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Role of freshwater fish aquaculture on the food security of Latin America and Caribbean region

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Thesis of the PhD dissertation

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1. INTRODUCTION AND RESEARCH OBJECTIVES

The aquaculture sector in Latin American and Caribbean (LAC) has been analyzed mainly at global level, even together with capture fisheries sector, limiting the information specifically on the aquaculture development, impacts, and its contribution to the regional food security; as consequence, there is a lack of acknowledgment of the role of aquaculture sectors, such as freshwater aquaculture, narrowing its consideration by the policy makers in the design food security policies (Burns et al., 2014).

Being the Freshwater fish aquaculture a nascent activity to produce fish commodities and food, at the moment there is absence of data and recognition of the social and economic contribution of this sector to the region development; it has impeded the integration of this, and the whole fishing sector, in the national food security and nutritional policies and programs, besides its inclusion in countries' nutritional programs focusing on tackling micronutrient deficiencies (Béné et al., 2015).

The aim of this research is to provide wide details of the freshwater fish aquaculture contribution to the food availability and food access in LAC, analyzing it from economics aspects as international trade, fish price, and the role of fish as animal protein source in the region. Regarding food security, studies have analyzed the influence and consequence of economic indicators such as poverty (Allee et al., 2021; Iddrisu & Alagidede, 2020), food inflation (Fujii, 2013; Monsivais et al., 2010; Rodriguez-Takeuchi & Imai, 2013), and food balance (Arsenault et al., 2015; Liu et al., 2019), however the impacts of macroeconomic fluctuations on food insecurity have remained scantily explored (Erokhin & Gao, 2020), which was considered to evaluate in this research.

The results of this thesis provide data and statistics of the freshwater fish aquaculture relevance in LAC, the particularities of this fish sector to contribute to the food security and poverty reduction of the region. The study was done through analysis of indicators as production share, fish balance trade, and prices tendencies, considering other animal protein of the region (bovine, swine, poultry, and goat), and assessing the influence of external factor (oil prices) on the fish and other animal protein prices, as element of the food access analysis in LAC.

1.1. Objective

The research was structured for the achievement of one (1) main objective through the development of three (3) stages, defined as specific objectives, which provided inputs to establish the freshwater fish aquaculture status and elements of the sector's development on the food availability and food access of the region.

Main objective

Determine the contribution of the fish sector and freshwater fish aquaculture to the food security, economic development, and poverty reduction of the Latin America and Caribbean region.

Specific objectives

1) To identify the role of freshwater aquaculture sector, as animal protein source, in the food availability and food access of LAC, and its integration level with the food security policies of the top 10 largest producer countries of LAC.
2) Determine the most influential drivers forces associated to the freshwater fish aquaculture development in LAC, that support poverty alleviation and food security of the region, during 2000-2019.
3) To establish the emerging role of fish products as an animal protein source in LAC by 2030.

Hypotheses

The hypotheses considered for each of specific objectives are based on the scope, methods, and the statistical analysis performed in each objective.

Policy integration:

- Hypothesis 1 (H_1): The development of freshwater fish aquaculture in LAC has been supported with the integration of fishing and aquaculture sector on the Food Security national policies.

Multiple regression model for Prevalence of undernourishment

- Hypothesis 2 (H_2): Share of aquaculture production in LAC freshwater fish production is the fish driver force that most impacts the reduction of undernourishment.

- Hypothesis 3 (H_3): Share of freshwater fish production in the food balance trade of LAC influences positively on the prevalence of undernourishment.

Multiple regression model for poverty headcount ratio

- Hypothesis 4 (H_4): Share of aquaculture production in LAC freshwater fish production is the fish driver force that most impacts the reduction of poverty headcount ratio.

- Hypothesis 5 (H_5): Share of freshwater fish production in the food balance trade of LAC influence positively on the poverty indicator.

Co-integration - Phillips and Ouliaris Unit Root

- Hypothesis 6 (H_6): Oil prices have long-run influence on animal protein prices.

Granger Causality

- Hypothesis 7 (H_7): Oil prices have short -term influence on animal protein prices.

Instantaneous Causality:

- Hypothesis 8 (H_8): There is instantaneous causality of oil prices on the animal protein prices.

2. MATERIALS AND METHODS

2.1. Role of the freshwater aquaculture sector, as an animal protein source, in the food availability and food access of the LAC region

The contribution of fish to household food and nutrition security depends upon access and availability; this last one for food-fish has recognized a function of production, whereas the greatest influence on access to food is price, largely determined by markets and incomes trade (Beveridge et al., 2013). In this research the two components of food security are analyzed considering the following aspects:

- Food availability: The role of freshwater aquaculture is analyzed at regional and country level, through indicators on production, fish trade (exports – imports), and the identification of production methods.
- Food access: Analysis (regional and country-level) considering the indicators of fish trade, and prices.

The database considered are FAO Fisheries and Aquaculture Statistics (FishStat) for fish production (values and volume), imports, export, (values and volume), and commodities food balance sheet in the FAO yearbook (FAO, 2021).

2.2. Identifying the integration level of the freshwater aquaculture and food security in the public policies of the top 10 largest producer countries of LAC

It was adapted a methodology proposed by Koehn (2019) to determine the level of integration of freshwater aquaculture in the food security policy of each of the ten (10) LAC's countries, and the level of integration of food security in the aquaculture policies of these countries as well; implementing a content analysis of the national documents to determine with the following scale the level of integration.

Table 1. Scale for the assessment of the level of integration in the national policies.

Level	Description
Low	Only several mentions of the fields object of analysis
Moderate	The fields are included among the objectives of the policy
High	The Fields are included in objectives, with specific details and action items needed

Source: adapted by author from (FAO, 2020)

2.3. Influential drivers of the growth of freshwater aquaculture in LAC that contributes to the reduction of poverty and food insecurity in the countries of the region

The analysis of driver forces was done with multiple regression analysis, which is implemented to predict a dependent variable from two or more independent variables; with this regression is possible to forecast the scores on cases for which measurements have not yet been obtained or might be hard to obtain (Field, 2017). The regression equation can be used to classify, rate, or rank new cases. Multiple regression is developed for each aspect (poverty alleviation, and undernourishment), to identify the most influential drivers of freshwater fish aquaculture in each aspect.

In the Table 1 is presented the summary of fish indicators considered as independent variable for the two multiple regression models; one for Prevalence of Undernourishment (PoU), defined as proportion of the population whose habitual food consumption is insufficient to provide the dietary energy levels required to maintain a normal active and healthy life (FAO, 2014).

The second multiple regression model was developed with Poverty headcount ratio at $2.15 a day (2017 PPP) as dependent variable. This indicator is the percentage of the population living on less than $2.15 a day at 2017 purchasing power adjusted prices. As a result of revisions in PPP exchange rates, poverty rates for individual countries cannot be compared with poverty rates reported in earlier editions (World Bank, 2022).

The regression included multiple correlation coefficients such as R and R-squared; the last one shows the proportion of the variation in the dependent variable explained by the independent variables. ANOVA sig., in multiple regression helps to assess the overall significance of a model, if $P<0,05$ the model is significant (Field, 2017).

Table 1. List of variables for multiple regression analyses

Variable	Unit	Source	Expected Influence
Dependent variable			
Prevalence of undernourishment in LAC	% of population	World bank	
Poverty headcount ratio at $2.15 a day (2017 PPP) in LAC	% of population	World bank	
Independent variable			
Share of aquaculture production in LAC freshwater fish production	(Aquaculture production/ Total Freshwater fish Production) *100	FishStatJ	Negative
Share of freshwater fish aquaculture production in LAC fish production	(Freshwater fish aquaculture production / Total Fish Production) *100	FishStatJ	Negative
Share of freshwater fish production in LAC fish food production	(Freshwater fish production / Total fish Food Production) *100	FishStatJ	Negative
Share of freshwater fish exports in Total LAC fish food exports	(Freshwater fish exports/ Total Fish Food Exports) *100	FishStatJ	Positive
Share of Freshwater fish imports in Total LAC fish food imports	(Freshwater fish imports/ Total fish food imports) *100	FishStatJ	Positive

Source: elaborated by author

For the analysis of driver forces was established four (4) hypotheses; on one site hypothesis H_2 establishes that share of aquaculture production in the LAC freshwater fish production is the driver force that most impacts the reduction of undernourishment. Whereas hypothesis H_3 stated that shares of freshwater fish aquaculture production in the food balance trade of LAC influence positively on the prevalence of undernourishment.

Regarding the influence on poverty headcount ratio, hypothesis H_4 presents percentage of aquaculture production in LAC freshwater fish production as the most influential driver force on this poverty indicator. And hypothesis H_5 establishes that freshwater fish production shares in the food balance trade of LAC positively influence this dependent variable.

2.3. Emerging role of fish commodities as an animal protein source in LAC by 2030, and comparative analysis with developing regions

It was developed an analysis of food security from the food access approach, through the assessment of the crude oil prices influence on the trade of animal protein commodities (import-export prices and volume), in LAC region, and two developing regions (Middle East and North Africa (MENA), and East Europe and Central Asia (EECA).

Through statistical analysis of cointegration and causality, in the software R Studio, was determined the cointegration of oil crude prices with the export- import prices and trade of animal protein commodities (fish, bovine, swine, poultry, and goat), during 2000 to 2021, for each of the largest traded countries analyzed, to identify commodities and trade flow with the highest and lowest impact by crude oil prices fluctuations. Table 2 presents the variables and sources considered in this research, for each animal protein, and crude oil prices as independent variable.

Table 2. Variables details for animal protein analysis

Variables	Category	Source
Dependent variables		
Meat of **bovine** animals; fresh, chilled or frozen.	Import and export ➢ Quantity: Weight in kilograms ➢ Trade value: USD	UN Comtrade FAOSTAT
Meat and edible offal of **poultry** fresh, chilled or frozen.	Import and export ➢ Quantity: Weight in kilograms ➢ Trade value: USD	UN Comtrade FAOSTAT
Fish fillets, fish meat; fresh, chilled or frozen.	Import and export ➢ Quantity: Weight in kilograms ➢ Trade value: USD	UN Comtrade FAOSTAT
Meat of **swine**; fresh, chilled or frozen.	Import and export ➢ Quantity: Weight in kilograms ➢ Trade value: USD	UN Comtrade FAOSTAT
Meat of **sheep or goats**; fresh, chilled or frozen.	Import and export ➢ Quantity: Weight in kilograms ➢ Trade value: USD	UN Comtrade FAOSTAT
Independent variable		
Global Crude Oil Prices	USD per cubic meter	Crude oil prices (ourworldindata.org)

Source: elaborated by author

The data of production volume and trade value, for the animal protein commodities during the period analyzed (2000 – 2021), were obtained mainly from UN Comtrade database and complemented with FAOSTAT. It was defined the recent top five (5) of the largest exporters and importers countries in the three developing regions, based on trade value and volume.

The statistical analysis and econometrics methods used are detailed in Figure 1, describing the four (4) sections considered from the data treatment until the cointegration and causal analysis.

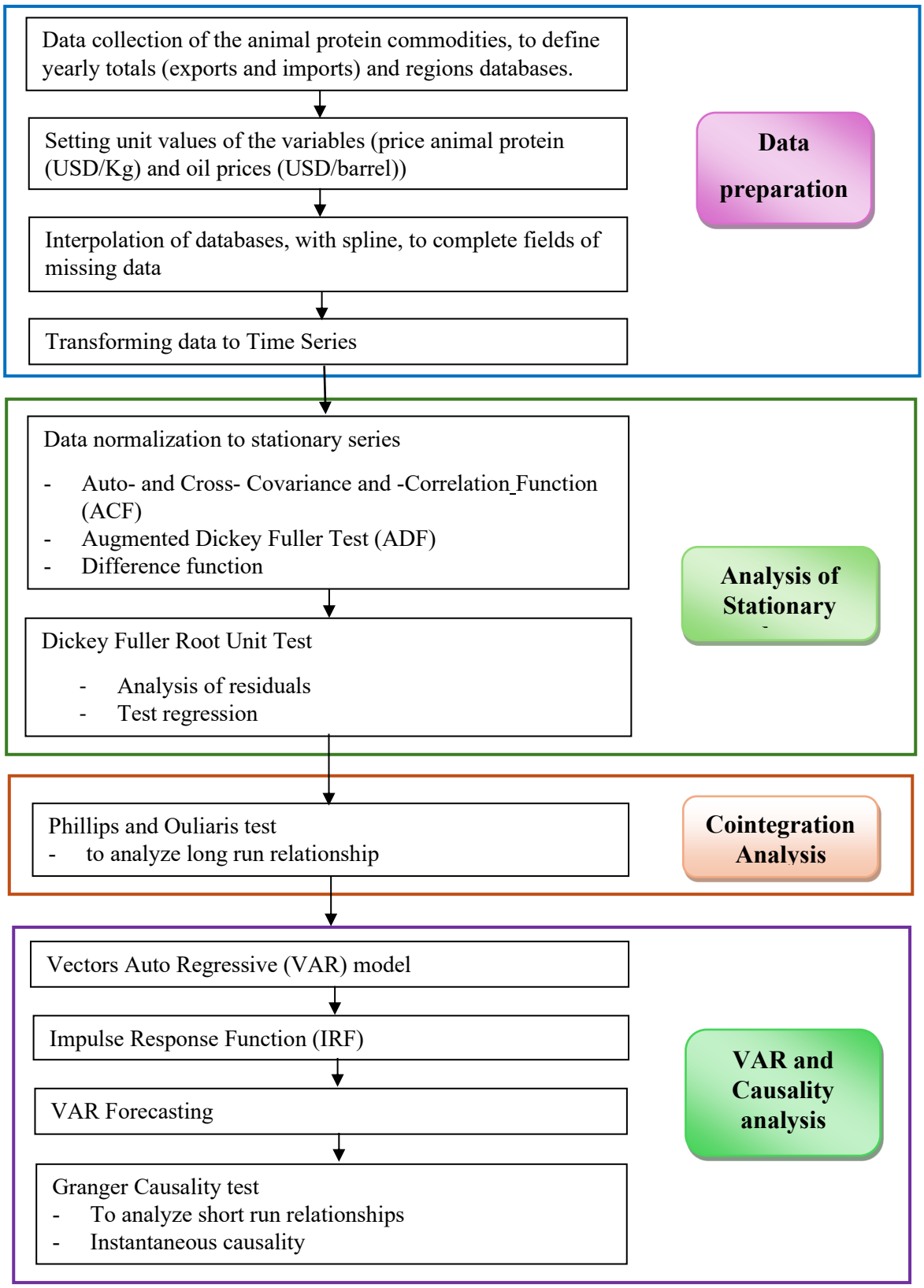

Figure 1. Process of statistical analysis for cointegration and causal analysis in animal protein prices.
Source: Elaborated by author

3. RESULTS AND DISCUSSION

3.1. Role of the freshwater aquaculture sector, as an animal protein source, in the food availability and food access of the LAC region

It was identified the characteristics and contributions of the LAC fish products and freshwater aquaculture activity to the region's food availability and access. The availability of these resources is assessed through production indicators, highlighting their role as sources of animal protein in the region. This analysis also includes a comparison with other significant sources of animal protein in LAC, such as bovine, poultry, swine, and goat products. Regarding food access component, trade value indicators, specifically the balance between exports and imports of fish and four other types of animal protein, were taken into account.

3.1.1. Food availability approach

The analysis of the role of fish commodities at the regional level employs indicators on production and fish trade, including exports and imports. This approach identifies the net trade of animal proteins in Latin America and the Caribbean (LAC) and highlights the significance of the fish sector. Figure 2 illustrates the animal protein products that contributed to the LAC trade balance from 2000 to 2021, showcasing the net trade and the proportion of each of the five commodities.

The observed surplus balance indicates that the region exports large quantities, primarily of bovine and poultry products, with 3.9 million tons and 2.6 million tons respectively, while importing smaller amounts of animal protein commodities. Swine and goat products presented highest imports than exports, at the beginning of the period analyzed and in 2015. Nevertheless, it is important to recognized that food import may also have a positive effect on the stability of domestic food availability in case of negative production shocks (Marson et al., 2023).

This situation let identified that during the period analyzed the net balance of fish products has maintained the third position among the animal protein products traded in LAC, nevertheless, regarding the proportion of the fish surplus trade growth, fish production traded has not been at the same level of growth to the biggest animal protein traded in LAC (poultry and bovine); the trade of fish commodities passed from occupied the second position to the third position with an extensive difference in the share respective bovine and poultry.

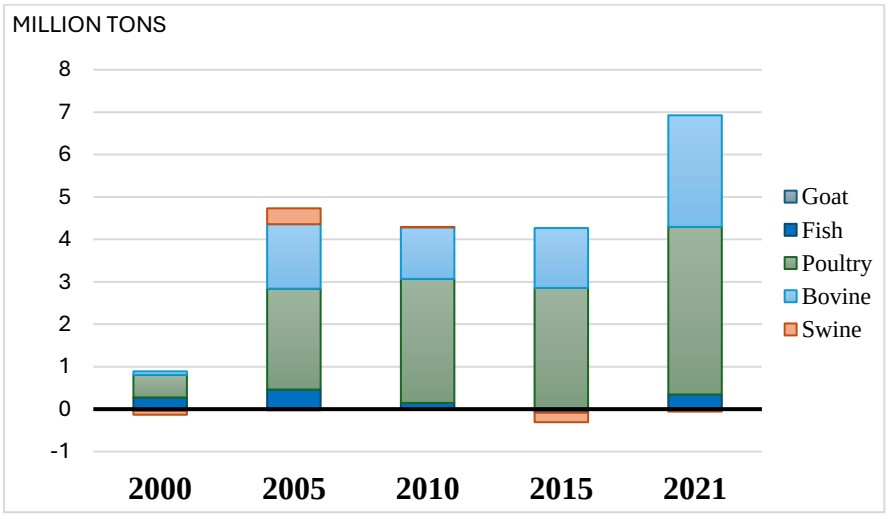

Figure 2. Trade balance of animal protein commodities in LAC region
Source: Elaborated by the author from statistical data of UN Comtrade (United Nations, 2024) and FAOSTAT (FAO, 2022)

The region is among the largest fish producer, and apart from Asia and China, it occupies major position in terms of volume, with growth prospects of 33% in the next 10 years. Chile, with Brazil and Ecuador, accounted for 77% of the South America volume production. Together with Mexico and Peru, these countries contribute 87% of LAC's aquaculture production, according to data from FishStatJ (FAO, 2023). In LAC, South America leads in volume terms, currently accounting for 90% of totals (FAO, 2016) and occupied the fourth position in world fish aquaculture producers (FAO, 2020), which was identified with the top five (5) of largest fish exporter countries of the region considered for this research, observed in Figure 3.

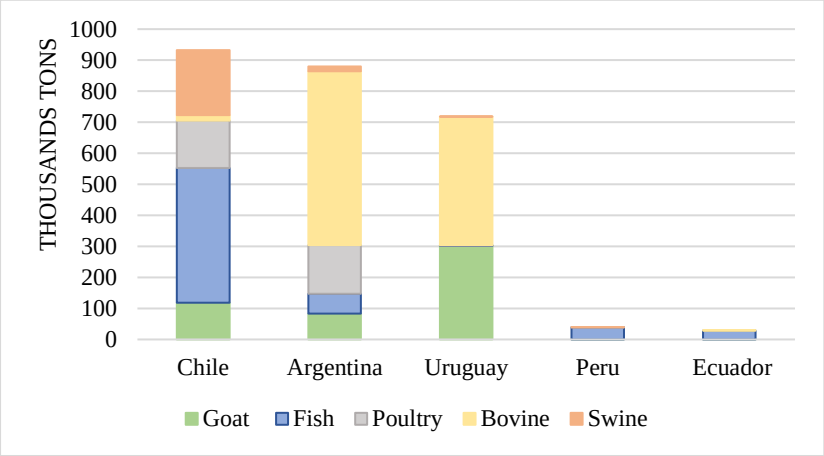

Figure 3. Animal protein exported in the largest fish exported countries of LAC, 2021
Source: Elaborated by the author from statistical data of UN Comtrade (United Nations, 2024) and FAOSTAT (FAO, 2022)

Aquaculture production is poised for continual expansion across all continents. According to projections from the FAO (2020), LAC region is anticipated to witness a substantial upswing of up to 33% by 2030. This expansion is evident in the participation of marine and freshwater aquaculture in fish production, as shown in Figure 4. Despite a reduction in the total fish production in the LAC region, aquaculture is steadily gaining more prominence in the industry.

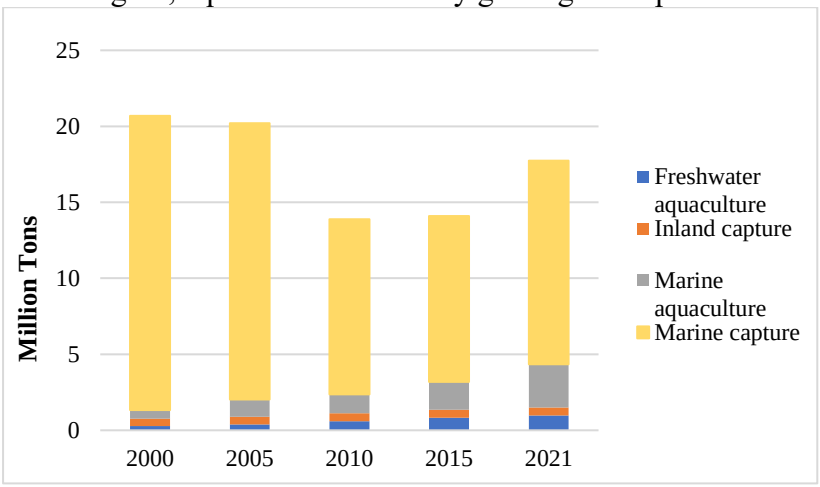

Figure 4. Source of fish production in LAC region 2000-2021
Source: Elaborated by the author from statistical data of FishStatJ database (FAO, 2023)

Capture fisheries and aquaculture play vital roles in bolstering the global animal-source protein supply. However, it is noteworthy that while the contribution of aquaculture to this supply is on

the rise, capture fisheries are not experiencing similar growth, as highlighted by Boyd et al., (2022).

The aquaculture sector has not simply increased the availability of fish, it has also prevented prices from rising as they would have if only wild fisheries were to meet the general increase in demand (Béné et al., 2016; World Bank, 2013). In the case of the LAC region, this scenario is not visible yet, since fish production is subject mainly on capture method (around 80% by 2021).

3.1.2. Food access approach

The analysis of fish trade indicators and prices is crucial in understanding the complex impact of trade on food security. This impact can affect food access by causing changes in real income, while food trade directly influences food availability and utilization through imports and exports. It is important to note that the fishery sector is a significant part of international trade, with many countries trading a wide variety of fish species and products

Due to most of databases and indicators available for fish commodities present totals of the production, without classified the source (capture or aquaculture), for this section of the research was analyzed the fish price and production of LAC as a whole, to identify its situation in relation to the other animal proteins , presenting export prices in Figure 4, and imports in Figure 6.

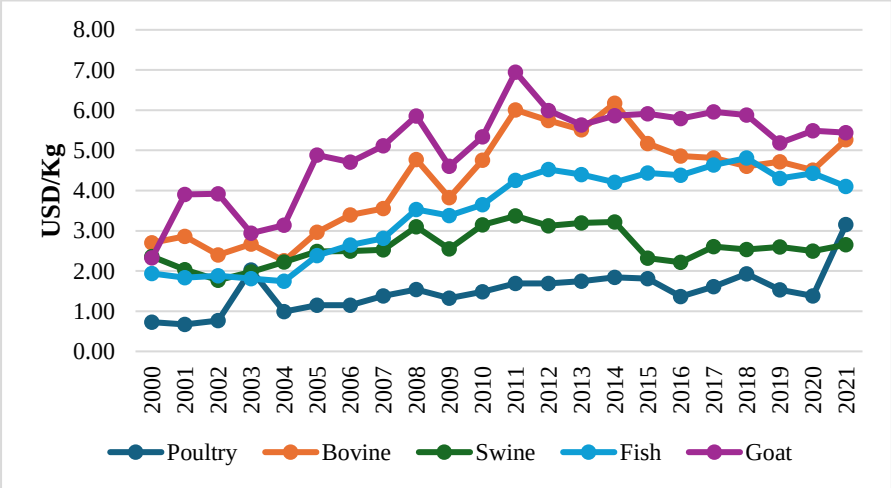

Figure 5. Export prices of animal proteins commodities (USD/Kg) in LAC region 2000-2021

Source: Elaborated by the author from statistical data of UN Comtrade and FAOSTAT

Respecting the differences between animal protein prices in LAC, the trade indicators analyzed let identifying that at the beginning of the period (2000 to 2021) there was not large differences between the animal protein prices; around 2004 began considerable variations, in export and import prices, and by 2020/21 is appreciated wider differences among the commodities prices.

In the situation of the fish trade, despite of the reduction in the total LAC fish production between 2005-2015, the export price per Kilogram traded maintained a growth trend, quite different to the association mentioned by Marson et al. (2023), that higher prices in international markets can incentivize domestic producers to divert production from national markets to export.

This might be presented by the sort of fish commodities exported by this time from LAC; the freshwater aquaculture productions is based on omnivores and herbivores, low trophic level species, with lower prices (Gyalog et al., 2022); however other fish source, as marine and capture, could contribute with carnivores fish species with high level and values, as the Ecuadorian's fish trade presented. Once the expansion of aquaculture reach out more participation in the LAC fish

production, this will cause that prices of farmed fish grow more slowly than other animal foods source, even this growth reigned in increases in the price of captured fish as Belton & Thilsted (2014) mentioned.

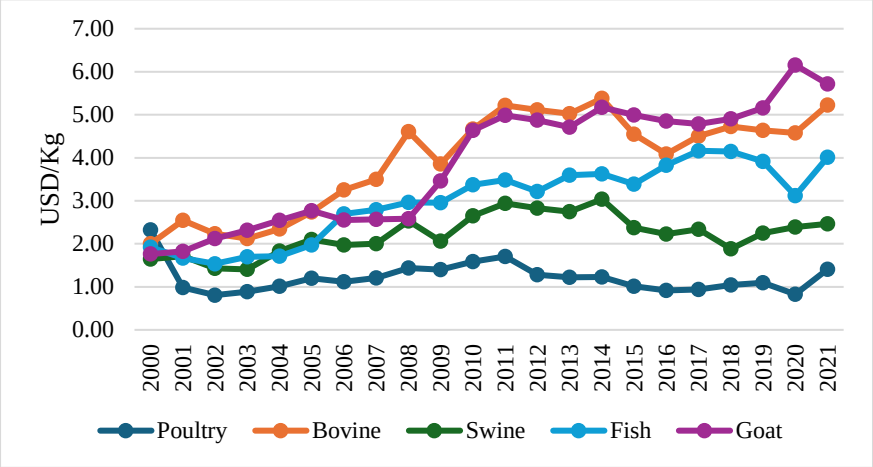

Figure 6. Import prices of animal proteins commodities (USD/Kg) in LAC region 2000-2021
Source: Elaborated by the author from statistical data of UN Comtrade and FAOSTAT

Several factors interact with market dynamics, adding force to, or on the contrary counterweighing the price effect caused by the increased supply of fish following the expansion of aquaculture. The decrease in price that is expected, in theory from the development of aquaculture, with some potential positive impact on the food intake of the local population, has yet to be confirmed and seems to be complicated by the unclear and still poorly documented economic interactions that exist between aquaculture and wild fisheries at the local level (Kawarazuka & Béné, 2010).

3.2. Identifying the integration level of the freshwater aquaculture and food security in the public policies of the top 10 largest producer countries of LAC

The review of the food security policies in the countries analyzed reflects that all of them establish goals, programs and strategies for long term, in the frame of these regulation. The policies are oriented to period between four to ten years. From the three criteria analyzed, climate change is the one that has been most integrated in the food security policies of these LAC countries, included it as a programmatic focus (Guatemala), identified as critical issue that can restrict food production (Mexico and Costa Rica), needed to implement measures of climate changes adaptation, to guarantee access to adequate food at every time (Peru and Honduras).

Regarding aquaculture, only three countries (Brazil, Peru and Honduras) included it in their food security polices, nevertheless the integration is considerably low, as it is scarcely mentioned as part of fish sector and agri-food systems.

Fish and fisheries are the most common concepts described in the policies and programs, with moderated level of integration in the countries of the region. The policies encompass all forms of fish production, including aquaculture, and fisheries activities, indicating a holistic view of the sector. Among the strategies to boost productive systems and fish consumption is highlighted the Ecuador's case, it had high integration of fish sector as focus action, through programs like "eat fish -eat healthy", and incorporating fish in the food programs of vulnerable communities. Similarly, Brazil's strategy to promote fish consumption as healthy food reflects a proactive stance towards leveraging the nutritional benefits of fish to enhance food security.

While climate change is a well-integrated aspect of food security policies in LAC countries, aquaculture remains underrepresented. The analysis highlights the importance of fish and fisheries in the region's food security strategies, with Ecuador and Peru providing notable examples of high integration of the fish sector into their policies, as can be observed in Table 3, with policies, and the integration level of the concepts considered.

Table 3. Integration in food security policy and strategies of LAC countries

	Type of Food security policy		Integration in the food security policies/Plan			Document analyzed
	National policy	Other	Climate change	Aquaculture only	Capture fisheries only	
Brazil		X	Moderate	Low	Low	National Plan of food security and nutrition 2016-2019 (CAISAN, 2018)
Colombia	X		Moderate	--	--	National Policy of food security and nutrition (Colombian government, 2008)
Mexico		X	Low	--	---	Institutional program of Mexican food security 2020-2024 (SADER & SEGALMEX, 2020)
Peru		X	High	Low	High	National strategy of Food and Nutrition security 2013-2021(Ministry of Agriculture and Irrigation & European Union, 2013)
Honduras	X	X	High	Low	Low	National Policy of Food and Nutritional security for long term, and National strategy (Honduras Government, 2018). National Strategy of Food and Nutrition security 2010-2022 (UTSAN, 2010)
Cuba		X	Low	--	Low	Plan of Food Sovereignty and nutritional education of Cuba (Ministry of Agriculture, 2020b)
Paraguay		X	Low	--	Moderate	National Plan of Food and Nutritional Sovereignty and Security 2009 (FAO & STP, 2009).
Ecuador		X	--	--	High	Intersectoral Plan of Food and Nutrition Ecuador 2018-2025 (Ministry of Health & FAO, 2018)
Costa Rica	X		High	--	--	National Policy of Food and Nutritional Security 2011-2021 (Ministry of Health, 2011)
Guatemala	X		Moderate	--	Low	National Policy of Food and Nutritional Security (SESAN, 2005)

Source: Elaborated by author

These integration results of the food security policies in LAC, reflect that most of the countries of the region have not acknowledged the key role that sustainable aquaculture can provided, such as nutritious food, generating income, and supporting livelihoods, thereby addressing multiple dimensions of food security.

Besides, this low integration identified between the sector and food security policies might be caused by the scarce information documented on the direct and indirect impacts of fish on nutritional status that Kawarazuka & Béné (2010) highlighted, fish as essential fatty acids has been well documented, however, few information has been given on the role of fish as a source of micronutrients, this is a potential entry points for improving household nutritional security.

It was identified the need in the LAC countries to promote through the food security policies aquaculture expansion and sustainability, to become this sector an integral component of national food security strategy, as it has been recommended by experts Kawarazuka & Béné (2010), incorporating strategies to recognized fish production and consumption as nutritious food.

Fish and aquaculture policies were part of the other scope, these policies are instrumental in ensuring food security by expanding the production and commercialization of fish and aquaculture products, thereby guaranteeing the availability of quality and safe products.

The integration of food security within fish and aquaculture policies varies, with most countries exhibiting a moderate to high level of integration, as is detailed in Table 4. Notably, Costa Rica and Paraguay stand out for having specific programs and plans dedicated to aquaculture development, indicating a proactive approach to leveraging aquaculture as a means to enhance food security. Approach needed since it has been recognized and demonstrated that aquaculture development aquaculture contributes to food and nutrition security (Belton et al., 2018).

Regarding climate change, despite that aquatic systems, which sustain aquaculture, are already effected by climate change, and projections indicate that these will be accentuated in the future (Kreiss et al., 2020), this component presents low level of integration in the fish and aquaculture policies of most of the LAC countries, highlighting, it is described as a key condition for fish production in Brazilian's policy.

Table 4. Integration in Fish - Aquaculture policy and strategies of LAC countries

	Type of Fish-Aquaculture Policy		**Integration in the Fish - Aquaculture Policies/Plan**		**Document analyzed**
	National policy	**Other**	**Climate change**	**Food security**	
Brazil		X	Low	Low	National plan of aquaculture 2022-2032 (MAPA, 2022)
Colombia	X		Low	Moderate	Integral policy for the sustainable development of fish (FAO & Ministry of Agriculture and Rural Development, 2015)
		X	-	High	Strategy for the Fish and aquaculture policy 2018-2022 (Ministry of Agriculture and Rural Development, 2019)
Mexico		X	Low	High	National program of fish and aquaculture 2020-2024 (Ministry of Agriculture, 2020a)
Peru	X		High	High	National policy of aquaculture 2030 (Ministry of production, 2023)
Honduras	X		-	Low	General law of fish and aquaculture 2015 (OSPESCA & SICA, 2017)
		X	Moderate	Moderate	Strategic plan to improve freshwater aquaculture (ONUDI & Honduras Government, 2022)
Cuba		X	-	Moderate	Fishing Law No. 129/2019 (Ministry of Production, 2020)
Paraguay		X	Low	Moderate	National program of sustainable development of aquaculture (Ministry of Agriculture andLivestock, 2015)
Ecuador		X	Low	Low	Organic law for the aquaculture and fishing development (Ministry of Production, 2020)
Costa Rica		X	Low	-	Program of sustainable development of fish and aquaculture (INCOPESCA, 2022)
		X	-	Moderate	Strategic plan for aquaculture 2019-2023 (SEPSA & INCOPESCA, 2023)
Guatemala	X		-	-	Integration policy of fish and aquaculture 2005 (OSPESCA & Central America Integration Systems, 2005)

Source: Elaborated by author

Considering the results from the policy integration, the hypothesis H_1 set is rejected, since the development of Freshwater fish Aquaculture in LAC has not been supported with the integration of fishing and aquaculture sector on the Food Security national policies. It was recognized that the

gaps on policy makers identified by Béné et al. (2016) are still present in LAC, such as unawareness of the causal relationship between aquaculture and food security, fish data management, articulation of poverty, and information of fish contribution to the diets. Direct impact on nutritional contribution through fish consumption, and on incomes increased purchasing power through the sale of fish (Kawarazuka & Béné, 2010).

Given the anticipated 30% increase in global demand for food fish by 2030, due to population growth, it is concerning that per capita fish consumption is expected to decline in regions such as Latin America, Europe, Central Asia, and Sub-Saharan Africa. Specifically, in Latin America and the Caribbean (LAC), per capita fish consumption is projected to decrease from 8.4 kg per person in 2010 to 7.5 kg per person by 2030 (World Bank, 2013). Considering this, it is crucial for fish and aquaculture policies to incorporate strategies aimed at boosting per capita fish consumption within the region. Despite LAC's status as a significant producer and net exporter of fish, this has not translated equivalently into nutritional benefits for the LAC population.

Reforming agricultural policies to address climate change mitigation objectives is a crucial step in combating the significant impact of agriculture on climate change. Agriculture is indeed a major driver of climate change, contributing to it through both direct on-farm emissions and indirect emissions from land use change. Direct on-farm emissions, such as methane and nitrous oxide, are released from agricultural activities like livestock farming and fertilizer use. Indirect emissions, on the other hand, result from changes in land use, such as deforestation for agricultural expansion, which releases stored carbon into the atmosphere.

3.3. Influential drivers of the growth of freshwater aquaculture in LAC that contributes to the reduction of poverty and food insecurity in the countries of the region

Studies have explored the relation between fish consumption and poverty (Garaway, 2005; Jahan et al., 2010), identifying in some cases that increased demand for fish might be linked to fisheries conflicts (Spijkers et al., 2021). Poor people in developing countries tend to depend essentially on carbohydrate-based diets for their nutritional intake, these are relatively low in protein and micronutrients. Then, fish can play a particularly important role in combating micronutrient deficiencies (Kawarazuka & Béné, 2010)

Considering the knowledge gaps in the fish sector, identified by Béné et al. (2016) and Bostock et al. (2016), this chapter developed the analysis to determine the factors/drives from fish and aquaculture activity that contribute the most to reduction of undernourishment and poverty in LAC.

3.3.1. Multiple regression analysis for Prevalence of undernourishment in LAC

With the five (5) independent variables, selected for the regression, was design the below formula for the linear model:

$$PoU\ LAC^{(1)} \sim \%\ FwAqP\ in\ LAC\ FP^{(2)} + \%\ AqP\ in\ LAC\ FwP^{(3)} + \%\ FwP\ in\_LAC\ FfP^{(4)} + \%\ FwE\ in\ LAC\ TFfE^{(5)} + \%\ FwI\ in\ LAC\ TFfI^{(6)}$$

(1) Prevalence of Undernourishment in LAC
(2) Share of Freshwater fish Aquaculture Production in LAC Fish Production
(3) Share of Aquaculture Production in LAC Freshwater fish Production
(4) Share of Freshwater fish Production in LAC Fish Food Production

(5) Share of Freshwater fish Exports in Total LAC Fish Food Exports
(6) Share of Freshwater fish Imports in Total LAC Fish Food Imports

The model summary and ANOVA test results; reflect F value data, which refers to the probability that the variation caused by the independent variables is real and not due to chance (Bevans, 2023); in this model three (3) variables presented considerable variations (% FwAqP in LAC FP, % AqP in LAC FwP, and % FwI in LAC TFfI), as higher F value as more likely that influence caused by the independent variable is real. In addition, all variations that are not explained by the independent variables are represented by the residual variance, 0.19 for this model.

The Pr (>F) is the p value of the F statistics, which shows how likely it is that the F value calculated occurs if the ANOVA's null hypothesis of no difference among group means were true. For this model, the same three independent variables with high variations, presented significant p value, meaning that % FwAqP in LAC FP, % AqP in LAC FwP, and % FwI in LAC TFfI have impact on the Prevalence of Undernourishment in LAC.

According to the results presented in Table 5, the model has 0.9651 of coefficient of determination (R2), therefore 96.51% of the PoU LAC is explained by the independent variables. The standard error of regression was 0.4378; this low value indicates that the observations are closer to the fitted line.

Table 5. Results of multiple regression between Fish Driver Forces and Prevalence of Undernourishment in LAC

Residual				
Min	**1Q**	**Median**	**3Q**	**Max**
-0.652	-0.190	0.012	0.142	0.802
Coefficients				
	Estimate	**Std Error**	**T value**	**Pr(>|t|)**
(Intercept)	17.934	1.992	9.003	**3.37e-^{07}**
% FwAqP in LAC FP	-0.740	0.803	-0.922	0.372
% AqP in LAC FwP	-0.155	0.063	-2.468	**0.027**
% FwP in_LAC FfP	0.224	0.302	0.742	0.470
% FwE in LAC TFfE	-0.121	0.067	-1.807	0.092
% FwI in LAC TFfI	0.096	0.038	2.563	**0.022**
Residual standard error: 0.4378 on 14 degrees of freedom				
Multiple R-squared: 0.9651		Adjusted R-squared: 0.9526		
F-statistic: 77.34 on 5 and 14 DF		p-value: 1.08e-09		

Source: Elaborated by author, based of regression analysis output from R Studio (Zeileis & Hothorn, 2002)

The predictor variables with significant value to influence the PoU LAC are % *AqP in LAC FwP* (p value 0.027), and % FwI in LAC TFfI (p value 0.022). Regarding % Aquaculture Production in LAC Freshwater fish Production, can be analyzed its negative relationship with PoU LAC, with the increase of the production of freshwater fish aquaculture in the region, from a share of 35.83% in 2000 (data per year in Appendix 2), to 65.60% of share in the total freshwater fish production of LAC, by 2019, thus, contributing to the food availability.

The second predictor variable (% Freshwater fish Imports in Total LAC Fish Food Imports) reflected a positive relationship with PoU LAC; during the period analyzed freshwater fish food

imports grew from 4.65% (2000) to occupied 31.94% of the total fish food imports of LAC in 2019, meaning that local production did not cover satisfactory this food demand, there was less availability of freshwater fish (food commodities) produced locally.

The equation of this model is defined as:

$$\textbf{PoU LAC} = 17.93+(-0.155)*X_1 + 0.096*X_2 \qquad R^2 = 0.9651$$

X_1= % Aquaculture Production in LAC Freshwater fish Production

X_2= % Freshwater fish Imports in Total LAC Fish Food Imports

The model presents that if the aquaculture production increase its share in the total fish freswater production of LAC by one (1) unit, the PoU LAC will decrease on 0.155 units. Thus, the hypothesis H_2 is accepted. Whereas, if the share of freshwater fish imports grows one (1) unit in the total LAC fish food imports, PoU LAC will increase 0.096 units; with this is rejected the hypothesis H_3, since export variable has negative relationship with the dependent variable.

3.3.2. Multiple regression analysis for Poverty Headcount Ratio in LAC

Considering the same five (5) independent variables, of the previous regression, was design the below formula for the linear model of Poverty Headcount Ratio (PHR LAC)

PHR LAC ~ % FwAqP in LAC FP + % AqP in LAC FwP + % FwP in_LAC FfP + % FwE in LAC TFfE) + % FwI in LAC TFfI

The model summary and ANOVA of this regression generated three (3) large F values, related to probability of variation caused by the independent variables on the Poverty Headcount Ratio in LAC. % FwAqP in LAC FP, % AqP in LAC FwP, and % FwI in LAC TFfI are the independent variables with the largest amounts, as well as in the model of Prevalence of Undernourishment; having residual value of 0.67

Regarding Pr (>F) p value of the F statistics, the results confirm that the three independent variables with the highest F value, present the significant p value as well, having influence on the Poverty Headcount Ratio of LAC region. At this point can be observed the relevance of the changes on the freswater aquaculture production and the fish food imports on the tendencies of poverty and undernourishment in LAC. The results of the PHR LAC regression are presented in Table 6, the model has 0.956 of coefficient of determination (R2), therefore 95.65% of the PoU LAC is explained by the independent variables. The standard error of regression was 0.816.

The predictor variables with significant value on PHR LAC are the ones related with balance trade, % FwE in LAC TFfE (p value 0.036), and % FwI in LAC TFfI (p value 0.021).

The one with negative influence, on the dependent variable, is % Freshwater fish Exports in Total LAC Fish Food Exports; with this is rejected the hypothesis H_5, due to only fish imports had positive impact on PHR LAC. In addition, hypothesis H_4 is rejected as well, since the share of aquaculture production did not influence the reduction of poverty headcount ratio.

Table 6. Results of multiple regression between Fish Driver Forces and Poverty Headcount Ratio in LAC

Residual				
Min	**1Q**	**Median**	**3Q**	**Max**
-1.506	-0.448	0.022	0.488	1.270
Coefficients				
	Estimate	**Std Error**	**T value**	**Pr(>|t|)**
(Intercept)	25.492	3.715	6.862	7.79e-^{06}
% FwAqP in LAC FP	-0.794	1.497	-0.531	0.604
% AqP in LAC FwP	-0.205	0.117	-1.745	0.102
% FwP in_LAC FfP	0.099	0.564	0.176	0.103
% FwE in LAC TFfE	-0.289	0.125	-2.321	**0.036**
% FwI in LAC TFfI	0.182	0.070	2.593	**0.021**
Residual standard error: 0.816 on 14 degrees of freedom				
Multiple R-squared: 0.956		Adjusted R-squared: 0.941		
F-statistic: 61.62 on 5 and 14 DF		p-value: *4.926e-^{09}*		

Source: Elaborate by author based of regression analysis output from R Studio (Zeileis & Hothorn, 2002)

Agriculture exports in the region are considered a driver of production growth, depending of open trade and the global market. This last one is increasingly volatile and fragile, with geopolitical fragmentation risk, improved internal market integration and functioning of small and medium enterprises, cooperatives and family farms could expand trade within the region, thus diversify market opportunities and improve the sector's resilience.

About Freshwater fish Imports in Total LAC Fish Food Imports, alike the previous regression with PoU, this variable presented positive relationship with PHR LAC; increments of Freshwater fish imports might generate less development of fish and aquaculture sector, affecting purchasing power and food access, as well.

The equation of this model is defined as:

$$\textbf{PHR LAC} = 25.492 + (-0.289) * X1 + 0.182 * X2 \qquad R^2 = 0.9565$$

$\mathbf{X_1}$= % Freshwater fish Exports in Total LAC Fish Food Exports

$\mathbf{X_2}$= % Freshwater fish Imports in Total LAC Fish Food Imports

The model presents that if the Freshwater fish Food Exports increase its share in the total Fish Food Exports of LAC by one (1) unit, the PHR LAC will decrease on 0.289 units. On the other side, if the share of Freshwater fish Imports grows one (1) unit in the Total LAC Fish Food Imports, PHR LAC will increase 0.182 units.

The results of these regressions confirm the strong influence of Fish Imports, World Bank (2013) projections identified increase of fish imports dependency in some regions, from 14% in 2000 to 34% in 2030.

The impact of freshwater fish exports on the reduction of PHR LAC, and the aquaculture production on the decrease of PoU LAC, as identified in the results of this chapter, are aligned with the benefits of aquaculture on household incomes observed in other studies (Kawarazuka & Béné, 2010).

For aquaculture, national and household studies tend to focus on export value chains and use diverse approaches. They suggest some degree of poverty alleviation and possibly other positive outcomes for adopters, but these outcomes also depend on the small-scale farming contexts and on whether adoption was emergent or due to development assistance interventions. (Béné et al., 2016). On the other side, population and income growth have been identified as key drivers on agricultural commodities, in the case of fish products, during 2013-2022 these were determined mainly by population growth (OECD/FAO, 2023)

3.4. Emerging role of fish products as an animal protein source in LAC by 2030, and comparative analysis with developing regions

It was performing an extended cointegration and causality analysis in this research, taking into account that previous studies have shown oil prices influence on food production index (Esmaeili & Shokoohi, 2011), meat prices index (Roman et al., 2020; Zmami & Ben-Salha, 2019), and agriculture raw materials (Tiwari et al., 2020).

The analysis was developed to determine crude oil prices influence on LAC fish prices, traded in exports and imports, and its substitute animal protein commodities; since it has been demonstrated that fish prices are impacted by increased competition from other protein sources. Augmented production and falling prices of other protein sources will lead to a softening of demand and reduced prices of aquaculture and capture fisheries products (OECD/FAO, 2023). Thus, the analysis of this macroeconomic factor impact was extended to the animal protein prices of other developing regions, as well.

OECD/FAO (2023) has identified a tendency of agriculture commodities traded between regions, the net exporting positions are kept by Americas, Eastern Europe and Central Asia, while the net importing ones are Asia, Middle East and Africa. This can be observed in the animal protein trade as well, as Figure 7 reflects with the three regions analyzed, where LAC has a strong export net and MENA region with trade deficit on these commodities.

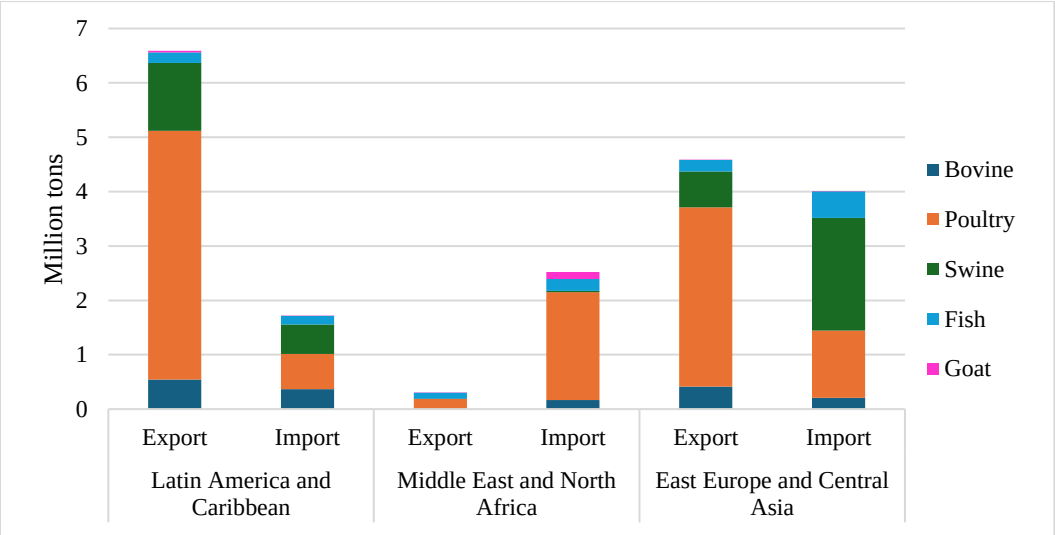

Figure 7. Distribution of animal protein traded in the developing regions, by 2021

Source: Elaborate by author with data from UN-Comtrade and FAO-STAT

It is evident that MENA and EECA presented a higher amount of animal protein imports than LAC. These regions are facing a significant challenge in meeting their protein needs, and the projection to increase in net trade deficit highlights the need of a multi-faceted approach that

considers both the quantity and quality of the imported protein, as well as the development of domestic production capabilities to ensure long-term food security in the region.

About world meat consumption, it continues to grow at one of the highest rates among major agricultural commodities; meat trade was led mostly by expansion of poultry and bovine shipments. Increased demand for meats will mostly stem from large economies in Asia, crude oil exporting countries in Latin America.

In the consideration of the fish role in the LAC region, price is an important aspect to analyze; projections refers to slightly reduction but remaining high relative to historic levels (OECD/FAO, 2023). Besides oil and energy prices as part of the analysis of agricultural sector, has been widely integrated, considered energy price forecasts for medium and long-term analysis s (OECD/FAO, 2012).

3.4.1. Analysis of Stationary data

As part of the data treatment for the statistical analysis of crude oil prices influence on animal protein prices traded during 2000 to 2021, Auto- and Cross- Covariance and -Correlation Function (ACF) and Augmented Dickey Fuller Test (ADF) were applied to all animal protein prices data of each country and the respective balance trade. Identifying the non-stationary condition of the time series data with ACF, and the p-value with the ADF test. Through difference function was applied 3 differences to all variables (oil prices, animal protein prices) to become the data stationary, thus running ADF again to each time series data was confirmed that all are with ADF p-value below 0.05.

The ACF plots support the confirmation that all data is stationary and enable to analyze. The second test developed to confirm the stationary of the data was the Augmented Dickey Fuller Test (ADF) , including the test regression. The results per animal protein prices, for exports and imports reflect that the whole data (fish, bovine, poultry, swine, and goat) considered for LAC, EECA and MENA rejected the null hypothesis (H0), meaning that the residual data to use in the statistical analysis is stationary, and can be considered for cointegration analysis.

3.4.2. Co – integration analysis

Based on the Phillips and Ouliaris test was determined the long-run relationship between global crude oil prices and animal protein prices (export – exports) for the most traded countries of these animal protein commodities in each developing region.

In LAC, the null hypothesis was rejected in most of the countries and trade balance (H0: there is not cointegration between the oil prices and animal protein prices), meaning that there is cointegration, as long-run relationship, between the oil prices and export-import prices of the animal protein prices in the LAC countries analyzed. The only case of exception for the long run relationship was the import prices of poultry in Chile, whose significant value reflects that there is not cointegration between these prices and the crude oil prices.

The results of the cointegration assessment of MENA countries rejected the null hypothesis, reflecting that the import and export prices traded for these commodities presented long term influence of the global crude oil prices, as well. Whereas EECA presented another exception case in Romania, goat import, which accepted the null hypothesis.

3.4.3. VAR model and causality analysis

The last component of the statistical analysis, to identify trend forecasting and short run relationships, involved the Vector Auto Regressive model (VAR), Impulse Response Function (IRS), forecasting and granger causality test. It was identified that the optimal lags, to develop the VAR model, were four (4), thus, the coefficient and equation were estimated for each of the animal protein, countries and regions.

3.4.3.1. Impulse Response Function (IRF)

The IRF plots results reflect that the responses of LAC animal protein prices to shocks or changes in oil prices were in most of the cases close to zero, interpreted as significantly low. For LAC export prices, there were cases of exception with high impulse response, in Argentinian prices of Bovine (-4 to 2), poultry (-8 to 6) and goat (-8 to 6), Dominican Republic with poultry prices (-60 to 60), Chile with goat prices (-10 to 10), and Ecuador, which had the highest fish export prices of the region, presented high impulse response on this as well (fish export, -4 to 2).

While import prices impulse response did not present large difference, but relatively similar ranges; there were three (3) high responses on Brazilian prices for bovine (-2 to 3), Uruguayan prices for swine (4 to 4), and Mexican prices for goat (-500 to 500).

In EECA export prices is highlighted the case of Poland that was part of the largest export countries of the region in four animal proteins, except by goat. The highest impulse response was on fish export prices, between -2 to 2. Russia presented the highest impulse response on swine (-2 to 1) and goat export prices (-5 to 5). While Hungary has similar impulse responses (-1.5 to .5) in the export prices of bovine, poultry, and swine. The impulse response on EECA import prices were, mainly, significantly lower. Few countries' exception, such as Poland with fish prices (-5 to 5), and Slovakia in poultry prices (-4 to 4).

In MENA, the results reflect impulse responses more heterogeneous, being swine's exporter countries, the ones that present most of the high IRF. The response is less significant in the animal protein import prices of MENA. Swine with Oman (-4 to 4) and Egypt (-10 to 10) presented high IRF; in fish import prices is highlighted Oman (-4 to 4); and bovine with Egypt (-4 to 2).

Considering the results of impulse responses, can be analyzed from three (3) approaches:

- From the perspective of animal protein commodity: there is not a pattern of high response focuses on a specific animal protein commodity; it was found that cases of exception were mainly linked with region's features.
- Trade flow: it was identified that export prices of countries in MENA and LAC presented more variation and larger ranges than in import prices. In the case of EECA, there were less high impulse responses than the other regions, thus there is not a considerable difference in the IRF of prices traded.
- Regional and countries features: this was identified as a relevant factor of the impulse responses of oil prices variation on animal protein prices, since the results of each region presented their particularities.
  For MENA region, swine export prices were the most influenced with oil prices shocks, three (3) of the largest countries presented wide ranges in the IRF, and the two (2) exception cases in swine imports had some of the highest ranges, as well.
  On its side, in LAC, Argentina was the country with more high responses in export prices (bovine, poultry and goat), this country presented some of the highest export prices of the region, for bovine and goat, then would be interesting to analyze in further studies if countries with high prices traded are more vulnerable to variation of oil prices.

3.4.3.2. VAR Forecasting

LAC fish prices for exports and imports are projected to have similar fluctuation ranges. Both, fish export and import, prices in the region are expected to rise. bovine export prices of the region are projected to fluctuate in the upcoming years, finalizing the period with increasing prices tendencies. While bovine imports prices are estimated to have slightly higher variation than export prices; nevertheless, ending the period with reduction in the import prices, by exception of Uruguay.

Poultry is the animal protein commodity that projects less export prices variation in LAC; while poultry import prices are projected to have a small increase at the end of the period, by except of Colombia.

It was identified common tendencies between the countries, depending on the commodity and its trade flow. Export prices tendencies in most of the largest exporter countries of LAC, specifically for poultry and swine, present decreasing projections. The outlook for import prices reflects an increasing trend in fish, poultry, and swine, while is estimated for bovine a decreasing tendency. Fish is the only commodity whose export and import prices would have the same tendency direction (to increase).

Regarding MENA prices, the tendencies are more diverse, it cannot be determined patterns in the price changes of group of countries from a commodity or a trade flow, since there are different directions on the projections of prices trends. Thus, the regional and country features are highlighted as the outstanding approach for the forecasting of animal protein prices in MENA. Swine prices traded in the region are estimated to have largest variations; and cases as Saudi Arabia and Oman reflect prices fluctuations with common tendencies among the commodities traded by same country.

For EECA, was identified more common prices tendencies between the countries, with general projections of decreasing export prices for fish and swine, increase import price of fish and reduction on import prices for poultry. Whereas, for bovine, goat, poultry export, and swine import are estimated diverse tendencies among the countries.

3.4.3.3. Granger Causality test

The last component was the Granger causality test, reflecting that in the period analyzed (2000 to 2021) oil price influence in short run was presented in reduced animal protein prices of LAC countries, those that rejected the null hypothesis (H0 = Oil price does not cause animal protein prices); implicating that the consideration of past and current prices of crude oil can predict future prices of those animal protein traded in the countries; highlighting that Mexico and Uruguay were the ones with more short term correlation between oil prices and commodities' prices traded.

Poultry prices were the unique animal protein that did not present short-term influence of oil prices in none of the largest LAC exporter and importer countries. Followed by swine, whose results show that there was not causality in none of swine importer countries, and by except of Brazil, all the swine exporter countries did not have short term impact of oil prices. The result of LAC fish export prices confirmed that there was not short-term influence from oil prices; and for fish import prices traded, particularly by Mexico and Peru, where the only countries that reject the null hypothesis, thus these prices reflected oil prices short term influence.

The short run impact of oil prices on the animal protein prices in LAC countries is not defined by the balance trade side, non the sort of animal protein commodity, but it might be for the particular conditions of each country.

From EECA countries' approach, was recognized that the few cases (7) of countries with Granger causality of oil prices on their animal protein prices traded, were mainly in export trade, and concentrated in Russia (Bovine imports, swine export, goat export), Croatia (fish import), Belarus (bovine export), Ukraine (bovine export), Poland (swine export). While in MENA region, at least one country presented short run relationship of oil prices and each of the animal protein commodities; eleven (11) granger causalities identified in the region; Egypt, Jordan and Oman are the countries with most of the causalities.

Regarding the instantaneous granger cause, it was identified that the consideration of future oil prices influences or allow to predict better the future prices of animal protein in LAC countries. This causality was found in countries of the five-animal protein analyzed, being bovine export and swine (export and imports), the ones with more countries that presented instantaneous causality.

In the results of MENA and EECA were observed that instantaneous granger cause has signicant results in the animal protein prices for both regions as well; in EECA, this impact was identified, largely, on swine export and import prices (Poland, Hungary and Czechia), and goat export prices (Bulgaria, North Macedonia and Slovakia). The fish export prices were the only segment in EECA on which all countries did not present this causality; whereas fish import prices present instantaneous causality in Russia and Belarus. Poultry was another animal protein in the region, whose import and export prices in most of the cases did not have instantaneous causality.

On the other side, instantaneous granger cause in MENA were established for the prices of fish exports (Oman, Tunisia, Saudi Arabia), fish imports (Kuwait, Lebanon, Oman), bovine imports (Jordan, UAE, Kuwait), and goat imports prices (Saudi Arabia, Qatar).

Taking into account the results presented in both regions, can be confirmed that in these exists the same feature that in LAC, concerning that short run and future influence of oil prices on the animal protein prices traded in these developing regions is defined mainly for particular conditions of each country, instead of balance trade flow, or animal protein commodity.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

All the LAC countries analyzed have developed policies and programs, with long term approach, to guarantee food and nutritional security to the population, and boost the fish and aquaculture activity. Nevertheless, in the integration analysis was identified that fisheries concept is widely used in the documents, tackling it as poverty population in fisheries areas, few of them highlight contributions of fish and aquaculture to the food availability. Thus, the hypothesis (H_1) set is rejected, since the development of Freshwater fish Aquaculture in LAC has not been supported with the integration of fishing and aquaculture sector on the food security national policies.

There are gaps still present in LAC on the knowledge of the contribution of this sector to improve purchase of power, be source of healthy and nutritious food, and unawareness of the causal relationship between aquaculture and food security. Ecuador is one of the countries with high integration of fishing, establishing it as strategies to of health food to vulnerable communities, through the fish consumption.

Aquaculture production has been growing in LAC, which is not reflected in rise on per capita fish consumption of the region, although its role in the trade of fishmeal is significant, achieving 40% of the global fishmeal exports.

Considering the three criteria contemplated in the integration analysis, climate change is the one that have been most integrated in the food security policies of the LAC countries, as part of programmatic focus (Guatemala), critical issue that can restrict food production (Mexico and Costa Rica), prioritized to implement measures of climate changes adaptation, to guarantee access to adequate food at every time (Peru and Honduras).

From the food availability approach results, it was recognized that LAC is a net exporter region of animal protein commodities, led by poultry and bovine products. During the period analyzed (2000 – 2021) fish production traded did not grow at the same level as the biggest animal protein traded in LAC. Fish commodities trade passed from occupied the second position in the region to the third one with an extensive difference in the shares, respective bovine, and poultry.

The region is among the largest fish producers, which is not reflected in rise on per capita fish consumption of the region, although the LAC role in the trade of fishmeal is significant, achieving 40% of the global fishmeal exports. Whereas the participation of Freshwater fish Aquaculture in the fish production of LAC, has been growing in the last decades, however its contribution is still considered low (5.51% by 2021). The importance of this sector remains on the food options from Freshwater fish commodities, on this, aquaculture is the dominant method of fish food production in LAC (65.60% by 2021).

Aquaculture production have been growing in LAC, and according to FAO's projections (2020), LAC aquaculture is anticipated to provide 33% of total fish production by 2030; it was identified that the share in 2000 was 4.05%, finalizing 2021 with 21.6%. However, the aquaculture benefits highlighted by several reports and studies on fish prices (Béné et al., 2016; Kawarazuka & Béné, 2010; World Bank, 2013), such as prevent rising prices, positive impact on the purchasing power of consumers and possibly on their nutritional intake, are not currently visible in LAC, because the region's production still falls mainly on capture method; by 2021 the share of capture production in LAC was around 80%. Once the expansion of aquaculture reach out more participation in the LAC fish production, this will cause that prices of farmed fish grow slower than other animal foods source, even this growth reigned in increases of capture fish price as Belton & Thilsted (2014) mentioned.

The fish export and import prices in LAC were the second (2^{nd}) cheapest animal protein (USD/Kg) traded at the beginning of the period analyzed (2000), and from 2007 has been maintained the third (3^{rd}) position as accessible animal protein exported and imported, leading by poultry, and followed by swine.

In the driver forces from the fish aquaculture production, it was identified that the most influential one, in the Prevalence of Undernourishment and Poverty Headcount Ratio in LAC, was Freshwater fish Imports share in Total LAC Fish Food Imports, presenting positive impact on these poverty indicators. During the period analyzed this import grew from 4.65% (2000) to 31.94% (2019).

There were two (2) other driver forces with influence, but negative relationship, % Freshwater fish exports in total LAC fish food exports had negative impact on poverty headcount ratio; and % aquaculture production in LAC Freshwater fish Production was the only driver force with negative influence on the Prevalence of Undernourishment in LAC. Considering this, the hypothesis H_2 of the multiple regression has been accepted, whereas H_3, H_4 and H_5 have been rejected, as Table 7 summarizes.

From the last specific objective developed, was identified long run influence of oil prices in the fish prices traded and all animal proteins considered in this research, confirming the hypothesis H_6. The long run relationship was not exclusively of one direction of the trade, but applied for both, imports and exports prices, and these results were reflected on the animal protein prices traded by the other developing regions analyzed (MENA and EECA) as well; despite of the difference on production, balance trade, and that LAC is the largest net exporter of agriculture and fisheries commodities, amongst all the regions.

Regarding the impulse response, it was recognized that regional and countries features is the most relevant factor to determine the impulse response of oil prices variation on the animal protein prices traded, further than the particular animal protein and the trade direction or flow (import or export). It is highlighted that export prices of countries in MENA and LAC presented more variation and larger ranges than in import prices. In the case of EECA, there were less high impulse responses than the other regions.

The granger causality results of LAC fish export prices confirmed that there was not short-term influence from oil prices, therefore, rejecting the hypothesis H_7. For fish import prices traded, particularly Mexico and Peru were the only countries that reject the null hypothesis, thus these prices reflected oil prices short term influence. The prices of poultry and fish exports are the only ones that do not present correlation, short run. The short run impact of oil prices on animal protein prices in LAC countries is not defined by the balance trade side, non the sort of animal protein commodity, but it might be for the particular conditions of each country.

Nevertheless, with the instantaneous causality was determined that, in the long term, past, current, and future oil prices allow to predict better future prices of animal protein. This causality was found in LAC countries of the five animal protein analyzed, being bovine export and swine (export and imports), the ones with more countries that presented instantaneous causality; thus, hypothesis H_8 is accepted. This causality has significant results in the animal protein prices for EECA and MENA regions as well. In EECA, this impact was identified, largely, on swine export and import prices (Poland, Hungary and Czechia), goat export prices (Bulgaria, North Macedonia and Slovakia). In MENA, at least one country presented relationship of oil prices and each of the animal protein commodities.

Table 7. Research hypotheses results.

No	Hypotheses	Result
H1	The development of Freshwater fish Aquaculture in LAC has been supported with the integration of fishing and aquaculture sector on the Food Security national policies.	**Rejected**
H2	Share of aquaculture production in LAC freshwater fish production is the fish driver force that most impacts the reduction of undernourishment.	**Accepted**
H3	Share of freshwater fish production in the food balance trade of LAC influence positively on the prevalence of undernourishment.	**Rejected**
H4	Share of aquaculture production in LAC freshwater fish production is the fish driver force that most impacts the reduction of poverty headcount ratio.	**Rejected**
H5	Share of freshwater fish production in the food balance trade of LAC influence positively on the poverty headcount ratio.	**Rejected**
H6	Oil prices have long-run influence on animal protein prices	**Accepted**
H7	Oil prices have short -term influence on animal protein prices.	**Rejected**
H8	There is instantaneous causality of oil prices on the animal protein prices.	**Accepted**

Source: Elaborated by author

4.2. Recommendations

Fish and aquaculture policies are instruments ensuring food security by expanding the production and commercialization of fish and aquaculture products, thereby guaranteeing the availability of quality and safe products. Due to the low integration in the policies analyzed, considering the result of this research, the internship experience of the author in Hungarian fishing and aquaculture research centers (Research Centre for Aquaculture and Fisheries, MATE university and Institute of Animal Science, Biotechnology and Nature Conservation, Debrecen university), it was identified six (6) main factors needed to incorporate to the Fish and aquaculture policies, and Food security policies of LAC countries:

- Fish food production management:

LAC as the largest fishmeal producing region in the world, (40 % of world's fishmeal supply), and world production of fishmeal expected to expand over the next decade with the proportion of fishmeal obtained from fish residues as the main driver (OECD/FAO, 2023), locate LAC fishmeal production to be even higher by 2023 (World Bank, 2013). Therefore, fish and aquaculture policies should establish programs for the management of fish food production, with strategies to share this increasing of fish production with the rise of fish availability for human consumption in LAC countries, and as an alternative of healthy and nutritious food from fish commodities.

Should be consider that the demand for fishmeal will likely become stronger, given the expansion of the global aquaculture. Fishmeal prices have been projected to rise by 90 % (World Bank, 2013); with higher fishmeal traded, species substitution in production is expected, and animal protein source as well.

- Competitiveness of the fish products:

LAC is a net exporter region in agriculture commodities, and is among the largest fish producers, however, the animal protein commodities that led the trade are poultry and bovine. Seeing the

result of this research, LAC fish and aquaculture sector should improve its factor of production and price, to generate a trade growth at the same level of these commodities.

Freshwater fish aquaculture has been growing in the last decades; however, its contribution is still considered low (5.51% by 2021), it is necessary to expedite the transition from capture to aquaculture production basis, thus will be reflected the benefits on cost production and low fish prices traded.

According to the price tendencies identified poultry is the animal protein commodity that projects less export prices variation in LAC, while its import prices are estimated to have a small increase by 2030. Whereas fish export and import prices would present a growth tendency. Therefore, strategies on production and cost efficiency in the fish and freshwater aquaculture sector are needed to be more competitive to poultry and swine commodities. In relation to projection of the World Bank, (2013) global tilapia production is expected to almost double from 4.3 million tons to 7.3 million tons between 2010 and 2030, being this the main freshwater fish commodity produced in LAC, it is an aspect to consider in the policies, for strategies on diversification of fish production.

- Integration of trade policies:

This research focused on the analysis of fish and aquaculture contribution to food security through the trade factors, and the results reflect the extensive importance of food trade on the availability and access to agriculture commodities in the regions.

Price transmissions are affected by trade policies, where restrictive policies can effectively dampen the transmission of price volatility to domestic markets. Thus, further than the integration of fish and aquaculture policies on the food security policies, and vice versa, should be considered the integration of the national and if applicable, regional trade policies and agreements, since objectives, program and restrictions established by these ones are impacting the food access, availability, and stability.

- Per capita fish consumption:

Aquaculture production has been growing in LAC, which is not reflected in rise on per capita fish consumption of the region, although its role in the trade of fishmeal is significant. The demand of food fish commodities in the last decade was determined mainly by population growth than per capita food demand growth (OECD/FAO, 2023). The decline in the per capita fish consumption of LAC is one of the priority aspects that fish and aquaculture policies should tackle, since was identified in the policies analyzed that countries did not integrate programs and strategies to boost per capita fish consumption, as source of nutrient food, these were focused on production and improve of fisheries communities' socio-economic conditions.

- Sustainable development of aquaculture:

The results of the integration analysis reflect that climate change is one of the most relevant criteria in the food security policies of most of the LAC countries, prioritizing to implement measures for climate changes adaptation, to guarantee access to adequate food at every time, as Peru and Honduras; this approach should be extended to all national policies.

Climate change has been identified to impact with high significance the productivity of capture fisheries, where aquaculture has become the main fish production strategy, adapting process and methods to the current environmental risk. Therefore, assessment and design actions to tackle climatic risk as "El Niño" should be include in the long-term planning.

- Fish food imports dependency:

Freshwater fish imports share in total fish food import of the region, was the most influential driver force in the LAC poverty indicators analyzed. This negative impact should be prioritized to be tackled, since the share of this LAC fish imports grew from 4.65% (2000) to 31.94% (2019).

On the other hand, LAC has maintained a net export in the fish trade, being the largest fish exporter region in the world, and projected to continue leading by 2030. However, it is needed programs to reduce the fish food import dependency, and do not became a net importer of fish, considering the upcoming growth on fish demand from Asia to feed fish and livestock production, which has been supplied by LAC.

Regarding further studies in this field, it is recommended to extend the analysis of:

- Fishing and aquaculture sector contribution to the food security, considering the four components of it (availability, access, stability, and utilization) since this research focuses specifically on the availability and access component.
- Role of women in food systems, as entrepreneurs, workers and consumers evidence gaps in food systems and food policies, as Burns et al. (2014) and Kawarazuka & Béné (2010) have identified, encouraging future research to bring a gender perspective to the aquaculture sector.
- Environmental impacts of agricultural production, GHG emissions.
- As the data records allow it, is suggested to include in the analysis of food security indicators on climate change, sustainability, and in general the Sustainable Development Goals (SDG) indicators. Another segment for future research might include post-Covid impacts, by extending the period to study.
- The analysis of the external factors on fish and animal protein prices can be widely explored, since this research focused on oil prices, further studies might cover other indicators that influence the supply chain, raw materials, or inputs along the production process.
- Considering the results of the impulse response to oil prices, further studies can be developed to identify if countries with high animal protein prices traded are more vulnerable to variation of global oil prices.

5. NEW SCIENTIFIC RESULTS

- This research involved the integration of large international literature, databases and institutional reports on social-economic aspects and fish sector management. With this work there is a contribution to reduce the existing knowledge gap in issues identified, with the application of methodologies and statistical analysis.

  The results accomplished in this research provided a new frame of knowledge on the fish sector gaps identified by Béné et al. (2016) and Bostock et al. (2016), providing insights into:

  - Socio-economic policies analysis, regarding the impact of commercial fish and aquaculture activities in developing countries.
  - Knowledge gap of causal relationships between aquaculture development and food security, economic growth.
  - Freshwater aquaculture production systems regarding market demand and competitiveness.
  - Evidence of how fish production and trade translate into developmental benefits and reduce poverty.

- The policies integration results enable to clearly identify that the recent development of freshwater fish Aquaculture in LAC has not been supported with the integration of fishing and aquaculture sector on the food security national policies. Due to there are significant gaps still present in LAC on the knowledge of the contribution of fish and aquaculture sector; whereas the integration of food security within fish and aquaculture policies varies, with most countries exhibiting a moderate to high level of integration.

- The new scientific results on fish production revealed that during the period analyzed fish production traded did not grow at the same level as the biggest animal protein traded in LAC. Regarding access, it was demonstrated that aquaculture sector growth in LAC has not contributed yet, to prevent fish prices from rising. Fish commodities prices were overshadowed, in terms of competitiveness and access, with substitute animal protein traded in the region.

- The results show that the main driver force from the freshwater aquaculture activity in LAC was imports share of freshwater fish. It influenced positively the prevalence of undernourishment and poverty headcount ratio of LAC, while aquaculture production and exports share freshwater fish were the driver forces that contributed to the reduction of these poverty indicators in the region.

- This study confirms the long run influence of oil prices on the fish prices and all animal proteins prices traded that were analyzed; this relationship was not exclusive of the trade direction. This long run impact was evidenced in the prices traded by the other developing regions analyzed (MENA and EECA) as well.

- The results proved that the short run impact of oil prices on the animal protein prices in LAC countries, and the other regions, was presented in scarce cases. Therefore, short run

influence and the impulse response of crude oil prices variation on the animal protein prices, in the developing regions, is not determined by the sort of animal protein or the trade direction, but it is determine by the countries and regions features or particularities.

- The finding of instantaneous causality between crude oil prices and the animal protein prices reveals that the inclusion of past, current, and future oil prices allow to predict better future prices of animal protein of these regions. This research developed the first analysis of oil price influences on animal protein prices, covering several commodities, providing details of cointegration with export and import prices, and allowing the contrast of results among developing regions. There was no published research on the impact of fish commodities, and specifically on animal protein products.

6. SUMMARY

The aim of this research is to provide wide details of the aquaculture and freshwater fish aquaculture contribution to the food availability and food access in LAC, analyzing it from economics aspects as international trade, fish price, and the role of fish as animal protein source in the region. This social and economic analysis considered the identification of the integration level of this economic sector in the food security policy of the region's countries, and its contribution to food production and affordability.

The research was developed through three specific objectives and the consideration of eight hypotheses; tackling policy integration analysis, driver forces from aquaculture production, and influence of crude oil prices, as external factor, on the animal protein prices traded (fish, bovine, poultry, swine, and goat) in LAC, and two developing regions, MENA and EECA.

The methods considered in this research involved content analysis for the identification of policies integration; structure of regional statistics considering production and trade indicators of the sector. Besides cross-sectional time-series data for multiple regression analysis; and for the last chapter was developed cointegration, Vector Auto Regressive (VAR), and causality analysis.

Among the results are highlighted that there has been a low integration of aquaculture in the food security policies of the region; climate change is one of the criteria that have been most integrated in the food security policies of the LAC countries.

It was demonstrated that freshwater fish aquaculture has been growing in the last decades, however its contribution is still considered low (5.51% by 2021). The importance of this sector remains on the food options from freshwater fish commodities, and this aquaculture activity is the dominant method of fish food production in LAC (65.60% by 2021). Moreover, the results confirmed long run influence of oil prices in the fish prices traded and all animal proteins considered in this research. This relationship was not exclusively of one direction of the trade, but applied for both, imports and exports prices. The results were reflected on the animal protein prices traded by the other developing regions analyzed (MENA and EECA) as well.

The short run impact of crude oil prices on the animal protein prices in LAC countries, and the other regions, was presented in scarce cases, identified that it might be defined by the particular conditions of each country. The impulse response of crude oil prices variation on the animal protein prices, in the three develping regions, is not determined by the sort of animal protein or the trade direction, but it is determine by the countries and regions features or particularities, as well.

The finding of instantaneous causality reveals that the inclusion of past, current, and future crude oil prices allow to predict better future prices of animal protein of these regions. Being bovine export and swine (export and imports) the ones on which was found more cases for LAC; swine export, import and goat export prices in EECA; while in MENA fish exports, imports, bovine imports, and goat imports.

Considering the new finding in the results and the contribution to the gap knowledge on the fish sector was recommended the integration of six factors to the fish and aquaculture policies, and food security policies of LAC countries:

- Fish food production management
- Competitiveness of the fish products
- Integration of trade policies
- Per capita fish consumption
- Sustainable development of aquaculture
- Fish food imports dependency.

Regarding further studies in this field, it is recommended to extend the analysis the four components of food security (availability, access, stability, and utilization) since this research focuses specifically on the availability and access; analysis women's role in food systems; assess environmental impacts of agricultural production, analysis of the external factors on fish and animal protein prices.

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