ICELAND OCEAN CLUSTER

100% Great Lakes Fish

Multi-Species Report 2023

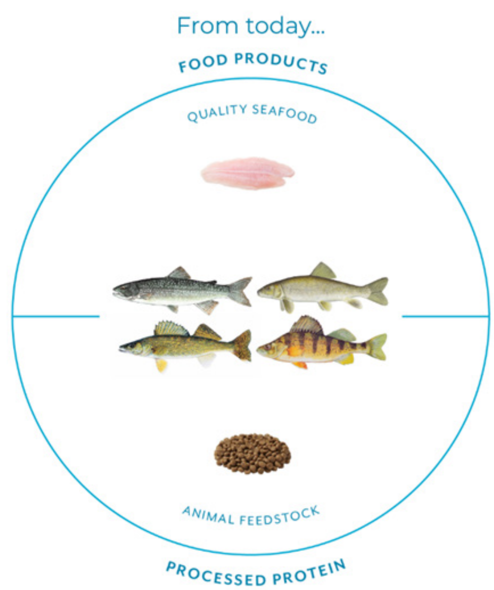
PREPARED BY

The Iceland Ocean Cluster for the 100% Great Lakes Fish Project and the Great Lakes St. Lawrence Governors & Premiers

Contents

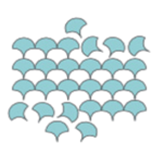
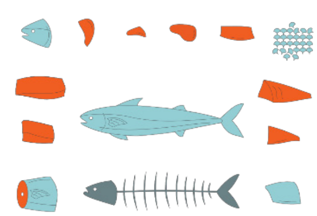
Executive Summary

The following report was commissioned by The Conference of Great Lakes St. Lawrence Governors and Premiers from the Iceland Ocean Cluster and focuses on the topic of moving toward full utilization of fish from the Great Lakes fishery as part of the 100% Great Lakes Fish initiative. The project complements ongoing work by the Great Lake Fishery Commission, the region's States and Provinces, and partners to improve fishery management and fish recruitment to protect the long-term sustainability of Great Lakes fish populations and the ecosystem.



The report details the existing catch, market and biotechnological profiles of four Great Lakes fish, Walleye, Yellow Perch, Lake Trout and White Sucker which currently have value creation for fillet flesh and low value, small scale secondary value chains for processing cut-offs to the mink industry and for fertilizer. The outcome of this project supports value creation, reduces waste of target catch and also offers a route to discourage and utilize bycatch discards.

The results of an in-depth biotechnological analysis were combined with collected knowledge of the Great Lakes fishery context and two complementary analyses; value-chain analysis and SWOT analysis to identify three best-case and highest commercial potential products. This report finds that it would be most advantageous to combine secondary biomass from different species (both commercially targeted and lower value species) to maximize the volume of material available for value creation. Given this, three high-potential cases are identified.

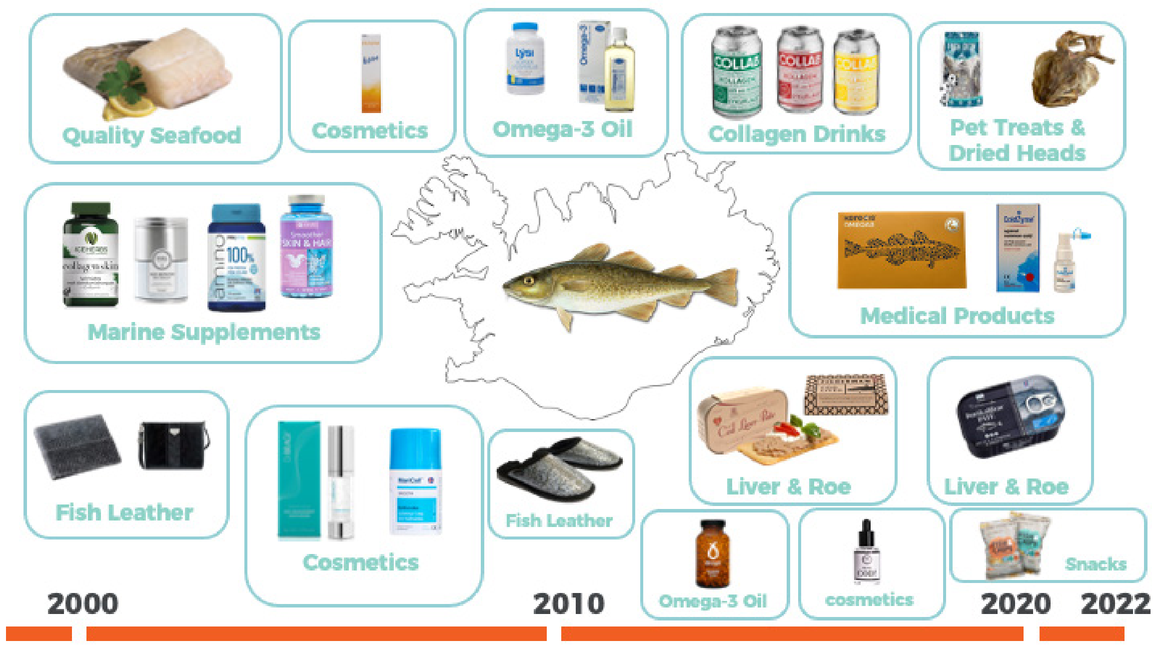
Case 1	Case 2	Case 3
High value – lower volume.	*Mid-value – mid volume.*	*Lower value – higher volume.*
		
Gelatin or collagen peptides from mixed species fish scales.	**Protein hydrolysates from mixed species fish heads**	**Fish meal from all rest material from mixed species.**

Detailed guidance is provided for developing the minimum viable product and evolving the route to market for these new value chains. Finally, the report includes recommendations to support the next stage of development toward 100% Great Lakes Fish. The results of this report can be combined with a prior report on Lake Whitefish and can be considered complementary documents. Given the outcome of both combined reports, the development of 100% Great Lakes Fish is seen as a highly promising endeavor for the environmental and economic sustainability of the Great Lake fishery.

1. Project description & context

This report was commissioned by the Conference of Great Lakes St. Lawrence Governors and Premiers from the Iceland Ocean Cluster and focuses on the topic of moving toward full utilization of fish from the Great Lakes fishery as part of the 100% Great Lakes Fish initiative. The project complements ongoing work by the Great Lake Fishery Commission, the region's States and Provinces, and partners to improve fishery management and fish recruitment to protect the long-term sustainability of Great Lakes fish populations and the ecosystem. This report addresses the need for parallel actions to explore win-win opportunities to create value from every part of captured fish, while at the same time reducing waste from the fisheries sector – improving the environmental footprint of the associated supply chain.

Iceland pioneered the "100% fish" strategy that has rejuvenated and expanded its 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 commercially caught fish from the Great Lakes today) to 90% resulting in high-value food and non-food products. A single cod that used to generate $12 for filets now generates a remarkable $4800 per fish in expanded value. In 2022, the first year of this project laid the groundwork for a similar transformation for the Lake Whitefish which acted as an initial model to inform the expansion of 100% fish to the wider Great Lake fishery. In this current report, further commercial fish species have been investigated, Yellow Perch (*Perca flavescens*), Walleye (Pickerel) (*Sander vitreus*), White Sucker (*Catostomus commersonii)* and Lake Trout (*Salvelinus namaycush*). The fish tested in this study were all caught from Lake Erie, but the results and species are relevant across the wider Great Lakes region.



This report's goal is to demonstrate the 100% fish model for all species tested and to lay comprehensive foundational research that can help to create more value and reduce waste across all Great Lakes fish. This project work builds on experience from successful experience of 100% fish in Iceland and research on increased utilization of seafood globally.

2. Building on the Lake Whitefish model

The 2022 report on 100% Lake Whitefish can be found at this link: gsgp.org/media/dleglcci/100-whitefish-report-3-23.pdf Lake Whitefish is primarily used by direct consumption of the fillet with some value-added products such as fish cakes and fish salad. Processing cut-offs are primarily discarded to landfills or in some cases collected for agricultural fertilizer or slurry mink feed. Biotechnological characterization, site visits, value chain, SWOT analysis and product prototype development supported the identification of high potential and most achievable (low-hanging fruit) value chains from Lake Whitefish. This process is illustrated by the product wheels for Lake whitefish shown in **Figure 1**.

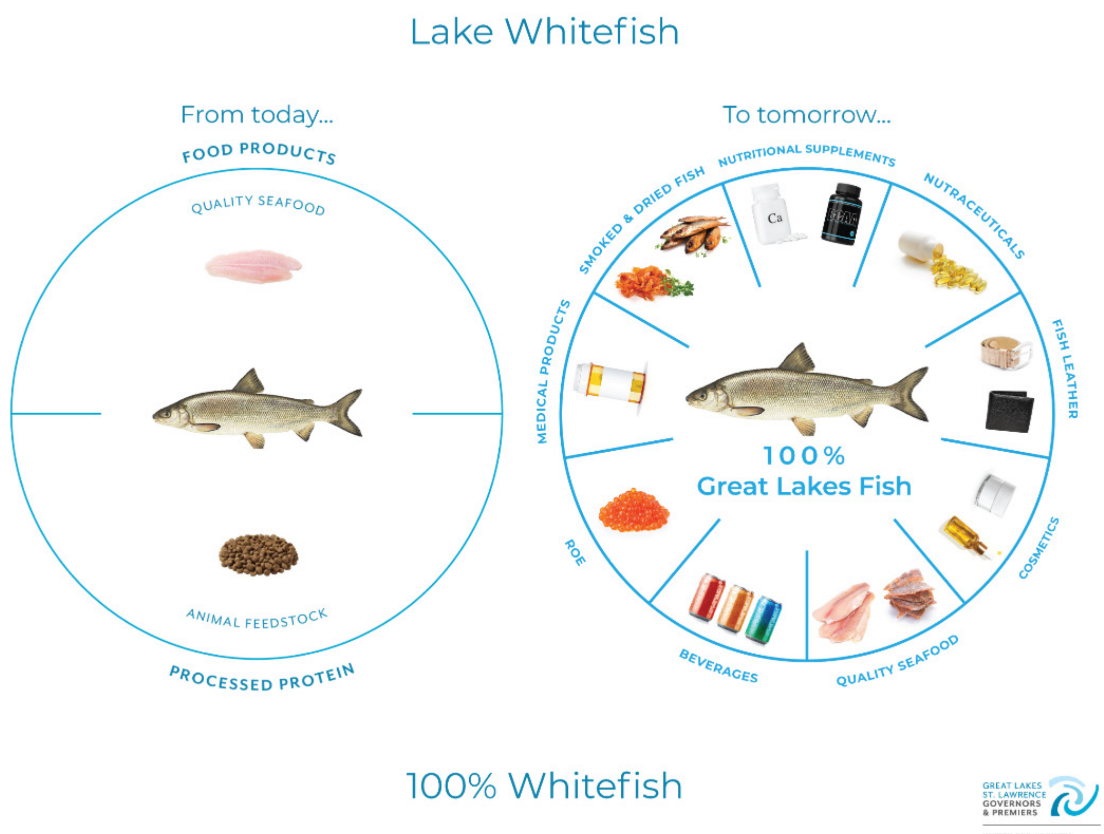


Figure 1. Lake Whitefish product wheel evolution developed in the first year of the project.

Three high potential best-case strategies were identified for Lake Whitefish and the priority steps to develop the value chains for these products were mapped. A summary of these best-case strategies are shown in **Table 1**. Those highlighted had both promising biotechnological results and did not require any changes to current processing techniques.

Table 1. Summary of identified high-potential, best-case strategies for Lake Whitefish.

Best Case Strategy	Priority Steps
Protein hydrolysates from heads	1. Identify volume of material available. 2. Identify innovation companies. 3. Connect processors with fish heads available.
Collagen from scales	1. Identify volume of material available. 2. Seek funding for method development. 3. Identify markets. 4. Develop supply chain.
Leather from skin	1. Identify volume of material available. 2. Connect fisheries and leather producers. 3. Connect designers for prototype development. 4. Develop appropriate scale business model.

3. Multi-species catch and processing

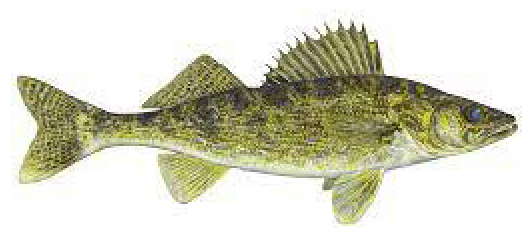
3.1. Basic biology and population characteristics

3.1.1. Yellow Perch

Yellow Perch populations in the Great Lakes have declined in recent years, especially in Lake Michigan. Lake Michigan is not the only Great Lake where there are concerns about the status of Yellow Perch. Lake Huron and parts of Lake Erie have also experienced a significant decline. There is concern that other lakes will experience a similar decline in population. The introduction of non-native species and other ecosystem changes appear to be negatively impacting Yellow Perch populations around the region.

Lake Erie Yellow Perch and Walleye have received MSC (Marine Stewardship Council) certification which is the global gold standard with third party verification that a fishery is well managed and sustainable.

3.1.2. Walleye (Pickerel)



The Walleye population in Lake Erie exploded during the past few years. The Ohio Department of Natural Resources estimates there are currently about 95 million Walleyes in the lake two years old or older – that translates into fish about 15 inches or longer, the minimum size for keeping. Walleyes are also commercially harvested on the Canadian side of Lake Huron, Lake Ontario and Lake Superior, though to a much lesser degree than Lake Erie.

3.1.3. White Sucker

White Sucker is one of the most common fish in the Great Lakes. The fish usually live in streams but can be found in lakes or along the shores of the Great Lakes. White Sucker is not usually commercially targeted, but they are a common bycatch species.

3.1.4. Lake Trout

Lake Trout can be found in all five of the Great Lakes and many large, deep, cold water inland lakes of Michigan, Minnesota, Wisconsin, New York and Ontario. Commercial overfishing and the introduction of the parasitic sea lamprey severely reduced the Lake Trout populations in the Great Lakes from 1935 to 1965. After decades of enhanced fisheries management and sea lamprey control efforts, Lake Trout stocks are beginning to show signs of recovery and are exhibiting limited natural reproduction. Lake Trout in Lake Michigan have become a more important commercial species for Tribes as Lake Whitefish populations have plummeted.

3.2. Capture volumes and methods

Catch rates vary from year to year. In 2020, Great Lakes commercial fishers harvested nearly 42 million pounds of fish (Great Lakes Fishery Commission 2022), excluding Lake Whitefish. Walleye, Yellow Perch and Lake Trout were an important part of this harvest. Collectively these fish provide a continuous source of catch all year around but each have different catch rates and different characteristics at different seasons too (e.g., breeding season).

3.2.1. Yellow Perch

A total of 3,133,950 lbs. were recorded by the Great Lakes commercial fishery in 2020 **Figure 2**. Yellow Perch are primarily caught commercially using gillnet and trap nets.

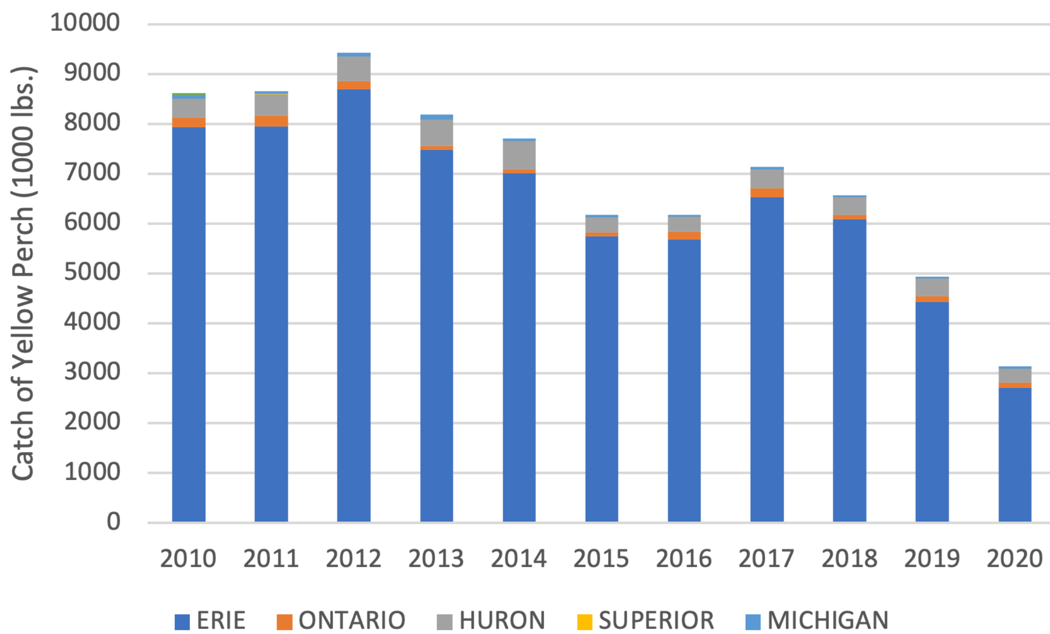


Figure 2. Total catch (1000 lbs.) of Yellow Perch in the Great Lakes from 2010 to 2020.

3.2.2. Walleye (Pickerel)

A total of 9,227,190 lbs. were recorded by the Great Lakes commercial fishery in 2020 **Figure 3**. Walleyes are primarily caught using gillnets.

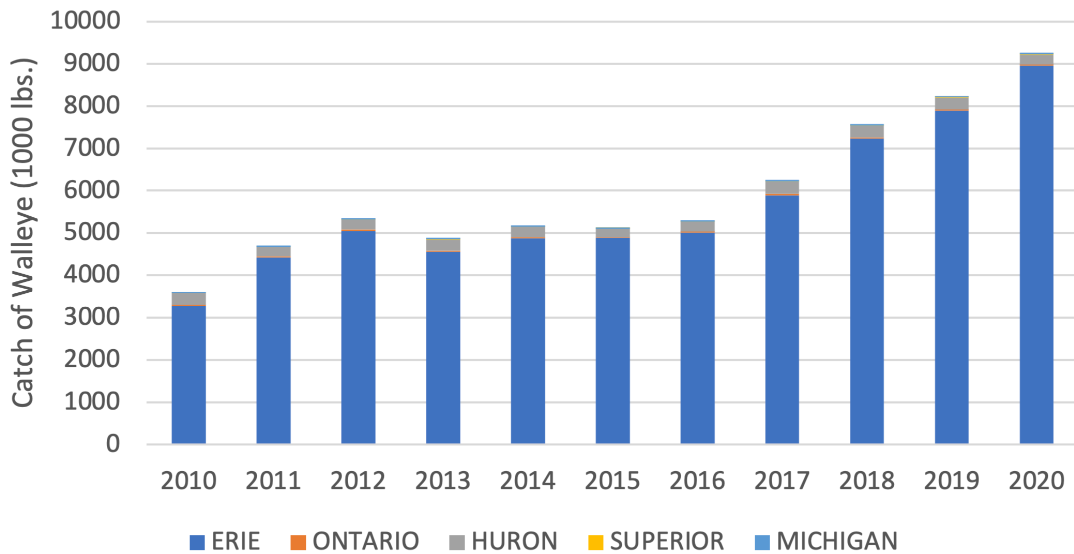


Figure 3. Total catch (1000 lbs.) of Walleye in the Great Lakes from 2010 to 2020.

3.2.3. White Sucker

A total of 38,285 lbs. were recorded by the Great Lakes commercial fishery in 2020 **Figure 4**.

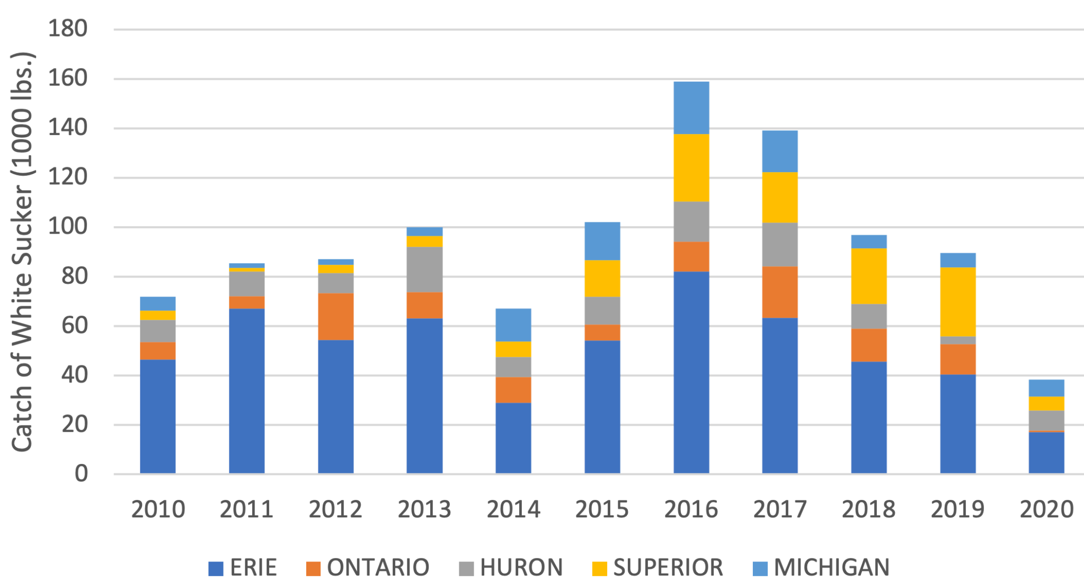


Figure 4. Total catch (1000 lbs.) of White Sucker in the Great Lakes from 2010 to 2020.

3.2.4. Lake Trout

A total of 1,306,580 lbs. were recorded by the Great Lakes commercial fishery in 2020 **Figure 5.**

The most common types of gear are trap nets and gill nets, and the commercial fishing season typically runs from April through October. In some regions, the fishers also harvest and process Lake Herring (Cisco) into December. Many fishers fish daily, if weather allows, or 2-3 times a week. Starting in the mid 2000's, Lake Trout harvests have averaged over 432,000 lbs.

Tribes in Michigan fish Lake Trout with gill nets and can keep very limited bag limits when using trap nets in Lake Michigan. Tribal commercial fishers are limited to an annual allocation of Lake Trout, prescribed by Lake Trout Management Units. There is also a commercial fishery and commercial market for Lake Trout in the Lake Superior waters of Wisconsin.

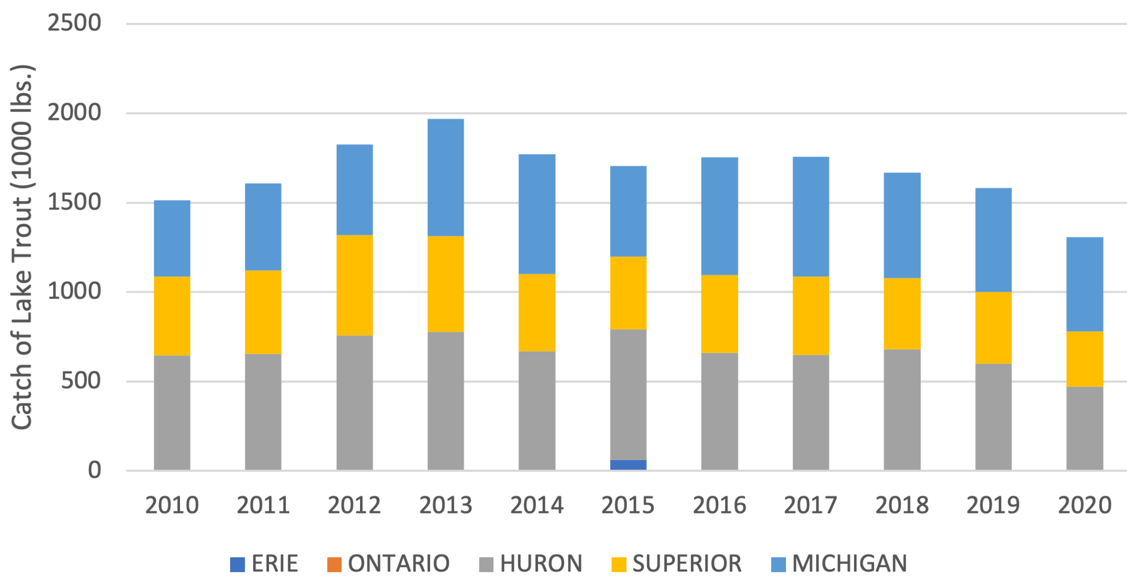


Figure 5. Total catch (1000 lbs.) of Lake Trout in the Great Lakes from 2010 to 2020. This graph does not include Siscowet Lake Trout for Lake Superior

3.3. Employment and commercial licenses

In Michigan in 2020, there were 51 state-licensed commercial fishers and 16 active businesses receiving income from commercial fishing (Michigan State University 2020). Wisconsin's Lake Michigan state-licensed commercial fleet predominantly harvests five species: Lake Whitefish, Yellow Perch, Menominee Whitefish, Chub and Smelt. Walleye and Lake Trout commercial harvest is not allowed. The number of commercial licenses varies year-to-year but is capped at 65. Wisconsin's Lake Superior state-licensed commercial fishery allows for a maximum of 10 commercial licenses and predominantly harvests Lake Whitefish, Cisco, Lake Trout and Chubs.

Ontario's licensed commercial fishery operates in the Great Lakes on Lakes Erie, Huron, Superior, Ontario and the St. Lawrence River. There are more than 600 active commercial fishing licenses in Ontario's portion of the Great Lakes. Nearly 900 people work in the commercial fishing industry, including boat and tug crew members, and over 900 are employed in packaging and processing fish. This figure does not include truck drivers or those working in distribution facilities, or the significant numbers of people that are employed in positions that are a spin-off of commercial fishing such as restaurants. Walleye, Yellow Perch and Lake Whitefish account for the majority (84%) of the commercial catch for Ontario (Government of Ontario 2023).

Ontario harvest statistics for recent years show the number of fish and the value of the four different species of fish studied in the most recent years **Table 2**.

Table 2. Weight (lbs.) of each fish and their associated landed value in 2020 and 2021.

	Ontario			
	2020		2021	
	Weight (lbs.)	Landed value (US$)	Weight (lbs.)	Landed value (US$)
Yellow Perch	2,375,928	$5,635,401.00	2,445,352	$7,067,278.34
Walleye	8,868,555	$11,473,090.50	11,392.472	$16,211,059.00
Lake Trout	274,989	$116,780.25	302 744	$125,074.12
White Sucker	4,552	$332.58	6 410	$618.34

Data collected on the catch rates are analyzed by Great Lakes regional agencies and biologists. They use this real-time data to inform population models which are the basis of the Total Allowable Catch (TAC) quotas that are set for commercial species in the Great Lakes. The annual TAC is announced in late March.

There are also sport fisheries that are conservatively regulated through daily harvest and minimum size limits to remain below the set quotas. These numbers are monitored with Angler (or Creel) surveys, questionnaires asked directly to the angler.

3.4. Processing volumes and methods

The Sea Grant Network estimates that roughly 50% of U.S. Great Lakes commercial fishers process their own catch (Michigan State University 2022). Harvested fish are generally sold to processors, fish markets, distributors or restaurants. Very few utilize farmers' markets (less than 20%), institutions (such as cafeterias, less than 9%) or dockside sales (boat to customer directly, less than 3%). Processing their own fish helps fishers make more money on their catch with larger profit margins and they can sell more fish within their local community.

Commercial processing chains vary. If the harvest is sold to wholesalers and distributors for export across the United States and Canada, minimal or no processing may occur upon landing. Or the fisher may process the harvest for local retail sale, for example, at a fresh fish market. For the most part, fishing licensees that sell their catch to wholesalers are often the state's/province's larger fishers that operate on volume. Because they harvest a larger number of fish, they can find success selling their catch at wholesale prices. Additional profit can be made by fishers willing to clean, fillet and sell their fish at retail. There are additional value-added products and processes such as smoking, canning, pickling, fish cakes, fish sticks, pre- seasoned and pre-made meals, bulk and individual packaged portions, just to name a few. Commercial fishing businesses that operate their own retail fish houses can make four to five times more on their catch than they would by simply selling their fish "in the round" to a wholesaler (Michigan Department of Natural Resources 2018), although of course these operations also involve higher costs.

White sucker

There is limited commercial processing of the White Sucker in the Great Lakes. Flesh is often processed into mince for fish cakes. In some cases, they are headed and gutted but in most cases they are processed whole for use as bait.

3.5. Existing Market

This table is based on a U.S. Great Lakes report (Jescovitch et *al*, Sea Grant, 2022), which does not include the Canadian fisheries on the Great Lakes. The Great Lakes Fishery Commission estimates that the Great Lakes commercial, recreational and tribal fisheries are collectively valued at more the $7billion /year, with Lake Whitefish, Walleye, Yellow Perch, and Cisco listed as the foundation of the commercial fishery (**Table 3**).

Table 3. Fishing and processing sales of different scale markets for key commercial Great Lakes fish organized according to volume of sales.

Market	Fishing sales	Processing sales
Local (within 60 miles)	46.5 %	68.1 %
Regional (within 1 days drive)	37.9 %	25.4 %
National	12.7 %	5.1 %
International	2.9 %	1.5 %

In Ontario, by contrast, a significant proportion of commercially caught fish of the species considered in this report are exported to wholesale markets in the United States and Europe, according to the Ontario Commercial Fisheries' Association. For example, in 2011, Ontario exported 14,682 tons of freshwater fish product for a total export value of US$66.75 million (Government of Ontario 2023). More recently, a study estimated a value of $226.5 million per year for the economic contribution of the Great Lakes commercial fishery for Canada (Salim Hayder 2014).

3.5.1. Yellow Perch

Yellow Perch carries a firm texture, mildly sweet taste and adapts to various cuisines which creates strong, continued market prospects for the fish. Historical demand for Yellow Perch has been centered in the Great Lakes region, in the U.S. and Canada, and demand continues to grow in several other areas. Markets have traditionally preferred an 8- to 10-inch fish processed into descaled fillets. However, the costs to process this product form can be high, approaching $3 per lb. or more depending on the volume being handled.

Because of where and when they land fish and their quantity, many fishers may have access to processors that will take their fish, but some must use other marketing options. Historically, Yellow Perch producers have utilized a few marketing channels including processors, seafood retailers and wholesalers, supermarkets and grocery wholesalers, restaurants and food service distributors. All these potential buyers require regular, year-round supplies. Companies operating in this market are increasingly focusing on providing a variety of frozen fish and ready-to-eat food.

In Ontario, as a popular eating fish, Yellow Perch had an annual average five-year dockside value of US$597,000 ($2.33/lbs.). At a market price of $22.95/lb., total revenue was over US$5.85 million in 2020. The market went higher in 2021 with total revenue of US$7 million. Yellow Perch has the highest selling price per pound of all the commercially caught fish in the Great Lakes (Schrank 2023).

3.5.2. Walleye (Pickerel)

Markets are currently supplied by significant harvests in Canadian waters and to a lesser extent harvest from Michigan, Minnesota and Wisconsin. Most commercial supplies of Walleye from the Great Lakes come from Canadian fisheries in Lake Erie. In the United States, commercial Walleye fisheries for state licensed fishers are prohibited in the Great Lakes to protect recreational Walleye fisheries (FishChoice 2021).

Preferred market sizes are 1 to 1.5 lbs. and market prices for these fish will probably range from $6.50 to $7.70 per lb. In recent years, premium quality large skinless fillets can sell at retail for more than $20 per lb. (Agriculture Marketing Resource Center 2022).

3.5.3. White Sucker

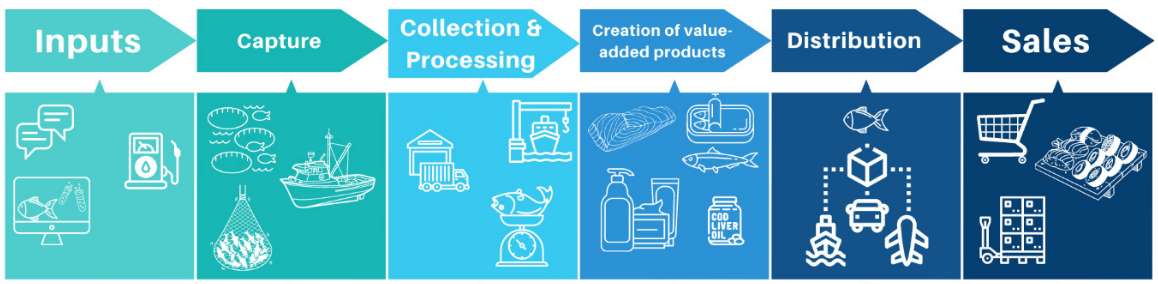
Very few commercial fishers in the Great Lakes target White Sucker or sell them commercially. For those who do, White Sucker are often smoked or ground and made into patties or cakes for the table. In Michigan, White Sucker recently sold for around 0.35$/lb.

3.5.4. Lake Trout

In Ontario, Lake Trout is often sold as fillet, smoked or as a transformed product such Lake Trout salad or as fish cakes. In marketing, it is described as a local favorite and as having a “rich, moist and gently pungent” flavor.

4. Existing value chains: multi-species

The existing value chains for each of these Great Lakes species are shown below to illustrate the existing sources of value at each step of the value chain, and provide some estimates of what the monetary value creation is at key steps. A model value chain for the Great Lakes fisheries is shown in **Figure 6**. There are six value chain steps and value is created in the primary value chain, at capture and processing, as well as sales of fish products.



Inputs

Fisheries management.

Fisheries equipment and fuel.

Communications between fisheries and higher value chain actors.

Capture

Primary wild capture.

Presentation, handling, quality and quantity of raw material landed.

Transport to processors.

Collection & Processing

Primary processing and product preparation.

Secondary product collection.

Secondary product storage, transport and disposal.

Creation of value-added products

Preservation, preparation, further treatment and processing of primary and secondary products that create additional value beyond purely fillet.

Distribution

Domestic or international logistics.

Product preparation and packaging.

Sales

Marketing and market.

Direct consumer segment.

Restaurant, wholesales and retails sales.

Storage and distribution.

Figure 6. Model value chain for the fisheries sector based on a traditional view of primary value chains and assuming the traceability of the products from start to end of life.

4.1. Walleye (Pickerel) value chain

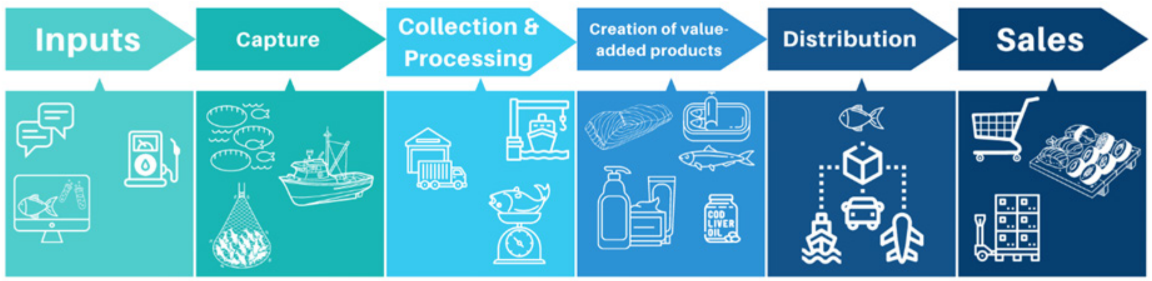
The existing value chain for Walleye is shown in **Figure 7,** with a dressed fillet value at a restaurant of $29 at the final sales value chain step. Secondary value chains for mink feed and fertilizer exist for some processors and tends to be localized.

Inputs	Capture	Collection & Processing	Creation of value-added products	Distribution	Sales
Lake committees and agencies in each jurisdiction with biologists that in some cases set TACs annually. Protection and limit or closed fishing during spawning season.	Gill netting, live trap, or recreationally using hook and line. Estimated price of fish to processor = ~$3 (2020 price)	Primary processing and product preparation. Secondary product collection. Secondary product storage, transport and disposal. The disposal of this organic matter costs the processor and only minimal value is created with sales to the mink industry.	Preservation, preparation, further treatment and processing of primary and secondary products that create additional value beyond purely fillet.	Domestic or international logistics. Product preparation and packaging.	Sold directly by fish mongers, or at larger retail stores (e.g. Seafood Markets LTD – 4lbs (10-12 fillets) skin on fillets **–$80.00**, 4lb skinless fillets **$96.00.** Sold as a fry kit for added value **$106.00.** Dressed fillet dish **- $29.99.** Breaded bites at a restaurant **$18.99**.

Figure 7. The existing value chain and price estimate for Walleye in the Great Lakes.

4.2. Yellow Perch value chain

The existing value chain for Yellow Perch is shown in **Figure 8**, with a dressed fillet value at a restaurant value of $58/lb. at the final sales value chain step. Secondary value chains for mink feed and fertilizer exist for some processors and tends to be localized.



Lake committees and agencies in each jurisdiction with biologists that in some cases set TACs annually. Protection and limit or closed fishing during spawning season.	Gill netting, live trap, trawl, or recreationally using hook and line. Estimated price of fish to processor = $2.93 (2020 price)	Primary processing and product preparation. Secondary product collection. Secondary product storage, transport and disposal. The disposal of this organic matter costs the processor and only minimal value is created with sales to the mink industry.	Preservation, preparation, further treatment and processing of primary and secondary products that create additional value beyond purely fillet.	Domestic or international logistics. Product preparation and packaging.	Sold directly by fish mongers, or at larger retail stories (e.g. Perch processed fillets: **$20/lb** Lockview restaurant: **$29 for 1/2lb ($58/ lb**) Retail price **$37/lb**

Figure 8. The existing value chain and price estimates for Yellow Perch in the Great Lakes.

4.3. Lake Trout value chain

The existing value chain for Lake Trout is shown in **Figure 9**, with a dressed fillet value at a restaurant of $38.50 at the final sales value chain step. Secondary value chains for mink feed and fertilizer exist for some processors and tends to be localized.

Lake committees and agencies in each jurisdiction with biologists that in some cases set TACs annually. Protection and limit or closed fishing during spawning season.	Gill netting, live trap, or recreationally using hook and line. Estimated price of fish to processor = ~$2.35 (2020 price)	Primary processing and product preparation. Secondary product collection. Secondary product storage, transport and disposal. The disposal of this organic matter costs the processor and only minimal value is created with sales to the mink industry.	Preservation, preparation, further treatment and processing of primary and secondary products that create additional value beyond purely fillet. Smoked lake trout pate estimated cost = **$10/half lb.**	Domestic or international logistics. Product preparation and packaging.	Sold directly by fish mongers, or at larger retail stories (e.g. Processed fillet: **$7/lb** (Big Stone Bay Fishery Co) Apache Trout grill restaurant: **$38.50** Crossroads fish fry Great Lakes trout: **$15.99** Whole fish**:$4.95** (Bodin Fisheries)

Figure 9. The existing value chain and price estimate for Lake Trout in the Great Lakes.

4.4. White Sucker value chain

The existing value chain for White Sucker is shown in **Figure 10**, the final sales value chain step for this species is a bait mince rather than a dressed fillet as the primary value chain based on online searching carried out for this report. There was also some evidence of mince processing for fish cakes but the volume of this is not readily available. In a number of cases, White Sucker is a common by catch and not a target commercial species.

Lake committees and agencies in each jurisdiction with biologists that set TACs annually. Protection and limit or closed fishing during spawning season.	Gill netting, live trap, or recreationally using hook and line. Estimated price of fish to processor = $0.30-$1 (202 price-estimated from Carp price)	Primary processing and product preparation. Secondary product collection. Secondary product storage, transport and disposal. The disposal of this organic matter costs the processor and only minimal value is created with sales to the mink industry.	Preservation, preparation, further treatment and processing of primary and secondary products that create additional value beyond purely fillet.	Domestic or international logistics. Product preparation and packaging.	Sold directly by fish mongers More often used for bait selling to retail use (e.g. Frankies Live Bait and Marine and Michigan Wholesale Bait) ~$5.99/12Oz (based on channel catfish bait price).

Figure 10. The existing value chain and price estimate for White Sucker in the Great Lakes.

From the value chains above, the year 1 report graphic has been adapted to show the current primary and secondary products of these species **Figure 11**.

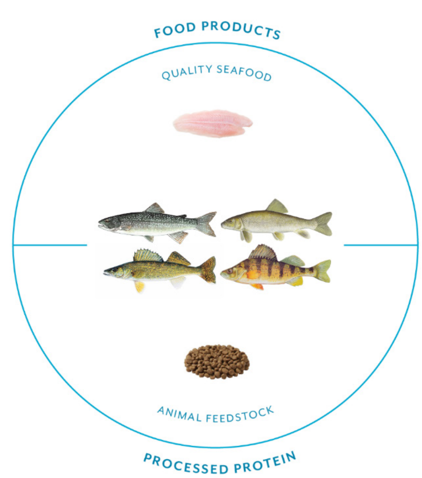


Figure 11. The starting point for this study for the species addressed, similar to Lake Whitefish, the processing "wastes" have limited and low value utilization at the current time.

5. Biotechnological analysis

5.1. Methodology and justification

The different parts of the fish and different fish species were treated differently to extract compounds in the highest quantities from each body part. Bones, scales, swim bladder, skin, heads, livers and roes were submitted to different extraction techniques. These measures were selected based on results detailed in the Lake Whitefish report, what we know about the species and how they are processed, and what was feasible based on the samples we received – with the key parts of the fish considered to be high interest and why (**Figure 12**). The aim was to extract fat, proteins and collagen mainly, and in appropriate high-potential cases, to extract minerals. A summary table of measurements carried out is shown in **Table 4.** All samples were taken in triplicate to support robust scientific reporting. All parts of the fish were separated and weighed to provide additional information.

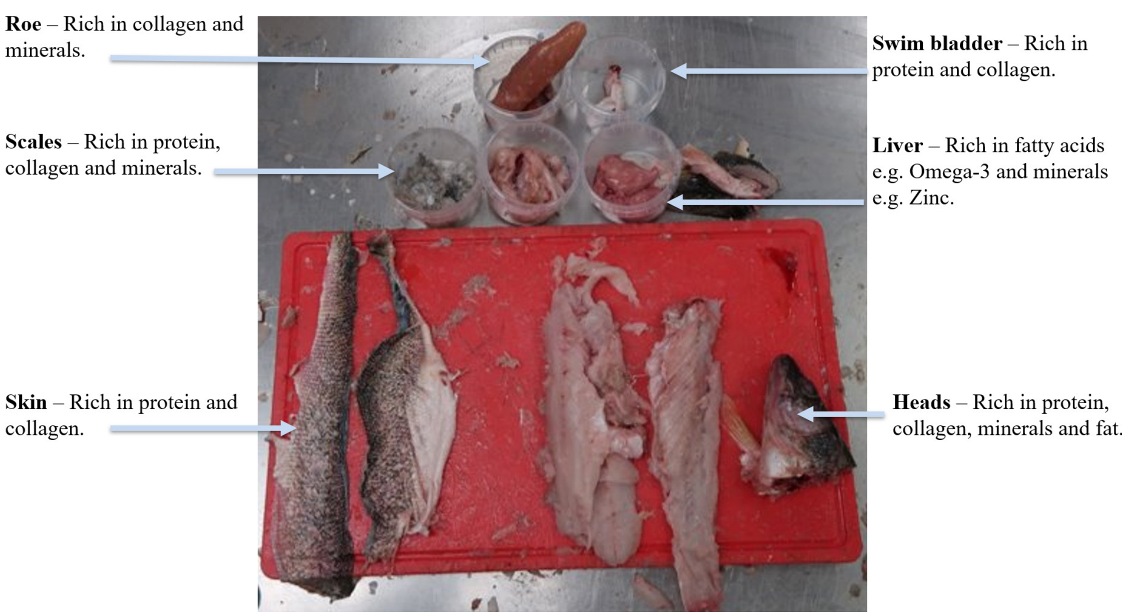


Figure 12. Key parts of the fish identified as high potential for further biotechnological analysis and why. This deconstructed fish used as an example is the Walleye.

Table 4. Summary table of biotechnical measures taken.

Fish	Body part	Measure taken
Yellow Perch	Head	Fatty acid composition, amino acid composition, macro-nutritional composition.
	Liver	Fat content and fatty acid composition.
	Skin	Hydroxyproline content, protein content, and moisture content.
	Scales	Hydroxyproline content, protein content, moisture content and selected minerals.
	Roes*	Fat content and fatty acid composition.

Walleye (Pickerel)	Head	Fatty acid composition, amino acid composition, macro-nutritional composition.
	Liver	Fat content and fatty acid composition.
	Skin	Hydroxyproline content, protein content, and moisture content.
	Scales	Hydroxyproline content, protein content, moisture content and selected minerals.
	Roes*	Fat content and fatty acid composition.
White Sucker**	Fillet	Protein content, amino acid composition, fat content and moisture content.
	Skin	Protein content, hydroxyproline content and moisture content.
	Bones	Moisture content, selected minerals.
	Scales	Protein content, hydroxyproline and moisture content.

*Some of the fish of both the Yellow Perch and Walleye contained roe which were also sampled to account for this seasonal and biological factor that may affect other compositional measures. Discussion with the local industry clarified that the fishing season for these species is all year round so it will be important to consider compositional differences of fish and products coming from fish at different seasons throughout the year. The roe in some cases was a fairly substantial size and contributed to body weight (**Figure 13**).

**White Sucker were shipped to Iceland headed and gutted.

Figure 13. Walleye example of a female with roe removed from the fish.

Lake Trout was not able to be shipped during the time period of this reporting due to import-export restriction of this species between Canada and Iceland. Lake Trout is from the genus *Salvelinus* which is the same genus as the Icelandic fish Arctic Char (*Salvelinus alpinus*). This species is a key Icelandic species and has been extensively investigated in biodiversity studies and for nutritional composition. To support the knowledge transfer in this report – a summary of relevant research on Arctic Char is provided that will provide a good foundation for future work on Lake Trout from the Great Lakes.

5.1.1. Biotechnological methods

Mass balance of samples

Samples were handled by the biotechnological analysis team at Matís, 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. The mass balance of the whole fish and the heads, skins, frames 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.

5.1.2. Preparation and processing of Yellow Perch samples

Frozen Yellow Perch, full fish with head and viscera intact, were received that had an average individual weight of 454.1g±55.8g when defrosted (**Figure 14**). All parts of the fish were separated and weighed, and the proportion of the fish part is shown in **Table 5**.

Figure 14. Whole defrosted Yellow Perch received from Presteve Foods for this study.

Table 5. Body part wet weight and proportion of Yellow Perch.

Body part	Wet weight (g)	Proportion of fish (%)
Fillet	105.4±17.5	23.2
Skin	26.8±4.6	5.9
Scales	18.3±4.8	4.0
Head	96.1±13.2	21.2
Viscera	12.9±3.8	2.8
Liver	8.1±1.9	1.8
Roe	76.1±14.1	16.8
Swim bladder	1.0±0.8	0.2
Bones (uncleaned)	45.8±7.1	10.1
Bones (cleaned)*	9.8±1.6	5.7
Rest raw materials**	65.2±15.4	2.2

*Bones were cleaned by sealing them in a vacuum bag and heating them in a 45°C water bath for 3 hours.

**Anything that was left behind after these parts were successfully separated.

5.1.2. Preparation and processing of Walleye samples

Frozen Walleye, full fish with head and viscera intact, were received that had an average individual weight of 1142.5±91.7g when defrosted (**Figure 15**). All parts of the fish were separated and weighed, and the proportion of the fish part is shown in **Table 6**.

Figure 15. Whole defrosted Walleye received from Presteve Foods for this study.

Table 6. Body part wet weight and proportion of Walleye.

Body part	Wet weight (g)	Proportion of fish (%)
Fillet	339.7±18.6	29.7
Skin	65.0±7.7	5.7
Scales	21.3±5.9	1.9
Head	220.7±15.3	19.3
Viscera	88.3±19.9	7.7
Liver	32.2±6.4	2.8
Roe	139.0±17.9	12.2
Swim bladder	10.5±1.9	0.9
Bones (uncleaned)	129.8±14.0	11.4
Bones (cleaned)	28.7±2.9	2.5
Rest raw materials	65.2±15.4	5.7

In the Walleye and Yellow Perch, the swim bladders were intact and easily removed to weigh them and work with them during prototype development, although it was decided due to the challenge of removing them intact during commercial processing not to do biotechnological analysis of the swim bladders in this report. The intact swim bladder of the Walleye can be seen in **Figure 16**.

Figure 16. Walleye with intact swim bladder that was preliminarily explored for weight and prototyping in this report.

5.1.3. Preparation and processing of White Sucker samples

Frozen, headed and gutted White Sucker fish were received that had an average individual weight of 1038.3±227.0g when defrosted (**Figure 17**). All parts of the fish available were separated and weighed and the proportion of the fish part is shown in **Table 7**.

Figure 17. Headed, gutted and defrosted White Sucker received from Presteve Foods for this study.

Table 7. Body part wet weight and proportion of White Sucker.

Body part	Wet weight (g)	Proportion of fish (%)
Fillet	496.7±82.6	45.2
Skin	81.8±18.5	7.9
Scales	77.8±32.8	7.5
Bones (uncleaned)	251.5±72.5	24.2
Bones (cleaned)	32.5±12.8	3.1
Rest raw materials	119.5±24.4	11.5

5.2. Results

5.2.1 Yellow Perch

Macro-nutritional composition and hydroxyproline measurements

The nutritional composition measured in Yellow Perch (**Figure 18**).

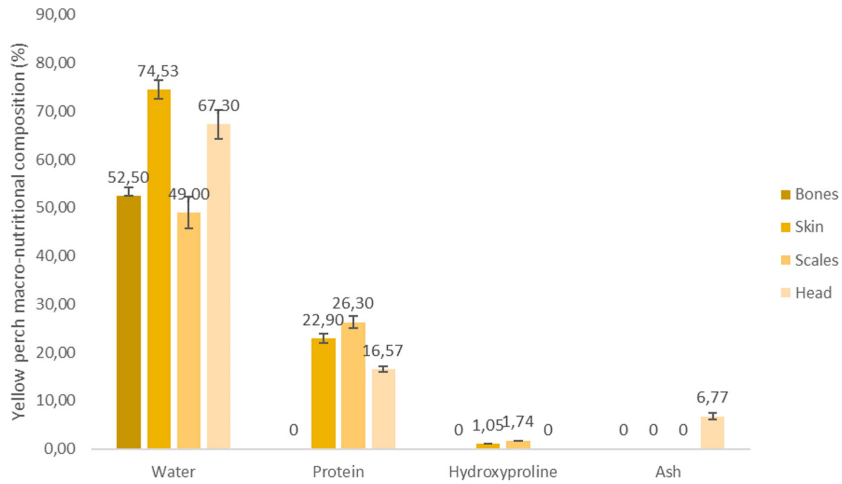


Figure 18. Macro-nutritional composition and hydroxyproline of Yellow Perch samples.

Fat and fatty acid composition

Fat content in the liver was 6.4% and the fatty acid composition of the liver is shown in **Figure 19** and the roe in **Figure 20**.

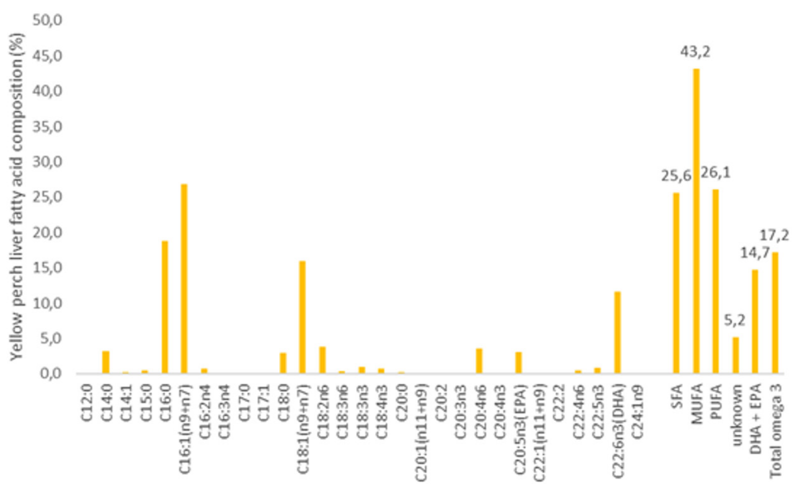


Figure 19. Fatty acid composition of Yellow Perch liver.

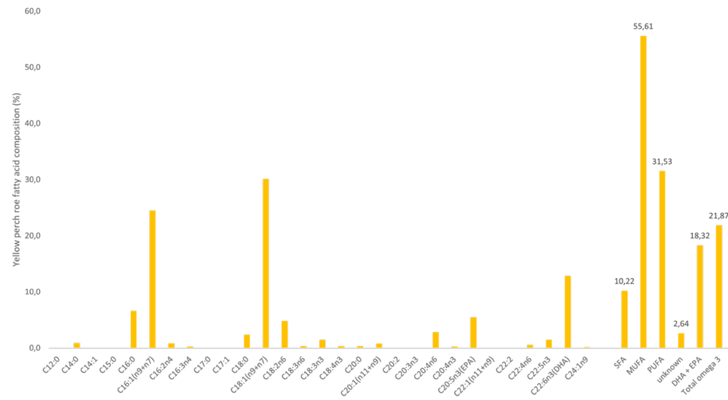


Figure 20. Fatty acid composition of Yellow Perch roe.

Mineral composition

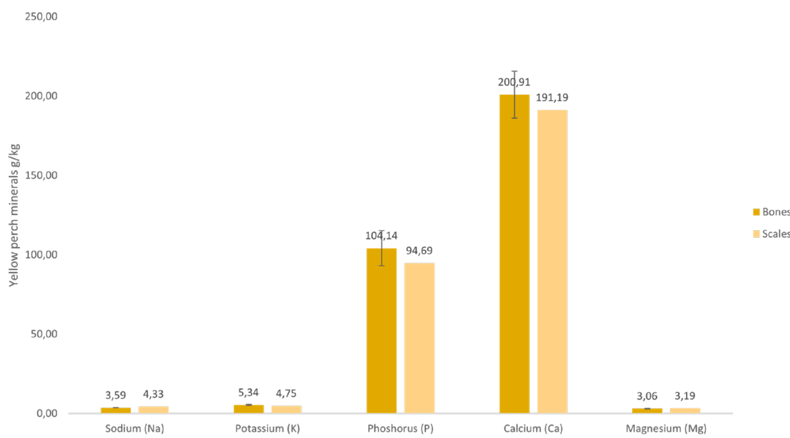


Figure 21. Mineral content of Yellow Perch bones and scales.

Amino acid composition

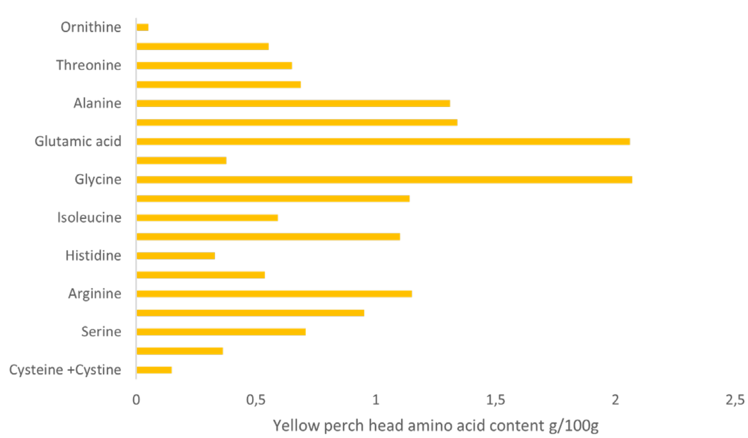


Figure 22. Amino acid composition of Yellow Perch heads. The measure for Ornithine was <0.05.

5.2.2. Walleye (Pickerel)

Macro-nutritional composition and hydroxyproline measurements

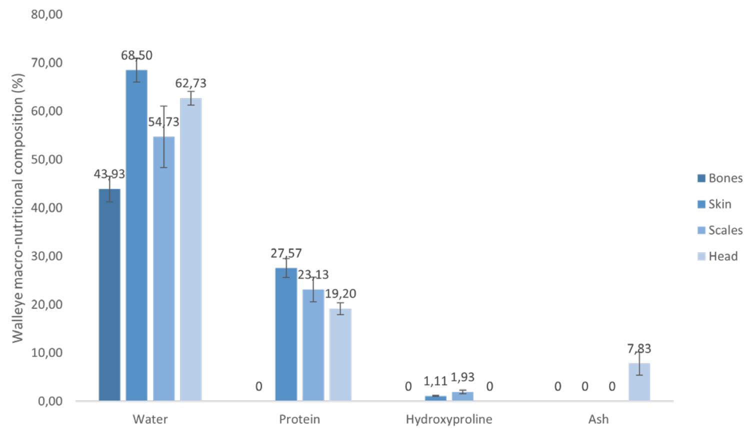


Figure 23. Macro-nutritional composition and hydroxyproline of Walleye samples.

Fat and fatty acid composition

Fish that contained roe (**Figure 24**) and those without (**Figure 25**) both had a liver fat content of 5.56% and the roe itself (**Figure 26**) had 15.43% fat content.

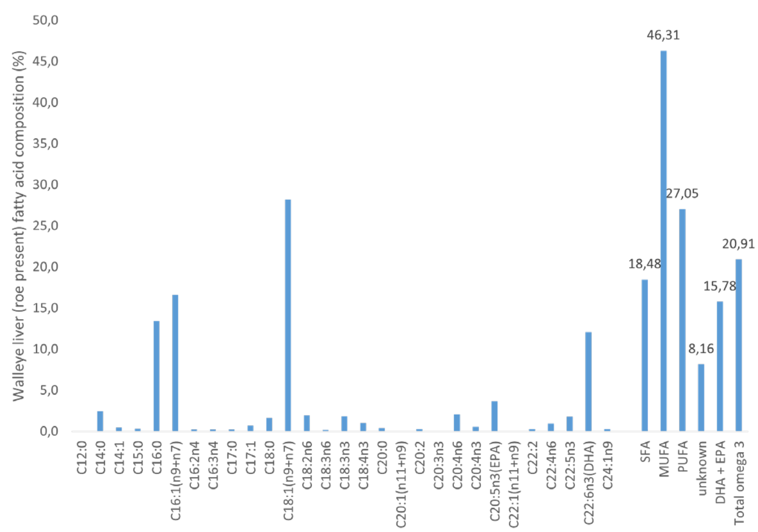


Figure 24. Fatty acid composition of Walleye liver in fish with roe present.

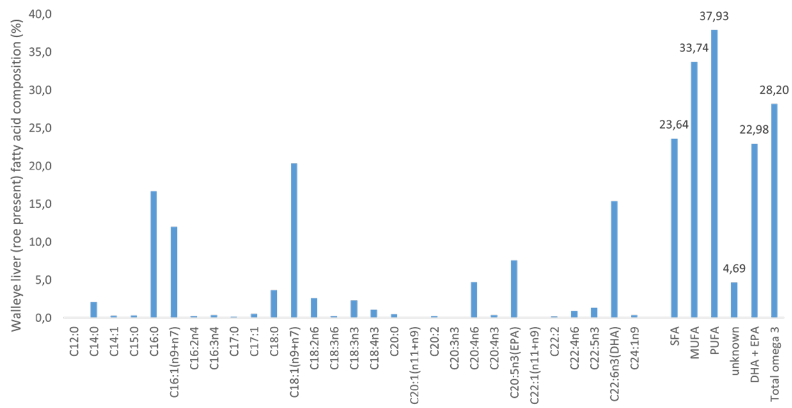


Figure 25. Fatty acid composition of Walleye liver in fish with roe absent.

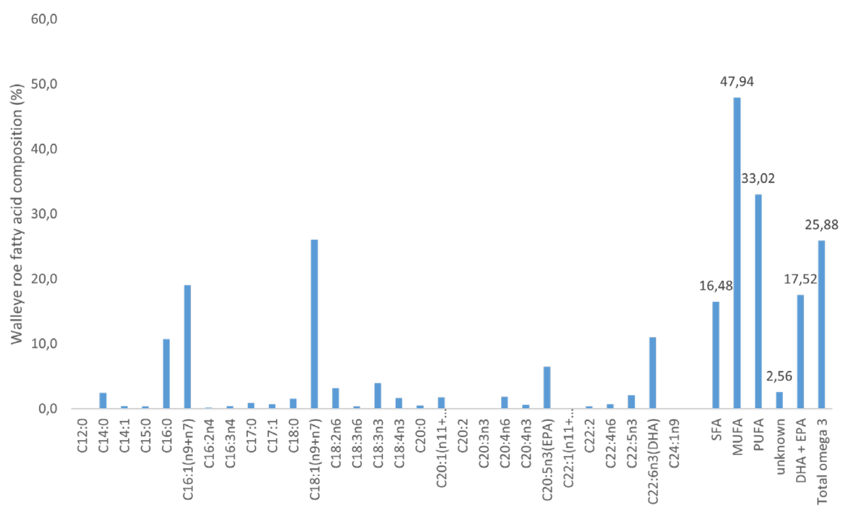


Figure 26. Fatty acid composition of Walleye roe.

Mineral composition

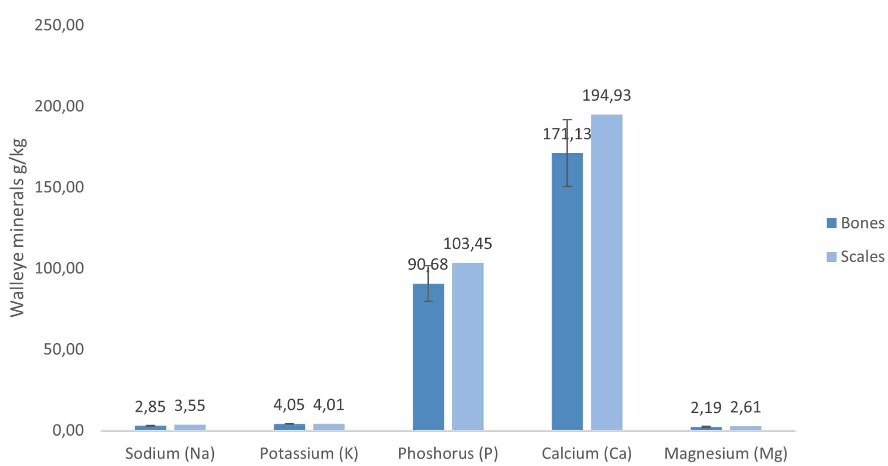


Figure 27. Mineral content of Walleye bones and scales.

Amino acid composition

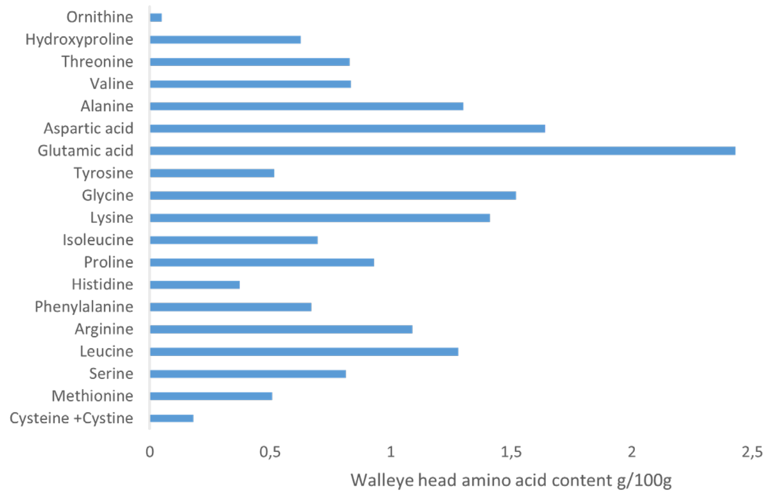


Figure 28. Amino acid composition of Walleye heads. The measure for Ornithine was <0.05.

5.2.3. White Sucker

Macro nutritional composition & hydroxyproline.

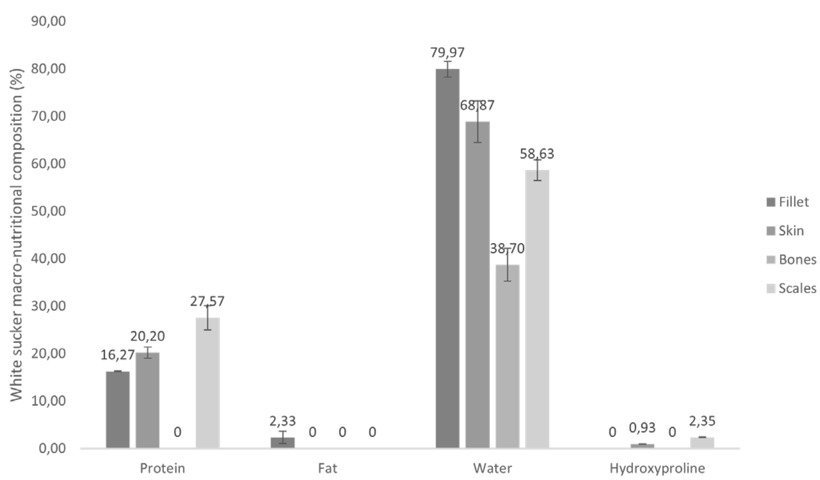


Figure 29. Macro-nutritional composition and hydroxyproline of White Sucker samples.

Mineral composition

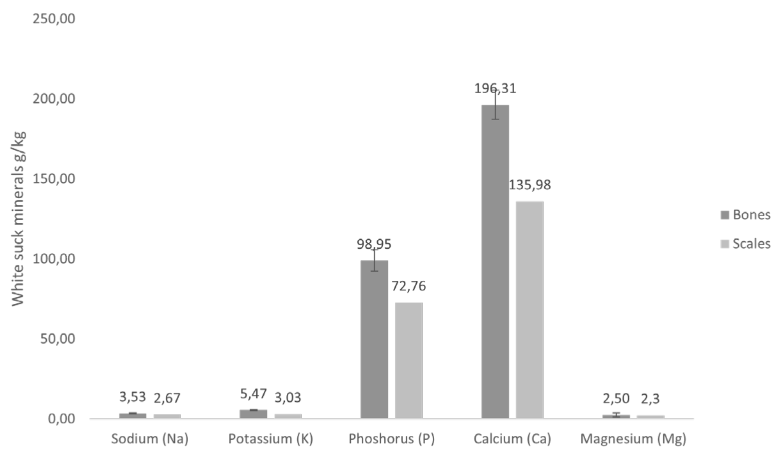


Figure 30. Mineral composition of White Sucker bones and scales.

Amino acid composition

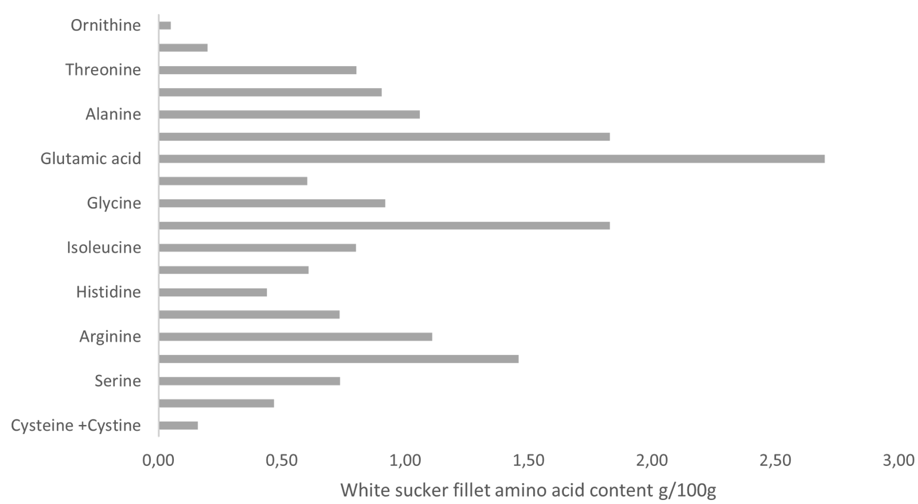


Figure 31. Amino acid composition of White Sucker fillets. The measure for Ornithine was <0.05 and hydroxyproline was <0.2.

5.2.4. Arctic Char and Lake Trout in the literature

For Arctic Char (*Salvelinus alpinus*), the majority (45-60%) of lipids are concentrated in the carcass (heads, fins, skeleton and skin), followed by 25-40% in the muscle and small amounts in the gut, liver, kidney and gonads (Jobling et al. 1997). TAG lipids are the most concentrated among all parts of the Arctic Char– especially high in the carcass where more than 75% of the lipids are TAG (Jobling et al. 1997). It is also estimated that 24-90% of the skeletal tissues are comprised of lipids (Jobling et al. 1997). Nutritional composition analysis finds that moisture content is high (approximately 75.85%), and crude fat, protein and ash account for the minority (Blanar et al. 2005).

For information on the Lake Trout (*Salvelinus namaycush*) from the literature, it is known that moisture accounts for the majority of the body composition (80-85%), followed by crude protein content (11.4-14.3%). Lipids account for 2.2-3.6% of the body composition, ash is 1.4-2.1% and phosphorous only 0.3-0.4% (Gunther et al. 2005). While little literature can be found on composition in the wild, some exists for Lake Trout under hatchery conditions. A study by Gunther et al. (2007) found similar results to Gunther et al. (2005), except they just analyzed the carcass composition rather than the whole body. Across the temperature ranges, they found the average relative carcass concentrations of water was highest at approx. 800g/kg of wet weight, crude protein (142.7 g/kg), lipid (36.2 g/kg), ash (20.9 g/kg) and phosphorus (4.1 g/kg).

6. Prototyping and testing

6.1. Methodology and justification

6.1.1. Processing of lab samples

Gelatin is a form of hydrolyzed collagen that is soluble and therefore used in many food products for its versatile function – and it contains identical amino acid profile and protein content as collagen (Liu et al., 2015). The yield for gelatin will be similar and likely even higher for collagen which is indicated by the amount of hydroxyproline present. If more enzymes are added to the gelatin, this will break it down further to collagen peptides which both have a range of functions and markets. Collagen peptides are used as a supplement or to enrich other peptides. Gelatin has a great range of functional properties in the cosmetic, pharmaceutical (e.g., drug delivery) and food industries. The gelatin from fish is high-quality and has different melting and gelling temperatures than other gelatin sources, yet have high strength and high viscosity making it a desirable product (Boran and Regenstein 2010). The selected product, either gelatin or collagen peptides, is usually dependent on the target market.

Fish protein hydrolysates (FPH) are breakdown products from fish protein that contain smaller peptides and amino acids (Kristinsson and Rasco 2000). They are high protein (81-93%), low fat (~5%) and have a range of market applications. Such applications include nutritional supplements, pet and fish feed, and, in lower grade volumes, fertilizer. There is a long history of FPH in human food, and so they have a high level of acceptability (Kristinsson and Rasco 2000).

FPH are produced by treating lean fish proteins with selected enzymes or an acidic or base treatment that break down the bonds in the protein to produce material that consists of the building blocks of proteins – this means the nutrition from this material can be more easily absorbed by humans, farmed animals and fish or in pet foods. Transforming fish protein into fish hydrolysate, particularly for cold-water species can increase the shelf life of these nutritionally valuable materials, and even have natural antioxidant activity (Desai et al., 2022).

Gelatin extraction method 1 – for skin and swim bladder

The extraction process for those four samples (swim bladder from Walleye and skins from the other three species) was comparable to standard scientific methods and developed upon during the Lake Whitefish study in 2022.

The samples were first soaked in a 0.1M NaOH solution twice for 30 minutes with a ratio of 1:10. This step was used to remove the non-collagenous proteins. Then, they were rinsed with water until the pH went back to around 8-9. After that, the samples were soaked in 0.05M acetic acid twice for 45 minutes to remove the impurities of the skin (fat, ash, etc.). The ratio used was 1:10. Then, the samples were soaked again in the 0.05M acetic acid solution with a ratio of 1:10 to allow the protein matrix to swallow and then be ready for the gelatin extraction. The samples stayed in that solution for two hours. Once all those steps were done, the samples were rinsed until their pH was again around 6-7 and then weighed. The samples were put in a ratio of 1:3 in water at 45°C for 16 hours (overnight) to allow the gelatin to dissolve in the hot water (gelatin is partially hydrolyzed collagen that is soluble in water). After the extraction overnight, the liquid (where the gelatin was) and the solid (rest parts of the samples) were separated with a 50μm pore size cheese cloth. The liquid part was freeze dried and the gelatin was weighed and color as well as other parameters were studied. The rest parts of the samples were used for the glue extraction.

Gelatin extraction 2 – for bones and remaining bone parts of the head

The bone sample was soaked in 1M HCl with a ratio of 1:5 (w/v) for 36 hours (until its was soft when bent) at room temperature. Then, the sample was washed with cold water until the pH reached towards 3.6. Thereafter, the collagen was extracted with tap water with a sample/water ratio of 1:3 w/v at 80°C for 16 hours with continuous stirring (150 rpm) in an incubator shaker. Then, the mixture was filtered using cheesecloth with a pore size of 50 µm and weighed. Finally, extracted collagen was freeze-dried.

Gelatin extraction 3- for scales

The fish scales were washed twice in 10 wt.% of NaCl solutions (scales:solution = 1:10) to remove non-collagenous proteins on the surface by stirring the solution for 24 hours, then washed thoroughly with distilled water until the pH was neutral. Demineralization was performed by stirring the scales for 90 minutes in 0.4 mol/l HCl (scales:solution = 1:15), then washing the scales three times in distilled water to ready them for collagen extraction. The gelatin was extracted by heating it at 80°C overnight, then filtered.

Gelatin measures

All gelatin samples were measured for the dry weight of gelatin extracted from the wet sample – this quantifies the yield. The color of the gelatin extracted was measured using a standard scale across three color spectrums shown in three color values using a spectrometer; the L-value, the a-value and the b-value. These are used to calculate the Judd Whiteness (=100-SQRT((100-L-value)^2+(a-value)^2+(b-value)^2) which is indicative of the purity of the gelatin produced. The higher this Judd value, the greater the purity of the gelatin is likely to be. This can inform the applications that different gelatins produced are most suited for. A blooms test was also carried out which measures how firm the gelatin will be once set. The number calculated was both the raw value and the corrected value against a commercial standard gelatin from tilapia. In this measure, the higher the bloom strength value, the firmer the gelatin will be. This was carried out using standard bloom test procedures. Medium bloom gelatins range between 175–225 in bloom strength. Gelatins in this range are often used for food. For example, gelatin with a bloom of 225 can be found in frosting, whipped cream stabilizers, marshmallows and canned ham. High bloom gelatin ranges from 225–325 and is made from cow or pig collagen. It can be formulated to create a firm transparent gel. High bloom gelatin is most often used in gelatin desserts, jelly fillings, cream fillings, jellied meat products, soft gelatin capsules and ballistic gelatin. Finally, the melting temperature was measured.

Glue extraction

Glue extraction was carried out on all of the body parts that gelatin was extracted from as the final stage of byproduct utilization. After gelatin extraction, the rest of the fish parts were soaked in water at 70°C for two hours and then dried at 55°C for the skin and swim bladder. For scales, they were extracted in water at 90°C for two hours then oven dried at 55°C. Before drying, the rest pieces were taken out of the glue by filtrating with a 50µm pore size cheese cloth to only get the liquid glue to freeze drying. Some of the skins were still fatty, making it difficult get pure glue and therefore more difficult to process. If we would use them in the future, it would be necessary to do a defatting step previous to further processing. Once the glue was dried, to make it sticky and functional, it is necessary to rehydrate it with a ratio of approximately 1:0.5 w:w. The yield of the glue was recorded and a preliminary test of the glue was carried out to assess its function as a glue by attaching metal bars to the lab bench.

Processing of heads for protein hydrolysates

The heads were mixed with cold water of a ratio of 1:3 and homogenized at 15 000 rpm for 90 seconds. The solution pH was adjusted up to pH 11 by slowly adding 2M NaOH. Then, the solution was incubated in ice for 10 minutes followed by centrifugation at 5000 x g, 40C for 20 minutes to facilitate soluble protein, oil and collagenous components. After the centrifugation, three layers were generating a consistent top emulsion layer, mid layer and bottom layer. The top emulsion layer was scooped out using a spatula and frozen at -200C for two hours. Then, the sample was defrosted with running tap water and centrifuged at 5000 x g, 40C for 10 minutes. The supernatant was separated and weighed. The remaining solution was added to the mid layer from primary fractionation containing soluble proteins. The mid layer was collected from primary fractionation and the soluble protein was precipitated by adjusting the solution pH into 5.3 using 3M HCl. Protein isolate was drained through the 50 µm pore size cheese cloth to remove soluble impurities. Then, the fish protein isolate was weighed. The protein isolate was frozen at -180C and freeze dried. This was carried out to confirm that producing a protein hydrolysate would be possible. The yield was measured, and the color measured using the colorimetric analysis as for the gelatin.

Fat extract – preliminary testing

A test was also carried out to see if fats could be extracted from the liver and roe of the Yellow Perch and Walleye to see if there was a useable yield. Fat extraction was done by mixing ratio 2:1 liver with water or liver with a 1% solution papain (enzyme); heating them up at 55°C for 2 hours and then centrifugating at 5100rpm for 20 minutes to separate the layers and get the fat ratio. The idea for this approach came from https://www.e-fas.org/archive/view_article?pid=fas-25-2-76. The results were different regarding the different species and parts. For both livers, the extraction process made only with water was not enough. No fat was visible after centrifugation while with papain a significant amount of fat was recovered from the liver of the Walleye and a tiny bit recovered from the liver of the Yellow Perch.

Regarding the roe, only water was tried, not papain as the roe is known to be more sensitive to harsh treatments. For the Walleye, again, a good amount of fat was recovered while for the Yellow Perch no visible fat was found on top. Those analyses could be adapted once we know the fat amount in the parts of each species.

6.2.2. Automation test processing

Curio, part of Marel, received Walleye from the Great Lakes region during the reporting period, and these results are shared here. Walleye were tested with the Curio C-2011 filleting machine and the Marel FleXicut waterjet pin-boning and portioning machine. This was done to explore options for increased or improved automation for the fish processing sector in the Great Lakes.

6.2. Prototyping results

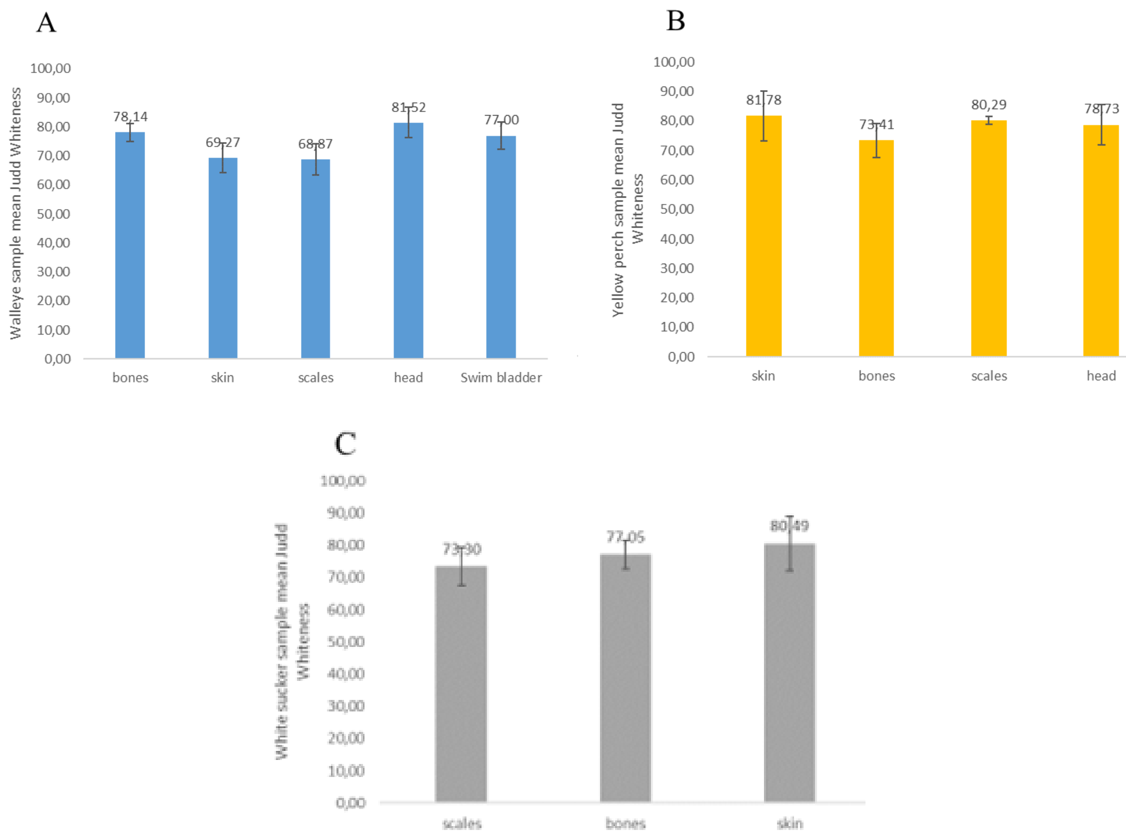
6.2.1. Gelatin prototypes

The yield of gelatin was highest for Walleye skin and White Sucker scales (**Table 8**).

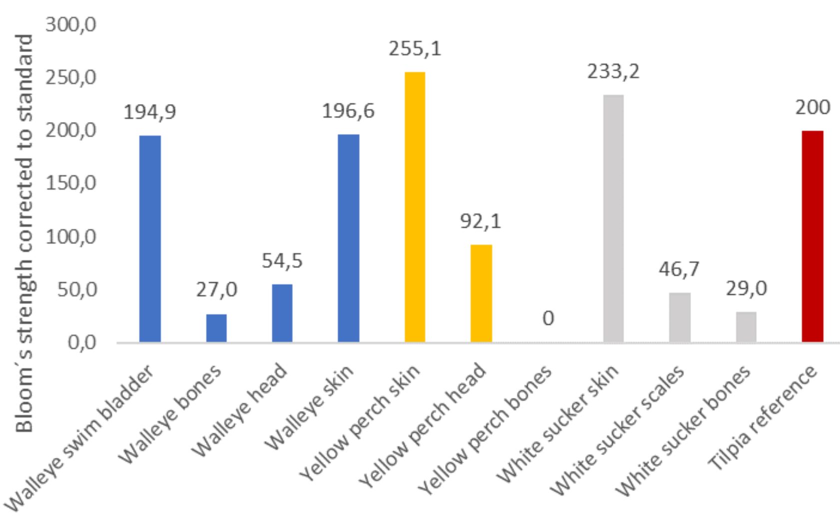
Table 8. Gelatin dry weight yield as a proportion of the volume of wet source material extracted from.

Source	Dry yield as a % of total wet weight from source
White Sucker skin	8.7
Walleye skin	11.4
Yellow Perch skin	10.4
Walleye swim bladder	8.5
White Sucker bones	5.6
Yellow Perch bones	7.6
Walleye bones	5.0
Yellow Perch scales	6.2
Walleye scales	6.4
White Sucker scales	8.9

The average Judd´s whiteness and standard deviation is presented in bar graph **Figure 32A** for Walleye, **Figure 32B** for Yellow Perch and **Figure 32C** for White Sucker.



Bloom´s strength – The commercial reference used for this analysis was from Tilapia where the bloom strength is 200. The gelatin from the Yellow Perch did not solidify during the test hence its value in the **Figure 33** of 0. Melting points for all samples were between 12.5°C and 19.5°C.



6.2.2. Glue prototypes

The yield of glue was greatest for Walleye skin, Yellow Perch scales and White Sucker scales **Table 9**.

Table 9.

Source	Volume of material (g)	Dry glue weight (g)	Wet glue yield (%)
Walleye skin	121	4.94	4.1
Walleye scales	1.2	0.04	3.3
Walleye swim bladder	234	5.57	2.4
Yellow Perch skin	115	1.12	1.0
Yellow Perch scales	5.7	0.28	4.9
White Sucker skin	212	1.77	0.8
White Sucker scales	126	56.1	3.7

6.2.3. FPH prototype

Yield calculated as a % of the total volume of the heads of the Walleye and Yellow Perch used in this test **Table 10**.

Table 10.

Source	Volume of material used (g)	Wet yield%
Walleye head	343.51	8.81
Yellow Perch head	347.54	7.0

The FPH was measured using the Whiteness Judd and the Whiteness Hunter. For Walleye (Judd: 44.4, Hunter: 27.1). For Yellow Perch (Judd: 41.3, Hunter: 21.5), suggesting a high redness level.

6.2.4. Fat extraction prototype

Table 11 shows the yield of extracted fat from liver samples using two different methods.

Table 11. Yield of extracted fat (g).

Source	Sample volume (g)	Extracted fat (g)
Yellow Perch liver in water	10.63	Not separable
Yellow Perch liver in papain	13.34	3.12
Walleye liver in water	50.31	Not separable
Walleye liver in papain	50.06	18.63
Yellow Perch roe in water	50.91	Not separable
Walleye roe in water	50.36	15.48

6.2.2 Automation test

A separate report was prepared by the team at Marel and Curio where detailed results of the automation test on Walleye can be found. It was considered that the test was highly successful and the Walleye a good candidate for automation. The yields are shown in **Table 12**.

Table 12. Results from Marel Curio testing of automated filleting yield of Walleye.

Whole round (lbs)	Heads	J cut	Fillets Skin on
1.9	22.7%	70.5%	52.3%
2.2	24.0%	68.0%	54.0%
4.2	22.9%	65.6%	50.0%
5.3	20.8%	69.2%	53.3%

7. Identifying best case scenarios

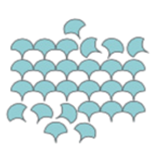
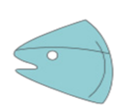
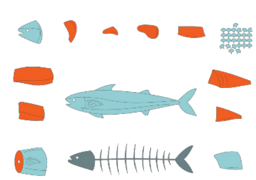
Based on the results of the biotechnological analysis and the prototype tests, combined with contextual knowledge gathered from the year one site visit to the Great Lakes region and a visit from Wheatley-area (southwest Ontario) processors to Iceland in 2023, several best cases have been identified for more in-depth analysis as being the most promising for the Great Lakes region.

Since one of the biggest challenges that emerged from site visits and discussion with the processing industry of the Great Lakes region was the volume of different species caught and storage availability, this has been considered. Alongside this, for the potential of products to be considered as high, it will be essential that they are easily adopted by the processing industry, which means it will be key to select solutions that require the least adaptation of the current processing practices and process chains.

To address the first challenge of volume, the solutions that have been identified are those that can combine the by-products from multiple species to create new higher value products. This could include key commercial species such as the Lake Whitefish from the year one report and the Lake Trout, Yellow Perch and Walleye from this report, and also those fish that are landed but have smaller or lower value markets, or potentially those that are by-catch (if carefully regulated) such as White Sucker, Sheepshead (freshwater Drum), Shad or the invasive carp species that are increasingly landed in some parts of the region. A previous report was carried out that provides some biotechnological detail for the Silver Carp and Bighead Carp carried out by the Iceland Ocean Cluster and Matís, Iceland that could support knowledge development for such mixed species solutions.

The "mediator" company role (identified as a need in the year one report) has been further explored in the following sections. For the latter challenge, the solutions that had the least impact to existing processing practices in combination with promising biotechnological results were selected and are shown in **Table 13**.

Table 13. The three best cases identified by this report. In each case, the products would be sourced from multiple species.

Case 1	Case 2	Case 3
High value – lower volume.	*Mid-value – mid volume.*	*Lower value – higher volume.*
Gelatin or collagen peptides from mixed species fish scales.	**Protein hydrolysates from mixed species fish heads**	**Fish meal from all rest material from mixed species.**
		

The protein and hydroxyproline content of all fish tested proved interesting. For all species, the range of hydroxyproline, an indicator of potential gelatin and collagen peptide yield, was 1.74-2.35% from scales which had the highest measure of the body parts analysis. Scales make up between 1.9% (Walleye) and 7.5% (White Sucker) of fish body mass. This is comparable with other fish species scales that have been measured including Carp (Cyprinus carpio) (Duan et al., 2009), Red Seabream (*Pagrus major*) and Nile Tilapia (*Oreochromis niloticas*). For commercial Atlantic Cod (*Gadhus morue*), collagen is usually harvested from skin rather than scales (since scales are very small). Hydroxyproline measures of Atlantic Cod skin can be up to 8% (ref). For Lake Whitefish, combined skin and scale hydroxyproline from the year one report was on average 2.47%. The prototype yields of gelatin from the fish scales ranged from 6.2-8.9% and had promising purity (63.37-80.2 Judd´s Whiteness). For White Sucker scales, bloom´s strength reached 46.7 - suggesting a combined material might have a medium purity and strength that has a range of potential applications. Further enzyme treatment could also be applied to produce collagen peptides which can provide a different target market with product.

The protein and amino acid profile of fish heads showed promising results. Heads make up 19.3% and 21.2% of Walleye and Yellow Perch body weight respectively (White Sucker was sent without heads) and collectively contain high levels of glutamic acid, glycine, alanine, aspartic acid and isoleucine. The White Sucker fillet was used as a proxy for the head amino acid content and similarly has high glutamic acid, aspartic acid and also high lysine and leucine content. These amino acids have a number of essential roles in human, animal and fish nutrition. For example, glutamic acid is a source of glutamine which can improve growth and immune development in farmed fish (Li et al., 2020) and lysine increases growth and nutrient conversion in Rainbow trout (*Oncorhynchus mykiss*) (Ahmed and Ahmad 2021). Glycine has important roles in human and animal nutrition for metabolism, neurological function and anti-oxidative reactions (Wang et al., 2013). The successful prototype production of FPH from fish heads suggests this might be an interesting option.

Fish head amino acid composition and protein content indicates that a high protein, low fat product might be yielded from heads (16.57% Yellow Perch-19.2% Walleye), skin (22.9% Yellow Perch, 27.57% Walleye, and 20.2% White Sucker) and fillets (White sucker 16.27%, **on average this is 20.45% protein**). If livers or roes (which all had >30% PUFAs and >14% EPA and DHA – key to human, animal and fish nutrition) were included, this could increase the fish oil yield too.

All the best-case opportunities listed above are not new to the international market and would build on existing know-how and processes, creating a strong foundation to launch Great Lakes value chains from.

8. Value chain analysis and SWOT for these results

Two analyses were applied to the three identified best cases to gather more information, identify strengths and weaknesses, and highlight next step priorities for these high-potential value chains. The first analysis was a value chain analysis and the second was a SWOT analysis, both of which are described in more detail in the following section. The outcome of these two analyses for each high-potential product will inform the priorities and recommendations of this report.

8.1.1. Value chain analysis

A value chain analysis considers each step of the value chain and evaluates the activities to understand where value is currently added and where there might be opportunity to increase that value, and highlights where value might currently be being lost **Figure 33**.

Since the identified best-case examples consider mixed species solution, this value chain analysis reflects that. A three-row table has been added to each of these value chain analyses. The first row considers the "existing" value-add, the second row estimates the "potential" value-add for the best-case products based on existing markets and products, and the third row estimates a monetary value chain for that value chain step. The "existing" values are based on a range from the species considered in this report, as well as the year one Lake Whitefish report. The Input step has been removed for the purpose of this analysis since it is normally governmentally or externally regulated.

Existing	The current value and money generated by the value chain.
Potential	The potential value generated by the best-case value chain.
Value	The potential money generated by the best-case value chain.

Figure 33. Value chain analysis model used for this report.

8.1.2. SWOT analysis

A Strengths, Weakness, Opportunities, and Threats (SWOT) analysis examines key questions regarding internal and external factors for each of the identified best-case product value chains. This analysis complements the value chain analysis and helps to explore where strategic action might be needed to improve those value chains and bring these best-case products to market. **Figure 34** shows the SWOT analysis and the questions that each aspect of the analysis will consider.

STRENGTHS

What competencies are available to achieve this value chain?

What might be a source of internal competitive advantage?

WEAKNESSES

What internal factors are lacking for this value chain to function successfully?

What internal factors might limit the success of this value chain?

OPPORTUNITIES

What emerging trends might be sources of added value?

What existing or emerging market opportunities in the region?

THREATS

What external negative trends might this value chain face?

What uncontrollable external factors might negatively impact this value chain?

Figure 34. Key questions and structure of the SWOT analysis used in this report.

8.2. Gelatin or collagen from scales

8.2.1. Value chain analysis for gelatin or collagen from scales

Inputs	Capture	Collection & Processing	Creation of value-added products	Distribution	Sales
Existing	**~$1-5** for fish in the round.		**~$9-14** for salads and fish cakes. Low values for mink slurry ~$5/250ml or when packaged and sold as bait.		**~$10/lb-$20/lb** for undressed and dressed fillets.
Potential	Increased range of species that were not generally considered commercially valuable that are valuable for scale.		Collected scales to be stored and shipped to an existing collagen producer, or for collagen production to be established as part of the fish processing supply chain of one or more Great Lakes processors. Non-scale parts of fish still available for other value-add chains.		**~$10/lb-$20/lb** for undressed and dressed fillets.
Value	**$-** based on what processors would be willing to pay for scales considering value chain returns.		Pure fish collagen products marketed at **$60.27/300g** (0.66lbs).		

8.2.2. SWOT analysis for collagen or gelatin from scales

STRENGTHS

All fish processors already have knowledge and equipment to de-scale commercially processed fish, and it is done as standard.

Scales are already collected in separate capture units as distinct biomass.

Scales from multiple fish species have been analyzed and tested to confirm if collagen or gelatin production is possible.

The process of transforming fish skin/scales into collagen and gelatin is established and there are already commercial producers in North America that have this know-how and equipment and process. Steps are known and accessible.

WEAKNESSES

To achieve needed quantities, different species would likely need to be mixed. Each species will have collagen of differing characteristics, purity and yield – so combing them will create a mixed quality product.

Limited storage solutions, or storage distributed in specific locations and owned privately.

No established supply chain for utilizing scales and other byproducts from Great Lakes processors and for FPH.

Scales are quite wet, often accumulating more water in badly draining capture units over a processing day- takes up more space and energy to dry scales.

Volumes produced by individual processing companies will be low and there is no existing collaboration or collection of specific scales that is shared between companies in the region.

OPPORTUNITIES

Additional fish are being landed and brought to processors that currently have little to no market value but are still landed as low target volume or as biomass- having a use for the scales would create more value for these species for both the fishermen and the processors.

There are already multiple, established, domestic and international markets for different quantities and qualities of collagen and gelatin with high consumer acceptability.

There are companies in the region that already have a model that could facilitate the collection of scales and act as a mediator company between processors.

There is an opportunity for groups of processing companies to collaborate around a source of potential value gain, where storage from one processor might combine with scale supply from others.

THREATS

Environmental challenges and variations in fish population which may affect the volumes of fish and, consequently, scales available.

The fisheries supply chain is time rigid and if new value-add products and activities are brought in and are poorly executed, might create challenges for the primary products from processing.

There are currently not fish-based collagen products being produced from Great Lakes fish by-products – such an emerging market might take time to establish which might challenge the scale-up of product production and require more patient investment if new facilities are to be established.

8.3. Fish Protein Hydrolysates from heads

8.3.1. Value chain analysis for FPH from heads

Inputs	Capture	Collection & Processing	Creation of value-added products	Distribution	Sales
Existing	**~$1-5** for fish in the round. Additional species e.g. Carp current $0.30 (2020 price).		**~$9-14** for salads and fish cakes. Low values for mink slurry ~$5/250ml or when packaged and sold as bait.		**~$10/lb-$20/lb** for undressed and dressed fillets.
Potential	Increased range of species that were not generally considered commercially valuable that are valuable for heads or each whole body toward FPH.		Acid bulk treatment of fish heads after de-heading. Can also be mixed with other organic materials to add bulk. If only heads are used, other material available for other applications.		**~$10/lb-$20/lb** for undressed and dressed fillets.
Value	**$-** based on what processors would be willing to pay for additional species e.g. Carp and Shad.		Pure FPH marketed as a nutritional supplement marketed at **$20.89/67g** (0.15lbs) bottle. More bulk version from an industrial supplier marketed at fertilizer (mixed organic wastes market **$22/32oz**.		

8.3.2. SWOT analysis for FPH from heads

STRENGTHS

Processing methods well known and once processed, FPH can be stored at room temperature.

Many processors in the Great Lakes region already practice de-heading of commercial fish species, and heads in general are easily separated.

Short supply chain from fisheries to processors mean short times to capture heads for markets where freshness is important.

Protein content of a number of key commercial species has already been mapped.

Expertise available in the region for transforming fish into bioresources such as protein hydrolysates: http://www.merinov.ca

WEAKNESSES

To achieve needed quantities, different species would likely need to be mixed. Different species will have differing protein content and amino acid profiles – so combining them will create a mixed quality and profile product that will be variable with season and landings.

Limited storage solutions, or storage distributed in specific locations and owned privately.

No established supply chain for utilizing heads and other byproducts from Great Lakes processors and for FPH.

Potentially large and wet quantities of fish byproducts that would be costly to transport between processor and FPH producer.

OPPORTUNITIES

High demand for FPH from food, feed and agricultural markets--both in the region and globally.

Flexible preparation and processing of material dependent on destination market.

Fisheries species that are currently low value could bring new value both from heads, or whole body too if correct market selected.

Emerging aquaculture sector in the Great Lakes region may also be able to feed into volumes.

THREATS

Quality and safety of the product is dependent on the environmental quality of Great Lakes and fish populations.

Volume and characteristics of FPH produced may vary seasonally and with fluctuations in fish population so target markets may have to be diverse or flexible.

Competition with imported FPH from established international markets.

Unclear regulation for what markets the FPH from fish processing byproducts may be applied to and hygiene rules for differing markets.

8.4. Fish meal from remaining biomass.

8.4.1. Value chain analysis for fish meal from remaining biomass

Inputs	Capture	Collection & Processing	Creation of value-added products	Distribution	Sales
Existing	**~$1-5** for fish in the round.		**~$9-14** for salads and fish cakes. Low values for mink slurry ~$5/250ml or when packaged and sold as bait.		**~$10/lb-$20/lb** for undressed and dressed fillets.
Potential	Increased range of species that were not generally considered commercially valuable that are valuable for scale.				**~$10/lb-$20/lb** for undressed and dressed fillets.
Value	**$-** based on what processors would be willing to pay for new species, but could also be space for value creation with the aquaculture sector here- both on supply and demand.		**~US$3000/ton** based on global trends in the fish meal sector and a further **~US$1600ton** if fish oil also generated in fish meal processing.		

8.4.2. SWOT analysis for fish meal and fish oil from remaining biomass

STRENGTHS

Production of fish meal and fish oil does not require any separation of byproducts from processing and mixed species, sources and body parts can be used- including viscera and bones to produce meal.

Processes for producing fish meal and fish oil are well established and different methods and scales exist to suit different supply chain sizes and needs.

Equipment to produce fish meal and fish oil from mixed sources are available as plug-and-play units such as: https://proteinplant.is/

When combined across processing companies, there are high volumes of byproducts that are available for utilization.

WEAKNESSES

Different species will have differing protein content and amino acid profiles – so combining them will create a mixed quality and profile product that will be variable with season and landings.

Limited storage solutions, or storage distributed in specific locations and owned privately.

Individual processors have small volumes, so the supply for fish meal production must be combined from multiple processors – a practice and supply chain that does not currently exist.

Transport from multiple processors to a fish meal product site may be economically and environmentally costly.

There is not currently a strong brand or supply chain around products such as fish meal and fish oil from the Great Lakes – so time and sales skills will be needed to establish this.

OPPORTUNITIES

There is a large and growing market for fish meal and fish oil of varying compositions and qualities for pet, agriculture and fish farm feeds that means there would be high demand for the product.

It will be possible to utilize other fish landed in the Great Lakes region for a combination of fish meal and fish oil- that would not require any further processing of those landed fish as with the other two cases for heads and scales.

Opens opportunities for collaboration with aquaculture which will also have processing and organic waste that, while it cannot be fed back to the same species, could be used for other markets.

THREATS

The quality, safety and useability of fish meal and fish oil from the Great Lakes is dependent on the environmental health of the Great Lakes waters and fish populations.

There will be seasonal variation in the catch volume, protein content, amino acid profile and fatty acid composition that will require flexible market management.

Market fluctuations in fish meal and fish oil price are possible dependent on global supply and demand.

9. Mapping the minimal viable product pathways

9.1. Collagen or gelatin from scales

It will be key to map the volume of scales produced from de-scaling machines across the Great Lakes region and to identify the means of collection and storage of these scales as an essential part of the business model development. Identifying the market and preparing a sales plan will follow, and this process will be informed by the purity and yield of the collagen or gelatin produced from the scales. The quality, characteristics and yield, as well as the domestic investment potential, will inform the business model development and determine if the final product focus should be gelatin or collagen production. As part of the business model development, it will be necessary to determine the volume of scales available in the region, and identify collection and storage opportunities.

- Step 1: Collection of **1kg volume** of sales from mixed commercial species in drainable baskets.
- Step 2: Pressing scales to reduce water volume, and storage in cool facility (-20°C) for short time period
- Step 3: Ship by cooled transport to established collagen/gelatin for single batch test.
- Step 4: Recieve prototype and send for characteristic and quality testing.
- Step 5: Develop business model and seek investment for bulk production either internally in the Great Lakes region or out-sourced.

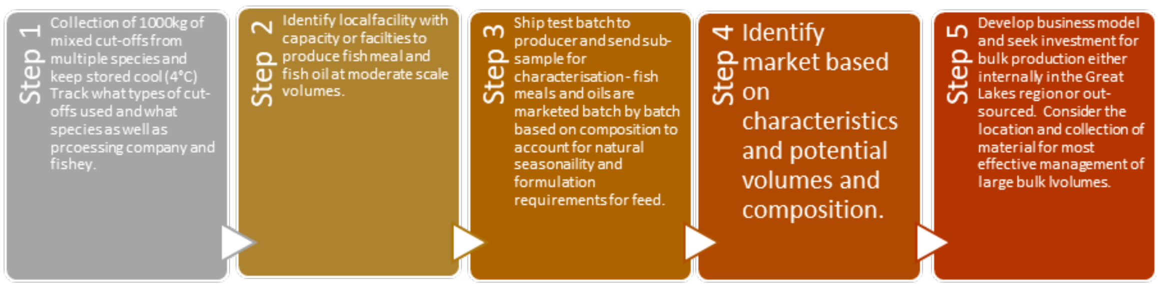
9.2 Fish protein hydrolysates from heads

The production process for FPH has been well documented as there are large existing markets both for high quality and lower quality products. It will be necessary to test a prototype scale of mixed fish heads from the Great Lakes region in a commercial production process to optimize yield and determine what are achieve yield and volume characteristics of this material. This will help to identify which type of markets to target and will inform the business model development. Characterization of this material will be necessary so feed, fertilizer or supplement producers can identify if this product matches the nutrient needs of the given market. As part of the business model development, it will be necessary to determine the volume of heads available in the region, determine how many processing companies are de-heading fish (automatically or manually) and identify collection storage opportunities.

- Step 1: Collection and freezing of 100kg of heads from mixed commercial species from companies already using de-heading equipment.
- Step 2: Frozen shipment sent to company with capacity to develop a prototype at lab scale.
- Step 3: Lab scale prototype produced and sent for characterisation and testing to help identify target market.
- Step 4: Hygine, food safety and regulations for FPH for different markets clearly mapped to help identify key market.
- Step 5: Test at commercial scale prototype development to ensure product consitency at higher - market relevant volumes.
- Step 6: Develop business model and seek investment for bulk production either internally in the Great Lakes region or out-sourced.

9.3 Mixed-species fish meal & fish oil

The route to development of fish meal and fish oil products to scale primarily requires the identification of the processing method and characterization of the resulting protein and fat content of a mixed species meal and oil. These products are both sold on formulations, and this will be essential to identify the applicable market. Since there are opportunities both domestically and internationally for feed ingredient markets for aquaculture and poultry feed, it may be important to include these industries in the dialogue to ensure that the products developed suit the intended markets. As part of the business model development, it will be necessary to determine the volume of cut-offs available in the region and identify collection and storage opportunities.



10. Business model development

There are dedicated companies that can support business model development. A strong model will be important to the success of all the aforementioned high-potential value chains for the Great Lakes region. An example of spin-offs developed from the Iceland Ocean Cluster circular economy business models is shown in **Figure 34**.

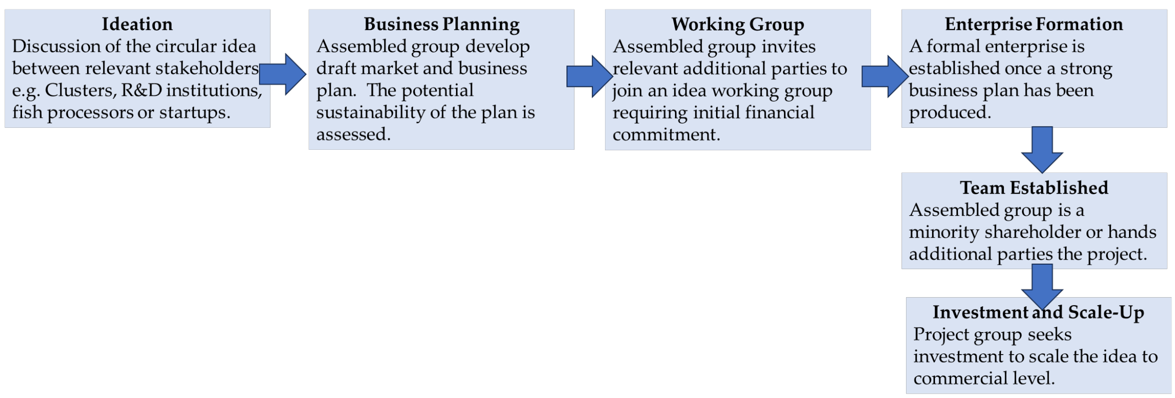


Figure 34. Example business model development based on successful framework used for IOC spin-off companies.

11. Branding in the Great Lakes

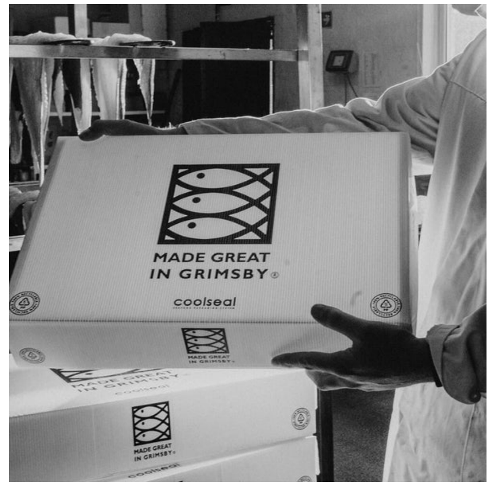


Figure 35. Made Great in Grimsby branding for United Kingdom seafood region.

For successful development of new value chains in the Great Lakes region, particularly those that would be new to the market or at least from a new source to existing markets, branding may play an important role. There are good examples of how region-specific seafood and seafood product brands have successfully created a strong message and reputation in the market, and those that have been most successful are those that connect the brand across the value chain, from capture through to resturant. One strong example of this is the Grimsby region of the United Kingdom, a former hub of fisheries in the country that, due to declining local catch, had to redesign its fisheries sector. Branding was a key part of this redesign and has created a strong image for seafood companies, and periphery companies in the region that means all these companies have strong and collanborative market visibility, high levels of trust and collectively reach a bigger audience than individual company brands. This example is called "Made Great in Grimsby" and the brand logo is shown in **Figure 35.** More details can be found at: https://www.madegreatingrimsby.co.uk/.

A preliminary investigation of Great Lakes food branding for this report is shown in **Figure 36,** along with a local information poster for the Great Lakes commercial fishery. These are good foundations that might be used as a stepping-stone to build a cohesive brand.

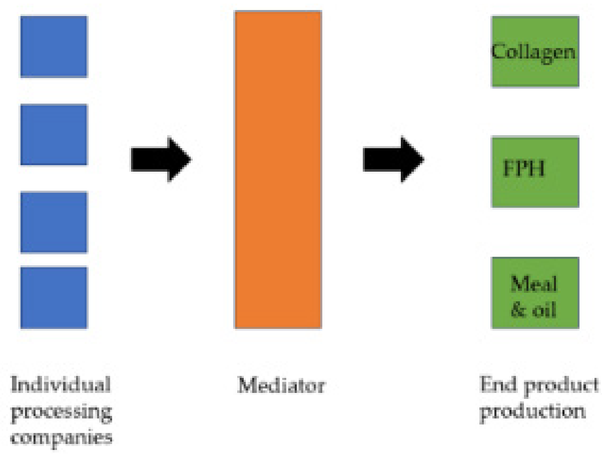
Figure 36. Existing brand and consumer market outreach in the Great Lakes region to consider when building a cohesive brand for the Great Lakes fisheries value chain.

In this brand building, it will be important to understand what local stakeholders and the wider community associate with the Great Lakes and what the market has a strong interest in. Strong visibility--locally and internationally--will be important. It will likewise be important to understand and address any negative associations that potential consumers may have with products from the Great Lakes, for example issues around environmental health, sustainability, traceability or the safety of seafood. Bringing stakeholders into the conversation early on in brand building can be an effective practice, as it helps to make the community a steward of the brand and connects local businesses in a cohesive network that will support a collective brand approach further.

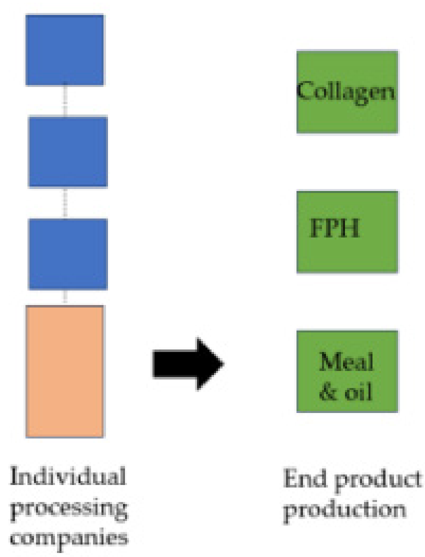
12. Collection and storage of material

There are a number of different models that could be developed for the secondary value chains identified for the Great Lakes region. In all cases, one of the key challenges will be appropriate and timely collection, storage and logistics for this material. Three potential models are preliminarily suggested here that may support business model development.

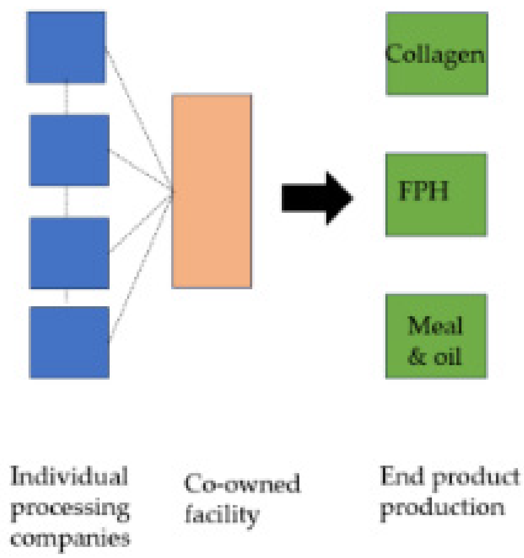
Model 1- A third-party mediator company that acts as a middle-man.



Model 2- A large-scale processor supports a cluster of processors.



Model 3-A new collective facility co-owned by a cluster of processors is established.



A detailed analysis would be required to identify which model is best for the Great Lakes region and will be dependent on the sources of financing for such facilities.

13. Recommended priority steps

The outcomes of this report have highlighted several key priorities that are recommended to advance toward 100% Great Lakes Fish. These recommendations are as follows.

i. A high-resolution data collection to map the volume and locational spread of secondary materials; initially scales, heads and then remaining materials both from commercial target catch and lower value species.

ii. Determine the seasonal variability, long-term stability and predictability of these volumes and the biotechnological characteristics of these biomasses.

iii. Develop appropriate business models for each of the high-potential value-creation cases.

iv. Develop a Great Lakes collective fish brand that considers sustainability and traceability.

v. Connect the research community, processors and government to create a domino effect for full utilization and to support the development and scale-up of 100% Great Lakes products.

vi. Increase dialogue on the topic of collaboration for mutual benefit among fish processing companies in the Great Lakes region.

Conclusion

This report details the existing catch, market and biotechnological profiles of four Great Lakes fish--Walleye, Yellow Perch, Lake Trout and White Sucker. The results of this biotechnological analysis was combined with collected knowledge of the Great Lakes fishery context and two complementary analyses (value-chain analysis and SWOT analysis) to identify three best-case and highest commercial potential products from the mixed species rest raw materials of these four fish species and other low value or low catch level fish (e.g. Sheephead, Shad and Carp). These were collagen or gelatin production from fish scales, fish protein hydrolysate production from fish heads, and fish meal and fish oil from the remaining mixed rest raw materials. Guidance is provided for developing the minimum viable product and the route to market for these new value chains. Finally, recommendations are provided to support the next stage of development toward 100% Great Lakes Fish. The results of this report can be combined with a prior report of the Lake Whitefish and can be considered complementary documents.

References

Agriculture Marketing Resource Center. 2022. Aquaculture Fish Species. Available at: https://www.agmrc.org/commodities-products/aquaculture/aquaculture-fin-fish-species [Accessed: 15/8/23].

Ahmed, I. and Ahmad, I. 2021. Dietary lysine modulates growth performance, haemoato-biochemical indices, non-specific immune response, intestinal enzymatic activities and antioxidant properties of rainbow trout, Oncorhynchus mykiss fingerlings. Aquaculture Nutrition 27(S1), pp124-139. DOI: 10.1111/anu.13409.

Blanar, C.A., Curtis, M.A. and Chan, H.M., 2005. Growth, nutritional composition, and hematology of Arctic charr (Salvelinus alpinus) exposed to toxaphene and tapeworm (Diphyllobothrium dendriticum) larvae. Archives of Environmental Contamination and Toxicology, 48, pp.397-404.

Boran, G. and Regenstein, J M. 2010. Fish Gelatin. Advances in Food and Nutrition Research 60, pp119-43. DOI: 10.1016/S1043-4526(10)60005-8.

Desai, A., Brennan, M., Gangan, S. and Brennan, C. 2022. Chapter seven – Utilisation of Fish Waste as a Value-Added Ingredient: Sources and Bioactive Properties of Fish Protein Hydrolysate. Sustainable Fish Production and Processing pp203-225. DOI: 10.1016/B978-0-12-824296-4.00004-9.

DNR (Department of Natural Resources) Michigan. 2018. History of State-Licensed Great Lakes commercial fishing. Available at: https://www.michigan.gov/dnr/managing-resources/fisheries/business/commercial/history-of-state-licensed-great-lakes-commercial-fishing [Accessed: 15/8/23].

Duan, R., Zhang, J., Du, X., Yao, X. and Konno, K., 2009. Properties of collagen from skin, scale and bone of carp (Cyprinus carpio). Food chemistry, 112(3), pp.702-706.

FishChoice. 2021. Walleye. Available at: https://fishchoice.com/buying-guide/walleye [Accessed: 15/8/23]

GLFC (Great Lakes Fishery Commission). 2022. Commercial fish production in the Great Lakes 1867–2020. Available at: http://www.glfc.org/great-lakes-databases.php [Accessed 15/8/23].

Government of Ontario. 2023. Commercial Fishing. Available at: https://www.ontario.ca/page/commercial-fishing [Accessed: 15/8/23]

Gunther, S.J., Moccia, R.D. and Bureau, D.P., 2005. Growth and whole body composition of lake trout (Salvelinus namaycush), brook trout (Salvelinus fontinalis) and their hybrid, F1 splake (Salvelinus namaycush× Salvelinus fontinalis), from first–feeding to 16 weeks post first-feeding. Aquaculture, 249(1-4), pp.195-204.

Gunther, S.J., Moccia, R.D. and Bureau, D.P., 2007. Patterns of growth and nutrient deposition in lake trout (Salvelinus namaycush), brook trout (Salvelinus fontinalis) and their hybrid, F1 splake (Salvelinus namaycush× Salvelinus fontinalis) as a function of water temperature. Aquaculture Nutrition, 13(3), pp.230-239.

Jescovitch, Lauren. Michigan Sea Grant, Michigan State University Extension; Sharon Moen and Titus Seilheimer, Wisconsin Sea Grant; and Fatima Abdl-Haleem. June 27, 2022. Today's Great Lakes commercial fishing and fish processing industries look to future. Available at: https://www.canr.msu.edu/news/today-s-great-lakes-commercial-fishing-and-fish-processing-industries-look-to-future-msg22-jescovitch22 [Accessed: 01/9/23]

Jobling, M.A., Pandya, A.R.P.I.T.A. and Tyler-Smith, C.H.R.I.S., 1997. The Y chromosome in forensic analysis and paternity testing. International journal of legal medicine, 110, pp.118-124.

Kristinsson, H G. and Rasco, B A. 2000. Fish Protein Hydrolysates: Production, Biochemical and Functional Properties. Critical Reviews in Food Science and Nutrition 40(1), pp 43-81. DOI: 10.1080/10408690091189266.

Li, X., Zheng, S. and Wu, G. 2020. Nutrition and metabolism of glutamate and glutamine in fish. Amino Acids 52(5), pp671-691. DOI: 10.1007/s00726-020-02851-2.

Liu, D., Nikoo, M., Boran, G., Zhou, P. and Regenstein, J M. 2015. Collagen and Gelatin. Annual Review of Food

Science and Technology 6(1), pp527-557. DOI: 10.1146/annurev-food-031414-111800.

Michigan State University. 2020. 2020 Status of the Industry: Michigan's commercial fishing and fishing processing business. Available at: https://www.canr.msu.edu/news/2020-status-of-the-industry-michigan-s-commercial-fishing-and-fish-processing-businesses-msg21-jescovitch21-nelson21 [Accessed: 15/8/23].

Michigan State University. 2022. Today's Great Lakes commercial fishing and fish processing industries look to future. Available at: https://www.canr.msu.edu/news/today-s-great-lakes-commercial-fishing-and-fish-processing-industries-look-to-future-msg22-jescovitch22 [Accessed: 15/8/23]

Ontario Commercial Fisheries Association. 2023. Ontario's commercial fishing industry. Available at: https://www.ocfa.ca/fisheries-industry [Accessed: 15/8/23]

Salim Hayder. 2014. Socio-Economic Impact of the Presence of Asian Carp in the Great Lakes Basin. Available at: https://www.dfo-mpo.gc.ca/species-especes/publications/ais-eae/report-SE-rapport/page06-eng.html#_4 [Accessed: 15/8/23]

Schrank, A. 2023. Egg-to-Market Yellow Perch Project. Available at: https://seagrant.umn.edu/programs/fisheries-and-aquaculture-program/egg-market-yellow-perch-project [Accessed: 15/8/23]

Venugopal, V. 2016. Chapter Three – Enzymes from Seafood Processing Waste and Their Applications in Seafood Processing. Advances in Food and Nutrition Research 78, pp47-49. DOI: 10.1016/bs.afnr.2016.06.004

Wang, W., Zhenlong, W., Dai, Z., Yang, Y., Wang, J. and Wu, G. 2013. Glycine metabolism in animals and humans: implications for nutrition and health. Amino Acids 45(3), pp463-477. DOI: 10.1007/s00726-013-1493-1.

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