An Examination of Fish Consumption and Human Health and the Potential Role of Fish Species Diversity on Nutrient and Fatty Acid Composition

by

Lu Bai

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Science

in

Kinesiology

Waterloo, Ontario, Canada, 2022

Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

The scoping review study in chapter 3 was designed by the sole author of this thesis Lu Bai with feedback from Dr. Ken D. Stark. Two independent reviewers (Lu Bai and Dr. Ken D. Stark) were involved in review selection (title, abstract, and full-text screening) from results generated from original search of three electronic databases: PubMed, EMBASE, and Cochrane Library.

The fish samples analyzed in chapter 5 are part of a collaborative effort. Fish samples were collected from the Canadian subarctic and Arctic by the efforts of Tara N. Boag, Mallory Drysdale, Dr. Heidi K. Swanson, and Dr. Brian D. Laird in collaboration with fishers in First Nations communities of the Northwest Territories, Canada. Dani Chalil assisted in determining the fatty acid composition of the fish samples by gas chromatography.

Abstract

Fish is a major food source for the global human population and is a source of various nutrients, including unsaturated fatty acids especially n-3 polyunsaturated fatty acids (PUFA), high-quality proteins, vitamins, and minerals. Numerous studies have demonstrated that fish consumption reduces the risk of chronic disease and promotes human health. However, heavy metal and environmental contamination is a concern. The objectives of this thesis were to 1) collect evidence from the literature to determine issues related to human health and fish intake; 2) use online databases for estimates of global and Canadian fish consumption, the diversity of commercial fish species, and nutrient composition coverage of fish commonly consumed in Canada; and 3) examine the fatty acid composition of wild caught fish species consumed by an Indigenous population in northern Canada in comparison to national food nutrient databases. In the first study, a scoping review of the effects of fish consumption on human health was conducted. N-3 PUFA is the most studied nutrient component of fish in present review literatures contributing to the health benefits from fish consumption, and other nutrients in fish are understudied. Also, the potential health benefits of fish intake appear to outweigh the risk of detrimental contaminants (e.g., MeHg) in fish. The second study used FAOSTAT to determine the amount of fish produced and consumed by world and G20 and FishBase was used to determine the diversity of commercial fish species, and the Canadian Nutrient Profile (CNF), United States Department of Agriculture (USDA) and FishBase nutrient data was compared for the most popular fish consumed in Canada. G20 members consumed slightly more fish than they produced, and their fish production was dependent mainly on capture fisheries, except for China that has developed a large aquaculture industry. Low fish consumption, regions with cold water temperature and industrialization of the fish food supply appear to have less commercial fish

diversity. The FishBase Nutrient Analysis Tool covered a wide range of fish species but at this time appears to be too crude to be used to estimate dietary intakes. The CNF and USDA databases did not cover all the commercial fish species for Canada as indicated by FishBase. In the third study, the fatty acid composition of Canadian Subarctic and Arctic wild freshwater fish was compared with CNF estimates except for Longnose sucker that was not available. The wild fish contained more than 135 mg EPA+DHA /100 g fish muscle but there were large differences in some estimates particularly the Cisco species. More research is required to determine the effect of other components of fish on human health rather than indiscriminately promoting fish intake. Fish diversity and variation in nutrient content due to ecological variation and errors in databases are problematic and limit the ability to assess n-3 PUFA intakes from fish consumption especially in smaller populations such as Indigenous peoples.

Acknowledgements

First, I am thankful to my supervisor Dr. Ken. D. Stark for giving me the opportunity to join the Stark lab, and always being patient and willing to help me. I am truly gratefully for the countless time and huge help you have given me to discuss the study design, run the statistics, edit my thesis, and especially perform the full-text screening of over 150 review papers for my scoping review study. This thesis cannot be made without your help. Thank you for being the greatest supervisor I can ever imagine.

I would like to thank my advisory committee members, Dr. Robin E. Duncan and Dr. Brian D. Laird, for their support and guidance throughout this research work. I would also like to thank Tara N. Boag, Mallory Drysdale, Dr. Heidi K. Swanson, and Dr. Brian D. Laird and fishers in First Nations communities of the Northwest Territories, Canada for providing fish samples.

I am also thankful to the fantastic members in the Stark lab, Tianchunlu Yu and Klaudia Steckel, with special thanks to Juan Aristizabal Henao for teaching me all the laboratory techniques I know in this lab and Dan for assistance with preparing fish samples and analyzing fish samples by gas chromatography.

Last but not the least, I would like to thank my friends and family, my brother, my parents, and Blandine for providing me with incredible support and encouragement throughout my studies and making my time at Waterloo unforgettable.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

PUFA	Polyunsaturated Fatty Acids
EPA	Eicosapentaenoic Acid (C20:5n-3)
DHA	Docosahexaenoic Acid (C22:6n-3)
n-3 PUFA	Omega-3 Polyunsaturated Fatty Acids
MeHg	Methyl Mercury
PCBs	Polychlorinated Biphenyls
CNF	Canadian Nutrient File
LA	Linoleic Acid (C 18:2n-6)
ALA	Alpha-linolenic Acid (C 18:3n-3)
18:1 n-9	Oleic Acid
FADS	Fatty Acid Desaturase
ELOVL	Elongase
Hg	Mercury
iHg	Inorganic Mercury
Cd	Cadmium
As	Arsenic
Pb	Lead
POPs	Persistent Organic Pollutants
DDT	Dichlorodiphenyltrichloroethane
CVD	Cardiovascular Diseases
TG	Triacylglycerol
FAO	Food and Agriculture Organization of the United Nations
G20	Group of 20
USDA	U. S. Department of Agriculture
FAME	Fatty Acid Methyl Ester
GC-FID	Gas Chromatography-Flame Ionization Detection
SFA	Saturated Fatty Acid
MUFA	Monounsaturated Fatty Acid
DPA	Docosapentaenoic Acid

Chapter 1

Introduction

In the past several decades, global food fish consumption increased along with an increasing population [1]. In 2018, the world fish production from wild fish catch and aquaculture was 179 million tonnes, out of which 156 million tonnes were used for human consumption [2]. Fish has always been considered as an important part of the nutritional human diet with multiple beneficial bioactive constituents such as lipids (mainly long-chain n-3 polyunsaturated fatty acids (PUFA)), proteins, vitamins, and minerals [3]. Fish intake is associated with various health promotion benefits, mainly supporting the cardiovascular system, and enhancing neurodevelopment and maternal health [4-6]. It has also been noted that there is a potential inverse relationship between fish consumption and risk of a wide range of diseases including neurological decline, cancer, depression, inflammatory disease, and all-cause mortality [7-11].

It has been suggested that among the multiple nutrients present in fish, n-3 PUFA, mainly eicosapentaenoic acid (20:5n-3, EPA) and docosahexaenoic acid (22:6n-3, DHA), are the main valuable nutrients responsible for most of the health benefits of fish intake [12, 13]. However, variation in assessing n-3 PUFA intake from fish is a challenge. Despite n-3 PUFA being the main beneficial nutrient component of fish, it has been controversial whether the health efficacy of fish oil and/or n-3 PUFA supplements differs from direct fish consumption [14]. A six-week study on healthy adults reported that EPA and DHA from salmon were incorporated into plasma lipids at a higher effectiveness [15]. Furthermore, n-3 PUFA in supplements are also more prone to oxidation, which may cause adverse health effects [16]. It has also been suggested that fish

provides more than n-3 PUFA as it is high in a wide range of other vital nutrients, such as high-quality protein, vitamins, and mineral, which provides more comprehensive benefits to the overall human health [17, 18]. Fish consumption can also contribute to health through a substitution effect by replacing less healthy food choices in a diet [19]. Therefore, fish consumption is suggested over n-3 PUFA supplements for better health effects. If eating fish is not possible, it is important to use high quality n-3 PUFA supplements with low lipid oxidation to minimize the side-effects.

Several studies have revealed that edible fish and fish oil may also contain undesired substances due to the exposure to environmental contaminants such as methyl mercury (MeHg), polychlorinated biphenyls (PCBs) and dioxins [20-25]. MeHg is the major neurotoxic substance found in some fish species which affects neurodevelopment in children [26]. Long-term exposure to it may also lead to higher risk of immunotoxicity, neurotoxicity, cancer, cardiovascular and reproductive diseases [27]. PCBs and dioxins may increase the risk of cancers (e.g., kidney, liver, lung, and breast cancer), suppress the immune system to reduce the body's resistance to many infections such as infectious respiratory diseases, and can impair neurologic development [20, 28-30]. Therefore, fish species of elevated risk level of environmental contaminants including swordfish, shark, tilefish, king mackerel, and albacore-tuna should be avoided for adverse health effects [31]. A very large number of studies have been conducted on the nutritional benefits of fish as food and there are several review papers examining this topic. However, there is no previous attempt at systematically synthesizing the exiting review literature through a scoping review to provide a comprehensive overview of the existing topics related to fish intake for human health.

This thesis aimed to collect and evaluate the available evidence on the health effects of human fish consumption, examine estimates of fish consumption and the diversity of species consumed, and assess the comprehensiveness of current nutrient databases that includes determining the fatty acid composition of Canadian wild freshwater fish species to better understand the nutritional value of typical fish species consumed by Canadian population. The overall hypothesis is that n-3 PUFA is the main nutrient within fish that provides health benefits that override potential health detriments but determining human intakes of n-3 PUFA from fish is a challenge due to variability in the estimated n-3 PUFA content of fish in nutrient databases due to the number and diversity of fish species, and the difficulty of incorporating regional and seasonal effects on n-3 PUFA content of fish. In the first study, a scoping review of the effects of fish consumption on human health guided by the six-staged methodology framework developed by Arksey and O'Malley was conducted to synthesize evidence from available review articles and identify potential research gaps [32]. The second study identified fish production & consumption database, fish species databases, and current electronic nutrient databases to determine the amount of fish consumed, the diversity of food fish species and the comprehensiveness of nutrient data reported by those databases. In the third study, the fatty acid composition of wild freshwater fish samples collected from the Canadian Subarctic and Arctic was determined by gas chromatography-flame ionization detection [33]. Last but not the least, fatty acid composition data generated from the third study were compared to the recorded data in Canada's official nutrient databases: Canadian Nutrient File (CNF) Database.

Chapter 2

Background

2.1 Fish Consumption around the World

Over the past six decades, global food fish consumption has been increasing steadily, from an average of 9.0 kg per capita in 1961 to 20.3 kg per capita in 2017 [2]. The annual growth rate of total food fish consumption (3.1 percent) was twice of that of world population (1.6 percent) for the same period [2]. Fish is an important part of nutritional diet, it accounted for approximately 17% of the worlds need for animal protein and 7% for all proteins in 2017, and about 3.3 billion people worldwide depended on fish as their principal source of animal protein [2]. In 2018, 156 million tonnes out of 179 million tonnes of fish produced globally were used for human consumption, which is equivalent to an annual supply of around 20.5 kg per capita. The average fish consumption per capita for North America, Latin America and the Caribbean, Asia, Africa, Europe, and Oceania was 22.4, 10.5, 24.1, 9.9, 21.6, and 24.2 kg, respectively [2]. Fish consumption is highly variable between different areas of the world as well as between different (inland vs. coastal) regions of countries due to consumers' geographic, cultural, and social characteristics [34]. At the country level, Asian countries have higher fish consumptions compared with North America. In 2017, Japan, China, Canada, and United States had an averaged fish consumption per capita of 45.5, 38.2, 22.5, and 22.4 kg, respectively. The lowest fish consumption per capita was South Africa with 6kg per capita [35]. The trend of increased global demand for fish is continuing. Beside increases driven by population growth, other factors contributing to increased fish consumption include technological developments in processing,

shipping and storage, rising incomes worldwide that enable fish purchasing, and enhanced awareness of the health effects of fish intake by increasingly health-conscious consumers [13].

2.2 Content of Nutrients in Fish

2.2.1 Lipids

Lipids are defined as substances which are insoluble in water but soluble in organic solvents such as chloroform, hexane, ether, or benzene [36]. They are grouped into six main classes: free fatty acids, triacylglycerols, diacylglycerols, monoacylglycerols, phospholipids, and sterols [37]. Lipids are the crucial source of cellular energy and play a vital role in maintaining the integrity of living organisms as structural compounds by creating a barrier between the living cell and the outside environment [38]. The lipid content of fish is highly variable between different fish species ranging from 0.2 to 25% of total body weight that fish are grouped into four groups by fat content: lean (< 2% fat), low fat (2-4% fat), medium fat (4-8% fat), and high fat (>8% fat) [39]. Of the fish lipids, n-3 PUFA have been shown to be beneficial to human health [40]. In general, marine fish tend to have higher long chain n-3 PUFA content than freshwater fish because freshwater fish are closer linked to terrestrial food resources that have relatively high 18:2n-6 and 18:3n-3 content [41, 42].

2.2.2 N-3 Polyunsaturated Fatty Acids

The n-3 and n-6 polyunsaturated fatty acids are considered essential fatty acids because humans and mammals are not able to desaturate in the n-3 and n-6 positions to form carbon-carbon double bonds [43]. Specifically, mammals are unable to make linoleic acid (LA, 18:2n-6) and alpha-linolenic acid (ALA, 18:3n-3) due to the lack of methyl-end desaturase that place

double-bonds in the Δ12 and Δ15 position of oleic acid (18:1n-9) [44]. The main sources of LA and ALA in the human diet are plant oils [45].Plants can generate LA using fatty acid desaturase 2 (FADS2), an endoplasmic Δ12 and ALA using FADS3, an endoplasmic Δ15 as well as plastid n-3 desaturases, FADS7 and FADS8 that are associated with chloroplasts [46]. Humans can metabolize LA and ALA to longer chain PUFA [44].

Although ALA is considered the essential n-3 PUFA, many of the biological benefits are associated with EPA (20:5n-3) and DHA (22:6n-3) that can be either consumed preformed or synthesized from ALA [47]. Synthesis of DHA from ALA includes several desaturation and elongation steps [48]. The first step involves the desaturation of ALA to stearidonic acid (18:4n-3) by Δ6-desaturase (FADS2) followed by subsequently elongation by elongase 5(ELOVL5) to eicosatetraenoic acid (20:4n-3), which can then be desaturated to EPA by Δ5-desaturase (FADS1) and the elongated (ELOVL2) to docosapentaenoic acid (DPAn-3, 22:5n-3) [49]. The generation of DHA from DPAn-3 is a net Δ4 desaturation but involves elongation to tetracosapentaenoic acid (24:5n-3), desaturation by Δ6-desaturase (FADS2) to 24:6n-3, translocation from the endoplasmic reticulum to the peroxisome for β-oxidation to DHA (**Figure 1)** [49]. However, the rate of this bioconversion of ALA to EPA and DHA is extremely limited in humans (< 4%) that the intake of ALA alone may not be enough to provide health benefits [50]. This makes it important to include fish, an excellent source of preformed EPA and DHA in the daily diet.

Fish, similar to mammals, are not capable of synthesizing n-3 PUFA *de novo* and fish share the conventional n-3 PUFA biosynthetic pathway with some additions [51]. Fish are excellent source of dietary long chain n-3 PUFA such as EPA and DHA as their food chain

includes microalgae, which are the primary producers of long chain n-3 PUFA that bioaccumulates in the fatty tissue of organisms [52, 53]. Factors that influence the fatty acid composition of fish include their biome (freshwater vs. marine), latitude zone (tropical vs. temperate vs. polar), feeding mode (herbivore vs. omnivore vs. carnivore) as well as their taxonomy with marine polar carnivores typically having the highest amount of EPA and DHA [54]. There are also differences in n-3 PUFA biosynthesis pathway between humans and fish that result in different fatty acid profiles. Fish have higher tissue levels of n-3 PUFA with 4 carbon-carbon doubles bonds such as 18:4n-3 and 20:4n-3 and some fish can have relatively high amounts of DHA as a result of additional elongation (Elovl8) and Δ8 and Δ4 desaturation activities by FADS2 (**Figure 2**) [55, 56].

EPA and DHA vital role in human health are largely mediated as components of the phospholipids of cell membranes and their subsequent use as substrates for lipid signalling that are involved in various biological processes from conception through each stage of human development, maturation, and aging [12]. DHA specifically, is highly concentrated in human brain and retina and is required for optimal development and maintenance of the cognitive and visual system [57, 58]. Previous studies have confirmed that dietary intake of n-3 PUFA, especially EPA and DHA, is associated with cardioprotective effect and cognitive enhancement, lower risk of stroke, decreased risk of psychological disorders, and reduced danger of cancer [6, 8, 59-61].

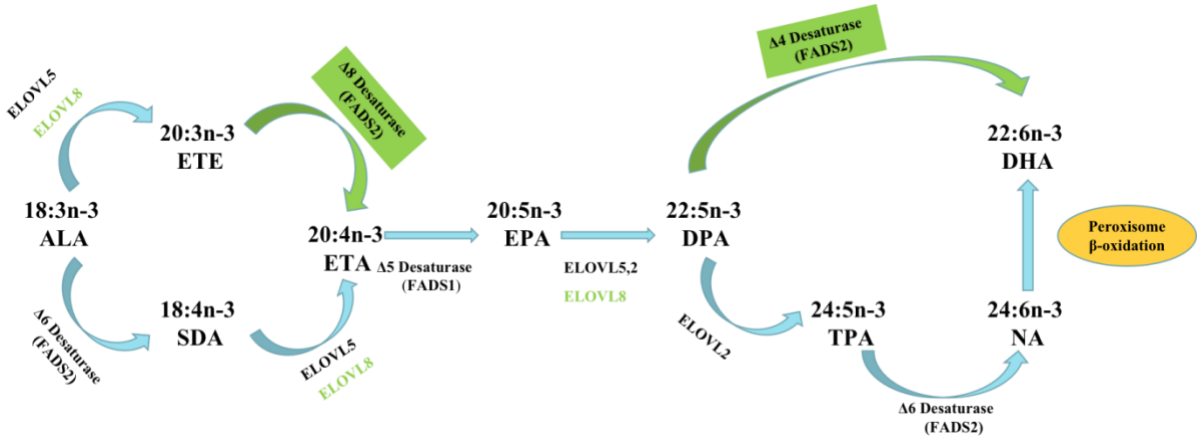


Figure 1. Biosynthetic pathway of n-3 PUFA from dietary alpha-linolenic acid in human and fish. Items in green are unique to fish (ELOVL8, Δ8 desaturase and Δ4 desaturase activity of FADS2). ALA, alpha-linolenic acid (18:3n-3); SDA, stearidonic acid (18:4n-3); ETE (eicosatrienoic acid, 20:3n-3); ETA, eicosatetraenoic acid (20:4n-3); EPA, eicosapentaenoic acid (20:5n-3); DPA, docosapentaenoic acid (22:5n-3); TPA, tetracosapentaenoic acid (24:5n-3); NA, nisinic acid (24:6n-3); DHA, Docosahexaenoic acid (22:6n-3); FADS, fatty acid desaturase; ELOVL, Elongase. Figure is adapted from [56].

2.2.3 Proteins

Fish have a higher percentage of protein than most terrestrial meats which makes it an important source of high-quality protein for humans [62]. Fish proteins are considered having a high nutritional value, which are highly digestible due to low connective tissue content and slightly elevated amounts of the essential amino acids, lysine, methionine and threonine compared with terrestrial meat proteins [62]. It is reported that fish proteins also contain antioxidative activity and they are a rich source of beneficial health molecules such as growth factors, secretagogues, and calciotropic hormone [63]. It is also suggested that bioactive amino acid sequences in fish-derived peptides can positively affect pathways involved in hypertension, lipid profile, body composition, and blood glucose metabolism [64].

2.2.4 Vitamins

In addition to the profitable lipid and protein composition, fish is also a significant source of major vitamins (vitamin A, vitamin B, vitamin D, and vitamin K) essential to the physiological functioning of the body [65]. Among those vitamins, vitamin A, vitamin D and vitamin K are fat soluble with vitamin A being necessary for vision, normal cell growth, cell differentiation and reproduction [66], vitamin D playing a crucial role in regulating cellular growth, modulating immune system, and promoting bone formation and mineralization [67] and vitamin K is an indispensable compound for blood clotting and maintaining healthy bone tissue [68]. Water-soluble B vitamins, which are required for normal enzyme functioning involved in energy metabolism, are vital for cell growth and oxygen transport [69].

2.2.5 Minerals

Fish is a rich source of most of the minerals that can be found in water, such as iodine, selenium, and calcium. These minerals in fish are highly bioavailable which can be easily absorbed by human body [65]. Among those minerals, iodine is a critical component of thyroid hormones which are involved in regulating body metabolism such as protein synthesis and enzymatic activity [70]. Fish intake in iodine deficient areas is associated with decreased thyroid cancer risk [71]. Selenium from fish functions in humans mainly in the form of selenoproteins that support redox enzyme such as glutathione peroxidase [72]. Calcium plays an important role in bone formation and mineralization and is also an indispensable elements in maintaining signal transduction, functioning of muscle and the release of neurotransmitters [65, 73].

2.3 Content of Potential Contaminants in Fish

2.3.1 Heavy Metals

Mercury (Hg) is one of the most dangerous and toxic heavy metals. While elemental mercury is poorly absorbed in the gastrointestinal tract, water-soluble inorganic mercury (iHg) compounds such as mercuric chloride ($HgCl_2$) and methylmercury (MeHg) can be absorbed in the gastrointestinal system, especially organic MeHg (up to 90-95% absorbed) [74-76]. As such, MeHg is the most toxic form of Hg. MeHg is initially formed from elemental Hg by aquatic microbes and bioaccumulates in the aquatic food chain. The highest MeHg concentrations can be found in large predatory fish such as shark, king mackerel, pike, swordfish, and large tuna [77]. Once ingested and absorbed, MeHg can strongly bind sulfhydryl groups that negatively effects the activity of a variety of enzymes involved in energy production, ion channels, and receptors [78]. Collectively, iHg and MeHg ingested by human from fish can be toxic to several organs (e.g., liver and kidney), the nervous system (especially in infants), the cardiovascular system, the gastrointestinal tract, and/or can increase inflammation [74-76].

Cadmium (Cd) is another toxic heavy metal found in some seafood, especially shellfish. The ionic form of Cd is usually combined with ionic forms of chlorine to yield highly absorbable cadmium chloride ($CdCl_2$) in fish [22]. Cd tends to accumulate in and damage the liver and particularly the kidney as well as being neurotoxic and causing weak and brittle bones [79, 80]. Cadmium ions increase oxidative stress in cells by catalyzing the production of hydrogen peroxide [81].

Arsenic (As) exists in both inorganic and organic forms. Inorganic As typically present in groundwater as arsenate (pentavalent form) can be converted to arsenite (trivalent form) by reduction in the body [82, 83]. It is believed the trivalent state may react with protein thiols and inhibit enzymatic activities while the pentavalent state can also have effects by replacing phosphate in certain reactions [82]. The trivalent arsenicals interaction with protein thiols is believed to lead to cellular dysfunction and cytotoxicity which then result in regenerative proliferation of cells that increase the risk of cancer development [83]. The organic As compounds that are typically found in fish are less toxic to humans [78]. Arsenobetaine tends to be the most common form As in shellfish and fish, while arsenosugars (high in seaweed), arsenolipids and methylated arsenicals can also be present [84]. While inorganic As content is very low in finfish, there are detectable amounts in shellfish and seaweed based on region, particularly the As content of the soil and water of the region [84]. Long term exposure to the organic pentavalent dimethylarsinate (DMA^{V}), once used as a pesticide and also the predominant metabolite of iAs and arsenosugar exposures, may have cytotoxic effects in skin, bladder, liver and lung, cells and may increase the risk of cancer [78, 85]. *In vitro* models have suggested potential hazards from Arsenolipids, e.g., via As Hydrocarbons, As Fatty Acids, and/or DMA^{v} metabolites but additional research is required to determine the relevancy of these observations to human populations [84].

Lead (Pb) is a common environmental pollutant and occupational exposure is the main cause of lead poisoning that workers in the metal trades are with high risk of Pb exposure [86]. Fish can bioaccumulate Pb from both waterborne exposure and dietary exposure with the gill and gastrointestinal tissues having the highest accumulation rates while fish muscle accumulating relatively low amounts [87]. Pb also exists in both inorganic and organic forms with inorganic

iPb being the predominant form in fish [88]. Organic Pb poisoning is rare, because organic lead compounds (e.g., gasoline additives) has been withdrawn [89]. In humans, lead can accumulate in blood, soft tissues and bone, and it can have several harmful effects by binding to enzyme thiol groups, displacing various metallic enzyme cofactors, and interfere with metallic ion pumps [90]. Chronic exposure of Pb to excessive level in human can cause toxicity in nervous system, cardiovascular system, and haematological system [89].

2.3.2 Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation and include dioxins, polychlorinated biphenyls (PCBs), and pesticides such as dichlorodiphenyltrichloroethane (DDT). POPs can volatize and travel long distances in the air before being redeposited, thus POPs are not restricted to their site of origin and can be distributed across the globe [91]. Although POPs have relatively low solubility in water, they bioaccumulate with compounds of high lipid solubility and accumulate in fatty tissues of organisms where they can remain for long periods of time [21]. POPs are found in higher concentrations in large predatory fish but also in bottom-feeding fish that live in relatively shallow bays as sediments are sinks for POPs [92]. Some POPs (e.g., PCBs and dioxins) act as carcinogens and may disrupt receptors and signalling pathways of the endocrine, reproductive, central nervous and immune systems [93].

PCBs are highly lipophilic manufactured industrial chemicals that derived from biphenyl by substitution of hydrogen atoms by chlorine atoms, they were banned for being highly carcinogenic in 1979, however, legacy PCBs are still present in aquatic systems [94]. Multiple adverse health effects in humans have been linked to exposure to high levels of PCBs, including

cancers (e.g., skin, lung, liver cancers), low birth weight of infants, and negative effects on the nervous, immune, endocrine, and reproductive systems [95, 96].

Dioxins are also toxic man-made compounds that are formed as by-products of chlorine-containing manufacturing process [97]. The general population are exposed to dioxins mainly through foods such as fish [97]. Like PCBs, dioxins are also carcinogenic to humans and the adverse health effects associated with exposure to dioxins include cancers (e.g., lung and liver cancer), cardiovascular disease and impaired nervous, immune, endocrine, and reproductive systems [98].

DDT is a toxic organochlorine pollutant that were once widely used synthetic pesticide, and it and its metabolites were and remain persistent in the environment and are considered to be human carcinogens [99] . DDT mainly exists in sediment in aquatic ecosystem but can accumulates in in fish tissue through aquatic food web [100, 101]. The possible adverse health effects reported to human exposure of DDT include cancers (e.g., breast and pancreatic cancer), cardiovascular disease, neurologic toxicity, immune, endocrine, and reproductive diseases [102].

2.3.3 Biological Hazards

The adverse health effects of fish consumption are not only associated with the chemical contaminants mentioned above, but also related to harmful biological agents such as pathogenic bacteria or their toxins, parasites, and biogenic amines that can cause food borne illness when consuming fish. Scrombotoxin and ciguatoxin are the most commonly reported outbreaks as both these toxins are heat stable and not affected by cooking [103].Scrombotoxin occurs in scromboid fish such as tuna when gram negative bacteria convert tissue histidine to histamine between catch

to table while ciguatoxin occurs when fish in low lying shores or costal reefs feed on dinoflagellate *Gamabierdiscus toxicus* that contains the toxin [12, 104]. *Salmonella*, *Clostridium botulinum* and Norovirus outbreaks are also commonly reported, but tend to be a result of improper food handling of the raw fish/improper cooking or cross contamination [103]. The most common parasitic infections from raw or undercooked fish are roundworms (nematodes), flatworms or flukes (trematodes) and tapeworms (cestodes) [105].

Chapter 3

Scoping Review of Review Studies on Beneficial Effects of Fish Consumption on Human Health

3.1 Rationale and Objectives

Fish consumption have been associated with positive effects on cardiovascular health, neurodevelopment and maternal health, bone health, mental health, cancer, obesity, diabetes, and multiple inflammatory diseases [8, 9, 59, 106-108]. The beneficial effects of fish consumption on human health potentially involves multiple compounds in fish and multiple dietary and molecular mechanisms. Fish provides consumers with a variety of nutritional components such as EPA and DHA, high-quality proteins, vitamins, and minerals [13, 109]. The n-3 fatty acids content is highly variable among fish species. The fatty acid composition of fish is highly variable between and within species because of the wide diversity of aquatic life and the way fish are processed [20, 110]. Fatty fish such as salmon, sardines, mackerel, tuna and trout have high content of EPA and DHA, while lean white fish such as whiting sole, hake, grouper, bass and perch have low EPA and DHA content [111].

Beside the tremendous beneficial effects of human fish consumption reported in the literature, there can be some adverse health effects due to environment contaminant exposure especially for some fish species. For example, fish intake is the major food source of MeHg contamination and chronic exposure to MeHg can cause permanent damage to brain, kidneys, and developing fetus [112-114]. The risk of MeHg contamination is the highest for predatory

marine fish such as swordfish, shark, or tuna [115] and freshwater fish such as walleye, northern pike and lake trout [116].

There is a large volume of published review studies providing evidence on the beneficial effects of fish intake but there is no scoping review of those review studies. The scoping review is of particular use to examine the extent, range, and nature of research activity in a certain topic area, and the purposes of a scoping review are to 1) summarize and disseminate research findings, 2) provide an overview of the reviewed literature without criticizing individual studies or synthesizing evidence from different studies, and 3) identify research gaps in the existing literature [32]. To my knowledge this would be the first scoping review of the review literature on health benefits of human fish consumption. The ***objective*** of this scoping review is to 1) broadly collect and evaluate the existing literature about human health and fish consumption and 2) identify potential research gaps for future endeavours.

3.2 Hypotheses

1. Multiple components of fish can provide health benefits.
2. N-3 PUFA will be the main nutrient examined from fish in the review studies.
3. Cardioprotective properties of n-3 PUFA will be the health benefit most examined with fish consumption.

3.3 Methods, Materials and Study Design

The scoping review was informed by the six-staged methodology framework developed by Arksey and O'Malley [32], with the methodology enhancement by Levac et al. [117]. The review included the following five key stages: (1) identifying the research question, (2)

identifying relevant studies, (3) selecting studies, (4) charting the data, and (5) collating, summarizing, and reporting the results. A sixth stage (consulting with relevant stakeholders) was suggested by Arksey and O'Malley to identify additional references about potential studies and get their feedback about the findings uncovered by the scoping review, but it was not included in this review because of time and budget constraints.

3.3.1 Research Question

This review was guided by the question, 'What are the effects of fish consumption on human health?' The research sub-questions included: 1) 'What are the beneficial nutrient components in fish?' 2) 'Which human populations have been studied the most in regard to the consumption of fish?' and 3) What other recurring themes exist in the review literature related to fish consumption.

3.3.2 Data Sources and Literature Search Strategy

The original search was implemented in three electronic databases (PubMed, EMBASE, and Cochrane Library) to identify relevant review literatures (Narrative review, Systematic review, and Meta-Analysis) from 1976 to August 14, 2020. Terms including: (1) fish/seafood consumption OR fish/seafood fat, (2) fish/seafood nutrient OR fish/seafood nutrition were searched as keywords in both the tile and/or abstract (**Table 1**). An *ad hoc* additional search was performed using the PubMed database on July 10, 2022, that included the additional term "OR toxic*/contaminant" (see full search in **Table 5**) to assess the amount of literature related to potential environmental contaminants found in fish that may have been missed in the original

search. The same entering period as the original search was used (Jan 1,1976 to August 14, 2020) and all the searches were restricted to studies in humans but not limited by language.

3.3.3 Citation Management

All citations were imported into the reference management tool EndNote X9.3.3 (EndNote-Clarivate, Philadelphia, PA). The duplicate citations were removed from the imported reference list and then title, and abstract relevance screening and data characterization of full-text articles were applied afterwards.

3.3.4 Eligibility Criteria

Literature from original search meeting the following criteria were included: (1) studies conducted in humans, (2) exposure of interest was finfish consumption or dietary n-3 fatty acids, and (3) outcome of interest was health benefits or risks. Studies did not meet the inclusion criteria were excluded. For the same review literature reported in more than one publication, only the literature reporting the most complete data set was kept.

3.3.5 Title and Abstract Screening

Two reviewers (Lu Bai and Ken D. Stark) were involved in review selection from results generated from original search independently. For the initial level of screening, only the title and abstract of included review articles were reviewed to exclude the review articles that did not focus on fish or seafood intake on human health in neither title nor abstract.

3.3.6 Full Text Screening and Characterization

Relevant citations from original search retained after the initial title and abstract screening were captured for subsequent full-text review. A form was developed by two independent reviewers to confirm relevance and record literature characteristics such as publication year, type of reviews, nutrient of focus, population of focus, health aspects of focus, and main findings. As for the categorization of nutrient of focus, “All nutrients” represents a combination of multiple nutrients of fish. As for the categorization of population of focus, participants aged from 18 to 65 years was categorized as “Adults”, mother-child pair was categorized as “Maternal / Infant”, participants aged over 65 years was categorized as “Older adults’, mixed population was categorized as “Other Mixed”, and participants aged from 2 to 18 years was categorized as “Children”. Review literatures were excluded either if they were found to not meet the eligibility criteria or if the full text was not obtainable.

3.3.7 Data Summary and Synthesis

The following data were extracted or coded for all review studies yielded from original search: title, author (s), type of studies, year of publication, journal, impact factor of journal, examined nutrients, examined contaminants, examined populations, health outcomes, unique topics, and implications of findings. All data for this scoping review were assembled and exported into Microsoft Excel for coding.

3.4 Results

3.4.1 Distribution of Types of Reviews Included in this Scoping Review

Preliminary results of the scoping review were presented as a poster at the 2021 Virtual International Society for the Study of Fatty Acids and Lipids Congress (May 10-14, 2021 (Appendix 1). The literature searches conducted during August 2020 resulted in 284 articles from PubMed, 167 from EMBASE, and 42 from Cochrane. After removing duplicates, a total of 423 unique reviews were identified for abstract screening. Abstract screening resulted in 158 reviews being selected for full-text reading and full-text screening resulted in 153 reviews included in this scoping review (**Figure 2**). Reviews on the health effects of fish intake first appeared in 1989 but were relatively sporadic until the 2000s (**Figure 3**). Since 2000, the interest in conducting review studies on health effects of fish intake increased as 95% of the included reviews were published as of that date with the highest percentage of papers (17%) being published in 2012. Narrative reviews were the most abundant type of included reviews which accounted for 64% of the total review articles with the remaining reviews being systematic reviews (36%) (**Table 3**). Of the systematic reviews, 72% were meta-analysis sub-types that accounted for 26 % of total reviews (**Figure 4**). The first systematic review was published in 2004.

The reviews were published in a range of journal types with the 153 articles being published in 103 different journals. As shown in **Table 2**, 26 reviews (17% of the total) were published in 17 journals with an impact factor > 10, 69 reviews (45% of the total) were published in 39 journals with an impact factor between 4 and 10, and 58 reviews (38% of the total) were published in 47 journals with an impact factor < 4. These impact results were based on the Journal Citation Reports (JCR), Edition 2020. The journal *Nutrients* published the most review articles with a total of 11 followed by the *American Journal of Clinical Nutrition* (6 reviews) and *Public Health Nutrition* (5 reviews).

3.4.2 Reported Beneficial Constituents of Fish, Health & Disease Focus and Populations Examined

The health benefits of multiple bioactive components of fish have been examined in the literature. The nutrient(s)/topic(s) of focus were identified for each review paper (Table 3). N-3 PUFA was the nutrient in fish examined the most as it was included in 56.2% (86 out of 153) of the total reviews. Whole fish was the second most examined components in fish, accounting for 36.6% (56 out of 153) of the total reviews. All nutrient components were examined in 11.1% (17 out of 153) of the total reviews. Only 7.8% (12 out of 153) of the total review articles (mainly narrative reviews) examined the combined topics of iodine (3 articles), selenium (3 articles), carotenoids (2 articles), vitamin D (2 articles), or protein in fish (2 articles). Non-nutrient topics that were examined as a focus included toxicity at 24.2% of all reviews (37 of 153) and sustainability at 3% (3 of 153). There were also considerable overlaps of nutrient/topic foci within a paper as illustrated by a Venn diagram in **Figure 5** as it was rare for a paper to focus on only one aspect of fish intake and human health. When the nutrient/topic of focus was examined by type of review article, there was evidence that the narrative reviews were more comprehensive when examining fish intake and human health, while systematic reviews, by design were more focused. For example, the main focus of the systematic reviews were fish (71%) and n-3 PUFA (46%) that overlapped in several papers. Only three systematic reviews examined other topics that included toxicity (2 reviews) and iodine (1 review). In contrast, the narrative reviews were broader in their topic coverage and reflected the coverage of all the reviews combined but with a higher percentage of reviews examining n-3 PUFA (62%) and a lower percentage of reviews focused on whole fish (17%).

The reviews were also categorized according to health conditions examined. The cardiovascular diseases and stroke category was the most examined, accounting for 35% of the total review articles, followed by general health (17%), neurodevelopment & maternal health (14%), and cancer (11%). Neurological decline, autoimmune and inflammatory disease, obesity and diabetes, and bone health were also reported in 3-5% of the total review articles each, while there were 10 reviews examining various mixed conditions (**Table 3**). The health conditions examined in the narrative versus the systematic reviews were relatively similar with a few exceptions. General health was not examined by any systematic review as to be expected in contrast to 26% of the narrative reviews discussing general health related to fish intake. Also, conditions related to neurodevelopment and maternal health were examined in 17% of the narrative reviews, but only 7% of the systematic reviews while cancer was only examined in 6% of the narrative reviews but 18% of the systematic reviews. There was also a higher percentage of systematic reviews for autoimmune and inflammatory disease, obesity and diabetes, and bone health which were rarely examined in narrative reviews.

Finally, the reviews were categorized by population examined. The majority of the included review articles examined issues related to an adult population (54%) or general population (19%), followed by maternal / infant (14%), older adults (7%), other mixed (5%) and children (2%) (**Table 3**). Again, by their nature, the systematic reviews did not examine the general population, with most of the focus on adults (71%) and there was less focus on maternal/infant populations in the systematic reviews (9%) as compared with the narrative reviews (16%). Other mixed populations were examined more in systematic reviews (9%).

3.4.3 Reported Contaminants in Fish and Associated Adverse Health Benefits

Concerns about toxicity and fish was the focus of 24% of the total reviews (**Table 3**). "Toxicity" is a broad and vague term, therefore the specific contaminants in fish that could cause potential adverse health effects were examined in the reviews from the search results. The most examined contaminant in fish was the mercury with 37 reviews examining this toxic heavy metal (**Figure 6**). Other heavy metals were examined less regularly included cadmium (8 reviews), arsenic (7 reviews), and lead (4 reviews). The heavy metal intakes from fish were mainly associated with disease and detriments to the cardiovascular, immune, endocrine, renal, and hepatic systems, and 31 reviews examined the impact of mercury on neurodevelopmental toxicity (**Figure 6**). Polychlorinated biphenyls (PCBs) were the second most examined contaminant with 23 articles reviewing this group of persistent organic pollutant (POP) (**Figure 6**). Other POP examined included dioxins (14 reviews), and dichlorodiphenyltrichloroethane (DDT) (3 reviews). The main adverse health effects examined by the POP included diseases and detriments of the immune, endocrine, reproductive, renal and hepatic diseases, with several reviews examining the roles of PCBs and dioxins on cancer (19 reviews), diabetes (5 reviews), low-birth weight (3 reviews), and neurodevelopmental toxicity (11 reviews) (**Figure 6**). Biological hazards such as parasites, pathogenic bacteria and biogenic amines were also examined in 4 reviews, with scombroid poisoning, being examined the most often (2 reviews).

3.4.4 Themes and Implications of Findings Reported in the Selected Review Articles

During the scoping review, specific themes, and interpretations of the implications of the review findings emerged. A summary of these themes and implications can be found in **Table 4**. The mechanism of action of nutrients in fish was the most abundant theme examined and it was examined in 34.6% (53 out of 153) of the total reviews. The impact of the type of fish on human

health was examined in 9.2% of the total reviews followed by examinations of the difference between n-3 PUFA supplements versus fish intake (5.2%) and the impact of cooking methods on the nutritional value of food fish (4.6 %). As for the type of reviews examining these themes, narrative reviews were more likely to address the themes, as 43% of the narrative reviews examined the mechanism of action of nutrients as compared with 20% in the systematic reviews. In addition, the impact of the type of fish was not examined in any of the systematic reviews and issue related to n-3 PUFA supplements versus fish intake were examined in only one systematic review. Surprising, the effect of cooking on the nutritional value of fish was examined in systematic reviews (5.5%) at a rate similar to narrative reviews (4.1%).

For implications of findings reported in the reviews, 25% of the total identified strength and limitations of research, but this was mainly due to a high rate by the systematic reviews (64%) as narrative reviews rarely reflected on this topic (3.1%) (**Table 4**). Narrative reviews, however, were more likely to make recommendations for policy or practice on fish consumption (33%) as compared with systematic reviews (5.5%). Recommended topics or questions for future research were examined in 20% of the total reviews with this finding implication being made almost twice as often in the systematic reviews (29%) as the narrative reviews (15%).

3.4.5 Search Results from the *Ad Hoc* Search

The original PubMed search resulted in 284 review articles that contributed 281 original abstracts that were screened down to 111 full-text and articles included in the final 153 articles in the original search. The *ad Hoc* PubMed search with the additional 'OR toxic*/contaminant' term conducted on July 17. 2022 returned 431 results in PubMed (**Table 5**). Of these 431 review articles, 147 were new articles after comparing with the original PubMed search of 284 articles.

Abstract screening of the new search indicated that 129 of these 147 new articles were relevant abstracts. Of these 129 abstracts, 115 were focused on toxins, contaminants and other illnesses related to fish consumption, and 14 were more focused on health benefits of food consumption.

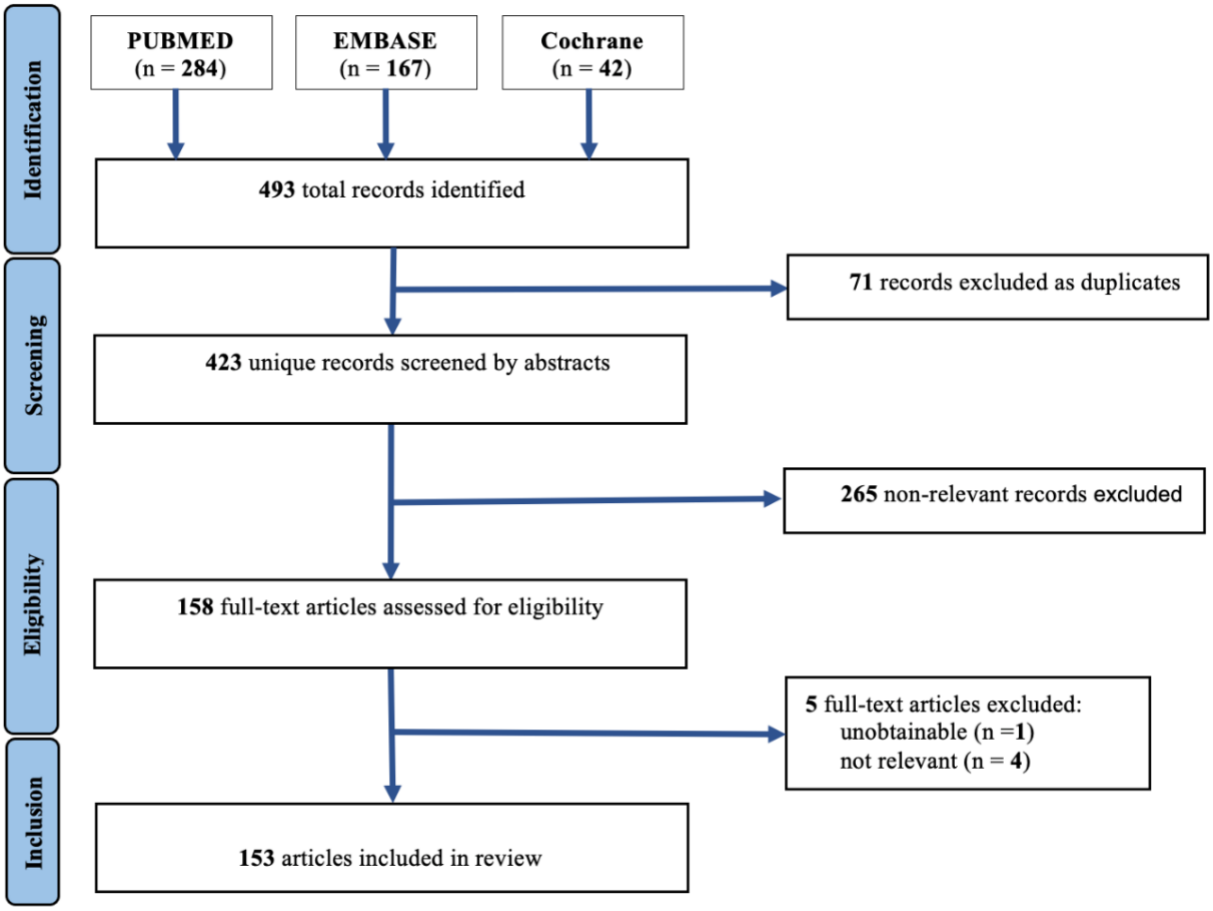


Figure 2. Flowchart of selection of studies on health effect of human fish consumption. All literature searches were conducted on August 14, 2020.

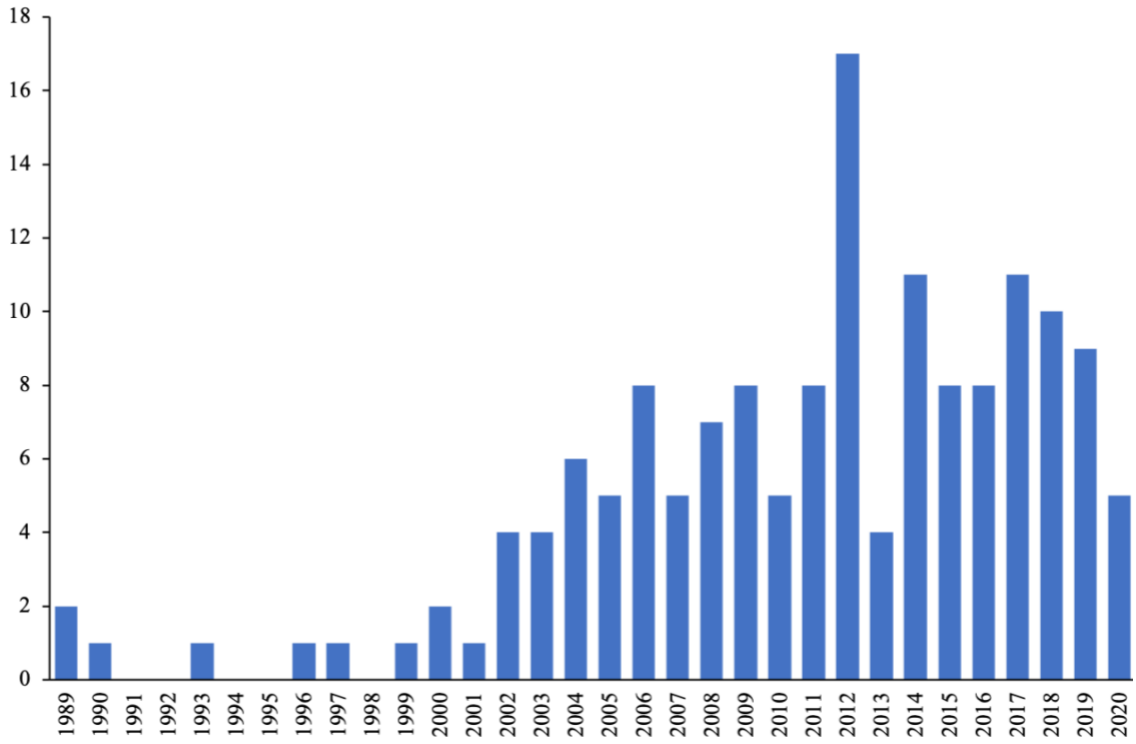


Figure 3. Papers by Publication date

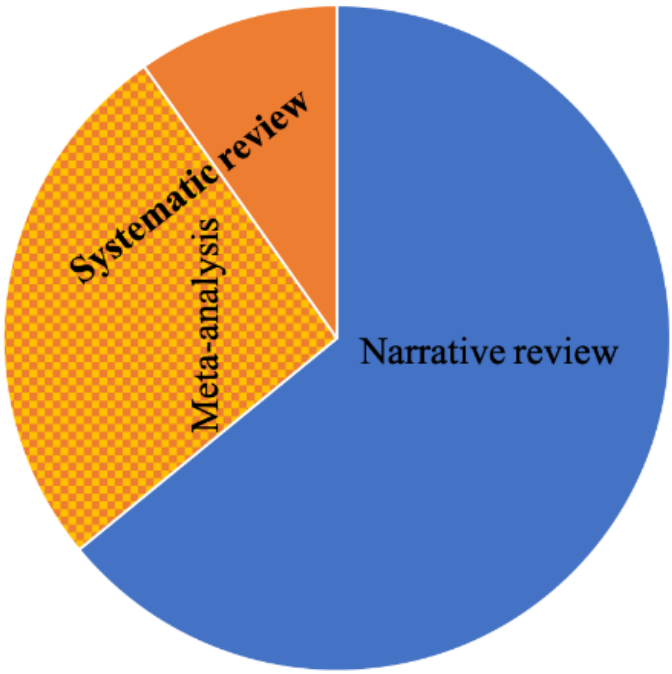


Figure 4. Types of included reviews

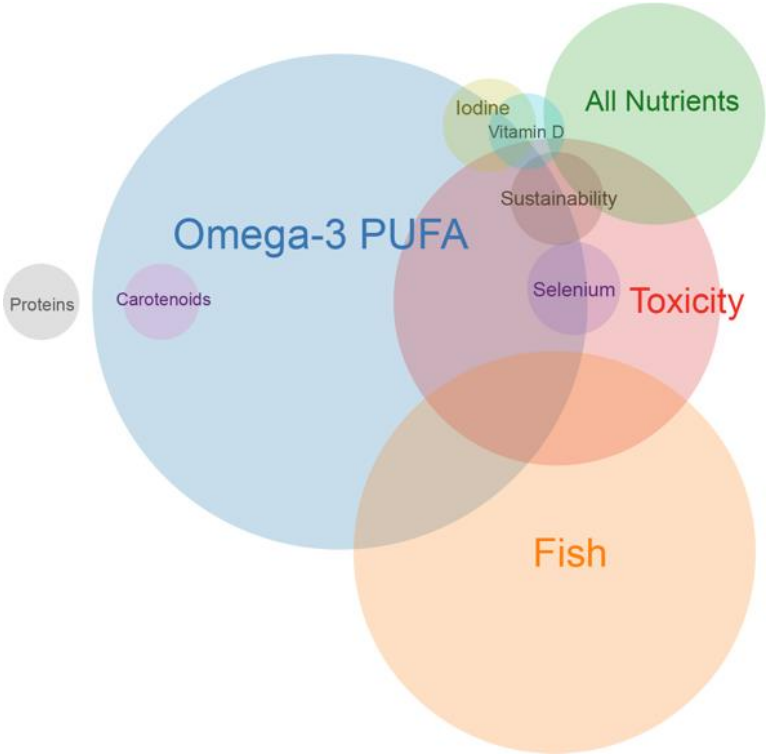


Figure 5. Nutrient and topic focus and overlap

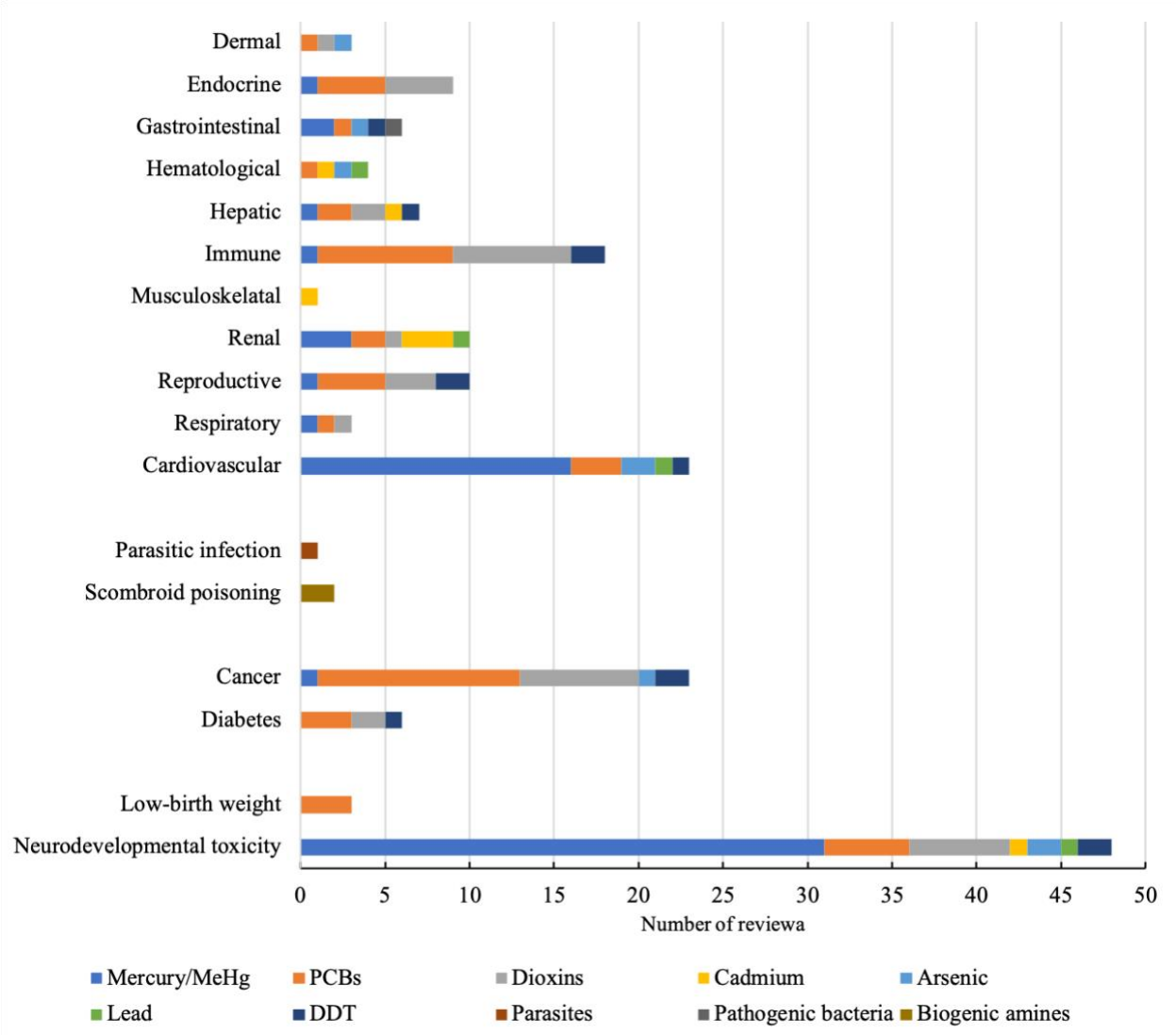


Figure 6. Fish contaminants associated with adverse health effects in the selected reviews studies with a focus on toxicity. MeHg, methylmercury.

Table 1. Database search strategy

Databases	Search terms
PubMed	"((fishes[Mesh] OR (seafood[Mesh])) OR ((fish*[title]) OR (seafood[title])) AND ((health OR benefit)) AND ((nutri* OR diet)) AND ((intake OR consumption))"
EMBASE	"(fish*:ti OR seafood:ti) AND (health OR benefit) AND (nutri* OR diet) AND (intake OR consumption)"
Cochrane Library	fish* OR seafood in Title Abstract Keyword AND health OR benefit in All text AND nutri* OR diet in All text AND intake OR consumption in All text

All database searches were completed on August 14th, 2020. Study types were limited to human. Publication types were limited to review, systematic review, and meta-analysis.

Table 2. Distribution of papers according to journal impact factor

Impact factor	Number of journals (%)	Number of papers (%)
0 to <2.5	25 (24.2)	31 (20.3)
2.5 to <4	22 (21.4)	27 (17.6)
4 to <6	22 (21.4)	29 (19.0)
6 to <10	17 (16.5)	40 (26.1)
> 10	17 (16.5)	26 (17.0)
Total	103 (100)	153 (100)

Table 3. General characteristics of included reviews

Characteristics		Number of reviews (% within column)	Number of narrative reviews (% within column)	Number of systematic reviews (% within column)
Total reviews		153	98	55
Nutrient/Topic of focus				
	Omega-3 PUFA	86 (56.2)	61 (62.2)	25 (45.5)
	Fish	56 (36.6)	17 (17.3)	39 (70.9)
	Toxicity	37 (24.2)	35 (35.7)	2 (3.6)
	All nutrients	17 (11.1)	17 (17.3)	0
	Sustainability	3 (2.0)	3 (3.1)	0
	Iodine	3 (2.0)	2 (2.0)	1 (1.8)
	Selenium	3 (2.0)	3 (3.1)	0
	Carotenoids	2 (1.3)	2 (2.0)	0
	Vitamin D	2 (1.3)	2 (2.0)	0
	Protein	2 (1.3)	2 (2.0)	0
Health/ Disease of focus				
	CVD & Stroke	54 (35.3)	33 (33.7)	21 (38.2)
	General health	26 (17.0)	26 (26.5)	0
	Neurodevelopment & Maternal health	21 (13.7)	17 (17.3)	4 (7.3)
	Cancer	16 (10.5)	6 (6.1)	10 (18.2)
	Other mixed	10 (6.5)	6 (6.1)	4 (7.3)
	Neurological decline	8 (5.2)	5 (5.1)	3 (5.5)
	Autoimmune & Inflammation	7 (4.6)	2 (2.0)	5 (9.1)
	Obesity & Diabetes	7 (4.6)	2 (2.0)	5 (9.1)
	Bone health	4 (2.6)	2 (2.0)	2 (3.6)
Population examined				
	Adults	79 (51.6)	40 (40.8)	39 (70.9)
	Adult men	3 (2.0)	2 (2.0)	1 (1.8)
	Adult women	1 (0.7)		1 (1.8)
	General population	29 (19.0)	29 (29.6)	0
	Maternal / Infant	21(13.7)	16 (16.3)	5 (9.1)
	Older adults	10 (6.5)	7 (7.1)	3 (5.5)
	Other mixed	7(4.6)	2 (2.0)	5 (9.1)
	Children	3 (2.0)	2 (2.0)	1 (1.8)

CVD, cardiovascular disease; Omega-3 PUFA, omega-3 polyunsaturated fatty acid.

Table 4. Reporting of themes and implications of findings of included reviews (n=153)

Characteristics		Number of total reviews (% of 153)	# Number of Narrative reviews (% of 98)	# Number of Systematic reviews (% of 55)
Themes	Mechanism of action of nutrients	53 (34.6%)	42 (42.9)	11 (20.0)
	Impact of type of fish	14 (9.2%)	14 (14.3)	0
	N-3 PUFA vs. fish intake	8 (5.2%)	7 (7.1)	1 (1.8)
	Cooking methods	7 (4.6%)	4 (4.1)	3 (5.5)
Implications of findings	Identified strength & limitations	38 (24.8%)	3 (3.1)	35 (63.6)
	Recommendations for policy or practice	35 (22.9%)	32 (32.7)	3 (5.5)
	Recommendation for future research	31 (20.3%)	15 (15.3)	16 (29.1)

Omega-3 PUFA, omega-3 polyunsaturated fatty acid.

Table 5. PubMed searching with advanced search terms conducted on July 17, 2022

Database	Search terms	Total results	New results*	Relevant Abstracts
PubMed	"((fishes[Mesh] OR (seafood[Mesh])) OR ((fish*[title]) OR (seafood[title])) AND ((health OR benefit)) AND ((nutri* OR diet OR toxic* OR contaminant)) AND ((intake OR consumption))"	431	147	129

As compared to the original search that did not contain "OR toxi OR contaminant" terms.

3.5 Discussion

To my knowledge, this is the first scoping review of review articles examining the health effects of fish intake. The goal was to collect current reviews and identify the focus of the reviews to potentially uncover knowledge gaps in the existing literature. This scoping review included 153 review articles with over 95% of these papers being published after 2000. Around 61% of the included review papers were published in journals with an impact factor of >4, suggesting that the health effects of fish intake is a topic that is acceptable for high quality journals [118, 119].

3.5.1 Overview of the Scoping Review

Multiple bioactive components (n-3 PUFA, protein, iodine, vitamin D, selenium, and carotenoids) of fish contributed to the various human health benefits according to the examined reviews. As such, the first hypothesis that multiple components of fish can provide health benefits, was accepted. From the total number of 153 review papers, n-3 PUFA (reported in 56.2% of total reviews) was found to be the most reported beneficial nutrient in fish and its cardioprotective effect (reported in 35.3% of total reviews) was the most examined health benefits in the review studies (**Figure 6**). These findings agreed the second and the third hypotheses that n-3 PUFA would be the main nutrient examined from fish in the review studies and cardioprotective properties of n-3 PUFA would be the health benefit most examined with fish consumption.

The cardioprotective properties of n-3 PUFA tend to be maximized with approximately 2g n-3 LCPUFA/day and include: reducing plasma triacylglycerol (TG) levels by decreasing

hepatic very low-density lipoprotein cholesterol synthesis, increasing high-density lipoprotein levels, and reducing platelet aggregation through the modulation of prostaglandins [4, 120, 121]. It is also suggested that n-3 PUFA have potent anti-inflammatory and immune-modulating effects and the potential mechanisms included: reducing formation of inflammatory eicosanoids and leukotrienes, cytokines, favourably altering endothelial and cell-cell activation, and improving immune cell function [122, 123]. Other nutrient components of fish (iodine, selenium, carotenoids, vitamin D, and protein) were examined in < 5 papers in the database during the chosen timescale of this study. Fish protein was only examined in 2 narrative reviews. These reviews suggest more research is needed to examine the effect of the nutrients and components of fish other than n-3 PUFA on human health.

3.5.2 Fish Diet is Preferred over n-3 PUFA Supplements

As mentioned above, n-3 PUFA (mainly EPA and DHA) have been identified as the major nutrients in fish responsible for its beneficial effects on CVD & stroke. This combined with the challenge of incorporating fish into Western diets has led to the availability of a variety of n-3 PUFA supplements on the market today that are promoted to improve for cardiovascular health. However, the evidence on the cardioprotective effect of n-3 PUFA supplements has been inconsistent with some studies and systematic reviews showing no benefit of fish oil / n-3 PUFA supplements on cardiac disease and stroke [124, 125]. These findings have prompted recommendations for fish intake rather than n-3 PUFA supplements, yet the findings of this scoping review indicate that the other components of fish are understudied. It has been noted that the bioavailability and functioning of nutrients from direct food consumption may differ from supplements [14]. Therefore, it is plausible that the beneficial health effects of fish may

contribute to a variety of nutrients such as high-quality protein, vitamin D, and some trace elements (e.g., calcium, iodine, and selenium) in combination with n-3 PUFA. Further studies are needed to investigate the interactions between n-3 PUFA and other nutrients of fish despite the challenge of performing multicomponent randomized controlled trials. Another possible reason for the cardioprotective effect of fish consumption relative to supplements is that adherence to fish consumption may be higher as it is recognized a more challenging intervention and participants in fish consumption studies receive more interventional support [18]. Moreover, increased consumption of fish may be associated with decreased consumption of red meat, which can increase the risk of cardiovascular disease due to high saturated fatty acid and cholesterol content [126-128].

For n-3 PUFA supplements, most of them are in the form of encapsulated fish oils, liquid fish oils, or concentrated supplements, and lipids within those supplements are present as TAG containing around 30% EPA + DHA [16]. N-3 PUFA are highly prone to oxidation due to the great amount of double bonds and the position of double bonds within the fatty acid chain [129, 130]. Although there is no clear evidence on the detrimental effects of oxidized n-3 PUFA on humans, animal studies have shown that oxidized lipids may lead to cancer, inflammation, advanced atherosclerosis and organ damage [131]. Approximately 50% of the tested North America n-3 PUFA supplement products (171 products in total) exceeded the international voluntary safety recommended levels for total oxidation, and another 18% of these tested products approached the limits within 1 to 3 years before expiration [132]. It is possible that the n-3 PUFA supplements used in some clinical trials have been oxidized, which may contribute to the inconsistent findings with n-3 PUFA intervention studies.

3.5.3 Contaminant Concern

While fish intake can be beneficial to human health, fish can also contain potentially hazardous environmental contaminants. Around 24% (mainly narrative reviews) of the included review articles in the original search examined the potential contaminants in fish and the relative adverse health effects from fish consumption. The risk of fish consumption reported so far mainly includes exposure to heavy metal, persistent organic pollutants, pathogenic bacteria, parasites, and biogenic amines [108, 133, 134]. The exposure to those environmental pollutants has been linked to systematic diseases (e.g., cardiovascular, immune, endocrine, renal, and hepatic diseases), food-borne diseases (e.g., scombroid poisoning and parasitic infection), neurodevelopmental toxicity, cancer, and diabetes [21-23, 134].

As toxicity related to fish consumption was found to be a major issue and scoping reviews are an iterative process, an *ad hoc* hypothesis was generated to determine whether the original search terms used in this scoping review study were able to properly capture review studies on toxicity of fish consumption. The *ad Hoc* PubMed search with the additional 'OR toxic*/contaminant' term added to the AND (nutri* OR diet) term search (ie. nutri* OR diet OR toxic* OR contaminant) was conducted and returned 129 new relevant abstracts. Of these 129 abstracts, 115 examined environmental contaminants and other illnesses related to fish consumption and surprisingly, another 14 abstracts were more focused on health benefits of food consumption. The large number of new results generated from *ad Hoc* PubMed search indicates the fact that the original search term was limited to capture review articles on the health benefits of fish consumption but failed to capture review articles on the adverse health effects related to environmental toxicity of fish consumption. It also suggests that understanding the effects of fish

intake on human health requires insights from a dietary and nutritional perspective and a toxicology and food contaminant perspective and that these research field may use different terminologies. Future scoping and systematic reviews in this area should examine more encapturing search terms for both positive and negative health effects of fish intake to provide more comprehensive results on the health effects of fish intake.

Given that many reviews examined contaminants in fish, it was surprising that type of fish and fish processing methods were only examined in a few reviews as they are known to impact the nutritional value of fish [135, 136]. Of the 153 total reviews, 14 papers examined the effect of fish choice on the health benefits of fish consumption. The environmental pollutants content of fish mainly varies by species of fish, and larger predatory fish species, such as shark, swordfish, tilefish, and king mackerel, were found to be the most contaminated fish species [110, 137]. Health Canada advises people to limit the consumption of tuna, swordfish, and shark to 150 g per week except for women who are or may become pregnant and breastfeeding mothers who should limit intake to 150g per month [138]. Furthermore, fatty fish and lean fish have different content of n-3 PUFA and other nutrients, and therefore have different health effects [139, 140]. While fatty fish contain higher level of n-3 fatty acids in their tissues, lean fish were found to contain more iodine than fatty fish [141]. As the health benefits of fish intake are mostly attributed to the amount of n-3 PUFA [127], fatty fish, such as salmon, herring, anchovies, and tuna are recommended over lean fish for better health benefits of fish consumption [142]. Of the 153 total reviews, only 7 papers examined the effect of cooking methods on the health value of fish consumption. It has been suggested that processing methods may alter the vascular benefits of fish consumption [143]. For example, frying may decrease the amounts of n-3 PUFA in fish, which is the main nutrient of fish contributing for its cardiovascular benefits, and therefore

diminish the benefits of n-3 PUFA in fish [143, 144]. Fried fish intake has also been shown to associate with cardiac dysfunction, while broiled and baked fish intake were associated with improved cardiac function [145]. Furthermore, fried fish may generate trans-fatty acids, oxidized lipids, or food mutagens, such as benzo polycyclic aromatic hydrocarbons and heterocyclic amines, which may increase the risk of human cancer [131]. Instead, boiled, grilled, or baked fish are recommended over fried fish for higher nutritional value to achieve the health benefits of fish consumption [135, 146].

3.5.4 Narrative versus Systematic Reviews

Sixty-four percent of the total review articles were narrative reviews and 36% were systematic reviews. The narrative reviews mainly examined the individual nutrients of fish and the common health effects (cardioprotective and neurodevelopmental benefits) of fish consumption by both the general population and minor groups. Narrative reviews are used to broadly assess multiple issues within a given topic, they are comprehensive but potentially biased and not reproducible [147]. The breadth of narrative reviews was evident in this scoping review by the higher percentage of narrative reviews examining the mechanism of action of nutrients, the impact of the type of fish and examining issues between n-3 PUFA supplements versus fish intake. The potential for bias was also evident as the narrative reviews rarely reflected on strengths and weaknesses of the review but were more likely to make recommendations for policy or practice. The systematic reviews had a large focus on adult populations and whole fish on cardiovascular disease and stroke, but a higher percentage of reviews examining cancer, and other clinical outcomes such as autoimmune diseases, obesity, and diabetes than the narrative reviews. Systematic reviews are used to critically synthesize evidence to address a well-defined

question, they are with high validity, low reviewer bias, and reproducible [148]. The focus of the systematic reviews on clinical conditions and the low rates of examining themes such as mechanism of action, the type of fish and supplements versus fish intake reflect this specific design. Surprisingly, despite a design for high validity, low bias and reproducibility, systematic reviews rarely provided recommendations for policy and practice. The contrast between making recommendations in narrative (33% or reviews) versus systematic (6%) reviews is striking and should be examined more extensively. It is possible that narrative reviews are often authored by individuals that are considered experts in the research field whereas systematic reviews are completed by individuals with expertise in systematic reviews and apply these skills to different fields. Overall, it appears that narrative reviews and systematic reviews have different strengths and weakness in summarizing a research field and both should be consulted. Future studies are recommended to try to evaluate and characterize the authors of narrative reviews vs. systematic reviews. Determining metrics such as number of papers authored on the related topic, the H-index, and the number of citations of the author may provide better insight on the perspective and bias of the authors of each type of review.

3.5.5 Strength and Limitations

This scoping review has several strengths. Firstly, this scoping review used thorough a patent method guided by published scoping review protocol throughout the entire research process [32, 117]. The relevance screening form was pretested and revised by two independent reviewers prior to implementation. Each review article was reviewed by both reviewers for inclusion and characterisation. Secondly, to capture as much relative literature as possible, the search strategy included three electronic databases, namely, PubMed, EMBASE, and Cochrane

Library, which are considered to be the most relevant databases for this research topic. In addition, the citation management software (EndNote X9.3.3) was used to ensure that all cited articles were properly accounted for during the study process. Last, but not the least, as review studies included in this analysis were performed in different populations, the findings of this scoping review are therefore generalizable.

Conversely, this scoping review includes some limitations. For this scoping review, only two independent reviewers were involved to determine whether each individual review paper met inclusion criteria, and characterization of the included reviews were subject to reviewer bias. This scoping review may not have collected all relative reviews despite attempts to be as comprehensive as possible. The original search terms were limited to the benefits of fish consumption and found not to be comprehensive enough to capture all the relative review articles as there might be adverse health effects from fish intake due to environmental exposure to undesired substances. Specifically, it appears terms such as diet, nutrition and nutrients are not routinely used by researchers in the contaminants in fish research field and therefore other search strategies should be considered in the future to better examine this area. In addition, possible language bias could exist because the search was conducted using English terms only. Nevertheless, this scoping review included articles published in either English or any languages, to some extent, and articles not published in English were manually translated using Google Translate to attempt to reduce the language bias. As a scoping review of reviews, the results may not necessarily reflect the amount or original research on the topics examined. For example, the searches were repeated with filters for review articles versus original research studies set with the term n-3 PUFA or fish peptide added. The ratio of original articles to review articles was 0.88 for n-3 PUFA and 3.75 for fish peptides suggesting popular topics in the literature are

disproportionally represented in the review literature. Finally, the confirmation steps of a scoping review were not completed as the grey literature was not assessed after identifying the main issues, and relevant shareholders (e.g., dietitians, relative government agency, fish industries, and fish oil supplement companies) were not consulted for additional references and resources about fish intake and health that may have been missed as well as their feedback about the findings uncovered by this scoping review.

3.6 Conclusion

In conclusion, this scoping review of reviews examined the existing published literature about human health and fish consumption. Most of the literature suggested that the benefits of fish consumption outweigh the risks of contaminant exposure even for vulnerable consumer groups. However, this was not consistent across all the literature as estimating the degree of health benefits from fish consumption was variable due to differences in assessing fish intake because of different fish species that are consumed and different fish processing methods. The amount of research on the effect of components of fish other than n-3 PUFA on human health was very limited and suggests that there is a lack of knowledge on the effects and the specific mechanisms of bioactive components of fish other than n-3 PUFA. However, despite the lack of supporting evidence for the other components of fish providing benefits, recommendations about fish consumption tended to be preferred over n-3 PUFA specific recommendations. At this time, there does not appear to be a need to publish more review papers on n-3 PUFA in fish unless unique perspective or new studies/data included. Future studies should be designed to investigate the potential contribution of fish protein or peptides, trace elements, and vitamins on human

health along with confounding factors such as fish choice, processing methods and human adherence to dietary recommendations should be taken into consideration.

Chapter 4

Global Fish Consumption and Diversity of Commercial Fish Species, and An Examination of Nutrient Composition of Fish in North American Databases

4.1 Rationale and Objectives

Fish consumption has been promoted to improve human health and reduce the risk of chronic disease. With the rapid development of online databases for scientific use, assessing fish related information system is getting more efficient and feasible. FAOSTAT database (https://www.fao.org/faostat) by the Food and Agriculture Organization of the United Nations (FAO) provides data from over 245 countries and territories. In 2018, FAO reported that global total fish production (fisheries and aquaculture) had increased by 3.4% from 2017 to 179 million tonnes [2]. Of the 179 million tonnes, 87% of the total fish production was used for human consumption, which is equivalent to an annual consumption of around 20.5 kg per capita [2]. The remaining 13% of fish production was used for bait/game fishing and to produce fish oil supplements and fishmeal [2]. Therefore global fish consumption has more than doubled in the past 5 decades from 72 million tonnes in the late eighties to 156 million tonnes in 2018 [2]. China had both the highest amount of fish production (around 63 million tonnes) and fish consumption (around 55 million tonnes), while populations in North America only consumed 8.1 million tonnes in 2017 [2]. The per capita food fish consumption of China and North America are 38.2 kg and 22.4 kg, respectively. Although FAO has published detailed data on the fish production and consumption of each specific region or country, it remains unknown if the fish production of across all the G20 (Group of Twenty, an intergovernmental organization consisting of 19 countries : Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia,

Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States, and the European Union) surpasses their consumption.

In addition, to the FAOSTAT database, there are other online resources available for information about fish. FishBase (https://www.fishbase.se), a global species information system of fish species, is the largest electronic fish database on the web, which provides fish species data including information on the biology of fish, fish uses, and global fish species diversity, and multiple fish accessing tools such as Nutrient Analysis Tool [149]. The Canadian Nutrient File (CNF) is a national food composition database that provides generic nutrient profile data of foods including fish available in Canada [150]. However, a considerable amount of the data in CNF are derived from the more comprehensive United States Department of Agriculture (USDA) National Nutrient Database for Standard Reference [151]. The USDA National Nutrient Database for Standard Reference (https://fdc.nal.usda.gov) is the national food composition database of the United States, it is the vital foundation of most food composition databases [152]. Nutrition researchers usually assume CNF and USDA National Nutrient Database being comprehensive regards to provide the nutrient profile of food, but the difference of the nutrient data of food fish consumed in north America recorded in CNF or USDA Nutrient Database (FoodData Central) remains unclear. We are unaware of reports that have crosschecked data from CNF, USDA, FishBase and FAOSTAT.

The ***objectives*** of this study are to: 1) assess fish production and consumption pattern of the world and G20 members through FAOSTAT database, 2) evaluate the diversity of commercial fish species of the G20 countries and provinces and territories of Canada through FishBase, 3) check the fish species in the CNF and USDA nutrient databases versus the species

listed for Canada in FishBase, and 4) compare the nutrient data of commonly consumed fishes reported in CNF, USDA Food Composition Database, and FishBase.

4.2 Hypotheses

1. The fish production of G20 exceeds their fish consumption.

2. Fish species consumed in North America as indicated by FishBase database will be found in the CNF and USDA databases.

3. FishBase, CNF and USDA databases have similar nutrient data for similar food fishes.

4.3 Methods, Materials and Study Design

4.3.1 FAOSTAT Database Searching Method

Food Balances (2010-) of FAOSTAT database were searched to generate report on fish production and consumption globally and of the G20 by country, region, and special group. Search year was set to 2019 for most up to date results. (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, the United States, and the European Union) Value of "Fish, Seafood" under "Production Quantity", "Food", and "Food supply quantity (kg/capita/yr)" were collected and imported into Microsoft Excel for coding. See the flowchart of FAOSTAT database searching method for the step-by-step procedures of the data collection (**Figure 7**).

4.3.2 FishBase Searching Method

Under “Information by Country / Island” section in FishBase, the nineteen individual G20 countries and 13 provinces and territories (Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Prince Edward Island, Quebec, and Saskatchewan) of Canada were selected individually to access detailed information on available commercial fish species and the total amount of them. The European Union was not a searchable single group, and the 27 individual countries were not examined for this exercise. See the flowchart of FishBase database searching method for the step-by-step procedures of the data collection (**Figure 8**).

“Species Nutrient Search Tool” under “Tools” section in FishBase was searched by the scientific name of chosen fish (Salmon: *Oncorhynchus gorbuscha, Oncorhynchus keta, Oncorhynchus kisutch, Oncorhynchus nerka,* and *Oncorhynchus tshawytscha*; Tuna: *Thunnus albacares,Thunnus thynnus (L.)*, and *Euthynnus pelamis (L.)*; Cod: *Gadus macrocephalus*, and *Gadus morhua*; Herring: *Clupea harengus*, and *Clupea pallasii pallasii*; and Sardine: *Sardinops sagax*) to access predicted nutrient values for calcium, iron, selenium, zinc, vitamin A, and total n-3 PUFA. Those nutrient values were collected and imported into Microsoft Excel for database comparison.

4.3.3 CNF Database Searching Method

The CNF database can be accessed through an online web portal and/or by downloading database as either CSV, EXCEL or ACCESS files. As for access by the online search, “fish” was the “Food name” searched in food search section of CNF. The searching results from whole fish

were counted for the diversity of food fish species supplied in Canada, and the nutrient profiles of the chosen fish (Salmon: *Oncorhynchus gorbuscha, Oncorhynchus keta, Oncorhynchus kisutch, Oncorhynchus nerka,* and *Oncorhynchus tshawytscha*; Tuna: *Thunnus albacares,Thunnus thynnus (L.)*, and *Euthynnus pelamis (L.)*; Cod: *Gadus macrocephalus*, and *Gadus morhua*; Herring: *Clupea harengus*, and *Clupea pallasii pallasii*; and Sardine: *Sardinops sagax*) in 100 grams of edible portion were generated, collected, and imported into Microsoft Excel for species comparison. For access by the offline search, food group code (#15) representing "Finfish and Shellfish Products" was used to search the downloaded Excel files together with manual checks to generate results on consumed fish species in Canada.

4.3.4 USDA Nutrient Database (FoodData Central) Searching Method

The USDA nutrient database can be accessed through the FoodData Central online web portal and/or by downloading database as either CSV or JSON files. For access by the online search, "fish" was searched in food search section of FoodData Central, and results from whole fish were counted for the diversity of food fish species in America. The nutrient profile in 100 grams of edible portion of selected fish (Salmon: *Oncorhynchus gorbuscha, Oncorhynchus keta, Oncorhynchus kisutch, Oncorhynchus nerka,* and *Oncorhynchus tshawytscha*; Tuna: *Thunnus albacares, Thunnus thynnus (L.)*, and *Euthynnus pelamis (L.)*; Cod: *Gadus macrocephalus*, and *Gadus morhua*; Herring: *Clupea harengus*, and *Clupea pallasii pallasii*; and Sardine: *Sardinops sagax*) were then generated, collected, and imported into Microsoft Excel for species comparison. For access by the offline search, food group code (#15) representing "Finfish and Shellfish Products" were searched for in the downloaded CSV files together with manual checks using Excel to generate results on consumed fish species in America.

4.3.5 Databases Comparison

The scientific name of fishes from the CNF, USDA and FishBase databases were collected and imported into Microsoft Excel to determine the fish species common across the databases and fish species unique to each database. After assessing the comparison of the fish diversity among databases, the comparison of nutrient value of the top five fishes consumed in Canada (salmon, tuna, cod, herring, and sardine) [153] were examined. The nutrient contents from individual species for each type of fish (ie. yellowfin, bluefin, and skipjack tuna) were collected and imported into Microsoft Excel and then averaged for database comparisons. While CNF and the USDA provided relatively comprehensive nutrient content of fish, FishBase only presented seven nutrients (calcium, iron, selenium, zinc, vitamin A, and total n-3 PUFA) using predictive modelling [154]. Therefore, the seven major nutrient contents of fish were chosen for comparison across databases.

4.4 Results

4.4.1 Fish Production and Consumption of the World and G20 Members

Global fish production (171.09 million tonnes) was higher than global food fish consumption (152.36 million tonnes). However, G20 members had slightly lower fish production (118.91 million tonnes) than their fish consumption (120.09 million tonnes). Among the G20 producing more than 5 million tonnes fishes, China had the highest fish production of 63.36 million tonnes followed by Indonesia, India, European Union, United States, Russia, and Japan with productions above 2 million (see **Figure 9** for details). Fish production of the remaining 13 countries were less than 2 million tonnes per country with Saudi Arabia having the lowest (0.12

million tonnes). As for fish consumption, China had the highest amount of 56.41 million tonnes followed by Indonesia, European Union, India, United States, Japan, and South Korea with consumptions above 2 million tonnes (**Figure 9**). Fish consumption of the remaining 12 countries were less than 2 million tonnes with Saudi Arabia having the lowest (0.38 million tonnes). Canada had a production of 1.03 million tonnes and a consumption of 0.82 million tonnes. Eleven G20 members including the European Union, the United States, Japan, South Korea, Brazil, the United Kingdom, France, Italy, Germany, Australia, and Saudi Arabia had fish consumptions that exceeded fish productions. When fish consumption was expressed as per capita (kg/year), Asian countries including South Korea (57.05), Japan (46.06), Indonesia (43.7), and China (38.49) had the highest consumption while Turkey has the lowest consumption by capita (4.77) (**Figure 10**). The United States (22.13) and Canada (21.84) had relatively similar consumptions when expressed per capita.

4.4.2 Commercial Fish Diversity of G20 Countries and Provinces of Canada

The number of commercial fish species present in each of the nineteen G20 countries (excluding the European Union) as determined using FishBase is shown in **Figure 11**. Indonesia had the highest number of commercial fish species (690), which is more than two-fold of the number of commercial fish species in India (above 250) and three-fold of the number of commercial fish species in Australia (above 210). The number of commercial fish species available in six G20 countries ranged from 200 to 100 in descending order: Brazil, Japan, Mexico, United States, South Africa, and Canada **(Figure 11**). The remaining 10 out of 19 G20 countries had no more than 100 species of commercial fish with Saudi Arabia having the poorest

diversity of commercial fish (below 10 species). Note that China fell in this group of countries with relatively low diversity of commercial fish species (92 species).

Within Canada, the number of commercial fish species present in the thirteen provinces and territories (112 species in total) ranged from 75 in British Columbia to 16 in Prince Edward Island **(Figure 12)**. Quebec was found to be the province with the second highest commercial fish diversity (just under 50 species) followed by New Brunswick, Ontario, Newfoundland and Labrador, Nova Scotia, and Yukon (all above 30 species). Manitoba, Northwest Territories and Nunavut all had 30 commercial fish species while Alberta and Saskatchewan had 24 commercial fish species**.**

4.4.3 Fish in the CNF and USDA versus FishBase (in Canada)

There was some diversity across fish species consumed in North America by the CNF, and USDA databases whereas FishBase was comprehensive. The total number of fish species reported by CNF and USDA were 86 (**Table 6)** with CNF having more fish species **(**83) than USDA (79). Of the reported fish species, 77 were common to both databases, while 6 species were unique to CNF, and 2 species were unique to USDA. All the fish species reported by CNF and USDA were identified as being in Canada by FishBase, whereas FishBase had more species identified. The total number of fish species present in Canada reported by FishBase was 1103, with 112 of them being commercial fish.

4.4.4 Nutrient Content of Top5 Consumed Fishes in CNF, FoodData Central, and FishBase

The seven major nutrient contents of the top 5 consumed fishes (salmon, tuna, cod, herring, and sardine) among Canadians from CNF, USDA's FoodData Central, and FishBase are

shown in **Table 7**. For each type of fish, the nutrient contents from individual species were averaged. The seven major nutrient contents of each individual species (5 salmons, 3 tunas, 2 cods, 2 herrings, and 1 sardine) from CNF, the USDA, and FishBase can be found in **Appendix 2**.

In general, the FishBase nutrient estimates varied from the CNF and USDA databases the most (**Table 7**). For calcium, FishBase estimates were higher for salmon (44 mg/100g vs 24.2 mg/100g in CNF & 13.0 mg/100g in USDA), tuna (89.0 vs 13.7 mg/100g), and herring (97.8 vs 70 mg/100g), and lower for sardine (184 vs 240 mg/100g), but close to the CNF and USDA estimates for cod (15.9 vs 12.0 mg/100g). For iron, the FishBase estimate for tuna (2.9 mg/100g) was two times higher than CNF and USDA (1.0 mg/100g), but relatively similar to these databases for the other species. For selenium, FishBase estimates were higher for salmon and tuna and lower for cod and herring, but close to the CNF and USDA estimates for sardine. For zinc and protein, FishBase estimates were similar to the CNF and USDA estimates among all analyzed fishes. For vitamin A, FishBase estimates were lower for salmon, tuna, and sardine, but similar for cod and herring. For total n-3 PUFA, FishBase estimates were higher for salmon and cod and lower for sardine, but close to the CNF and USDA estimates for tuna and herring.

The CNF estimates of the 7 major nutrients were relatively consistent with the USDA estimates of most fishes, but there were some exceptions. The average calcium content of salmon in CNF (24.2 mg/100g) was higher compared with the USDA (13.0 mg/100g) due to the higher CNF value of pink salmon: *Oncorhynchus gorbuscha* (29.0 mg/100g) and chum salmon: *Oncorhynchus keta* (44.0 mg/ 100g) (**Table 7 & Appendix 2**). The average contents of calcium of other fish species were the same in CNF and USDA's FoodData Central. The average content

total n-3 PUFA of salmon in CNF (1.5 g/100g) was higher compared with the USDA's FoodData Central (1.1g /100g) due to differences between the CNF estimate (1.6 g/100g) and USDA estimate (0.6 g/100g) of pink salmon, *Oncorhynchus gorbuscha* (**Table 7 & Appendix 2**). There were slight differences between estimates for herring and sardine, with CNF estimates again being slightly higher that the USDA estimates, while the estimates for tuna and cod and tuna were similar **(Table 6)**. For iron, selenium, zinc, vitamin A, and protein, the CNF versus USDA estimates were the same for all the species except for minor differences in the salmon content of zinc (0.5 vs. 0.4 mg/100g) and vitamin A (63 vs. 61.2 μg/100g), respectively **(Table 7**).

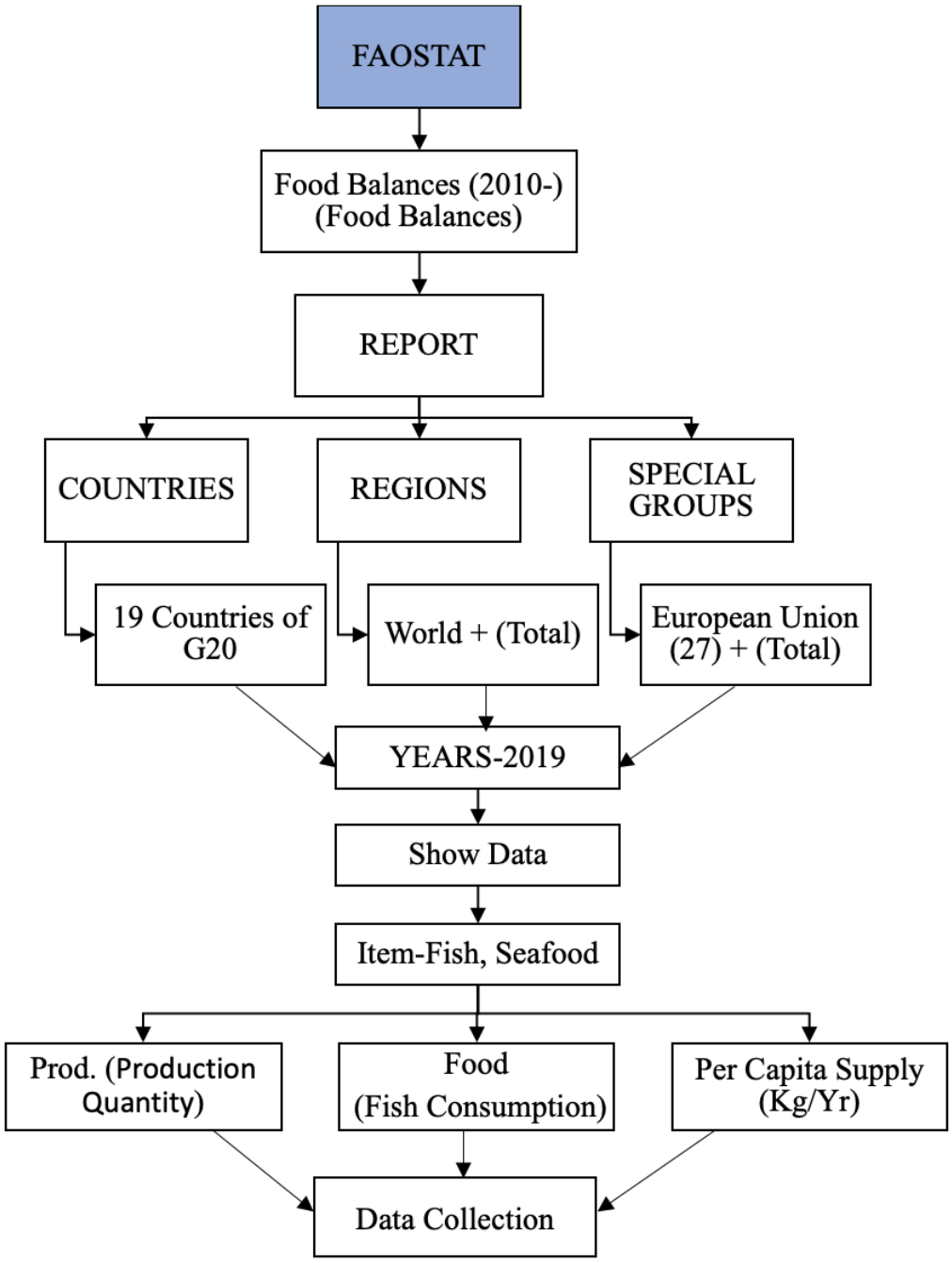


Figure 7. Flowchart of FAOSTAT database searching method. G20 includes 19 countries **(**Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States) and European Union.

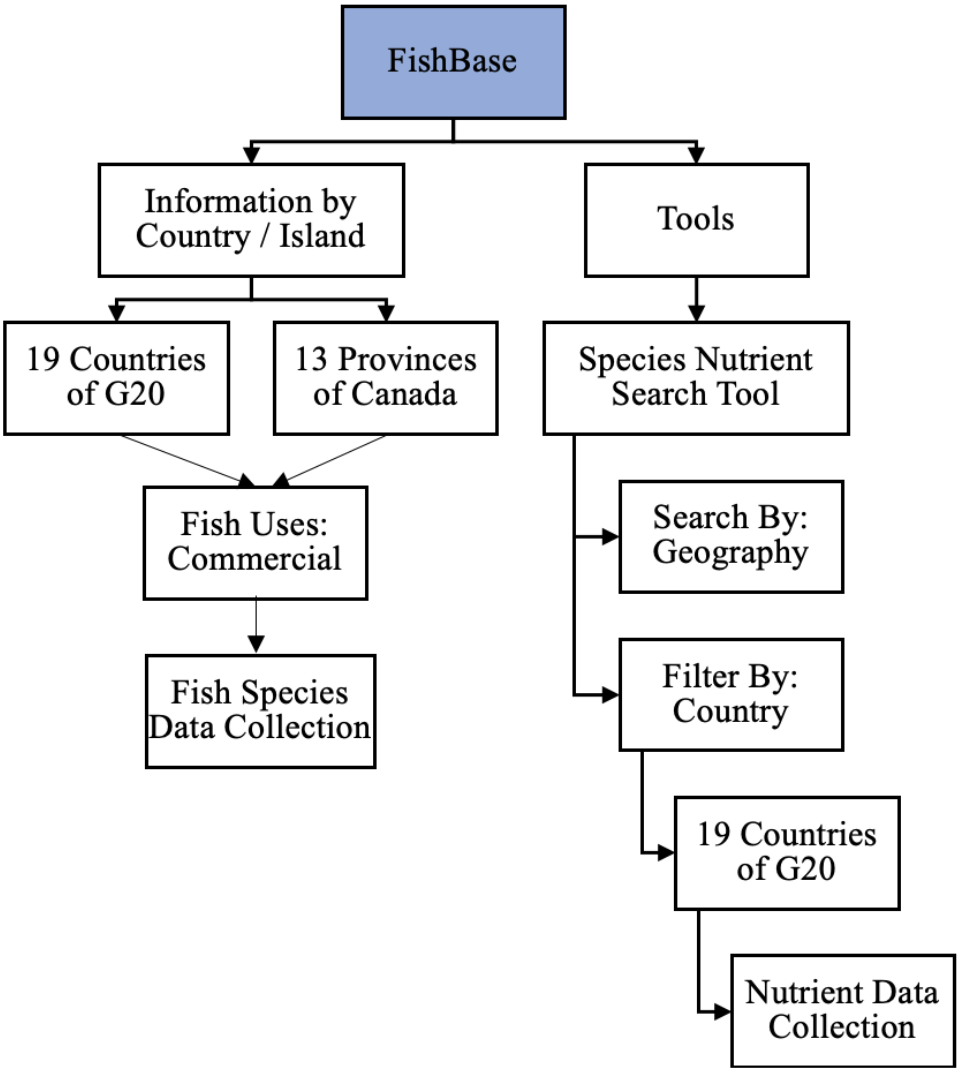


Figure 8. Flowchart of FishBase database searching method. 19 Countries of G20 includes: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States. European Union is excluded due to unavailable accessibility.

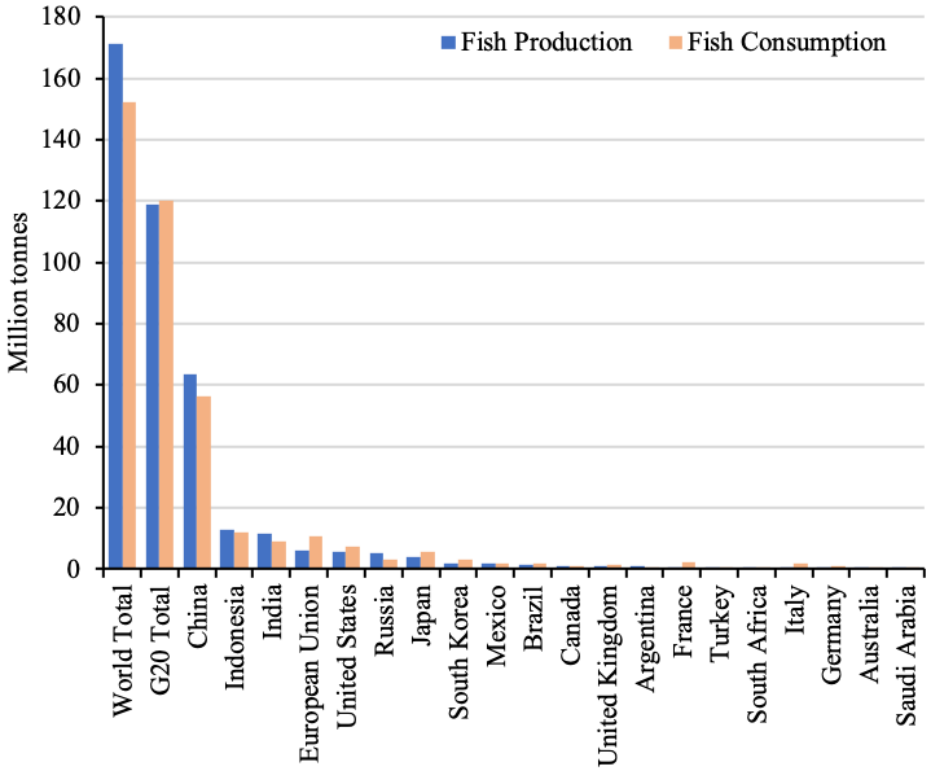


Figure 9. Fish production and consumption (in million tonnes) of the world and G20 in year 2019 [155].

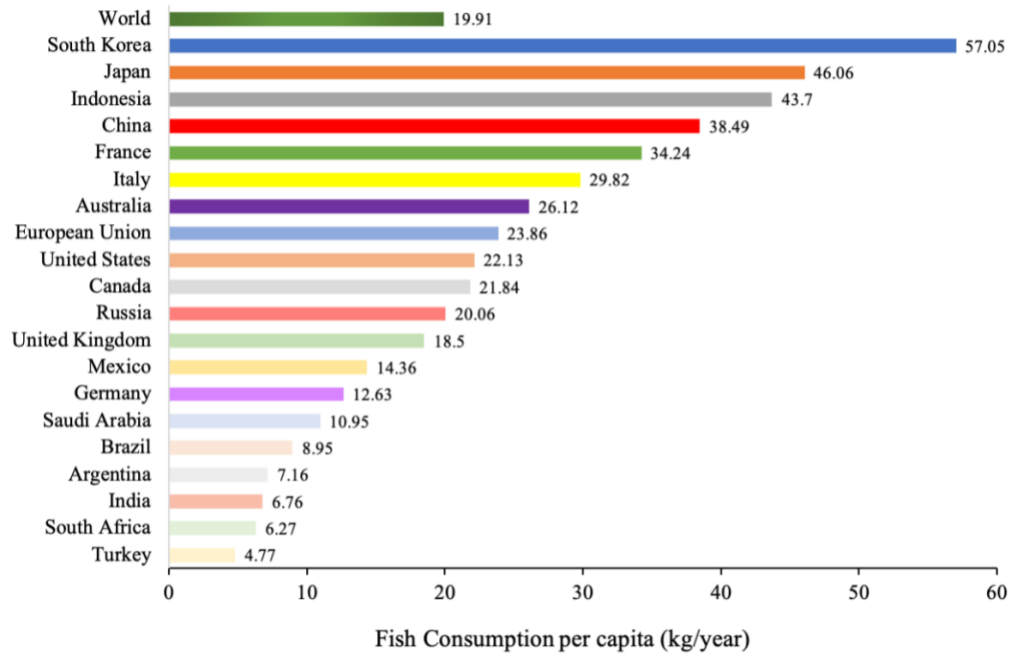


Figure 10. Fish consumption per capita (kg/year) of the world and G20 countries in year 2019 [155].

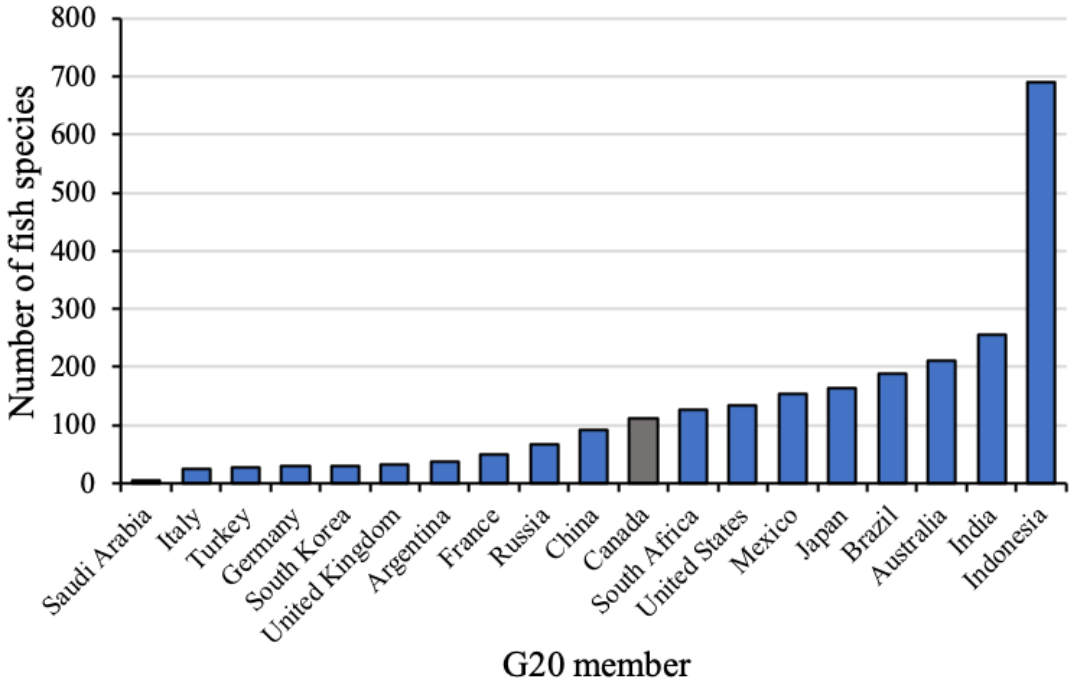


Figure 11. Number of commercial fish species present in G20 members

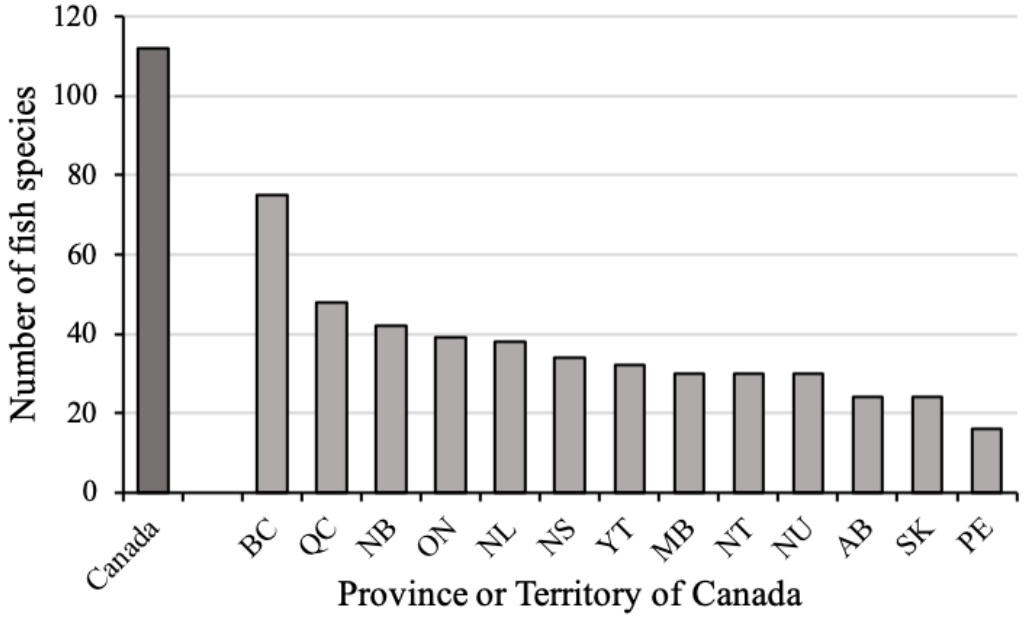


Figure 12. Number of commercial fish species present in Canada's provinces and territories

BC, British Columbia; QC, Quebec; NB, New Brunswick; ON, Ontario; NL, Newfoundland and Labrador; NS, Nova Scotia; YT, Yukon; MB: Manitoba; NT, Northwest Territories; NU, Nunavut; AB, Alberta; SK, Saskatchewan; and PE: Prince Edward Island.

Table 6. Fish in CNF and USDA

Common name	Scientific name	Common name	Scientific name	Common name	Scientific name
Common species (77)					
Sturgeon*	*Acipenser spp.*	Atlantic and Pacific halibut	*Hippoglossus hippoglossus L. and H. stenolepis Schmidt*	Atlantic pollock	*Pollachius virens L.*
American shad	*Alosa sapidissima*	Orange roughy	*Hoplostethus atlanticus*	Bluefish	*Pomatomus saltatrix L.*
Atlantic wolffish	*Anarhichas lupus L.*	Channel catfish	*Ictalurus punctatus*	Greenland halibut	*Reinhardtius hippoglossoides*
Eel*	*Anguilla spp.*	Spot	*Leiostomus xanthuras Lacepede*	Rainbow trout	*Salmo gairdneri Richardson*
Sablefish	*Anoplopoma fimbria*	Pumpkin seed sunfish	*Lepomis gibbosus L.*	Atlantic salmon	*Salmo salar L.*
Drum	*Aplodinotus grunniens Rafinesque*	Monkfish	*Lophius piscatorius L.*	Trout*	*Salmonidae*
Sheepshead	*Archosargus probatocephalus*	Tilefish	*Lopholatilus chamaeleonticeps Goode and Bean*	Brook trout	*Salvelinus fontinalis*
Flatfish (flounder and sole species)	*Bothidae and Pleuronectidae*	Burbot	*Lota lota L.*	Pacific Sardine	*Sardinops sagax*
Cusk	*Brosme brosme*	Snapper*	*Lutjanidae*	Atlantic mackerel	*Scomber scombrus L.*
White sucker	*Catostomus commersoni*	Ocean pout	*Macrozoarces americanus Schneider*	Pacific and jack mackerel*	*Scomber spp. and Trachurus spp.*
Sea bass*	*Centropristes striata L. and Lateolabrax japonicus*	Haddock	*Melanogrammus aeglefinus L.*	King mackerel	*Scombermorus cavalla*
Milkfish	*Chanos chanos*	Atlantic croaker	*Micropogonias undulatus L.*	Spanish mackerel	*Scombermorus maculatus*
Atlantic herring	*Clupea harengus harengus L.*	Ling	*Molva molva L.*	European turbot	*Scophthalmus maximus L.*
Pacific herring	*Clupea harengus pallasi Valenciennes*	Perch*	*Morone americana Gmelin and Perca flavescens*	Atlantic Ocean perch	*Sebastes marinus L.*
Cisco	*Coregonus artedi Lesueur*	Striped bass	*Morone saxatilis*	Pacific rockfish*	*Sebastes spp.*
Whitefish*	*Coregonus spp.*	Striped mullet	*Mugil cephalus L.*	Yellowtail*	*Seriola spp.*
Mahimahi	*Coryphaena hippurus L.*	Devilfish	*Myoxocephalus*	Shark*	*Squaliformes*
Seatrout*	*Cynoscion spp.*	Pink salmon	*Oncorhynchus gorbuscha*	Scup	*Stenotomus chrysops L.*
Carp	*Cyprinus carpio L.*	Chum salmon	*Oncorhynchus keta*	Walleye	*Stizostedion vitreum vitreum*
European anchovy	*Engraulis encrasicholus L.*	Coho salmon	*Oncorhynchus kisutch*	Pollock	*Theragra chalcogramma*
Grouper*	*Epinephelus spp.*	Sockeye salmon	*Oncorhynchus nerka*	Yellowfin tuna	*Thunnus albacares*
Northern pike	*Esox lucius L.*	Chinook salmon	*Oncorhynchus tshawytscha*	Bluefin tuna	*Thunnus thynnus L.*
Skipjack tuna	*Euthynnus pelamis L.*	Lingcod	*Ophiodon elongatus Girard*	Florida pompano	*Trachinotus carolinus L.*
Whiting*	*Gadidae*	Rainbow smelt	*Osmerus mordax*	Swordfish	*Xiphias gladius L.*
Pacific cod	*Gadus macrocephalus Tilesius*	Butterfish	*Peprilus triacanthus*	Tilapia	
Atlantic cod	*Gadus morhua L.*	Fresh water bass*	*Percichthyidae and Centrarchidae*		
Species unique to CNF (7)					
Sculpin	*Acanthocottus groenlandicus*	Goldeye	*Hiodon alosoides*	Arctic char	*Salvelinus alpinus (naresi)*
Sauger	*Sander canadensis*	Inconnu	*Stenodus leucichthys*	Pollock	*Theragra chalcogramma (Pallas)*
Grayling	*Thymallus arcticus*				
Species unique to USDA (2)					
Blackfish	*Dallia pectoralis*	Sheefish	*Stenodus nelma*		

*Indicates mixed species.

Table 7. Seven major nutrients data of top 5 consumed fishes from CNF, USDA, and FishBase

Fish Name	Database	Calcium (mg/100g)	Iron (mg/100g)	Selenium (µg/100g)	Zinc (mg/100g)	Vitamin A (µg/100g)	Total n-3 PUFA (g/100g)	Protein (g/100g)
Salmon	CNF	24.2	0.5	29.5	0.5	63.0	1.5	21.2
	USDA	13.0	0.4	29.4	0.4	61.2	1.1	20.8
	FishBase	44.0	0.8	245.0	0.7	13.0	2.1	18.8
Tuna	CNF	13.7	1.0	54.5	0.6	229.7	0.6	23.2
	USDA	13.7	1.0	54.5	0.6	229.7	0.6	23.2
	FishBase	89.0	2.9	101.2	0.9	40.7	0.5	22.8
Cod	CNF	12.0	0.3	28.0	0.4	7.0	0.2	16.6
	USDA	12.0	0.3	28.0	0.4	7.0	0.2	16.6
	FishBase	15.9	0.2	16.4	0.45	8.5	0.8	16.3
Herring	CNF	70.0	1.1	36.8	0.8	30.0	1.8	17.2
	USDA	70.0	1.1	36.8	0.8	30.0	1.7	17.2
	FishBase	97.8	0.7	15.0	1.3	26.2	2.0	17.2
Sardine	CNF	240.0	2.3	40.6	1.4	32.0	1.7	20.9
	USDA	240.0	2.3	40.6	1.4	32.0	1.5	20.9
	FishBase	184.0	2.5	46.3	1.7	11.6	0.8	20.9

N-3 PUFA, omega-3 polyunsaturated fatty acids; CNF, Canadian Nutrient File; USDA, United States Department of Agriculture.

4.5 Discussion

Fish is the major source of high-quality and affordable protein for billions of people worldwide, it accounted for 17% of the animal protein consumed by the global population in 2017 [2]. In total, fish supplied over 3.3 billion people worldwide with 20% of their average per capita consumption of animal proteins [2]. In this chapter, the fish production and consumption pattern of the world and G20 members were assessed through FAOSTAT database, and the diversity of commercial fish species of the nineteen G20 countries (excluding the European Union) and provinces and territories of Canada were determined through FishBase, then the food fish species in the CNF and USDA nutrient database versus the species reported to in Canada by FishBase were compared. Lastly, the nutrient data of commonly consumed fishes reported in CNF, USDA Food Composition Database, and FishBase were compared for assessing database differences.

4.5.1 Fish Production of G20 Exceeds Their Consumption?

The G20, an intergovernmental forum, gathered together the major economies of the world that more than 60% of the world's population, 75% of global trade and 80% of the global GDP are contributed by G20 members [156]. Without any surprise, G20 members remained their leading role on fish production and consumption which accounted for 70% of the global fish production and 79% of the global fish consumption, respectively (**Figure 9)**. Although global fish production exceeded the consumption, the fish production of G20 members (118.91 million tonnes) did not satisfy their fish consumption (120.09 million tonnes). As such, the first hypothesis that the fish production of G20 would exceed their fish consumption, was rejected.

As shown in **Figure 9**, nine countries of G20 achieved higher fish production than consumption, and they included China, Indonesia, India, Russia, Mexico, Canada, Argentina, Turkey, and South Africa. Of those countries, China's fish production of 63.36 million tonnes was more fish than the rest of the G20 combined. This finding agrees with the FAO report indicating that China is the main fish producer as well as the major fish exporter since 2002 [2]. Surprisingly China was ranked as only the ninth country of the G20 for diverse commercial fish species (**Figure 11**), despite being the world's largest fish producer. Unlike North America, Europe, and Africa regions whose fish production are mainly based on capture fisheries, China's fish production is mainly through aquaculture (76.5% of total fish production) rather than capture fisheries (33.5% of total fish production) [2]. China is also the largest fish consumer which consumed 56.41 million tonnes of fish in 2019 as China is the most populated country in the world with 1.41 billion population and a relatively high per capita consumption (38.49 kg/yr), which justifies the investment in aquaculture to meet the large market demand [157, 158].

For the fish consumption as per capita (kg/year), Asian countries including South Korea (57.05), Japan (46.06), Indonesia (43.7), and China (38.49) had the highest consumption (**Figure 10**). The demand for fish in Asia has resulted in the expansion of aquaculture in Asia to produce farmed fish in vast volumes that has resulted in lower prices for fish, which has made food fish more accessible especially to consumers with low income [159]. The United States and Canada had relatively similar consumptions as per capita (22.13 and 21.84, respectively) that were close to the global average (19.91). This finding agrees with previous research on the per capita fish consumption by region in 2015, which indicated that fish consumption North America was similar with the global average [160]. South Africa and Turkey had the lowest consumption by capita 6.27 kg/year and 4.77 kg/year, respectively. The low per capita fish consumption of South

Africa might be caused by the limited fisheries and aquaculture and a high price for fish along with lower prices for other animal proteins [161, 162]. In Turkey, the lowest per capita fish consumption as red meat is the major component of the Turkish diet and most Turkish consumers were found to eat fish only in the winter months rather than evenly across the year [34].

4.5.2 Global and Canada Provincial Diversity of Commercial Fish

Indonesia, India, and Australia had the highest number of commercial fish species (above 200) among G20 countries. These countries share the same marine area that has been recognized with an extremely high marine biodiversity due to the rich amount of natural marine resources [163-165]. Industrialisation and the state of the commercial fish industry appear to influence commercial species diversity. In contrast to the large number of commercial species available in Indonesia, six G20 countries ranged from 200 to 100 species and the remaining 10 out of 19 G20 countries had no more than 100 species of commercial fish. Indonesia fisheries are largely capture based for local consumption with very little exports [2]. In contrast, European countries had relatively low diversity of commercial fish species. European countries tend to export fish [2] and therefore focus on a select few species. In addition, there are large areas of persistent oxygen depletion in European Seas such as the Baltic Sea and Black Sea, which limited the habitat to many marine species and therefore could led to the low marine diversity [166-168]. China had a relatively low diversity of commercial species due to a large aquaculture industry as mentioned above. South Korea, which had the highest per capita intake (57.05 kg/yr) had one of the lowest numbers of commercial fish species which appears to related to a large dependency on fish imports to compensate for production shortfalls [169]. Saudi Arabia had the poorest

diversity of commercial fish (below 10 species), due to the low fish intake per capita and because of the small volume of water bodies available in the Arabian region, which barely provides freshwater habitats for fishes and therefore severely limits their fish diversity [170].

Canada has one of the world's largest freshwater habitats, accounting for 60% of the world's freshwater lakes and 26% of the fresh water on the surface of Earth [171, 172]. It had 112 commercial fish species and was ranked as the ninth country with the most diverse commercial fish species. Among the thirteen provinces and territories of Canada, British Columbia, on the Pacific coast had the highest commercial fish diversity (75 species) followed by Quebec with approximately 50 species. Southern parts of Canada have rich fish species biodiversity due to the relatively warmer regional temperatures [173]. Prince Edward Island was an exception of southern regions of Canada with rich fish diversity, as it had the lowest diversity of fish species (16 species). However, this is largely due to the small size of Prince Edward Island as it has a small and relatively homogeneous habitat as compared with the larger regions [174]. Previous findings reported by a case study of Char Lake that northern regions of the Canada had poor fish species biodiversity because of the low temperatures and low nutrient loadings [175] which was supported by low commercial species reports for Yukon, Manitoba, Northwest Territories, Nunavut ,Alberta and Saskatchewan.

4.5.3 CNF vs. USDA vs. FishBase Diversity and Nutrient Comparisons

The CNF, USDA and FishBase databases are all freely available online, therefore, it is of great interest to investigate the types of fish in the database and to compare the nutrient estimates. The CNF database is frequently used by healthcare providers (e.g., doctors and dietitians) and scientific researchers to assess nutrient content of food items supplied in Canada

and make public dietary recommendations; however, it relies heavily on the USDA nutrient database among others (see below) [151, 176]. For over 100 years, the USDA Agricultural Research Service has been comprehensively and self-reliantly analyzing food to determine the dietary intakes of Americans and the FoodData Central is a relatively new web-based system for providing access to their database [177]. FishBase is the well-known global information system providing reliable ecological information on fish that has had a high scientific impact [178]. In 2021, the FishBase Nutrient Analysis Tool (more details below) was added to provide predicted values of seven key nutrients (calcium, iron, selenium, zinc, vitamin A, n-3 PUFA, and protein) for both marine and inland fish species. For diversity, FishBase provides a list of the common name and scientific name from various restrictions such as country (Canada in this case) and uses (commercial in this case), whereas the CNF and USDA databases contain fish as various types of food servings. Therefore, for CNF and USDA, eliminating duplicates of species of fish in different food preparations was required. In order to compare the nutrients estimates of the three databases, the top 5 consumed fish in Canada [153] were compared for the seven major nutrients available in FishBase and preference was given to "raw" fish data in CNF and USDA.

All fishes reported in CNF and USDA were found in the FishBase database, but not all commercial fish species in Canada indicated by FishBase were found in the CNF and/or USDA databases. Therefore, the second hypothesis that fish species consumed in North America as indicated by FishBase database would be found in the CNF and USDA databases was rejected. CNF had 6 unique species as compared to the USDA (**Table 6**). Two of these had data from Canadian labs (Sauger and Goldeye) and the others were from the scientific literature. Two fish in the USDA were not found in the CNF. This finding agrees with a previous report that indicated that the CNF uses different data source but has a high reliance on the USDA nutrient

database although updates by CNF are not always complete and can be infrequent [179]. Therefore, the CNF database may not reflect the nutrient composition of food fishes produced within Canada as the database appears to be dependent on data generated from fish from other regions of the world.

As it was expected, the FishBase nutrient estimates varied from the CNF and USDA databases the most (**Table 7**). Surprisingly, FishBase estimates on the content of iron, zinc, and protein were relatively close to CNF and USDA estimates of the top 5 fish consumed in Canada. There were however discrepancies for the calcium, selenium, vitamin A, and total N-3 PUFA estimates as compared with the CNF and USDA estimates which is not surprising given that they were generated by a novel predictive modelling by the FishBase Nutrient Analysis Tool. The FishBase Nutrient Analysis Tool uses a Bayesian hierarchical statistical model that includes both the phylogenetic information (interrelatedness of fish species) and trait-based information (fish diet, energetic demand, and thermal regime) [154]. These predictions were based on information from no more than 10% of fish species to estimate the nutrient content of the remaining 90% plus species, which may provide either reasonable or bad estimates for fishes [154]. Therefore, the predicted nutrient data in FishBase need to be used with caution.

The CNF estimates of the 7 major nutrients were almost the same with the USDA estimates of most fishes since a large amount of the CNF data were from the USDA. There were some discrepancies between the non-USDA sourced nutrient data in CNF and the USDA data. CNF data may be derived from up to 20 different data sources (**Appendix 3**). For instance, the higher CNF calcium value of pink salmon: *Oncorhynchus gorbuscha* (29.0 mg/100g) and chum salmon: *Oncorhynchus keta* (44.0 mg/ 100g) came from the "Canadian product analyzed by non-

government lab" (**Appendix 2**) [180, 181]. The higher total n-3 PUFA of pink salmon, *Oncorhynchus gorbuscha* by CNF (1.6 g/100g) versus USDA (0.6 g/100g) was calculated from "data other than USDA" (**Appendix 2**) [180]. Due to the uncertainty of predicted nutrient data in FishBase and various data sources of CNF data, the third hypothesis that FishBase, CNF and USDA databases would have similar nutrient data for similar food fishes, was rejected.

4.5.4 Addressing the Limitations

This study had several limitations. Firstly, when collecting the information on the commercial fish diversity of G20 members from FishBase, the European Union was not searchable, and the 27 individual countries were not examined for this exercise due to time limits. Secondly, the fish production and consumption of provinces and territories of Canada were not accessible through FAOSTAT, therefore the diversity of commercial fish species of regions in Canada could not be easily linked to their fish production and consumption. Fisheries and Oceans Canada has open data on the fish production of 6 provinces and fish consumption data expressed as expenditures for financial purposes appear to be available from StatCan upon request, but it is not clear how comparable these estimates are to FAOSTSAT outputs. Additional research appears to be required. Lastly, the comparison of nutrient data of top 5 type of consumed fishes by Canadians reported by different databases is likely a conservative estimate of the variation across the databases, as these are fish that are widely studied and examined due to their commercial implications. Looking at a wider range of fish, especially those consumed less regularly or those consumed in specific regional populations is likely to reveal greater variation across the databases.

4.6 Conclusion

In conclusion, the FAOSTAT database allowed for the comparison of the production and consumption of the G20 members that consumed slightly more fish than they produced, and that fish production was dependent on capture fisheries, except for China that has developed a large aquaculture industry. The FishBase database was able to identify the diversity of commercial fish species for individual countries, but not groups of countries such as the European Union. Fish diversity generally increased in warmer regions and commercial fish diversity was low in regions with low fish consumption and reliance on terrestrial foods, but commercial fish diversity also appeared to decrease with increased industrialization of the fish food supply. These patterns appear to be reflected within Canada but cannot be confirmed without provincial production and consumption information. As for the nutrient databases assessed, the FishBase Nutrient Analysis Tool is an interesting approach for estimating the nutrient content of types of fish but appears to require testing and validation before it could be used for dietary intakes. The CNF and USDA databases did not cover all the commercial fish species listed for Canada in FishBase, but those not covered were generally considered as “minor commercial” or “subsistence fisheries” by FishBase. This suggests that CNF and USDA databases may have limitations for fish species consumed in smaller regions of Canada and populations that rely on local capture rather industrialized fish production for their fish food. This was examined further in Chapter 5.

Chapter 5

Fatty Acid Composition of Wild-Harvested Fish Species from the Canadian Subarctic and Arctic

5.1 Rationale and Objectives

Wild harvested freshwater fish in the Canadian subarctic and Arctic can serve as an important dietary component of country foods to improve nutrition and food security in First Nations communities of the Northwest Territories, Canada [182, 183]. They are significant sources of n-3 PUFA, high-quality protein, and essential micronutrients such as selenium and zinc, and is an important dietary component of many populations including Indigenous populations [184, 185]. Typically, the fish muscle is mainly consumed but Burbot liver is also collected and consumed regularly by Indigenous peoples living in Peel River Kutchin, Circumpolar, Lillooet, and Shuswap. [186, 187].

The intake of fish-derived n- 3 PUFA, mainly eicosapentaenoic acid (20:5n-3, EPA) and docosahexaenoic acid (22:6n-3, DHA), are associated with various health benefits such as maintaining healthy body function, supporting the cardiovascular system, improving cognitive ability, and promoting bone development [4, 188, 189]. Furthermore, n-3 PUFA intake has also been shown to reduce the risk of heart disease, stroke, cancer, psychological disorder, and asthma [8, 59, 190-192]. However, due to the variability of fatty acid compositions between fish species [193, 194], different portions of fish of different fish species are required to achieve certain dietary recommendation goals.

The content of n-3 PUFA in various species of fish which are commonly consumed by the population in the Canadian subarctic and Arctic are not well characterized. The ***objectives*** of this study are to: 1) investigate the fatty acid profiles in wild harvested freshwater fish species commonly captured in the Canadian Arctic and Subarctic for food (eight species), and 2) compare the fatty acid concentration data of these fish to data in the CNF.

5.2 Acknowledgement

The samples analyzed in this Chapter are part of a collaborative effort. Fish samples were collected from the Canadian subarctic and Arctic by the efforts of Tara N. Boag, Mallory Drysdale, Heidi K. Swanson, and Brian D. Laird in collaboration with fishers in First Nations communities of the Northwest Territories, Canada. Dan Chalil assisted in determining the fatty acid composition of the samples by gas chromatography.

5.3 Hypotheses

1. Fatty acid composition (weight %) and concentration (mg/100g) of skeletal muscle in examined fishes will vary between species.

2. DHA and EPA will be the main n-3 PUFA in the eight fish species.

3. These fish species will be found in the CNF database and the fatty acid concentration data determined by my laboratory analyses will be consistent with the data in the CNF.

5.4 Methods, Materials and Study Design

5.4.1 Materials and Chemicals

Skeletal muscle samples of eight species of freshwater fish as: Burbot (*Lota lota*, n = 27), Cisco (*Coregonus artedi*, n = 5), Lake Trout (*Salvelinus namaycush*, n = 9), Lake Whitefish (*Coregonus clupeaformis*, n = 37), Northern Pike (*Esox lucius*, n = 23), Walleye (*Sander vitreus*, n = 26), White Sucker (*Catostomus commersonii*, n = 4) and Longnose Sucker (*Catostomus catostomus*, n = 1), and liver tissue of a subset of the Burbot (n = 21) were collected from the Canadian Subarctic and Arctic in collaboration with local fishers. Chemicals used for this study include hexane and heptane that were purchased from Fisher Scientific, 14% BF3 in Methanol purchased from Sigma-Aldrich, docoasatrienoic (22:3n-3) methyl ester as internal standard purchased from Nu- Chek Prep, and the external standard GLC-462 from Nu-Chek Prep.

5.4.2 Preparation of Fatty Acid Methyl Esters (FAME)

Frozen fish muscle or liver sample were weighted (30-50mg) and homogenized after the addition of 3mL of 3.33g/mL docoasatrienoic (22:3n-3) in 2:1 chloroform: methanol (v/v) internal standard. Then the mixture was vortexed for 1 minute and then 500 μL of 0.2M NaH_2PO_4 buffer was added. Following this, the mixture was capped, inverted twice and then centrifuged at 3000 rpm for 5 minutes. The bottom organic layer containing the lipids was collected and transferred to a 15 mL test tube and dried under a stream of N_2 gas. Next, 1mL of 14% boron trifluoride in methanol and 300 μL of hexane was added to the dried lipid extract, and the mixture was then enclosed with a silicon lined cap. The mixture was transesterified for one hour at 100°C on a block heater [195]. After being allowed to cool to room temperature, 1 mL of

ultra-pure water and 1 mL of hexane were added. Then the mixture was vortexed for 1 minute and centrifuged at 3000 rpm for 5 minutes. The top hexane layer containing the FAME was then collected and dried again under a stream of N_2 gas. Following this, 65 μL of hexane was added and the mixture was vortexed before being transferred to GC vials for analysis by fast-gas chromatography [196].

5.4.3 Gas Chromatography-Flame Ionization Detection (GC-FID)

The isolated FAME containing internal standard was analyzed on a Varian 3900 gas chromatography equipped with nitroterephathalic acid modified polyethylene glycol, capillary column with 15 m length, 0.10 mm i.d., and 0.10 μm film thickness (J and W Scientific from Agilent Technologies, Mississauga, ON) with hydrogen as the carrier gas at a flow rate of 0.5 mL/min. One μL aliquots were introduced by a Varian CP-8400 autosampler into the injector heated to 250°C with a split ratio of 200:1. The initial column temperature was held for 0.25 minute at 150°C followed by a 35°C/min ramp to 200°C. An incline of 8°C/min ramp was followed to reach 225°C with a 3.2 minutes hold and then an 80°C/min ramp to reach 245°C with a 15-minute hold at the end [33]. The flame ionization detector was set to 300°C, air and nitrogen make-up gas flow rates were 300mL/min and 25mL/min, respectively, and the sampling frequency was 50Hz [33]. The FAME was identified by comparing retention times to the external standard mix (GLC-462, Nu-Chek Prep, Elysian, MN, USA).

5.4.4 Statistical Analyses

Results were presented as means ± standard deviation. The differences between mean values of composition (weight %) and concentration (mg/g) of fatty acid of skeletal muscle

samples of all fish species except Longnose sucker (n = 1) were tested by one way analysis of variance (ANOVA) followed by Bonferroni post-hoc multiple comparisons test to evaluate specific differences in the levels of fatty acids after a significant F-value (significance is inferred at $p < 0.05$). Pairs of means corresponding to the fatty acid percentage and concentration in skeletal muscle and liver of Burbot fish was compared by using paired samples t-test (significance is inferred at $p < 0.05$). All statistical analyses were performed using Statistical Package for Social Science (SPSS) version 20 for Windows.

5.4.5 Fatty Acid Profile Comparison with the CNF

Fish names were searched in food search section of CNF. Among the eight fish species examined, the nutrient data of Longnose Sucker was not in the CNF and therefore excluded from the comparison. As for the Lake Trout, there was no information on the Lake Trout species in the CNF, so the nutrient information of mixed trout species was used instead. The search results were limited to native raw fish only and the nutrient profile of 100 grams of edible portion were generated, downloaded, and imported into Microsoft Excel to isolate the fatty acid data. The mean concentration (mg/100g) data of fatty acids in skeletal muscle of all examined fish species except Longnose sucker were then compared with concentration (mg/100g) data of fatty acids in the CNF by visual checks to identify if the fatty acid data looked consistent.

5.5 Results

5.5.1 Fatty Acid Profile of Wild Fish Muscle Samples

Total fat content of the fish muscle ranged from 255 - 2766 mg/100g skeletal muscle and there was significant difference in fat content of all analyzed fish species ($P < 0.05$). Lake Trout

(1231±675 mg/100g) and Lake Whitefish (1166±505 mg/100g) had the highest average amount but White Sucker (977±235 mg/100g) and Cisco (811±180 mg/100g) were statistically similar (**Table 8**). Walleye, Northern Pike and Burbot had significantly lower total fat content (averages ranging from 436 to 655 mg/100g) than Lake Trout and Whitefish but were similar to White Sucker and Cisco. The single Longnose Sucker sample had a total fat content (977mg/100g) that mirrored the White Sucker average.

The wt % of total saturated fatty acids (SFA) was the highest in Cisco (33.5%) and the lowest in Lake Trout (26.1%). Individual SFA varied by species, with palmitic acid (16:0) being the most abundant SFA in all species, whereas tricosanoic acid (23:0) was the least abundant SFA in all species (**Table 9**). The wt % of total MUFA ranged from 8.7% in Cisco to 29.4% in Longnose Sucker. The predominant MUFA was oleic acid (18:1 n-9), ranging from 4.5% in Cisco to 15.1% in Lake Trout (**Table 9**). The proportion of PUFA ranged from 42.0% in Longnose Sucker to 61.2% in Northern Pike. The n-6/n-3 ratio indicated that all the fish had much less n-6 PUFA relative to n-3 PUFA with values ranging from 0.2 (Cisco) to 0.5 (Burbot).

Total fat concentration was largely predictive of DHA, EPA + DHA, and total n-3 PUFA concentrations. Total n-3 PUFA concentrations were the highest in Lake Trout (398 ± 233 mg/100g), Lake Whitefish (389 ± 97 mg/100g) Cisco (382 ± 103 mg/100g) and Whitenose sucker (300 ± 84 mg/100g) and Burbot was the lowest (164 ± 39 mg/100g) (**Table 8**). Walleye (268 ± 84 mg/100g) and Northern Pike (265 ± 62 mg/100g) were intermediary but statistically similar to Cisco. Longnose sucker n-3 PUFA amounts (299 mg/100g) again reflected Whitenose sucker. The muscle of the eight fish species contained high average amounts of n-3 PUFA, ranging from 19 to 54 wt% and including DHA, EPA, and docosapentaenoic acid (DPA, 22:5n-

3) as major components (**Table 9**). DHA was the most abundant n-3 PUFA among all species ranging from 8.3 to 40.2 wt% of total fat followed by EPA varying from 2.4 to 12.0 wt% of total fat and DPA varying from 1.8 to 6.1%. As for the individual n-3 PUFA content, Lake Whitefish had significantly higher concentrations of EPA (80 ± 22 mg/100g) than the other species. Interestingly, Whitenose sucker had the next highest amount of EPA (71 ± 16 mg/100g) that was considerably higher than Longnose Sucker EPA (34 mg/100g). Cisco was the species containing the highest concentration of DHA (263 ± 72 mg/g) but it was similar to levels in Lake Whitefish (227 ± 55 mg/g), Lake Trout (207 ± 124 mg/g) and Northern Pike (185 ± 38 mg/g). Burbot (94 ± 21 mg/100g) had significantly lower DHA than the other species. Longnose sucker (202 mg/100g) appeared to have more DHA than White sucker (156 ± 27 mg/g) (**Table 8**).

5.5.2 Fatty Acid Profile of Skeletal Muscle Versus Liver of Burbot Fish

Total fat identified in the Burbot muscle was 449 ± 106 mg/100g and Burbot liver was 10604 ± 3846 mg/100g and as such the concentration of every fatty acid was significantly higher in liver as compared with muscle **(Table 10)**. The quality of the fat was also different as there were significant differences in the relative weight percentages for 28 of the 33 fatty acids measured (**Table 10**). The largest differences were observed between the proportion of total MUFA and total PUFA. The Burbot liver tissue had over 2 times higher proportion of total MUFA (32.3 ± 5.7 wt%) than muscle (12.7 ± 2.0 wt%), while the Burbot muscle tissue contained higher proportion of total PUFA (58.0 ± 3.4 wt%) than liver (43.7 ± 7.1 wt%). This was largely driven by much higher proportions of 16:1, 18:1n-7 and 18:1n-9 in liver and much higher proportions of 20:4n-6, EPA and DHA in muscle. Interestingly, 18:2n-6, 18:3n-6 and 18:4n-3 were proportionally higher in liver despite the higher total PUFA portion in muscle.

5.5.3 Fatty Acid Concentration of Experimental Results Versus the CNF Records

Among the eight analyzed fish species, seven were found in the CNF database with fatty acid concentration data available. The nutrient profile of Longnose Sucker was absent in CNF. The total fatty acid content recorded in the Canadian Nutrient File were consistently higher than the experimental determinations for all the fish species (**Table 11**) with the experimental values ranging from approximately 19-75% of the CNF values. The discrepancy between CNF vs. analyzed was the highest for Lake Trout (6610 vs. 1231 mg/100g), Cisco (4000 vs. 811 mg/100g) and Lake Whitefish (3800 vs. 1166 mg/100g), followed by White Sucker (2320 vs. 977 mg/100g), Walleye (1220 vs. 655 mg/100g), Burbot (650 vs. 436 mg/100g) and Northern Pike (800 vs. 582 mg/100g) (**Table 11**). In addition to total fat there were several other values that were visibly different between CNF estimates and the experimental determinations. This included the MUFA content of Cisco, Lake Trout and Lake Whitefish being 40, 9.3 and 3.7 times higher by CNF estimates as compared with the experimental determinations, respectively (**Table 11**). The Cisco and Lake Trout also had several other discrepancies between CNF and the analyzed values, with Cisco CNF values being particularly inconsistent. In addition to total MUFA, Cisco and Lake Trout had abnormally high CNF estimates for total saturates, 16:0, and 18:1. Cisco also had peculiar CNF estimate values for total n-6 PUFA (19470 mg/100g) and 20:3n-6 (420 mg/100g) that were 224 and 210 times the analytical determinations, respectively (**Table 11**). Even with the overly high estimate of 20:3n-6, the sum of the individual n-6 PUFA in Cisco was only 670 mg/100g as compared with total n-6 PUFA of 19480 mg/kg that was almost 5 times higher than the CNF estimate for Cisco total fat (4000 mg/kg).

Despite the overestimates in the CNF data there were some agreeable patterns between the CNF estimates and the experimental analyses. Both the CNF estimates and analytical determinations ranked Mixed/Lake Trout as the fish containing the highest amount of total fat and Burbot as the fish containing the lowest amount of total fat among the seven fish species examined. Furthermore, both the CNF and experimental values indicated DHA as the most abundant n-3 PUFA followed by EPA across the fish species. The EPA + DHA content recorded in the CNF were all higher as compared with experimental which would be expected with an overestimation of total fat. The higher CNF estimates of Burbot (166 vs. 137 mg/100g), Cisco (630 vs. 306 mg/100g), Lake Trout (730 vs. 265 mg/100g), Lake Whitefish (500 vs. 306 mg/100g), Northern Pike (273 vs. 227 mg/100g), Walleye (311 vs. 217 mg/100g), and White Sucker (479 vs. 228 mg/100g) ranged between 1.2 – 2.8 times higher than the experimental determinations (**Table 11**). For n-6 PUFA, except for Cisco, the ranking of 20:4n-6 as the most abundant PUFA across the species was consistent and there appeared to be some agreement in the species that had high and low 18:2n-6 content.

Table 8. Fatty acid concentration (mg/100g) of skeletal muscle of eight species of fish from the Canadian Subarctic and Arctic

	Burbot[1] (N=27)	Cisco[2] (N=5)	Lake Trout[3] (N=9)	Lake Whitefish[4] (N=37)	Northern Pike[5] (N=23)	Walleye[6] (N=26)	White Sucker[7] (N=4)	Longnose Sucker (N=1)
12:0	8.44±17.97	18.76±29.52	6.66±7.22	8.77±10.23	1.11±1.67	7.64±11.61	6.02±11.81	0.00
14:0*	1.79±1.08[2,3,4]	18.94±15.52[1,5]	24.24±17.26[1,5,6]	14.36±12.84[1,5,6]	3.21±2.61[2,3,4]	5.81±5.52[3,4]	8.35±5.20[2,3]	7.12
16:0*	77.62±19.19[3,4,6]	155.69±16.57	168.63±68.17[1,5]	217±83.16[1,5,6]	100.72±35.52[3,4]	127.58±43.61[1,4]	163.43±34.81	187.75
17:0*	1.17±0.80[2,3,4,6,7]	5.17±0.76[1]	6.53±4.13[1,5,6]	5.76±3.39[1,5,6]	2.12±1.98[3,4]	3.31±1.54[1,3,4]	6.09±1.91[1]	4.85
18:0*	27.55±6.64[3,4,7]	44.43±4.91	58.63±21.9[1,5,6]	55.11±19.75[1,5,6]	33.54±11.66[3,4]	38.92±9.44[3,4]	55.4±12.94[1]	53.90
20:0*	1.45±0.61[3,4]	2.04±1.44[3,4]	12.23±7.79[1,2,5,6]	10.13±8.85[1,2,5,6]	1.86±1.74[3,4]	1.92±0.99[3,4]	4.10±1.80	4.64
22:0*	1.42±0.83[3,4]	2.04±0.31[3]	4.62±2.71[1,2,5,6]	3.45±1.98[1,5,6]	1.31±0.66[3,4]	1.50±0.69[3,4]	2.43±0.18	1.67
23:0*	0.46±0.28[3]	0.42±0.16	1.94±3.22[1,4,5,6]	0.60±0.45[3]	0.50±0.51[3]	0.67±0.41[3]	1.30±0.77	1.06
24:0*	8.27±3.17[2,3,6]	20.57±4.47[1,5,7]	20.79±18.96[1,4,5,7]	11.92±6.52[3]	8.73±4.76[2,3]	14.37±5.91[1]	3.03±0.25[2,3]	15.53
Total SFA*	**128.18±43.88[2,3,4]**	**268.11±42.47[1]**	**303.98±137.07[1,5]**	**327.19±134.30[1,5,6]**	**153.13±53.20[3,4]**	**201.78±69.81[4]**	**250.19±56.01**	**276.56**
14:1*	0.01±0.02[4]	0.15±0.21	0.48±1.31	0.44±0.61[1]	0.06±0.19	0.38±0.45	0.61±0.46	0.26
16:1*	5.57±3.36[3,4,7]	11.73±8.86[4,7]	68.59±45.98[1,5,6]	73.93±63.74[1,2,5,6]	16.89±35.97[3,4,7]	17.4±18.89[3,4,7]	115.10±49.40[1,2,5,6]	89.35
18:1n-7*	16.27±5.31[3,4,7]	17.17±7.29[4,7]	59.29±30.93[1,5,6]	57.89±37.67[1,2,5,6]	18.10±23.92[3,4,7]	20.18±12.7[3,4,7]	74.33±23.84[1,2,5,6]	78.16
18:1n-9*	31.14±8.34[3,4]	36.94±14.37[3,4]	208.04±153.37[1,2,5,6]	157.30±128.62[1,5,6]	41.40±29.77[3,4]	51.79±35.89[3,4]	93.44±33.37	106.13
20:1n-9*	1.26±0.77[3,4]	0.82±0.37[4]	4.59±3.14[1,5,6]	4.60±3.70[1,2,5,6]	1.26±1.07[3,4]	1.08±0.59[3,4]	2.96±0.95	5.20
22:1n-9*	1.18±0.61[3]	1.14±0.76[3]	3.59±3.40[1,2,4,5,6]	1.30±0.98[3]	0.66±0.39[3]	0.80±0.52[3]	1.90±0.83	1.79
24:1n-9*	1.79±1.84[3]	4.40±2.07	5.42±5.38[1]	3.70±3.33	2.18±1.87	3.06±2.28	1.27±0.36	6.76
Total MUFA*	**57.21±17.74[3,4]**	**72.37±30.30[3,4]**	**350.02±231.25[1,2,5,6]**	**299.17±229.68[1,2,5,6]**	**80.56±87.31[3,4]**	**94.71±68.91[3,4]**	**289.61±107.60**	**287.65**
18:2n-6*	8.71±3.05[3,4]	21.64±14.72	51.03±34.78[1,5,6]	42.09±36.74[1,5,6]	16.07±10.78[3,4]	12.62±10.4[3,4]	37.22±11.05	31.86
18:3n-6*	1.50±0.81[3]	0.71±0.67[3]	5.06±7.14[1,2,5,6]	2.56±1.96	1.04±1.59[3]	0.86±0.57[3]	1.88±0.53	2.51
20:2n-6*	1.67±0.68[3,4]	2.96±2.37	6.83±4.99[1,6]	6.94±5.73[1,5,6]	3.12±1.75[4]	2.18±1.46[3,4]	2.95±0.90	3.95
20:3n-6*	1.74±0.58[3,4,7]	1.61±0.35[3]	7.1±4.66[1,2,4,5,6]	4.19±2.11[1,3,5,6]	1.61±1.27[3,4,7]	1.75±0.91[3,4,7]	5.15±1.6[1,5,6]	3.55
20:4n-6*	58.48±10.95[1,5]	28.84±1.97[1,4,7]	51.27±22.65	63.88±19.08[2,5,6]	44.00±17.39[1,4,7]	46.70±14.57[4]	73.18±14.03[2,5]	56.23
22:2n-6*	1.05±0.84[3]	1.72±1.77[3]	6.08±6.28[1,2,4,5,6,7]	1.82±1.36[3]	1.02±0.85[3]	1.18±1.41[3]	1.48±0.62[3]	1.09
22:4n-6*	2.93±0.80[3,4]	2.58±0.23[3,4]	16.90±9.12[1,2,4,5,6,7]	7.95±4.88[1,2,3,5,6]	2.52±1.08[3,4]	4.22±1.45[3,4]	3.75±0.95[3]	2.88
22:5n-6*	9.76±3.16[2,3,4,6]	26.81±3.60[1,5,7]	32.02±21.55[1,4,5,6,7]	18.32±6.64[1,3]	13.30±2.56[2,3]	19.71±7.87[1,3]	8.83±1.34[2,3]	9.83
Total N-6*	**85.85±15.52[3,4]**	**86.86±19.22[3]**	**176.28±89.99[1,2,5,6]**	**147.75±71.99[1,5,6]**	**82.67±31.23[3,4]**	**89.23±34.49[3,4]**	**134.43±28.60**	**111.90**
18:3n-3*	2.75±1.72[3,4,7]	21.67±9.23	30.71±23.22[1,5,6]	27.59±21.43[1,5,6]	8.31±8.55[3,4]	9.45±8.23[3,4]	26.79±9.51[1]	16.86
18:4n-3*	2.19±1.57[2,3,4]	10.90±6.84[1,5]	11.64±10.25[1,5,6]	7.82±6.85[1,5,6]	2.52±1.3[2,3,4]	3.78±3.04[3,4]	4.25±1.43	3.14
20:3n-3*	1.77±1.12[4,6]	5.13±1.58	4.60±4.17	4.94±3.08[1,5]	2.48±1.63[4]	4.48±2.61[1]	4.44±1.73	6.81
20:4n-3*	3.62±1.7[2,3]	17.06±4.43[1,4,5]	23.23±20.15[1,4,5,6,7]	6.89±5.11[2,3]	3.85±1.42[2,3]	7.45±5.87[3]	5.81±0.85[3]	4.47
20:5n-3(EPA)*	42.93±11.82[4]	43.52±6.28[4]	57.75±25.43[4]	79.85±22.10[1,2,3,5,6]	42.81±17.72[4]	38.06±15.93[4,7]	71.41±15.65[6]	34.44
22:4n-3*	1.57±1.03[3]	3.92±1.71[3]	9.88±8.44[1,2,4,5,6,7]	2.83±1.72[3]	1.76±1.01[3]	3.56±2.94[3]	1.20±0.69[3]	3.75
22:5n-3*	15.42±5.15[3,4]	17.00±5.01[3]	53.22±37.49[1,2,4,5,6,7]	32.62±11.05[1,3,5,6]	18.34±6.10[3,4]	22.16±9.76[3,4]	29.69±5.83[3]	27.00
22:6n-3(DHA)*	93.58±20.78[2,3,4,5,6]	262.73±72.11[1,6]	207.05±123.56[1]	226.61±55.17[1,6]	184.54±38.05[1]	179.14±45.11[1,2,4]	156.10±27.21	202.34
Total N-3*	**163.84±39.01[2,3,4,5,6]**	**381.95±103.48[1]**	**398.09±232.72[1,5,6]**	**389.14±97.23[1,5,6]**	**264.60±61.82[1,3,4]**	**268.08±84.31[1,3,4]**	**299.68±60.15**	**298.81**
20:3n-9	0.35±0.28	0.98±0.78	0.85±0.54	1.11±1.88	0.32±0.16	0.46±0.39	0.44±0.25	0.36
Total PUFA*	**249.70±51.55[2,3,4]**	**468.81±122.54[1]**	**574.38±318.32[1,5,6]**	**536.88±159.81[1,5,6]**	**347.28±87.44[3,4]**	**357.31±117.53[3,4]**	**434.12±88.54**	**410.72**
EPA+DHA*	136.51±30.36[2,3,4,5,6]	306.25±77.98[1]	264.80±146.00[1]	306.46±64.51[1,5,6]	227.35±49.26[1,4]	217.20±58.13[1,4]	227.51±42.35	**236.79**
Total FA*	**436.39±103.99[3,4]**	**811.31±180.26**	**1231.14±674.83[1,5,6]**	**1165.88±505.16[1,5,6]**	**582.03±216.55[3,4]**	**655.12±249.98[3,4]**	**977.41±234.70**	**977.14**

Data is mean ± standard deviation; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; FA, fatty acid; Total FA, total amount of fatty acids, in mg/100g weight. The concentration (mg/100g) of fatty acid of skeletal muscle in all fish species except Longnose sucker were compared by one-way ANOVA, with significant F-value ($P<0.05$) indicated by*. Each species was assigned a numerical superscript based on alphabetical/column order. Superscripts were then used to indicate species that were significantly different from a mean value by Bonferroni post-hoc testing.

Table 9. Fatty acid composition (weight %) of muscle of eight species of fish from the Canadian Subarctic and Arctic

	Burbot[1] (N=27)	**Cisco[2] (N=5)**	**Lake Trout[3] (N=9)**	**Lake Whitefish[4] (N=37)**	**Northern Pike[5] (N=23)**	**Walleye[6] (N=26)**	**White Sucker[7] (N=4)**	**Longnose Sucker (N=1)**
12:0	1.54±3.09	2.35±3.59	0.41±0.39	0.68±0.73	0.20±0.30	1.06±1.31	0.61±1.20	0.00
14:0*	0.39±0.15^{2,3,4}	2.14±1.17^{1,4,5,6,7}	1.85±1.08^{1,4,5,6,7}	1.05±0.51^{1,2,3,5}	0.51±0.22^{2,3,4}	0.80±0.37^{2,3}	0.81±0.37^{2,3}	0.73
16:0*	17.82±1.47^{3,6}	19.58±2.47^{3}	15.07±3.55^{1,2,4,6}	18.95±1.36^{3,5}	17.33±0.99^{4,6}	19.62±1.14^{1,3,5}	16.86±1.15	19.21
17:0*	0.26±0.14^{2,3,4,6,7}	0.67±0.18^{1,5}	0.55±0.31^{1,5}	0.48±0.13^{1,5}	0.34±0.11^{2,3,4,6,7}	0.50±0.15^{1,5}	0.62±0.09^{1,5}	0.50
18:0*	6.33±0.65^{3,4}	5.58±0.60	5.23±1.16^{1,6}	4.88±0.60^{1,5,6}	5.80±0.36^{4}	6.16±0.89^{3,4}	5.68±0.19	5.52
20:0*	0.33±0.09^{3,4}	0.24±0.11^{3,4}	0.96±0.43^{1,2,5,6,7}	0.76±0.35^{1,2,5,6}	0.31±0.19^{3,4}	0.29±0.06^{3,4}	0.41±0.13^{3}	0.47
22:0*	0.33±0.19	0.26±0.04	0.44±0.33^{5,6}	0.29±0.10	0.23±0.11^{3}	0.25±0.11^{3}	0.26±0.06	0.17
23:0*	0.11±0.06^{2,4}	0.05±0.02^{1,3,6,7}	0.12±0.13^{2,4}	0.05±0.03^{1,3,6,7}	0.09±0.09	0.11±0.10^{2,4}	0.13±0.06^{2,4}	0.11
24:0*	1.91±0.59^{4,7}	2.67±0.83^{4,7}	1.46±0.94	1.12±0.67^{1,2,6}	1.58±0.88^{6,7}	2.26±0.76^{4,5,7}	0.32±0.08^{1,2,5,6}	1.59
Total SFA*	**29.03±3.88**^{2,5}	**33.53±4.34**^{1,3,4,5,7}	**26.06±3.13**^{2,6}	**28.29±1.64**^{2,6}	**26.39±1.40**^{1,2,6}	**31.06±1.78**^{3,4,5,7}	**25.71±1.41**^{2,6}	**28.30**
14:1*	0.01±0.01^{6}	0.02±0.03	0.03±0.08	0.03±0.04	0.01±0.02^{6}	0.05±0.05^{1,5}	0.06±0.04	0.03
16:1*	1.25±0.57^{3,4,7}	1.36±0.68^{3,4,7}	5.42±2.64^{1,2,5,6,7}	5.44±2.60^{1,2,5,6,7}	2.09±2.54^{3,4,7}	2.34±1.21^{3,4,7}	11.36±2.85^{1,2,3,4,5,6}	9.14
18:1n-7*	3.71±0.71^{2,4,5,7}	2.08±0.50^{1,3,4,7}	4.84±0.87^{2,5,6,7}	4.66±1.13^{1,2,5,6,7}	2.66±1.44^{1,3,4,7}	2.93±0.58^{3,4,7}	7.47±0.79^{1,2,3,4,5,6}	8.00
18:1n-9*	7.13±0.95^{3,4}	4.48±0.81^{3,4}	15.08±5.95^{1,2,5,6}	11.90±4.89^{1,2,5,6}	6.81±2.31^{3,4}	7.48±1.80^{3,4}	9.34±1.57	10.86
20:1n-9*	0.28±0.14^{6}	0.11±0.06^{3,4}	0.34±0.12^{2,6}	0.36±0.14^{2,5,6}	0.20±0.09^{4}	0.16±0.06^{1,3,4}	0.30±0.04	0.53
22:1n-9*	0.27±0.14^{4,5,6}	0.15±0.10	0.32±0.26^{4,5,6}	0.11±0.08^{1,3}	0.12±0.08^{1,3}	0.13±0.09^{1,3}	0.19±0.07	0.18
24:1n-9	0.41±0.40	0.53±0.20	0.45±0.45	0.35±0.35	0.39±0.34	0.47±0.31	0.14±0.06	0.69
Total MUFA*	**13.06±2.23**^{3,4,7}	**8.72±1.68**^{3,4,7}	**26.48±7.61**^{1,2,5,6}	**22.86±7.85**^{1,2,5,6}	**12.28±5.70**^{3,4,7}	**13.57±3.39**^{3,4,7}	**28.85±5.18**^{1,2,5,6}	**29.44**
18:2n-6*	1.99±0.46^{3,4,7}	2.52±1.04	3.80±1.53^{1,5,6}	3.24±1.19^{1,6}	2.63±0.57^{3,6}	1.76±0.57^{3,4,5,7}	3.76±0.29^{1,6}	3.26
18:3n-6*	0.33±0.13	0.08±0.05	0.49±0.86^{6}	0.20±0.08	0.20±0.40	0.13±0.03^{3}	0.19±0.03	0.26
20:2n-6*	0.38±0.12^{4}	0.34±0.18	0.59±0.26^{6}	0.55±0.21^{1,6}	0.54±0.26^{6}	0.32±0.12^{3,4,5}	0.30±0.03	0.40
20:3n-6*	0.40±0.10^{2,3,5,6}	0.21±0.07^{1,3,7}	0.58±0.26^{1,2,4,5,6}	0.36±0.09^{3,5,6}	0.26±0.11^{1,3,4,7}	0.26±0.09^{1,3,4,7}	0.52±0.06^{2,5,6}	0.36
20:4n-6*	13.69±1.98^{2,3,4,5,6,7}	3.65±0.55^{1,4,5,6,7}	4.60±1.60^{1,5,6,7}	5.81±1.15^{1,2,5,6}	7.62±1.39^{1,2,3,4}	7.27±1.00^{1,2,3,4}	7.63±1.05^{1,2,3}	5.75
22:2n-6*	0.23±0.16^{3}	0.19±0.14^{3}	0.70±0.89^{1,2,4,5,6,7}	0.15±0.07^{3}	0.20±0.18^{3}	0.18±0.18^{3}	0.15±0.04^{3}	0.11
22:4n-6*	0.69±0.18^{2,3,5}	0.32±0.04^{1,3,4,6}	1.39±0.37^{1,2,4,5,6,7}	0.66±0.18^{2,3,5}	0.45±0.19^{1,3,4,6}	0.67±0.18^{2,3,5}	0.39±0.08^{3}	0.30
22:5n-6*	2.31±0.81^{2,4,6,7}	3.43±0.78^{1,4,7}	2.42±0.67^{7}	1.67±0.56^{1,2,5,6}	2.42±0.54^{4,6,7}	3.05±0.72^{1,4,5,7}	0.96±0.37^{1,2,3,5,6}	1.01
Total N-6*	**20.02±2.20**^{2,3,4,5,6,7}	**10.74±0.67**^{1,3,5,6}	**14.56±1.96**^{1,2}	**12.65±1.27**^{1,5}	**14.32±2.15**^{1,2,4}	**13.64±1.19**^{1,2}	**13.92±1.43**^{1}	**11.45**
18:3n-3*	0.61±0.30^{2,3,4,5,6,7}	2.60±0.52^{1,5,6}	2.30±0.68^{1,5,6}	2.20±0.87^{1,5,6}	1.31±0.50^{1,2,3,4,7}	1.32±0.53^{1,2,3,4,7}	2.69±0.46^{1,5,6}	1.73
18:4n-3*	0.49±0.31^{2}	1.27±0.47^{1,4,5,6,7}	0.80±0.33^{5}	0.59±0.31^{2}	0.43±0.13^{2,3}	0.54±0.23^{2}	0.43±0.05^{2}	0.32
20:3n-3*	0.41±0.25^{6}	0.63±0.10	0.37±0.20^{6}	0.42±0.15^{6}	0.43±0.21^{6}	0.66±0.19^{1,3,4,5}	0.46±0.14	0.70
20:4n-3*	0.82±0.31^{2,3}	2.09±0.20^{1,4,5,6,7}	1.59±0.72^{1,4,5,6,7}	0.55±0.24^{2,3,6}	0.69±0.21^{2,3,6}	1.06±0.47^{2,3,4,5}	0.61±0.12^{2,3}	0.46
20:5n-3(EPA)*	9.80±1.17^{2,3,4,5,6}	5.45±0.67^{1}	5.64±3.56^{1}	7.41±1.94^{1,6}	7.37±1.04^{1,6}	5.79±1.08^{1,4,5}	7.45±1.29	3.52
22:4n-3*	0.35±0.22^{3}	0.50±0.23	0.75±0.67^{1,4,5,7}	0.26±0.17^{3,6}	0.34±0.27^{3}	0.53±0.24^{4}	0.12±0.06^{3}	0.38
22:5n-3*	3.49±0.66^{2,4}	2.08±0.19^{1,3,5,6}	4.06±0.99^{2,4,5}	2.95±0.65^{1,3}	3.20±0.36^{2,3}	3.36±0.52^{2}	3.10±0.46	2.76
22:6n-3(DHA)*	21.62±2.94^{2,5,6}	32.15±1.58^{1,3,4,7}	17.14±5.60^{2,5,6}	21.60±6.57^{2,5,6}	33.07±5.81^{1,3,4,6,7}	28.26±3.96^{1,3,4,5,7}	16.29±2.12^{2,5,6}	20.71
Total N-3*	**37.59±3.47**^{2,5}	**46.78±2.27**^{1,3,4,7}	**32.65±7.80**^{2,5,6}	**35.98±7.51**^{2,5,6}	**46.84±5.89**^{1,3,4,6,7}	**41.52±3.05**^{3,4,5,7}	**31.15±3.87**^{2,5,6}	**30.58**
20:3n-9	0.09±0.08	0.11±0.06	0.09±0.07	0.09±0.11	0.06±0.04	0.08±0.06	0.05±0.04	**0.04**
Total PUFA*	**57.61±3.21**^{3,4,7}	**57.51±2.62**^{3,4,7}	**47.21±6.92**^{1,2,5,6}	**48.63±7.65**^{1,2,5,6}	**61.15±5.67**^{3,4,6,7}	**55.16±3.30**^{3,4,5,7}	**45.07±5.28**^{1,2,5,6}	**42.03**
EPA+DHA*	31.42±3.01^{3,5}	37.60±1.53^{3,4,7}	22.78±8.74^{1,2,5,6}	29.01±7.59^{2,5,6}	40.44±5.96^{1,3,4,6,7}	34.05±3.94^{3,4,5,7}	23.75±3.36^{2,5,6}	24.23

Data is mean ± standard deviation; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; The relative percent (%wt) of fatty acid of skeletal muscle in all fish species except Longnose sucker were compared by one-way ANOVA, with significant F-value ($P<0.05$) indicated by*. Each species was assigned a numerical superscript based on alphabetical/column order. Superscripts were then used to indicate species that were significantly different from a mean value by Bonferroni post-hoc testing.

Table 1010. Fatty acid composition of skeletal muscle and liver of Burbot fish

NAME	Muscle (mg/100g)	Liver (mg/100g)	Muscle (weight %)	Liver (weight %)
12:0	10.80±19.83	24.24±7.77*	1.97±3.32	0.26±0.13*
14:0	1.87±1.16	311.97±143.34*	0.40±0.16	2.91±0.68*
16:0	78.63±20.14	1548.62±644.58*	17.51±1.49	14.45±2.35*
17:0	1.12±0.72	90.58±42.98*	0.25±0.12	0.84±0.20*
18:0	27.97±6.72	355.58±109.81*	6.25±0.67	3.47±0.65*
20:0	1.48±0.65	94.82±33.95*	0.33±0.10	0.94±0.30*
22:0	1.43±0.94	17.81±5.35*	0.31±0.20	0.18±0.05*
23:0	0.50±0.30	5.18±6.67*	0.11±0.06	0.05±0.08*
24:0	8.19±3.41	73.60±33.03*	1.82±0.56	0.74±0.32*
Total SFA	**132.01±47.53**	**2522.69±929.51***	**28.96±4.39**	**23.84±2.16***
14:1	0.01±0.02	9.19±5.19*	0.01±0.01	0.09±0.06*
16:1	5.61±3.23	937.35±446.61*	1.23±0.56	8.59±2.07*
18:1n-7	15.83±4.77	890.16±288.50*	3.51±0.54	8.58±1.49*
18:1n-9	31.21±7.68	1553.00±693.06*	6.97±0.87	14.38±3.30*
20:1n-9	1.32±0.71	34.92±13.84*	0.29±0.14	0.34±0.11
22:1n-9	1.30±0.63	5.30±3.36*	0.30±0.15	0.05±0.03*
24:1n-9	1.77±1.70	31.96±31.07*	0.41±0.40	0.30±0.28
Total MUFA	**57.05±15.86**	**3461.91±1409.29**	**12.71±1.99**	**32.33±5.72***
18:2n-6	9.10±2.66	549.39±230.90*	2.04±0.42	5.12±0.77*
18:3n-6	1.61±0.87	77.19±26.24*	0.35±0.14	0.74±0.12*
20:2n-6	1.62±0.64	86.54±29.74*	0.36±0.12	0.84±0.16*
20:3n-6	1.85±0.59	49.88±14.54*	0.41±0.11	0.49±0.08*
20:4n-6	59.70±11.60	416.68±128.56*	13.53±1.83	4.03±0.59*
22:2n-6	1.09±0.94	33.73±15.53*	0.23±0.18	0.32±0.07
22:4n-6	3.12±0.79	128.98±59.20*	0.71±0.18	1.25±0.48*
22:5n-6	8.51±2.04	93.60±38.8*	1.92±0.34	0.91±0.33*
Total N-6	**86.61±16.59**	**1436.00±492.91***	**19.56±1.89**	**13.70±1.50***
18:3n-3	2.93±1.69	304.28±187.52*	0.64±0.30	2.71±0.94*
18:4n-3	2.60±1.54	247.95±174.01*	0.57±0.30	2.16±0.94*
20:3n-3	1.68±1.15	57.15±24.75*	0.36±0.19	0.53±0.10*
20:4n-3	4.08±1.66	178.74±101.14*	0.90±0.30	1.63±0.61*
20:5n-3(EPA)	45.12±11.13	653.77±321.07*	10.06±0.97	6.04±1.45*
22:4n-3	1.58±1.07	26.72±12.34*	0.35±0.22	0.26±0.08
22:5n-3	16.56±4.98	479.24±157.80*	3.67±0.62	4.71±1.44*
22:6n-3(DHA)	97.17±19.82	1219.48±387.54*	21.89±2.79	11.93±2.96*
Total N-3	**171.72±37.66**	**3167.35±1261.51***	**38.44±3.36**	**29.98±5.83***
20:3n-9	0.35±0.31	6.44±3.86*	0.09±0.09	0.06±0.03
Total PUFA	**258.33±51.35**	**4603.35±1736.87***	**58.00±3.36**	**43.68±7.05***
EPA+DHA	142.29±29.15	1873.26±656.33*	31.95±2.96	17.97±3.31*
Total N-6/N-3	0.51±0.08	0.47±0.07*	0.51±0.08	0.47±0.07*
Total FA	**448.85±105.86**	**10603.58±3846.17***	-	-

Data is means ± standard deviation (n=21); SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA, eicosapentaenoic acid (20:5n-3); DHA, docosahexaenoic acid (22:6n-3); FA, fatty acid; Total FA, total amount of fatty acids. Pairs of means corresponding to the skeletal muscle and liver of Burbot fish were compared by two-tailed paired samples t-test and those that were significantly different ($P<0.05$) are shown (*).

Table 1111. Fatty acid concentration (mg/100g) of skeletal muscle of selected species of fish from the Canadian Subarctic and Arctic compared with estimates calculated from the Canadian Nutrient File database

Name	Burbot CNF	*Burbot (n=27)*	Cisco CNF	*Cisco (N=5)*	Trout, mixed species CNF	*Lake Trout (N=9)*	Lake Whitefish CNF	*Lake Whitefish (N=37)*	Northern Pike CNF	*Northern Pike (N=23)*	Walleye CNF	*Walleye (N=26)*	White Sucker CNF	*White Sucker (N=4)*
Food code	2989		2996		3204		3208		3036		3202		3072	
12:0		*8*	10[10]	*19*	0[0]	*7*		*9*	0[10]	*1*	0[0]	*8*		*6*
14:0	6[0]	*2*	130[10]	*19*	185[0]	*24*	100[10]	*14*		*3*	18[0]	*6*	48[0]	*8*
16:0	120[0]	*78*	**810[10]**	*156*	**815[0]**	*169*	600[10]	*217*	100[10]	*101*	197[0]	*128*	333[0]	*163*
18:0	37[0]	*28*	130[10]	*44*	148[0]	*59*	100[10]	*55*		*34*	34[0]	*39*	66[0]	*55*
Total SFAs	163[0]	*128*	**1210[10]**	*268*	1149[0]	*304*	800[10]	*327*	100[10]	*153*	249[0]	*202*	452[0]	*250*
16:1	26[0]	*6*	60[10]	*12*	701[0]	*69*	400[10]	*74*		*17*	98[0]	*17*	382[0]	*115*
18:1	98[0]	*47*	**1030[10]**	*54*	**1440[0]**	*267*	700[10]	*215*	100[10]	*59*	196[0]	*72*	303[0]	*168*
20:1n-9	6[0]	*1*	70[10]	*1*	280[0]	*5*		*5*	0[10]	*1*	0[0]	*1*	14[0]	*3*
22:1n-9	3[0]	*1*	60[10]	*1*	830[0]	*4*		*1*	0[10]	*1*	0[0]	*1*		*2*
24:1n-9		*2*	10[10]	*4*		*5*		*4*	0[10]	*2*		*3*		*1*
Total MUFA	133[0]	*57*	**2870[10]**	*72*	**3245[0]**	*350*	**1100[10]**	*299*	100[10]	*81*	294[0]	*95*	706[0]	*290*
18:2n-6	9[14]	*9*	40[14]	*22*	170[14]	*51*	200[14]	*42*	19[14]	*16*	20[14]	*13*	60[14]	*37*
20:2n-6		*2*	10[10]	*3*		*7*		*7*	0[10]	*3*		*2*		*3*
20:3n-6		*2*	**420[14]**	*2*		*7*		*4*	0[12]	*2*		*2*		*5*
20:4n-6	96[14]	*58*	190[14]	*29*	180[14]	*51*	100[14]	*64*	55[14]	*44*	50[14]	*47*	100[14]	*73*
22:4n-6		*3*	10[10]	*3*		*17*		*8*		*3*		*4*		*4*
Total N-6		*86*	**19470[2]**	*87*	350[2]	*176*		*148*	74[2]	*83*	70[2]	*89*	160[2]	*134*
18:3n-3		*3*	20[14]	*22*	150[14]	*31*	100[14]	*28*	7[14]	*8*	10[14]	*9*	50[14]	*27*
18:4n-3		*2*		*11*	64[0]	*12*		*8*		*3*	0[0]	*4*	32[0]	*4*
20:5n-3 (EPA)	70[0]	*43*	120[10]	*44*	202[0]	*58*	200[10]	*80*	73[2]	*43*	86[0]	*38*	190[0]	*71*
22:5n-3	26[0]	*15*	50[2]	*17*	183[0]	*53*	57[2]	*33*	26[2]	*18*	38[0]	*22*	73[0]	*30*
22:6n-3 (DHA)	96[0]	*94*	510[10]	*263*	528[0]	*207*	300[10]	*227*	200[10]	*185*	225[0]	*179*	289[0]	*156*
Total N-3		*164*	700[2]	*382*	1050[2]	*398*		*389*	306[2]	*265*	340[2]	*268*	590[2]	*300*
Total PUFA	297[0]	*250*	1330[10]	*469*	1499[0]	*574*	1700[10]	*537*	200[10]	*347*	447[0]	*357*	807[0]	*434*
EPA+DHA	166	*137*	630	*306*	730	*265*	500	*306*	273	*227*	311	*217*	479	*228*
Total FA	650[10]	*436*	**4000[10]**	*811*	**6610[0]**	*1231*	**3800[10]**	*1166*	800[10]	*582*	1220[0]	*655*	2320[0]	*977*

SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; FA, fatty acid; Total FA, total amount of fatty acids. Data not shown in table are unavailable in the Canadian Nutrient File. Data in regular size represents data collected from the Canadian Nutrient File with different superscripts indicating data sources. [0], no change from USDA; [2], nutrient calculated from data other than USDA; [10], nutrient derived from scientific literature; [12], nutrient value is an assumed zero; [14], provisional data. Data in italic represents data from current research analyses. Values appearing to be abnormal are bolded.

5.6 Discussion

5.6.1 Fatty Acid Profiles Vary Across All Analyzed Fish Species

Prior studies have noted that fish are the vertebrates with the highest species diversity and the fatty acid profiles of fish vary the most by species difference [197]. As hypothesised, the fatty acid profiles including both the composition (weight %) and concentration (mg/100g) of skeletal muscle differed significantly in the fish species analyzed. The fatty acid levels in fish collected from Canadian Subarctic and Arctic region appear to be quite similar to those of fish collected from the Great Lakes Region, and Lake Ontario [194, 198, 199]. The present analytical results for total fat content of Lake Whitefish (1166 ± 505mg/100g muscle) and Walleye (655 ± 250 mg/100g muscle) were close to previous reports of 2480 ± 1020 mg/100g for Lake Whitefish and 820 ± 240 mg/100g for Walleye [199]. The experimental determination for the fat content of Cisco (811 ± 180 mg/100g) was also consistent with the recent literature (751 mg/100g fish) [200] and result for the total fat content of White Sucker (977 ± 234 mg/100g muscle) was consistent with values (1110 ± 120 mg/100g muscle) determined by Mai and Kinsella [201]. The experimental fat content of Northern Pike (582 ± 217 mg/100g) was a bit lower but still close to the results from previous literature (750 ± 130 mg/100g) [202]. The present result for the species with the lowest fat content, Burbot fish (436 ± 104 mg/100g), was similar to a previous report on Burbot from the Dehcho Region, Northwest Territories from our laboratory (348 ± 67 mg/100g) [203] but lower than Burbot from Italian subalpine lakes (1,134 ±83 mg/100g) reported by others [204]. The USDA database lists Burbot as having 810 mg/100g and CNF as 650 mg/100g [150, 205]. The literature results on the fat content of Lake Trout has been quite inconsistent, the result (2690 ± 1590 mg/100g) from Grosbois et al. [206] being over

two times of the present result (1231 ± 675) whereas the result by Williams et al. (800 ± 360 mg/100g) is lower [194]. The coefficient of variation for the Lake Trout total fat determinations are consistently high (≥45%) indicating that there is considerably natural variation in this species. The different results between my analysis and previous literature reports may be explained by the different ecological conditions fish were exposed to in different regions, and variations in fishing season, which significantly impact the lipid content in wild fish [197] as fish caught in the Fall have higher fat content compared with fish caught in the spring [207].

For the individual fatty acids in muscle, there were numerous differences between the species by concentration and relative weight percentages, but there were several consistent patterns. Palmitic acid (16:0) was the predominant saturate followed by stearic acid (18:0) and oleic acid (18:1 n-9) was the most abundant MUFA all the fish species analyzed. These findings are in agreement with findings from various previous research [194, 199, 202, 204]. While diet intake of these fatty acids may influence these fatty acids, these three fatty acids are all endogenously synthesized *de novo* in response to excess energy intake and are typically high in most organisms. Arachidonic acid (20:4n-6) was the most abundant n-6 PUFA across all species. DHA was the most abundant n-3 PUFA followed by EPA across all species which supported the second hypothesis of this research chapter. This also agreed with earlier observations by others that showed high levels of DHA (16 to 31 wt%) and relatively moderate levels of EPA (5.7 to 15.9 wt%) in wild freshwater fish [204, 208]. As for the EPA + DHA content, the present results for all analyzed fish species were in the range of previous results from the same fish species collected in the same region with Cisco, Lake Whitefish , and Lake Trout having the highest content [203].

These long chain n-3 (EPA, DHA) and n-6 PUFA (20:4n-6) varied dramatically across species. PUFA are essential fatty acids in fish that must be consumed, although shorter chain PUFA can be converted to longer chain PUFA. The 18 carbon PUFA made relatively small contributions to skeletal muscle composition with linoleic acid (18:2n-6) contributing the most to the total (range of 1.76 to 3.80 wt%). As a comparison, docosapentaenoic acid n-3 ranged from 2.08 to 4.06 wt% across species. The PUFA composition of skeletal muscle tends to be dominated by the long chain PUFA given that there is a high proportion of fatty acids in the phospholipids of cell membranes contributing to the total fatty acid content as compared with fatty acids in storage fat as triacylglycerols [209]. In the human diets, 16:0, 18:0, 18:1n-9 and 18:2n-6 make up 90% of the fatty acids consumed in agro-industrialized countries across the globe [210] alt. The present results confirm that fish is relatively low in 18:2n-6 content, and it has been documented that the consumption of seed oils is the main source of 18:2n-6 in the human diet [211]. The content of long chain n-3 PUFA in fish appear to be at least somewhat dependent on the consumption of preformed EPA and DHA based on aquaculture studies as reviewed recently [212].

Interestingly, total fat content of Longnose Sucker was found to be the same as the mean fat content of White Sucker although no statistical testing was possible, because only 1 sample of Longnose Sucker was collected. The White Sucker and Longnose Sucker are genetically and biochemically distinctive [213], but the appearance of the Longnose Sucker is quite similar to White Sucker such that they are commonly confused by fishermen. While total fat content of the White and Longnose suckers was similar, the one Longnose sucker examined had 46mg/100g (30%) more DHA than the average of the White suckers but less than half the EPA (34 vs. 71 mg/100g). The ratio of EPA to DHA also appeared to be higher in White sucker (n = 19) as

compared with Longnose sucker (n = 16) in the Dehcho Region, Northwest Territories [203]. Longnose suckers appear to have similar dietary habits as White suckers, although the size of a sucker (which was not available for the n=1 sample) can shift diet as bigger prey can be consumed as the sucker get larger [214]. So while caution is required for considering these EPA and DHA differences as "real" from an n=1, differences in the ratio of EPA to DHA is an indication of different PUFA metabolism by elongase and desaturase activities that is of great interest in the food supply [215], so further studies examining PUFA metabolism in White and Longnose suckers may be worthwhile.

5.6.2 Fatty Acid Profiles Vary between Skeletal Muscle and Liver of Burbot Fish

The Burbot (*Lota lota*) is a vital food fish for Indigenous North American peoples (including First Nations, Métis, and Inuit) and the skeletal muscle and liver are consumed [186, 187]. The Burbot is a freshwater gadiform (cod-like) fish which produces delicate flesh fillet and liver that therefore a potential candidate for aquaculture unlike saltwater gadiforms [216, 217]. Burbot livers are large and rich in bioactive components (particularly n-3 PUFA, vitamin A, and vitamin D), and it has been a culturally significant and traditional food component for Indigenous people living in Northwest Territories in Canada [218]. Burbot fish fillet and liver were available, thus providing an opportunity to compare the fatty acid content from different edible tissues of a single fish species. Unlike fatty fish species that predominantly accumulate lipid in skeletal muscle, lean fish have low lipid levels in muscle and accumulate lipids primarily in the liver [219] and Burbot is an example of a lean fish [220]. The total fat identified in the Burbot liver was dramatically higher (over 20 times) than Burbot muscle. In addition to the fatty acid concentration (mg/100g), the fatty acid composition (weight %) of the Burbot muscle

significantly differed from the Burbot liver tissue. The different fatty acid composition is indicative of differences beyond the liver having just a higher amount of fat, but differences in the type of fat, which is caused by differences in the structure of skeletal muscle and liver. There is no data available of the phospholipid and triacylglycerol content of Burbot muscle and liver. For cod, concentration data is also surprisingly elusive in the literature, but it has been anecdotally reported that in the lean muscle, most of the fat is from polar membrane lipids of the various phospholipid classes while cod liver is 95% triacylglycerols [221]. The higher proportion of MUFA and lower proportion of long chain n-3 PUFA and the very high concentration of total fat in Burbot liver indicate that the liver is high in triacylglycerol as compared with Burbot muscle. Characterization of the complex lipids of fish muscle versus fish liver appears to be understudied, particularly regarding reporting quantitated results rather than relative weight percentages.

As a source of dietary EPA + DHA in fishes, the proportion of EPA + DHA in Burbot muscle tissue (32.0 ± 3.0 wt%) was higher than in Burbot liver tissue (18.0 ± 3.3 wt%). This pattern has been observed in other fish such as *Sardinella maderensis* with 18.7 EPA + DHA wt% in muscle tissue and 9.5 wt% in liver tissue [222]. However, while the proportion of EPA + DHA is higher in the Burbot muscle, the concentration of EPA + DHA in Burbot liver (1873 ± 656 mg/100g) is markedly higher (13 times). Therefore, Burbot liver has higher nutritional value than Burbot muscle in regards to major n-3 PUFA content. These findings were also observed in the fatty acid composition of muscle vs. liver of *Sardinella maderensis*, *Sardinella aurita*, and *Cephalopholis taeniops* [222]. Fish liver also contains high levels of other lipids including cholesterol, vitamin D and vitamin A that contribute to the nutritive value with potential for both positive and negative effects. Burbot liver is however consider a good source of protein and

vitamin A and can play an important role in the food supply for communities in the Northwest Territories [223]. In particular, the high levels of vitamin A in liver can cause toxicity if amounts of liver are not restricted [224], and fish liver may also accumulates environmental contaminants (e.g., arsenic, cadmium, and lead) [225]. Levels of vitamin A in wild-harvested burbot liver from the Northwest Territories are not yet known and little information is available on Vitamin A levels among Dene populations of the Northwest Territories. As such, future work to more precisely and comprehensively describe the risks and benefits of burbot liver may be warranted. In the meantime, efforts to promote EPA + DHA intakes from traditional foods, with an emphasis on the muscle of particular fish species, should be designed in full consultation with northern Indigenous communities [226].

5.6.3 Fatty Acid Analytical Results Vary from CNF Records

As mentioned in previous research chapter, the CNF database is frequently used as a valid reference by healthcare providers to assess nutrient content of food items supplied in Canada and make public dietary recommendations [176]. While it is generally understood that dietary databases have considerable limitations, these limitations are not well documented in the literature as the focus tends to be on limitations in measuring actual food intake [227]. Therefore, the nutrient content on fatty acid concentration from chemical analyses of the fish species from the Northwest Territories was compared to the nutrient data for these species in the CNF database. The fatty acid concentration data of 7 out of 8 analyzed fish species were found in the CNF database and those fatty acid concentration data were compared with present analytical data. The nutrient profile of Longnose Sucker was absent in CNF. Longnose Sucker has been culturally important to the Indigenous peoples of Northwestern North America, and is of

particular dietary importance among people living in areas that lacked salmon as a dietary fish [228]. This finding, while preliminary, suggests that CNF and Health Canada should capture the nutrient profile of more fish species consumed by citizens across Canada, including Indigenous peoples given Federal mandate for reconciliation.

In general, the fatty acid concentration values of each included fatty acid component from my laboratory analyses were markedly lower than the CNF values. As such, the third hypothesis that fish species will be found in the CNF database and the analytical results and database records of fatty acid concentration would agree, was rejected. The experimental values of total fat content were approximately 40-75% of the CNF values except for the Lake Trout, Cisco, and Lake Whitefish which were only 19-31% of anticipated values. A possible explanation for the higher fat content data in the CNF than present analytical results is that the data from the CNF were based on the whole fish, whereas the analytical data were based on the fish muscle only. The vital fat storage sites in fish includes skeletal muscle but also include liver, and adipose tissue [229]. Therefore, the fat content of whole fish is expected to be higher than fish muscle solely. Furthermore, the CNF nutrient values may not accurately reflect foods supplied in Canada because the CNF is mostly based on the USDA nutrient database and is infrequently updated to address changes particular to the Canadian food supply [179]. The fat content values recorded in the CNF database are a generic representation of relative fatty acids derived from various data sources (**Appendix 3**), which further contributes to the variability of the CNF data. Other impact factors of the fat content in fish included the fishing season, fishing location, and age, body weight, and reproductive status of fishes [197]. Since those factors were unknown, comparison of the individual fatty acid content of fish from my analyses with CNF values must be done with caution.

The EPA + DHA content experimental measured was relatively consistent across species in the CNF database. The mean concentrations of EPA + DHA of present experimental results were approximately 45-85% of the CNF values except for Lake Trout, which was 36% of the CNF reported values. The experimentally determined Lake Trout was compared with "Trout (mixed species)" in CNF as it was the only information available for Trout fishes. The various species of trout have been reported to have a range of EPA + DHA of 500-3000 mg/100g [230, 231] and Lake Trout from the Northwest Territories have been reported to have a very wide range of EPA + DHA content (165-2332 mg/100g) by our laboratory previously [203]. Lake Whitefish was also observed to have a wide range of EPA + DHA in this previous study (182-1048 mg/100g) [203]. Lake trout and Lake Whitefish are known to have "sympatric morphs" or different phenotypes within a species living in the same area [232, 233]. These morphs are often a result of resource competition and segregation as the fish adapt to their environment which can increases the morphological and biochemical variability of a species including their nutrient content [232, 233]. In addition, Lake Trout are known to dramatically cycle their weight seasonally in response to food availability especially in Arctic conditions [234].

The fatty acid concentration data from CNF for Cisco appears to be incorrect as the concentration of total n-6 PUFA (19470 mg/100g) was higher than the sum of individual n-6 PUFA and even exceeded the total fat content (4000 mg/100g). The Cisco also reported a 20:3n-6 content of 420 mg/100g which was higher than 20:4n-6 (190 mg/100g in CNF) when 20:4n-6 was consistently the highest n-6 PUFA in all the fish species by CNF estimates and by our laboratory measurements. The Cisco concentrations from my analyses and those in the recent literature [200], were consistent for total saturates (268 vs. 262 mg/100g), total MUFA (72 vs. 128 mg/100g), total n-6 PUFA (87 vs. 61 mg/100g) and total fat content of (811 vs. 751

mg/100g). According to the data source provided by CNF, the Cisco data were derived from "Nutrient calculated from data other than USDA" or "Nutrient derived from scientific literature" but the specific data sources were not trackable. The CNF is expected to cite the data of fatty acid profile from certain valid source and regularly monitor those data to increase the consistency and accuracy of the reported nutrient data. The USDA indicates Cisco total fat is 1910 mg/100g while our previous analyses indicted a total fat content of 1039 ± 431 mg/100g [203].

5.6.4 Addressing the Limitations

There are several limitations to this study. Firstly, the seasonality of the fishing and age or body weight of fishes were not considered in this thesis and adding this information in the future may help with understanding the diversity of the fatty acid profile of the fishes examined [197]. For example, previous researchers have noted the seasonal changes in the lipid content of some fish species, and fatty acid concentration in Fall was significantly higher than spring because fish exhibited increased feeding rates in Fall to prepare for overwinter survival as fish have the lowest fatty acid content after the winter fasting period [235, 236]. Secondly, the observations of analytical results versus CNF records were from eye-catch only as statistical testing between the experimental data and the single CNF average value data-point is not possible since CNF provided the average value of each fatty acid content only. Lastly, as for the fatty acid profile of Burbot muscle and liver, quantitative analysis of complex lipids and their fatty acid compositions need to be completed for better insights into differences between muscle and liver.

5.7 Conclusion

In this research study, the fatty acid composition of wild harvested freshwater fish commonly captured in the Canadian Arctic and Subarctic for food were investigated and the nutritional quality of those freshwater fish were compared. The analyzed fatty acid composition data of these fish were then compared to data available in the CNF. This study revealed that almost all the examined fish species captured from the Canadian subarctic and Arctic could be a good source of EPA+DHA as they all contained more than 135 mg /100 g fish muscle. Dietary recommendations for EPA + DHA vary but generally they range from 250 mg/d to 500 mg/d [237]. Median intakes of EPA + DHA have been estimated to be lower than 100 mg/d [209]. Among the examined fish species, Cisco, Lake Whitefish and Lake Trout had EPA + DHA contents above 300 mg/100g fish muscle and therefore represent promising sources of EPA + DHA by First Nation communities in Northwest Territories, Canada. This information as well as lake-specific contaminant data [238] and local traditional knowledge should be considered when co-developing dietary messages related with northern community partners. As for the comparison between my laboratory results and the CNF data, my results suggest that further species such as the Longnose sucker should be added as they are consumed by some Indigenous populations. My results and others indicate the CNF Cisco data is not valid and CNF should at least adapt the USDA values or better consult the recent published literature from Cisco caught in Canada.

Chapter 6

General Discussion

6.1 Overview

The main objectives of this thesis were to 1) collect evidence from available review papers to determine issues related to human health and fish intake; 2) examine available online databases for estimates of global and Canadian fish consumption, the diversity of commercial fish species, and nutrient composition coverage of fish commonly consumed in North America; and 3) examine the fatty acid composition of wild caught fish species consumed by Indigenous population in northern Canada in comparison to food nutrient databases. These objectives were completed by conducting a scoping review of review articles on the health effects of human fish intake, identifying fish related databases (FAOSTAT, FishBase, CNF, and USDA) and comparing the data obtained from them, and determining the fatty acid profile of fishes captured from northern Canada using gas chromatography-flame ionization detection and then comparing the analytical data to data from CNF database. My preliminary research aimed to determine the fatty acid composition of commonly consumed fishes by Chinese versus Canadians using gas chromatography, but the limited access to the laboratory during covid 19 pandemic forced me to transition my research to online database research projects.

The overall hypothesis of this thesis was that n-3 PUFA is the main nutrient within fish that provides health benefits over potential health detriments but assessing human intakes of n-3 PUFA from fish is a challenge due to variation in the estimated n-3 PUFA content of fish in nutrient databases as a consequence of the large number and diversity of fish species, and the

difficulty of incorporating regional and seasonal effects on n-3 PUFA content of fish. The results of this thesis indicate that n-3 PUFA is the most studied nutrient component of fish and appears to contribute the most to the health benefits (mainly cardiovascular and neurodevelopmental benefits), but there are other nutrients in fish that are understudied. Consuming fish is typically recommended rather than consuming fish oil supplements. This is despite the risk of detrimental contaminants (e.g., MeHg) in fish as it is assumed the overall health benefits outweigh the potential health detriments of fish intake. The FAOSTAT database provided data on fish consumption and production and indicated that production by the G20 countries was dependent mainly on capture fisheries, except for China that has developed a large aquaculture industry. The FishBase database provided insight on the diversity of commercial fish by individual countries and regions within Canada. Low fish consumption, regions with colder water temperatures and industrialization of the fish food supply appears to reduce commercial fish diversity. For the nutrient databases assessed, the FishBase Nutrient Analysis Tool provides predicted nutrient content of a wide range of fish species but needs more testing and validation prior to be used for dietary intake assessments. The CNF and USDA databases did not capture all the commercial fish species in Canada as indicated by FishBase. All of fish species captured from the Canadian subarctic and Arctic, were good sources of EPA + DHA containing more than 135 mg/100 g fish muscle, with Cisco, Lake Whitefish and Lake Trout having above 300 mg/100g fish muscle. Longnose sucker was not in the CNF but was indicated to be consumed in Canada by FishBase and is consumed regularly by some Indigenous peoples of Northwestern North America [228]. This indicates that the CNF (and USDA) database(s) may not be comprehensive enough to capture nutrient information of fish species consumed in specific regions and subpopulations in Canada, including Indigenous people. Considerable

inconsistencies were observed between some of the data in CNF and ours and others analyses, particularly Cisco.

Based on the evidence on various health benefits of n-3 PUFA from fish intake in the literature, fish oil supplements are popular, but whether they can substitute for fish in the diet is controversial. Although the effects and mechanisms of n-3 PUFA on human health have been studied extensively, the variability in the design, analysis, reporting, and interpretation across studies makes it difficult to translate the findings into n-3 PUFA specific recommendations [239]. Proper assessment of background diet and adherence to fish oil use during clinical trials has been recommended to address the inconsistencies in fish oil studies [239] and in nutrition intervention studies in general [240]. These measures are needed to better inform decisions about the effect of fish oil versus fish intake on human health. Also, research on the other bioactive components in fish are needed as it is not even possible to determine variation in health outcomes in these understudied components. Indiscriminately promoting fish intake over fish oil supplementation appears to be a default recommendation that lacks true scientific support. General recommendations for fish consumption have multiple challenges due to the large diversity of fish species consumed by human in different regions of the world and during different seasons. The CNF relies heavily on the USDA database and as such may not represent regional differences. In particular, smaller regions and specific populations in Canada such as Indigenous peoples rely more on local capture fisheries rather industrialized fish production for their fish food. These differences will likely get larger as aquaculture grows in North America as it has in China. Given the ecological impact on the fatty acid content of fish [197, 241], significant variation of fatty acid concentration of fish examined between my analyses and CNF estimates should have been expected. Inconsistencies in estimating dietary n-3 PUFA intake

from fish are real and problematic. Nutrient databases may need to consider capturing and reporting variation rather than just mean values to properly reflect the fatty content of fish. The average could still be used for estimating intake amounts, while the variation would give insight on the dispersion of the possible nutrient content.

6.2 Conclusion

In conclusion, this thesis identified controversial topics related to the health benefits of fish intake and research gaps present in the research field. The n-3 PUFA within fish have been studied the most, yet fish intake is typically promoted over n-3 PUFA supplementation despite limited supporting evidence for the other components of fish providing benefits on human health. To verify this, further studies should be performed to examine the effect of bioactive components in fish such as protein or peptides, vitamins, and trace elements on human health together with confounding factors including fish choice, processing methods, and human adherence to dietary recommendations being intervened. In addition, complex interactions with environmental contaminants that cause health detriments need to be examined in more detail to safely promote fish intake. Since the nutritional value of fish varies across the large diversity of fish species and ecological conditions, the nutrient data of fish in nutrient databases must be considered as crude estimates. The limitations of the CNF and USDA databases for estimating nutrient intakes from fish should be studied systematically across regions and subpopulations and fish species not in the database need to be added. Adding a variation component to the databases may be prudent and informative for public health initiatives but also for human intervention studies. Improving the ability to estimate nutrient intakes from fish appears to be necessary to determining the true impact of fish and n-3 PUFA on human health.

References

[1] J. Guillen, F. Natale, N. Carvalho, J. Casey, J. Hofherr, J.-N. Druon, G. Fiore, M. Gibin, A. Zanzi, J.T. Martinsohn, Global seafood consumption footprint, Ambio 48(2) (2019) 111-122.

[2] FAO, The State of World Fisheries and Aquaculture 2020, FAO Fisheries and Aquaculture Department, Rome, 2020.

[3] S.A. Ashraf, M. Adnan, M. Patel, A.J. Siddiqui, M. Sachidanandan, M. Snoussi, S. Hadi, Fish-based bioactives as potent nutraceuticals: Exploring the therapeutic perspective of sustainable food from the sea, Marine Drugs 18(5) (2020).

[4] A. Goel, N.V. Pothineni, M. Singhal, H. Paydak, T. Saldeen, J.L. Mehta, Fish, fish oils and cardioprotection: Promise or fish tale?, International Journal of Molecular Sciences 19(12) (2018).

[5] C.J.R. Hibbeln, P. Spiller, J.T. Brenna, J. Golding, B.J. Holub, W.S. Harris, P. Kris-Etherton, B. Lands, S.L. Connor, G. Myers, J.J. Strain, M.A. Crawford, S.E. Carlson, Relationships between seafood consumption during pregnancy and childhood and neurocognitive development: Two systematic reviews, Prostaglandins Leukotrienes and Essential Fatty Acids 151 (2019) 14-36.

[6] A. Alhassan, J. Young, M.E.J. Lean, J. Lara, Consumption of fish and vascular risk factors: A systematic review and meta-analysis of intervention studies, Atherosclerosis 266 (2017) 87-94.

[7] M. Fotuhi, P. Mohassel, K. Yaffe, Fish consumption, long-chain omega-3 fatty acids and risk of cognitive decline or Alzheimer disease: a complex association, Nat Clin Pract Neurol 5(3) (2009) 140-52.

[8] F. Li, X. Liu, D. Zhang, Fish consumption and risk of depression: a meta-analysis, J Epidemiol Community Health 70(3) (2016) 299-304.

[9] H. Mozaffari, E. Daneshzad, B. Larijani, N. Bellissimo, L. Azadbakht, Dietary intake of fish, n-3 polyunsaturated fatty acids, and risk of inflammatory bowel disease: a systematic review and meta-analysis of observational studies, European Journal of Nutrition 59(1) (2020).

[10] A. Sala-Vila, P.C. Calder, Update on the relationship of fish intake with prostate, breast, and colorectal cancers, Crit Rev Food Sci Nutr 51(9) (2011) 855-71.

[11] Y. Wan, J. Zheng, F. Wang, D. Li, Fish, long chain omega-3 polyunsaturated fatty acids consumption, and risk of all-cause mortality: a systematic review and dose-response meta-analysis from 23 independent prospective cohort studies, Asia Pac J Clin Nutr 26(5) (2017) 939-956.

[12] A. Gil, F. Gil, Fish, a Mediterranean source of n-3 PUFA: benefits do not justify limiting consumption, Br J Nutr 113 Suppl 2 (2015) S58-67.

[13] R. Hosomi, M. Yoshida, K. Fukunaga, Seafood consumption and components for health, Glob J Health Sci 4(3) (2012) 72-86.

[14] P.M. Kris-Etherton, A.M. Hill, N-3 fatty acids: food or supplements?, J Am Diet Assoc 108(7) (2008) 1125-30.

[15] F. Visioli, P. Risé, M.C. Barassi, F. Marangoni, C. Galli, Dietary intake of fish vs. formulations leads to higher plasma concentrations of n-3 fatty acids, Lipids 38(4) (2003) 415-8.

[16] H.K. Maehre, I.J. Jensen, E.O. Elvevoll, K.E. Eilertsen, ω-3 Fatty Acids and Cardiovascular Diseases: Effects, Mechanisms and Dietary Relevance, Int J Mol Sci 16(9) (2015) 22636-61.

[17] L. Dahl, T. Bjørkkjaer, I.E. Graff, M.K. Malde, B. Klementsen, [Fish--more than just omega 3], Tidsskr Nor Laegeforen 126(3) (2006) 309-11.

[18] S.S. Leung Yinko, K.D. Stark, G. Thanassoulis, L. Pilote, Fish consumption and acute coronary syndrome: a meta-analysis, Am J Med 127(9) (2014) 848-57.e2.

[19] T.B. Nielsen, A.M.L. Würtz, A. Tjønneland, K. Overvad, C.C. Dahm, Substitution of unprocessed and processed red meat with poultry or fish and total and cause-specific mortality, British Journal of Nutrition 127(4) (2022) 563-569.

[20] D. Mozaffarian, E.B. Rimm, Fish intake, contaminants, and human health: evaluating the risks and the benefits, Jama 296(15) (2006) 1885-99.

[21] S. Bushkin-Bedient, D.O. Carpenter, Benefits versus risks associated with consumption of fish and other seafood, Rev Environ Health 25(3) (2010) 161-91.

[22] M.I. Castro-González, M. Méndez-Armenta, Heavy metals: Implications associated to fish consumption, Environmental Toxicology and Pharmacology 26(3) (2008) 263-271.

[23] L.G. Costa, Contaminants in fish: risk-benefit considerations, Arh Hig Rada Toksikol 58(3) (2007) 367-74.

[24] M.Y. Hong, J. Lumibao, P. Mistry, R. Saleh, E. Hoh, Fish Oil Contaminated with Persistent Organic Pollutants Reduces Antioxidant Capacity and Induces Oxidative Stress without Affecting Its Capacity to Lower Lipid Concentrations and Systemic Inflammation in Rats, J Nutr 145(5) (2015) 939-44.

[25] N. Burca, R.R. Watson, Chapter 36 - Fish Oil Supplements, Contaminants, and Excessive Doses, in: R.R. Watson, F. De Meester (Eds.), Omega-3 Fatty Acids in Brain and Neurological Health, Academic Press, Boston, 2014, pp. 447-454.

[26] E. van Wijngaarden, S.W. Thurston, G.J. Myers, D. Harrington, D.A. Cory-Slechta, J.J. Strain, G.E. Watson, G. Zareba, T. Love, J. Henderson, C.F. Shamlaye, P.W. Davidson, Methyl mercury exposure and neurodevelopmental outcomes in the Seychelles Child Development Study Main cohort at age 22 and 24years, Neurotoxicol Teratol 59 (2017) 35-42.

[27] G. Genchi, M.S. Sinicropi, A. Carocci, G. Lauria, A. Catalano, Mercury Exposure and Heart Diseases, Int J Environ Res Public Health 14(1) (2017).

[28] Assessment of the health risk of dioxins: re-evaluation of the tolerable daily intake (TDI). Geneva, Switzerland, 25-29 May 1998, Food Addit Contam 17(4) (2000) 223-369.

[29] David O. Carpenter, Polychlorinated Biphenyls (PCBs): Routes of Exposure and Effects on Human Health, Reviews on Environmental Health 21(1) (2006) 1-24.

[30] R. Kudyakov, A. Baibergenova, M. Zdeb, D.O. Carpenter, Respiratory disease in relation to patient residence near to hazardous waste sites, Environ Toxicol Pharmacol 18(3) (2004) 249-57.

[31] D. Fussenegger, D. Suppin, A. Raheem, K. Widhalm, What kind of fish on the table? Omega-3 fatty acids versus mercury contamination, Journal fur Ernahrungsmedizin 9(3) (2007) 6-13.

[32] H. Arksey, L. O'Malley, Scoping studies: towards a methodological framework, International Journal of Social Research Methodology 8(1) (2005) 19-32.

[33] A.H. Metherel, A.Y. Taha, H. Izadi, K.D. Stark, The application of ultrasound energy to increase lipid extraction throughput of solid matrix samples (flaxseed), Prostaglandins Leukot Essent Fatty Acids 81(5-6) (2009) 417-23.

[34] M. Can, A. Gunlu, H. Can, Fish consumption preferences and factors influencing it, Food Science and Technology 35 (2015) 339-346.

[35] H. Ritchie, M. Roser, Biodiversity: Fish and Overfishing, Our World in Data (2021).

[36] P. Capriel, T. Beck, H. Borchert, J. Gronholz, G. Zachmann, Hydrophobicity of the organic matter in arable soils, Soil Biology and Biochemistry 27(11) (1995) 1453-1458.

[37] F.V. Dulf, I. Oroian, D.C. Vodnar, C. Socaciu, A. Pintea, Lipid Classes and Fatty Acid Regiodistribution in Triacylglycerols of Seed Oils of Two Sambucus Species (S. nigra L. and S. ebulus L.), Molecules 18(10) (2013).

[38] A. Maurya, I. Hari, O. Verma, G. Pandey, J. Pal, B. Shukla, H. Verma, International Journal of Fisheries and Aquatic Studies 2018; 6(2): 427-430 A review on role of fish in human nutrition with special emphasis to essential fatty acid, Journal of Fisheries and Aquatic Science (2018).

[39] R.G. Ackman, Nutritional composition of fats in seafoods, Prog Food Nutr Sci 13(3-4) (1989) 161-289.

[40] S. Khalili Tilami, S. Sampels, Nutritional Value of Fish: Lipids, Proteins, Vitamins, and Minerals, Reviews in Fisheries Science & Aquaculture 26(2) (2018) 243-253.

[41] G. Li, A.J. Sinclair, D. Li, Comparison of lipid content and Fatty Acid composition in the edible meat of wild and cultured freshwater and marine fish and shrimps from china, J Agric Food Chem 59(5) (2011) 1871-81.

[42] C. Parzanini, S. Colombo, M. Kainz, A. Wacker, C. Parrish, M. Arts, Discrimination between Freshwater and Marine Fish using Fatty Acids: Ecological Implications and Future Perspectives, Environmental Reviews 28 (2020).

[43] E. Sokoła-Wysoczańska, T. Wysoczański, J. Wagner, K. Czyż, R. Bodkowski, S. Lochyński, B. Patkowska-Sokoła, Polyunsaturated Fatty Acids and Their Potential Therapeutic Role in Cardiovascular System Disorders-A Review, Nutrients 10(10) (2018).

[44] D.R. Tocher, M.J. Leaver, P.A. Hodgson, Recent advances in the biochemistry and molecular biology of fatty acyl desaturases, Prog Lipid Res 37(2-3) (1998) 73-117.

[45] R. Micha, S. Khatibzadeh, P. Shi, S. Fahimi, S. Lim, K.G. Andrews, R.E. Engell, J. Powles, M. Ezzati, D. Mozaffarian, Global, regional, and national consumption levels of dietary fats and oils in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys, Bmj 348 (2014) g2272.

[46] A.A. Dar, A.R. Choudhury, P.K. Kancharla, N. Arumugam, The FAD2 Gene in Plants: Occurrence, Regulation, and Role, Front Plant Sci 8 (2017) 1789.

[47] P. Calder, A.D. Dangour, C. Diekman, A. Eilander, B. Koletzko, G. Meijer, D. Mozaffarian, H. Niinikoski, S. Osendarp, P. Pietinen, A. Schuit, R. Uauy, Essential fats for future health. Proceedings of the 9th Unilever Nutrition Symposium, 26–27 May 2010, European journal of clinical nutrition 64 Suppl 4 (2010) S1-13.

[48] E. Abedi, M.A. Sahari, Long-chain polyunsaturated fatty acid sources and evaluation of their nutritional and functional properties, Food Sci Nutr 2(5) (2014) 443-63.

[49] L.A. Durkin, C.E. Childs, P.C. Calder, Omega-3 Polyunsaturated Fatty Acids and the Intestinal Epithelium-A Review, Foods 10(1) (2021).

[50] F. Shahidi, P. Ambigaipalan, Omega-3 Polyunsaturated Fatty Acids and Their Health Benefits, Annual Review of Food Science and Technology 9(1) (2018) 345-381.

[51] R.J. Henderson, Fatty acid metabolism in freshwater fish with particular reference to polyunsaturated fatty acids, Arch Tierernahr 49(1) (1996) 5-22.

[52] L. Pottel, M. Lycke, T. Boterberg, I. Foubert, H. Pottel, F. Duprez, L. Goethals, P.R. Debruyne, Omega-3 fatty acids: physiology, biological sources and potential applications in supportive cancer care, Phytochemistry Reviews 13(1) (2014) 223-244.

[53] S. Senroy, R. Pal, Microalgae in Aquaculture: A Review with Special References to Nutritional Value and Fish Dietetics, Proceedings of the Zoological Society 68 (2014).

[54] C. Parzanini, S.M. Colombo, M.J. Kainz, A. Wacker, C.C. Parrish, M.T. Arts, Discrimination between freshwater and marine fish using fatty acids: ecological implications and future perspectives, Environ Rev 28(4) (2020) 546-559.

[55] W.C. Tu, B.S. Mühlhäusler, M.J. James, D.A. Stone, R.A. Gibson, An alternative n-3 fatty acid elongation pathway utilising 18:3n-3 in barramundi (Lates calcarifer), Biochem Biophys Res Commun 423(1) (2012) 176-82.

[56] D. Xie, C. Chen, Y. Dong, C. You, S. Wang, Ó. Monroig, D.R. Tocher, Y. Li, Regulation of long-chain polyunsaturated fatty acid biosynthesis in teleost fish, Progress in Lipid Research 82 (2021) 101095.

[57] P. Spiller, J.R. Hibbeln, G. Myers, G. Vannice, J. Golding, M.A. Crawford, J.J. Strain, S.L. Connor, J.T. Brenna, P. Kris-Etherton, B.J. Holub, W.S. Harris, B. Lands, R.K. McNamara, M.F. Tlusty, N. Salem, Jr., S.E. Carlson, An abundance of seafood consumption studies presents new opportunities to evaluate effects on neurocognitive development, Prostaglandins Leukot Essent Fatty Acids 151 (2019) 8-13.

[58] G. Querques, R. Forte, E.H. Souied, Retina and omega-3, J Nutr Metab 2011 (2011) 748361-748361.

[59] M. Correia-da-Silva, E. Sousa, M.M.M. Pinto, A. Kijjoa, Anticancer and cancer preventive compounds from edible marine organisms, Semin Cancer Biol 46 (2017) 55-64.

[60] A.T. Bakre, R. Chen, R. Khutan, L. Wei, T. Smith, G. Qin, I.M. Danat, W. Zhou, P. Schofield, A. Clifford, J. Wang, A. Verma, C. Zhang, J. Ni, Association between fish consumption and risk of dementia: a new study from China and a systematic literature review and meta-analysis, Public Health Nutr 21(10) (2018) 1921-1932.

[61] C. Bouzan, J.T. Cohen, W.E. Connor, P.M. Kris-Etherton, G.M. Gray, A. König, R.S. Lawrence, D.A. Savitz, S.M. Teutsch, A quantitative analysis of fish consumption and stroke risk, Am J Prev Med 29(4) (2005) 347-52.

[62] A.G.J. Tacon, M. Metian, Fish Matters: Importance of Aquatic Foods in Human Nutrition and Global Food Supply, Reviews in Fisheries Science 21(1) (2013) 22-38.

[63] M. Rousseau, I. Batista, Y. Gal, M. Fouchereau-Peron, Purification of a functional antagonist for calcitonin gene related peptide action from sardine hydrolysates, Electronic Journal of Biotechnology (ISSN: 0717-3458) Vol 4 Num 1 4 (2001).

[64] H.F. Dale, L. Madsen, G.A. Lied, Fish-derived proteins and their potential to improve human health, Nutr Rev (2019).

[65] A. Maurya, I. Hari, O. Verma, G. Pandey, J. Pal, B. Shukla, H. Verma, A review on role of fish in human nutrition with special emphasis to essential fatty acid, Journal of Fisheries and Aquatic Science (2018).

[66] M. Md Noh, D.-N. Rathi, S. Mustar, Vitamin A in Health and Disease, 2019.

[67] M.F. Holick, Vitamin D: its role in cancer prevention and treatment, Prog Biophys Mol Biol 92(1) (2006) 49-59.

[68] M. Komai, H. Shirakawa, [Vitamin K metabolism. Menaquinone-4 (MK-4) formation from ingested VK analogues and its potent relation to bone function], Clin Calcium 17(11) (2007) 1663-1672.

[69] B. Þorgilsson, M.L. Nunes, H. Gunnlaugsdóttir, Review of evidence for the beneficial effect of fish consumption, (2010).

[70] P. Trumbo, A.A. Yates, S. Schlicker, M. Poos, Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc, J Am Diet Assoc 101(3) (2001) 294-301.

[71] Z.T. Liu, A.H. Lin, Dietary factors and thyroid cancer risk: a meta-analysis of observational studies, Nutr Cancer 66(7) (2014) 1165-78.

[72] D.H. Holben, A.M. Smith, The diverse role of selenium within selenoproteins: a review, J Am Diet Assoc 99(7) (1999) 836-43.

[73] B. Mohanty, S. Ganguly, A. Mahanty, T. Mitra, S. Patra, D. Karunakaran, S. Mathew, K. Chakraborty, B. Paul, D. Sarma, J. Dayal, S. Singh, S. Ayyappan, FISH IN HUMAN HEALTH AND NUTRITION, 2019, pp. 189-218.

[74] D. Mozaffarian, Fish, mercury, selenium and cardiovascular risk: Current evidence and unanswered questions, International Journal of Environmental Research and Public Health 6(6) (2009) 1894-1916.

[75] I. Sioen, S. De Henauw, J. Van Camp, Evaluation of benefits and risks related to seafood consumption, Verh K Acad Geneeskd Belg 69(5-6) (2007) 249-89.

[76] G. Chiocchetti, C. Jadán-Piedra, D. Vélez, V. Devesa, Metal(loid) contamination in seafood products, Critical reviews in food science and nutrition 57(17) (2017) 3715-3728.

[77] S. Díez, Human health effects of methylmercury exposure, Rev Environ Contam Toxicol 198 (2009) 111-32.

[78] G. David, I. Isangedighi, Heavy Metals Contamination in Fish: Effects on Human Health, 2 (2019) 7-12.

[79] A.C. Scherer, A. Tsuchiya, L.R. Younglove, T.M. Burbacher, E.M. Faustman, Comparative analysis of state fish consumption advisories targeting sensitive populations, Environ Health Perspect 116(12) (2008) 1598-606.

[80] V. Sirot, J.C. Leblanc, I. Margaritis, A risk-benefit analysis approach to seafood intake to determine optimal consumption, British Journal of Nutrition 107(12) (2012) 1812-1822.

[81] W. Maret, J.-M. Moulis, The Bioinorganic Chemistry of Cadmium in the Context of Its Toxicity, in: A. Sigel, H. Sigel, R.K.O. Sigel (Eds.), Cadmium: From Toxicity to Essentiality, Springer Netherlands, Dordrecht, 2013, pp. 1-29.

[82] M.F. Hughes, Arsenic toxicity and potential mechanisms of action, Toxicology Letters 133(1) (2002) 1-16.

[83] S.M. Cohen, L.L. Arnold, B.D. Beck, A.S. Lewis, M. Eldan, Evaluation of the carcinogenicity of inorganic arsenic, Critical Reviews in Toxicology 43(9) (2013) 711-752.

[84] V. Taylor, B. Goodale, A. Raab, T. Schwerdtle, K. Reimer, S. Conklin, M.R. Karagas, K.A. Francesconi, Human exposure to organic arsenic species from seafood, Sci Total Environ 580 (2017) 266-282.

[85] K. Straif, L. Tallaa, R. Baan, Y. Grosse, B. Lauby-Secretan, F. Ghissassi, V. Bouvard, N. Guha, C. Freeman, L. Galichet, V. Cogliano, A review of human Carcinogens part C: Metals, arsenic, dusts and fibres, The lancet oncology 10 (2009) 453-4.

[86] H. Needleman, Lead Poisoning, Annual Review of Medicine 55(1) (2004) 209-222.

[87] J.-W. Lee, H. Choi, U.-K. Hwang, J.-C. Kang, Y.J. Kang, K.I. Kim, J.-H. Kim, Toxic effects of lead exposure on bioaccumulation, oxidative stress, neurotoxicity, and immune responses in fish: A review, Environmental Toxicology and Pharmacology 68 (2019) 101-108.

[88] I.J. Tamele, P. Vázquez Loureiro, Lead, Mercury and Cadmium in Fish and Shellfish from the Indian Ocean and Red Sea (African Countries): Public Health Challenges, Journal of Marine Science and Engineering 8(5) (2020) 344.

[89] A.L. Wani, A. Ara, J.A. Usmani, Lead toxicity: a review, Interdiscip Toxicol 8(2) (2015) 55-64.

[90] M. Balali-Mood, K. Naseri, Z. Tahergorabi, M.R. Khazdair, M. Sadeghi, Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic, Front Pharmacol 12 (2021) 643972.

[91] A. Beyer, D. Mackay, M. Matthies, F. Wania, E. Webster, Assessing Long-Range Transport Potential of Persistent Organic Pollutants, Environmental Science & Technology 34(4) (2000) 699-703.

[92] S. Panseri, L. Chiesa, G. Ghisleni, G. Marano, P. Boracchi, V. Ranghieri, R.M. Malandra, P. Roccabianca, M. Tecilla, Persistent organic pollutants in fish: biomonitoring and cocktail effect with implications for food safety, Food Additives & Contaminants: Part A 36(4) (2019) 601-611.

[93] W. Guo, B. Pan, S. Sakkiah, G. Yavas, W. Ge, W. Zou, W. Tong, H. Hong, Persistent Organic Pollutants in Food: Contamination Sources, Health Effects and Detection Methods, Int J Environ Res Public Health 16(22) (2019) 4361.

[94] K. von Stackelberg, Polychlorinated biphenyls, in: J.O. Nriagu (Ed.), Encyclopedia of Environmental Health, Elsevier, Burlington, 2011, pp. 346-356.

[95] Vandana, M. Priyadarshanee, U. Mahto, S. Das, Chapter 2 - Mechanism of toxicity and adverse health effects of environmental pollutants, in: S. Das, H.R. Dash (Eds.), Microbial Biodegradation and Bioremediation (Second Edition), Elsevier2022, pp. 33-53.

[96] O. Wine, A.R. Osornio-Vargas, I. Buka, Fish consumption by children in Canada: Review of evidence, challenges and future goals, Paediatrics and Child Health (Canada) 17(5) (2012) 241-245.

[97] J.K. Huwe, Dioxins in Food: A Modern Agricultural Perspective, Journal of Agricultural and Food Chemistry 50(7) (2002) 1739-1750.

[98] P.A. Bertazzi, D. Consonni, S. Bachetti, M. Rubagotti, A. Baccarelli, C. Zocchetti, A.C. Pesatori, Health Effects of Dioxin Exposure: A 20-Year Mortality Study, American Journal of Epidemiology 153(11) (2001) 1031-1044.

[99] J. Beard, DDT and human health, Science of The Total Environment 355(1) (2006) 78-89.

[100] S. Di, R. Liu, Z. Tian, C. Cheng, L. Chen, W. Zhang, Z. Zhou, J. Diao, Assessment of tissue-specific accumulation, elimination and toxic effects of dichlorodiphenyltrichloroethanes (DDTs) in carp through aquatic food web, Sci Rep 7(1) (2017) 2288.

[101] G. Kasza, T. Izsó, E.Z. Csenki, A. Micsinai, B. Nyirő-Fekete, B. Urbányi, B. Alpár, Assessment of Dietary Exposure and Risk of DDT Concerning Freshwater Fish Aquaculture, Applied Sciences 10(24) (2020) 9083.

[102] M.P. Longnecker, W.J. Rogan, G. Lucier, The human health effects of DDT (dichlorodiphenyl-trichloroethane) and PCBs (polychlorinated biphenyls) and an overview of organochlorines in public health, Annual review of public health 18 (1997) 211.

[103] Fish-Associated Foodborne Disease Outbreaks: United States, 1998–2015, Foodborne Pathogens and Disease 14(9) (2017) 537-543.

[104] J. Uradziński, B. Wysok, M. Gomółka-Pawlicka, Biological and chemical hazards occurring in fish and fishery products, Pol J Vet Sci 10(3) (2007) 183-8.

[105] A.M. Adams, K.D. Murrell, J.H. Cross, Parasites of fish and risks to public health, Rev Sci Tech 16(2) (1997) 652-60.

[106] S.S. Khora, Therapeutic benefits of Ω-3 fatty acids from fish, International Journal of Drug Development and Research 5(2) (2013) 55-65.

[107] P.M. Kris-Etherton, W.S. Harris, L.J. Appel, Fish Consumption, Fish Oil, Omega-3 Fatty Acids, and Cardiovascular Disease, Circulation 106(21) (2002) 2747-2757.

[108] J. Oehlenschläger, Seafood: nutritional benefits and risk aspects, Int J Vitam Nutr Res 82(3) (2012) 168-76.

[109] D. Banerjee, A.P. Rajan, Consuming fish for nutrition and medicine is boon or doom: A review on scientific perspective, International Journal of Research in Ayurveda and Pharmacy 8 (2017) 80-85.

[110] E. Oken, A.L. Choi, M.R. Karagas, K. Mariën, C.M. Rheinberger, R. Schoeny, E. Sunderland, S. Korrick, Which fish should I eat? Perspectives influencing fish consumption choices, Environ Health Perspect 120(6) (2012) 790-8.

[111] Á. Alonso, M.Á. Martínez-González, M. Serrano-Martínez, Fish omega-3 fatty acids and risk of coronary heart disease, Medicina Clinica 121(1) (2003) 28-35.

[112] F.M. Al-Ardhi, M.R. Al-Ani, Maternal fish consumption and prenatal methylmercury exposure: a review, Nutr Health 19(4) (2008) 289-97.

[113] H.M. Chan, G.M. Egeland, Fish consumption, mercury exposure, and heart diseases, Nutr Rev 62(2) (2004) 68-72.

[114] K.R. Mahaffey, E.M. Sunderland, H.M. Chan, A.L. Choi, P. Grandjean, K. Mariën, E. Oken, M. Sakamoto, R. Schoeny, P. Weihe, Balancing the benefits of n-3 polyunsaturated fatty acids and the risks of methylmercury exposure from fish consumption, Nutrition reviews 69(9) (2011) 493-508.

[115] G. Brambilla, M.C. Abete, G. Binato, E. Chiaravalle, M. Cossu, E. Dellatte, R. Miniero, R. Orletti, P. Piras, A. Roncarati, A. Ubaldi, G. Chessa, Mercury occurrence in Italian seafood from the Mediterranean Sea and possible intake scenarios of the Italian coastal population, Regulatory Toxicology and Pharmacology 65(2) (2013) 269-277.

[116] D.C. Depew, N.M. Burgess, M.R. Anderson, R. Baker, S.P. Bhavsar, R.A. Bodaly, C.S. Eckley, M.S. Evans, N. Gantner, J.A. Graydon, K. Jacobs, J.E. LeBlanc, V.L. St Louis, L.M. Campbell, An overview of mercury concentrations in freshwater fish species: a national fish mercury dataset for Canada, Can J Fish Aquat Sci 70(3) (2013) 436-451.

[117] D. Levac, H. Colquhoun, K.K. O'Brien, Scoping studies: advancing the methodology, Implementation Science 5(1) (2010) 69.

[118] S. Saha, S. Saint, D.A. Christakis, Impact factor: a valid measure of journal quality?, J Med Libr Assoc 91(1) (2003) 42-6.

[119] K. Toom, Chapter 10 - Indicators, in: J. Andersen, K. Toom, S. Poli, P.F. Miller (Eds.), Research Management, Academic Press, Boston, 2018, pp. 213-230.

[120] C. Galli, P. Risé, Fish consumption, omega 3 fatty acids and cardiovascular disease. The science and the clinical trials, Nutr Health 20(1) (2009) 11-20.

[121] K. He, Fish, long-chain omega-3 polyunsaturated fatty acids and prevention of cardiovascular disease--eat fish or take fish oil supplement?, Prog Cardiovasc Dis 52(2) (2009) 95-114.

[122] T.A. Mori, Omega-3 fatty acids and cardiovascular disease: epidemiology and effects on cardiometabolic risk factors, Food Funct 5(9) (2014) 2004-19.

[123] T.A. Mori, L.J. Beilin, Omega-3 fatty acids and inflammation, Curr Atheroscler Rep 6(6) (2004) 461-7.

[124] A. Grey, M. Bolland, Clinical Trial Evidence and Use of Fish Oil Supplements, JAMA Internal Medicine 174(3) (2014) 460-462.

[125] D. Mozaffarian, R. Marchioli, A. Macchia, M.G. Silletta, P. Ferrazzi, T.J. Gardner, R. Latini, P. Libby, F. Lombardi, P.T. O'Gara, R.L. Page, L. Tavazzi, G. Tognoni, Fish oil and postoperative atrial fibrillation: the Omega-3 Fatty Acids for Prevention of Post-operative Atrial Fibrillation (OPERA) randomized trial, Jama 308(19) (2012) 2001-11.

[126] A.M. Parian, G.E. Mullin, Fish Consumption and Health: The Yin and Yang, Nutr Clin Pract 31(4) (2016) 562-5.

[127] S.K. Raatz, J.T. Silverstein, L. Jahns, M.J. Picklo, Issues of fish consumption for cardiovascular disease risk reduction, Nutrients 5(4) (2013) 1081-97.

[128] J.R. Sargent, A.G. Tacon, Development of farmed fish: a nutritionally necessary alternative to meat, Proc Nutr Soc 58(2) (1999) 377-83.

[129] I.F. Benzie, Lipid peroxidation: a review of causes, consequences, measurement and dietary influences, Int J Food Sci Nutr 47(3) (1996) 233-61.

[130] F. Shahidi, Y. Zhong, Lipid oxidation and improving the oxidative stability, Chem Soc Rev 39(11) (2010) 4067-79.

[131] B.B. Albert, D. Cameron-Smith, P.L. Hofman, W.S. Cutfield, Oxidation of marine omega-3 supplements and human health, Biomed Res Int 2013 (2013) 464921.

[132] S.A. Jackowski, A.Z. Alvi, A. Mirajkar, Z. Imani, Y. Gamalevych, N.A. Shaikh, G. Jackowski, Oxidation levels of North American over-the-counter n-3 (omega-3) supplements and the

influence of supplement formulation and delivery form on evaluating oxidative safety, J Nutr Sci 4 (2015) e30.

[133] M. Gochfeld, J. Burger, Good fish/bad fish: a composite benefit-risk by dose curve, Neurotoxicology 26(4) (2005) 511-20.

[134] M.E. Turyk, S.P. Bhavsar, W. Bowerman, E. Boysen, M. Clark, M. Diamond, D. Mergler, P. Pantazopoulos, S. Schantz, D.O. Carpenter, Risks and benefits of consumption of Great Lakes fish, Environ Health Perspect 120(1) (2012) 11-8.

[135] H. Uran, N. Gokoglu, Effects of cooking methods and temperatures on nutritional and quality characteristics of anchovy (Engraulis encrasicholus), J Food Sci Technol 51(4) (2014) 722-8.

[136] M. Marquès, C.M. Torres, F. García-Fernández, A. Mantur-Vierendeel, M. Roe, A.M. Wilson, M. Reuver, M. Nadal, J.L. Domingo, FishChoice 2.0: Information on health benefits / risks and sustainability for seafood consumers, Food and Chemical Toxicology 155 (2021) 112387.

[137] G. Pandey, A.B. Shrivastav, Contamination of mercury in fish and its toxicity to both fish and humans: An overview, International Research Journal of Pharmacy 3 (2012) 44-47.

[138] Health Canada. Fish Consumption Advice, 2019. Available from: https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/environmental-contaminants/mercury/mercury-fish-questions-answers.html.

[139] I.V. Hagen, A. Helland, M. Bratlie, K.A. Brokstad, G. Rosenlund, H. Sveier, G. Mellgren, O.A. Gudbrandsen, High intake of fatty fish, but not of lean fish, affects serum concentrations of TAG and HDL-cholesterol in healthy, normal-weight adults: a randomised trial, Br J Nutr 116(4) (2016) 648-57.

[140] C. Tørris, M. Molin, M.C. Småstuen, Lean Fish Consumption Is Associated with Beneficial Changes in the Metabolic Syndrome Components: A 13-Year Follow-Up Study from the Norwegian Tromsø Study, Nutrients 9(3) (2017).

[141] J.U. Skåre, A.L. Brantsæter, L. Frøyland, G.I. Hemre, H.K. Knutsen, I.T.L. Lillegaard, Å.K. Andreassen, E.O. Elvevoll, L.F. Andersen, B. Hjeltnes, Benefit-risk assessment of fish and fish products in the Norwegian diet–an update. Opinion of the Scientific Steering Committee of the Norwegian Scientific Committee for Food Safety, VKM Report (2014).

[142] E.B. Rimm, L.J. Appel, S.E. Chiuve, L. Djoussé, M.B. Engler, P.M. Kris-Etherton, D. Mozaffarian, D.S. Siscovick, A.H. Lichtenstein, Seafood Long-Chain n-3 Polyunsaturated Fatty Acids and Cardiovascular Disease: A Science Advisory From the American Heart Association, Circulation 138(1) (2018) e35-e47.

[143] V. Demarin, M. Lisak, S. Morović, Mediterranean diet in healthy lifestyle and prevention of stroke, Acta Clin Croat 50(1) (2011) 67-77.

[144] Z. Zhang, G.C. Chen, Z.Z. Qin, X. Tong, D.P. Li, L.Q. Qin, Poultry and Fish Consumption in Relation to Total Cancer Mortality: A Meta-Analysis of Prospective Studies, Nutr Cancer 70(2) (2018) 204-212.

[145] D. Mozaffarian, J.S. Gottdiener, D.S. Siscovick, Intake of tuna or other broiled or baked fish versus fried fish and cardiac structure, function, and hemodynamics, Am J Cardiol 97(2) (2006) 216-22.

[146] S. Goswami, K. Manna, Comparison of the effects of cooking methods on nutritional composition of fresh and salted Tenualosa ilisha, Aquaculture and Fisheries 5(6) (2020) 294-299.

[147] R. Ferrari, Writing narrative style literature reviews, Medical Writing 24 (2015) 230-235.

[148] J.A. Collins, B.C.J.M. Fauser, Balancing the strengths of systematic and narrative reviews, Human Reproduction Update 11(2) (2005) 103-104.

[149] R.P. Froese, Daniel., FishBase 2000: concepts, design and data sources, ICLARM, Los Baños, Laguna, Philippines, 2000, p. 344p.

[150] Health Canada, Food and Nutrition. Canadian Nutrient File, 2015. Available from: https://food-nutrition.canada.ca/cnf-fce/index-eng.jsp.

[151] J. Deeks, M.-F. Verreault, W. Cheung, Canadian Nutrient File (CNF): Update on Canadian food composition activities, Journal of Food Composition and Analysis 64 (2017) 43-47.

[152] USDA, Composition of Foods Raw, Processed, Prepared USDA National Nutrient Database for Standard Reference, Release 28 (2015) Documentation and User Guide, (2015).

[153] X.F. Hu, H.M. Chan, Seafood Consumption and Its Contribution to Nutrients Intake among Canadians in 2004 and 2015, Nutrients 13(1) (2020).

[154] Fishbase Nutrient Analysis Tool (2021, July 17). Mamacneil. Retrieved August 29, 2022, from https://github.com/mamacneil/NutrientFishbase.

[155] FAO, FAOSTAT-Food Balances (2010-), 2022.

[156] A. Cahyadi, R. Magda, Digital Leadership in the Economies of the G20 Countries: A Secondary Research, Economies 9(1) (2021) 32.

[157] J. Ning, Main Data of the Seventh National Population Census. Available from: http://www.stats.gov.cn/english/PressRelease/202105/t20210510_1817185.html, 2021.

[158] K. Dai, S. Shen, C. Cheng, Evaluation and analysis of the projected population of China, Scientific Reports 12(1) (2022) 3644.

[159] B. Belton, S.R. Bush, D.C. Little, Not just for the wealthy: Rethinking farmed fish consumption in the Global South, Global Food Security 16 (2018) 85-92.

[160] R.L. Naylor, A. Kishore, U.R. Sumaila, I. Issifu, B.P. Hunter, B. Belton, S.R. Bush, L. Cao, S. Gelcich, J.A. Gephart, C.D. Golden, M. Jonell, J.Z. Koehn, D.C. Little, S.H. Thilsted, M. Tigchelaar, B. Crona, Blue food demand across geographic and temporal scales, Nat Commun 12(1) (2021) 5413.

[161] A. Gordon, Finegold, C., Crissman, C. C., & Pulis, A., Fish production, consumption and trade in Sub-Saharan Africa: A Review analysis., (2013).

[162] C.Y. Chan, N. Tran, S. Pethiyagoda, C.C. Crissman, T.B. Sulser, M.J. Phillips, Prospects and challenges of fish for food security in Africa, Global Food Security 20 (2019) 17-25.

[163] T. Peristiwady, Ichthyological Research and Biodiversity of Marine Fishes in Indonesia, IOP Conference Series: Earth and Environmental Science 789(1) (2021) 012009.

[164] J. Keesing, T. Irvine, Coastal biodiversity in the Indian Ocean: The known, the unknown and the unknowable, 34 (2005).

[165] A.J. Butler, T. Rees, P. Beesley, N.J. Bax, Marine biodiversity in the Australian region, PLoS One 5(8) (2010) e11831.

[166] D.J. Conley, S. Björck, E. Bonsdorff, J. Carstensen, G. Destouni, B.G. Gustafsson, S. Hietanen, M. Kortekaas, H. Kuosa, H.E. Markus Meier, B. Müller-Karulis, K. Nordberg, A. Norkko, G. Nürnberg, H. Pitkänen, N.N. Rabalais, R. Rosenberg, O.P. Savchuk, C.P. Slomp, M. Voss, F. Wulff, L. Zillén, Hypoxia-Related Processes in the Baltic Sea, Environmental Science & Technology 43(10) (2009) 3412-3420.

[167] A. Capet, J.-M. Beckers, M. Grégoire, Drivers, mechanisms and long-term variability of seasonal hypoxia on the Black Sea northwestern shelf - Is there any recovery after eutrophication?, Biogeosciences 10 (2013) 3943-3962.

[168] F. Bastardie, E.J. Brown, E. Andonegi, R. Arthur, E. Beukhof, J. Depestele, R. Döring, O.R. Eigaard, I. García-Barón, M. Llope, H. Mendes, G. Piet, D. Reid, A Review Characterizing 25 Ecosystem Challenges to Be Addressed by an Ecosystem Approach to Fisheries Management in Europe, Frontiers in Marine Science 7 (2021).

[169] Government of Canada. (2021, March 3). Sector Trend Analysis – Fish and seafood trends in South Korea. Retrieved August 29, 2022, from https://agriculture.canada.ca/en/international-trade/market-intelligence/reports/sector-trend-analysis-fish-and-seafood-trends-south-korea.

[170] N. Garcia, I. Harrison, N. Cox, M. Tognelli, The Status and Distribution of Freshwater Biodiversity in the Arabian Peninsula, 2015.

[171] M.L. Messager, B. Lehner, G. Grill, I. Nedeva, O. Schmitt, Estimating the volume and age of water stored in global lakes using a geo-statistical approach, Nature Communications 7(1) (2016) 13603.

[172] C. Dey, A. Rego, M. Bradford, K. Clarke, K. McKercher, N. Mochnacz, A. Paiva, K. Ponader, L. Robichaud, A. Winegardner, C. Berryman, P. Blanchfield, C. Boston, D. Braun, J. Brownscombe, C. Burbidge, S. Campbell, A. Cassidy, C. Chu, M. Koops, Research priorities for the management of freshwater fish habitat in Canada, Canadian Journal of Fisheries and Aquatic Sciences 78 (2021) 1-11.

[173] C. Chu, C. Minns, N. Mandrak, Comparative regional assessment of factors impacting freshwater fish biodiversity in Canada, Canadian Journal of Fisheries and Aquatic Sciences 60 (2003) 624-634.

[174] F.T. Marcelo, M.-T. Laura, K. Dan, L. Dwayne, M. Gerry, M. Todd, C. Joseph, A. Noel, T. Bill, C. Neil, G.S. Kevin, Freshwater key biodiversity areas in Canada, International Union for Conservation of Nature, IUCN, IUCN Species Survival Commission (SSC), IUCN Global Species Programme, Conservation International, 2017.

[175] F.H. Rigler, Limnology in the high Arctic: a case study of Char Lake, SIL Proceedings, 1922-2010 20(1) (1978) 127-140.

[176] A.S. Parpia, P.B. Darling, M.R. L'Abbé, M.B. Goldstein, J. Arcand, A. Cope, A.S. Shaikh, The accuracy of Canadian Nutrient File data for reporting phosphorus, potassium, sodium, and protein in selected meat, poultry, and fish products, Can J Public Health 109(1) (2018) 150-152.

[177] N.K. Fukagawa, K. McKillop, P.R. Pehrsson, A. Moshfegh, J. Harnly, J. Finley, USDA's FoodData Central: what is it and why is it needed today?, The American journal of clinical nutrition 115(3) (2022) 619-624.

[178] K. Stergiou, A. Tsikliras, SCIENTIFIC IMPACT OF FISHBASE: A CITATION ANALYSIS, Fisheries Centre Research Reports 14 (2006) 2-6.

[179] I. Csizmadi, L. Kahle, R. Ullman, U. Dawe, T.P. Zimmerman, C.M. Friedenreich, H. Bryant, A.F. Subar, Adaptation and evaluation of the National Cancer Institute's Diet History Questionnaire and nutrient database for Canadian populations, Public Health Nutr 10(1) (2007) 88-96.

[180] Canadian Nutrient File (2015). Fish, salmon, pink (humpback), raw. from https://food-nutrition.canada.ca/cnf-fce/report-rapport.do.

[181] Canadian Nutrient File (2015). Fish, salmon, chum (keta), raw. from https://food-nutrition.canada.ca/cnf-fce/report-rapport.do.

[182] L.J.S. Tsuji, S.R.J. Tsuji, A.M. Zuk, R. Davey, E.N. Liberda, Harvest Programs in First Nations of Subarctic Canada: The Benefits Go Beyond Addressing Food Security and Environmental Sustainability Issues, Int J Environ Res Public Health 17(21) (2020) 8113.

[183] H.V. Kuhnlein, O. Receveur, Dietary change and traditional food systems of indigenous peoples, Annual review of nutrition 16(1) (1996) 417-442.

[184] M. Ratelle, K. Skinner, M.J. Laird, S. Majowicz, D. Brandow, S. Packull-McCormick, M. Bouchard, D. Dieme, K.D. Stark, J.J.A. Henao, R. Hanning, B.D. Laird, Implementation of human biomonitoring in the Dehcho region of the Northwest Territories, Canada (2016-2017), Arch Public Health 76 (2018) 73.

[185] J.L. Domingo, Nutrients and Chemical Pollutants in Fish and Shellfish. Balancing Health Benefits and Risks of Regular Fish Consumption, Critical Reviews in Food Science and Nutrition 56(6) (2016) 979-988.

[186] M.A. Stapanian, V.L. Paragamian, C.P. Madenjian, J.R. Jackson, J. Lappalainen, M.J. Evenson, M.D. Neufeld, Worldwide status of burbot and conservation measures, Fish and Fisheries 11(1) (2010) 34-56.

[187] A. Hayward, E. Sjoblom, S. Sinclair, J. Cidro, A New Era of Indigenous Research: Community-based Indigenous Research Ethics Protocols in Canada, Journal of Empirical Research on Human Research Ethics 16(4) (2021) 403-417.

[188] P.M. Emmett, L.R. Jones, J. Golding, Pregnancy diet and associated outcomes in the Avon Longitudinal Study of Parents and Children, Nutr Rev 73 Suppl 3(Suppl 3) (2015) 154-74.

[189] S. Perna, I. Avanzato, M. Nichetti, G. D'Antona, M. Negro, M. Rondanelli, Association between Dietary Patterns of Meat and Fish Consumption with Bone Mineral Density or Fracture Risk: A Systematic Literature, Nutrients 9(9) (2017).

[190] G.C. Román, R.E. Jackson, R. Gadhia, A.N. Román, J. Reis, Mediterranean diet: The role of long-chain ω-3 fatty acids in fish; polyphenols in fruits, vegetables, cereals, coffee, tea, cacao and wine; probiotics and vitamins in prevention of stroke, age-related cognitive decline, and Alzheimer disease, Rev Neurol (Paris) 175(10) (2019) 724-741.

[191] D. Swanson, R. Block, S.A. Mousa, Omega-3 fatty acids EPA and DHA: health benefits throughout life, Adv Nutr 3(1) (2012) 1-7.

[192] H. Yang, P. Xun, K. He, Fish and fish oil intake in relation to risk of asthma: a systematic review and meta-analysis, PLoS One 8(11) (2013) e80048.

[193] M.C.W. Williams, E.W. Murphy, H.B. McCarty, B.D. Snyder, C.S. Schrank, P.J. McCann, B.S. Crimmins, Variation in the essential fatty acids EPA and DHA in fillets of fish from the Great Lakes region, Journal of Great Lakes Research 43(3) (2017) 150-160.

[194] M.C.W. Williams, C. Schrank, H.A. Anderson, Fatty acids in thirteen Wisconsin sport fish species, Journal of Great Lakes Research 40(3) (2014) 771-777.

[195] W.R. Morrison, L.M. Smith, Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride–methanol, Journal of lipid research 5(4) (1964) 600-608.

[196] K. Stark, N. Salem, Fast gas chromatography for the identification of fatty acid methyl esters from mammalian samples, Lipid Technology 17(8) (2005) 181.

[197] O. Taşbozan, M. Gokce, Fatty Acids in Fish. In (Ed.), Fatty Acids. IntechOpen. https://doi.org/10.5772/68048

2017.

[198] U. Strandberg, S.P. Bhavsar, M.T. Arts, Estimation of omega-3 fatty acid (EPA+DHA) intake from Lake Ontario fish based on provincial consumption advisories, Journal of Great Lakes Research 43(6) (2017) 1132-1140.

[199] M.J. Dellinger, J. Olson, B. Holub, M.P. Ripley, Fatty Acids in Ten Species of Fish Commonly Consumed by the Anishinaabe of the Upper Great Lakes, J Great Lakes Res 44(3) (2018) 521-526.

[200] A.G. Dvoretsky, F.A. Bichkaeva, O.S. Vlasova, S.V. Andronov, V.G. Dvoretsky, Fatty Acid Content of Four Salmonid Fish Consumed by Indigenous Peoples from the Yamal-Nenets Autonomous Okrug (Northwestern Siberia, Russia), Animals (Basel) 12(13) (2022).

[201] J. MAI, J.E. KINSELLA, LIPID COMPOSITION OF DARK AND WHITE MUSCLE FROM WHITE SUCKER (Catostomus commersoni), Journal of Food Science 44(4) (1979) 1101-1105.

[202] Z. Linhartová, J. Krejsa, T. Zajíc, J. Másílko, S. Sampels, J. Mráz, Proximate and fatty acid composition of 13 important freshwater fish species in central Europe, Aquaculture International 26(2) (2018) 695-711.

[203] M.J. Laird, J.J.A. Henao, E.S. Reyes, K.D. Stark, G. Low, H.K. Swanson, B.D. Laird, Mercury and omega-3 fatty acid profiles in freshwater fish of the Dehcho Region, Northwest Territories: Informing risk benefit assessments, Science of The Total Environment 637-638 (2018) 1508-1517.

[204] M. Vasconi, F. Caprino, F. Bellagamba, M.L. Busetto, C. Bernardi, C. Puzzi, V.M. Moretti, Fatty Acid Composition of Freshwater Wild Fish in Subalpine Lakes: A Comparative Study, Lipids 50(3) (2015) 283-302.

[205] U.S. Department of Agriculture, Agricultural Research Service. FoodData Central, 2019. Available from: https://fdc.nal.usda.gov.

[206] G. Grosbois, M. Power, M. Evans, G. Koehler, M. Rautio, Content, composition, and transfer of polyunsaturated fatty acids in an Arctic lake food web, Ecosphere 13(1) (2022) e03881.

[207] M. Stanek, J. D¹browski, A. Rooelewska, B. Kupcewicz, B. Janicki, Impact of Different Fishing Seasons on the Fatty Acids Profile, Cholesterol Content, And Fat in the Muscles of Perch, Perca Fluviatils L. from the Włocławski Reservoir (Central Poland), Archives of Polish Fisheries 16 (2008) 213-220.

[208] C. Martinez-Palacios, S. Concha-Santos, E. Toledo-Cuevas, M. Ríos-Durán, C. Martínez Chávez, P. Navarrete-Ramírez, L. Raggi, C. Strussmann, J. Hualde, M. Demicheli, J. Fonseca-Madrigal, High levels of docosahexaenoic acid are present in eight New World silversides (Pisces: Atherinopsidae), Neotropical Ichthyology 18 (2020).

[209] K.D. Stark, A.C. Patterson, EPA and DHA--protein, not fat is "where it's at"?, Prostaglandins Leukot Essent Fatty Acids 87(1) (2012) 49-51.

[210] K.D. Stark, Applications of Innovative Lipidomic Methods for Blood Lipid Biomarkers, J Oleo Sci 68(6) (2019) 503-510.

[211] T.L. Blasbalg, J.R. Hibbeln, C.E. Ramsden, S.F. Majchrzak, R.R. Rawlings, Changes in consumption of omega-3 and omega-6 fatty acids in the United States during the 20th century, Am J Clin Nutr 93(5) (2011) 950-62.

[212] K. Kwasek, A.L. Thorne-Lyman, M. Phillips, Can human nutrition be improved through better fish feeding practices? a review paper, Critical Reviews in Food Science and Nutrition 60(22) (2020) 3822-3835.

[213] R.J. Beamish, H. Tsuyuki, A Biochemical and Cytological Study of the Longnose Sucker (Catostomus catostomus) and Large and Dwarf Forms of the White Sucker (Catostomus commersoni), Journal of the Fisheries Research Board of Canada 28 (2011) 1745-1748.

[214] K.M. Furey, H.C. Glassic, C.S. Guy, T.M. Koel, J.L. Arnold, P.D. Doepke, P.E. Bigelow, Diets of Longnose Sucker in Yellowstone Lake, Yellowstone National Park, USA, Journal of Freshwater Ecology 35(1) (2020) 291-303.

[215] J.Y. Zhang, K.S.D. Kothapalli, J.T. Brenna, Desaturase and elongase-limiting endogenous long-chain polyunsaturated fatty acid biosynthesis, Current Opinion in Clinical Nutrition & Metabolic Care 19(2) (2016) 103-110.

[216] M.A. Stapanian, C.P. Madenjian, Introduction to a Special Section: Ecology, Culture, and Management of Burbot, Transactions of the American Fisheries Society 142(6) (2013) 1659-1661.

[217] T.J. Bruce, S. Gulen, L.P. Oliver, J. Ma, K.D. Cain, Evaluation of commercial and experimental grower diets for use in intensive burbot (Lota lota maculosa) culture, Aquaculture 528 (2020) 735490.

[218] A. Wong, Lipidic profiles of tissue and liver oil of burbot, Lota lota (L.), Acta Ichthyologica Et Piscatoria 38 (2008) 55-61.

[219] S. Ando, Y. Mori, K. Nakamura, A. Sugawara, Characteristics of Lipid Accumulation Types in Five Species of Fish, NIPPON SUISAN GAKKAISHI 59(9) (1993) 1559-1564.

[220] P.C. Calder, Preface, in: P.J. García-Moreno, C. Jacobsen, A.-D. Moltke Sørensen, B. Yesiltas (Eds.), Omega-3 Delivery Systems, Academic Press2021, pp. xiii-xiv.

[221] S. Meier, S.A. Mjøs, H. Joensen, O. Grahl-Nielsen, Validation of a one-step extraction/methylation method for determination of fatty acids and cholesterol in marine tissues, J Chromatogr A 1104(1-2) (2006) 291-8.

[222] J.M. Njinkoué, G. Barnathan, J. Miralles, E.M. Gaydou, A. Samb, Lipids and fatty acids in muscle, liver and skin of three edible fish from the Senegalese coast: Sardinella maderensis, Sardinella aurita and Cephalopholis taeniops, Comp Biochem Physiol B Biochem Mol Biol 131(3) (2002) 395-402.

[223] Burbot (Loche). Health and Social Services. Retrieved September 20, 2022, from https://www.hss.gov.nt.ca/en/services/environmental-contaminants/burbot-loche.

[224] R.M. Hayman, S.R. Dalziel, Acute vitamin A toxicity: a report of three paediatric cases, J Paediatr Child Health 48(3) (2012) E98-100.

[225] M. Varol, M.R. Sünbül, Macroelements and toxic trace elements in muscle and liver of fish species from the largest three reservoirs in Turkey and human risk assessment based on the worst-case scenarios, Environmental Research 184 (2020) 109298.

[226] J. Gyapay, K. Noksana, S. Ostertag, S. Wesche, B.D. Laird, K. Skinner, Informing the Co-Development of Culture-Centered Dietary Messaging in the Inuvialuit Settlement Region, Northwest Territories, Nutrients 14(9) (2022) 1915.

[227] A. Naska, A. Lagiou, P. Lagiou, Dietary assessment methods in epidemiological research: current state of the art and future prospects, F1000Res 6 (2017) 926.

[228] T. Royle, The Use and Cultural Importance of Suckers (Catostomidae Cope, 1871) among the Indigenous Peoples of Northwestern North America: An Ethnographic Overview, 55 (2021) 97-124.

[229] G. McClelland, J.-M. Weber, G. Zwingelstein, G. Brichon, Lipid composition off tissue and plasma in two mediterranean fishes, the gilt-head sea bream (Chrysophyrys auratus) and the European seabass (Dicentratchus labrx), Canadian Journal of Fisheries and Aquatic Sciences 52 (2011) 161-170.

[230] G.A. Spiller, Lipids in human nutrition, CRC Press, New York. p, 1996.

[231] Y.J. WANG, L.A. MILLER, M. PERREN, P.B. ADDIS, Omega-3 Fatty Acids in Lake Superior Fish, Journal of Food Science 55(1) (1990) 71-73.

[232] P.-A. Amundsen, R. Knudsen, A. Klemetsen, R. Kristoffersen, Resource competition and interactive segregation between sympatric whitefish morphs, Annales Zoologici Fennici 41(1) (2004) 301-307.

[233] M.J. Hansen, N.A. Nate, L. Chavarie, A.M. Muir, M.S. Zimmerman, C.C. Krueger, Life history differences between fat and lean morphs of lake charr (Salvelinus namaycush) in Great Slave Lake, Northwest Territories, Canada, Hydrobiologia 783(1) (2016) 21-35.

[234] E.H. Jørgensen, H.K. Johnsen, Rhythmic life of the Arctic charr: Adaptations to life at the edge, Marine Genomics 14 (2014) 71-81.

[235] C.P. Madenjian, R.F. Elliott, T.J. DeSorcie, R.M. Stedman, D.V. O'Connor, D.V. Rottiers, Lipid Concentrations in Lake Michigan Fishes: Seasonal, Spatial, Ontogenetic, and Long-Term Trends, Journal of Great Lakes Research 26(4) (2000) 427-444.

[236] S. Kaçar, M. Başhan, S.A. Oymak, Effect of seasonal variation on lipid and fatty acid profile in muscle tissue of male and female Silurus triostegus, J Food Sci Technol 53(7) (2016) 2913-2922.

[237] A.C. Patterson, A. Chalil, J.J. Aristizabal Henao, I.T. Streit, K.D. Stark, Omega-3 polyunsaturated fatty acid blood biomarkers increase linearly in men and women after tightly controlled intakes of 0.25, 0.5, and 1 g/d of EPA + DHA, Nutr Res 35(12) (2015) 1040-51.

[238] Government of the Northwest Territories, Resources, 2022, September 21. https://www.hss.gov.nt.ca/en/resources?f%5B0%5D=field_resource_category%3A179&f%5B1%5D=field_resource_category%3A183.

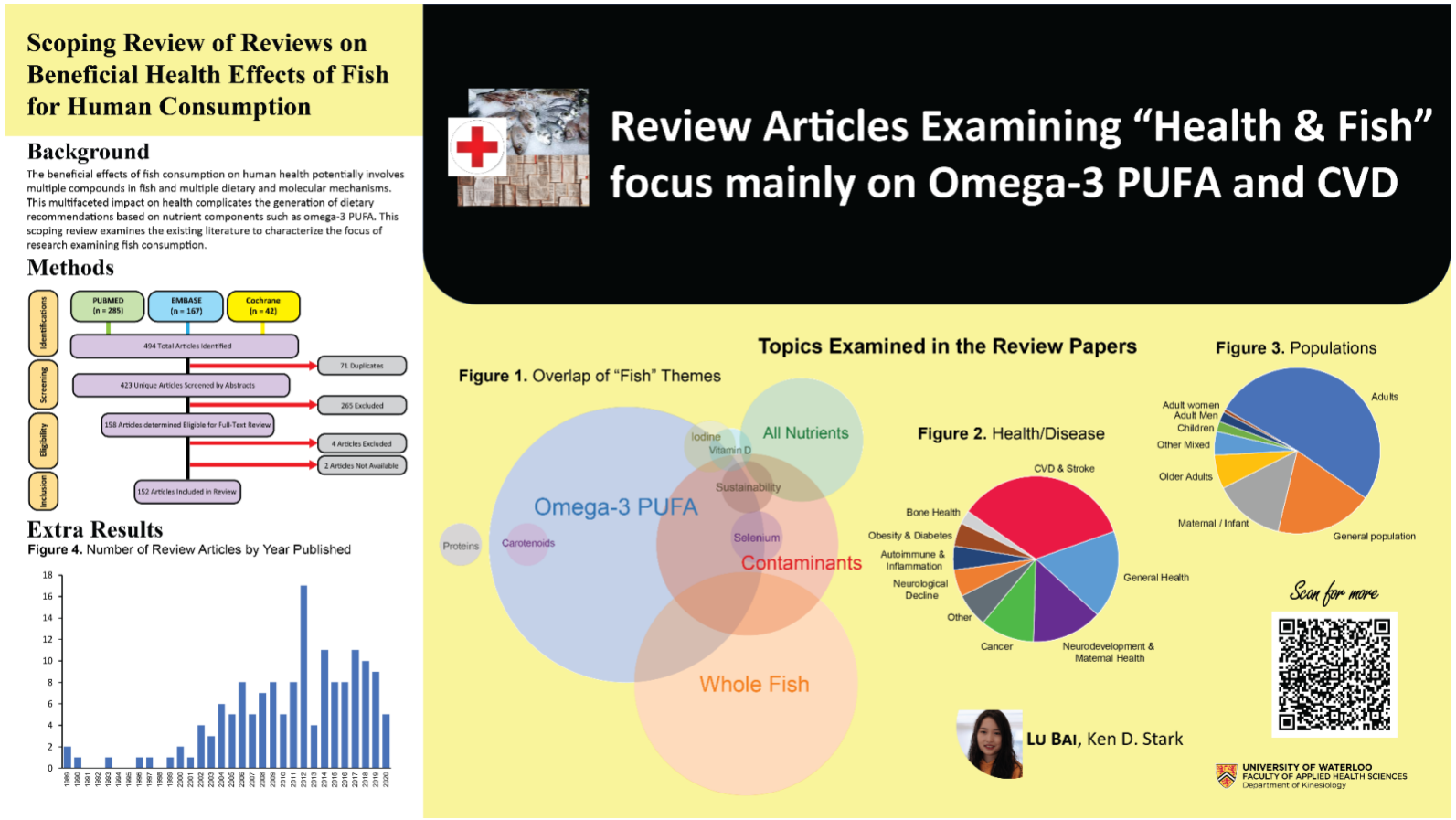
[239] J.T. Brenna, M. Plourde, K.D. Stark, P.J. Jones, Y.-H. Lin, Best practices for the design, laboratory analysis, and reporting of trials involving fatty acids, The American Journal of Clinical Nutrition 108(2) (2018) 211-227.

[240] K.D. Hall, Challenges of human nutrition research, Science 367(6484) (2020) 1298-1300.

[241] X. Zhang, X. Ning, X. He, X. Sun, X. Yu, Y. Cheng, R.-Q. Yu, Y. Wu, Fatty acid composition analyses of commercially important fish species from the Pearl River Estuary, China, PLOS ONE 15 (2020) e0228276.

Appendices

Appendix 1. ISSFAL 2021 Poster



Appendix 2. Seven major nutrients data of top 5 consumed fishes from CNF, USDA, and FishBase

Fish Name	Database	Calcium (mg/100g)	Iron (mg/100g)	Selenium (µg/100g)	Zinc (mg/100g)	Vitamin A (µg/100g)	Total n-3 PUFA (g/100g)	Protein (g/100g)
Pink salmon	CNF	29.0	0.8	31.4	0.7	35.0	1.6	20.5
Oncorhynchus gorbuscha	USDA	7.0	0.4	31.4	0.4	35.0	0.6	20.5
	FishBase	77.1	1.2	319.0	0.7	6.9	1.8	19.1
Chum salmon	CNF	44.0	0.7	36.5	0.6	30.0	1.0	23.1
Oncorhynchus keta	USDA	11.0	0.6	36.5	0.5	30.0	0.7	20.1
	FishBase	26.2	0.3	193.0	0.6	12.3	2.4	18.2
Colo salmon	CNF	12.0	0.3	12.6	0.4	56.0	1.5	21.3
Oncorhynchus kisutch	USDA	12.0	0.3	12.6	0.4	56.0	1.2	21.3
	FishBase	48.8	1.4	240.0	0.8	15.7	1.9	19.2
Sockeye salmon	CNF	10.0	0.4	30.6	0.4	58.0	1.3	21.3
Oncorhynchus nerka	USDA	9.0	0.4	29.8	0.5	49.0	0.9	22.2
	FishBase	31.4	0.5	161.0	0.6	7.3	2.9	18.7
Chinook salmon	CNF	26.0	0.3	36.5	0.4	136.0	2.3	20.0
Oncorhynchus tshawytscha	USDA	26.0	0.3	36.5	0.4	136.0	2.3	20.0
	FishBase	36.6	0.8	312.0	0.7	22.7	1.5	18.8
Yellowfin tuna	CNF	4.0	0.8	90.6	0.4	18.0	0.2	24.4
Thunnus albacares	USDA	4.0	0.8	90.6	0.4	18.0	0.1	24.4
	FishBase	60.0	3.7	112.0	0.7	52.1	0.6	22.4
Bluefin tuna	CNF	8.0	1.0	36.5	0.6	655.0	1.3	23.3
Thunnus thynnus (L.)	USDA	8.0	1.0	36.5	0.6	655.0	1.3	23.3
	FishBase	62.0	3.0	99.5	0.6	66.1	0.3	23.5
Skipjack tuna	CNF	29.0	1.3	36.5	0.8	16.0	0.3	22.0
Euthynnus pelamis (L.)	USDA	29.0	1.3	36.5	0.8	16.0	0.3	22.0
	FishBase	145.0	2.0	92.0	1.5	4.0	0.5	22.4
Pacific cod	CNF	8.0	0.2	22.9	0.3	2.0	0.2	15.3
Gadus macrocephalus	USDA	8.0	0.2	22.9	0.3	2.0	0.1	15.3
	FishBase	18.7	0.2	17.3	0.4	5.0	0.6	16.2
Atlantic cod	CNF	16.0	0.4	33.1	0.5	12.0	0.2	17.8
Gadus morhua	USDA	16.0	0.4	33.1	0.5	12.0	0.2	17.8
	FishBase	13.0	0.2	15.5	0.5	11.9	1.0	16.4
Atlantic herring	CNF	57.0	1.1	36.5	1.0	28.0	1.7	18.0
Clupea harengus	USDA	57.0	1.1	36.5	1.0	28.0	1.6	18.0
	FishBase	92.6	0.5	16.2	1.3	33.4	1.8	16.9
Pacific herring	CNF	83.0	1.1	37.0	0.5	32.0	1.9	16.4
Clupea pallasii pallasii	USDA	83.0	1.1	37.0	0.5	32.0	1.8	16.4
	FishBase	103.0	0.8	13.7	1.3	19.0	2.2	17.4
Pacific sardine (canned)	CNF	240.0	2.3	40.6	1.4	32.0	1.7	20.9
Sardinops sagax	USDA	240.0	2.3	40.6	1.4	32.0	1.5	20.9
	FishBase	184.0	2.5	46.3	1.7	11.6	0.8	20.9

N-3 PUFA, omega-3 polyunsaturated fatty acids; CNF, Canadian Nutrient File; USDA, United States Department of Agriculture.

Appendix 3. List for data sources of Canadian Nutrient File [150]

Identifier	Data source name
0	No change from USDA
1	Nutrient levels changed to meet the Canadian regulations
2	Nutrient calculated from data other than USDA
3	Nutrient analyzed in a Canadian government lab
4	Nutrient calculated from USDA data
5	Nutrient imputed from a similar USDA food
6	Nutrient from Canadian industry. Documentation incomplete.
7	Nutrient analyzed in Canadian product (non-government lab). Documentation
8	Nutrient value of food created for the Nutrition Canada Survey
9	Nutrient from the label declaration
10	Nutrient derived from scientific literature
12	Nutrient value is an assumed zero
14	Provisional data
15	Nutrient value imputed from data other than USDA
16	Calculated field
17	Calculated from analytical Canadian data
18	Imputed data that USDA has deleted
51	Calculated using a recipe
82	Danish Food Composition Databank (revision 5.0) Danish Institute for Food and Veterinary Research (revision 5)
83	Finnish food composition database. National Public Health Institute