100% Whitefish

Report

PREPARED BY

The Iceland Ocean Cluster for the Great Lakes St. Lawrence Governors & Premiers

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Executive Summary

Lake whitefish are a key freshwater species in North America and the Great Lakes region. A trend of declining population and international priority on the sustainable use of aquatic resources led to the development of the 100% whitefish project. This project, led by the Great Lakes St. Lawrence Governors and Premiers, aims to increase the utilization of caught fish, drive greater economic returns, create jobs and help develop rural economies. This project is the first of its kind in the region and builds on successful models for 100% fish utilization in Iceland.

The following report details a comprehensive background of the Lake whitefish fisheries and the regional Great Lakes fish processing sector, as well as the existing value chains in the region. Matís carried out a detailed biotechnical analysis of Lake whitefish samples followed by a series of site visits in the Great Lakes region by the Iceland Ocean Cluster (IOC). The IOC then followed with an analysis of the value chain and the Strengths Weaknesses Opportunities and Threats (SWOT) of each value chain step. This allowed the IOC to identify three of the best-case value-add strategies that represent low hanging fruit opportunities for increased utilization of the Lake whitefish. Working closely with the research, innovation and industry sectors in the Great Lakes region and Iceland, this report also explores two early-phase prototype tests from the identified value-add strategies and assesses the application of larger-scale automation uses for Lake whitefish.

At the start of this project, the primary use of Lake whitefish was direct consumption of the fillet, some value-added products (such as Lake whitefish salad) and processing cut-offs that were primarily discarded to landfills, or in some limited cases, were distributed to the agriculture sector as fertilizer or to mink farms for feed. These two examples of by-product utilization of Lake whitefish processing present an important foundation for this project and will be key for the development of 100% whitefish in the Great Lakes region.

Based on the findings of this report and the 100% whitefish project, the three best case value-add strategies that the IOC identified as low-hanging fruit opportunities and are recommended for increasing utilization include: First, extraction of fish protein hydrolysates (FPH) from the heads of Lake whitefish for the feed and food sector. Second, collagen extraction from the scales of Lake whitefish for the functional food and cosmetics sector. Third, production of leather from the skin of Lake whitefish, for the fashion and artisan product sector. Common priorities and needs arose to successfully implement these three value-add strategies. First, the need to fully map the volume and seasonal availability of identified by-products in the region (skin, scales, heads). Second, in two of the value-add cases, the need to pool byproducts from multiple small-scale fish processors to have an economically feasible volume supply. Third, the need for greater connectivity across existing value chain actors and other sectors, such as the fashion and cosmetics sectors. Finally, there is a need for further research, development and investment to optimize these value-add strategies and further opportunities for the 100% utilization of Lake whitefish. While it is not within the scope of this report, it is important to note that the success of all value chains discussed are reliant on a sustainable and well-managed Lake whitefish fishery and the environmental health of the Great Lakes.

There is future opportunity to apply the learnings from this project and report to a wider array of other important fish species in the Great Lakes. There are biological and morphological similarities between Lake whitefish and several other species present in the lakes, such as Walleye, Cisco (Lake herring) and Lake trout where findings from this project could also support the further utilization of these species.

Figures and Tables

1. Project background

1.1. Project context

This report is prepared for the project titled "Protecting and increasing the value of the Great Lakes St. Lawrence Commercial Fishery-100% Whitefish," led by the Conference of Great Lake St. Lawrence Governors & Premiers (GSGP). The project focuses on Lake whitefish (*Coregonus clupeaformis*), a species that has seen consistent declines in commercial catch rate particularly in Northern Lakes Huron and Michigan. There is ongoing work by the Great Lake Fishery Commission and other organisations to improve fishery management and fish recruitment to protect the long-term sustainability of this fishery, but it is also essential to consider parallel actions to support this protection. To support the future of the Lake whitefish fishery it is important to understand how to do more with what is caught, creating new value for all parts of the catch and therefore increasing the total economic value of the fishery.

Iceland pioneered the "100% fish" strategy that has rejuvenated and expanded the country's fish-dependent economy through innovation and entrepreneurship. The Iceland Ocean Cluster works across business sectors to maximize the beneficial use of the entire Atlantic cod, moving toward full utilization or 100% use of the fish. As a result of this cluster-based effort, the utilization rate of the Icelandic cod's biomass has increased from 40% when utilization was almost exclusively filets for human consumption (similar to Lake whitefish today) to 90% resulting in high-value food and non-food products. A cod that used to generate $12 for filets now generates a remarkable $4800 per fish in expanded value. This project will lay the groundwork for a similar transformation for the commercial Lake whitefish as an example of what can be done with the broader Great Lakes fishery. Significant economic benefits could flow from greater utilization and reduced waste with consequent implications for the management of the fisheries.

The project covers the entire geographical region of the North American Great Lakes region. For this initial project, fish from Lake Superior, Lake Huron and Lake Michigan were selected as being representative of the Lake whitefish across the region (**Figure 1**).

Lake whitefish is an endemic species found in the lakes of Canada and the United Sates. They are most abundant in in the Great Lakes region in the province of Ontario, Canada, and Minnesota, Wisconsin and Michigan in the United States (Lakes Superior, Michigan and Huron). This species represents one of the most valued commercial species of the Lakes and the region (Mohr & Nalepa, 2005). It is also the largest and oldest fishery in the Great Lakes region. Lake whitefish have an average length of 38 cm. and have a distinctive silvery color with a smaller head and a single dorsal fin compared to the other freshwater species.

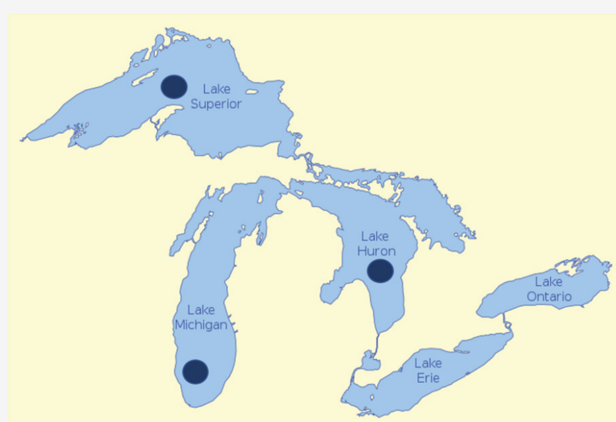


Figure 1. Map of the Great Lakes highlighting the three lakes where studied fish were selected.

To maximize the value of this fish, it is of interest to use it fully. Currently, Lake whitefish are primarily used for their fillets, with some secondary use in fish meal used in diets for farmed minks (**Figure 2**). The use of their skins and scales as well as the heads and frames for further added value would be of interest. A 2020 publication from Michigan Sea Grant reported that for the Michigan commercial fisheries there were 16 active businesses providing 97 jobs. Yet, the existing processed value of the commercial harvest is five times more than the landed value alone with minimal processing of filleting, deboning and packaging for sale. Value-added approaches provide an opportunity for additional sources of revenue and economic growth. In the case of the Icelandic model for full utilization, there is a positive feedback loop for economic growth in the startup sector, with startups developing new products from 100% fish and supporting blue economy opportunities for employment and technology.

The Great Lakes region has 6,651 startups according to Crunchbase, with 9,755 founders registered.

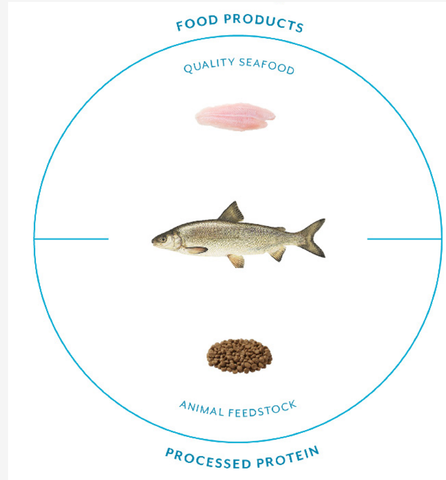


Figure 2. GSGP graphic visualizing the current products from Lake whitefish in North America.

1.2. Project goal

The project's goal is to demonstrate a 100% fish model for commercially caught Lake whitefish in the Great Lakes region. This project is the first of its kind in the Great Lakes region but builds on successful experience in Iceland and elsewhere globally. A 100% fish strategy holds tremendous promise for the region to more fully utilize caught fish, drive greater economic returns, create jobs and help develop rural economies. Furthermore, techniques and infrastructure developed as a result of this project will provide a valuable foundation for principles to be applied to other important species in the Great Lakes.

2. Current Lake whitefish value chain

2.1. Fisheries catch

The Lakes' whitefish population and the harvest records have been collected over long periods of time, allowing a long term perspective for understanding the variation in the population. The total catch of Lake whitefish has been falling across all lakes. This decline from the 1990s onwards has been linked to regulatory changes, higher levels of fishing intensity and lowered lake productivity linked to a rise in invasive species such as the Dreissenid mussel (*Dreissena polymorpha*) (Rook et al., 2022). Data from the three lakes in this report, Lake Superior, Lake Michigan and Lake Huron are shown in **Figure 3** from Rook et al. (2022) which monitor Michigan waters and provide an indication of patterns across other US states and Canadian provinces. This highlights the importance of fisheries management, quotas and the need to maximize value from the catch obtained.

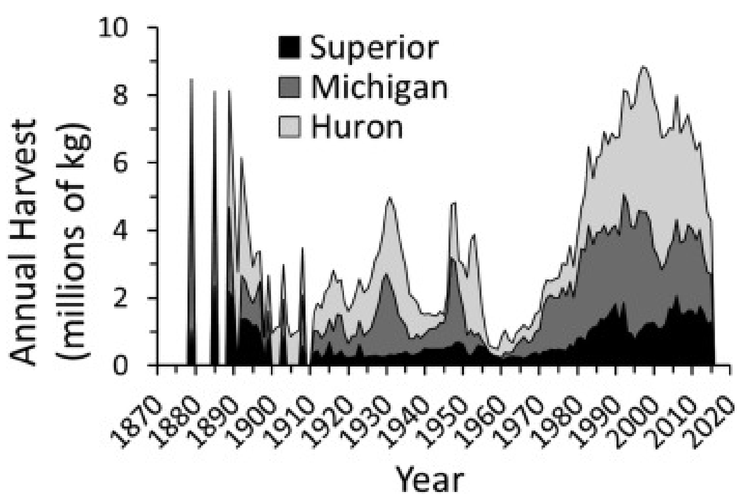


Figure 3. Timeseries of catch data for Lake whitefish between the years 1870-2020 from Lakes Superior, Michigan, and Huron.

The volumes of the commercial harvest for state-licenced fisheries in Lake Superior from 1990 to 2021 are shown at a higher resolution (**Figure 4**) from the Wisconsin Department of Natural Resources for Lake Superior and from the State of Michigan across all three lakes from 1990-2021 at higher resolution and as a percentage of the overall catch (**Figure 5**).

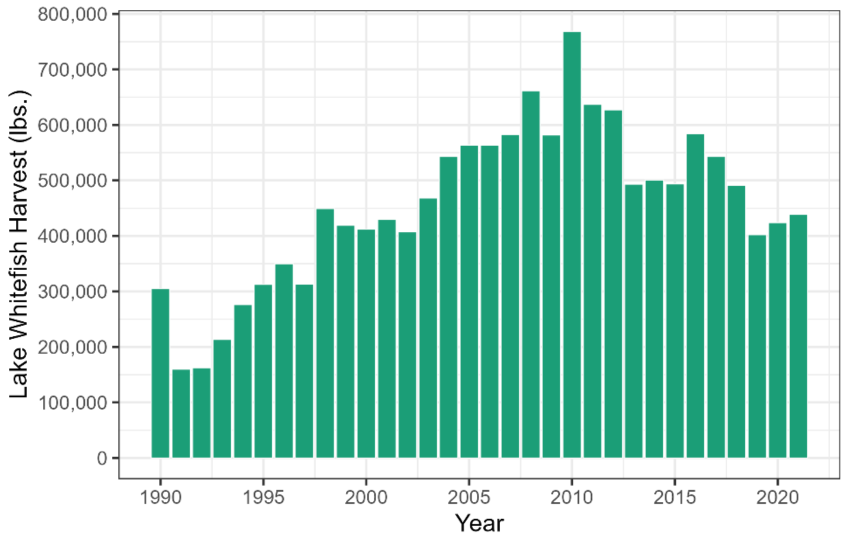


Figure 4. Fisheries catch data for Wisconsin state-licenced fisheries in Lake Superior from 1990 to 2021 for Lake whitefish.

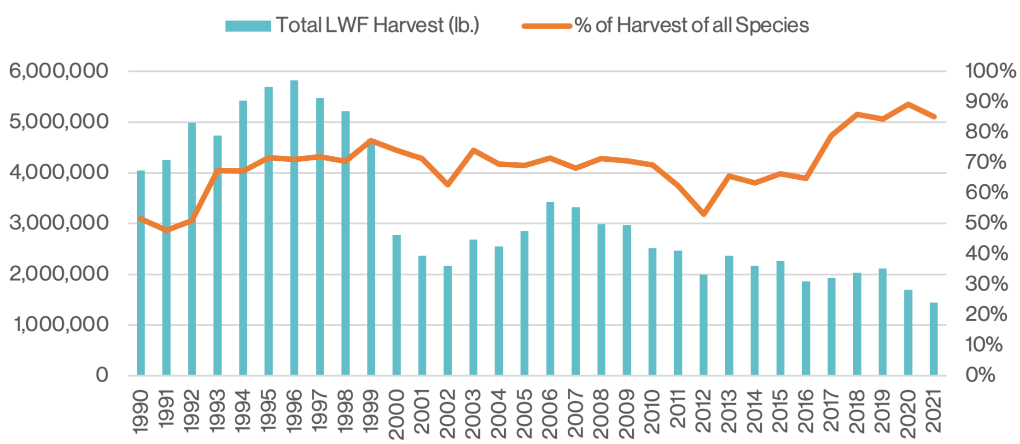


Figure 5. Fisheries catch data for Lake whitefish across all three lakes (blue bar) and as a percentage of the total harvest (red line) from Michigan.

All three lakes are monitored for biodiversity, fisheries stock health and contaminants. Detailed reports can be found in the records of official bodies in the region, including the Michigan Department of Natural Resources, Great Lakes Fisheries Commission and the United States Environmental Protection Agency's Great Lakes Fish Monitoring and Surveillance Program.

2.2. Fisheries processing and market

2.2.1. Canadian Processing

Data from the harvest of Lake whitefish from Ontario processing facilities across four of the main lakes is shown in lbs from data collected by GSGP and converted from kgs. to lbs. for this report (**Table 1**).

Table 1. Lake whitefish per year (lbs.) processed in Ontario between 2011-2021.

	Total All Lakes	Lake Huron	Lake Superior	Lake Ontario	Lake Erie
2021	1.743,777	1.240,259	334,739	87,505	80,978
2020	1.504,912	996,547	252,540	100,993	154,574
2019	1.569,399	1.066,417	321,820	102,916	77,977
2018	177,003	1.350,969	320,069	55,913	42,777
2017	1.990,146	1.618,318	2.742,749	67,866	28,875
2016	209,158	1.679,610	286,097	95,260	30,261
2015	1.811,064	1.387,885	226,277	130,709	65,883
2014	1,977	1.584,559	216,038	66,788	109,003
2013	2.744,885	2.319,216	233,396	101,508	90,297
2012	3.466,327	2.924,515	261,052	72,917	207,251
2011	3.598,142	2.763,655	245,265	77,814	510,794

Ontario's facilities are much more centralized than comparable U.S. facilities. There are more large-scale facilities than smaller ones in the province. Below are examples of facilities in Ontario.

I. All Temp Foods

The 2,500 square meter processing plant is equipped with the latest state of the art technology and professional staff who have doubled the size of the company in each of the last five years. Ongoing expansion efforts have resulted in strategically positioning five storage and receiving plants in Leamington, Kingsville, Wheatley and Port Stanley. These various locations allow All Temp Foods to receive and ship fish from across North America. The main facility is located in Leamington near Lake Erie. The facility buys from fishers directly, processing day catch and selling them at the facility and in the supermarket. The company takes great pride in becoming one of the most diversified fish processing operations in Ontario and can produce a wide range of quality products. All Temp Foods takes control of the receiving, storage and shipping responsibilities at the head office in Leamington, leaving Etna to handle all of the processing duties. The company has been processing and delivering fresh and frozen products throughout Canada, the U.S., Europe, Asia and other markets. They process: Yellow Perch, White Perch, White Bass, Lake Whitefish, Lake Trout, Yellow Pickerel, Sunfish, Lake Smelt and Mullet. All Temp Foods has owned the MacPac trademark since 1998 which sells different types of processed fish such as fillets, cheeks, portions of fish, etc.

II. John O's Foods, Inc

John O's Foods is a family owned and operated fish company in Wheatley, Ontario, specializing in freshwater lake fish from Canada and Europe. John O's Foods is the second largest producer of lake fish in Ontario. Its 5,100 square meter processing plant is HACCP (Hazard Analysis Critical Control Point) approved, globally certified and third-party audited. The company has its own fishers, fishing out of Wheatley on the company's boats. They fish for Walleye, Yellow Perch, Lake Whitefish, Steelhead, Zander, European Perch, White Bass, White Perch, Rainbow Smelt, Sauger and Northern Pike. John O's Foods also partners with the Sheshegwaning First Nation and together operate a fish farm off the shore of Manitoulin Island to produce Steelhead. The company supplies restaurants as well as other distributors throughout Canada and the US.

III. **Presteve Foods Ltd.**

Presteve is the largest deliverer of wild-caught, freshwater fish to North America. They operate year-round catching, processing and delivering fish. They sell Lake whitefish from Lakes Huron, Michigan, Superior, Ontario and inland lakes. Preseteve Foods currently has two brands--La Nassa, based in Kingsville, Ontario, and Purepac, based in Wheatley, Ontario. Purepac specializes in fish from the Great Lakes while La Nassa sells fish exclusively from Lake Erie. La Nassa products are delivered to North American retail chains and food service distributors. Presteve is also known for adapting products for food service, dining, and retail clients. For example, during Covid-19 it started offering frozen portion products of Great Lakes fish, individually vacuum packed to restaurants. The company can customize portion cuts to meet the needs of customers. The company is owned by Ulysses Pratas and Purewater Foods, a holding company within the Founders Group of Food companies (investing group in the food sector, controlling investment in over 80 companies).

2.2.2. United States processing

Processing data from the State of Michigan is shown in **Table 2** based on the data available for each wholesaler for the year 2021. Data is shown in lbs. from data collected by GSGP and converted from kgs. to lbs. for this report.

Table 2: Lake whitefish purchased by Michigan State Licensed Wholesalers in 2021 (lbs.).

Wholesaler	Dressed	Fillets	Roe	Round	Grand Total
BIG STONE BAY FISHERY, INC.	143,365	12,498	3,364	481,668	640,895
JOHN CROSS FISHERIES, INC.	37,635	4,979	0	331,654	374,268
T & K FISHERIES, INC.	214,163	0	3,725	50,129	268,017
SUPERIOR FOODS COMPANY	171,336	80,018	0	5,487	256,843
GAUTHIER & SPAULDING FISHERIES	209,882	8,171	7,324	0	225,375
MASSEY FISH COMPANY	16,287	1,208	0	154,460	171,954
MICHAEL HERMES	121,508	0	0	18,341	139,850
ERNEST KING	77,022	266	0	36,278	113,566
THOMAS BOWLES	104,353	0	792	946	106,091
CARLSON'S FISHERY	0	0	0	92,624	92,624
MACKINAC STRAITS FISH COMPANY	12,448	42,594	1,536	35,361	91,936
BRUCE OSTERHAVEN	11,825	69,751	0	0	81,576
HALPERN'S STEAKS & SEAFOODS	510	50,893	0	0	5,1405
PRESTEVE FOODS LIMITED	9,803	0	0	38,553	48,356
UNITED FISH DISTRIBUTORS	11,387	33,396	0	0	44,781
NORTHERN LAKES SEAFOODS & MEAT	8,197	32,531	0	0	40,726
LYNDA SANTINI	4,497	26,957	0	0	31,456

SYSCO FOOD SERVICE OF G.R.	0	27,300	0	0	27,300
US FOODS - DETROIT DIVISION	70	23,327	0	0	23,397
ADAM THILL	3,401	12,738	0	4,019	20,159
PETERSON'S FISH MARKET	197,47	0	0	0	197,47
KRUEGER'S FISH MARKET	7,621	5,104	0	4,798	17,523
REINHART FOODSERVICE, LLC	0	16,529	0	145	16,674
WEYAND FISHERIES, INC.	0	11,772	0	0	11,772
CARL FRAZIER	0	0	0	10,716	10,716
WREGES FISH COMPANY	9,706	653	0	0	10,358
STACI HAYMAN	4,211	5,691	0	0	9,902
CAROL SCHOENBORN	8,879	0	0	0	8,879
BODIN FISHERIES	7,225	0	0	0	7,225
DENNIS JAMES VANLANDSCHOOT MR	6,090	200	0	0	6,290
WELLMAN'S PARTY & BAIT	1,448	1,236	0	3,491	6,175
WALTERS FISHERIES SCHRINK	5,986	0	0	0	5,986
LOU ANN ROBINSON	0	3,689	0	2,213	5,900
WOLVERINE PACKING COMPANY	0	5,713	0	0	5,713
SCOTT FRAME	207	5,410	0	0	5,617
BAY PORT FISH COMPANY	3,491	238	0	0	3,729
MICHAEL DONLAN	2,409	570	0	0	2,979
DAN SCHWARZ	0	0	2,321	0	2,321
ALNAMER WHOLESALE	2,079	81	0	0	2,160
DAVID WARKENTEIN	0	1,522	0	0	1,522
JACK WHYTE	0	0	0	1,287	1,287
CARAMAGNO FOODS	0	1,263	0	0	1,263
DMS FISH SUPPLY, LLC	288	924	0	0	1,210
SERAFIN FISHERY	0	999	0	0	999
ERNST HOTEL SUPPLY COMPANY	0	933	0	0	933
C.E. LIXIE FISHERIES, INC.	0	748	0	0	748
RULEAU BROTHERS, INC.	0	0	504	0	504
PEOPLES FISH & POULTRY MARKET	180	255	0	0	433
RAMZI AJO	145	4	0	235	385
BREY'S FISHERIES	20	0	0	0	20

Michigan has around 100 wholesale fish businesses. Most of them are small scale, locally owned and operated. Most of those facilities process fish by hand for shipping to larger processors in Chicago or New York. Examples of facilities in Michigan are listed below:

I. **John Cross Fisheries**

This long-standing staple has been serving the Charlevoix community for over seventy years. Catching up to 10,000 pounds of fresh fish daily, they process 362,874 kg. / year of fish. The catch can vary daily but typically include Salmon, walleye, Lake whitefish, trout, and perch among other seasonal fish.

II. **Big Stone Bay Fishery**

Big Stone Bay Fishery processes Lake whitefish, Lake trout, walleye and perch for wholesale and for sale in its own retail store in Mackinaw City. It sells smoked Lake trout, salmon and chubs as well as Lake whitefish spread and sausage. This is a relatively smaller facility, typical of those in Michigan.

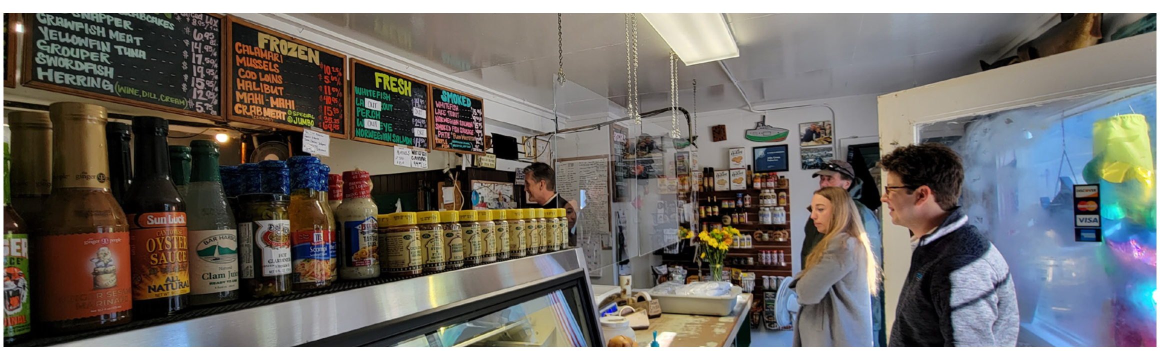
Comparatively in Wisconsin, there are roughly 110 wholesale fish dealers licensed by the State. Most of them are small family-owned operations, selling locally with a small capacity. Examples of such facilities are listed below:

I. **Henriksen Fisheries**

In 2021, Henriksen's Fish House opened in Ellison Bay, Wisconsin. The business continues to expand with online sales. The company helped the fishery to pivot to direct consumer sales. Starting with just fillets, it then worked to develop dips, fish cakes and pet treats made with fish. It sells these products at local farmers' markets and to more than 30 local restaurants and smokehouses. Among its products are boneless Lake whitefish filets, spread, cake, caviar, soup and pet treats. Henriksen owns and operates its own boat which fishes all year long.

II. **Fortune International**

Many Lake whitefish that cannot be processed by hand in Michigan or Wisconsin are sent to Fortune International which has facilities in Chicago, Illinois, and Wisconsin. It then processes Lake whitefish into different frozen or canned products to sell internationally. Fortune International's Neesvig fulfilment centre in DeForest, Wisconsin, has over three decades of experience with a particular focus on frozen food. There are three different facilities and over 70,000 square feet of climate-controlled shipping and storage space. La Fortune is a large-scale processor that also sells meat and cheese. Lake whitefish is primarily bought from Door County and processed into smoked Lake whitefish salad. Fortune's fleet of refrigerated trucks covers Alabama, Arkansas, Florida, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Texas, and Wisconsin. The headquarters are in Chicago near O'Hare airport.



2.2.3. Retailers and products

There are different types of Lake whitefish sellers in the region: the supermarket, the fish market, the smoke house, and the local fishery. They sell different products, such as Lake whitefish fillets (fresh or frozen, depending on the location) and smoked products (spread, salad and fish).

Lake whitefish can be found across the Great Lakes states at fisheries, stores and restaurants. The fisheries and fish markets can usually sell a larger variety of products, including cooked Lake whitefish and fresh Lake whitefish. These fish are cleaned, packaged and sold from their own retail counters to wholesale buyers or at local farmers' markets. The fish markets and fisheries are well spread out in the different states and provinces of the Great Lakes region. The Michigan Fish Producers Association has created an interactive map for most of the U.S fisheries selling Lake whitefish. The map, shown in **Figure 6** as a static image, includes the contact information for each selling point and is divided into retail Lake whitefish selling (Buy Fish – Retail | Michigan Fish Producers Association (mfpa.us) and wholesale Lake whitefish selling (https://mfpa.us/buy-fish-wholesale/) which can be found in the original map online.

Figure 6. Static map of the key retail and wholesale locations around the Great Lakes from the Michigan Fish Producers Association.

In cities like Chicago, seafood markets such as Fulton Market, Hagen's Fish Market, Dirk's Fish & Gourmet Shop and Robert's Fish Market sell Lake whitefish. They sell to local customers and can be suppliers for restaurants for example, Isaacson & Stein Fish Company, a 50-year-old family business. It is possible to purchase whole Lake Superior whitefish or walleye as a skinned and deboned fillet.

Lake whitefish fillet can also be found online from big seafood companies that sell and deliver frozen and fresh seafood. Those companies, such as Oceanside Seafood and Walleye Direct, are considered fish markets, offering deliveries and online shopping through the states surrounding the Great Lakes.

The smoked fish products of the Lake whitefish are most commonly found in supermarkets. Big smoking companies, such as Blue Hill Bay (ACME smoke house), have a variety of smoked Lake whitefish products such as spreads, salads, fish portions and whole fish. Blue Hill Bay is the largest fish smoke house in the United States and has a large smoke house in Brooklyn, New York, where it smokes the Lake whitefish from the Great Lakes. The fish is then sold to supermarkets, such as Whole Foods, Mariano's, Jewel-Osco, Walmart, Costco and Sobeys. Some examples of these products are shown along with their retail price in **Figure 7**.

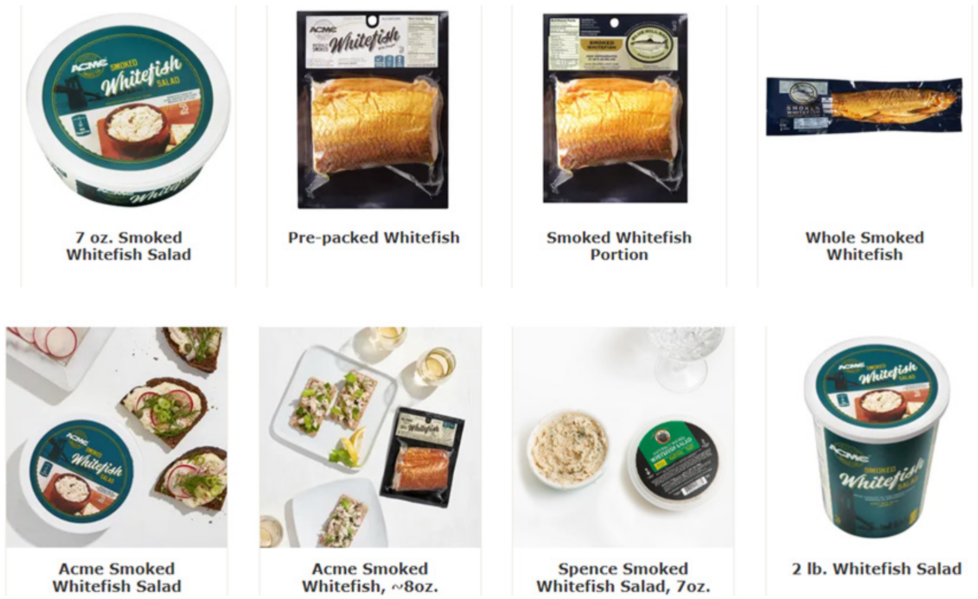


Figure 7. A range of Lake whitefish products on the market in the Great Lakes region from major retailers.

3. Analysis for value creation

3.1. Biotechnological analysis methods

Fish samples were collected from Lake Huron, Lake Michigan and Lake Superior.

Presteve Foods sent fish from the Great Lakes by air freight. Fish were shipped pre-gutted but with all other parts intact. Fish were shipped frozen solid and packed in dry ice in polystyrene boxes to maintain temperature of the samples. Samples were collected at Keflavík cargo terminal within 24 hours and delivered directly to the laboratory at Matís ohf, Iceland, for biotechnological analysis.

3.1.1. Mass balance of samples

The biotechnological analysis team at Matís ohf handled the samples. Prior to mass balance and separation of the pieces of interest, the fish were defrosted overnight at 4°C on a tray cover with a plastic sheet to prevent drying. The mass balance of the whole fish and the heads, skins, frame and fillets was done. For all those parts the proximate composition (water (ISO 6496-1999) , protein (ISO 5983-2 (2005)), ash (ISO 5984 (2022)) and fat (soxhlet method AOCS Ba 3-38 (2017)) was measured as well as more specific analysis of amino acid composition (method EU 152/2009 (F), ISO 13903:2005, AMSUR, IC-UV for the amino acid composition and method EU 152/2009 (F), ISO 13903:2005, IC-UV for cysteine and methionine; method EU 152/2009, LC-FLD for the tryptophane) on the heads and hydroxyproline content (SO 13903:2005, IC-UV) on the skins and frames. On the frames, the mineral composition (NMKL 186 (2007), mod) was also studied.

Three replicates were used for each lake, as the size of fish were different across the lakes. For Lake Superior and Huron two fish samples were pooled to constitute a single to create one replicate (so six fish in total were used) while for Lake Michigan, only one fish was used per replicate (so three fish in total).

3.1.2. Proximate composition and chemical analysis of samples

Between six and ten fish from Lake Huron, Lake Michigan and Lake Superior were shipped gutted and frozen to Iceland. Prior to mass balance and separation of the pieces of interest, the fish were defrosted overnight at 4°C on a tray cover with a plastic sheet to prevent drying.

Three replicates were used for each lake. As the size of fish were different according to the lake, to have enough material for the chemical analysis; for Lake Superior and Huron two fish were pulled together to create one replicate (so six fish in total were used) while for Lake Michigan, only one fish was used per replicate (so three fish in total).

3.1.3. Statistical analysis

Kruskal-Wallis H test was used to analyse if there was any difference in the average composition of the fish between Lakes. The Dunn test was then performed as a post-test to evaluate significant differences between Lakes. The adjustment due to the limited amount of sample was realized through the Bonferroni method. All statistical analysis was done using R studio software and the graphs were made with the package ggplot2.

3.2. Biotechnical results

The results from the samples sent from the Great Lakes region are displayed the following section. This section is split into two parts, *6.1. Whole Body Analysis*, *6.2. Compositional Analysis*.

3.2.1. Whole body analysis

The analysis of whole-body weight of the samples showed that the Lake whitefish from Lake Michigan had a significantly higher body weight than the ones from Lake Superior **Figure 8**. The size (length and width) of the fish from Lake Michigan were longer and wider than the ones from Lakes Huron and Superior. While this is relevant to interpreting the results of the current study, these fish sizes are not a representative sample across different fishing grounds and over time, so are purely used to inform the output of the value chain analysis and not as a population scale survey of the lakes.

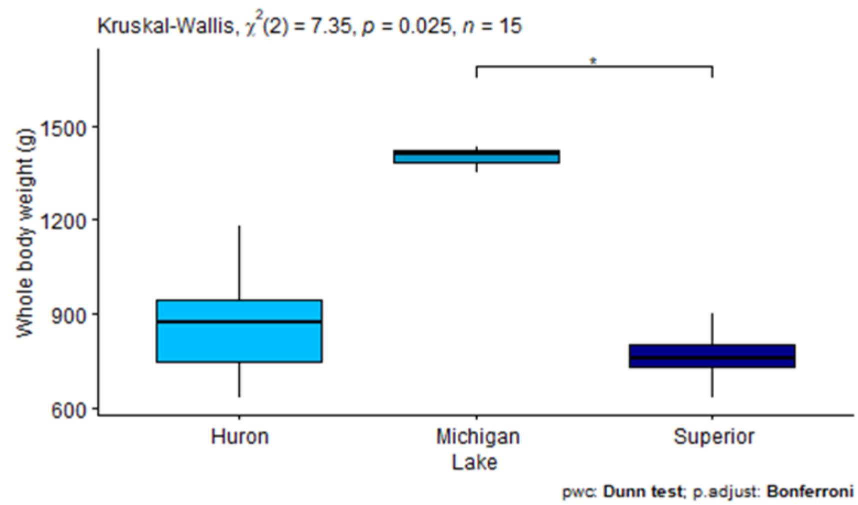


Figure 8. Whole body weight of samples used during this study to explore valorisation (g).

Multiple reasons explain the difference in the weight and size of the fish from the different lakes. The difference of size can be related to the environment where the fish live. Temperature difference can have an impact on the growth speed with colder temperature decreasing the growing speed of the fish (Elliott & Hurley, 2003). Other environmental factors can also have an influence (feed availability and type). Long term records and data from fisheries catch management should be used to determine patterns in the general Lake whitefish size.

Analysis of the percentage composition of different key body components was performed on gutted fish **Figure 9**. 100% is not reached in all cases due to the missing weight from the water leaking from the defrosted fish as well as the fins and some rest of the viscera/blood system that were taken out of the mass balance due to the use of the pieces for further analysis. For all three lakes, the whole-body ratio was similar. The fillets represented between 41% and 50% of the whole-body weight of gutted Lake whitefish. 12 to 13% of the whole-body weight was composed by the head; 7 to 8% was the skin; and, 7 to 9% were the bones. Overall, the difference in the total weight of the fish did not influence the body composition ratios.

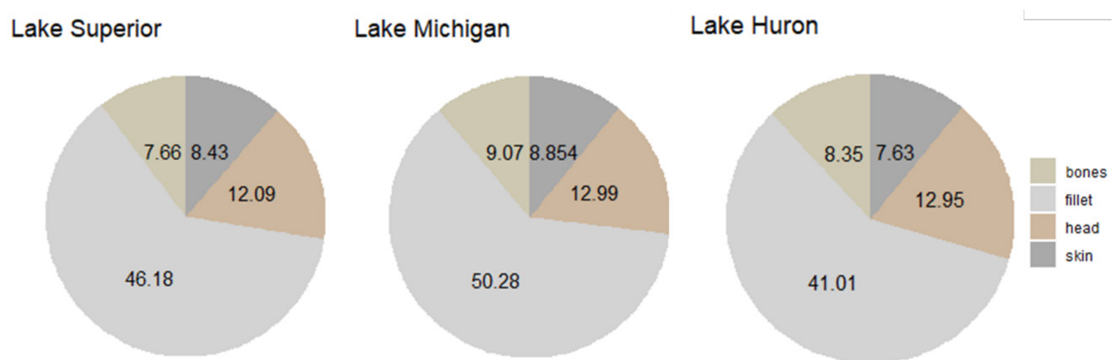


Figure 9. Percentage of body composition of key body parts of interest for Lake whitefish.

The quantity of raw material that would be available to create added value (rest raw material utilization) and the average harvest data from each lake from the year 2015 to the year 2020 are used as reference. In all the lakes studied (Canadian fisheries for Lake Huron and Superior and US fisheries for Lake Michigan), for the last five years an average of 2 197 491 kg. (4 834 480 lbs.) of Lake whitefish (Great Lakes Fishery Commission, 2022) was fished per year. If we consider that 15% of that weight is viscera, then 233 483 kg. (513 663 lbs.) of head, 149 429 kg. (328 744 lbs.) of skin and 153 165 kg. (336 963 lbs.) of bones could be used as rest raw material for added value per year from those three lakes.

As the allowable catch for Lake whitefish is specific for each lake, **Table 3** shows how much rest raw material could be recovered in each Lake if the total allowable catch was harvested.

Table 3. Average quantity (in lbs) of rest raw material available per year in each lake.

Avg. quantity lbs. per year	Lake Superior	Lake Michigan	Lake Huron
Heads	31 350	308 803	187 594
Skin	21 945	181 931	110 521
Bones	19 855	198 689	120 701

Analysing the proximate composition of the different parts studied would allow to see if the origin of the fish could have an influence on the nutritional benefits for human consumption or on the possible utilization.

3.2.2. Compositional analysis

The fillets from the three lakes were studied to evaluate the impact of the feeding pattern on the proximate composition of the part of the fish which is eaten. Lake whitefish is known to have a mild and sweet taste. The more detailed analysis was split into several key body parts of the Lake whitefish displayed in **Figure 10**.

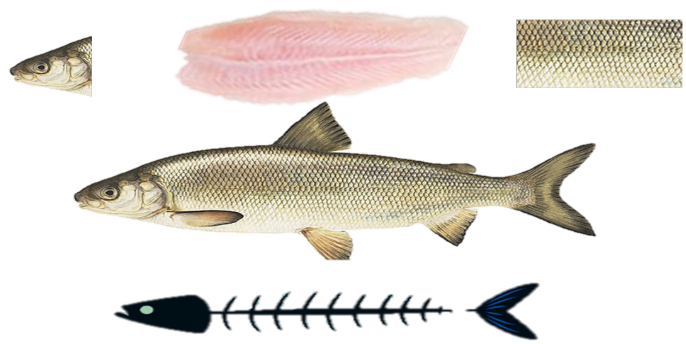


Figure 10. The key body parts that were analyzed in this report.

I. Lake whitefish fillet

The proximate composition of Lake whitefish fillets showed a water content between 72.6% and 77.1%, a protein content between 19.2% and 21.7%, a fat content of 2.3% to 3.3% and an ash content between 1.1% and 1.4% **Figure 11**. As only one pooled sample was measured per lake, the difference of composition between the lakes cannot be confirmed here. However, proximate composition of the fillets has been measured in the past as well as the fatty acid composition and it was shown that there were significant differences between the lakes (Pantazopoulos et al., 2013). Those differences were expected to be caused by a different feeding pattern and diversity between the lakes (temperature, phytoplankton and zooplankton diversity).

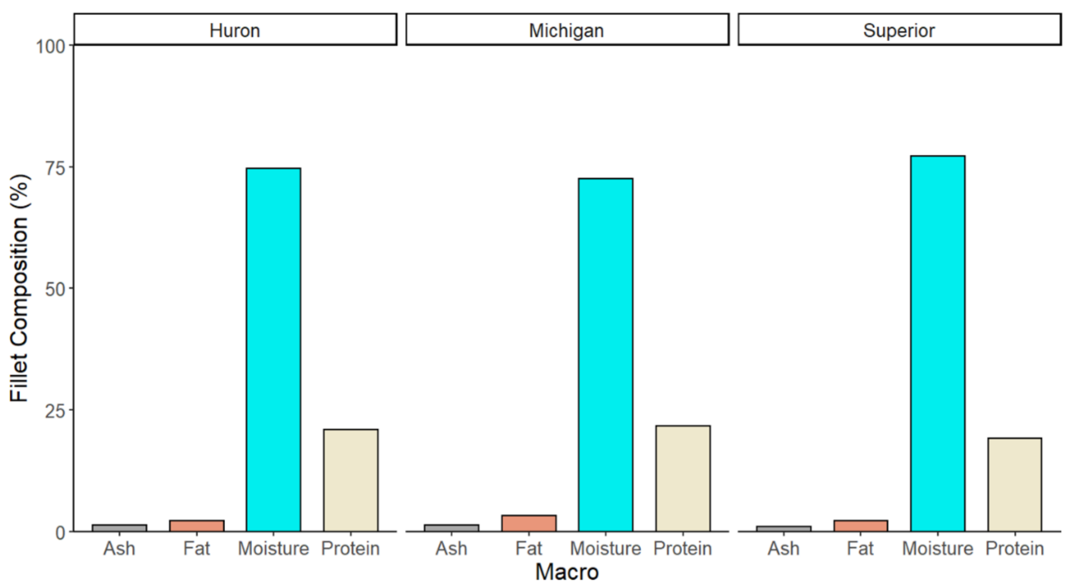


Figure 11. Macro-composition of fillets of lake whitefish from each lake (%).

There are existing studies that have measured the fatty-acid composition of both the Lake whitefish and Lake trout which provide additional useful data that supplements the data in this biotechnological report. This data comes from Pantazopoulos et al., 2013 and values are expressed in (mg fatty acid/100g) **Figure 12.**

Species/lake	N		Total fat	Total SFA	Total MUFA	Total PUFA	Total omega 3	Total omega 6	EPA	DHA	EPA + DHA
Lake trout											
Erie	10	Mean ± SD	9448 ± 5365	2272 ± 1240	4286 ± 2358	2890 ± 1774	1901 ± 1191	811 ± 461	412 ± 263	629 ± 336	1041 ± 597
		Min, max	3720, 21,498	1033, 4997	1639, 9591	1048, 6910	657, 4559	313, 1829	146, 998	255, 1344	401, 2341
Huron	10	Mean ± SD	7324 ± 2496	1774 ± 575	3339 ± 1072	2211 ± 947	1361 ± 635	718 ± 268	261 ± 129	556 ± 269	817 ± 397
		Min, max	3546, 12,736	898, 2968	1654, 5570	994, 4198	574, 2701	350, 1250	118, 562	220, 1120	338, 1682
Michigan	9	Mean ± SD	12,197 ± 3325	2692 ± 695	5163 ± 1239	4342 ± 1557	2754 ± 1064	1396 ± 467	494 ± 183	1116 ± 385	1610 ± 564
		Min, max	7774, 16,552	1738, 3490	3157, 6877	2485, 6259	1375, 4065	891, 1967	267, 708	608, 1557	875, 2222
Ontario	10	Mean ± SD	10,835 ± 2505	2519 ± 553	5028 ± 1218	3288 ± 848	2101 ± 553	968 ± 255	447 ± 121	736 ± 178	1183 ± 294
		Min, max	7516, 15,638	1721, 3394	3461, 7498	2059, 4746	1293, 2870	601, 1520	238, 581	484, 996	724, 1571
Superior	8	Mean ± SD	4282 ± 1329	1067 ± 284	1955 ± 608	1260 ± 460	816 ± 313	399 ± 140	142 ± 62	331 ± 111	472 ± 172
		Min, max	2815, 6416	724, 1527	1340, 2910	751, 1979	475, 1282	246, 635	75, 244	217, 514	293, 758
All trout	47	Mean ± SD	9006 ± 4207	2111 ± 922	4047 ± 1819	2848 ± 1552	1817 ± 1023	872 ± 459	359 ± 207	682 ± 366	1041 ± 561
		Min, max	2815, 21,498	724, 4997	1340, 9591	751, 6910	475, 4559	246, 1967	75, 998	217, 1557	293, 2341
Whitefish											
Erie	10	Mean ± SD	5160 ± 1347	1340 ± 320[i]	2941 ± 913	879 ± 222	478 ± 141	213 ± 48	149 ± 53	157 ± 48[h]	306 ± 99
		Min, max	2742, 7814	758, 1911	1386, 4789	584, 1286	232, 713	154, 314	63, 236	69, 219	132, 454
Huron	10	Mean ± SD	3292 ± 1003	837 ± 205	1544 ± 516	911 ± 305	542 ± 179	258 ± 79	158 ± 64	203 ± 61	362 ± 121
		Min, max	2141, 5066	588, 1236	811, 2448	555, 1414	330, 862	162, 402	79, 265	136, 322	215, 586
Superior	10	Mean ± SD	3497 ± 702	900 ± 129	1521 ± 258	1076 ± 401	698 ± 317	306 ± 80[h]	153 ± 70	285 ± 139	439 ± 207
		Min, max	2898, 5353	708, 1172	1230, 2100	766, 2081	450, 1468	231, 515	81, 322	167, 604	262, 926
All whitefish	30	Mean ± SD	3983 ± 1324	1026 ± 319	2002 ± 905	955 ± 319	573 ± 237	259 ± 78	154 ± 60	215 ± 104	369 ± 154
		Min, max	2141, 7814	588, 1911	811, 4789	555, 2081	232, 1468	154, 515	63, 322	69, 604	132, 926
All fish	77	Mean ± SD	7049 ± 4179	1688 ± 915	3250 ± 1823	2111 ± 1536	1332 ± 1014	633 ± 469	279 ± 193	500 ± 371	779 ± 555
		2141, 21,498	2141, 21,498	588, 4997	811, 9591	555, 6910	232, 4559	154, 1967	63, 998	69, 1557	132, 2341

Figure 12. Fatty acid composition of whole fish from the Great Lakes from both Lake whitefish and Lake trout (mg fatty acid/100g fish).

Additional data for the macro- nutritional composition of the flesh and liver from lake fish can be found in Belinsky et al., 1996, which support the findings for the fillet of Lake whitefish in this study and provide further information on other key lake fish. **Figure 13** is taken from the Belinsky paper to support these findings in this study and provide additional data. In addition, there is a compositional analysis of "Lipid composition of indigenous foods eaten by the Sahtú" which provides further interesting analysis particularly about different parts of the fish, such as the tail (Appavoo et al., 1991).

PROXIMATE COMPOSITION PER 100 g FRESH RAW FISH SAMPLE

Species	Location	n	Part	g moisture	g fat	g protein	g ash	g carbohydrate[1]	Energy (kcal/100g wet wt.)	Energy (kjoules/100g wet wt.)
Whitefish	Caniapiscau	5	flesh	79±1.1	0.7±0.39	15±2.85	0.9±0.18	3.2	82.3	344.4
Whitefish	Lac Temoin	5	flesh	78±0.54	1.1±0.48	15±2.06	0.9±0.14	4.1	88.5	370.3
Whitefish	Vermeulle	5	flesh	80±0.96	0.8±0.65	14±2.14	0.8±0.16	3.9	80.7	337.4
Lake Trout	Caniapiscau	5	flesh	79±3.47	2±1.6	10±3.7	0.4±0.12	7.6	92.4	386.6
Lake Trout	Lac Temoin	3	flesh	80±1.1	0.4±0.17	15±0.72	1.0±0.07	2.0	74.6	312.0
Pike	Vermeulle	5	flesh	79±1.0	0.4±0.11	17±0.66	0.9±0.06	2.1	82.3	344.1
Pike	Dollier	5	flesh	79±0.94	0.4±0.09	16±0.86	0.9±0.05	2.4	80.2	335.4
Brook Trout	Lac Serigny	1	flesh	77.7	0.92	17.3	1.2	2.9	89.0	372.2
Whitefish[2]	Wemindji	5	flesh	75.9	1.7	16.2	0.99	5.2	101.1	423.1
Cisco[2]	Wemindji	5	flesh	72.6	3.4	14.1	0.89	8.9	123.0	514.5
Brook Trout[2]	Wemindji	5	flesh	76.0	1.6	16.4	1.1	4.9	99.6	416.9
Pike[2]	Vermeulle	5	liver	74.9	7.1	7.7	0.69	9.6	132.9	556.1
Pike[2]	Dollier	5	liver	77.0	4.4	2.4	0.22	15.9	113.1	473.0
Lake Trout[2]	Caniapiscau	5	liver	78.1	2.2	9.7	0.82	9.2	95.5	399.4
Whitefish[2]	Caniapiscau	5	eggs	64.7	7.0	11.9	0.74	15.7	173.5	725.8
Whitefish[2]	Lac Temoin	4	eggs	63.5	8.3	10.9	0.68	16.7	184.8	773.1
Cisco[2]	Wemindji	5	eggs	58.9	14.4	4.5	0.38	21.8	234.7	981.8
Lake Trout[2]	Caniapiscau	5	eggs	67.6	2.6	19.6	1.0	9.1	138.5	579.7

Figure 13. Additional data on proximate composition of Lake whitefish alongside other key commercial Lake species for comparison from Belinsky et al., 1996.

II. **Lake whitefish head**

The Lake whitefish heads were analyzed both for the proximate composition and their amino acid content. The heads were chosen for the amino acid content as they are an average representation of the whole body. The water content of the heads was between 65.3% and 68.9%; the protein content between 14.7% and 16.1%; the fat content between 11.3% and 13.8%; and, the ash content between 4.1% and 4.8% **Figure 14**. The Lake Michigan fish were lower in water and ash content compared to the Lakes Huron and Superior fish and higher than them for protein and fat. When the statistical analysis was done, the protein and fat content of the Lake Michigan fish were first detected as significantly higher with the pairwise comparison with the Dunn test but when the adjustment through the Bonferroni method was realized, due to the low number of replicates, the difference was not significant anymore (p=0.06). However, this trend differentiating Lake Michigan from the two others can be related to the bigger size of the fish as well as their feeding pattern.

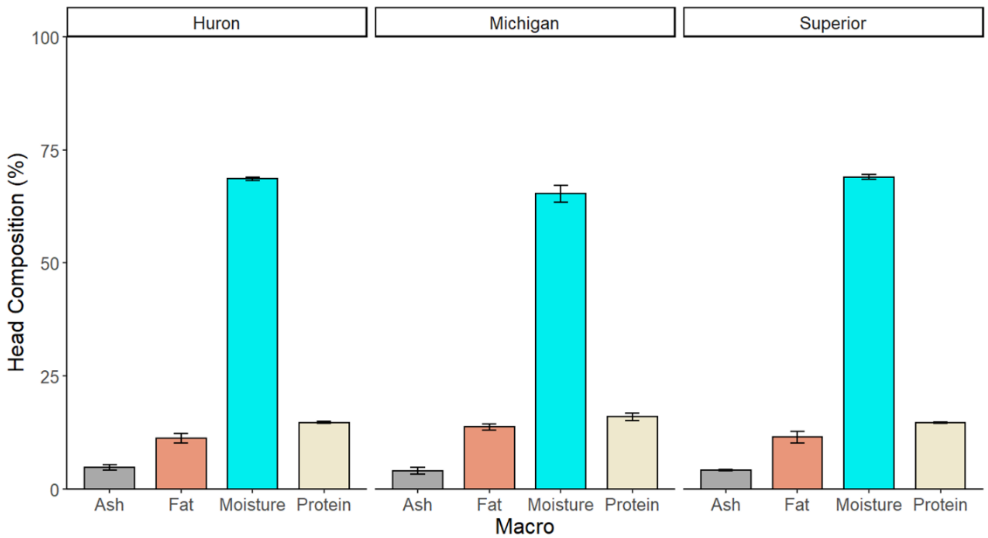


Figure 14. Macro-nutritional composition of the Lake whitefish heads.

The amino acid composition of the heads from each lake had been studied due to their importance for human nutrition to synthesize proteins. As some amino acids (Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan and Valine) are only provided through food intake, it was of interest to see if those ones would be present in high quantity in those fish and therefore specifically of interest for human health. Those values will be used as comparison with the data from Mohanty et al., 2014 to evaluate the levels of the individuals amino acids.

The amino acids have been classified in different categories for their importance in human nutrition. They were traditionally classified as essential amino acid (EAA), conditionally essential (CEAA) and non-essential (NEAA). A fourth category has been developed to classify amino acid which have a role and impact in in key metabolic pathway, therefore improving health, development and other essential functions in the body, they are named functional amino acid (FAA).

In the Lake whitefish samples, some amino acids were considered high compared to other species (Mohanty et al., 2014). In **Table 4**, the main amino acid (the ones detected as in medium to high quantity) are detailed.

Table 4. Amino acid analysis of Lake whitefish heads assigned to levels defined by Mohanty et al., 2014.

Amino acid	Quantity (average from the three lakes in g./100g. protein)	Levels analysis	Classification
Arginine	5.55±0.35	High	EAA-FAA
Methionine	2.35±0.15	Medium	EAA
Alanine	6.30±0.23	Medium-High	NEAA
Proline	4.62±0.36	High	CEAA-FAA
Leucine	6.14±0.34	Medium	EAA-FAA
Phenylalanine	3.49±0.19	Medium-High	
Aspartic acid	8.15±0.38	Medium	NEAA
Glutamic acid	11.4±0.67	High	CEAA-FAA
Glycine	8.39±1.16	Medium-High	CEAA
Threonine	3.79±0.19	Medium	EAA
Valine	4.27±0.23	Medium	EAA

The levels of arginine detected in all the samples were higher than all the other fish analysed in Mohanty et al., 2014. Arginine has an important role in numerous functions like cell division. It is a precursor for biological synthesis of nitric oxide which plays a role in neurotransmission and blood clotting and is supplemented for recovery of disease like preeclampsia and hypertension. As it is high in Lake whitefish, those fish can be recommended as a good supplement in case of arginine deficiency.

Proline is one of the amino acids that on a per-gram basis for human nutrition has the highest requirement. It is a key regulator in multiple biochemical and physiological processes of the cells like signalling molecule and superoxide anion participating in redox reactions. It also has a role in cell differentiation and serves as a major amino acid in the synthesis of polyamines (regulator of DNA and protein synthesis) of the small intestine and placenta (Wu et al., 2011). In Lake whitefish, it is higher than in most fish species except Oncorhynchus mykiss (9.6±1.4)(Mohanty et al., 2014).

Leucine is the only amino acid which can stimulate muscle protein synthesis and plays a therapeutic role in stress conditions such as burn or trauma. It has also been highlighted that it could be useful to help reduce obesity and achieve some weight loss (Layman, 2003). Levels of leucine in Lake whitefish are considered good compared to some other fish species such as Neolissochilus hexagonolepis (2.1±0.2) but low compared to others like Rastrelliger kanagurta (10.3±0.4). Within the freshwater fish group, the Lake whitefish has a medium quantity of leucine (Mohanty et al., 2014).

Glutamic acid has an important role in metabolism due to its role in transamination reactions and its necessary presence in the synthesis of key molecules such as glutathione. Compared to most fish, the glutamic acid content of Lake whitefish was higher, except in Catla catla where it reached 13.8±3.5 (Mohanty et al., 2014).

Overall in Lake whitefish, eight essential or conditionally essential amino acids as well as four functional amino acids have been found in medium to higher levels than in most fresh and seawater fish which make it a good candidate for fish protein hydrolysate. For three of those amino acids with a specific interest, significant difference ($p<0.05$) between the content in the Lake whitefish coming from Lake Superior and Lake Michigan were found. Leucine, Aspartic acid and Threonine content were significantly higher in the fish from Lake Michigan than the ones from Lake Superior. The quantity of Isoleucine, Serine and Lysine were also significantly higher in the fish from Lake Michigan than the fish from Lake Superior (Appendix 3). The difference of quantity of those amino acids could be caused either by the difference of the size of the fish, with a higher protein content/more developed muscle part in Lake Michigan, due to a possible different feeding pattern.

The biotechnological analysis indicates that the heads are of interest due to their high value in interesting amino acids for human consumption. Isoleucine and leucine in the heads of Lake whitefish are high (respectively 1g./100g. and 0.5g/100g.) and those amino acids are not produced by the human body. Supplements made from the heads could therefore be interesting as the quantity of heads available per year could be close to 103 054 kg.

III. Lake whitefish bones

The frame (and other small bones) of the Lake whitefish were analysed for proximate composition as well as for mineral composition and hydroxyproline. In the frames, the spinal cord was still inside with the bone marrow so the whole skeleton system is considered in this analysis.

The water content of the bones was between 58.5% and 61.7%; the protein content between 17.8% and 18.3%; the fat content between 11.3% and 13.1%; and, the ash content between 7.3% and 8.7% **Figure 15**. No significant difference between the proximate composition of the bones from the different lakes was found. The fat content detected in the bones of the Lake whitefish compared to the fat content found in the fillets was high. However, it has been reported before that the lipid content in the fish bones could range from 1% to 27% (Toppe et al., 2007). The lipid levels in the bones have an impact on the protein and ash content found. Usually fatty species will have lower protein and ash levels in their bones than the lean ones. As the lipids are partially absorbed on the bones' surface, this could explain the difference (Toppe et al., 2007).

The bone mineral composition contains particularly high levels of phosphorus and calcium (40g/kg and 60g/kg respectively). In fact, the ratio of the minerals in the bones is close to what humans would need as intake per day as a ratio (1.5 times more calcium than phosphorus) which make them a good candidate for human dietary supplements.

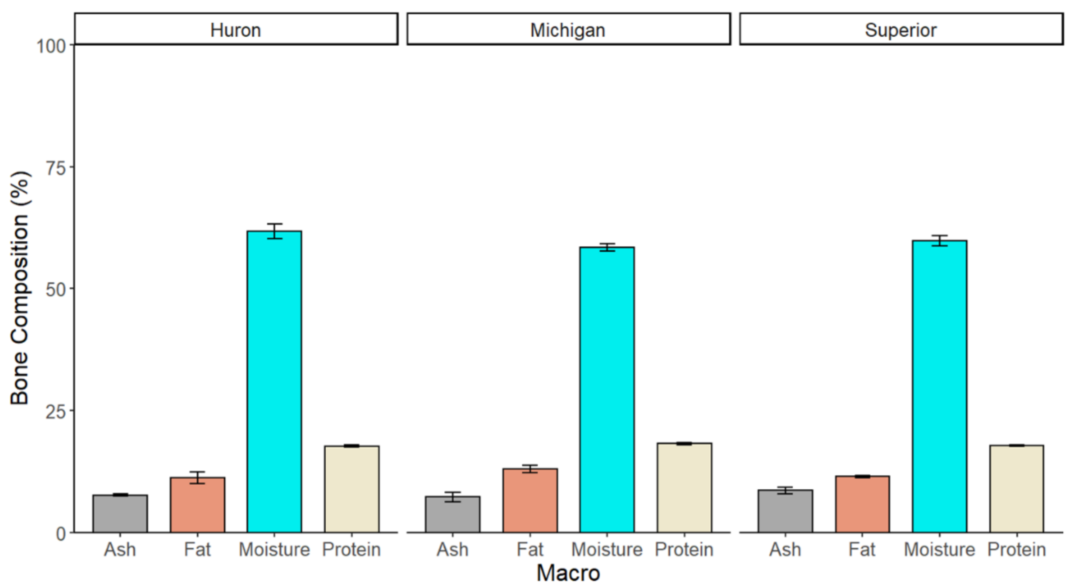


Figure 15. Average macro-nutritional composition of Lake whitefish bones (%).

The macro-mineral composition of the bones is usually related to the ash content. No difference between the fish from different lakes was found (Figure 6). Bone mineralization is associated with its hardness which is positively correlated to levels of phosphorus and calcium in them. When compared to mineral data from ten sea species (Toppe et al., 2007), even when the mineral content of the Lake whitefish bones was transformed as fat free and water free, the levels of phosphorus, calcium and sodium were similar. On the contrary, the potassium content was higher than what was found in the sea water fish. The Lake whitefish potassium content in the bones was around 9.5g./kg. while for the sea water fish it was between 2.6 and 8.2g./kg. **Figure 16**. A similar trend of higher potassium content in fatty seawater fish was found. With the comparison to seawater fish, the bones' mineral and proximate composition of the Lake whitefish would be closer to fatty seawater fish like mackerel (*Scomber* *scombrus*) or salmon (*Salmo salar*).

When the hydroxyproline content of the bones was studied **Figure 17**, it was with the purpose to know how much collagen was present in the bones and how much could be extracted. As the hydroxyproline is an amino acid specific of collagen proteins, knowing levels of hydroxyproline would allow us to know how much collagen should be present (Szpak, 2011). Tests have shown that in fish bones the ratio of hydroxyproline content is lower in cold-water fish than in warm-water fish. In fish bones' collagen, the hydroxyproline content of the collagen is known to be between 8.5% and 12.5% (Sotelo et al., 2016). The levels of hydroxyproline content found in Lake whitefish bones did not show any difference between the fish from the three different lakes but were lower than the levels from the bones of other fish (both from cold and warm water fish). The levels of hydroxyproline in Lake whitefish was as average 2.47±0.35g./100 g. protein while in cod it is known to be around 5.2g./100 g. protein (Toppe et al., 2007). Therefore, the bones are a better candidate for mineral valorisation as supplement, than for collagen/gelatine extraction. It would additionally be possible to use the bones for gelatine production since there is a moderate to high presence of hydroxyproline with a level of 0.4 g./100g., with a potential for yielding a 5% content of gelatine.

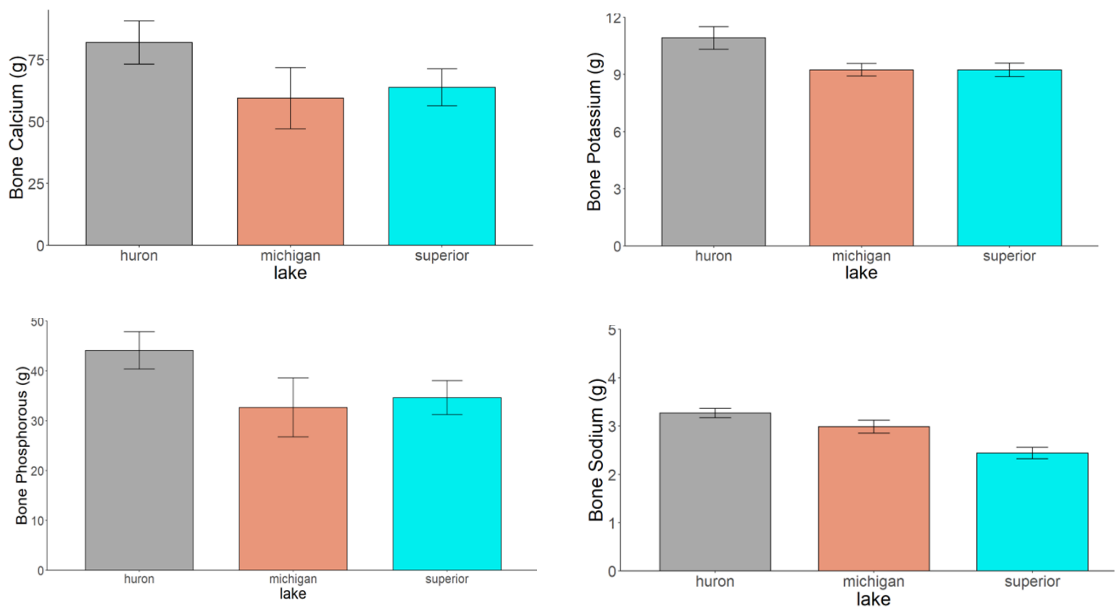


Figure 16. Average mineral content (g.) for calcium, potassium, phosphorous and sodium measured in Lake whitefish bones.

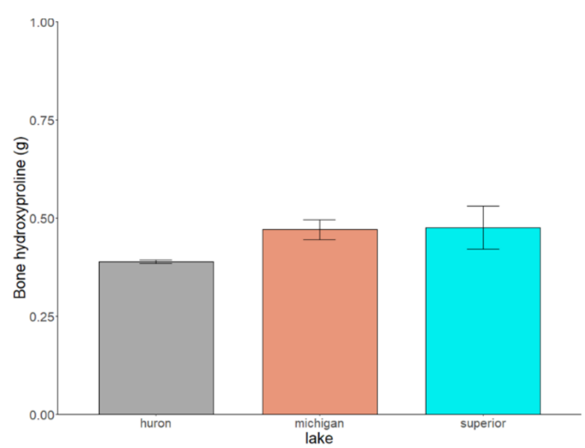


Figure 17. Average hydroxyproline content (g.) in Lake whitefish bones.

IV. Lake whitefish skin

The skin measurements were realized on the skin with the scales on. The present results show information of two subparts pooled. Therefore, the ash content was between 4.2% and 5.2% and the protein content was between 23.6% and 25.0%. No difference in protein and ash content was found between the skins from the different lakes. The fat and water content showed significant differences between lakes with significantly higher ($p=0.05$) content of fat and significantly lower water content in the skin of the Lake Michigan whitefish compared to the skin of the Lake Superior whitefish **Figure 18**. The higher fat content in the skin of Lake Michigan whitefish could be linked to the bigger size of the fish analyzed, which means either the presence of probably slightly more dark muscle close to skin which is rich in lipid, or a different feeding pattern with fattier food in Lake Michigan.

The hydroxyproline content in the skin is measured to know how much collagen/gelatine is present in it and could therefore be extracted. In most of the fish skins, the quantity of hydroxyproline detected is around 1% (Skierka & Sadowska, 2007) and in the Lake whitefish those levels were confirmed with hydroxyproline content being 0.99±0.13 % **Figure 19**. When evaluated as a quantity of g./100g. protein in the skin, the hydroxyproline content was 4.13±0.59 as average from the skin from the three lakes. As 13% to 14% of the fish skin collagen is made of hydroxyproline, we could expect an extraction yield of 13% to 14% of the whole skin and up to 55% of the protein content of the skins.

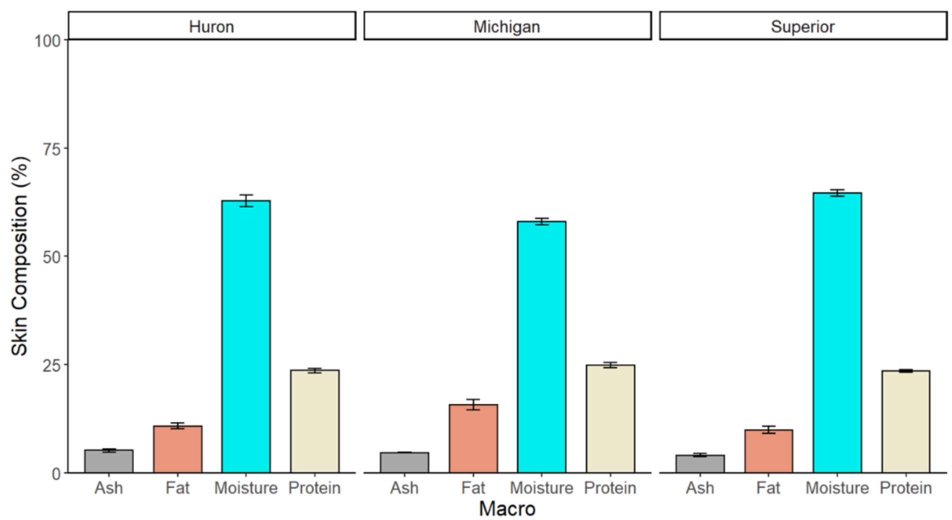


Figure 18. Average macro-nutritional composition of Lake whitefish skin (%).

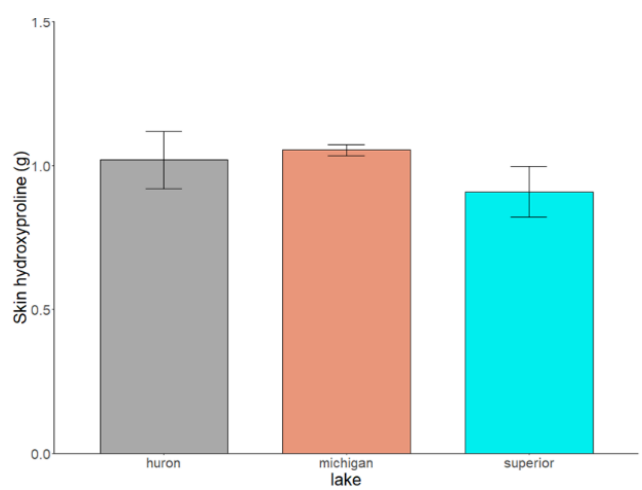


Figure 19. Average hydroxyproline content (g) in Lake whitefish skin.

4. Site visit findings

A detailed visit agenda was arranged by GSGP to give an overview of the fisheries sector for the Lake whitefish in both Canada and the United States, and for meetings and site visits with Tribes in the region. **Table 5** shows summarized information about the visits and activities carried out at each location.

Table 5. Summarised information about the visits and activities carried out during the visit from the Iceland team for the 100% whitefish project.

Date	Location	Value chain step	Activity
28.09.22	Presteve Foods, Ontario	Processing	Visit

Key Findings

Presteve Foods works with a range of species including the Lake whitefish. This included yellow perch and walleye with small amounts of white bass. Majority of their catch comes from Lake Erie and Lake Winnipeg and all catch is filleted by hand. Around 70% Lake whitefish are sold skin on both fresh and frozen, the rest as skinned fillets. Additional products included salted roe. Cut-offs from processing are collected and transported to mink farms, scales collected separately and discarded.

Date	Location	Value chain step	Activity
28.09.22	Ontario Commercial Fish Industry Representatives, Leamington, Ontario	Various	Presentation of project and discussion

Key Findings

The project outline, goals and initial findings were shared with the representatives of the Ontario Commercial Fisheries Association. There was interest from the audience and discussion of how such projects would promote innovation growth in the region. Fish processing companies present expressed interest in how they might independently start creating more value from their by-products as additional revenue streams for their companies. Discussion was also around the ecosystem health of the fisheries and the change in species composition over time, particularly the need to manage invasive species. The industry need for balance between collaboration and competition was discussed.

Date	Location	Value chain step	Activity
28.09.22	John O´Foods, Ontario	Processing	Visit

Key Findings

John O´Foods were primarily processing walleye, yellow perch and Lake whitefish. The facility also hosted a large cooling house (-20°C). For both walleye and Lake whitefish, scales were collected separately and discarded. Skins from walleye were also collected separately after de-scaling making this a high potential for value-add for this species too.

Date	Location	Value chain step	Activity
29.09.22	Motor City Seafoods, Detroit, Michigan	Processing	Visit

Key Findings

Motor City Seafoods have recently scaled up with Great Lakes Wine and Food. This facility was not yet in operation but was prepared for an increased level of automation and use of machines. This facility will also have a test kitchen for developing new products and menus. This company works with domestic Great Lakes species and also a wide range of internationally sourced seafood. Lake whitefish made up a small proportion of their volume and was primarily for the domestic market. Currently all cut-offs from processing are disposed of.

29.09.22	Chartreuse, Detroit, Michigan	Restaurant	Media visibility event

Key Findings

This media event at Chartreuse brought together fish processors from Motor City Seafood (Matthew Wiseman, Co-founder), GSGP (David Naftzger, Executive Director), Iceland Ocean Cluster (Dr. Thor Sigfusson, Founder and Chairman), Michigan Department of Natural Resources (Dan Eichinger, Director) and Chartreuse Kitchen & Cocktails (Doug Hewitt, Executive Chef). The purpose of this event was to showcase the opportunities of a "head to tail" approach to using different parts of the Lake whitefish (not just the fillet, but the belly, liver, head and fins) in food culture of the Great Lakes region. Examples of this included an Asian style Bao with non-fillet whitefish, a terrine of liver from the Lake whitefish, topped with Lake whitefish roe along with a fish curry with stewed fish head. There was good media coverage of this event. The links for some of these publications can be found below:

- https://www.detroitnews.com/story/life/food/2022/09/29/great-lakes-orgs-team-up-to-launch-100-whitefish-infinitive/69527508007/
- https://www.crainsdetroit.com/food-economy/100-whitefish-aims-boost-great-lakes-commercial-fishing
- https://www.michigan.gov/dnr/about/newsroom/releases/2022/09/29/100-percent-whitefish
- https://www.miningjournal.net/news/front-page-news/2022/09/100-whitefish/
- https://www.linkedin.com/feed/update/urn:li:activity:6981307678241300480/

29.09.22	Carlson's Fishery, Leland, Michigan	Processing and direct sales	Visit

Key Findings

Carlson's fishery had processing along with product development and a fish counter for direct customer sales on site. There was also a smoker onsite for added-value products. Business model strongly connected to the local community and tourism in the region. Filleting and processing done by hand, scales collected separately and discarded. Cut-offs of flesh from pin-bone were used in Lake whitefish sausages that were mixed with the walleye. Lake whitefish fillets were sold fresh, smoked and pickled. Remaining cut-offs discarded.

29.09.22	Fishtown, Leland, Michigan	Commercial high street shops	Visit

Key Findings

Seasonal tourism hub. A new dock had just been put into place and there was a lot of fisheries heritage information and a mature tourist market setup. While there were a number of artisanal crafts sold in Fishtown, there seemed to be a lack of very local materials used and no art products coming from fish e.g., fish skin leather products. There were leisure craft and recreational fishing trips leaving from this dock and the smoker, processing site and dock from Carlson's fishery onsite here.

29.09.22	**Arthur Duhamel reservation fisheries, Michigan**	**Fisheries, processing, market**	**Visit**

Key Findings

Onsite we saw almost the whole supply chain. The reservation fishery had small fishing boats in the harbor onsite and then individual processing units available to members of the Tribe community with HACCP certifications.

Lake whitefish, Cisco and walleye were caught and directly processed at this site. Many processing units used by family businesses that are involved in every stage of the supply chain from catch to consumer. Fish were hand-processed both into fillet cuts, and fillets were also cubed and made into fish cakes as a value-add product. Cut-offs were used for fertilizer at an agriculture site on the reservation.

30.09.22	**John Cross Fisheries, Charlevoix, Michigan**	**Processing and direct sales**	**Visit**

Key Findings

John Cross Fisheries does primary processing and secondary value add processing of Lake whitefish and walleye. There is also a smoker onsite as well as a fish counter for direct sales. Fillets are sold fresh, smoked and paté, and salted roe is also produced onsite. A mixture of manual and automated processing was used. Cut-off heads are currently sent to local agricultural producers for fertilizer.

30.09.22	**Little Traverse Bay Bands of Odawa Indians Office**	**Various**	**Presentation of project and discussion**

Key Findings

A meeting was held by the local Tribe authorities regarding the 100% fish project and the initial findings. There was interest in the project activities and there were a number of projects being carried out locally which are working toward full utilization of seafood. These projects will be important for the growth in value-add and circular economy.

5. Lake whitefish value chain mapping and analysis

The Iceland Ocean Cluster value chain for Atlantic Cod consider the value chains for fish value creation using a value pyramid model as shown in **Figure 20.**

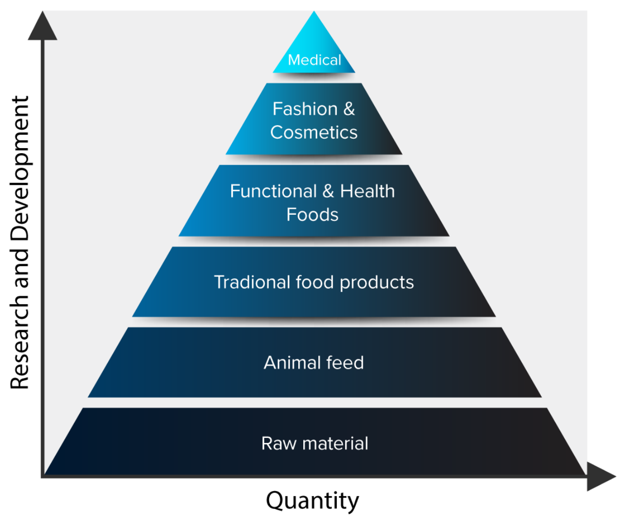


Figure 20. The product value pyramid which illustrates that volume of the resource available for value-added solutions and the increasing level of time, expertise and development required.

Iceland has reached ~90% utilization of Atlantic cod. **Figure 21** shows key examples of products and gives real-world scenarios that currently populate the innovative Icelandic 100% fish market sector. This list is not exhaustive but illustrates the Icelandic cod case study of full utilization. In the lower steps of the Icelandic pyramid example, it is notable that there is an important role of mediators who facilitate the 100% fish program, functioning as collectors of bulk frozen side-stream material. These mediators are separate companies from the fish processors, and they are paid to collect the bulk material. These mediators will then manage the transport and sale of this side-stream material both domestically and internationally, generating at least some value and preventing bulk material going to landfill. In 2015, the export of pure cut-offs were 238 tons with a value of 49 million ISK ($342,318 USD) (Matís Report Jónsson & Viðarsson, 2016). This approach of selling pure cut-offs is used most often when there has been a large landing and not enough time for processing companies to sort all the material themselves. This has gradually created a market for side-streams in Iceland. This bulk side-stream market could now be developed domestically by the extension of these mediator companies into the secondary processing of raw materials, making them a value-add participant in the supply chain, and not just a connecting link to other value chain actors. This will advance the knowledge of side-streams from the fisheries sector, driving changes in both material handling (such as differentiation) and quality management as new value-added actors emerge with a demand for such material.

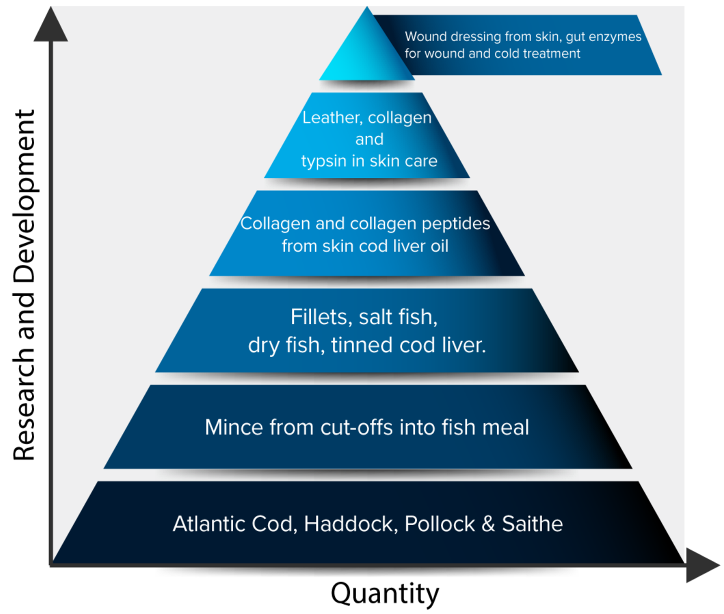


Figure 21. The Icelandic product value pyramid and example of extant products for Atlantic Cod, Haddock, Pollock and Saithe.

Each step on the pyramid and each product sector has a unique value chain that has developed through collaboration, research and innovation to reach the market with a finished product. This following section will detail value chains for each of these steps on the pyramid for the Lake whitefish. The value chain mapping will follow a standard model that maps the primary activities as shown in **Figure 22** where each activity adds value by creating a link in the chain. This chain is built from combined information from IOC case studies, FAO report by Asche & Nielsen (2006) and Primefish (Horizon 2020 project). During this project, an early 100% Lake whitefish mapping was visualized by GSGP and illustrates possible market sectors and products for the Great Lakes region. It is a powerful communication tool and also informs the value chain mapping in this report **Figure 23**.

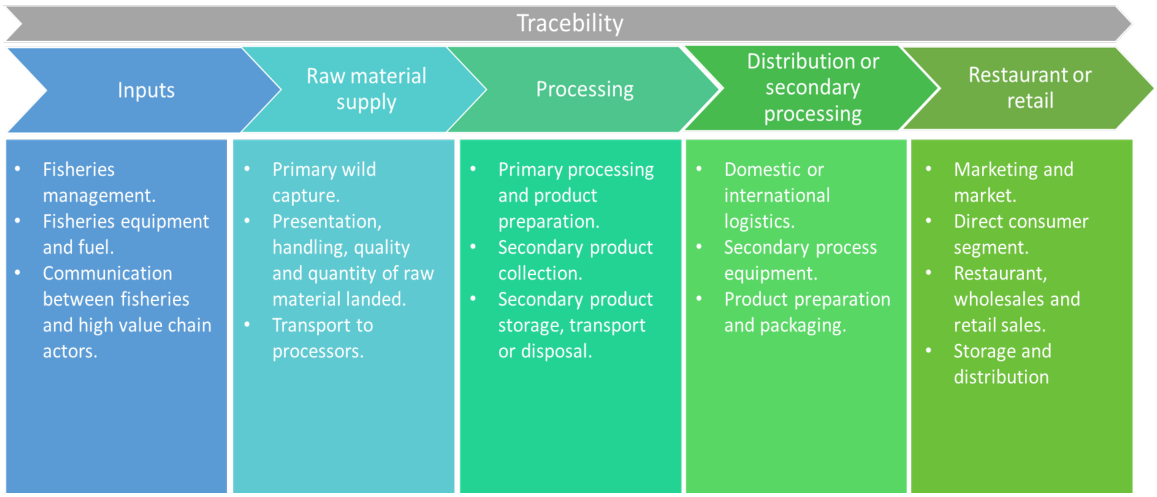


Figure 22. Base value chain that will be applied in the value chain mapping for Great Lake whitefish. The input link is consistent across all the value chains mapped and so will be omitted from the value-chain specific maps in the following section.

Figure 23. Potential product wheel developed by GSGP to illustrate 100% fish opportunities for Lake whitefish.

5.1. Primary product value chain

The dominant value chain for Lake whitefish is for the dressed fish and fillet, which are the primary products **Figure 24**. The numerical values stated are based on information collected during the site visits in September 2022 and may fluctuate. If this is taken as the standard pricing and an average individual fish is 2.5 lbs., value-add for this chain is an increase of $9.75 or 812.5% which is usually going direct to the processor and filtering down to the fishery (indirectly or through vertical integration). Additional data necessary to map this value chain further would be the sale value of fillets and dressed fish from the processor to the restaurant which was not available; however, market trends suggest that the mark-up is likely highest for restaurants at the end of the value chain.

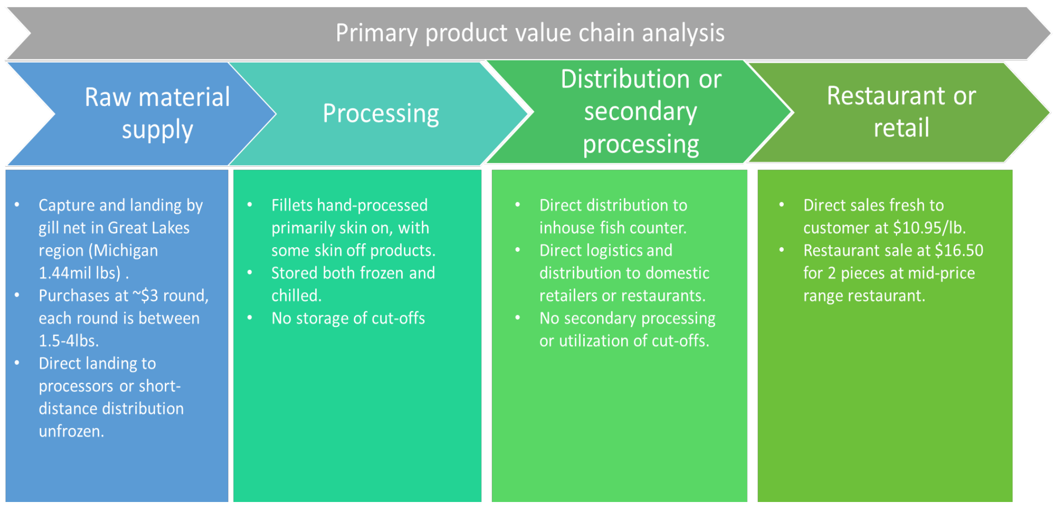


Figure 24. The primary product value chain for the dressed fish and fillet of Lake whitefish.

It would be beneficial to develop a database of the average sales profit margin at each step of the value chain to give a more detailed picture and illustrate the extent that values vary over time, season and location within the larger Great Lakes region. The major bottleneck for this value chain is the volume and stability of the raw material supply. Long-term fisheries and environmental management systems in the region will be increasingly important to maintain the quality and volume of primary product to feed into this value chain. Programs that stabilise and even increase the fisheries population of Lake whitefish in the Great Lakes must therefore be a priority. There are opportunities to raise the value of the primary product through marketing campaigns domestically and by investigating the potential international market growth for this product. There are also opportunities around expanding the consumer definition of what a primary product is to expand the product options in this value chain.

5.2. Animal feed & fertilizer

In the Great Lakes region, fish are primarily filleted by hand with some automation present in most locations such as de-scaling machines and de-headers, and with filleting in almost all cases observed, being carried out manually on a processing line. After the primary product of the dressed fish or fillet was produced, a mixed biomass containing all the cut-offs was left over. In some cases, this was collected and transported directly to a landfill, but in others there was small scale collection by both local farmers, who used the mixed biomass as a source of fertilizer and also in a small number of cases, fish meal producers supplying the mink farming industry. This value chain is shown in **Figure 25**. In this case, the final step of the value chain from fish meal can extend to the fur and fashion sector where high value can be added by designers and brand managers, although this value does not tend to filter down to the earlier value chain stages.

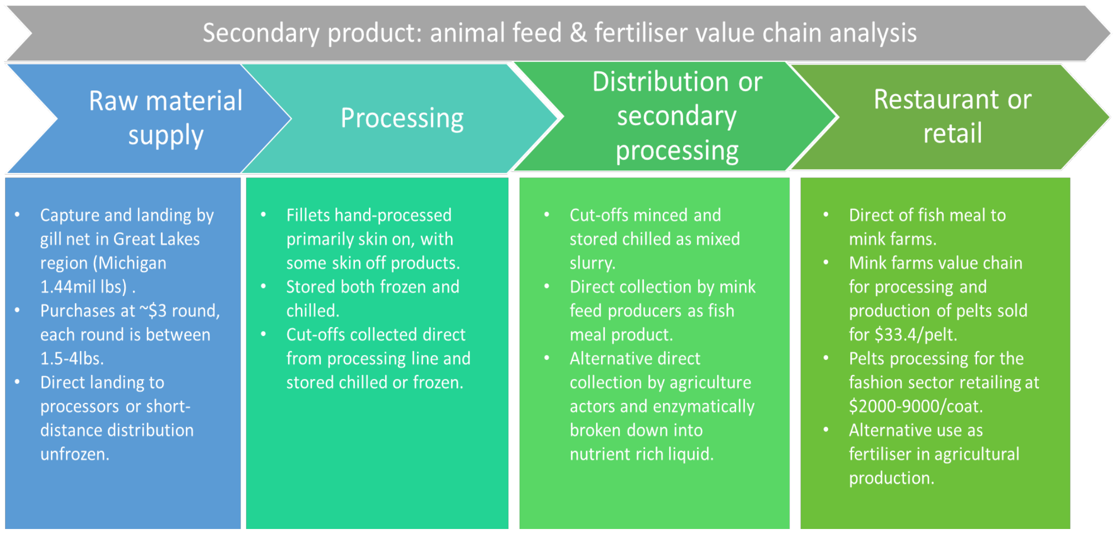


Figure 25. The animal feed and fertilizer value chain for Lake whitefish.

One of the major challenges for this value chain is the management, storage and distribution of the mixed organic material. If there was collective management of this organic material it would be possible to apply scalable solutions, for example, if all the organic material was collected and pooled from multiple fish processors in the Great Lakes region (for example by a mediator company) then supply chains for the fish meal and fertilizer sector would be more cost and time efficient. This would be aided by the fisheries sector to work more closely with the agriculture and mink farm sectors in order to improve the value creation at the distribution stage of the value chain. This would address one of the major bottlenecks faced by an industry that has many small-scale actors, that individually do not have the economic or person power to manage organic material streams. In such a model too, the mediator or industry collaboration group would likely need to invest in cold storage solutions as this also currently limits the scale and efficiency of this value chain. Such a mediator company has the opportunity to grow and create jobs in the region by investing in further infrastructure and equipment that can add value, such as protein plants (www.proteinplant.is) which can produce high quality fish meal from mixed biomasses rapidly and with lower-energy input.

It will also be important to consider other markets where both fish meal and fish oil have increasing importance and value, such as the fish farming sector which has high demand for high protein fish meal for formulated feed. The data collected and literature examined for this report suggests that the amino acid and fatty acid profiles of Lake whitefish are highly favorable for animal and fish feed inclusion which should be further explored through connection with the feed sector. Demand and market price for fish meal for aquaculture is high in years when other sources of fish meal have fluctuated, for example during low periods for Caplin biomass in Iceland and fisheries closures in Peru, as well as fluctuations in the availability of cereal crops since the war in Ukraine that are used as alternative aquaculture protein (FAO, 2022). In 2022, the market for fish meal reached 1800 USD/ton (increased by 200 USD/ton since 2021) and the market for fish oil reached 3000 USD/ton (increased by 700 USD/ton since 2021) **Figure 26**. From 100 kg. of mixed raw material for fish biomasses, on average, it could be expected to get 21 kg. of fish meal and 3-6 kg. of fish oil using standard processing techniques (European Commission, Directorate General for Maritime Affairs and Fisheries, & EUMOFA., 2021).

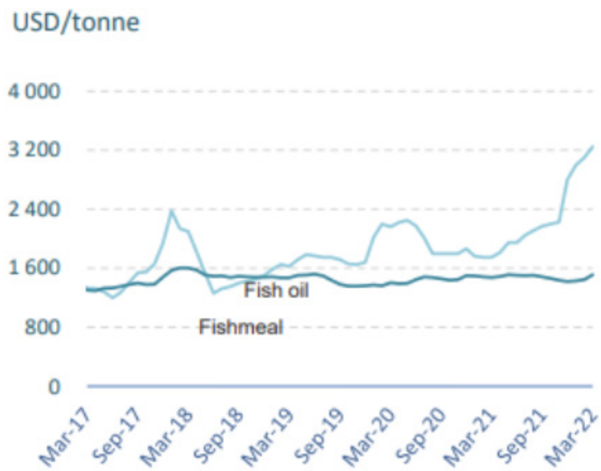


Figure 26. Price evolution of fish meal and fish oil between 2017-222 in Europe.

Likewise for the agricultural sector, equipment that can improve the characteristics of what is currently fish waste for fertilizer and the consistent availability of the biomass will be beneficial. This might include application of enzymatic degradation (hydrolyzation) of the fish proteins which produces a liquid product that is rich in peptides and minerals that is more effective that direct application of what is currently fish waste as a fertilizer. It should be noted that the use of what is currently fish waste as a fertilizer has a lower market value than fish meal and fish oil applications (Jónsson & Viðarsson, 2016).

5.3. Traditional value-added food products

There is an existing consumer market and array of products from Lake whitefish that include added-value food products. These use a mixture of fillet, pin-bone cut-offs and other fleshy cut-offs from the Lake whitefish. These are then produced using low-tech equipment to produce smoked fillets, sausages (which often are mixed with other species to increase the fat content), fish cakes, roe, pickled fish and Lake whitefish salad. All these products create additional value compared to the fillet alone, although not a high margin of increase compared with the time necessary to prepare these products. In the greatest value-add example observed, Lake whitefish sausages sold at $12.30, an increase of 1025% from purchase on the round by the processing company **Figure 27**. In almost all cases, these value-add products were made onsite by the small-scale fish processing companies that had additional equipment to produce small quantities.

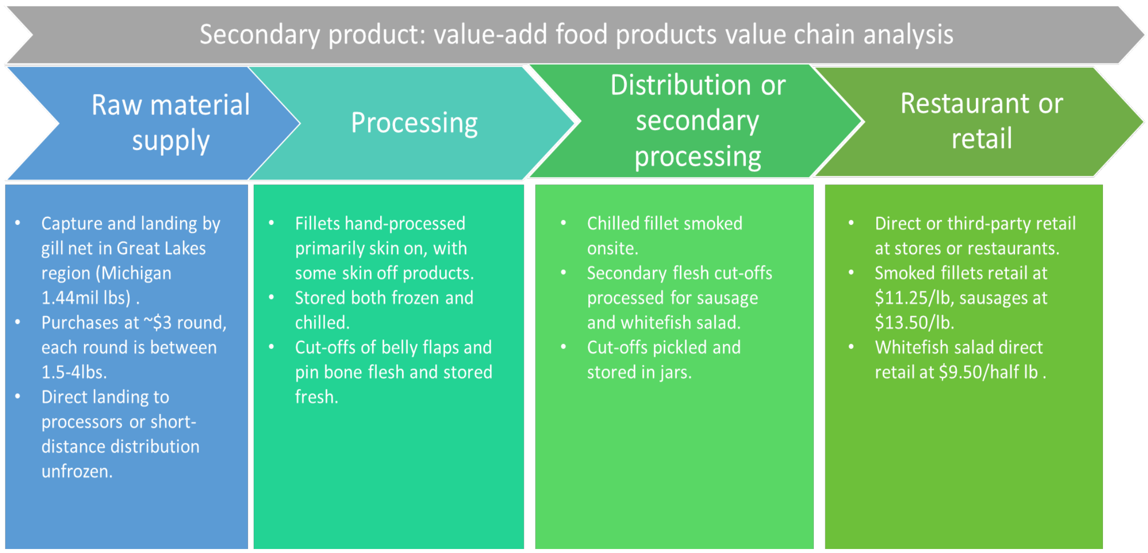


Figure 27. The value-add food products value chain for Lake whitefish.

The bottleneck for this value-chain is also the small-scale and dispersed nature of the fisheries processing industry in the Great Lakes region for Lake whitefish, which limits all production of these value-added food stuffs to the small-scale and very local market as there is limited distribution or storage in the current supply chain. Similarly to the management of mixed biomasses from the processing factories that would benefit from being pooled to create a large mass of, in this case, high quality food grade cut-offs could benefit from a mediator company that could add a step to the supply chain and produce a standardised, higher volume of value-add products and also develop branding and marketing that could increase the profit margin of the value-added products too. Alternatively, there are opportunities for value-add products to remain independently produced by fish processors. But, value could be added by associations that connect local producers with common branding and marketing, both domestically and internationally, that could also help to raise the value and sales price of such products. Such branding associations could also support the development of dishes and menus with the local restaurant sector to drive new food trends that raise the profile of these value-add foods. This opportunity was well illustrated in this project by Chef Doug Hewitt who was able to create an experimental "head to tail" menu**.**

There are also opportunities to diversify products for the value-add foodstuffs market, for example, there are restaurants in the Great Lakes region that have fish head soup on their menus. These restaurants do not currently use Lake whitefish as there is no supply chain or separated collection of Lake whitefish heads, but fish head soup retails at $11 per serving on average in the region. This is also potentially a good fit, since we know the amino-acid profile is highly nutritional from Lake whitefish and in a number of processing factories one of the automations that was present were de-headers, even in small processors. Food technologies that preserve food and are low-tech should also be further explored, for example the canning of livers. However, a bottle neck currently exists for livers as they are generally discarded with viscera and the processing line would have to be redesigned to collect them separately.

5.4. Functional foods and cosmetics

A value-chain for the production of functional foods and cosmetics is not currently present for the Lake whitefish fishery sector in the Great Lakes region, but a hypothetical value-chain map was developed in **Figure 28** to explore the bottlenecks and opportunities to establish and develop this value chain. The examples of secondary processing and retail products and their market cost are taken from real examples on the international and domestic markets.

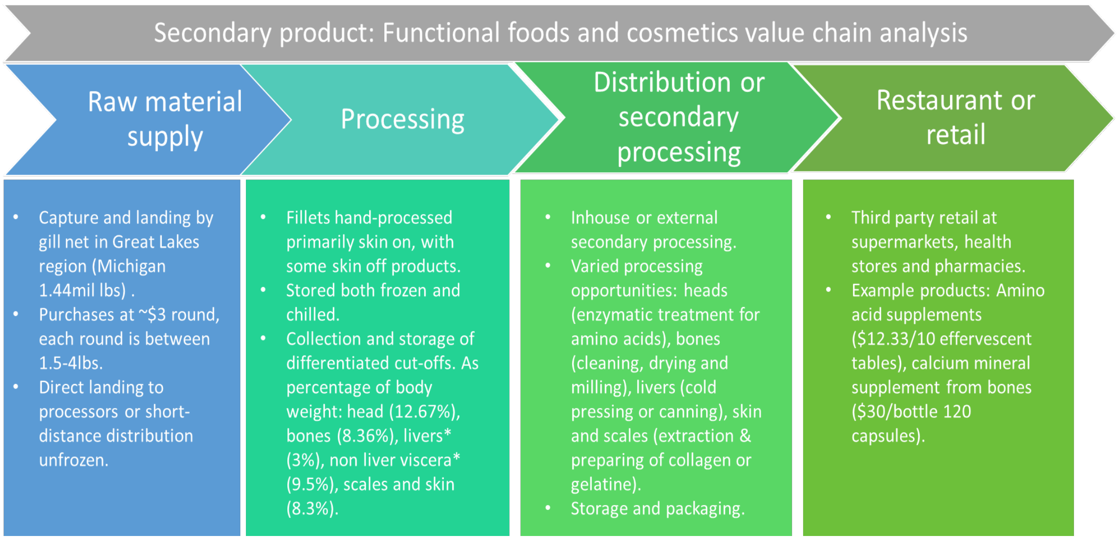


Figure 28. The functional foods and cosmetics value chain for Lake whitefish.

The primary bottlenecks that have limited the establishment of this value chain are related to the distributed and small-scale nature of the fish processing sector in the Great Lake region; a lack of differentiated processing (e.g. livers, guts, heads, skin separated); a lack of connection between the fisheries and fish processing sector with the biotechnological and innovation sector; and, limited regional development of functional or cosmetic products from fish products.

However, if some of these bottlenecks can be addressed, there is potential for a high level of value creation with such functional or cosmetic products. There are particular opportunities to build from differentiation of processed products that were observed in multiple processing factories during the site visit. For example, many fish processors were using de-scalers prior to hand-filleting Lake whitefish. These de-scalers automatically create a supply of wet scales that are differentiated on the processing floor. These scales were added into the mixed organic material for landfill or mink feed, but they present an opportunity that does not create additional work for the existing processing line. This is likewise in the examples where de-headers are used for Lake whitefish. In order to take advantage of these opportunities, it would be important to ensure the materials are handled based on the requirements of the functional or cosmetic application (e.g., hygiene, cold storage, time-sensitivity) and that sources of demand are identified or fostered. This would require collaboration with the innovation or industry sectors that could use these materials and would, in the case of small-processing companies, likely also require a mediator to facilitate this process.

In the case of the scales, collagen could be produced as functional or cosmetic products. Collagen is one of the structural proteins present in different parts from the body, mainly in the skin and the bones of fish. Collagen from fish has gained interest in the last years for both social (for example, following the bovine spongiform encephalopathy disease that touched cows in the 90s, people tend to be more cautious) and religious reasons (for example, pork and beef collagen are only acceptable if prepared in a specific way in Islamic culture). Collagen has numerous applications from the food processing industry to the health industry. In the food industry, it is mainly used to improve rheological properties of food products like sausage. It can also act as a good emulsifier in acidic products or as a meat replacer in some formulations. It could also be added in drinks to work as healthy drinks to give active people better recovery (Hashim et al., 2014). In health products, it is often added in cream or in pills/tablets to improve textural properties or as a complement to help regenerate bone damages (Jafari et al., 2020). Gelatine is the water-soluble part of the collagen, and it is usually extracted from cold water fish. It has extremely good emulsifying and film forming properties (Jónsson & Viðarsson, 2016).

Setting up an industrial collagen extraction process requires large investments both in equipment and process development.

This is currently done commercially in Iceland and Canada from the skin rather than the scales of species like

Atlantic Cod and Haddock and developed into functional products, for example by companies like Feel Iceland (https://us.feeliceland.com/). The yield from skin (~13%) is on average greater than that from scales (3-5%), although in the context of the Lake whitefish, this would require additional processing steps and differentiation to be established. The market price of fish collagen is between $10-50/kg. making it a high value creation step.

In the case of the heads, there are opportunities to produce fish protein hydrolysates (FPH). FPH is created by mixing enzymes with fish mix to cleave covalent bonds and create peptides. The fish are grounded and then mixed in a ratio 1/100 with enzyme. Once the proteins have been hydrolyzed, they become liquid (just as when silage is produced) and it can then be dried (by removing water) and used as a food component or additive. FPH have both antioxidant properties and interesting sensory properties. They can also improve water holding capacity and texture of the food products they are used in. FPH prices vary depending on the quality and the amino acid composition of the biomass, but on average could range from $1,500 -10,000/ton. The recovery of raw material after transformation is known to be between 50-70% of the initial wet protein value (Ghaly et al., 2013, Nurdiani et al., 2022). As a dry product, the yield of fish protein hydrolysate is around 10% (Thankamma et al., 1979). Additionally, this could be taking a step further for increased value production as fish protein isolate (FPI), which is a purified fish protein (at least 90% of the dry material is protein). It is usually obtained through a pH shift process (solubilization of muscle proteins at high pH (pH 11.2) and solubilized proteins are precipitated by lowering the pH to 5.5. Protein isolates are usually used in the food industry, as they have a number of desirable properties such as gelation properties and some foaming-emulsion properties. They can also be used for surimi production. The advantage of this process is a high recovery of protein for a relatively low cost (Kristinsson & Liang, 2006). The market and value creation of fish protein isolate is similar to the one of fish protein hydrolysate.

5.5. Fashion value chain

A value-chain for the productions of fashion textiles and materials is not currently present for the Lake whitefish fishery sector in the Great Lakes region, but a hypothetical value-chain map was developed in **Figure 29** to explore the bottlenecks and opportunities to establish and develop this value chain. The examples of secondary processing and retail products and their market cost are taken from real examples on the international and domestic markets. The applications of fish by-products directly to the fashion sector are limited and the market is dominated by fish skin leather. There are several international commercial retailers that supply products that use fish skin leather, primarily in small pieces e.g., as detailing. Companies of note include Prada and Nike which have a wide market appeal and audience.

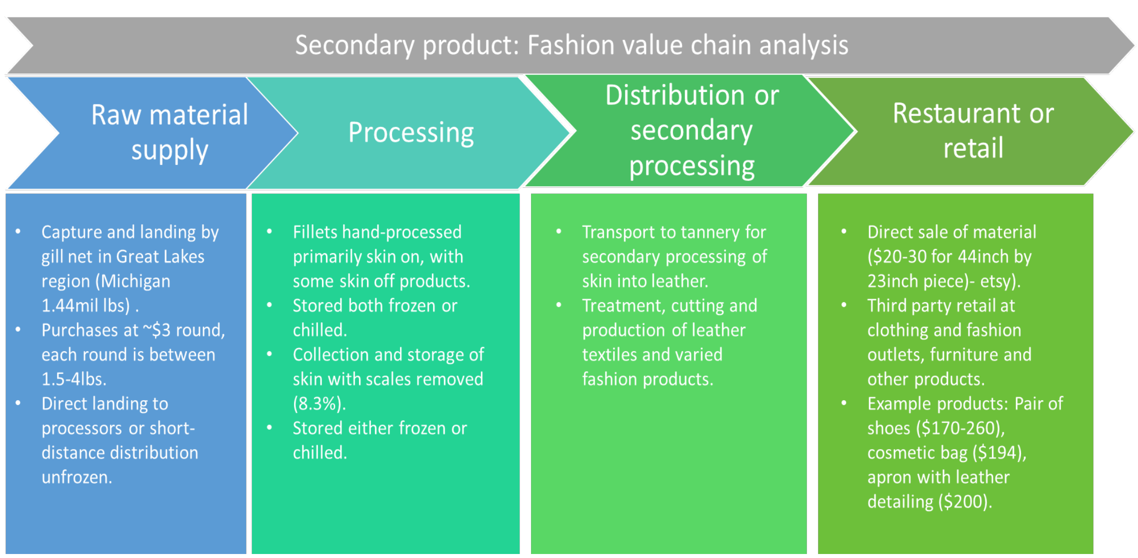


Figure 29. The fashion value chain for Lake whitefish.

A bottleneck for this value chain would be the separation and storage of fish skins, which is not widely practiced for Lake whitefish in the Great Lakes region. This would add additional processing time and require additional expertise by skilled hand-filleters or automated machinery that can handle the delicate flesh of this species. While this was not observed for the Lake whitefish, there was differentiation of some Great Lake fish species (walleye) observed during site visits which offered some potential opportunities for early exploitation and presents an existing model which could be easily adapted to Lake whitefish. The opportunities for developing this value chain are high, since the processes is well established and does not require further costly research and development and there is a growing market for sustainable textiles in the fashion sector on a global scale (Blanco et al., 2007, Thanikaivelan et al., 2005) as well as environmentally sustainable methods documented in the literature, for example by Duraisamy et al. 2016. Additionally, once leather is tanned, it is dried, preserved and light-weight so it can be easily distributed to fashion brands or clothing designers. There are also flexible production opportunities based on existing models globally for both large scale (Nordic Fish Leather, Iceland https://nordicfishleather.com/) and medium to small scale local production (The Netherlands, https://www.visleer.nl/, Etsy, https://www.etsy.com/shop/ShadiLeather?ref=l2-about-shopname) which could suit the initial development of this value chain in the Great Lakes region. As in the case of the other value chains explored, a mediator role and pooling of fish skin biomass would address supply volume limitations from individual processors that may limit the economic feasibility of this supply chain.

5.6. Medical value chain

A value-chain for the productions of medical products is not currently present for the Lake whitefish fishery sector in the Great Lakes region, but a hypothetical value-chain map was developed in **Figure 30** to explore the bottlenecks and opportunities to establish and develop this value. The examples of secondary processing and retail products and their market cost are taken from real examples on the international and domestic markets. It should be noted that at the international level this is a limited value chain with few companies operating and even fewer at scale as medical product development often takes high levels of research, time and capital to reach market.

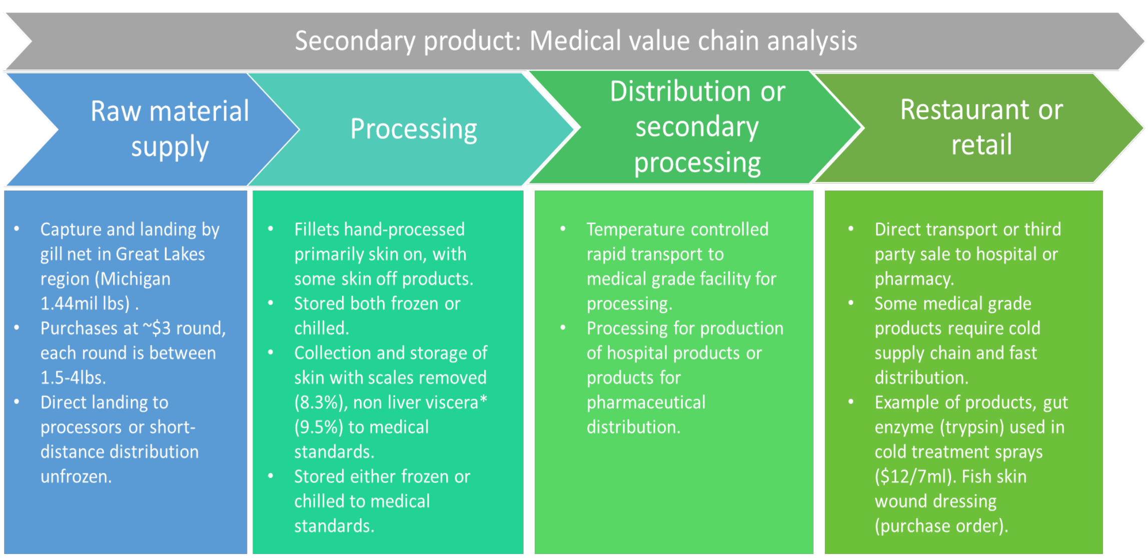


Figure 30. The medical value chain for Lake whitefish.

The primary bottlenecks of this value chain are the limited amount of research and development on products from fish by-products in general and particularly in Lake whitefish that has not received biomedical attention. There is also a supply chain challenge since biomedical materials need to be carefully handled; rules are often stricter and timeframes shorter; and, limited similar supply chains are present in the region to act as a model. Key steps to develop the medical value chain for Lake whitefish-derived medical products would be with close collaboration between biomedical research, the pharmaceutical sector and research projects that build on knowledge and creation of value chains from other seafood by-products for the biomedical sector. While this is a challenging value chain to develop, the potential economical and societal value is high so it would still be beneficial for fish processing associations or fisheries to connect with the biomedical research sector in order to lay the foundation for such product development.

6. Lake whitefish value chain SWOT

A Strengths Weaknesses Opportunities and Threats (SWOT) analysis examined each step of the Lake whitefish value chain, applying key questions regarding internal and external factors which can help to establish the research and development priorities to address in order to improve value creation, maximize the resource use and reduce risk throughout the value chain for Lake whitefish. It also highlights where strategic action is needed. The model and key questions used in this SWOT analysis are shown in **Figure 31**. This model represents an initial analysis and could be strengthened by discussion and data collection from focus groups and surveys in the Great Lakes region. The input step of the value chain was not considered here as it was considered to be outside the remit of this project as much of the information relies on regional environmental and fisheries legislation and management.

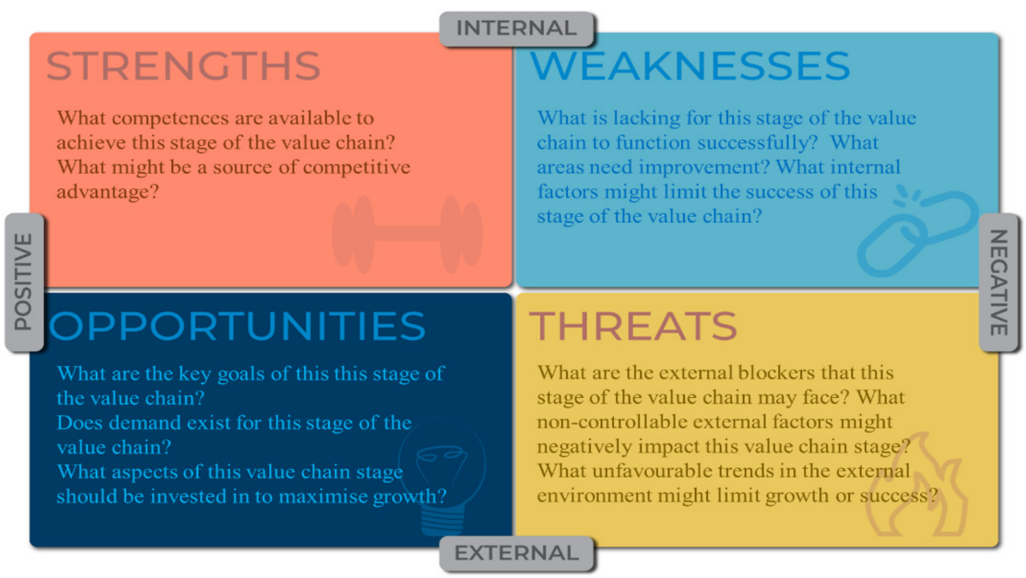


Figure 31. SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis model with key questions used for this analysis.

6.1. Raw material supply SWOT

Figure 32. A SWOT analysis for the raw material supply step of the Lake whitefish value chain.

6.2. Processing SWOT

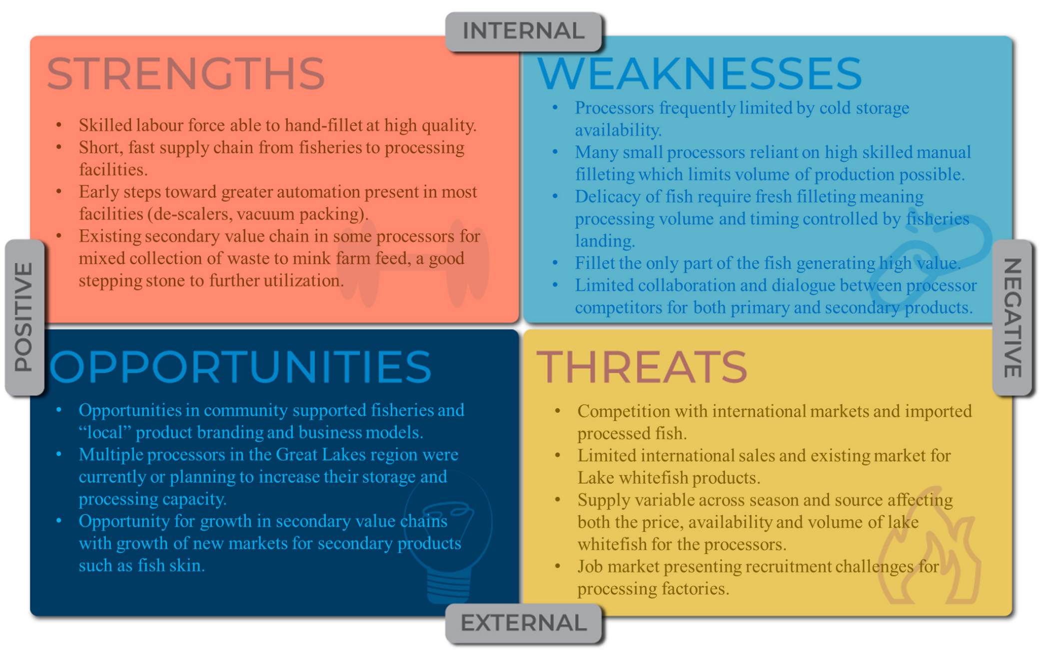


Figure 33. A SWOT analysis for the processing step of the Lake whitefish value chain.

6.3. Distribution or secondary processing SWOT

Figure 34. A SWOT analysis for the distribution and secondary processing step of the Lake whitefish value chain.

6.4. Restaurant or retail

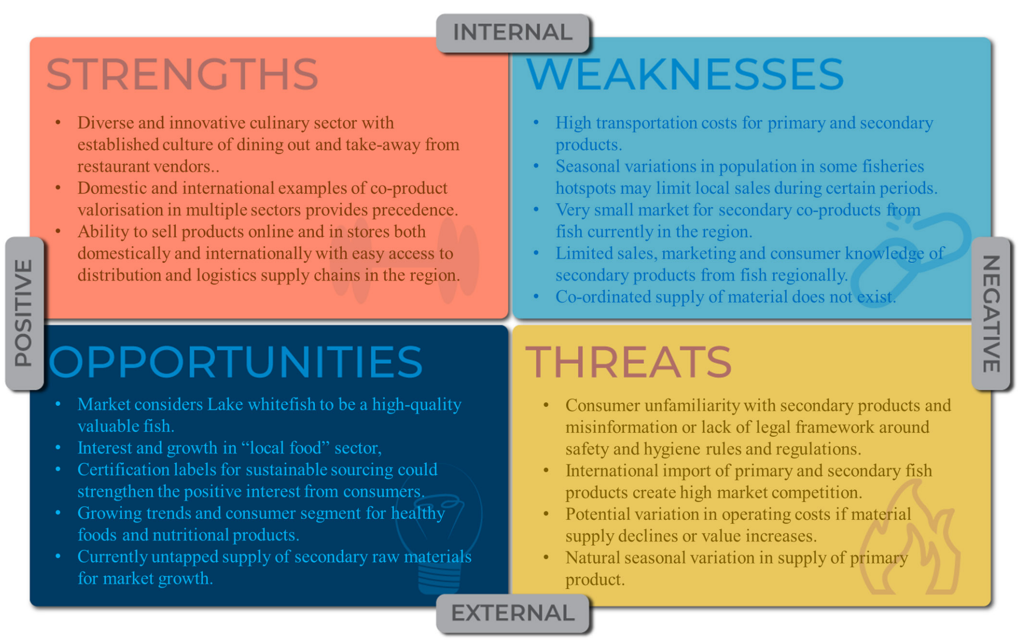


Figure 35. A SWOT analysis for the restaurant or retail step of the Lake whitefish value chain.

7. Best case value-added strategies

In this section, a total of three best-case value-added strategies has been highlighted based on the findings of the site visit, the value chain analysis and the SWOT analyses for each value chain step for the Great Lakes region and the Lake whitefish. The first two best-case strategies are ones that require larger volumes and coordination of the supply chain and the respective by-product but present easy uptake cases of the current processing models present in the Great Lakes region. The third best-case strategy presents a value-add option which could be scaled, either developed for small scale artisan operations or for larger scale commercial production if the supply chain is developed.

7.1. Best case strategy one: Utilize heads

The priority best-case strategy highlighted by this report is utilization of the heads of Lake whitefish. This has been highlighted for several reasons, firstly, the amino-acid profile is highly favourable for nutrition in both feed and food. Secondly, this was one of the by-products that in a number of processing facilities was processed separately. Thirdly, there is already a regional model for differentiation of this material and because there are multiple potential value-add use cases for this by-product that are based in established research and markets. In particular, the use case that is recommended by this report to optimize the value creation is fish protein hydrolysates (FPH) based on their market price, and the range of markets, both for human food and supplements or for the high-end animal or aquaculture feed market.

The priority next steps to establish and develop this value chain would be to:

i. Identify the volume of the material that is currently available and differentiated (by de-headers) in existing processing workflows and explore opportunities to expand the use of this small-scale automation in the region.

ii. Identify an existing or emerging early-stage innovation company that has the potential to utilise this material from one of the possible FPH market sectors.

iii. Connect fish processing companies with available fish heads together, either with each other in an association or with a mediator body (a third-party), that could pool Lake whitefish heads to maximise the volume available.

A potential limitation in this case would be that there are no existing regional users of FPH across the multiple potential market sectors. It would then be necessary to draw from international knowledge transfer and collaborate with the research and start-up community and seek financing to establish such a use case.

7.2. Best case strategy two: Collagen

The second best-case strategy highlighted by this report is the utilization of the scales for collagen production. This was highlighted because there were multiple examples of fish processors that already differentiate the scales from Lake whitefish, the hydroxyproline content (an indicator of possible collagen yield) of the scales and skin combined showed promising values. There is a high market demand for fish collagen sources that span several sectors including food, functional foods (like nutritional supplements) and skin care products that provide a number of variable market opportunities. Furthermore, there are already established and commercialized processes for collagen extraction from fish skin, increasing the opportunity to realize this value case.

In the following section (8), a prototype test has been carried out based on known methodologies to see if it was possible to extract collagen from either the scales or the skin of Lake whitefish, since this has not been done before.

The priority next steps to establish and develop this value chain would be to:

i. Identify the volume of scales available and differentiated (by de-scalers) in the existing processing workflows and explore opportunities to expand the use of this low-tech machinery in the region.

ii. Seek grant or investment funding in collaboration with existing international collagen extraction companies such as Marine Collagen Iceland to carry out further methodological development of collagen extraction from Lake whitefish scales and assess the quality of the collagen produced.

iii. Identify functional food and cosmetic companies at a regional or international level that are seeking fish collagen sources. There is a growing market for such products in the United States, Europe and Asia.

iv. Develop an optimised supply chain for this new value chain depending on the outcome of the above steps, considering the potential of a mediator organisation or association to facilitate this.

7.3. Best case strategy three: Fish skin leather

Fish skin leather from Lake whitefish was also identified as a high potential case to valorise fish skin. Alternative leathers are a growing market and offer domestic and international product distribution opportunities. Despite this, it offers a flexible value chain development model which may be suitable for the small scale and local fisheries and processing sectors of the Great Lakes region. Leather has production models that are small scale and, separately, commercial large-scale. There is a well-established tradition and methodology for such materials and textiles with a wide variety of textile use cases. In a small-scale scenario, this could offer development of locally produced, artisanal products for the regional tourist market and this would also benefit the community of artists with new sources of material. Examples of such products can be produced from both large and small pieces of tanned fish leather.

In the following section (8), a prototype test has been carried out based on known methodologies to see if it was possible to produce leather from the skin of Lake whitefish, since this has not been done before. Furthermore, a local artisan used this prototype to explore product development opportunities.

The priority next steps to establish and develop this value chain would be to:

i. Identify the volume of skin potentially available from the Lake whitefish sector.

ii. Connect the fisheries processors either directly or through a third party with a regional leather producer or an artisan able to tan leather on a small scale.

iii. Connect with textile companies and designers to develop prototypes for market testing.

iv. Develop a business model suitable for small-scale production of leather from Lake whitefish.

8. Prototyping

The following section details the biotechnological extraction and treatment of Lake whitefish side streams for production of prototype value-added products. It was possible to explore two the of the recommended best-case options in this prototyping phase although these results are preliminary and will require further development to bring such products to market.

8.1. Prototype production

8.1.1. Collagen extraction from skins

The water-soluble collagen was extracted according to the method of Phanturat et al. (2010) with slight modifications. The skins were cut in 3 squared cm. and then rinsed for five minutes in cold water to remove the impurities (left scales, pieces of muscles, etc.). They were then transferred into a 0.1M NaOH solution (ratio 1:10) for 3 times 30 minutes at room temperature. This step removed the non-collagenous proteins. After that, they were washed under cold water to have a pH close to 7. Samples were then placed into a 0.05M acetic acid solution (ratio 1:10) for two times 45 minutes to remove the rest of the impurities and after that for three hours to allow the swelling of the protein matrix. They were then rinsed again with cold water to bring the pH back to close to 7. The gelatine was extracted in water at 45°C for 14 hours at 100 rpm. The solution was then filtered through 50 µm cheese cloth and then freeze dried.

8.1.2. Collagen extraction from scales

Fish scales were extracted with 0.1 M NaOH for six hours at a ratio of sample versus alkali solution of 1:8 (w/v) to remove non-collagenous proteins, washed fully with cold distilled water. The scales were decalcified with 0.5 M EDTA–2Na (pH 7.5) at a ratio of sample versus EDTA solution of 1:10 (w/v) for 24 hours and then washed with cold distilled water. The residue was extracted with 0.5 M acetic acid at sample/acid ratio of 1:2.5 (w/v) for four days. The ossein (scales after the decalcification process) was then extracted with water at 55°C for six hours and then filtered through Whatman 4 and the filtered extract was freeze dried.

8.1.3. Leather production from skin

Leather was produced from Lake whitefish for this project using the commercial processes developed and used by the Icelandic company, Nordic Fish Leather, Iceland, to produce leather and to dye fish skin. Samples of this leather were then applied to commercial accessories and products by a company in Minnesota.

8.2. Prototype assessment

8.2.1. Collagen from skins and scales

The water-soluble collagen extracted from the skins gave promising results for further development. The yield (ratio of freeze-dried product, from initial wet weight of the skins) was 7.7%. The color of the freeze-dried product was white as seen in **Figure 36** and the texture was smooth. The freeze-dried product did not have a fishy smell. The water-soluble collagen extracted from the scales was promising but requires improvement. The yield was only 4.1% and from observation analysis it seems that some mineral went into the product as the texture was rather hard and the color less white than the collagen extracted from the skins. It is expected that an optimized process could increase the yield of collagen from the scales. Since the hydroxyproline content of the skin and scales combined was close to 1 g./100 g., there is a potential in an optimised process to extract up to 13-14% collagen yield in total. Since the skin (with scales) represents on average 8% of the fish biomass from a gutted fish and the average weight of a fish investigated in this study was around 1 kg., this suggests a possible yield 130 g. per fish.

Figure 36. Collagen prototypes produced for this project from Lake whitefish skin (A) and scales (B) by the labs of Matís ohf, Iceland. After collagen extraction, biomass remains from both skin and scales (C) and that also has potential to be utilized for glue production.

8.2.2. Leather and leather products from skin

The leather prototype production was successful, and two colours were produced **Figure 37A** and were successfully applied to accessories **Figure 37B.**

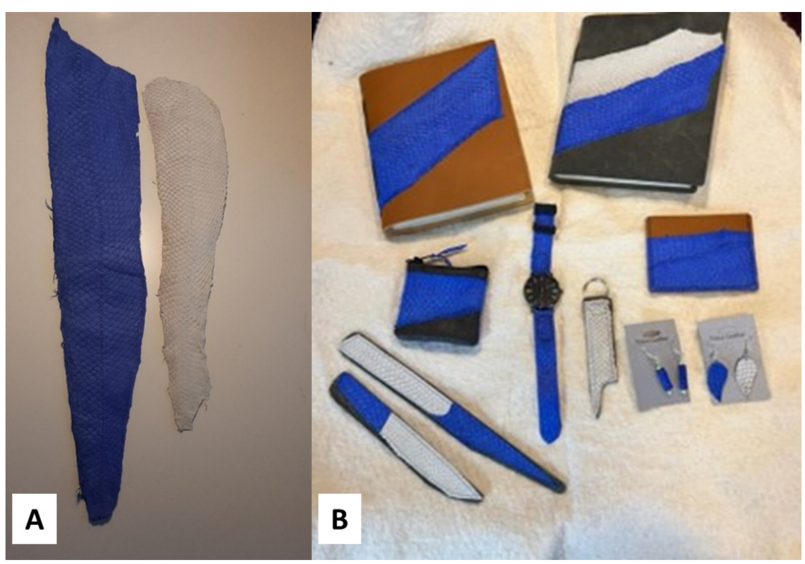


Figure 37. Leather prototype produced for this project from the Lake whitefish skin by commercial fish skin leather producer, Nordic Fish Leather, Iceland, and then applied to commercial accessories and products by a company in Minnesota.

9. Filleting Test

In the Great Lakes region, much of the filleting is done by hand, with some examples of specific automation applications, for example de-scalers, de-headers and vacuum packing. In Iceland, there is extensive use of automation in the Atlantic cod and Haddock fisheries that allow for high volume and high precision filleting and high speeds. While the fish processing landscape in the Great Lakes region is currently dominated by many small-scale processors, a number of these companies had expansion of their operation planned or underway. It was therefore determined to be relevant to this project to test the opportunities for using automation for Lake whitefish fisheries. Furthermore, it has been the case in Iceland that automation has enhanced the capacity for full utilization of fish byproducts.

In total, five fish were used as test samples for the Curio automated filleting machine, all weighing individually 846-1404 g. The Curio machine used for this test had been assembled in Iceland by the Curio team for a client with a larger species requirement. The fish used in this process were those that had been shipped frozen to Iceland, then were delivered frozen to Curio who then fully defrosted them prior to testing them in the filleting machine. The transit through the filleting machine is shown in **Figure 38**.

Figure 38. Curio filleting machine trial with Lake whitefish sample.

The machine was calibrated for J-cut shown in **Figure 39**, since this was standard for the species the machine was being assembled for. The fish were also manually skinned.

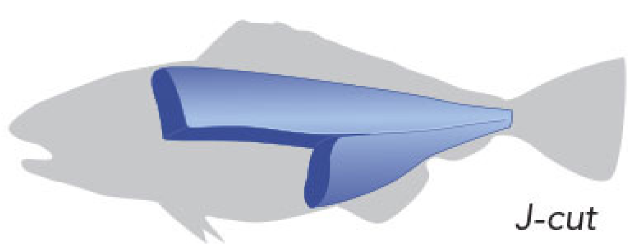


Figure 39. Graphic of the J cut commonly used in fish processing in Iceland.

The Curio team provided feedback on their experience using their filleting technology on these Lake whitefish samples along with body part weight composition (%) **Figure 40**. The trial was non-optimal since the fish had been frozen for international transport and this left the consistency of the flesh much more delicate. Following the visit to the Great Lakes region, it was clear that all filleting of Lake whitefish is currently done on fresh fish and no freezing prior to hand-filleting is used. The trial went well despite this, but the quality of the fillet post-machine was a poor consistency and fell apart more than a fresh fillet would. The machine was also designed for a bigger fish than those tested as part of this trial. The machine would be calibrated and optimised if it was built for Lake whitefish. It was discovered too that where fisheries cut the fish in the Great Lakes region for gutting was in a different location than cod, so machines would have to be calibrated for this. The Curio team considered this a promising first trial and think the results would be greatly improved with a fresh sample. Automation will therefore be an important part of the dialogue for the future development of the Lake whitefish fisheries in the Great Lakes region.

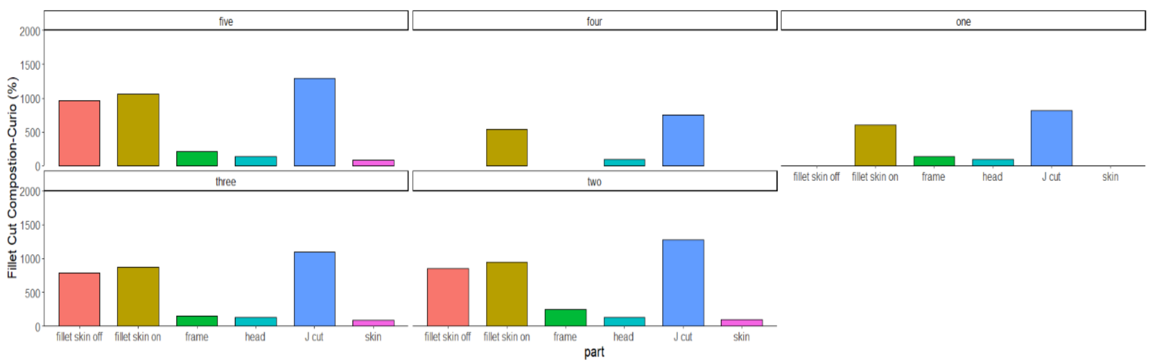


Figure 40. Post-filleting body part weight composition of the Lake whitefish samples processed using the Curio device.

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