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Assessing Consumer Implications of Reduced Salmon Supply and Environmental Impact in North America

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Abstract: This study investigates the impact of the Canadian government's decision to reduce the supply of farm-raised salmon in British Columbia (BC) on domestic prices, the level of imports, and the environment. By drawing upon data from diverse sources, this study employs the SARIMAX model to forecast future trends in salmon prices up to 2026. The forecasted results reveal that retail salmon prices will exhibit greater unpredictability and a predicted price increase of over CAD 30 per kilogram by 2026. In addition, increased consumption of imported salmon due to BC farm closure is expected to contribute to heightened carbon emissions and result in job losses within rural and indigenous communities. In short, BC salmon farm closure carries profound consequences for both the environment and market dynamics.

Keywords: salmon farming; aquaculture; sustainability; salmon global trades; Canada and North American markets

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1. Introduction

The aquaculture sector in British Columbia (BC) stands out as a global exemplar of conscientious seafood cultivation practices [1]. Salmon farming, introduced in the early 1970s, thrives in the cool, well-flushed waters of BC, particularly in regions like the Broughton Archipelago and the West Coast Sounds. These geographic features, coupled with BC's prime location on Canada's west coast, position it as a commercial crossroads between the Asia-Pacific region and North America. With aquaculture accounting for 60% of Canada's overall salmon production in quantity and value, the industry wields significant influence over both provincial and national economies [2]. Consequently, the salmon industry in BC strengthens Canada's position as the fourth-largest producer globally, trailing only behind Norway, Chile, and the UK.

According to a comprehensive report published by the BC Salmon Farmers' Association (BCSFA) in autumn 2020, the BC salmon farming sector generated CAD 1.9 billion in economic activity. This translated to an infusion of CAD 721 million into Canada's Gross Domestic Product (GDP) and provided employment to 7560 Canadian citizens. However, salmon farming in BC is undergoing closure, which has a multifaceted historical context shaped by environmental concerns, economic interests, and governmental responses. Salmon farming in the region has been a contentious issue for decades, with its economic benefits counterbalanced by environmental impacts, including disease transmission to wild salmon populations, pollution from waste, and the spread of sea lice [3]. The collapse of wild salmon populations in the early 2000s heightened scrutiny of the industry, leading to inquiries such as the Cohen Commission, which identified salmon farms as a potential threat to wild salmon stocks [3].

In recent years, public concern and activism surrounding salmon farming in BC have grown significantly, with Indigenous communities, environmental organizations, and citizens calling for stricter regulations or even the cessation of the industry due to its environmental impacts [4]. This pressure culminated in the provincial government's decision. In a significant development on 17 December 2020, the former Minister of Fisheries, Oceans, and the Canadian Coast Guard, Bernadette Jordan (the current minister is Diane Lebouthillier), issued a declaration outlining the federal government's intent to gradually phase out existing salmon farming installations within the Discovery Islands (DI) region [5,6]. A lack of social license was cited as the reason for the decision.

The closure of salmon farms in the Discovery Islands in 2022 reduced salmon farming in BC by 24% [7], and the further transition plan includes reduction in current licenses by up to 50%. While the decision has been welcomed by environmentalists and Indigenous groups, concerns have been raised about the economic impact on coastal communities that rely on the industry for employment and income [8] and its significant and far-reaching impact on the North American marketplace. Farm-raised salmon, the most popular seafood choice of Canadians, has long been BC's top agri-food export and has one of the lowest carbon footprints of animal proteins [9,10]. The direct consequence of curtailing the remaining 65,800 tonnes of farmed salmon production is the triggering of substantial economic disruptions and food insecurity. Specifically, the BC salmon farming sector will face an annual economic loss of CAD 1.2 billion across Canada, a CAD 447 million decrease in GDP contributions, the elimination of over 4690 job opportunities, and a resulting reduction in family incomes of CAD 266 million annually.

This development should be seen in the context of a global salmon market characterized by historically high levels of demand. The impending reduction in domestic supply has the potential to exacerbate this already heightened demand, a situation with multifaceted repercussions. Canada's imports of salmon have increased rapidly since 2021; Canada imported approximately 20,000 tonnes more salmon in 2022 than in previous years, generating 58,000 more tonnes of CO_2—equal to the emissions of 80,000 vehicles/year [11]. Price stability or volatility depends on a complex interplay of factors, including domestic production, global supply chains, currency exchange rates, government policies, and market dynamics. An increase in imports has the potential to contribute to greater retail price fluctuations in Canada, which, in turn, might influence the overall domestic demand for salmon. It was estimated that higher salmon imports in 2022 generated approximately 9.9 million tonnes of CO_2, which was more than in 2020. The average Canadian vehicle releases 4.6 tonnes of CO_2 into the atmosphere every year. The estimated increase in CO_2 emissions released by the increased imports is equal to the emissions released by 2,152,000 vehicles a year in Canada [12,13].

Hence, the closure of BC salmon farms highlights their significant influence on environmental and market dynamics. Therefore, it is imperative to undertake a comprehensive examination and meticulous analysis of the implications of this decision for consumers. Given these considerations, the primary objective of this study is to discern the impact of curtailing the supply of BC farm-raised salmon on consumer pricing dynamics within the North American market. Three fundamental objectives underpin this study: (i) to discern and evaluate the intricate correlation between BC salmon farming and consumer pricing dynamics within the Canadian market; (ii) to scrutinize the multifaceted ramifications that result from the constrained operations of BC salmon farming under prevailing market conditions and investigate the dynamics governing consumer pricing within the broader North American context; and (iii) to investigate the prospective consequences associated with the reduction in the Canadian salmon supply and the concomitant expansion of the carbon footprint within the North American market.

This study concludes that the decision to close BC farms reverberates far beyond the boundaries of supply and demand. It has brought about transformative effects on salmon supply, consumer pricing dynamics, and market conditions while exacting a toll on environmental conditions through the upsurge in carbon emissions resulting from increased salmon imports in North America. The convergence of these multifaceted challenges underscores the intricate interplay between economic, environmental, and market forces, prompting a re-valuation of the strategies and policies governing the aquaculture industry.

The remainder of this study is organized as follows. Section 2 presents an overview of the existing literature on aquaculture and its implications for food security. Section 3 outlines the methodology and data employed in this research. Section 4 presents the results and discussion. Section 5 focuses on the forecasting of the main variables, and Section 6 concludes the study.

2. Literature Review

Food security, a fundamental aspect of human well-being, encompasses not only the quantitative dimension of food availability but also the nuanced aspects of accessibility and the temporal consistency of both availability and access [14]. With the global population projected to surge to 9.8 by 2050, representing a substantial increase in food demand, the imperative for sustainable food production practices becomes ever more pressing. It will necessitate a corresponding rise in food consumption by a margin of 60% to 100% [15,16]. In the face of this challenge, aquaculture emerges as a beacon of sustainable promise, poised to contribute significantly to the pursuit of food security, encompassing broader socio-economic dimensions beyond mere sustenance.

Currently, aquaculture stands as the leading sector in global food production, playing a pivotal role in ensuring food security for millions [17,18]. Fish, a primary product of aquaculture, nourish 3.3 billion people globally, accounting for a significant 20% of their animal protein intake. Notably, per capita fish consumption has witnessed a remarkable upsurge, from a modest 9 kg in 1961 to a substantial 20.5 kg in 2018, highlighting its growing significance in diets worldwide [17,18].

With its lower ecological footprint compared to terrestrial animal farming, aquaculture emerges as a sustainable alternative for meeting the rising demand for animal-derived protein [19–23]. Moreover, seafood products, particularly those from aquaculture, offer essential nutrients and fatty acids crucial for human health, which are often lacking in terrestrial alternatives [24–29].

In the broader context of sustenance, fisheries and aquaculture remain steadfast pillars, providing sustenance, nutritional strength, economic stimulus, and livelihoods to vast populations worldwide [24,27,29,30]. With its growing trajectory, aquaculture distinguishes itself by demonstrating a lower ecological footprint compared to alternative sources of animal-derived food. In some regions, domestic aquaculture directly enhances food security through internal consumption, while in others, its contribution takes an indirect path, fostering economic prosperity through export-oriented growth [23,31].

In the specific context of salmon aquaculture, the interplay of economic prosperity and food security becomes evident. For instance, Canada's reliance on salmon consumption reflects a dynamic blend of domestic sustenance and export-driven growth [32]. Over the past decade, while Canada's salmon exports remained stable, domestic demand surged, leading to an increase in imports to meet the shortfall [32]. This trend underscores the critical role of salmon aquaculture in supporting both internal food security objectives and economic prosperity through trade [33].

Aligned with this trend, Canadian protein consumption from fish and seafood reached 8.5% in 2019, surpassing other meat proteins such as pork (6.2%) and all other meats (6.1%) [34]. Hence, aquaculture, particularly salmon farming, stands as a multifaceted solution to the challenges of food security, offering sustainable production practices, nutritional benefits, and economic opportunities. As nations navigate the complexities of meeting their food needs in a rapidly changing world, the role of aquaculture, including salmon farming, remains indispensable in shaping a secure and resilient food future.

3. Methodology and Data

In this paper, we employ machine learning models, specifically the SARIMAX model, to predict salmon prices using historical data from Canada and the U.S. The data were preprocessed for consistency, and the SARIMAX model was selected for its effectiveness in incorporating seasonality and exogenous variables. We analyzed the model's performance using the Mean Absolute Error (MAE) to measure the accuracy of the predictions. This approach provides a clear, data-driven basis for forecasting salmon market conditions.

3.1. Machine Learning in Salmon Price Prediction

Predicting salmon prices is fundamentally a time-series task, and machine learning approaches are renowned for their power and flexibility [35]. These methods encompass advanced supervised learning algorithms, such as regression models [36], facilitating the forecasting of salmon prices, a critical endeavor for market participants [37]. The extensive application of machine learning models to predicting salmon prices has provided valuable insights and opportunities to the salmon industry [38,39]. However, research in this area remains relatively scarce. Bloznelis [37] conducted short-term salmon price forecasting of Norwegian-farmed Atlantic salmon prices, achieving accurate predictions up to five weeks ahead using methods like k-nearest neighbor and vector error correction.

In a recent study by Bjørnstad et al. (2023) [40], four forecasting models—Autoregressive Integrated Moving Average (ARIMA), Seasonal Autoregressive Integrated Moving Average (SARIMA), Seasonal Autoregressive Integrated Moving Average Exogenous (SARIMAX), and Long Short-Term Memory (LSTM)—were developed and tested on historical data, with the SARIMAX model outperforming others due to its consideration of seasonality. The process of predicting salmon prices using machine learning models involves analyzing historical data from Canada and the U.S. to gain data-driven insights into the salmon market's dynamics. Subsequently, following McHugh et al. [41], this study, leveraging the SARIMAX model, aims to develop a forecasting tool to predict future salmon prices and market conditions.

SARIMAX, a robust time-series forecasting model, combines the capabilities of ARIMA with exogenous variables, proving particularly effective in predicting prices and other time-dependent data. By summarizing statistical information for each exogenous variable, SARIMAX characterizes price dynamics comprehensively. The accuracy of the SARIMAX model is evaluated using metrics like the Mean Absolute Error (MAE), which measures the mean absolute difference between predicted values and actual values in a dataset. A lower MAE indicates a better fit of the model to the data. However, it is important to note that MAE is presented on the same scale as the target prediction, and there is no universal rule for an ideal MAE score—it must be interpreted within the context of the specific dataset being analyzed.

3.2. Data

This study draws data from diverse sources, enabling a comprehensive examination of salmon production and market conditions in both Canada and the United States. Government repositories like Statistics Canada [42], the BC Government [43], the U.S. Census Bureau, and the Department of Fisheries and Oceans Canada [44] were utilized, alongside non-conventional sources such as gray literature and popular media outlets like CBC News and documents from the BC Farmers Association. Additional insights into salmon transition strategies in BC were gathered from the Global Salmon Production and Market Update by Kontali and Nielsen's Salmon Retail Sales Report in the United States.

For Atlantic salmon production, a publicly available dataset spanning 1991–2021 from Statistics Canada was used to analyze historical trends and project future patterns. Retail salmon price data from January 2017 to April 2022 was sourced from Statistics Canada, which facilitated the scrutiny of historical price trends and the construction of a forecasting model. Concurrently, salmon sales data were obtained from Nielsen's salmon retail sales report, covering the years 2017 to 2022. To comprehensively understand consumer demand in both Canada and the U.S., a dataset pertaining to Canadian seafood consumption from 2017 to 2022 from Nourish Food Marketing was compiled.

Insights into market distribution were collected through data on Atlantic salmon trade volume and supply from the Government of Canada's online trade records and the U.S. Census Bureau, spanning 2019 to 2022. Supplementary information sources, such as Kontali's Global Salmon Production and Market Update, enhanced the understanding of salmon market dynamics in North America.

4. Results and Discussion

4.1. Global Atlantic Salmon Production and Canada Share

To gain a comprehensive understanding of the scale and capacity of salmon aquaculture in Canada, particularly within the province of BC, we conducted a detailed analysis of historical data pertaining to salmon production. Our investigation reveals a notable trend: Canada's share of global salmon production has exhibited a downward trajectory, starting at 5.3% in 2019 and consistently declining to 4.9% in 2020. This proportion remained stable in both 2021 and 2022 (see Table 1). It is worth noting that BC plays a pivotal role in this context, as it significantly contributes to the global salmon market.

Salmon production and its associated economic value in Canada have generally followed an upward trajectory over the years, despite experiencing marginal declines in 2004, 2014, and 2022. Nonetheless, these brief setbacks were swiftly rectified as production levels rebounded in the subsequent year. In the contemporary context, the dynamics of salmon production and its corresponding economic worth have shown a degree of volatility. Specifically, from 2017 to 2021, salmon production fluctuated within the range of 120,553 tonnes to 120,186 tonnes. Concurrently, the monetary value of this production witnessed a decline, decreasing from CAD 1.05 million in 2017 to CAD 0.99 million in 2021. These trends warrant closer examination and analysis within the context of Canada's salmon industry (see Figure 1).

Table 1. Atlantic salmon production, North America, Canada, US, and BC share (in tonnes).

Year	Global Atlantic Salmon Production	North America Harvest Quantity	Canada Share	USA Share	BC Share
2019	2,577,900	158,300	137,500	20,800	81,500
2020	2,712,600	156,800	136,800	20,000	87,000
2021	2,896,000	161,000	142,000	19,000	79,000
2022	2,865,700	151,000	131,500	19,500	81,500

Data Source: Kontali [45].

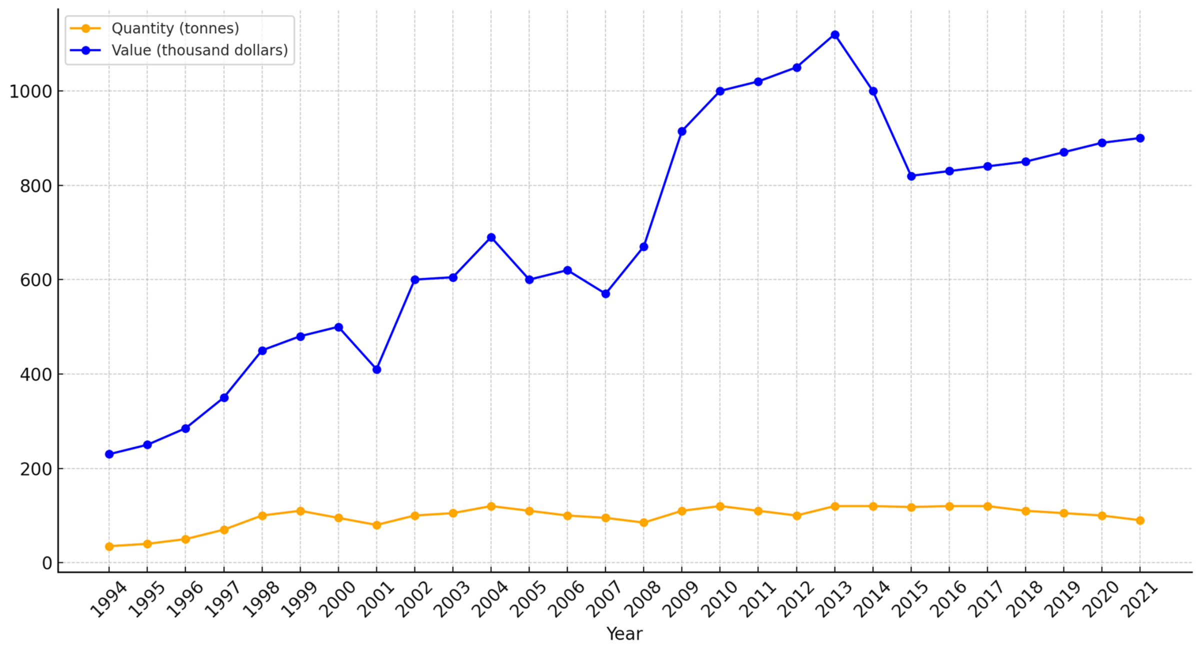


Figure 1. Salmon production and value in Canada. Data Source: Statistics Canada [46].

4.2. Retail Price of Salmon

In line with global and Canadian production trends, it is crucial to understand the historical affordability dynamics of salmon. Figure 2, without adjusting for inflation's impact on food affordability, offers a comprehensive view of the average monthly retail price per kilogram from January 2017 to June 2023. The data reveals a volatile pattern in salmon pricing, marked by numerous fluctuations throughout the year.

Figure 2. Monthly average retail price for salmon (per kilogram) from January 2017 to June 2023. Data Source: Statistics Canada [46].

Of particular note are the highest price points for salmon (all types), observed around May 2022, reaching a peak of CAD 29.16 per kilogram, and similarly in May 2023, hitting a comparable peak at CAD 29.09. These fluctuations underscore the significant volatility in the salmon market, prompting further examination within the context of economic analysis and consumer behavior. It is important to emphasize that importing a food commodity, such as salmon, introduces additional variables and can contribute to increased volatility in retail prices [47,48]. Price stability or volatility depends on a complex interplay of factors, including domestic production, global supply chains, currency exchange rates, government policies, and market dynamics.

4.3. Market Distribution

In the global Atlantic salmon trade, Canada ranks as the second-largest supplier to the United States, with Chile occupying the top position. A clear trend in this trade landscape is the declining trend in salmon exports from Canada. From 2019 to 2022, there was a notable drop of 18% in the volume of salmon Canada exported to the United States. By 2022, Canada's share of the U.S. salmon market had contracted to 14%. This decline in Canadian salmon exports to the United States holds considerable significance and warrants a thorough analysis in the field of international trade studies (see Figure 3).

The United States serves as the primary recipient of Canadian Atlantic salmon exports, with the second-largest portion allocated for domestic consumption. As illustrated in Figure 4, the decrease in salmon production led to a reduction in export volume from 2019 through 2022. Concurrently, there has been a notable capacity to adequately satisfy domestic demand (see Figure 4).

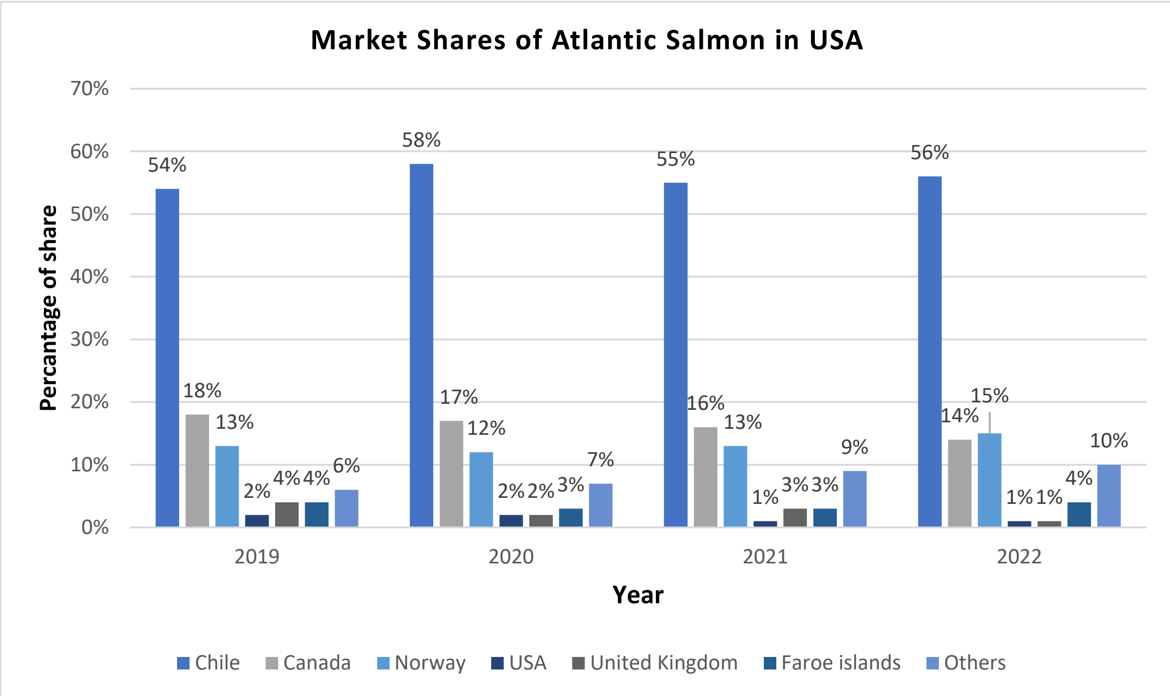
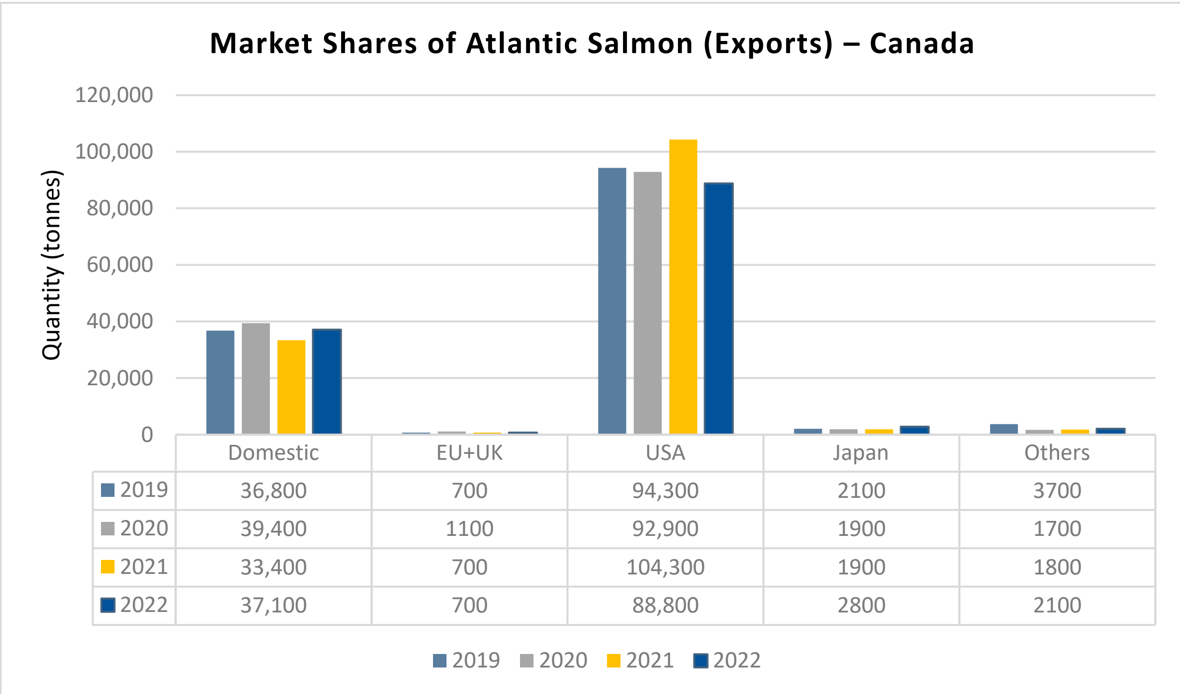


Figure 3. Market shares of Atlantic salmon in the USA. Data Source: Kontali [45].



	Domestic	EU+UK	USA	Japan	Others
2019	36,800	700	94,300	2100	3700
2020	39,400	1100	92,900	1900	1700
2021	33,400	700	104,300	1900	1800
2022	37,100	700	88,800	2800	2100

Figure 4. Market shares of Atlantic salmon (exports)—Canada. Data Source: Kontali [45].

4.4. Market Shares of Salmon (Imports)—Canada

During the period from 2019 to 2022, the importation of salmon exhibited a substantial upward trajectory. In specific terms, the volume of salmon imports surpassed the 2 million mark in 2019 and witnessed a significant surge, exceeding 4 million units by the year 2022. This pronounced increase in salmon imports underscores a notable trend in international trade dynamics, warranting scholarly scrutiny and analysis within the context of this study (see Figure 5). Given the limited data availability on Atlantic salmon imports, the analysis encompasses the volume of Pacific, Atlantic, and Danube Salmonidae imports.

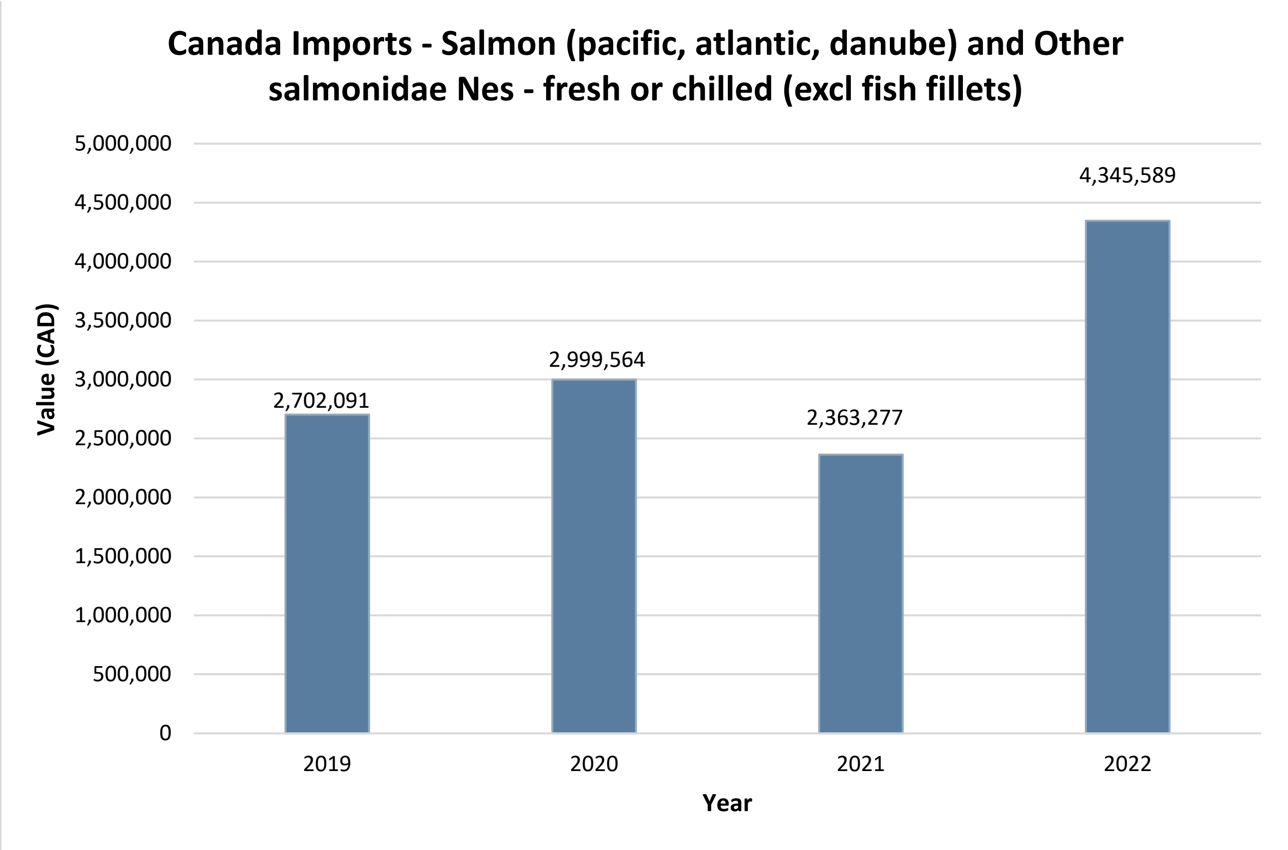


Figure 5. Market shares of Salmon (Imports)—Canada. Data source: Government of Canada Trade Data Online.

4.5. Farmed Atlantic Salmon Supply in Canada and BC

Figure 6 presents the exports of farmed Atlantic salmon from 2012 (January–August) to 2023 (January–August). The blue line represents Canadian exports, while the green line represents exports specifically from the BC region. Notably, from 2021 to 2023, exports in Canada decreased from 59,300 tonnes to 42,214 tonnes. Similarly, exports from BC mirrored this trend, with quantities dropping from 31,515 tonnes to 21,848 tonnes. The graph clearly demonstrates the interdependence of Canadian exports of farmed Atlantic salmon on BC exports.

4.6. Canadian Farmed Atlantic Salmon Supply, World versus USA

Between 2021 and 2023, the global supply of farmed Atlantic salmon has exhibited a substantial contraction, characterized by a pronounced decline in both quantity and value. Specifically, the total volume of Atlantic salmon supplied to international markets has experienced a substantial reduction, decreasing from 59,300 tonnes to 42,214 tonnes from August 2021 to August 2023. Concomitantly, exports of farmed Atlantic salmon to the United States, a critical market in this context, have declined from 56,697 tonnes to 40,816 tonnes. This marked reduction in export volume to the United States underscores a substantial shift in the dynamics of the international Atlantic salmon trade landscape (see Figure 7).

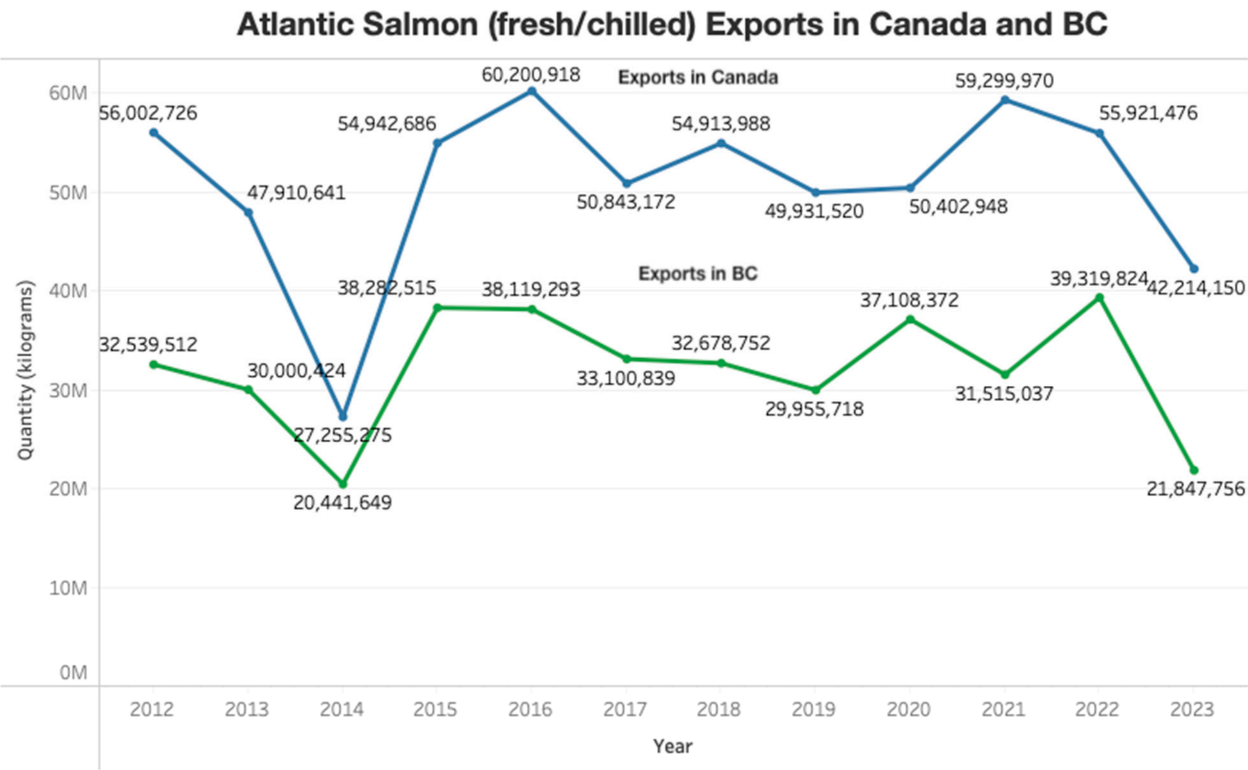


Figure 6. Farmed Atlantic salmon (fresh/chilled) exports in Canada and BC (January–August 2012, to January–August 2023). Data source: Government of Canada Trade Data Online.

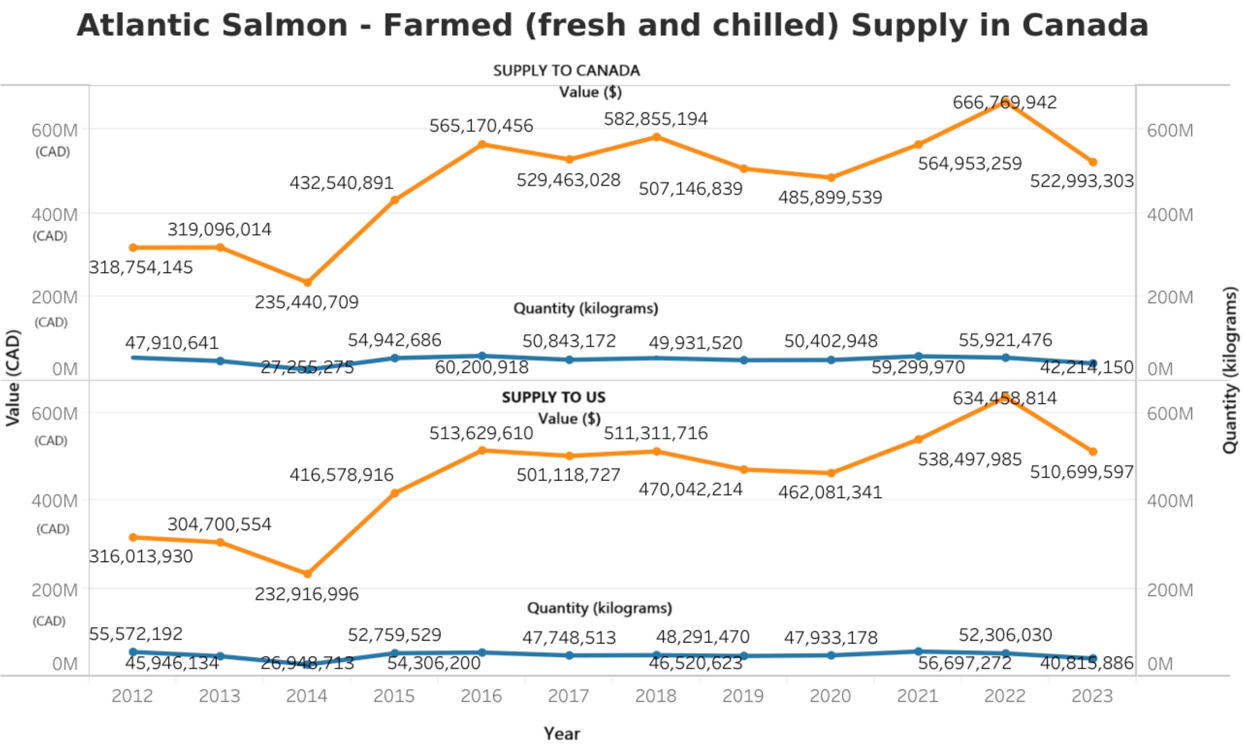


Figure 7. Farmed Atlantic salmon (fresh/chilled) export quantity and value in Canada to the world and to the USA (January–August 2012, to January–August 2023). Data source: Government of Canada Trade Data Online.

4.7. Salmon Sales and Consumer Demand

The trajectory of salmon retail sales exhibited a significant upward trend from 2017 through 2020. Nevertheless, in the subsequent years, there has been a consistent and discernible decline in sales, resulting in a volume of 95,158 metric tonnes recorded in 2022 (see Figure 8).

Figure 8. The retail sales volumes of Salmon in the USA from 2017 to 2022. Data Source: Nielsen [49].

4.8. Seafood Consumption in Canada

Studies show that fish and seafood hold a prominent place in the Canadian diet. A survey conducted in 2023 (Colombo and Charlebois (2023), unpublished) revealed that 86.7% of Canadians regularly include fish and seafood in their meals. The primary reason to eat seafood is nutrition (64%), rather than affordability (21%). In terms of regional feeding preferences, BC tops the list, with the highest preference for fish and seafood consumption every week (45.8%). In contrast, Quebec has the lowest weekly consumption rate (27.2%) (refer to Figure 9).

Household income significantly influences preferences for farmed fish. Households with incomes exceeding CAD 150,000 showed the highest preference (53.3%), followed by those in the CAD 35,000–CAD 74,999 bracket at 50.2%, and the CAD 75,000–CAD 149,000 bracket at 48.6% [50].

Another survey conducted by Osmond [51] reported that 55% of Canadians would be more inclined to consume farm-raised salmon if they were fed an environmentally friendly diet. Table 2 clearly demonstrates that among various meat protein food sources, chicken consumption demonstrated the most pronounced increase, with a notable growth of 1.3% from 2019 to 2022, followed by beef and fish or fish dishes. While there was a marginal decline of 0.6% in fish consumption in 2019, this trend was not observed for other food sources. Conversely, poultry (including chicken), pork, and various meats exhibited an upward trajectory in consumption.

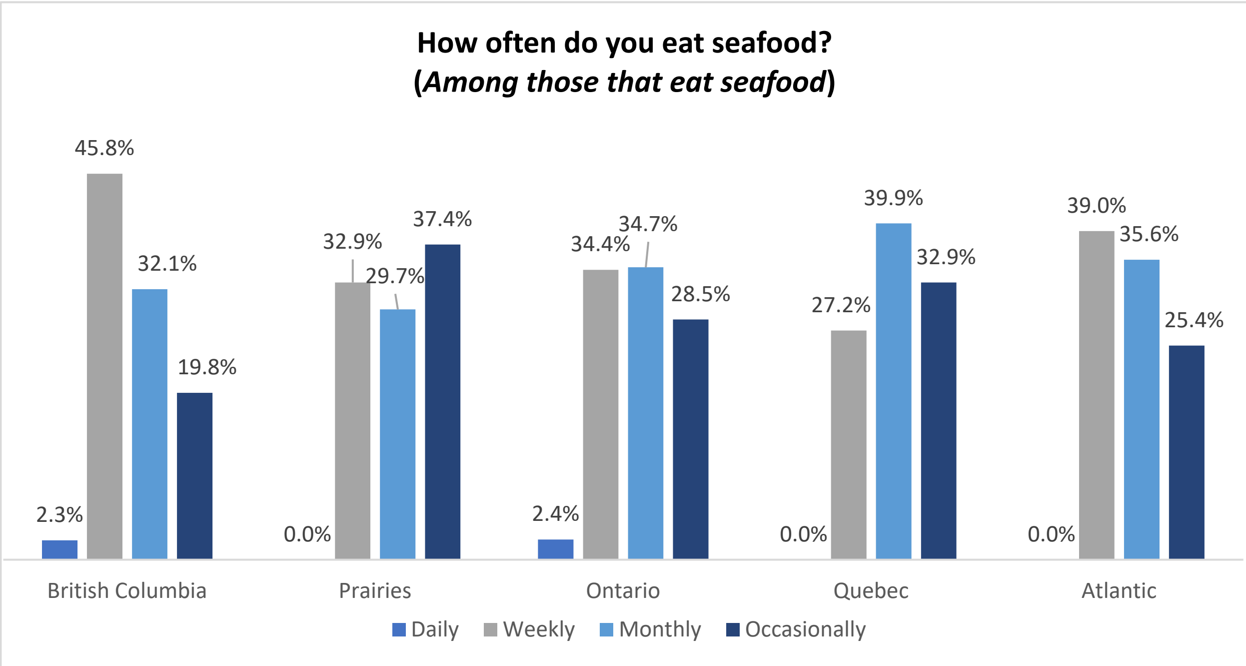


Figure 9. Seafood preference and consumption.

Table 2. Overall protein consumption by Canadians.

	2019	2020	2021	2022
Chicken	29.5%	30.7%	30.3%	30.8%
Beef	12.6%	13.2%	13.0%	12.2%
Fish/Fish Dishes	8.5%	7.9%	8.5%	7.9%
Pork	6.2%	6.5%	6.5%	6.3%
Turkey	1.7%	1.6%	1.4%	1.2%
All other Meat	6.1%	6.7%	6.2%	6.7%
Other Protein (meat alternative)	35.4%	33.4%	34.1%	34.9%

4.9. Canadian Average Eating per Capita of Fish/Seafood

In 2022, the average per capita consumption of meat protein in Canada amounted to 575 instances annually. Conversely, there was a reduction in the frequency of fish and seafood consumption, declining from 61 occasions per year to 54. Notably, in 2022, the specific consumption of salmon registered a relatively modest figure, with individuals partaking in this particular fish variety only 11 times within the same interval (see Table 3).

Table 3. Average number of occasions per capita of fish/seafood consumption.

	2019	2020	2021	2022
Meat Protein	585	569	586	575
Fish/Seafood	61	56	62	54
Fish/Fish Dishes	44	42	45	40
Salmon Fillet/Steaks	13	12	13	11
Seafood/Seafood Dishes	17	14	17	14

Data source: Nourish Food Marketing [34].

5. Forecasting

The global seafood industry, driven by evolving consumer preferences, shifting market dynamics, and environmental factors, is experiencing a profound transformation. Within this intricate tapestry, salmon, often referred to as the "pink gold" of the sea, holds paramount significance due to its economic and nutritional values and substantial contribution to international trade. In recent years, the salmon industry has witnessed pricing fluctuations driven by supply chain disruptions, environmental concerns, regulatory changes, and consumer demand. The inherent volatility of salmon prices necessitates a thorough understanding of the underlying dynamics to inform strategic decisions made by stakeholders, ranging from producers and distributors to policymakers and consumers. This section aims to forecast salmon prices up to 2026, serving as an indispensable tool for policymakers addressing sustainability, trade, and food security challenges while also empowering consumers to make informed dietary and purchasing decisions based on anticipated price trends.

5.1. Forecasting the Monthly Average Retail Price of Salmon up to 2026

This section introduces the forecasting model to predict salmon prices from June 2023 to May 2026, built on historical data from January 2017 to June 2022, using the SARIMAX model, a widely recognized approach in time series forecasting. The forecasting model projected salmon prices for a period of 7 years, spanning from 2023 to 2026, utilizing data from January 2017 to May 2023. The model is illustrated in Figure A1, Tables A1 and A2 in Appendix A. The prediction suggests that salmon prices will experience more frequent fluctuations and a predicted price increase of over CAD 30 per kilogram by 2026 (nominal). This increase is anticipated to intensify with the reduction in the volume of salmon production in the future.

An important observation from the forecasting model is the presence of a discernible seasonal pattern. This recurring pattern follows a 12-month cycle, with salmon prices exhibiting consistent fluctuations over time. Seasonality in time series data is a well-documented phenomenon characterized by systematic variations at regular intervals, influenced by various factors such as vacations, climatic conditions, and holidays.

To evaluate the model's performance, the dataset is split into two segments. Of the total 77 observations, the initial 30 serve as the training dataset, while the remaining 30 constitute the test dataset. The forecasted salmon price values closely align with the actual price values in the training dataset, with minimal differences observed. The model's performance is deemed satisfactory, as indicated by a Mean Percentage Error (MPE) metric value of 1.28. MPE is a commonly used evaluation metric for time-series forecasting models, where a value closer to zero signifies superior performance in forecasting future trends.

5.2. Carbon Footprint

In recent years, there has been a discernible shift in the dynamics of the salmon trade, marked by a reduction in exports and a simultaneous surge in imports, particularly from 2019 to 2022. While this transition signifies multifaceted economic dynamics, it is crucial to highlight its environmental ramifications, particularly concerning carbon emissions.

Most of the salmon consumed by Canadians came from BC. However, reduced production has led to increased salmon imports to meet domestic consumption demands. Canada is now importing more salmon from different parts of the world, with import quantities rapidly rising since 2021. Canada imported approximately 86,300 and 86.387 tonnes of salmon in 2021 and 2022, respectively, which is about 20,000 tonnes more than in previous years. The imports include various forms of salmon, including fresh, preserved/prepared, frozen, and canned, primarily sourced from Norway, the United Kingdom, Chile, China, Mexico, and Iceland (see Table A3 in the Appendix A). It is estimated that the salmon imports from these countries generated approximately 84.56 million tonnes of CO_2 emissions per kilometer in 2021 and 86.3 million tonnes in 2022, which is approximately 9.9 million tonnes more than in 2020.

The average Canadian vehicle releases 4600 kg of CO_2 into the atmosphere every year. The estimated increase in CO_2 emissions (from 2020) released by the increased imports is equal to the emissions released by 2,152,000 vehicles a year in Canada. Table 4 provides the estimates of carbon footprints generated by the distance between the countries by airplane transport. Imports from China and Chile produce the highest number of emissions, as the distance is far from Canada compared to other countries.

Table 4. Estimated carbon footprints from imports of salmon from the six dominant countries to Canada from 2021 to 2023 (August).

Salmon Supplier	Distance from Border to the Border (km)	Kg CO_2—eq/Tonne km	Estimated in Million Tonnes CO_2 Emissions km (2020)	Estimated in Million Tonnes CO_2 Emissions km (2021)	Estimated in Million Tonnes CO_2 Emissions km (2022)	Estimated in Million Tonnes CO_2 Emissions km (Until August 2023)
Norway	1190	702.5	1.577	2.6956	3.2389	2.0591
UK	2849	1681.8	0.605	1.4836	1.543	0.7285
Chile	6686	3946.8	62.378	64.8652	61.263	53.8973
China	4745	2800.98	10.9577	9.2078	10.4917	5.9561
Mexico	1808	1067.27	0.5933	5.5515	7.9834	6.295
Iceland	1647	972.23	0.2446	0.7559	1.7773	0.7124
	Total CO_2 emissions Produced		76.3556	84.5596	86.2973	69.6484

Note: Distance is calculated using Distance Calculator: https://distancecalculator.globefeed.com/ (accessed on 21 October 2023). Carbon emissions are calculated using: The Dalhousie seafood carbon emission tool: http://seafoodco2.dal.ca/ (accessed on 21 October 2023).

In 2019, the export of 83,180 tonnes of farmed salmon in BC, valued at CAD 771 million, significantly contributed to the creation of 353 million meals enriched with high-quality protein while minimizing CO_2 emissions [52]. Indeed, salmon emerged as an exemplar of environmentally conscious protein sourcing, generating a mere 0.6 g of CO_2 emissions in 2019 in BC. In stark contrast, other conventional meat sources such as chicken, pork, and beef accounted for 0.88 g, 1.3 g, and 5.92 g of CO_2 emissions, respectively (as depicted in Figure 10).

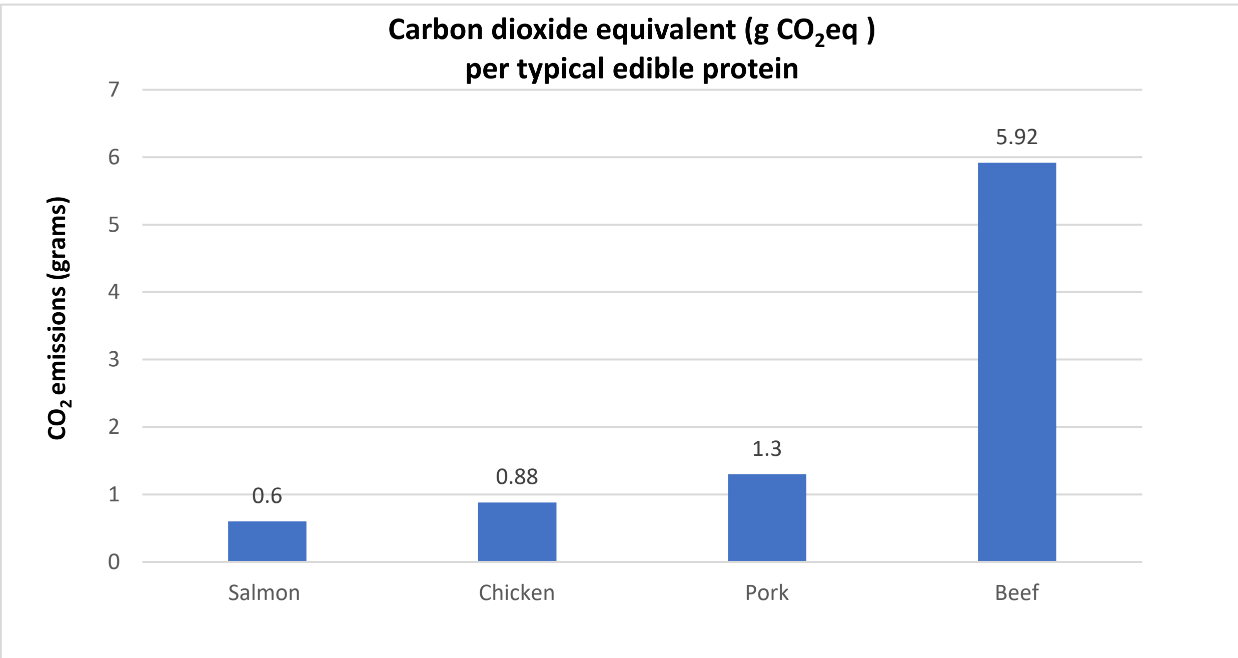


Figure 10. Carbon dioxide equivalent (e.g., CO_2eq—one gram of CO_2) per typical edible protein (2019). Data source: Kontali [45].

Unfortunately, the years following 2019 have seen a decrease in salmon consumption in Canada, paralleled by an upswing in the consumption of other types of meat alternatives. This shift, indicative of evolving dietary preferences, carries environmental implications.

Importantly, the increased demand for other protein sources necessitates higher production, which is associated with higher carbon emissions. Therefore, the heightened demand for alternative protein sources in Canada inadvertently exacerbates the carbon footprint generated by meat production.

This nuanced interplay between shifting dietary preferences, trade dynamics, and carbon emissions underscores the importance of comprehending the intricate relationship between global trade and environmental sustainability. As Canada navigates this transition in its dietary landscape, it becomes imperative to consider not only environmental but also socio-economic factors when formulating trade and consumption policies. This recalibration of priorities is essential for mitigating the environmental consequences associated with changes in protein consumption patterns.

6. Conclusions

The closure of 19 salmon farms in British Columbia (BC) has significantly impacted the sustainable supply of salmon to consumers in both Canada and the United States. This reduction in production is reflected in historical trends, showing declining production volumes and market values since 2019. Historically dominant in the North American salmon market, Canada has seen its market share steadily decline since 2019. This coincides with noticeable shifts in consumer behavior, including rising retail prices and reduced demand for salmon. Beyond economic concerns, these reductions in salmon production and supply chain disruptions have environmental consequences, as decreased salmon production leads to increased imports and a higher carbon footprint associated with North American consumption patterns.

As discussed, increased imports may amplify retail price fluctuations in Canada, influencing domestic demand for salmon. This shift reflects North Americans' gradual move toward alternative sources of meat protein, affecting both dietary preferences and carbon emissions. Conversely, reduced Canadian availability has driven the U.S. to seek salmon from alternative suppliers, such as Norway and Chile, inadvertently increasing carbon emissions linked to salmon imports. Projections suggest a further decline in Canadian salmon production, affecting both global and domestic markets, GDP, and salmon consumption patterns in North America. Canada, once a leader in aquaculture, now faces the challenge of meeting growing market demand. While forecasting future retail salmon prices in Canada presents a formidable challenge, predictive models suggest intensified price fluctuations with decreased domestic production.

Hence, the closure of BC farming facilities extends beyond supply and demand dynamics, triggering transformative effects on salmon supply, consumer pricing, and market conditions while also contributing to increased carbon emissions from salmon imports in North America. This convergence of challenges underscores the intricate interplay between economic, environmental, and market forces, prompting a revaluation of strategies and policies governing the aquaculture industry.

However, the methodology for predicting salmon prices and analyzing market dynamics acknowledges a few limitations. For example, the assumption of stationarity in time-series forecasting may not accurately reflect real-world market behavior. Additionally, some studies referenced in the methodology have narrow timeframes or focus on specific regions, potentially limiting generalizability. Moreover, the complexity of market dynamics, influenced by various interconnected factors, may not be fully captured in the analysis. Future studies could address these limitations by conducting sensitivity analyses, exploring alternative modeling techniques, or incorporating additional data sources to enhance the accuracy of salmon price predictions and market analyses.

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Appendix A

Table A1. Forecasting salmon prices per kilogram from January 2024 to December 2026.

Date	Forecasted Price	Date	Forecasted Price	Date	Forecasted Price
24 January	29.06	25 January	29.65	26 January	30.23
24 February	28.67	25 February	29.25	26 February	29.84
24 March	29.12	25 March	29.71	26 March	30.29
24 April	28.6	25 April	29.18	26 April	29.77
24 May	29.76	25 May	30.34	26 May	30.92
24 June	29.43	25 June	30.01	26 June	30.59
24 July	28.79	25 July	29.37	26 July	29.96
24 August	27.86	25 August	28.44	26 August	29.02
24 September	28.5	25 September	29.08	26 September	29.66
24 October	27.05	25 October	27.64	26 October	28.22
24 November	28.41	25 November	28.99	26 November	29.58
24 December	27.23	25 December	27.82	26 December	28.4

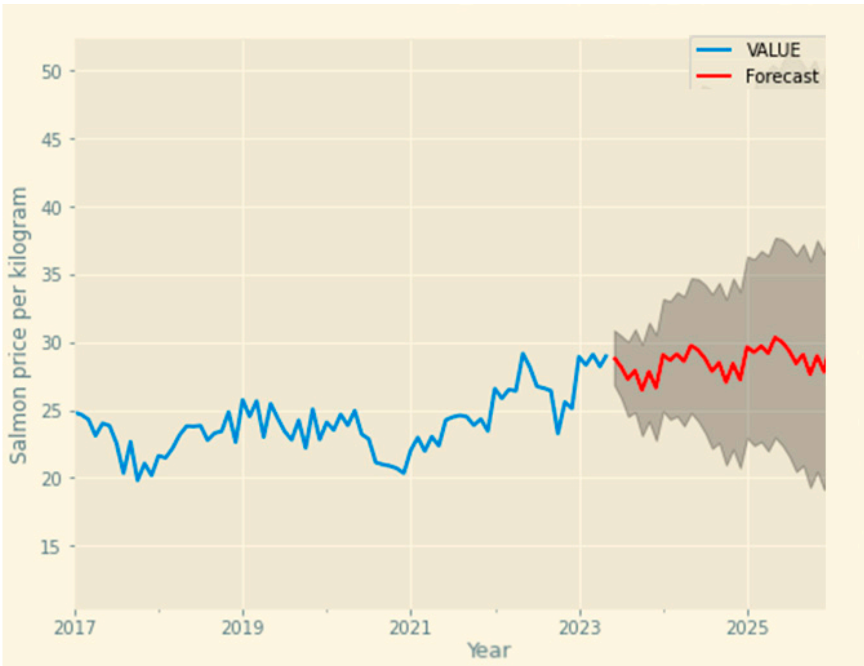

Figure A1. Forecasting salmon prices per kilogram from January 2024 to December 2026. The projections indicate a potential fluctuation in salmon prices from 2024 to 2026, as depicted by the shaded gray area in the graph. By 2026, the upper-bound price projection exceeds $35 per kilogram, while the lower-bound projection falls to $20.

Table A2. Statistical summary of salmon pricing forecasting model (SARIMAX results).

Variable	Coefficient	*z*-Statistics
AR(1)	−0.445 *** (0.136)	−3.264
MA.S(12)	−1.000 (1166.307)	−0.001
σ^2	0.897 (1046.328)	0.001
AIC	158.842	
BIC	164.637	
Jarque-Bera	1.180	

Note: *** denotes significance at the 1% level.

Table A3. Imports of salmon (all types) to Canada from Jan 2020 to August 2023.

Country	2020	2021	2022	2023 (Until August)
USA	38,302,333	49,327,231	47,256,253	25,944,836
Chile	15,804,696	16,434,882	15,522,162	13,655,955
Norway	2,244,782	3,837,213	4,610,537	2,931,071
China	3,912,098	3,287,334	3,745,725	2,126,420
Mexico	555,861	5,201,595	7,480,236	5,898,253
Iceland	251,567	777,498	1,828,093	732,743
United Kingdom	359,778	882,171	917,462	433,171
Lithuania	450,538	614,487	689,109	249,751
Thailand	1,369,993	1,649,477	1,018,263	495,149
Poland	615,508	806,309	385,082	144,016
New Zealand	151,218	469,326	108,543	87,521
Netherlands	172,603	98,559	91,274	65,690
Sweden	31,557	36,661	58,255	62,695
Italy	859	52,967	67,904	31,685
Türkiye	0	776	18,038	89,910
Denmark	67,101	108,581	261,189	113,595
Canada	213,181	161,847	230,967	62,330
Ireland	172,542	35,571	5938	14,181
France	74,746	1983	177	94,369
Faroe Islands	19,123	28,843	61,351	11,915
Panama	332,051	490,781	740,358	51,325
Colombia	3374	13,858	56,392	4064
Japan	108,280	19,151	8166	4492
Brazil	0	0	6357	4240
Trinidad and Tobago	0	8848	83,188	3026
Viet Nam	19	12,415	18,419	1145
Sri Lanka	0	0	284	4417
Iran	45	134	89	1655
Germany	9527	3681	38,338	1170
Guyana	0	0	944	1350
Portugal	1053	5030	1229	844
Morocco	0	200,016	0	16
Australia	0	2	125	5
Benin	0	0	0	2
Korea, South	0	112	0	0
Argentina	237,345	481,388	468,932	0
Bangladesh	0	0	0	0
Belarus	112	428	0	0
Cameroon	0	47	0	0
Costa Rica	0	0	191	0
Ecuador	4082	1067	727	0

Table A3. *Cont.*

Country	2020	2021	2022	2023 (Until August)
Egypt	0	1	0	0
Finland	0	2	0	0
Ghana	0	902	0	0
Greenland	0	453	0	0
Honduras	0	11,610	1315	0
Hong Kong	0	2	0	0
India	0	0	0	0
Indonesia	44,089	20,583	226	0
Israel	349	10	0	0
Kenya	0	0	0	0
Latvia	3656	13,676	27,287	0
Mauritania	435	100,000	35	0
Mozambique	0	0	0	0
Nigeria	20	37	1	0
Peru	1588	111,903	30,566	0
Philippines	0	0	1688	0
Russian Federation	874,604	969,688	539,149	0
Saudi Arabia	0	0	0	0
Senegal	1	0	18	0
Singapore	3	0	0	0
Spain	40,848	19,455	542	0
Switzerland	1334	0	4839	0
Taiwan	44	0	60	0
United Republic of Tanzania	0	635	0	0
Togo	12,318	0	9	0
Tunisia	0	0	210	0
Ukraine	0	1155	648	0
Total imports Quantity	66,445,261	86,300,381	86,386,890	53,323,007

Source: Statistics Canada data retrieved from CATSNET Analytics, AAFC.

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