olafsen et al. (2013)	%	43,00 %
Amount of by-products after "average" processing	Olafsen et al. (2013)	%	50,00 %
Amount of by-products after "average" processing	Olafsen et al. (2013)	%	17,23 %
Scrap use percentage Gadiforms FLC	Olafsen et al. (2013)	%	1,54 %
Scrap use percentage Pelagic NLC	Olafsen et al. (2013)	%	98,00 %
Scrap use percentage Gadiforms NLC	Olafsen et al. (2013)	%	33,54 %
Scrap use percentage Shellfish and Crustaceans NLC	Olafsen et al. (2013)	%	36,00 %
Krill meal reduction efficiency (dry weight)	Personal communication	%	16,50 %
Krill meal to oil reduction efficiency	Personal communication	%	15,00 %
Krill meal to krill oil production volume	Personal communication	%	25,00 %
Krill residual fat in krill meal	Personal communication	%	25,00 %
Krill EPA + DHA in fresh krill (Norwegian+Antarctic)	Lambertson (1978), pers. comm.	%	1,50 %
Krill EPA + DHA in Antarctic krill meal average	Personal communication	%	10,00 %
Krill EPA + DHA in krill oil Antarctic minimum	Personal communication	%	18,00 %
Laminaria hyperborea TL % dry weight	van Ginneken et al. (2014)	%	1,80 %

Ascophyllum nodosum TL % dry weight	van Ginneken et al. (2014)	%	4,50 %
Laminaria hyperborea EPA + DHA % TL	van Ginneken et al. (2014)	%	26,48 %
Ascophyllum nodosum EPA + DHA % TL	van Ginneken et al. (2014)	%	3,51 %
Seaweed dry matter percentage	Personal communication	%	18,00 %
Fish meal reduction efficiency (kg meal/kg fish)	Ytrestøyl et al. (2011)	%	24,00 %
Fish oil reduction efficiency (% fat in oil/TL) - FM&O	Ytrestøyl et al. (2011)	%	90,00 %
North Atlantic type fish mix (Pelagic) TL	Assumption, NIFES (2014)	%	12,30 %
Pelagic (Herring) by-products TL blended	Østvik et at. (2009)	%	13,50 %
Pelagic (Herring) by-products EPA + DHA % of TL	Østvik et at. (2009)	%	16,20 %
Silage FPC yeld w/w with 50% TS @ 18% protein	Hjartarson et al. (1997)	%	34,00 %
35/4 FPC 50% dry matter, 35% protein fat percentage	Personal communication	%	4,00 %
Silage oil percentage harvested	Hjartarson et al. (1997); Slizyte et al. (2009)	%	95,70 %
FPH yield % @60% TS @14,6 protein	Østvik et at. (2009)	%	13,00 %
FPH process sediment meal yield	Østvik et at. (2009)	%	14,00 %
FPH oil percentage harvested % oil/TL	Østvik et at. (2009)	%	84,00 %
FPH processing leftover lipids percentage in FPH @ 50% w/w	Østvik et at. (2009)	%	1,50 %
FPH leftover lipids in sediment meal (100% dry)	Østvik et at. (2009)	%	25,00 %
FPH percentage of "fresh" producing FPH	Olafsen et al. (2013)	%	61,27 %
Alginate efficiency of conversion from *L. hyperborea*	Personal communication	%	4,02 %
Feed conversion ratio (Feed in/Fish out) 2011	Ytrestøyl et al. (2011)	%	134,10 %
Percentage of M&O from scrap 2012	FHL (2013)	%	28,00 %
Rapeseed oil % of feed 2012	FHL (2013)	%	18,20 %
Other plant ingredients % of feed 2012	FHL (2013)	%	47,00 %
Import OIL 2012 Unknown oil type	Ytrestøyl (2014), assumption	%	15,94 %
Import OIL 2012 North Atlantic type fish oil from scrap % import	Ytrestøyl (2014), assumption	%	13,02 %
Import OIL 2012 Menhaden type fish oil % import	Ytrestøyl (2014), assumption	%	5,72 %
Import OIL 2012 North Atlantic type whole fish oil % import	Ytrestøyl (2014), assumption	%	14,94 %
Import OIL 2012 Anchovy type fish oil % import	Ytrestøyl (2014), assumption	%	50,37 %
Use of "other" meal in 2012 fish feed - Assumed krill	Ytrestøyl (2014), assumption	%	3,20 %
Import MEAL 2012 meal type (unknown) *not used in aquaculture*	SSBd (2014; calculation - Lambertson (1978)	%	26,34 %
Import MEAL 2012 North Atlantic whole fish type meal	Ytrestøyl (2014), assumption	%	12,84 %
Import MEAL 2012 North Atlantic scrap type meal % of imported	Ytrestøyl (2014), assumption	%	19,86 %
Import MEAL 2012 Anchovy type meal % of imported meal	Ytrestøyl (2014), assumption	%	40,96 %
Whitefish to FM&O	Rubin (2011)	%	24,07 %

Whitefish to silage	Rubin (2011)	%	9,26 %
Whitefish to non-food animal feed (frozen)	Rubin (2011)	%	20,00 %
Whitefish to human consumption (seafood)	Rubin (2011)	%	42,83 %
Whitefish to extracts	Rubin (2011)	%	3,84 %
Pelagic to FM&O	Rubin (2011)	%	60,90 %
Pelagic to silage	Rubin (2011)	%	36,58 %
Pelagic to non-food animals (frozen)	Rubin (2011)	%	1,00 %
Pelagic to human consumption	Rubin (2011)	%	1,30 %
Aquaculture to silage % of cuts/guts	Rubin (2011)	%	37,80 %
Aquaculture to non-food animals (frozen/raw silage)	Rubin (2011)	%	4,00 %
Aquaculture to fresh oils/hydrolysate (% of cuts/guts)	Rubin (2011)	%	54,00 %
Aquaculture to human consumption (% of cuts/guts)	Rubin (2011)	%	4,00 %
Shellfish to FM&O	Rubin (2011)	%	18,18 %
Shellfish to human consumption/extracts/specialty	Rubin (2011)	%	81,82 %
Whole body salmon TL	Ytrestøyl (2014)	%	21,00 %
EPA + DHA retention percentage whole fish	Ytrestøyl (2014)	%	41,00 %
Import % high quality oil for refining and re-export	Richardsen (2011)	%	35,71 %
Import % high quality oil for omega-3 products and pharmaceuticals	Richardsen (2011)	%	57,14 %
EPA + DHA content of refined omega-3 products and pharmaceuticals	Norwegian customs (2012)	%	55,00 %
Vegetable ingredients in fish feed 2012	Ytrestøyl (2014)	%	68,30 %
Feed lost during feeding	Wang et al. (2012)	%	3,00 %
Average EPA + DHA content of exported seafood products	Derived from SSBd. (2014); Lambertson (1978)	%	1,17 %
Norwegian consumption of whitefish	Rørtveit & Nerland (2012)	%	55,01 %
Norwegian consumption of salmon + farmed trout	Rørtveit & Nerland (2012)	%	21,04 %
Norwegian consumption of shrimp and crustaceans	Rørtveit & Nerland (2012)	%	11,33 %
Norwegian consumption of pelagic fish	Rørtveit & Nerland (2012)	%	12,63 %
SCENARIOS - EPA + DHA content of avg fish oil	Assumption, EWOS spotlight (2013)	%	20,00 %
SCENARIOS - EPA + DHA content of av fish meal	Assumption, calculated NA meal	%	2,50 %
SCENARIOS - Fish oil inclusion percentage 2000	Ytrestøyl (2014)	%	31,10 %
SCENARIOS - Fish oil inclusion percentage 2002	Cermaq sustainability report 2012	%	23,40 %
SCENARIOS - Fish oil inclusion percentage 2004	Cermaq sustainability report 2012	%	24,00 %
SCENARIOS - Fish oil inclusion percentage 2006	Cermaq sustainability report 2012	%	20,50 %
SCENARIOS - Fish oil inclusion percentage 2008	Cermaq sustainability report 2012	%	17,40 %

SCENARIOS - Fish oil inclusion percentage 2010	Cermaq sustainability report 2012	%	17,80 %
SCENARIOS - Fish oil inclusion percentage 2012	Cermaq sustainability report 2012	%	11,20 %
SCENARIOS - Fish meal inclusion percentage 2000	Ytrestøyl (2014)	%	33,70 %
SCENARIOS - Fish meal inclusion percentage 2002	Cermaq sustainability report 2012	%	35,80 %
SCENARIOS - Fish meal inclusion percentage 2004	Cermaq sustainability report 2012	%	33,60 %
SCENARIOS - Fish meal inclusion percentage 2006	Cermaq sustainability report 2012	%	32,50 %
SCENARIOS - Fish meal inclusion percentage 2008	Cermaq sustainability report 2012	%	28,80 %
SCENARIOS - Fish meal inclusion percentage 2010	Cermaq sustainability report 2012	%	24,30 %
SCENARIOS - Fish meal inclusion percentage 2012	Cermaq sustainability report 2012	%	20,10 %
SCENARIOS - EPA + DHA percentage of feed calculated in 2012	Calculated from system	%	2,90 %
SCENARIOS - EPA + DHA percentage of "Marine Ingredients" in 2012	Calculated, table 3.2.1	%	6,28 %
SCENARIOS - Growth rate required for global aquaculture	Olafsen et al. (2012)	%	4,00 %
SCENARIOS - Growth rate projected for marine ingredients	Olafsen et al. (2012)	%	7,00 %

System Flows

Table 16: Table of flows derived from system parameters

Flow Name and **Process**	From	To	Product weight (t)	EPA + DHA (t)	t/t (%)
Fisheries landing and processing process (1)					
Whitefish landed, foreign fleet	0	1	1,36E+05	2,09E+03	1,53 %
Pelagic fish landed, foreign fleet	0	1	1,47E+05	3,66E+03	2,49 %
Shellfish landed, foreign fleet	0	1	4,95E+03	2,65E+01	0,54 %
Whitefish landed, Norwegian fleet	0	1	7,73E+05	1,18E+04	1,53 %
Pelagic fish landed, Norwegian fleet	0	1	1,25E+06	3,11E+04	2,49 %
Shellfish and zooplankton landed, Norwegian fleet	0	1	1,19E+05	1,79E+03	1,50 %
Marine mammals landed, Norwegian fleet	0	1	6,55E+02	1,61E+01	2,46 %
Wild *Laminaria hyperborea* harvest	0	1	1,24E+05	1,07E+02	0,09 %
Wild Ascophyllum nodosum harvest	0	1	1,66E+04	4,72E+00	0,03 %
Whitefish by-products dumped at sea, foreign fleet	1	0	5,77E+04	1,11E+03	1,92 %
Pelagic fish by-products dumped at sea, foreign fleet	1	0	5,44E+02	1,19E+01	2,19 %
Shellfish by-products dumped at sea, foreign fleet	1	0	1,58E+03	6,43E+00	0,41 %
Whitefish by-products dumped at sea, Norwegian fleet	1	0	2,21E+05	4,25E+03	1,92 %
Pelagic fish by-products dumped at sea, Norwegian fleet	1	0	4,62E+03	1,01E+02	2,19 %
Shellfish by-products dumped at sea, Norwegian fleet	1	0	8,37E+03	3,40E+01	0,41 %
Wild seafood for human consumption	1	13	1,41E+06	2,22E+04	1,58 %
Marine mammals to processing	1	13	6,55E+02	1,72E+01	2,63 %
Wild caught zooplankton for meal and oil production	1	3	9,32E+04	1,40E+03	1,50 %
Wild *Laminaria hyperborea* harvest	1	4	1,24E+05	1,07E+02	0,09 %
Wild Ascophyllum nodosum harvest	1	4	1,66E+04	4,72E+00	0,03 %
Whole fish to fish meal and oil production	1	5	2,63E+05	5,66E+03	2,16 %
Whitefish by-products	1	2	1,12E+05	2,14E+03	1,92 %
Pelagic fish by-products	1	2	2,53E+05	5,53E+03	2,19 %
Shellfish by-products	1	2	5,60E+03	2,28E+01	0,41 %
Mass Balance (Inflows - Outflows)			9,03E+02	8,01E+03	
Marine by-products market (2)					
Whitefish by-products	1	2	1,12E+05	2,14E+03	1,92 %
Pelagic fish by-products	1	2	2,53E+05	5,53E+03	2,19 %
Shellfish by-products	1	2	5,60E+03	2,28E+01	0,41 %
Aquaculture processing by-products	12	2	2,33E+05	3,89E+03	1,67 %
Category 2 fish from pens (whole fish)	12	2	5,79E+04	9,14E+02	1,58 %
Slaughterhouse rejects (whole fish)	12	2	2,60E+04	4,11E+02	1,58 %
Whitefish by-products to FM&O	2	5	2,68E+04	1,53E+02	0,57 %

Pelagic fish by-products to FM&O	2	5	1,54E+05	3,37E+03	2,19 %
Whitefish livers for cod liver oil processing	2	5	1,01E+04	1,31E+03	13,00 %
By-products for extract processing	2	5	7,71E+03	2,85E+01	0,37 %
Total by-products to FM&O processing	2	5	1,99E+05	4,86E+03	2,45 %
By-products (salmon) to fresh processing	2	6	1,26E+05	2,10E+03	1,67 %
Whitefish to silage	2	7	1,03E+04	5,87E+01	0,57 %
Pelagic to silage	2	7	9,25E+04	2,02E+03	2,19 %
Salmon heads, cuts and guts to silage	2	7	8,79E+04	1,47E+03	1,67 %
Salmon category 2 and slaugterhouse waste	2	7	8,39E+04	1,32E+03	1,58 %
Total feed BP to silage processing	2	7	1,91E+05	3,55E+03	1,86 %
By-products to non-food animals processing	2	9	3,75E+04	3,86E+02	1,03 %
By-products as seafood to human consumption	2	13	4,82E+04	9,11E+02	1,89 %
Mass Balance (Inflows - Outflows)			1,95E+03	-2,24E+02	
Zooplankton processing (3)					
Wild zooplankton landed	1	3	9,32E+04	1,40E+03	1,50 %
Imported zooplankton meal	0	3	1,51E+03	1,51E+02	10,00 %
Norwegian meal for feed	3	8	1,15E+04	1,15E+03	10,00 %
Imported zooplankton meal	3	8	1,13E+03	1,13E+02	10,00 %
Imported zooplankton oil	3	8	5,66E+01	1,02E+01	18,00 %
Norwegian zooplankton oil	3	8	5,77E+02	1,04E+02	18,00 %
Imported zooplankton protein concentrate	3	8	3,21E+02	7,21E-02	0,02 %
Norwegian zooplakton protein concentrate	3	8	3,27E+03	7,35E-01	0,02 %
Mass Balance (Inflows - Outflows)			7,78E+04	1,68E+02	
Macroalgae processing (4)					
Wild *Laminaria hyperborea* harvest	1	4	1,24E+05	1,07E+02	0,09 %
Wild *Ascophyllum nodosum* harvest	1	4	1,66E+04	4,72E+00	0,03 %
Imported dried algae (uknown origin)	0	4	1,52E+01	2,41E-02	0,16 %
Macroalgae by-products unutilized	4	0	2,04E+04	1,11E+02	0,55 %
Macroalgae protein meal (Algea)	4	8	2,06E+02	3,25E-01	0,16 %
Specialty macroalgae products, alginat, extracts, etc	4	8	5,00E+03	0,00E+00	0,00 %
Mass Balance (Inflows - Outflows)			1,15E+05	0,00E+00	
Fish meal and oil processing (5)					
Whole forage fish	1	5	2,63E+05	5,66E+03	2,16 %
Whitefish by-products to FM&O	2	5	2,68E+04	1,53E+02	0,57 %
Fresh by-product (liver) from whitefish processing	2	5	1,01E+04	1,31E+03	13,00 %
Fresh by-products for extract processing	2	5	7,71E+03	2,85E+01	0,37 %

Pelagic fish by-products to FM&O	2	5	1,54E+05	3,37E+03	2,19 %
Imported fish for feed	0	5	1,70E+01	4,24E-01	2,49 %
North Atlantic type (- whitefish) fish meal whole	5	9	6,29E+04	1,58E+03	2,52 %
North Atlantic type (- whitefish) fish meal scrap	5	9	3,70E+04	9,42E+02	2,55 %
North Atlantic type (-whitefish) fish oil whole	5	9	2,90E+04	4,08E+03	14,06 %
North Atlantic type (- whitefish) fish oil scrap	5	9	1,87E+04	2,43E+03	12,96 %
Whitefish type fish meal + cod liver oil press cake	5	9	9,51E+03	2,46E+02	2,59 %
Whitefish scrap oil	5	9	6,04E+02	1,16E+02	19,21 %
Fresh cod liver oil and extracts	5	9	5,00E+03	1,10E+03	22,03 %
Total fish meal	5	9	1,09E+05	2,77E+03	2,54 %
Total fish oil	5	9	4,83E+04	6,62E+03	13,70 %
Exported fish for feed production	1	0	7,25E+02	1,81E+01	2,49 %
Mass Balance (Inflows - Outflows)			3,03E+05	1,08E+01	
Fresh oils by-product processing (6)					
Fresh by-products from aquaculture processing	2	6	1,26E+05	2,10E+03	1,67 %
Fresh processed non-oil fraction to silage (w/w)	6	7	2,65E+04	9,64E+01	0,36 %
Fresh salmon protein hydrolysate (60% dw)	6	9	1,00E+04	1,93E+01	0,19 %
Fresh salmon sediment meal	6	9	1,08E+04	1,89E+02	1,75 %
Fresh salmon by-product oils	6	9	2,22E+04	1,77E+03	7,97 %
Mass Balance (Inflows - Outflows)			5,62E+04	3,21E+01	
Silage processing (7)					
Total mixed fish by-products to silage processing for feed	2	7	1,91E+05	3,55E+03	1,86 %
Category 2 and slaughter rejects whole salmon	2	7	8,39E+04	1,32E+03	1,58 %
Fresh processed non-oil salmon fraction to silage (unprocessed)	6	7	2,65E+04	9,64E+01	0,36 %
Silage based mixed fish oil for feed	7	9	3,12E+04	3,49E+03	11,18 %
Silage based Cat 2 salmon oil for non-feed use	7	9	1,69E+04	1,27E+03	7,52 %
Silage based mixed fish protein concentrate for feed	7	9	7,39E+04	1,46E+02	0,20 %
Silage based salmon protein concentrate for non-feed animals	7	9	2,85E+04	5,30E+01	0,19 %
Mass Balance (Inflows - Outflows)			1,51E+05	1,49E+01	
New marine ingredients market (8)					
Norwegian zooplankton meal	3	8	1,15E+04	1,15E+03	10,00 %
Imported zooplankton meal	3	8	1,13E+03	1,13E+02	10,00 %
Imported zooplankton oil	3	8	5,66E+01	1,02E+01	18,00 %
Norwegian zooplankton oil	3	8	5,77E+02	1,04E+02	18,00 %
Imported zooplankton protein concentrate	3	8	3,21E+02	7,21E-02	0,02 %
Norwegian zooplankton protein concentrate	3	8	3,27E+03	7,35E-01	0,02 %
Macroalgae meal (Algea)	4	8	2,06E+02	3,25E-01	0,16 %

Specialty macroalgae products, alginat, extracts, etc	4	8	5,00E+03	0,00E+00	0,00 %
Plant Ingredients	0	8	1,12E+06	0,00E+00	0,00 %
Non-GMO microorganisms	0	8	0,00E+00	0,00E+00	0,00 %
Marine mammal oil for aquaculture	14	8	0,00E+00	0,00E+00	0,00 %
EPA and DHA cultivated oil to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Macroalgae meal to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Microalgae oils to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Marine mammal oil to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Total zooplankton protein concentrate for feed production	8	10	3,59E+03	8,07E-01	0,02 %
Total zooplankton meal to aquaculture	8	10	1,27E+04	1,27E+03	10,00 %
Plant Ingredients	8	10	1,12E+06	0,00E+00	0,00 %
Total zooplankton oils to human consumption	8	13	6,33E+02	1,14E+02	18,00 %
Algae products for human consumption	8	13	5,21E+03	3,25E-01	0,01 %
Mass Balance (Inflows - Outflows)			0,00E+00	0,00E+00	

Traditional marine ingredients market (9)					
By-products to non-food animals processing	2	9	3,75E+04	3,86E+02	1,03 %
Domestically produced fish meal	5	9	1,09E+05	2,77E+03	2,54 %
Oil fraction from fish meal	5	9	4,83E+04	6,62E+03	13,70 %
Fresh cod liver oil oil and extracts	5	9	5,00E+03	1,10E+03	22,03 %
Fresh salmon protein hydrolysate (60% dw)	6	9	1,00E+04	1,93E+01	0,19 %
Fresh salmon sediment meal	6	9	1,08E+04	1,63E+02	1,51 %
Fresh salmon by-product oils	6	9	2,22E+04	1,77E+03	7,97 %
Silage based mixed fish oil for feed	7	9	3,12E+04	3,49E+03	11,18 %
Silage based Cat 2 salmon oil for non-feed use	7	9	1,69E+04	1,27E+03	7,52 %
Silage based mixed fish protein concentrate for feed	7	9	7,39E+04	1,46E+02	0,20 %
Silage based salmon protein concentrate for non-feed animals	7	9	2,85E+04	5,30E+01	0,19 %
SUM Imported fish meal	0	9	2,51E+05	6,80E+03	2,71 %
Imported fish meal unknown origin for unknown use	0	9	5,63E+04	1,44E+03	2,55 %
Imported North Atlantic whole fish meal	0	9	3,22E+04	8,11E+02	2,52 %
Imported North Atlantic scrap meal	0	9	4,98E+04	1,27E+03	2,55 %
Imported Peruvian Anchoveta meal	0	9	1,03E+05	3,28E+03	3,20 %
SUM Imported fish oil for feed	0	9	1,59E+05	3,56E+04	22,40 %
Imported fish oil unknown origin for unknown use	0	9	4,25E+04	5,51E+03	12,96 %
Imported North Atlantic scrap fish oil	0	9	2,07E+04	2,68E+03	12,96 %
Imported Menhaden oil	0	9	9,09E+03	2,04E+03	22,50 %
Imported North Atlantic whole fish oil	0	9	2,37E+04	3,33E+03	14,06 %
Imported Peruvian Anchoveta oil	0	9	8,00E+04	2,20E+04	27,50 %
Imported marine oils not for feed (omega-3 market)	0	9	3,17E+04	8,72E+03	27,50 %
Imported misc. marine feed ingredients	0	9	2,50E+04	4,93E+01	0,20 %
Salmon oil exported (Med fish feed, some agriculture)	9	0	4,12E+04	3,27E+03	7,93 %

Category 2 grade oil for technical use or non feed animals	9	0	1,69E+04	1,27E+03	7,52 %
Fur industry feed	9	0	3,75E+04	3,86E+02	1,03 %
Miscellaneous feed ingredients (meal, dried scrap, protein concentrate)	9	0	2,35E+04	3,56E+02	1,51 %
SPC and other salmon waste for agriculture + pels (ca. 10k in Norway)	9	0	8,82E+04	3,24E+02	0,37 %
Imported fishmeal unknown type unknown use	9	0	5,02E+04	1,28E+03	2,55 %
Imported fish oil unknown type unknown use	9	0	4,25E+04	5,51E+03	12,96 %
Exported Norwegian fish feed	10	0	2,95E+04	8,65E+02	2,94 %
Fish meal for salmon aquaculture feed	9	10	3,04E+05	8,29E+03	2,73 %
FPC (pelagic and whitefish) for salmon aquaculture	9	10	3,50E+04	8,33E+01	0,24 %
Fish oil for salmon feed (imported, FM&O and silage)	9	10	1,76E+05	3,86E+04	21,95 %
Imported marine oil for omega-3/HC market	9	11	3,17E+04	8,72E+03	27,50 %
Domestic cod liver oil and salmon oil for omega-3 market	9	11	6,00E+03	1,18E+03	19,69 %
Mass Balance (Inflows - Outflows)			-2,19E+04	-1,20E+03	
Aquaculture feed production (10)					
EPA and DHA cultivated oil to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Macroalgae meal to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Microalgae oils to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Marine mammal oil to aquaculture	8	10	0,00E+00	0,00E+00	0,00 %
Zooplankton meal to aquaculture	8	10	1,27E+04	1,27E+03	10,00 %
Zooplankton protein concentrate for feed production	8	10	3,59E+03	8,07E-01	0,02 %
Plant Ingredients	8	10	1,12E+06	0,00E+00	0,00 %
Fish meal for salmon aquaculture feed	9	10	3,04E+05	8,29E+03	2,73 %
FPC (pelagic and whitefish) for salmon aquaculture	9	10	3,50E+04	8,33E+01	0,24 %
Fish oil for salmon feed (imported, FM&O and silage)	9	10	1,76E+05	3,86E+04	21,95 %
Aquaculture feed produced in Norway	10	14	1,64E+06	4,82E+04	2,94 %
Mass Balance (Inflows - Outflows)			9,79E+03	0,00E+00	
Refined omega-3 oils (11)					
Imported high quality marine oil for refinement	9	11	3,17E+04	8,72E+03	27,50 %
Domestic cod liver oil and salmon oil for omega-3 market	9	11	6,00E+03	1,10E+03	22,03 %
Domestic cod liver oil and salmon oil for omega-3 market	11	13	6,00E+03	1,10E+03	22,03 %
Refined omega-3 oils for re-export	11	13	1,13E+04	3,12E+03	27,50 %
Omega-3 marine oils or pharmaceuticals	11	13	6,09E+02	3,35E+02	55,00 %
Mass Balance (Inflows - Outflows)			1,98E+04	5,27E+03	
Aquaculture and processing to seafood products (12)					
Norwegian aquaculture feed for Norwegian aquaculture	10	12	1,64E+06	4,82E+04	2,94 %
Imported fish feed	0	12	2,82E+04	8,27E+02	2,94 %

Feed lost during feeding	12	0	5,01E+04	1,47E+03	2,94 %
Feed ingredients metabolized by fish (Emission + faeces)	12	0	2,27E+05	2,89E+04	12,73 %
Aquaculture processing by-products	12	2	2,33E+05	3,89E+03	1,67 %
Category 2 fish from pens and slaughter rejects (whole fish)	12	2	5,79E+04	9,14E+02	1,58 %
Slaughterhouse rejects (whole fish)	12	2	2,60E+04	4,11E+02	1,58 %
Farmed seafood to human consumption	12	13	1,08E+06	1,46E+04	1,36 %
Mass Balance (Inflows - Outflows)			0,00E+00	-1,23E+03	
Market for human consumption (13)					
Wild seafood for human consumption	1	13	1,41E+06	2,22E+04	1,58 %
By-products as seafood to human consumption	2	13	4,82E+04	9,11E+02	1,89 %
Zooplankton oils for human consumption	8	13	6,33E+02	1,14E+02	18,00 %
Algae products for human consumption	8	13	5,21E+03	3,25E-01	0,01 %
Domestic cod liver oil and salmon oil for human consumption	11	13	6,00E+03	1,18E+03	19,69 %
Refined omega-3 marine oils for re-export	11	13	1,13E+04	3,12E+03	27,50 %
Omega-3 marine oils in bottled or capsule form	11	13	6,09E+02	3,35E+02	55,00 %
Farmed seafood to human consumption	12	13	1,08E+06	1,46E+04	1,36 %
Imported seafood by-products + algae	0	13	8,03E+03	6,10E+00	0,08 %
Imported salmonoid products	0	13	2,44E+03	3,72E+01	1,53 %
Imported whitefish products	0	13	4,68E+04	1,59E+02	0,34 %
Imported pelagic	0	13	1,34E+05	5,21E+03	3,90 %
Imported shellfish products	0	13	2,09E+04	1,12E+02	0,54 %
Whale meat to human consumption	14	13	2,59E+02	1,04E+00	0,40 %
Sjømatråd Norwegian seafood consumption	13	0	1,00E+05	1,17E+03	1,17 %
SSB Exported oils and extracts	13	0	6,86E+04	4,75E+03	6,92 %
SSB Exported seafood by-products + algae	13	0	1,76E+04	2,06E+02	1,17 %
SSB Exported salmonoid products	13	0	1,05E+06	1,43E+04	1,36 %
SSB Exported whitefish products	13	0	5,24E+05	2,13E+03	0,41 %
SSB Exported pelagic products	13	0	7,70E+05	1,83E+04	2,37 %
SSB Exported shellfish products	13	0	1,32E+04	7,06E+01	0,54 %
Mass Balance (Inflows - Outflows)			2,23E+05	7,10E+03	
Marine mammals processing (14)					
Minke whales for processing	1	14	5,89E+02	1,45E+01	2,46 %
Seals for processing	1	14	6,60E+01	2,76E+00	4,17 %
Marine mammals oil domestic production from Norwegian landed animals	14	8	0,00E+00	0,00E+00	0,00 %
Whale meat to human consumption	14	13	2,59E+02	1,04E+00	0,40 %
Marine mammals dumped at sea	14	0	3,96E+02	1,62E+01	4,09 %
Mass Balance (Inflows - Outflows)			0,00E+00	0,00E+00	

SSB Imports/Exports

Table 17: SSB calculation using external trade statistics: imported and exported ingredients for fish feed

Product category description (translated from Norwegian)	HS Number	Export	Import
Forage fish (blue whiting, sand lance, Norway pout, not for human consumption	05119111	7,25E+02	1,70E-02
Algae, hereafter kelp and seaweed	12122110	3,28E+02	1,91E+03
Algae, hereafter kelp and seaweed	12122910	1,32E+05	5,00E+03
Algae, hereafter kelp and seaweed	12122990	4,30E+05	8,32E+03
Algae products category SUM	**--**	**5,63E+02**	**1,52E+01**
Meal and pellets made of fish, suitable for human consumption	03051000	0,00E+00	2,23E+04
Meal and pellets of fish, crustaceans, shellfish and other marine invertebrates unsuitable for human consumption	23012010	1,70E+07	2,50E+08
Meal and pellets of fish, crustaceans, shellfish and other marine invertebrates unsuitable for human consumption	23012090	1,30E+06	3,01E+03
Fish heads and scrap, dried also shredded, unsuitable for human consumption	05119112	4,41E+06	0,00E+00
Peptones and their derivatives	35040000	8,16E+05	7,32E+05
Dried and milled fish product category SUM	**--**	**2,35E+04**	**2,51E+05**
Tran (fish liver oil), hereafter veterinary tran	15041011	6,10E+04	8,14E+03
Tran (not hydrogenated), excluding medical, veterinary, industrial….	15041099	9,80E+05	5,23E+04
Fat and oils from fish including their fractions, excluding tran	15042011	2,09E+06	1,59E+08
Fat and oils from marine mammals including their fractions	15043011	0,00E+00	9,30E+01
Marine fats and oils products category SUM	**--**	**3,13E+03**	**1,59E+05**
Products of fish, crustaceans, shellfish and other marine invertebrates unsuitable for human consumption	05119119	1,17E+04	3,66E+01
Fish waste, excluding forage fish, fish heads and scrap, unsuitable for human consumption	05119113	2,43E+07	1,10E+07
Fish heads and scrap, dried also shredded, unsuitable for human consumption, excluding forage fish, unsuitable for humans	05119193	1,02E+07	8,33E+05
Products of fish, crustaceans, shellfish and other marine invertebrates unsuitable for human consumption	05119199	1,81E+06	8,32E+06
Prepared feed ingredients, not for pets or fish	23099099	3,22E+07	4,77E+06
Liquid or semi-liquid by-products category SUM	**--**	**6,84E+04**	**2,49E+04**
Total	**--**	**9,64E+04**	**4,34E+05**

Detailed Calculations

Estimation of EPA + DHA content of whole gadiform species

*Percentage of by-products from a whole fish (45% - Ministry of Fisheries) * Weighted average of EPA + DHA factor for gadiform species*
+
*Percentage of non-by-product meat and bones (55% - mass balance) * EPA + DHA factor for edible portion of Gadus morhua (0,27% - Nifes)*
=
Estimated EPA + DHA concentration of whole gadiform species as % of wet weight

Estimation of EPA + DHA content of non - Greenland halibut flatfish species

*Carcass percentage of round weight after removal of offal (93,5% - Berge & Storebakken) * EPA + DHA factor edible portion of Hippoglossus hippoglossus (0,569% - Nifes)*
+
*Liver percentage of round weight (2,1% - Berge & Storebakken) * EPA + DHA factor for liver of Gadus morhua (11,3% - Nifes)*
+
*Leftover non-liver offal percentage of round weight (4,4% - mass balance) * EPA + DHA factor of wild Saithe offal (1,9% - Lambertsen)*
=
Estimated EPA + DHA content of whole non-Greenland halibut flatfish species

Estimation of EPA + DHA content of species grouping "other deepwater/misc/unspecified fish"

The weighted average of Lambertsen's weighted average for the EPA + DHA content for three species groups "high fat, med fat and low fat" – proxy for all unknown fish
=
Proxy EPA + DHA parameter for unknown fish of unknown lipid profile (% of ww)

Estimation of EPA + DHA content of round weight Minke Whales

*Minke whale blubber percentage of bodyweight (25% - St.Meld.27) * Total lipids in blubber (96% - Shahidi & Wanasundra) * 90% fatty acids in blubber (Olsen & Grahl-Nielsen) * EPA + DHA factor for Minke Whale blubber (0,105 – Olsen & Grahl-Nielsen)*
+
*Marine mammal meat percentage of bodyweight (44% - Shahidi & Wanasundra) * EPA + DHA factor for Minke Whale meat (0,414% - Matis)*
=
Estimated EPA + DHA content of a whole Minke Whale

Estimation of EPA + DHA content of round weight Harp Seals

*Harp Seal blubber percentage of bodyweight (29% - Shahidi & Wanasundra) * Total lipids in blubber (96% - Shahidi & Wanasundra) * 90% fatty acids in blubber (Olsen & Grahl-Nielsen) * EPA + DHA factor for Harp Seal blubber (0,16 – Olsen & Grahl-Nielsen)*
+
*Marine mammal meat percentage of bodyweight (44% - Shahidi & Wanasundra) * Harp seal meat lipid content (2% - Olsen & Grahl-Nielsen) * 90% fatty acids in blubber (Olsen & Grahl-Nielsen) * EPA + DHA factor for seal meat (0,08% - Olsen & Grahl-Nielsen)*
=
Estimated EPA + DHA content of a whole Harp Seal

More Flow Calculation Examples

Calculation of mixed species silage oil, including one flow from mass balance in the process *Silage Processing*

*Whitefish by-products to silage (Tonnes) * Parameter "Total lipids of 7,6% liver wild gadiform offal" (%)*
+
*Pelagic by-products fish to silage (tonnes) * Parameter "Total lipids of herring by-products blended" (%)*
+
*Aquaculture by-products for feed to silage (tonnes) * Parameter "Total lipids of salmon offal" (%) * Parameter "Silage oil reduction efficiency" (%)*
+
Total lipids of non-hydrolyzed fraction (tonnes)
=
Silage based mixed fish oil for feed

Example 3 continued: "Total lipids of non-hydrolyzed fraction," is calculated as:

*Fresh by-products for feed from aquaculture to silage (tonnes) * Parameter "Total lipids of salmon offal" (%) * (1 - Parameter "Hydrolysate oil reduction efficiency"*
-
*Fresh salmon sediment meal (tonnes) * Parameter "Leftover lipids in salmon meal"*
-
*Salmon protein hydrolysate (tonnes) * Parameter "Leftover lipid fraction for fish protein hydrolysate 50% dry weight (%)*
=
Total lipids of non - hydrolyzed fraction to silage processing

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