100% Great Lake Fish

ONTARIO SUPPLY CHAIN ANALYSIS

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Ivey Centre for Building Sustainable Value

Prepared for

Great Lakes St. Lawrence Governors & Premiers

Photo credit: Bill Savage

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ABSTRACT

Southern Ontario offers valuable insights into the supply chain dynamics of fish harvesting and processing across the Great Lakes region. This report analyzes the existing supply of raw materials produced by fish processing plants and evaluates the feasibility of integrating these resources into other markets. This synthesized report compiles and integrates information from various databases. The analysis examines the quantities and rhythms of fish components from Walleye and Yellow Perch. The findings reveal that combining components from the two species can mitigate supply volatility throughout the year. Specifically, the analysis shows that the standard deviation of the weekly proportion of multi-species heads (1.09%) is smaller compared to the standard deviation of individual species – Walleye (1.27%) and Yellow Perch (1.45%). The reduced standard deviation for multi-species data suggests that incorporating diverse species smooths out extreme fluctuations in weekly supply, making it more attractive for new markets to incorporate these materials into their value chains. Additionally, the report identifies several viable upcycling models for repurposing fish by-products and highlights transformative upcycling models from other regions. The implications of this analysis suggest that substantial quantities of fish discards could lead to a broad range of upcycling opportunities for processing plants. By exploring these options, plants can enhance their economic and ecological performance.

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1. INTRODUCTION

Maximizing the value of fish does not stop with the fillets. Organizations worldwide have found many ways to extract the most economic value from commercially caught fish by creating additional value chains for raw materials that were once undervalued or discarded.

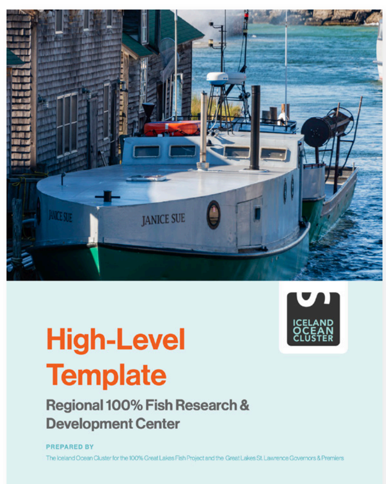
This report aims to analyze the supply of raw materials produced from fish processing plants and the feasibility of using those resources in other markets. These upcycling efforts could provide additional economic value to all stakeholders in the fishing industry while reducing waste and mitigating climate change, as observed in different food industries (e.g., Jain and Gualandris, 2023).[1]

Lake Erie's northern shore, a region rich in aquatic biodiversity, presents a unique case study that examines the relationship between natural fish populations and local fish harvesting and processing. Southern Ontario offers valuable insights that can inform a broader understanding of the supply chain dynamics of fish harvesting and processing throughout the Great Lakes region.

2. LITERATURE REVIEW

2.1 100% Great Lake Fish

The Iceland Ocean Cluster pioneered the 100% fish idea with the Icelandic cod. 60% of the fish was once discarded, much like fish from the Great Lakes region. Today, more than 90% of the cod is being used – with the value of the products made from each fish increasing from US$12 to over US$5,000. On March 3rd, 2023, the Iceland Ocean Cluster published a 52-page report commissioned by the Great Lakes and St. Lawrence Governors and Premiers (GSGP). The report examined how Lake Whitefish can be used to their maximum potential to augment economic returns, generate employment, and foster rural economic development.[2] Researchers employed biotechnological analysis to examine the physical composition of this species, seeking to identify the economic potential of fish parts usually discarded or undervalued. This research effort continued throughout the year, and on October 16th, 2023, a similar report expanded the scope to encompass four additional fish species.[3] These reports also delved into the various value chains' strengths, weaknesses, opportunities, and threats to recommend how businesses and governments can help make the 100% fish initiative, originally deployed in Iceland, feasible in a Great Lakes context.



1 Jain, Sourabh, and Jury Gualandris. 2023. "When Does Upcycling Mitigate Climate Change? The Case of Wet Spent Grains and Fruit and Vegetable Residues in Canada." Journal of Industrial Ecology 27 (2): 522–34. https://doi.org/10.1111/jiec.13373.

2 Great Lakes St. Lawrence Governors and Premiers. 100% Whitefish Report. March 2023. https://gsgp.org/media/dleglcci/100-whitefish-report-3-23.pdf

3 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf

It is worth mentioning that the specificity of these reports in terms of quantifying the fish ends with the yearly quantity of Whitefish, Yellow Perch, Walleye, Lake Trout and White Sucker. This information spans across each of the Great Lakes. The reports do not analyze monthly data. Additionally, these reports only provide the anatomical composition of these fish. Further research should be conducted in a similar manner to analyze the anatomical composition of all fish species in the Great Lakes region. The following section presents an overview of the data presented in the report.

3. DATA

3.1 Landings by Harbour – Total Data per Month 2014 - 2023

The *"Landings by Harbour"* dataset comprises ten Excel spreadsheets, each documenting a year's worth of monthly fish landings across eight harbours on Lake Erie. The data captures critical details, including the specific landing port, the month each landing occurred, the species name, and the catch's weight in pounds (lbs). The Ontario Commercial Fisheries' Association (OCFA) provided this comprehensive dataset in Excel format. Furthermore, to enhance geographical clarity, the coordinates of the eight ports were obtained using Google Maps and added to the database.

3.2 Species by plant data for 2023

The '*Species by Plant*' data represents fish purchases made by processing plants in 2023. It details the species of fish, the designated quota zone, and the quantity of fish purchased in lbs and kilograms (kg). GSGP provided this dataset in Excel format for illustrative purposes. Furthermore, to enhance geographical clarity, the coordinates of the processing plants were obtained using Google Maps and added to the database.

Photo credit: Bill Savage

3.3 Daily Harvest by Species

The *"Daily Harvest by Species"* dataset represents fish landings across Lake Erie from 2014 to 2023. It details the fish species, the quantity of fish landed in lbs, and the landing date (year, month and day). The OCFA provided this comprehensive dataset in Excel format.

3.4 Data Discrepancy

There is a notable discrepancy of 2,020,940 lbs between the *Landings by Harbour* and *Species by Plant* datasets for 2023. This difference represents an 8.32% variance. The *Landings by Harbour* data indicated 24,294,747 lbs of fish landed in 2023, whereas the *Species by Plant* data recorded only 22,273,807 lbs of fish purchased within the same year. While this research primarily analyzes the supply chain dynamics in the Great Lakes region, it will not investigate this discrepancy. This analysis assumes that the 2,020,940 lbs difference is attributable to fish being processed at plants other than those included in the data set and some amount of shrinkage (loss of fish or weight loss) during transportation.

4. SUPPLY OF RAW MATERIALS

In any industry committed to achieving zero waste, understanding the availability of raw materials is crucial for the success of innovative waste management strategies. Previous efforts to repurpose fish waste have not often been successful due to concerns about the inconsistency and seasonality of supply. Before addressing these concerns, it is essential to understand the supply of discarded raw materials; this knowledge can help identify feasible markets that may benefit from using such resources. Moreover, it will serve as a persuasive tool to demonstrate the consistency, reliability, and estimated quantity of discarded raw materials.

This section examines the quantity, variety, and rhythms that characterize the resources that would otherwise be wasted at processing plants. Our analysis is organized into three main parts. The first part analyzes the geographical relationships between fishing ports and processing plants. The second part analyzes each fish species' quantity, seasonality, and anatomical composition. The third part of the analysis aggregates the anatomical components of heads and scales across all species. This process can be repeated for all interested fish components. The goal is to provide a comprehensive overview of the quantity and seasonality of raw materials.

4.1 Mapping the Landings

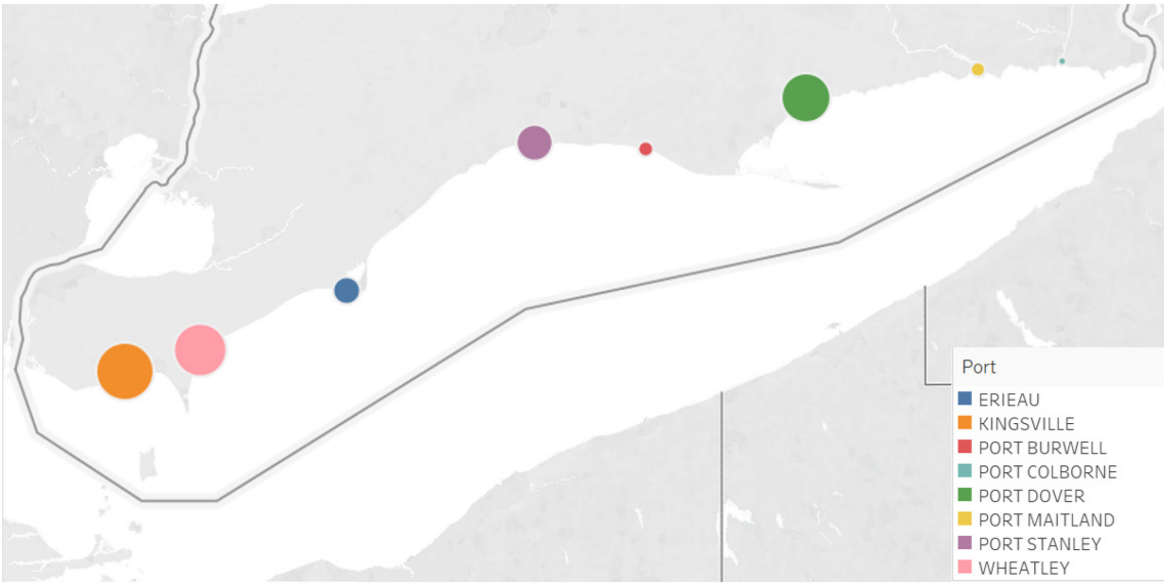
Figure 1 showcases different fishing ports on the northern shore of Lake Erie. The distance between these ports suggests a strategic spread along Lake Erie, likely to capitalize on different fishing grounds and fish migration patterns. In terms of quantity, there appears to be a concentration towards the west of the lake, possibly indicating areas with more abundant fishing resources or higher population densities that can sustain bigger port infrastructure. In 2023, the four largest ports by descending order were Kingsville (7,490616 lbs), Wheatley (6,242,517 lbs), Port Dover (5,392,303 lbs) and Port Stanley (2,802,249 lbs). The second stage of the analysis will explore these ports in more detail.

Figure 1: The Eight Major Fishing Ports

Figure 2 shows the locations of fish processing plants, primarily clustered in Southwestern Ontario. This clustering is due to proximity to transportation networks such as the 401 highway, workforce availability, and access to the

United States. The absence of processing facilities in certain parts of the coastline implies that fish caught at more distant ports must be transported overland to these central processing locations.

Figure 2: The 13 Major Fish Processors



Trucks transport the fish to processing facilities in large totes filled with ice to maintain freshness. This setup demands a logistics network that ensures timely and efficient delivery from ports to processing facilities.

4.2 Fish Species

Data on the quantity of landings, seasonality, and anatomical composition were collected for Walleye and Yellow Perch. Future research should grow the database on the anatomical compositions of various fish species and use the following template to add "target species" in the formula found in section 4.3.

Quantity refers to the weight of commercially caught fish landed in one of the eight Canadian ports on Lake Erie. The weight was converted to kgs using a conversion rate of 2.20462 lbs to 1 kg.

Seasonality refers to the rhythms of fish landings throughout the year. Five years of historical data were analyzed to determine the average percentage each week contributes to the total annual landings.

Anatomical composition of the species refers to a detailed breakdown of the different parts of the fish, such as fillets, bones, skin, and roe. This was calculated using the 100% Fish Multi-Species report prepared by the Iceland Ocean Cluster for GSGP.[4] The tables that the report provides were modified based on the following assumptions:

- The average weight for the whole fish and its various components is accurate enough to exclude significant systematic

4 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf

errors.

- The weight difference between the uncleaned and cleaned bones can be categorized as "Rest Raw Material."
- The calculation of "Rest Raw Material" ensures that our analysis accounts for 100% of the average fish weight.

Combining a species' anatomical composition with its quantity and seasonality provides a crucial estimate of the quantity and rhythms of various fish components. These estimates form the foundation to help evaluate alternate uses for fish resources and determine what minimum quantity thresholds can be consistently met.

Additionally, this insight aids in strategic storage planning, particularly when supply during low fishing seasons could fall short of the receiving markets' demand. By understanding the seasonality of fish components, processing plants can anticipate periods of low supply of fish discards and determine the necessary storage capacity to mitigate expected shortfalls for specific end markets.

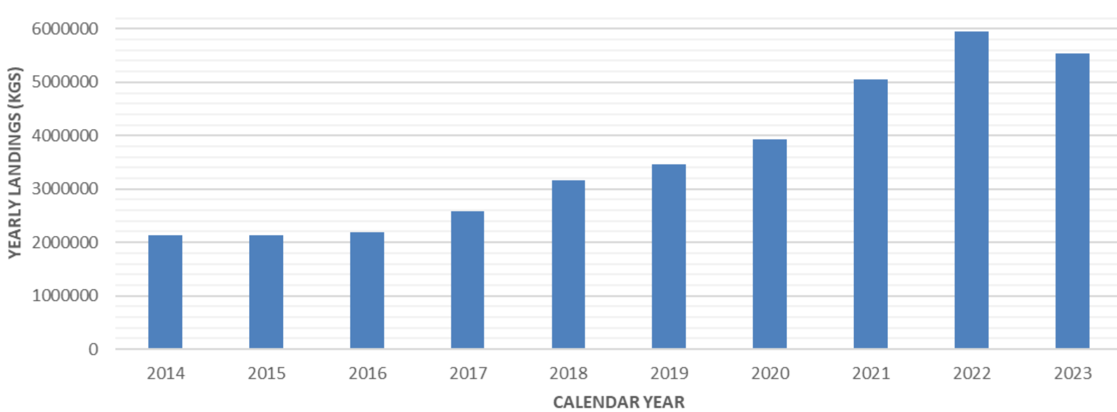
4.2.1 Walleye

4.2.1.1 Quantity

Between 2019 and 2023, the five-year average for yearly Walleye landings in Canadian ports on Lake Erie reached 4,782,697 kgs, reflecting substantial growth compared to the ten-year average of 1,637,987 kgs from 2014 to 2023. *Figure 3* highlights the significant growth in Walleye landings across the eight major ports, with a consistent upward trend peaking at the start of 2023. This growth could be due to several factors, including sustainable fishing strategies, increased Walleye populations, heightened demand leading to more intensive fishing efforts, or changes in fishing quotas.

Despite this overall growth, the most recent data shows a decline in landings. In 2023, the total quantity of Walleye landed dropped to 5,533,726 kgs, representing a decrease of 424,656 kgs compared to 2022. Nonetheless, Walleye remained the most prevalent species of Canadian-harvested fish on Lake Erie, accounting for 52.6% of all landings.

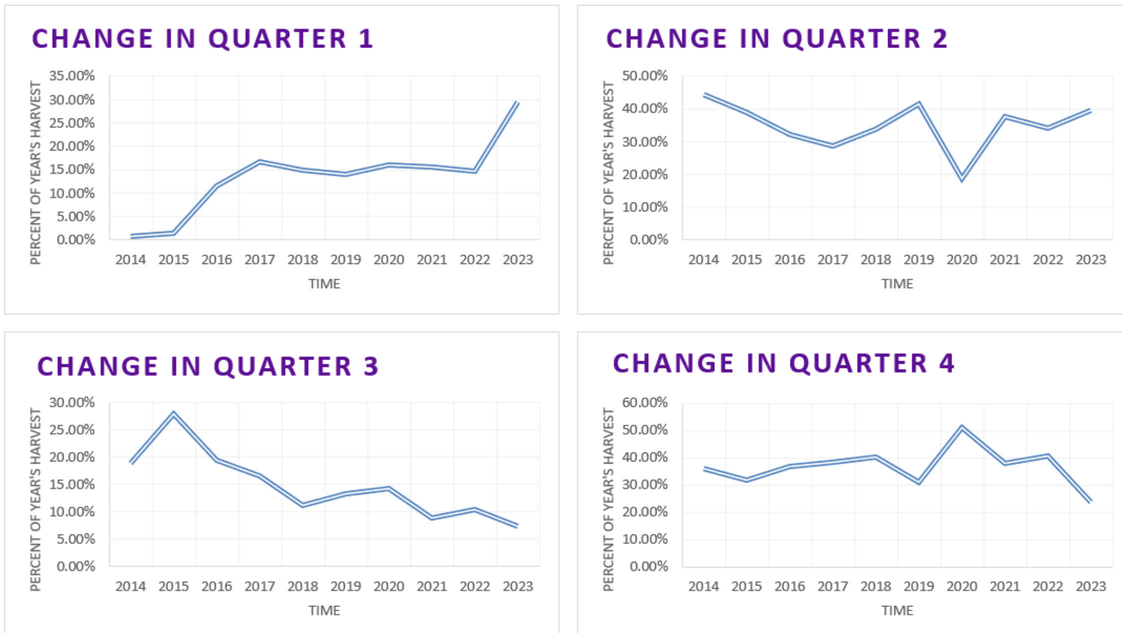
Figure 3: Walleye – Yearly Landings



4.2.1.2 Seasonality

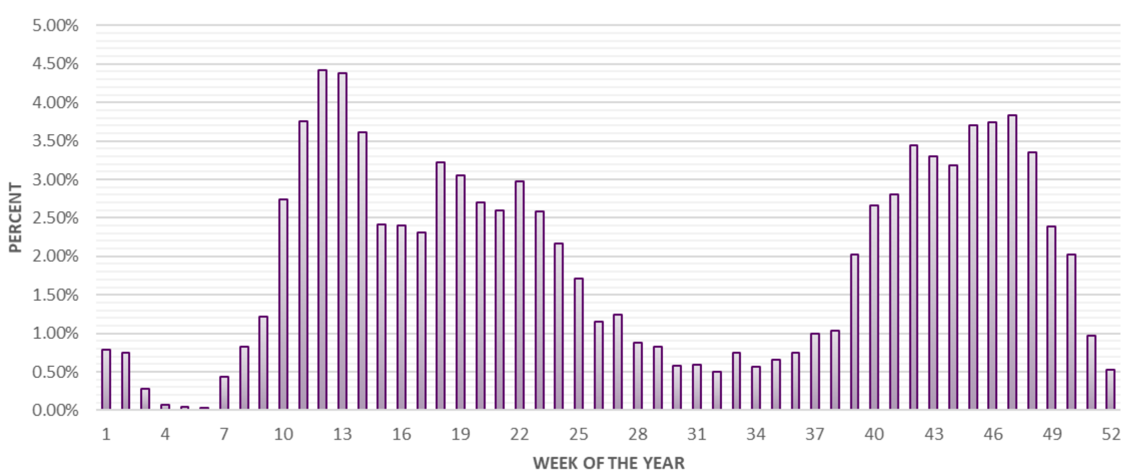
Over the years, there has been a noticeable shift towards higher landings earlier in the year. Q1 landings have increased significantly from 0.87% of total yearly landings in 2014 to 29.56% in 2023, indicating an earlier start of the fishing season. Q2 landings have remained consistently strong. However, Q3 landings have decreased considerably, from a high of 27.9% in 2015 to a low of 7.4% in 2023. Q4 landings have shown relatively minimal variability over the years. These patterns suggest changes in fishing strategies, fish behaviour, and seasonal conditions, highlighting the importance of focusing on recent data for more accurate forecasting. Therefore, only the past five years of data will be used to represent the expected seasonality. Refer to *Figure 4* for a visual representation of these temporal changes in seasonality.

Figure 4: Walleye – Changes in the Quarterly Distribution of Landings



The seasonal pattern represented in *Figure 5* uses five years of historical data to calculate the average proportion that each week constitutes of yearly landings. Note that week one represents the year's first whole week, Monday to Sunday, and week 52 includes the last whole week (and possibly the first few days of the new year, depending on how the week fell).

Figure 5: Walleye – Estimated Average Weekly Landings



The figure above highlights two high seasons during the year where the weekly proportion of landings exceeds the 52-week average of 1.92% (i.e., 100%/52 weeks). The first high season spans from week 10 to week 24, corresponding to early March through late June. The second high season occurs from week 39 to week 50, covering late September through mid-December.

Notably, the five lowest weeks for landings are consecutive, from week 3 to week 7, which falls between mid-January and mid-February. This period represents the lowest activity for landings throughout the year.

4.2.1.3 Anatomical composition

Table 1 below presents the anatomical composition of the average Walleye, breaking down the fish into various parts and highlighting the percentage of total weight each part constitutes. The detailed breakdown of the different fish parts was calculated using the 100% Fish Multi-Species report prepared by the Iceland Ocean Cluster for GSGP.[5] This analysis is crucial for understanding the estimated amount of waste material per Walleye.

It is important to note that the composition outlined in *Table 1* is an estimate and could vary by the fish processing plant due to the workers' degree of experience, adopted technology, and the company's incentive structures. Despite these factors, *Table 1* provides a useful approximation for understanding the anatomical composition of Walleye that can be used to guide further calculations.

Table 1: Composition of Walleye and Estimated Quantities of Walleye Components

Walleye			
Body part	**Wet weight (g)**	**Proportion of fish (%)**	**Estimated Quantity (kgs)***
Fillet	339.7	29.7%	1,420,461
Skin	65.0	5.7%	272,614
Scales	21.3	1.9%	90,871
Head	220.7	19.3%	923,061
Viscera	88.3	7.7%	368,268
Liver	32.2	2.8%	133,916
Roe**	139.0	12.2%	583,489
Swim bladder	10.5	0.9%	43,044
Bones cleaned***	28.7	2.5%	119,567
Rest raw materials****	197.1	17.3%	827,407
Total	**1142.5**	**100.0%**	**4,782,697**

* Estimated quantity using a five-year average of yearly landings.

** The proportion of roe changes depending on the season. The roe's weight and proportion of fish are the largest before spawning season.

***Bones were cleaned by sealing them in a vacuum bag and heating them in a 45°C water bath for 3 hours. They were weighed before and after this process, and the difference was added to the "rest raw materials"

****Anything that was left behind after these parts were successfully separated and the difference from bone boiling

5 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf Please note that the fillet (yield) percentage measured in the laboratory and included in the report may not precisely reflect yields measured in the field. The Ontario Commercial Fisheries' Association estimates that Walleye fillets represent between 29.7% and 40% of total weight in the field.

This initial fish species can serve as a template for other species, making subsequent analyses more concise.

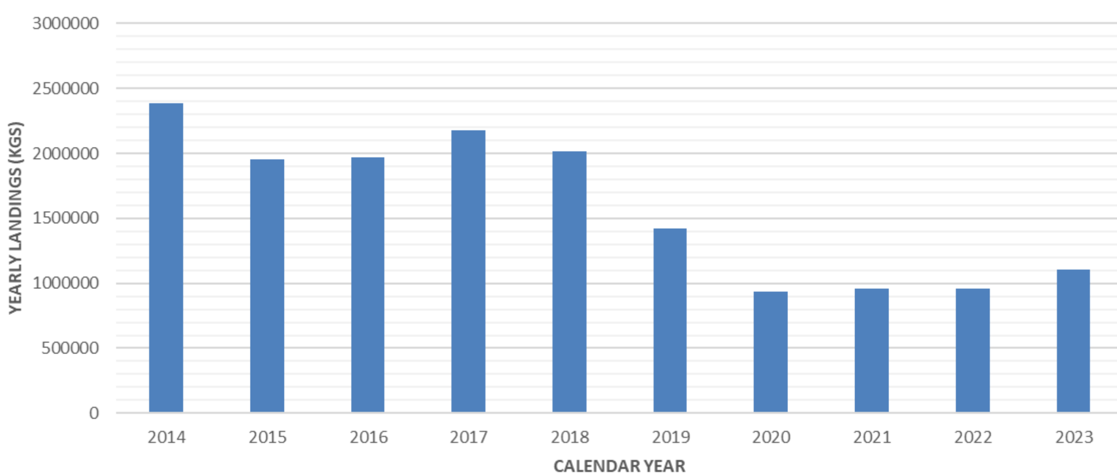
4.2.2 Yellow Perch

4.2.2.1 Quantity

Between 2019 and 2023, the five-year average for yearly Yellow Perch landings in Canadian ports on Lake Erie reached 1,075,338 kgs, reflecting a substantial decline compared to the ten-year average of 1,588,084 kgs from 2014 to 2023. *Figure 6* highlights a marked decline in Yellow Perch landings across the eight major ports over the past decade, with a trend showing a consistent downward trajectory that bottomed out in 2020. Several factors may have contributed to this decline, such as the implementation of stricter fishing quotas, a decrease in Yellow Perch populations, reduced demand, or possibly unsustainable fishing practices in earlier years.

Despite this overall decline, the most recent data shows a growth in landings. In 2023, the total quantity of Yellow Perch landings in Lake Erie increased to 1,105,650 kgs, up by 143,615 kgs compared to 2022. As of 2023, Yellow Perch remains the third most commonly harvested fish in the lake for Canadian ports, accounting for 10.5% of all landings.[6]

Figure 6: Yellow Perch – Yearly Landings

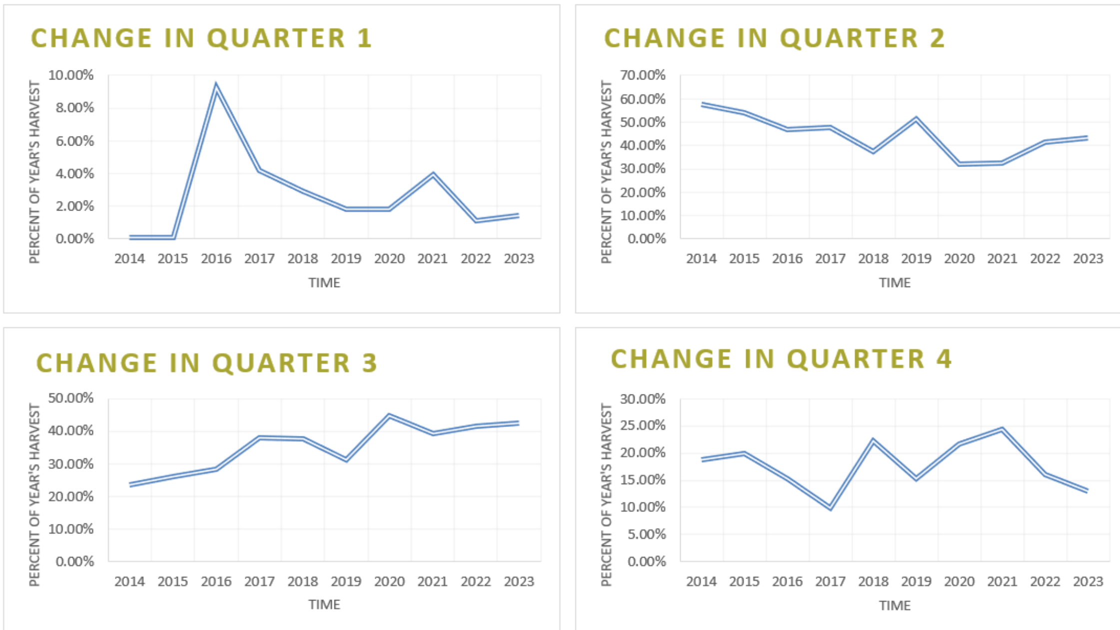


4.2.2.2 Seasonality

Over the years, the landings have seen a more even distribution between Q2 and Q3, mainly because of the decreasing trend in Q2. Q2 landings decreased considerably from 57.58% of total yearly landings in 2014 to a low of 31.94% in 2020. However, Q3 landings increased significantly, from a low of 23.65% in 2014 to 42.39% in 2023. Q4 landings have shown variability over the years. Refer to *Figure 7* for a visual representation of these changes.

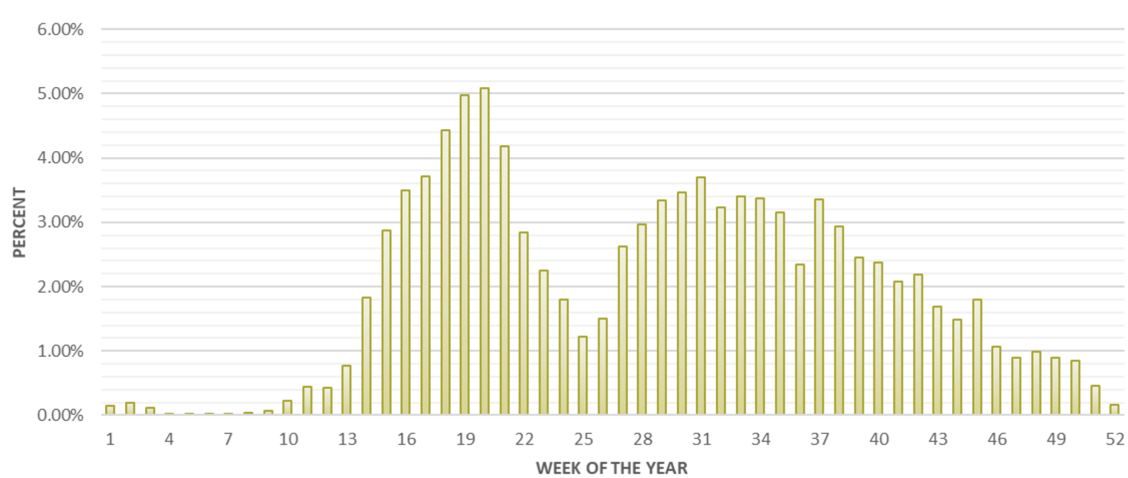
6 Anatomical composition has not yet been conducted on Rainbow Smelt, the second most commonly landed fish species across Lake Erie.

Figure 7: Yellow Perch – Changes in the Quarterly Distribution of Landings



The seasonal pattern represented in *Figure 8* uses five years of historical data to calculate the average proportion that each week constitutes of yearly landings. Week 1 represents the year's first whole week, Monday to Sunday, and week 52 includes the last whole week (and possibly the first few days of the new year, depending on how the week fell).

Figure 8: Yellow Perch – Estimated Average Weekly Landings



The figure above demonstrates two high seasons where the weekly proportion of landings exceeds the 52-week average of 1.92%. The first high season spans from week 15 to week 23, corresponding to early April through early June. The second high season occurs from week 27 to week 42, covering early July through mid-October. The five lowest weeks are consecutive – from week 4 to 8, which falls between late January through late February.

4.2.2.3 Anatomical composition

Table 2 presents the anatomical composition of the average Yellow Perch, breaking down the fish into various parts and highlighting the percentage of total weight each part constitutes.[7]

Table 2: Composition of Yellow Perch and Estimated Quantities of Yellow Perch Components

Yellow Perch			
Body part	**Wet weight (g)**	**Proportion of fish (%)**	**Estimated Quantity (kgs) ***
Fillet	105.4	23.2%	249,478
Skin	26.8	5.9%	63,445
Scales	18.3	4.0%	43,014
Head	96.1	21.2%	227,972
Viscera	12.9	2.8%	30,109
Liver	8.1	1.8%	19,356
Roe**	76.1	16.8%	180,657
Swim bladder	1.0	0.2%	2,151
Bones (cleaned)***	9.8	2.2%	23,657
Rest raw materials****	99.6	21.9%	235,499
Total	**454.1**	**100.0%**	**1,075,338**

* Estimated quantity using a five-year average of yearly landings.

** The proportion of roe changes depending on the season. The roe's weight and proportion of fish is largest before spawning season.

***Bones were cleaned by sealing them in a vacuum bag and heating them in a 45°C water bath for 3 hours. They were weighed before and after this process and the difference was plugged to rest raw materials

****Anything that was left behind after these parts were successfully separated and difference from bone boiling

4.3 Raw Material

Understanding the quantity and rhythm of various fish materials is crucial for maximizing resource utilization and increasing the reliability of supply. The following analysis will enable processing plants to identify the most suitable alternative markets that can use the waste material without facing supply-demand mismatches. By aggregating anatomical components across multiple species, processing plants can better compare their supply capabilities to market needs. Additionally, the insights gained from this analysis will guide necessary adjustments in storage practices to mitigate the effects of seasonality – a factor often cited by processing plants as an obstacle in their attempt to repurpose materials for products like pet food.

Our analysis will focus on assessing the operational feasibility of implementing storage adjustments, aiming to offer a consistent and reliable supply of raw materials throughout the year. However, it is pertinent to note that storage is not the only solution for mitigating the effects of seasonality. Alternatives could include selling excess materials to existing manufacturers in the respective markets, diverting supply from other products, using multi-species inputs,

7 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf Please note that the fillet (yield) percentage measured in the laboratory and included in the report may not precisely reflect yields measured in the field. The Ontario Commercial Fisheries' Association estimates that Yellow Perch fillets represent between 23.2% and 40% of total weight in the field.

partnering with other fish processors to even out supply variability, or stockpiling unrefrigerated finished products. Storage is included in this analysis because demand data has not yet been collected and synthesized.

This analysis will aggregate and examine the supply of raw materials from two fish species – Walleye and Yellow Perch. This approach aligns with the Iceland Ocean Cluster's Multi-Species Report, which suggests three potential use cases involving waste materials from mixed species.[8]

The formula to calculate the estimated weekly quantity of components from all target species is:

$$W_{(x,i)} = \sum_{s=1}^{S} (L_s \times P_{(s,i)} \times C_{(s,x)})$$

Where:

is the weight of fish component *x* in week *i*

is the total number of fish species

is the estimated total landings for species *s*

is the proportion of landings for species *s* in week *i*

is the proportion of component *x* in species *s*

With this information, the following analysis will include two sections for each raw material of interest. The first section will briefly analyze the quantity and rhythms of waste material from multiple species by referring to a dual-axis plot. This dual-axis plot represents the combined weight of a component from multiple species on the left y-axis and the weekly proportion of the total yearly weight on the right y-axis.

The second section will calculate and analyze the storage requirements needed to negate the seasonality of the fish component. Consistent supply throughout the different seasons may be important for producing certain products, although strategies other than storage may be more feasible and cost-effective. If storage is the preferred approach, excess fish material would have to be stored whenever the supply of that material exceeds 1.92% of the annual total. The calculation for the required percentage of component X in storage was performed using the following IF statement: if this week's estimated proportion of total landings () exceeds 1.92%, add the excess amount (– 1.92%) to storage. If the proportion is less than 1.92%, withdraw from the storage reservoir to meet the 1.92% target (1.92% - This calculation assumes that downstream demand and processing capacity in diverse markets is steady. A more valid storage capacity calculation would consider demand patterns and ordering policies downstream in the supply chain, as they may fluctuate throughout the year. However, this estimate helps determine the storage capacity required to maintain the maximal yet consistent supply of fish waste throughout the year.

4.3.1 Fish Heads

Five descriptive statistics are particularly noteworthy when evaluating the distribution of multi-species fish discarded materials: maximum, minimum, 25th percentile, 75th percentile, and standard deviation. Refer to *Figure 9* for a visual of the distribution and *Table 3* for the detailed descriptive statistics of multi-species fish heads.

8 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf

Figure 9: Fish Heads – Estimated Weight of Heads per Week

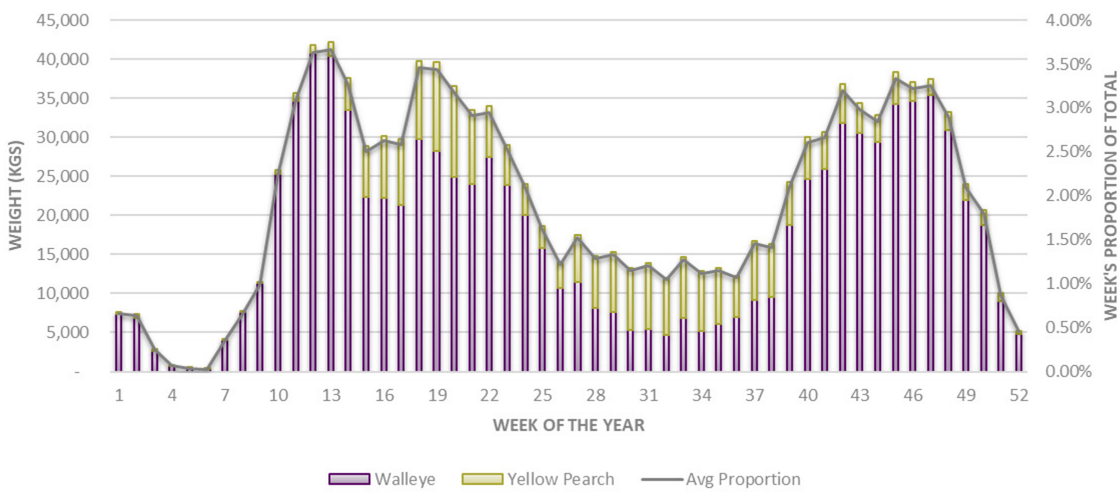


Table 3: Fish Heads – Descriptive Statistics of Species Weekly Distribution

Fish Species	Max			Min			25th Percentile		75th Percentile		Standard Deviation
Walleye	Week 12	4.42%	40821 kg	Week 6	0.03%	305 kg	0.75%	6,918 kg	3.00%	27,666 kg	1.27%
Yellow Perch	Week 20	5.09%	11585 kg	Week 6	0.00%	10 kg	0.46%	1,038 kg	3.17%	7,217 kg	1.45%
Multi-Species	**Week 13**	**3.66%**	**42179 kg**	**Week 6**	**0.03%**	**315 kg**	**1.11%**	**12,722 kg**	**2.92%**	**33,649 kg**	**1.09%**

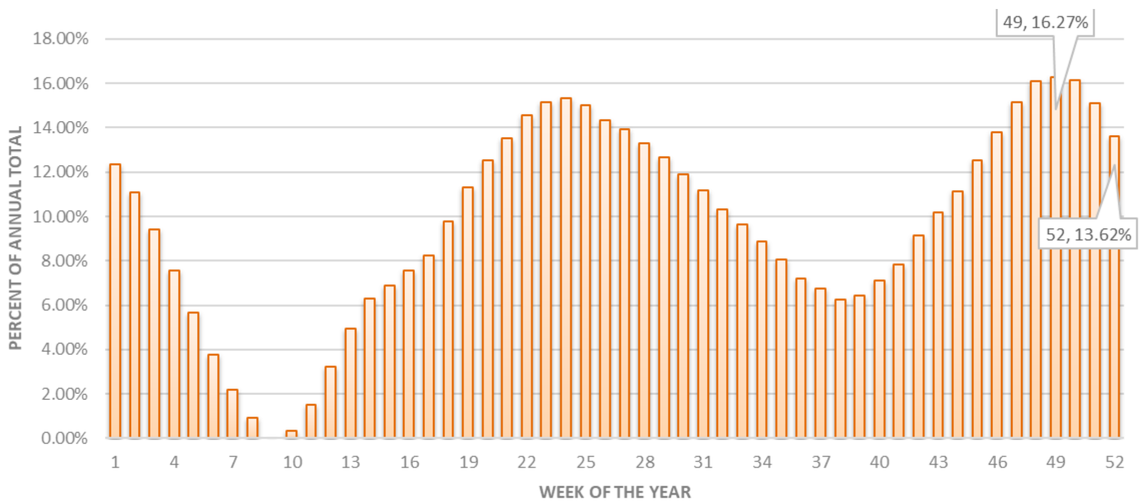
For multi-species fish heads, the maximum proportion of the week's supply relative to the annual total is 3.66%, while the minimum is 0.03%. The 25th percentile is 1.11%, indicating that 25% of the time, the weekly proportion of the annual total is at or below this value. The 75th percentile is 2.92%, showing that 75% of the time, the weekly proportion is at or below this value. The standard deviation is 1.09%, reflecting the variability in the weekly proportions throughout the year.

These statistics imply a moderate variability in the supply of multi-species fish waste. The relatively small maximum proportion and standard deviation compared to individual species like Walleye and Yellow Perch suggest that combining multiple species can smooth out extreme peaks in supply, leading to a more consistent distribution over the year. This reduction in volatility can be beneficial for processing plants, as it allows for more predictable and manageable storage requirements or greater flexibility to deploy alternative strategies. The higher 25th percentile compared to individual species also indicates that multi-species aggregation results in a more stable supply, minimizing periods of very low availability. This stability can ensure a more continuous operation and reduce the risk of supply shortages.

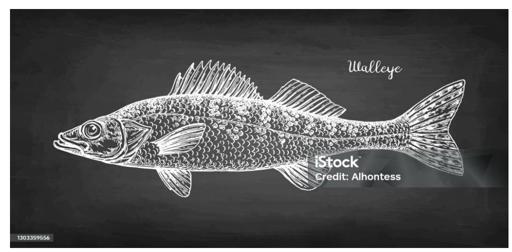
4.3.1.1 Negating Seasonality

To completely offset the seasonality of fish heads by using a storage strategy, processing plants in Southwestern Ontario would need a storage capacity that can hold 16.27% of the total fish heads processed in a year. Based on the five-year average landing quantities, this would require a combined storage capacity of 187,294 kgs (i.e., 1,151 tonnes of fish heads *16.27%=187 tonnes). This accumulation could either begin by storing 13.62% of the total quantity – 156,776 kgs – before the calendar year starts, or begin after week 9 when storage levels are expected to be at 0%. With this storage capacity, processing plants could maintain a consistent weekly supply of 22,137 kgs of fish heads. Refer to *Figure 10* for a summary of how this storage requirement is expected to change throughout the year.

Figure 10: Fish Heads – Estimated Percentage of Total in Storage Throughout the Year



4.3.2 Fish Scales



Five descriptive statistics are particularly noteworthy when evaluating the distribution of multi-species fish waste: maximum, minimum, 25th percentile, 75th percentile, and standard deviation. Refer to *Figure 11* for a visual of the distribution and *Table 4* for the detailed descriptive statistics of multi-species fish scales.

Figure 11: Fish Scales – Estimated Weight of Heads per Week

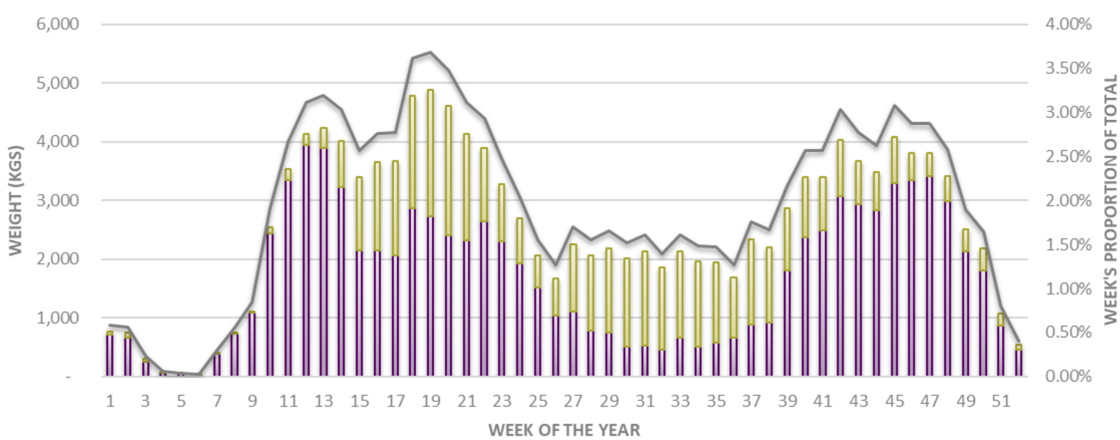


Table 4: Fish Heads – Descriptive Statistics of Species Weekly Distribution

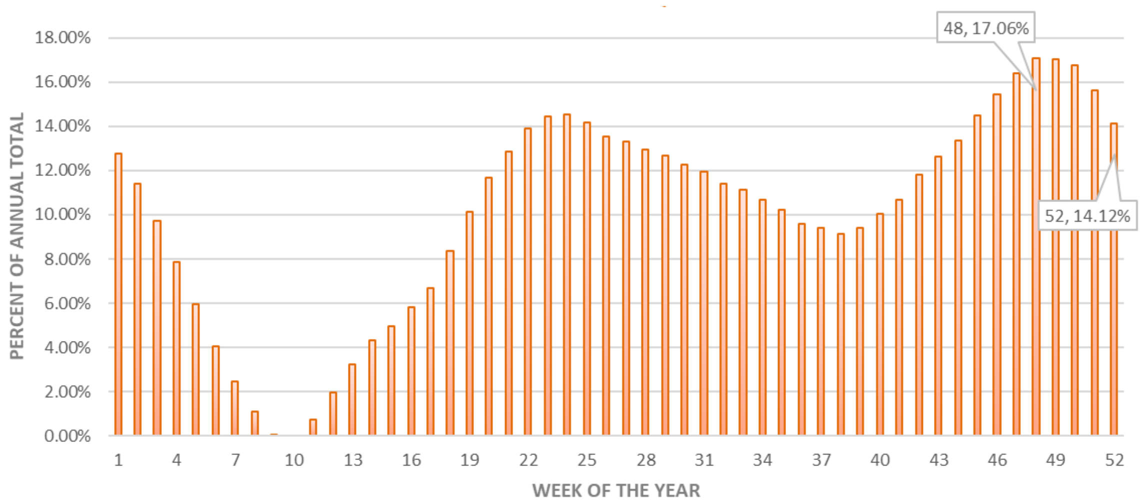
Fish Species	Max			Min			25th Percentile		75th Percentile		Standard Deviation
Walleye	Week 12	4.42%	3,940 kg	Week 6	0.03%	29 kg	0.75%	668 kg	3.00%	2,670 kg	1.27%
Yellow Perch	Week 20	5.09%	2,206 kg	Week 6	0.00%	2 kg	0.46%	198 kg	3.17%	1,374 kg	1.45%
Multi-Species	**Week 13**	**3.69%**	**4,884 kg**	**Week 6**	**0.02%**	**31 kg**	**1.37%**	**1,811 kg**	**2.77%**	**3,670 kg**	**1.02%**

For multi-species fish scales, the maximum proportion of the week's supply relative to the annual total is 3.69%, while the minimum is 0.02%. The 25th percentile is 1.37%, indicating that 25% of the time, the weekly proportion of the annual total is at or below this value. The 75th percentile is 2.77%, showing that 75% of the time, the weekly proportion is at or below this value. The standard deviation is 1.02%, reflecting the variability in the weekly proportions throughout the year.

4.3.2.1 Negating Seasonality

To completely offset the seasonality of fish scales by using a storage strategy, Southwestern Ontario processing plants would require a storage capacity that can hold 17.06% of the total fish scales processed in a year. Based on the five-year average landing quantities, the storage facilities would need a combined capacity of 22,602 kgs of fish scales. This storage accumulation could either be initiated by storing 14.12% of the total quantity – 18,706 kgs – before the calendar year begins or could start after week 10 when storage is expected to be 0%. With this storage capacity, processing plants could maintain a consistent weekly supply of 2,547 kgs of fish scales. Refer to *Figure 12* for a summary of how this storage requirement is expected to change throughout the year.

Figure 12: Fish Scales – Estimated Percentage of Total in Storage Throughout the Year



4.3.3 Mixed Species Total Quantity

Table 5 presents the total quantity of material derived from Walleye and Yellow Perch, with each component expressed as a percentage of the total fish mass and its corresponding estimated quantity in kgs. These estimates provide a quick overview of the supply available from each fish component, which can be instrumental in assessing the economic viability of repurposing this material or in estimating the costs associated with its disposal.

Table 5: Mixed Species – Total Quantity of Material

Total Raw Material		
Body part	**Average proportion of fish (%)**	**Estimated Quantity (kg) ***
Fillet	28.51%	1,669,939
Skin	5.74%	336,059
Scales	2.29%	133,885
Head	19.65%	1,151,033
Viscera	6.80%	398,377
Liver	2.62%	153,272
Roe**	13.04%	764,146
Swim bladder	0.77%	45,195
Bones (cleaned)***	2.44%	143,224
Rest raw materials****	18.14%	1,062,906
Total	**100%**	**5,858,035**

* Estimated quantity using the sum of the five-year average of yearly landings for Walleye and Yellow Perch.

** The proportion of roe changes depending on the season. The roe's weight and proportion of fish are largest before spawning season.

***Bones were cleaned by sealing them in a vacuum bag and heating them in a 45°C water bath for 3 hours. They were weighed before and after this process, and the difference was plugged into the rest raw materials

****Anything that was left behind after these parts were successfully separated and the difference from bone boiling

5. CURRENT WASTE MANAGEMENT

Understanding the current management of fish waste is crucial for enhancing sustainability within the industry. This section delves into the typical by-products from fish processing practices, examining how these by-products are either disposed of or repurposed. A closer look at these material streams provides valuable insights into current practices and potential areas for improvement.

Building on the earlier discussion of raw material supply, this section transitions into a detailed examination of waste management strategies, shedding light on how the raw material is generated and collected. This section is structured to explore two primary categories: fish scales and fish offal (fish head, bones, organs, and residual tissue). The operational processes involved in managing these materials will be analyzed for each category alongside the economic considerations that influence these practices.

5.1 Fish Scales

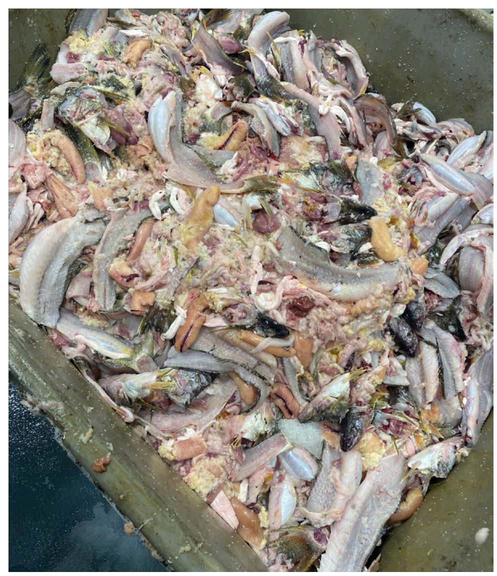
The first category of waste collected in fish processing plants consists of fish scales. These small, rigid plates cover the skin of most fish, providing essential protection and aiding in movement through water. The number and thickness of scales can vary significantly between species, influenced by evolutionary adaptation, habitat, and lifestyle.[9]

Rich in collagen, an essential structural protein, fish scales contribute to the integrity and strength of various tissues.[10] This high collagen content has made fish scales valuable in producing gelatin, cosmetics, and nutritional supplements. In addition to collagen, fish scales contain minerals like calcium and phosphorus.[11]

In Southern Ontario's fish processing plants, scales are generally removed using a fish descaler before the fish is sent to be filleted. A fish descaler is a machine designed to efficiently remove scales, typically featuring a rotating drum or abrasive rollers with rough surfaces that scrub the scales off as the fish passes through. Some descalers also use water jets or brushes to aid in the removal process. Industrial descalers often have adjustable settings to accommodate different species and sizes of fish, ensuring the scales are removed without damaging the skin. These machines significantly reduce the time and effort required compared to manual descaling, making them essential in the fishing industry.

The removed scales are typically collected in half-sized totes placed below the descaler. Due to water jets, the collected scales are saturated with moisture, which can pose challenges in handling and further processing. Processing plants in Southern Ontario incur transportation and dumping fees to remove this biomass from their facilities and dispose of it in landfills.

5.2 Fish Offal



The second category of waste collected in fish processing plants is the remaining biomass after the filleting process. This waste includes the fish head, bones, organs, and residual tissue. This by-product, often called fish offal, is rich in valuable components, including minerals, fats, and amino acids.[12]

Fish heads contain significant amounts of collagen, which, like the scales, is useful in producing gelatin and other collagen-based products.[13] The bones are a rich source of calcium and phosphorus. Depending on the species, the organs can contain high levels of omega-3 fatty acids and other beneficial fats, making them valuable for processing into fish oil or other nutritional products.

9 "Evolutionary patterns of scale morphology in damselfishes." Biological Journal of the Linnean Society 135, no. 1 (December 2021): 138-153. https://academic.oup.com/biolinnean/article/135/1/138/6448071.

10 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf

11 Ibid

12 Ibid

13 Ibid

In Southern Ontario's fish processing plants, the fish offal is generally collected in large totes after filleting. Processing plants use different strategies to discard this waste in the most operationally efficient and food-safe manner, ensuring they abide by their Hazard Analysis and Critical Control Points (HACCP) standards.

Fish processing facilities frequently direct this biomass to mink farms, where it serves as animal feed. This practice contributes to waste management efforts and enhances value by repurposing material that would otherwise be discarded. However, due to a decline in demand for mink fur, processing plants that were previously compensated for this material now often incur costs to have mink farms collect it.

Mink farms are responsible for ensuring the contents in the totes remain safe for mink consumption. The totes of fish waste are collected daily and cleaned every four days during the winter months or every two days during the warmer months. The mink farms use a mixture of bleach and water to disinfect the totes.[14]

6. POTENTIAL USE CASES

The potential use cases for repurposing fish waste are crucial for illustrating the immediate and long-term opportunities within the fish industry for upcycling discarded materials. This section serves as an example of what is possible with minimal effort in the short term, alongside innovative approaches that could be associated with higher economic rewards in the long term. It is structured into two parts: the first highlights established models that offer practical, short-term upcycling solutions, while the second focuses on transformational models that emphasize long-term innovation.

6.1 Established Upcycling Models

Established models refer to markets and supply chains near the Great Lakes that provide existing outlets for repurposing fish waste without requiring vertical integration by fish processing plants. These models operate within the current industry framework, offering straightforward and immediate use. Understanding established models for repurposing fish waste is crucial, as they provide practical short-term solutions. Analyzing these models helps identify ways to gain support from industry stakeholders, attract investors, and establish a foundation for future innovations. This section of the report will examine four key areas where fish material is being repurposed: mink feed, pet food manufacturing, natural fertilizer, and composting.

6.1.1 Mink Feed

American minks remain the most significant animal in the fur farming industry, both in terms of the number of pelts produced and the monetary value of their fur.[15] Mink fur is commonly used to create full-length coats, shorter jackets, and other outerwear, often regarded as symbols of luxury. In July 2024, the average price for a mink fur coat was around USD $5,000.[16] As carnivores, their diet primarily consists of animal-based protein. Approximately 70-80% of their feed is derived from wasted fish and poultry from processing plants as well as the offal from slaughterhouses. This feed is prepared in a paste format at mink farms and laid on the cages. The formula and quantity

14 "Visit a mink farm in Nova Scotia," YouTube video, posted by "Truth about Fur," December 3, 2012, https://www.youtube.com/watch?v=wbb9agOX-Gt8&list=PL4SjZ4Wvr8Zk4snvxz371rr-Xm4T22Wsm

15 Fur Institute of Canada, "Mink Farming," accessed September 6, 2024, https://fur.ca/fur-farming/mink-farming/

16 Fur Industry Statistics," accessed September 6, 2024, https://worldmetrics.org/fur-industry-statistics/

are adjusted throughout the year to meet the varying nutritional needs of pregnant minks and to achieve the desired target weight of the animals.

Despite their critical role in the fur industry, the number of mink farms in the United States has rapidly declined. According to the Department of Agriculture, the country was home to 236 mink fur farms in 2017.[17] By 2022, this number had dwindled to just 110. This steep decline reflects broader challenges within the industry, including economic pressures and shifting market dynamics. A similar decline has been observed in Canada, with an estimated 63 mink farms remaining in 2020, down from the industry's peak of 242 in 2011.[18] Consequently, the Ontario market has experienced a sharp decline in recent years, with an estimated market size of USD $6.40 billion in 2020 compared to USD $43.99 billion in 2013.[19] [20] [21]

Mink farms typically incur costs for transporting food discards from processing plants or slaughterhouses, but they do not pay the offal suppliers. Mink farms will remove the feed material at no charge, which mutually benefits suppliers who avoid costly disposal fees at landfills. Sometimes, mink farms will even charge a removal fee.

The decline in mink farming thus presents a significant challenge to fish processing plants. Mink farms, which have long been a viable option for offal disposal, are struggling to maintain profitability. According to the National Agricultural Statistics Service's Mink Report released in 2020, the average price per pelt was USD $33.70. [22] While this was an improvement from the previous year's average of USD $21.30, it still fell short of the breakeven cost of USD $35. The report highlights that 2020 marked the fifth time in the past six years that average pelt prices had remained below the breakeven point. This persistent inability to achieve profitable returns has led to a decline in mink farms, which, in turn, threatens fish processing plants' ability to repurpose their materials effectively.

6.1.2 Pet Food

Pet food is a commercially prepared product designed to meet the nutritional needs of domesticated animals. These foods incorporate various ingredients, such as meat, fish, grains, and vegetables into their formulas. Fish is a common ingredient in pet food, valued for its high protein content and rich supply of omega-3 fatty acids. These fatty acids are beneficial for maintaining healthy skin, coat, and overall health in pets.[23] Pet food companies can either buy pre-made fish meal or process fresh fish by grinding and drying it with other ingredients. This decision is influenced by the company's product positioning, labelling practices, and the quality they wish to offer. Fresh fish ingredients are typically found in premium pet food brands and formulas.

There are various formats of manufactured pet food, including wet food, dry food, and complementary treats. The format chosen often depends on the pet's dietary needs and the owner's preferences. Wet food, with high moisture content, supports

17 United States Department of Agriculture, "Quick Stats," accessed September 6, 2024, https://quickstats.nass.usda.gov/results/D966A425-53CC-3072-BA48-2A3C901447AA

18 Agriculture and Agri-Food Canada. "Mink Statistical Briefer." Accessed September 13, 2024. https://agriculture.canada.ca/en/sector/animal-industry/red-meat-and-livestock-market-information/mink-statistical-briefer

19 Ibid

20 Canadian Dollar to US Dollar Spot Exchange Rates for 2020." Exchange Rates UK. Accessed September 13, 2024. https://www.exchangerates.org.uk/CAD-USD-spot-exchange-rates-history-2020.html.

21 "Canadian Dollar to US Dollar Spot Exchange Rates for 2013." Exchange Rates UK. Accessed September 13, 2024. https://www.exchangerates.org.uk/CAD-USD-spot-exchange-rates-history-2013.html

22 Jim Keen, Mink Farming and SARS-CoV-2, March 2022, https://pgn.0f9.myftpupload.com/wp-content/uploads/2022/03/Mink-Farming-SARS-CoV-2-by-Jim-Keen-DVM-PhD.pdf

23 QRILL Pet, "Why Dogs Need Omega-3 Supplements," accessed September 6, 2024, https://www.qrillpet.com/blog-and-news/why-dogs-need-omega-3-supplements

hydration and appeals to picky eaters or animals unable to consume dry food. Dry food, known for its convenience and dental benefits, offers a longer shelf life and is easier to store.[24] Additionally, many pet food manufacturers, such as Canada's Orijen, emphasize using whole fish as a fresh ingredient. This approach presents a promising alternative use for fish byproducts, particularly if the seasonality of byproducts can be effectively managed.

Pet food manufacturing formulas differ widely between companies. Even at a company level, many brands offer a range of products, each using unique recipes. Due to this variability, determining a specific conversion rate for the weight of fish required to produce one ton of pet food is challenging. Additionally, the prices companies are willing to pay for fish ingredients depend on numerous factors, including the product's quantity, quality, and safety. Future research efforts should obtain quotes from pet food manufacturers for a better assessment of the economic feasibility of further using fish discards as a source of raw material. For a price estimate in this report, Orijen, a premium dog food brand that uses whole fish as an ingredient, is used as a reference. As of August 2024, Orijen's Original Dry Dog Food retails for USD $105.99 per 10.6 kgs on Amazon, equating to USD $2,270 per metric ton.[25] Moreover, the global pet food market was valued at approximately USD $103.3 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 4.4% from 2024 to 2030.[26] In 2023, Canada generated USD $3.738 billion in revenue in the pet food market worldwide.[27] Ontario was home to 135 of Canada's 421 animal food manufacturing establishments.[28]

Entering the pet food industry as a supplier of fresh fish presents several barriers, particularly in meeting stringent regulatory and safety standards. The United States, the largest export market for Canadian pet food companies, requires suppliers to adhere to the FDA's regulations to ensure the safety and quality of animal food. Although pet food does not require FDA pre-market review unless it contains a food additive, it must comply with the Federal Food, Drug, and Cosmetic Act (FD&C Act).[29] This includes ensuring the fish is safe to eat, produced under sanitary conditions, free from harmful substances, and accurately labelled.[30] Pet food manufacturers are also responsible for carefully selecting their suppliers and may be subject to inspections to ensure compliance with U.S. and Canadian regulatory standards. Despite these regulations, many pet food manufacturers have already started incorporating Great Lakes fish offal into their formulas. For example, U.S. pet food manufacturers incorporate fish and fish offal collected from fish weirs and recreational fish cleaning stations into their formulas.

6.1.3 Natural Fertilizer

Fertilizers are materials, either natural or synthetic, applied to soil or plants to provide essential nutrients that enhance plant growth and productivity. Chemical fertilizers, often produced using refined petroleum, are rich in macronutrients like nitrogen, phosphorus, and potassium. These fertilizers offer an immediate source of nutrition to plants, with standardized labelling indicating nutrient ratios and chemical sources.[31] In contrast, organic fertilizers contribute to soil health by increasing organic matter, improving soil structure, enhancing water retention, and reducing erosion. These natural fertilizers release nutrients slowly and consistently, making them environmentally friendly.[32]

24 Dr. Jennifer Coates, "Dry Food and Dental Disease in Dogs," PetMD, August 1, 2014, https://www.petmd.com/blogs/nutritionnuggets/dr-coates/2014/august/dry-food-and-dental-disease-dogs-31920

25 Amazon.com, "ORIJEN Original Dry Dog Food, Grain Free Dog Food for All Life Stages, Fresh or Raw Ingredients, 23.5 lb," accessed September 6, 2024, https://www.amazon.com/ORIJEN-Original-Biologically-Appropriate-Grain/dp/B01I3JW7PK.

26 Grand View Research, "Pet Food Industry," accessed September 6, 2024, https://www.grandviewresearch.com/industry-analysis/pet-food-industry.

27 "Revenue of the Pet Food Market Worldwide by Country." Statista. Accessed September 13, 2024. https://www-statista-com.proxy1.lib.uwo.ca/statistics/758605/revenue-of-the-pet-food-market-worldwide-by-country/

28 "Animal Food Manufacturers by Region Canada 2022." Statista. Accessed September 13, 2024. https://www-statista-com.ezproxy.canberra.edu.au/statistics/457622/number-of-animal-food-manufacturing-establishments-by-region-canada/

29 U.S. Food and Drug Administration, "Pet Food," accessed September 6, 2024, https://www.fda.gov/animal-veterinary/animal-food-feeds/pet-food.

30 Ibid

31 Green Sphere Lawn, "The Pros & Cons of Organic vs. Chemical Fertilizers," accessed September 6, 2024, https://greenspherelawn.com/blog/the-pros-cons-of-organic-vs-chemical-fertilizers.

32 Ibid

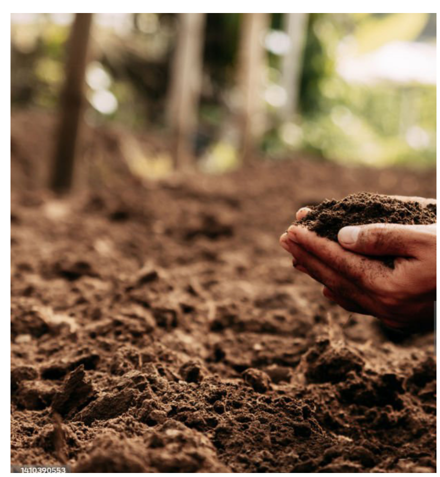
Beyond these differences, environmental concerns, preference for organic and "green" fertilizers, convenience of application, and product availability are all factors the end consumer considers when choosing between synthetic or natural fertilizers. Hence, distinct demand patterns and pricing schemes separate the two alternatives. The following analysis will focus on natural fertilizers.

Natural fertilizer is used in various practices. In agriculture, natural fertilizers are essential for boosting crop yields and ensuring the soil has adequate nutrients for large-scale food production. In residential and commercial gardening, natural fertilizers help maintain healthy plants, flowers, and lawns. Natural fertilizers are also used in landscaping to promote the health of trees, shrubs, and ornamental plants in parks, golf courses, and public spaces.

Liquid fish hydrolysate is a natural fertilizer made from fish. Manufacturers can produce these organic fertilizers by using fish offal from processing plants as the nitrogen-rich material. To produce one gallon (3.79 litres) of liquid fish fertilizer, approximately 10 lbs (4.54 kg) of offal is required. The average price per gallon of this fertilizer is USD $5.10. Assuming a similar density to water, this equates to USD $1,347 per metric ton. Moreover, the global organic fertilizer market was valued at approximately USD $11.6 billion in 2023 and is projected to grow at a CAGR of 5.9% from 2024 to 2030.[33]

Entering the natural fertilizer market with fish-based products presents significant challenges due to the need for consistency and accuracy in the final product. Achieving this requires extensive scientific knowledge, experience, and operational expertise, as fertilizers must consistently deliver the promised nutrient content. One of the key challenges for manufacturers is the variability in fish landings, as different species with varying anatomical compositions arrive at different times, making it difficult to maintain uniform standards. To mitigate these complexities, fish processing plants might consider supplying their by-products to existing fertilizer manufacturers. This approach can simplify operations, but it's important to note that different manufacturers have varying standards. For instance, some manufacturers may require material to be refrigerated until collection, while others may be equipped to pick up fresh material directly. Additionally, these manufacturers may face capacity constraints and reject some supply during peak fishing season.

6.1.4 Composting



Composting is the process of breaking down organic materials, such as plant and animal waste, to create a nutrient-rich substance that enhances soil quality. Compost acts as a powerful inoculum due to its high concentration of beneficial microbes, which kickstart microbial activity in the soil. This microbial activity is crucial as it helps decompose organic matter, converting it into nutrients that plants can readily absorb.

Compost has diverse applications. In agriculture, it enriches soil for crops, supporting robust plant growth and reducing dependence on synthetic fertilizers. In horticulture, compost promotes the healthy growth of flowers, shrubs, and trees, leading to more vibrant gardens. It is also used in erosion control and land reclamation, aiding in restoring degraded soils.

33 Grand View Research. "Organic Fertilizers Market Size, Share & Trends Analysis Report By Source (Plant, Animal, Mineral), By Form (Dry, Liquid), By Application (Cereals & Grains, Oilseeds & Pulses, Fruits & Vegetables), By Region, And Segment Forecasts, 2023 - 2030." Accessed September 11, 2024. https://www.grandviewresearch.com/industry-analysis/organic-fertilizers-market-report.

Composting involves mixing carbon-rich and nitrogen-rich materials and allowing them to decay. For fish waste composting, fish waste provides the nitrogen, while materials like wood chips, sawdust, and leaves supply the carbon. With a carbon-to-nitrogen ratio averaging four, the ideal mix combines one part of fish waste with approximately four parts of carbon-rich material.[34] Fish waste is highly desirable for composting due to its high nitrogen content, but it can also pose challenges because of its odour. Therefore, the delivery to the composting facility and the composting process must be managed carefully to minimize any potential nuisances.

Many fish processors are already active in the composting market, applying compost to farms under their ownership, supplying to other farms, or producing compost for sale. However, if they are not already in it, processing plants have several options for entering the composting market. In the business-to-business sector, they could partner with agricultural companies or farms. They can also sell to various commercial clients, such as landscaping firms and nurseries. This type of relationship may involve bulk pricing and purchasing, translating to a lower selling price per unit than selling the product directly to end consumers. For the business-to-consumer market, fisheries can target home gardeners, highlighting the sustainability of fish compost to attract eco-conscious customers. Additionally, savvy customers who may prefer fish compost based on its biochemical properties and performance may be interested in this product. Alternatively, fisheries could sell fish waste to existing compost companies or, as previously mentioned, to agricultural companies, farms, landscaping firms, or nurseries that compost themselves. This would enable processing plants to maintain current operations with minimal adjustments, which is beneficial for short-term actualization. Moreover, the global compost market, valued at approximately USD $5.975 billion in 2023, is projected to grow at a CAGR of 3.9% from 2024 to 2032.[35] The bulk retail price of fish compost is USD $548.62 per metric ton.[36]

6.2 Transformational Upcycling Models

Understanding transformational models for repurposing fish waste is essential, as it underscores the potential for innovation within the fish industry. Adopting a long-term perspective on the economic and environmental value that can be generated through such innovations serves as a compelling strategy to attract research funding and early investment. The following section examines four economically promising approaches to utilizing fish waste: the production of fish meal, fish oil, gelatin, and fish protein hydrolysates.

6.2.1 Fish Meal

Fish meal is a high-protein feed ingredient derived from processing fish and fish waste. The production of fish meal involves several stages, starting with chopping and heating the raw fish material to break down the tissue and remove some water.[37] The dried and heated material is then strained and pressed to remove liquids, including oil, leaving a powder. The final meal product typically contains a protein concentration ranging from 60% to 72%, making it an excellent source of protein for various applications.[38]

Fish meal is primarily used in animal feed, particularly aquaculture, livestock, and pet food. Its high protein content and essential amino acids make it a valuable ingredient for enhancing the nutritional quality of feed, promoting growth, and improving feed efficiency. In aquaculture, fish meal is crucial for the diet of farmed fish, providing nutri-

34 North Country Organics, “Carbon to Nitrogen Ratios of Various Waste Materials,” accessed September 6, 2024, https://norganics.com/wordpress/wp-content/uploads/2014/10/cnratio.pdf.

35 Business Research Insights, “Compost Market Report,” accessed September 6, 2024, https://www.businessresearchinsights.com/market-reports/compost-market-101514.

36 Black Swallow Living Soils, “Fish Compost,” accessed September 6, 2024, https://blackswallowsoil.com.

37 European Fishmeal and Fish Oil Producers, “Fishmeal and Fish Oil Report,” accessed September 6, 2024, https://effop.org/wp-content/uploads/2019/06/EUMOFA-Monthly-Highlights-April-2019-Fishmeal-and-Fish-Oil.pdf.

38 R. D. Miles and F. A. Chapman, “The Benefits of Fishmeal in Aquaculture Diets,” EDIS, University of Florida IFAS Extension, accessed September 6, 2024, https://edis.ifas.ufl.edu/publication/FA122.

ents that are otherwise difficult to obtain in captivity. In addition to its use in animal feed and pet food, fish meal can also be applied as a fertilizer due to its rich nitrogen and phosphorus content, which supports plant growth.[39]

The production of fish meal is reasonably efficient, with approximately 21 kgs of fish meal produced from every 100 kgs of fish material processed.[40] The economic value of fish meal is influenced by its protein content and overall quality. High-quality fish meal, with higher protein levels and lower impurities, commands higher market prices. According to IndexMundi, the price of fish meal in April 2024 was USD $ 1,702 per metric ton.[41] Moreover, the global fishmeal market was valued at approximately USD $9.50 billion in 2023 and is expected to grow at a CAGR of 7.3% from 2024 to 2030.[42]

A potential barrier to entering the fishmeal production market is that the initial costs may be substantial for those who grind and sell fishmeal independently. The equipment required in a fishmeal processing plant demands significant upfront investment. However, some companies provide a range of equipment, with machines capable of processing between 10 and 400 metric tons of raw material daily.[43] Alternatively, entering the market as a supplier of raw materials to existing fishmeal plants is an option that requires less capital. Doing so requires adequate transportation and logistics. Adherence to quality control standards may also be needed depending on the fishmeal plant's requirements. This would demand consistent monitoring and testing of the product to maintain the necessary concentrations of protein, moisture, and other essential parameters. Other fishmeal plants, particularly for the pet food market, would not necessarily involve these complexities.

6.2.1 Fish Oil

Fish oil is a valuable by-product obtained from processing fish or fish waste. Various methods are used to extract the oil, including wet rendering, dry rendering, solvent extraction, and ultrasound-assisted extraction.[44] The choice of extraction method depends on the desired quality and the capabilities of the processing facility. Wet rendering is the most widely used method for large-scale production, typically involving four key steps: heating, pressing, decanting, and centrifugation.[45] The resulting fish oil is rich in omega-3 fatty acids, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These fatty acids are essential nutrients known for their numerous health benefits, including supporting cardiovascular health, reducing inflammation, and promoting brain function.[46]

The applications of fish oil are diverse. In the dietary supplement industry, fish oil is a popular ingredient due to its high omega-3 content, which is beneficial for maintaining overall health and preventing various chronic diseases. It

39 Foodcom S.A., "Fish Meal: How to Use Organic Fertilizer," accessed September 6, 2024, https://foodcom.pl/en/fish-meal-how-to-use-organic-fertilizer/

40 European Market Observatory for Fisheries and Aquaculture Products, "EUMOFA Report 2023," page 3, accessed September 6, 2024, https://effop.org/wp-content/uploads/2023/10/EUMOFA-Report-2023.pdf

41 IndexMundi. "Fish Meal." Accessed September 9, 2024. https://www.indexmundi.com/commodities/?commodity=fish-meal

42 Grand View Research, "Fishmeal Market Report," accessed September 6, 2024, https://www.grandviewresearch.com/industry-analysis/fish-meal-market-report.

43 HPP Solutions, "HPP Solutions on Land," accessed September 6, 2024, https://proteinplant.is/hpp-solutions-on-land/

44 M. Nagaraju, Susan Vaska, Arun H. S., Manoj D., Umesh Chimmalagi, Jeevitha D., Vinay T. V., and Pavankumar Muralakar. "Trends in Production and Processing of Fish Oil." European Chemical Bulletin 12 (2023): 1705-1725. https://doi.org/10.48047/ecb/2023.12.si5a.049

45 Ibid

46 MedPark Hospital, "Omega 3 - Health Benefits of Nutrition," accessed September 6, 2024, https://www.medparkhospital.com/en-US/lifestyles/omega-3-health-benefits-of-nutrition.

is also widely used in animal feed, particularly aquaculture, where it helps enhance farmed fish's nutritional profile.[47] The high concentration of essential fatty acids in fish oil makes it a crucial component in the diets of both humans and animals. Additionally, fish oil has applications in the pharmaceutical industry, where it is utilized for its potential therapeutic properties, particularly in managing inflammatory conditions.[48]

The yield of fish oil from fish waste is typically around two to six kgs per 100 kgs of raw material processed.[49] The value of fish oil on the market is influenced by factors such as quality, purity, and the concentration of beneficial fatty acids. According to the European Market Observatory of Fisheries and Aquaculture Products (EUMOFA), the price of fish oil soared from January 2009 to May 2023, growing 477% to USD $4,298 per metric ton.[50] [51] Other sources, such as the Iceland Ocean Cluster, quote fish oil at a much lower price of USD $1,600 per ton in October 2023.[52] It's important to distinguish whether the oil is intended for animal feed or human consumption, as the price will vary accordingly. Regardless, these products are integral to various industries, underlining the economic importance of fish oil as a valuable resource derived from fish processing. Moreover, the global fish oil market was valued at approximately USD $3.08 billion in 2023 and is expected to grow at a CAGR of 4.6% from 2024 to 2030.[53]

The potential barriers to entering the fish oil industry are similar to those in the fishmeal sector. Entrance into the market to produce fish oil requires a high initial investment in specialized equipment, and partnering with existing producers may demand strict adherence to quality control standards to meet industry specifications, depending on the end market for the oil.

6.2.2 Gelatin

Gelatin is a translucent, colourless, and flavourless food ingredient derived from collagen. This collagen is extracted from animal connective tissues, including bones, skin, and scales. The production process involves the partial hydrolysis of collagen, resulting in a substance that can gel, thicken, stabilize, and clarify various materials.[54] Gelatin is widely used in culinary practices, particularly for solidifying jellies, making desserts, and stabilizing dairy products. It is also a key ingredient in the pharmaceutical industry, used to produce pill capsules and as a plasma expander. In cosmetics, gelatin is valued for its benefits to skin and hair. Industrial applications of gelatin include its use in the production of matches, sandpaper, glues, and specialized paper.

Research conducted by the Iceland Ocean Cluster has demonstrated that gelatin can be efficiently extracted from fish scales, such as those from Walleye. The gelatin yield from Walleye scales is reported to be up to 6.4%, making it a valuable source of this versatile ingredient.[55] The quality of gelatin was assessed through various measures, including Bloom Strength and Judd's Whiteness test. The bloom strength, which indicates the firmness of the gel,

47 Veterinaria Digital, "The Use of Fish Oil in Animal Feed," accessed September 6, 2024, https://www.veterinariadigital.com/en/articulos/the-use-of-fish-oil-in-animal-feed/.

48 MedPark Hospital, "Omega 3 - Health Benefits of Nutrition," accessed September 6, 2024, https://www.medparkhospital.com/en-US/lifestyles/omega-3-health-benefits-of-nutrition.

49 European Market Observatory for Fisheries and Aquaculture Products, "EUMOFA Report 2023," page 3, accessed September 6, 2024, https://effop.org/wp-content/uploads/2023/10/EUMOFA-Report-2023.pdf

50 European Market Observatory for Fisheries and Aquaculture Products, "EUMOFA Report 2023," page 6, accessed September 6, 2024, https://effop.org/wp-content/uploads/2023/10/EUMOFA-Report-2023.pdf.

51 Exchange Rates, "EUR to USD Exchange Rate History for May 17, 2023," accessed September 6, 2024, https://www.exchange-rates.org/exchange-rate-history/eur-usd-2023-05-17.

52 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf.

53 Grand View Research, "Fish Oil Market Report," accessed September 6, 2024, https://www.grandviewresearch.com/industry-analysis/fish-oil-market.

54 Rousselot, "From Manufacturing to Avant-Garde Cuisine: The Many Uses of Gelatin," accessed September 6, 2024, https://www.rousselot.com/functional/media/blog/from-manufacturing-to-avant-garde-cuisine-the-many-uses-of-gelatin.

55 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf.

was found to be 46.7 grams, while the Judd's Whiteness score, which measures the colour quality, was 68.8. These metrics are crucial for determining the suitability of gelatin for various applications. Generally, higher values indicate better quality and a higher potential selling price for the gelatin.[56] Gelatines with low bloom strength are suitable only for softer textured products and are intended for storage at cold temperatures (below 15°C).[57]

The market price of gelatin, particularly from sources like Walleye scales, is estimated to be around USD $67.58 per pound, equating to USD $148,988.22 per metric ton.[58] [59] Moreover, the global gelatin market was valued at approximately USD $6.51 billion in 2023 and is expected to grow at a CAGR of 10.1% from 2024 to 2030.[60]

Entering the gelatin production industry using fish scales involves significant barriers, primarily due to the need for consistent quality. Ensuring this consistency is challenging if processing scales from multiple fish species, as each has varying collagen content, which affects gelatin properties such as bloom strength. The seasonality of fish landings could further complicate production, potentially involving a substantial cost if storage is the solution used to maintain a steady supply of high-collagen scales throughout the year. These factors and the need for specialized equipment make it difficult for new producers to meet the stringent quality standards required to compete in the high-quality gelatin market. Regardless, there are potentially good opportunities for Great Lakes fish processors to sell fish scales to gelatin producers, particularly as scales are already removed during production and separated from other materials.

6.2.2. Fish Protein Hydrolysates

Fish Protein Hydrolysates (FPH) are derived from the enzymatic or chemical breakdown of fish proteins into smaller peptides and free amino acids. This process enhances the functional and nutritional properties of the proteins, making them highly valuable in various industrial applications. Hydrolysis improves the solubility, digestibility, and bioavailability of the proteins, allowing them to be used effectively in food products.[61] FPH is utilized as a milk substitute, protein supplement, and stabilizer in various food formulations. It also serves as a flavour enhancer, contributing to food products' water-holding, gelling, foaming, textural, whipping, and emulsification properties.[62] These functional attributes make FPH a versatile ingredient in the food industry. Additionally, it can be used in fertilizers.

The production of FPH involves extracting the protein from fish material, followed by hydrolysis to break down the proteins into smaller components. The yield of FPH in its wet form is approximately 8.81%.[63] This reduces significantly after drying, resulting in a final dry yield of around 1.32% of the original raw material weight.[64] The protein concentration in FPH typically ranges from 81% to 93%, depending on the degree of hydrolysis and the source material used.[65] This high protein content makes FPH particularly valuable in nutritional supplements and other high-protein products.

The market value of FPH varies depending on the application and protein concentration. When marketed as a nutritional supplement, FPH can retail for approximately USD $230.27 per kg, equating to USD $230,272.56 per metric

56 Custom Collagen, "Gelatin Bloom Strength - Understanding the Types and Uses," accessed September 6, 2024, https://customcollagen.com/gelatin-bloom-strength-types-and-uses/.
57 Dargentolle, Cécile, and Jónas Viðarsson, Cisco (Coregonus Artedi) Full Utilization: Great Lakes Cisco 2024 Report. Matís, 2024. https://gsgp.org/media/ypvh1pvo/matis-great-lakes-cisco-2024-report.pdf
58 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf.
59 Currency conversion based on an exchange rate of 1 CAD = 0.74 USD, as of August 2024
60 Grand View Research, "Gelatin Market Analysis," accessed September 6, 2024, https://www.grandviewresearch.com/industry-analysis/gelatin-market-analysis.
61 PubMed, "The Benefits of Fishmeal in Aquaculture Diets," accessed September 6, 2024, https://pubmed.ncbi.nlm.nih.gov/19474134/.
62 Maqsood, Muhammad, and Benjakul, Soottawat. "Production, Bioactive Properties and Potential of Fish Protein Hydrolysates: A Review." International Aquatic Research 10, no. 3 (2018): 207-223. https://doi.org/10.1007/s40071-018-0207-4.
63 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf
64 Ibid
65 ScienceDirect, "Measurement of azimuthal anisotropy of muons from charm and bottom hadron decays," accessed September 6, 2024, https://www.sciencedirect.com/science/article/pii/S0308814624012093

ton, reflecting the high protein content and its benefits in health and wellness products.[66] [67] In bulk form, where FPH is used for industrial purposes such as fertilizer, the retail value is significantly lower, estimated at around USD $17.95 per kg, equating to USD $17,945.85 per metric ton.[68] The pricing differences highlight the diverse uses and market segments for FPH, from high-value nutritional supplements to more cost-effective bulk applications. Moreover, the global FPH market was valued at approximately USD $317.20 million in 2023 and is expected to grow at a CAGR of 3.3% from 2024 to 2034.[69]

The barriers to entering the market to produce FPH involve technical and market-related challenges. High-quality FPH requires careful management of the hydrolysis process because even small changes can drastically affect the final product.[70] Furthermore, the predominance of the market in Europe introduces additional complexity, as producers must ensure compliance with European regulations and standards. Building an efficient distribution network to connect production facilities with European clients can also be costly and logistically challenging. Regardless, Great Lakes fish processors could potentially sell raw materials in bulk to FPH producers or create small-scale or boutique products using lower-cost production processes. Lab-scale production from Walleye heads and frames has already been completed, and European food processors have expressed initial interest.[71]

7. CONCLUSION

Although the current profitability of repurposing fish waste material may seem limited, often providing little more than cost coverage, there are good existing opportunities, and the landscape will likely change even with modest development. Today's challenge is that many of these value-added opportunities operate in separate realms, with fish processing plants restricted to sending their waste to a single type of end-user. Our analysis suggests that quantities and fish discards are substantial and their variabilities manageable, which could open a range of upcycling options for processing plants. With more options, with some in growing demand and at relatively high price points, these plants can explore meaningful ways to increase their economic and ecological performance while keeping by-products out of landfills. Companies, investors, and all stakeholders in the fishing industry should remain optimistic about the future, as it holds the promise of a more sustainable and economically robust industry.

66 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf

67 Currency conversion based on an exchange rate of 1 CAD = 0.74 USD, as of August 2024

68 Great Lakes and St. Lawrence Governors and Premiers, 100% Great Lakes Fish Multi-Species Report, prepared by The Iceland Ocean Cluster, 2023, https://gsgp.org/media/pvelbtj5/ioc-100_-gl-fish-multi-species-report_v4.pdf.

69 Precedence Research, "Fish Protein Hydrolysate Market," accessed September 6, 2024, https://www.precedenceresearch.com/fish-protein-hydrolysate-market.

70 Merinov, "Final Report: Walleye Hydrolysis," accessed September 6, 2024, https://gsgp.org/media/pjghj2rt/final-report-walleye-hydrolysis-24-03-07-merinov.pdf.

71 Ibid

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