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Impact of the Climate Change on the Production of the Fishing and Aquaculture Sectors of Latin America

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ABSTRACT

In the last decade, Latin American countries have been afflicted by climatic changes that may affect the productivity of their populations and affect their economies. The objective of this study is to identify the impact of climate change on the production of the fisheries and aquaculture sector of Latin America. Through a random-effects model, the factors and components of climate change that may have an impact on fisheries and aquaculture production were analyzed. It was observed that as the average temperature increased by 1%, the fisheries and aquaculture production decreased by −0.08%. However, the variable is not statistically significant. Similarly, during rainfall, a decrease in the aquaculture and fisheries production of −0.22% could be observed, but this is not significant in relation to 5%. Finally, concerning CO_2 emissions, these had an incidence in the increase of the fisheries and aquaculture production of 0.53%, being statistically significant. This work contributes to the literature on the effects of climate change on Latin American fisheries production, to serve future policies that help to mitigate these environmental effects.

Keywords: Aquaculture, Fisheries, Latin America, Production, Climate Change, Econometric Models
JEL Classifications: C5, F1, Q5, Q57

1. INTRODUCTION

The number of companies at an industrial level, as well as the number of artisans in the fisheries and aquaculture sector, has increased in Latin America. At the same time, the countries of this region have implemented regulations for the exploitation of fishery resources through extraction quotas for this productive factor, whereas, in the case of aquaculture, more production hectares have been created. The Commission for Small-Scale, Artisanal Fisheries, and Aquaculture for Latin America and the Caribbean (COPPESAALC), created in 1976 with the objective of promoting responsible fishing, is made up of Argentina, Bolivia, Brazil, Colombia, Chile, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Dominican Republic, Uruguay and Venezuela (FAO, 2019).

The Latin American Alliance for Sustainable Fishing and Food Security (Alpescas) is made up of the fishing industries of Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Mexico, and Peru, and was instituted in 2018 with the aim of promoting the development and sustainability of industrial fishing. At the sixth meeting of this conclave, its members signed an agreement with Bureo. Inc., to use nets and fishing gears that range from 1,500 tons as recycling material for the production of caps, an action that would seek to reduce the carbon footprint (El Universo, 2021).

Most of the Latin American countries that are off the Pacific and Atlantic coasts have been able to exploit a wide range of marine species thanks to their geographical location (Benseny, 2020); hence, the fishing industry has promoted trade, which is consequently depleting certain species that are now in danger of extinction. Scientists say that between 0.97% and 1.97%

of species have disappeared from the ocean due to garbage, agricultural runoff, and oil spills (Mood, 2010). During the 21st century, dynamic and positive fishing and aquaculture have been encouraged, as this sector has contributed to fighting poverty, hunger, and malnutrition. In addition, measures and solutions have been adopted for climate change, oceans, and sustainability (FAO, 2021).

Aquaculture is the study and technique of cultivating living species, animals, and plants in salt and fresh water; records of this ancient activity date back around 3,800 BC. in Asia. The cultivation and commercialization of microalgae, crustaceans, clams, oysters, mussels, and mollusks, the main species exploited, has generated economic growth worldwide. Technology and innovation have played a vital role in increasing production (FAO, 2014).

Human subsistence depends on aquatic products like fish, crustaceans, shellfish; resources from the sea, lakes, and rivers, which provide a substantial natural food pantry. It is worth noting that anyone can work extracting this resource (Gómez de la Maza, 2011). The world is experiencing climatic changes, whose origin is related to earth temperature, the increase in industrial technology, and the burning of fossil fuels such as carbon dioxide, according to scientists (CO_2) (United Nations, 2021).

On July 11, 2016, an agreement was made on Port State Control measures since illegal fishing threatens marine ecosystems, subsistence, and food security in the world (FAO, 2016). The International Plant Protection Convention (IPPC) aims to conscientiously prevent the contamination of resources and reduce waste and atmospheric, aquatic, and soil emissions (Department of Economic Development, Sustainability, and Environment, 2019).

The Intergovernmental Oceanographic Commission (IOC) must achieve objective 14, which determines the conservation and sustainability of the ocean and its resources by 2030. 150 member states work together for the salubrity of the ocean. This commission has a platform for the exchange of data (United Nations, 2019). The impact on climate change due to the increase in carbon dioxide emissions in the atmosphere in Latin America translates into variable temperatures: hot and cold waves, as well as meteorological phenomena such as typhoons, hurricanes, floods, droughts, and the rise in sea levels on the Pacific and Atlantic coasts due to the melting of glaciers (World Wildlife Fund, 2016).

At the global level, the ocean supports the economies of the countries, and also facilitates the transit of 90% of world trade, since it covers 70% of the earth's surface. Oceans constitute a determining factor of the weather and climate of the planet (World Meteorological Organization, 2019). The National Meteorological and Hydrological Services (NMHS) oversee the ocean through effects models and the changes that occur, considering that the ocean is an essential resource (World Meteorological Organization, 2019).

The International Convention for the Safety of Human Life at Sea, 1974 (SOLAS CONVENTION), is the most important treaty for the safety of merchant ships that verifies compliance with certified standards and procedures (International Maritime Organization, 1980).

The International Hydrographic Organization (IHO) promotes international cooperation and coordination. Furthermore, it expands hydrographic information to preserve vulnerable and protected marine areas worldwide (International Hydrographic Organization, 2021). Illegal, unreported and unregulated fishing (IUU fishing) carried out by national or foreign vessels without the consent of the territorial jurisdiction leads to the irresponsible exploitation of living marine resources (FAO, 2020).

Fisheries and aquaculture represent 3% of the total GDP of El Salvador, Honduras, and Nicaragua, countries that expand on the Gulf of Fonseca, a fragile ecosystem in the Central American Pacific, where a temperature increase of 1-2°C is expected for the years 2020-2050, and a temperature increase of 3-4°C is expected at the end of the 21st century (OSPESCA, 2020).

The Western Central Atlantic Fisheries Commission (WECAFC), founded in 1973 and made up of some Latin American countries, aims to promote the conservation, management, and efficient development of marine living resources under the code of conduct for responsible fishing practices (FAO, 2013). Ecosystem factors, such as variability and climate change, can affect the productivity of populations, which in turn affects the rebuilding of time frames (Sinclair and Crawford, 2005; Holt and Punt, 2009; Holsman et al., 2016).

This research aims to identify the impact of thermal temperature on fish and aquaculture production. Hene, it will be possible to identify at a global level if the countries of Latin America have been affected, considering that rainfall also affects this economic sector, in addition to analyzing whether the CO_2 emissions produced by industrialized and artisanal fishing boats that sail in the Atlantic and Pacific oceans decreased or increased. It should be noted that 90% of the Latin American countries are privileged due to their geographical location as they are surrounded by these two oceans.

Considering that fishing and aquaculture are food resources that provide added value to the labor and capital of the producing countries, these have been exploited and investigated in this last century. Consequently, an increase has been observed in the national and international markets due to their consumption (CEPAL, 2020). Latin American countries have been affected by various climatic changes in the last decade, which vary depending on the country and the season, and include deforestation, melting glaciers, hurricanes, heavy rains, landslides, cyclones, and droughts.

Through a panel data method, the production of the fishing and aquaculture sectors of Latin American countries will be studied during the period from 2014 to 2019 concerning the incidence that climate change may have, to identify if structural changes derive from the relation of production with the variables thermal temperature, rainfall, CO_2 emissions, and others. The results will allow identifying if there has been a significant change in this economic sector. Researchers Alnafissa et al. (2021) carried out this methodology in Saudi Arabia on how climatic factors influence fish production. While Ahmed et al. (2019) focused on a documentary level on how various climatic factors such as temperature and rainfall would affect future fish production.

2. THEORETICAL FRAMEWORK

In order to determine the impact of environmental factors on fisheries production in Latin America, a brief review of the existing literature was necessary to learn about the development of studies on these environmental determinants, concretely the fisheries field, from various perspectives and different contexts. This confrontation allows us to understand what progress has been made so far on the subject, the relationship between the factors studied, and how these experiences allow the understanding of the analysis exposed in these lines.

Recent research conducted in Saudi Arabia by Alnafissa et al. (2021) highlights an analysis of the effect of climate and environmental change on the sustainable performance of capture fisheries. The study focused on determining the current state of marine fishery production, taking into account the most relevant environmental factors that could affect production, thus, estimating the maximum sustainable yield in the Arabian Gulf and the Red Sea during the 2000-2019 period. A set of climatic, environmental, and economic variables was approached under descriptive statistical analysis and multiple regression, which revealed, through statistical evidence, the relationship between these variables and the impact.

The results obtained indicate that the most important factors in fishing production are wind speed, the number of boats, and fishermen. This shows a significant positive relationship between the sum of production and the number of boats and fishermen. This relationship is established through the Gordon-Schaefer Model applied in the Maximum Sustainable Yield, whose explanation is that fish production does not increase sustainable capacity, although it could increase with decreasing returns. The contribution of the study can be demonstrated in relation to the estimates using alternative statistical parameters.

The study by Zeng et al. (2019) on the "Effects of climate change and fisheries on the ecosystem and fisheries of the Pearl River Estuary (PRE)" examines the effects of climate change on fishing activities carried out in the Pearl River estuary, for this purpose, they implemented the Ecopath Software with Ecosim (EwE) that allows understanding marine ecosystems with significant levels of complexity. Study results showed that the warming factors of the oceans and changes in the net primary production (NPP) directly influence the biomass and the production of the fisheries in the Pearl River Estuary. Moreover, projections suggest that the transformation of fish species caused by climate change could be due to trophic interactions.

It is concluded that the combined impact of climate change and fishing causes a reduction in the catch in the Pearl River Estuary. Therefore, reduced fish catching will scale down the repercussion of climate change on selected functional groups. However, there is a non-linearity around the responses given by the estuarine ecosystem in the face of climate change patterns due to other environmental factors. In conclusion, the simulation (Ecopath with Ecosim (EwE)) of the effects caused by the warming of the oceans in a climate change scenario is decisive in fish production.

Along these lines, it is also worth mentioning the study carried out by Ahmed et al. (2019), who, in their article "global aquaculture productivity, environmental sustainability and adaptability to climate change," warn about the immense environmental challenges aquaculture production must face due to climate change. The researchers emphasize, through a review of the literature, that climatic variables are those that preponderantly influence the production of fish since the risks are concentrated in droughts, global warming, variation in rainfall, cyclones, floods, the elevation of the sea levels, and the alteration in the salinity levels of the waters. This puts production under high pressure, resulting in the stagnation of fisheries catches.

Ahmed et al. (2019) affirm that these factors represent a decisive environmental impact on the possibilities of increase and sustainability of aquaculture. Therefore, they consider that it is imperative to develop analyzes and estimates on the behavior of these environmental variables and their impact, to generate strategies and policies that allow sustainable aquaculture development. This study, like the previous ones, focuses on the analysis of environmental factors since these allow evaluating the sustainable possibilities of fishing, notwithstanding, they have proposed different approach methodologies, which coincide in that the estimates and valuations of environmental variables are crucial to favor the development of fish production.

On the other hand, the study by Wurmann (2019) presents an important experience. In "Aquaculture in Latin America and the Caribbean: Progress, Opportunities, and Challenges," Wurmann analyzes the role that fishing has had from 1990 to 2018, which has been decreasing over the years. The region crops represent 21% of regional landings, so its main R and D efforts have been directed towards the diversification of native species fisheries and the coexistence of various small and large-scale production models, the domestic market, passive exports, and variability in the levels of competitiveness, which evidence a low level with respect to other regions in the world.

The documentary course of the study is based on the analysis of categories such as fishing figures in the region, types of crops, and cultivated species. The result of these analyzes and reflections is reduced to a large factor that would be influencing the possibilities and opportunities for the development of fisheries in the region and implies governance, and its local difficulties, in which factors such as litigation and environmental situations intervene, the same that have an impact on the sustainability and better performance of fishing in the continent. Evidence of government problems, fishing users, management and little research, and environmental situations will imply a slowdown in the production levels.

Consequently, Bell et al. (2018) used a winter temperature estimation model, projecting future climate and fishing scenarios in their study "Reconstruction in the face of climate change" analyzed a group of species. Nevertheless, the research suggests it is unlikely that the species will recover to historical levels under the winter temperature since the impact recorded was lower in the projection. The study concludes that the change experienced and the climate changes affect the quality and quantity of the fish rearing and spawning and, hence, their productivity. These results provide relevant information on climatic factors that may affect the management of fish stocks in the future.

For their part, Parker et al. (2018) analyzed the use of fuel and greenhouse gas emissions produced by global fisheries practices. The study focused on quantifying the fuel inputs and greenhouse gas (GHG) emissions produced by the world fishing fleet between 1990 and 2011, comparing fishing emissions with other productions, such as agriculture. Study results showed consumption of approximately 40 billion liters of fuel in the 2011 period, which caused the emission of 179 million tons of CO_2 or greenhouse gases, which would be equivalent to 4% of emissions worldwide.

Similarly, emissions from industrial world fishing from 1990 to 2011 increased by 28%, which explains that an increase in production prompts an increase in fuel consumption emissions. This increase was mainly due to the increase in catches. However, the study suggests that if a higher proportion of landings made more catches for human consumption than for industrial consumption, the environment would be favored since these employ colossal amounts of fuel in fishing activities. It is interesting to observe how the results obtained by Bell et al. (2018) have important points that can be related to those obtained by Parker et al. (2018), by showing that the catch of fish can be affected by factors such as the winter season, as well as the increase in fishing exploitation, which will cause an impact due to the increase in fuel administered during the catch.

Another interesting study is the one published by Hobday et al. (2016); the research called "Seasonal forecasting for decision support in marine fisheries and aquaculture" points out that ocean temperature holds influence over fisheries and aquaculture production.

Therefore, based on their analysis and reviews of the scientific literature, the researchers suggest that seasonal forecasts allow obtaining information on environmental conditions, considering water temperature, rainfall, air temperature, and other climatic factors since they estimate that these factors can influence the development of cultivated species and the distribution of these aquaculture populations. The information on seasonal forecasts is utile for fisheries production and commercialization activities because it benefits decision-making, considering that there are currently various procedures and statistical tools that help to this end. In this regard, the study points to the planning of meteorological and climatic conditions, considering that they represent a risk in fishing management.

The study by Cheung et al. (2016) stands out, "Large benefits to marine fisheries of meeting the 1.5°C global warming target," where the authors projected the maximum potential for capture and rotation of species concerning climate change. Specifically, the authors modeled the influence of increased temperatures on 2 key measures for the sustainability of fishing: capture, and species rotation. It was concluded that limiting the temperature increase to 1.5°C considerably favored the capture potential and reduced the rotation of the species caught. According to projections of this study, catches would decrease by 3 million tons per degree Celsius of warming. Using a Dynamic Bioclimatic Envelope Model, the warming of the atmospheric and oceanographic surface was projected between 1950 and 2100, which led to the conclusion that the changes vary according to the ecosystems. The results of the study showed that reaching a global warming target of 1.5°C and maintaining it would have benefits for marine fisheries.

Although there is currently abundant literature that supports an undeniable effect of environmental factors on fish production, it is also patent that there are new approach methodologies that provide attractive data that add to the discussion, considering that climate scenarios, seasonal changes, and environmental conditions, in general, are uncertain, fluctuating, and could, in some way, present different manifestations concerning those already foreseen. This quick review revealed that Latin America, with respect to other regions, has a variation in climatic conditions throughout the year, which are generated as a result of the emission of greenhouse gases (Montecinos, 2011), and other natural phenomena, making this continent an attractive region for research. Researchers have noticed a complex marine reality, and that the factors can vary, depending on the characteristics of the reality studied. On this occasion, it is revealed that seasonal variables, environmental factors, and forecasts based on mathematical and statistical models ultimately contribute to the forecast.

Through a panel data analysis on the variables of fishery and aquaculture production with the incidence of climate change factors, temperature, rainfall, and CO_2, during the period from 2014 to 2019, the present study found a gap in Latin American literature on the effects of climate change on fish production to serve for future policies that help mitigate these environmental effects. As a result, the following hypotheses are established:
H1: Temperature has a negative and significant impact on Latin American aquaculture and fisheries production.
H2: Rainfall has a negative and significant impact on Latin American aquaculture and fisheries production.
H3: CO_2 emissions have a positive and significant impact on Latin American aquaculture and fisheries production.

3. DATA AND METHODOLOGY

3.1. Data Source and Variables

This section describes the data collection of aquaculture and fisheries production concerning climatic variables such as carbon dioxide emissions, temperature, and rainfall in the 18 countries that make up Latin America (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Dominican Republic, Uruguay) during the period 2014-2019. A panel data model that allows measuring the pooled effect of climatic factors on aquaculture and fisheries production at the Latin American level was selected for the joint analysis of the variables.

The dependent variable of fisheries and aquaculture production was obtained from the sum of aquaculture production, which consists of the cultivation of aquatic organisms, including fish, mollusks, crustaceans, and aquatic plants, measured in metric tons. In contrast, fisheries production measures the volume of marine species caught by a country for commercial, industrial, recreational, and subsistence purposes, measured in metric tons. Both variables were obtained by world development indicators of the World Bank. This variable was used by Alnafissa et al. (2021) to determine the impact of climate and environmental changes on the sustainable performance of capture fisheries in Saudi Arabia.

Regarding the independent variable of CO_2 emissions, these are derived from the burning of fossil fuels and the manufacture of cement. These include the carbon dioxide produced during the consumption of solid, liquid, and gaseous fuels, and the burning of gas, measured in kilotonnes.

This variable has been studied in the fishery sector by Greer et al. (2019), in relation to the global trends of carbon dioxide emissions derived from the burning of fuel in marine fisheries from 1950 to 2016, and has also been used by Tefera and Ali (2019) in their study on the impacts of climate change on fish production and its implications for food security in developing countries. Temperature is the degree or intensity of heat present in a substance or object, expressed according to a comparative scale and displayed by a thermometer or felt by touch, measured in degrees centigrade. Finally, precipitation is the long-term average in depth (over space and time) of annual precipitation in the country. Precipitation is defined as any form of water that falls from clouds in liquid or solid form, measured in average millimeters. All the variables were obtained by the world development indicators of the World Bank.

3.2. Econometric Model

The use of panel data methodology is defined as a cross-sectional time-series data set that ideally provides repeated measurements of a number of variables over a period of time in observed units. A cross-sectional data set consists of observations on a number of variables at a given time, while a time series data set consists of one or more variables of observations over several periods. In a panel data set, the number of repeated measurements on the same variables in the same population or sample can be as small as two (Hill et al., 2018).

One of the advantages of using panel data is increasing the number of observations for analysis. This is especially true for the pooled Ordinary Least Squares (OLS) model. Technically speaking, observations that are repeated over time allow lower standard errors compared to those estimated by cross-sectional data analysis. This implies a higher number of observations due to the accumulation of cross-sectional data, which increases the estimation accuracy and, therefore, there are increased possibilities for statistically significant estimates. However, the fundamental advantage of using panel data lies in its effectiveness, allowing researchers to examine cause and effect employing before and after observations (Stock and Watson, 2015).

Although cross-sectional data analysis is still effective in examining the causal relationship based on theoretical research models, in a strict sense, it is difficult to identify which variable "affects" others because it lacks the temporal dimension that is one of the essential components for the causal relationship. Similarly, the stability of the relationship between the dependent variable and the independent variables can be examined. The cross-sectional analysis only examines relations at a single point in time, whereas we can explore dynamic variations in relations with panel data.

Panel data contain information on temporal and spatial dimensions. The time dimension is the period in which repeated measurements are made, such as a month, a quarter, and a year, and the spatial dimension is the unit of observations, such as people, companies, and states. The general panel data regression model can be expressed as follows:

Equation 1

$$y_{it} = \beta_0 + \beta_1 x_{it,\,1} + \beta_2 x_{it,\,2} + \ldots + \beta_k x_{it,\,k}$$
$$+ v_{it}\,,\ i = 1,..,N; t = 1,..,T; k = 1,..,K$$

Where:
i is the unit of observation.
t is the time period.
k indicates the k-th explanatory variable.
β_0 is the intersection.
β_k is the coefficient of each explanatory variable.
v_{it} is the error term.

The so-called composite error term, v_{it} in equation 1 can be decomposed into two components: a specific error of the cross-sectional unit, $\alpha_{i,}$ and an idiosyncratic error, $\mu_{it} I$

Equation 2

$$v_{it} = a_i + \mu_{it}$$

The specific error of the transverse unit α_i does not change with time and idiosyncratic error μ_{it} varies along cross-sectional units and time (Gujarati, 2003). The motivation and benefits of decomposing the error terms into two parts is that if a part of them could be eliminated using panel data, it would be better in terms of minimizing concerns about omitted variable bias caused by factors specific to the unit not measured. By incorporating equation 2 into equation 1, we have the following equation:

Equation 3

$$y_{it} = \beta_0 + \beta_1 x_{it,\,1} + \beta_2 x_{it,\,2} + \ldots + \beta_k x_{it,\,k} + a_i + \mu_{it}$$

Equation 3 is called the error component model. The time constant and the unit-specific error α_i are unobserved factors. Examples include the capacity of the individual when the unit of observation is individuals and the unique culture and institutions of states where the unit of observation is the states. These factors can be considered invariant in time and, at the same time, it is extremely difficult to measure them. The estimation methods of the error component models are classified according to how they treat the error term α_i The pooled OLS model does not distinguish it from other types of errors, while the fixed effects model considers them as coefficients to estimate and the random effects model treats them as random variables (Wooldridge, 2013).

One of the most basic and simple methods to estimate Equation 1 is to simply pool the data and apply the OLS. To estimate Equation 1 using pooled OLS, it is required to assume that the composite error term v_{it} is not correlated with the explanatory variable x_{itk} (Wooldridge, 2013). This means that only when there are no cross-sectional or temporal effects can we pool the data and run OLS regression models. The combined OLS version of Equation 1 can be expressed as follows:

Ecuation 4

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + v$$

In equation 4, the subscripts i and t disappear due to the previous assumption. There are some drawbacks to the pooled OLS method. The dashboard data contains the information for time and cross-sectional dimensions. However, pooled OLS ignore this information from the dashboard data. Also, the pooled OLS assumption is unrealistic because it is not possible to measure all unit-specific and time constant effects α_i, and include them in the model. Therefore, when using OLS to analyze dashboard data, the assumption is usually violated. In this case, the pooled OLS estimator is biased and inconsistent (Wooldridge, 2013).

Fixed effects are variables that are constant between individuals, it could be argued that these variables could change over time. The opposite of fixed effects are random effects. These variables are, as the name suggests, random and unpredictable. In this sense, the fixed effects follow the following equation:

Ecuation V

$$y_{it} - \overline{y} = \alpha + \left(x_{1-}\overline{x}\right)'\beta + (e_{it} - \overline{e}_1 + \overline{e})$$

Instead, the random effects consist of an OLS estimate of the transformed model:

Ecuation VI

$$y_i - \hat{\lambda} y \overline{y_i} = \left(1 - \hat{\lambda}\right)\mu + \left(x_{it} - \hat{\lambda}\overline{x_i}\right)'\beta + v_{it}$$

$$v_{it} = \left(1 - \hat{\lambda}\right)\alpha_i + \left(e_{it} - \hat{\lambda}\overline{e_i}\right)$$

$$\lambda = 1 - \sigma_e / \sqrt{\sigma_e^2 + \sigma_\alpha^2}$$

In this study, a log-log model was applied since logarithms can interpret elasticities directly and show more efficient results compared to the functional form of a simple linear model (Ehrlich, 1996). In this sense, the panel data model can be expressed as follows:

Ecuation VII

$$LPROD = \beta_0 + \beta_{PREC} LPREC$$
$$+\beta_{TEMP} LTEMP + \beta_{PREC} LPREC + \varepsilon$$

Where:

- PROD: Fisheries and aquaculture production
- TEMP: Annual average temperature
- PREC: Average annual rainfall
- CO2: Carbon dioxide emissions

Regarding the expected signs, for the temperature variable, the expected sign is expected to be negative since Ahmed et al. (2019) indicate that global warming and the consequent increase in water temperature could have dramatic effects on the future aquaculture production. According to De Silva and Soto (2009), the variation in rainfall potentially undermines aquaculture production, so the expected sign is negative. Finally, with respect to CO_2 emissions, a positive sign is expected and this is due to the fact that as the fishing industry uses more resources such as fuels for its activities, this has an impact on the increase in carbon dioxide emissions (Parker et al. Fuel use and greenhouse gas emissions of world fisheries, 2018).

4. RESULTS

The evolution of aquaculture and fisheries production in Latin America during the 2014-2019 period is presented below. In general, it is observed that aquaculture and fisheries production has had an increasing behavior, being that in 2014 16.91 million metric tons were produced. For 2015 the figure grew by 17.02 million tons at a growth rate of 0.7%. For 2016, production decreased by 15.69 million metric tons at a rate of −7.9%. For 2017, a rebound in production was observed with a value of 17.15 million metric tons at a rate of 9.3%. In 2018 the trend continued, and a growth of 20.32 million metric tons evidenced a growth rate of 18.5%, and for 2019 production stabilizes and reaches a value of 21.38 million metric tons at a rate of 5.2 % (Figure 1).

The evolution of the average temperature in Latin America during the 2014-2019 period is presented below. It is generally observed that the temperature behavior has fluctuated, being that in 2014 it was 22.27°C. For 2015 the temperature grew by 22.55° at a growth rate of 1.2%. For the year 2016, the temperature decreased by 22.39° at a rate of -0.7%. For 2017, a slight increase was observed with a value of 22.40°C at a rate of 0.1%. In 2018, a drop of 22.06°C was evidenced at a rate of 1.4%, and for 2019 the average temperature increases again and reaches a value of 22.37° at a rate of 0.1% (Figure 2).

This paragraph analyzes the evolution of rainfall in Latin America during the period 2014-2019. In general, it is observed that rainfall

Figure 1: Evolution of fisheries and aquaculture production during the 2014-2019 period. Data obtained from the World Bank (2021)

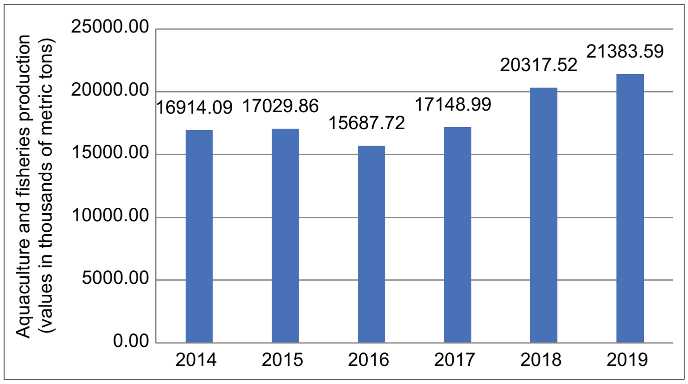
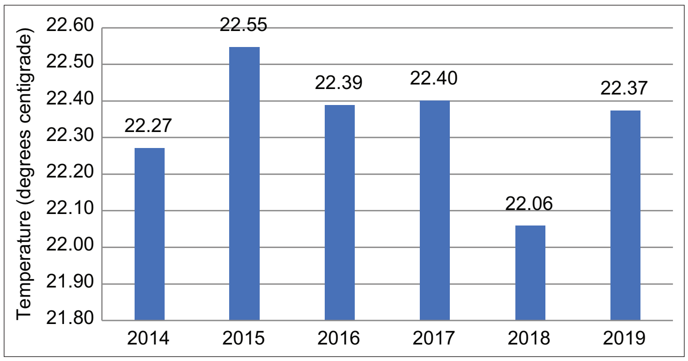


Figure 2: Evolution of the average temperature during the 2014-2019 period. Data obtained from the World Bank (2021)



has had a fluctuating behavior, being that in 2014 rainfall reached 30,262 millimeters. For 2015, rainfall decreased by 29,212 millimeters at a rate of -3.5%. For the year 2016, rainfall grew by 29,307 millimeters at a rate of 0.3%. For 2017, a rebound was observed with a value of 31,382 millimeters at a rate of 7.1%. In 2018, a drop of 30,016 millimeters was evidenced at a rate of −2.5%, and for 2019 rainfall is reduced again and reaches a value of 29,255 millimeters at a rate of −0.6% (Figure 3).

This section presents the evolution of CO2 emissions in Latin America during the 2014-2019 period. In general, it is observed that carbon dioxide emissions have had an increasing behavior, being that 1.61 million kilotonnes were produced in 2014. For 2015 the figure decreased by 1.60 million kilotonnes at a growth rate of -0.3%. For 2016, CO_2 emissions decreased by 1.58 million kilotonnes at a rate of −1.6%. For 2017, a rebound in production was observed with a value of 1.62 million kilotonnes at a rate of 2.8%. In 2018 the trend continued and a growth of 1.67 million kilotonnes was evidenced at a growth rate of 2.8%, and for 2019 production stabilizes and reaches a value of 1.72 million kilotonnes at a rate of 1.3% (Figure 4).

Below is the dispersion graph for fisheries and aquaculture production and the average annual temperature in Latin American countries. The results suggest a negative relationship between the study variables, so that an increase in temperature leads to a decrease in fisheries and aquaculture production (Figure 5).

Figure 3: Evolution of rainfall during the 2014-2019 period. Data obtained from the World Bank (2021)

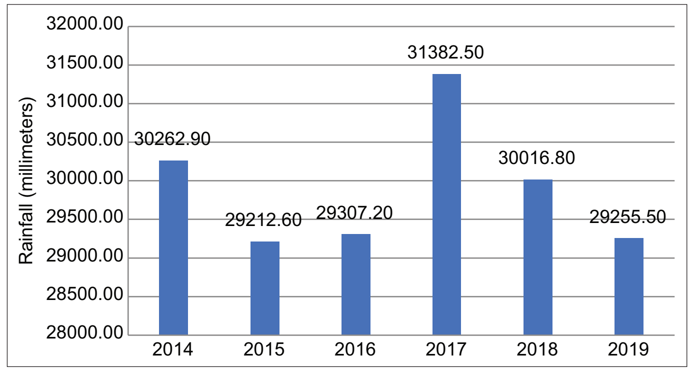


Figure 4: Evolution of CO_2 emissions during the 2014-2019 period. Data obtained from the World Bank (2021)

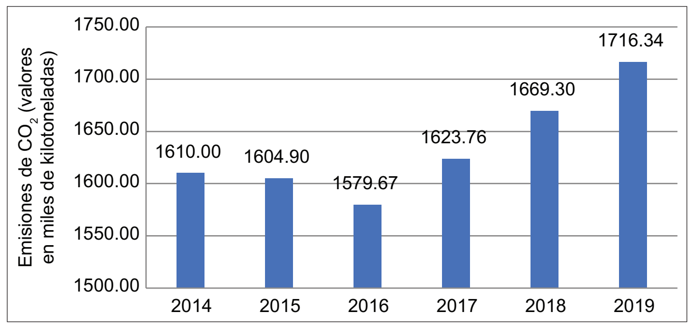
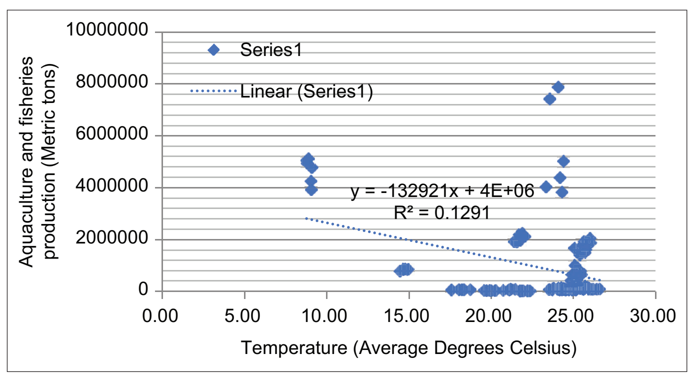


Figure 5: Scatterplot for fisheries and aquaculture production and temperature. Data obtained from the World Bank (2021)



Regarding the scatter plot for fisheries and aquaculture production and the average annual rainfall in Latin American countries, the results suggest that the variables behave inversely, that is, an increase in rainfall leads to a decrease in fishery and aquaculture production (Figure 6).

Regarding the scatter plot for fisheries and aquaculture production and CO_2 emissions in Latin American countries, results suggest that there is a positive relationship between the variables, so that an increase in carbon dioxide emissions would imply an increase in the fisheries and aquaculture production (Figure 7).

The results of the pooled model are shown below, where the Ordinary Least Squares (OLS) estimation methods, the pooled

Figure 6: Scatter plot for fisheries and aquaculture production and rainfall. Data obtained from the World Bank (2021)

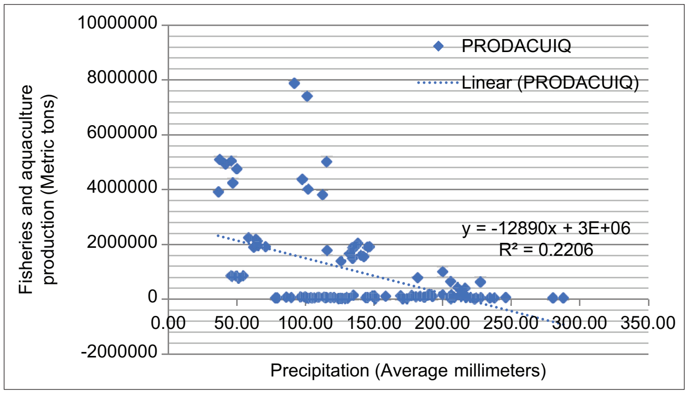
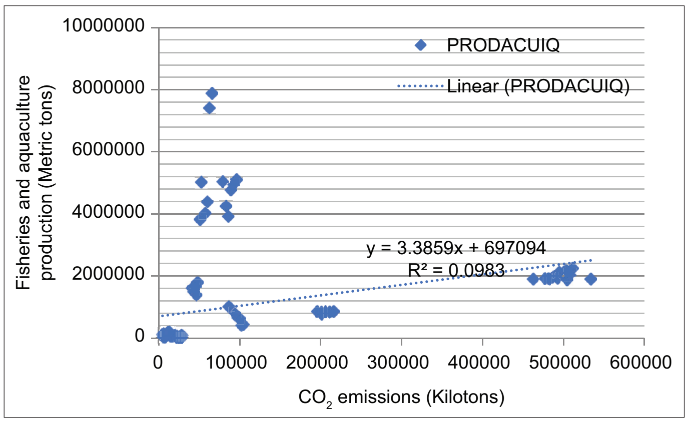


Figure 7: Scatter plot for fisheries and aquaculture production and CO_2 emissions. Data obtained from the World Bank (2021)



model, the fixed and the random-effects models have been used. The results suggest that for the OLS, the pooled and the random-effects models, the constant and CO2 emissions are significant for aquaculture and fisheries production. On the other hand, in the fixed-effects model it is observed that none of the climatic factors explains the fisheries and aquaculture production (Table 1).

With regard to the selection of the best model, the following diagnostic tests were used: the multiple Lagrange FF test, the individual F test or effects over time, and the Hausman test for panel models. In general, it is observed that the Lagrange test suggests using random effects on OLS. On the other hand, the F test suggests that fixed effects models should be used compared to the pooled model. Finally, the Hausman test was applied to determine whether to use fixed or random effects, where the p-value suggests the use of random effects instead of fixed effects (Table 2).

In this light, it should be noted that the random-effects model suggests that as the average temperature increases by 1%, fish and aquaculture production will decrease by −0.08%. However, the variable is not statistically significant. Regarding rainfall, it is observed that an increase of 1% of the same leads to a decrease in aquaculture and fishing production by −0.22%, but this is not significant at 5%. Finally, the 1% increase that CO_2 emissions imply in the 0.53% increase in fisheries and aquaculture production is statistically significant.

5. DISCUSSION

This study analyzed how climatic factors affect fisheries and aquaculture production in Latin America, for which a random effects panel data model was applied, where variables such as temperature, rainfall, and CO_2 emissions were analyzed as variables that explain the fisheries and aquaculture production. The results suggest that hypotheses 1 and 2, which refer to variables temperature and rainfall, although negatively affect production, do not have statistical significance, which is not fully proven. On the other hand, concerning hypothesis 3, it is observed that CO2 emissions significantly influence fisheries and aquaculture production by 0.53%, which has been proven. In this sense, the signs obtained were contrasted with the empirical evidence.

Hypothesis 1 suggests that the negative sign of water temperature shows that in tropical and subtropical regions, the temperature may have increased in recent years as a result of global warming, which could have severe effects on fish production. The global average temperature could rise 4°C by 2100 (IPCC, 2014). An increase in water temperature could exacerbate multiple consequences, including changes in the ecosystem functioning of freshwater ponds (Woodward et al. 2010). According to Ficke et al. (2007), a minuscule increase in water temperature (1-2°C) could cause sublethal physiological effects in tropical fish.

An increase in water temperature above 17°C would be detrimental to salmon aquaculture (De Silva and Soto 2009). Sea surface temperature could also increase due to the effect of GHGs and global warming (IPCC, 2014). Rising temperatures could intensify the incidence of toxic algal blooms and red tides, which pose a risk to shellfish production (De Silva and Soto 2009).

Regarding the second hypothesis on rainfall, climate change affects the intensity and variability of rainfall with adverse effects on fish productivity. Annual rainfall is likely to decrease in Mediterranean Africa, northern Sahara, and southern Africa, potentially reducing aquaculture opportunities in these regions (Barange and Perry, 2009). Water levels in fish ponds vary remarkably with relation to variations in rainfall, which has also increased the risk of floods and droughts. Early or late rainfall with sudden heavy rains can cause devastation in coastal and inland aquaculture.

Heavy rains also cause erosion and turbidity of the water, which reduces the productivity of fishing activities. By 2050, climate change may increase rainfall erosivity by 17% in the US (Nearing et al., 2004) and by 18% in Europe (Panagos et al., 2017). Abnormal rainfall patterns could affect salinity variation in brackishwater aquaculture. Low rainfall could increase the concentration of salinity in coastal aquaculture with adverse effects on brackish water ecosystems. Ultimately, variation in rainfall potentially undermines aquaculture production (De Silva and Soto 2009).

Finally, with respect to empirical evidence that supports the findings of hypothesis 3, Robb et al. (2017) explain that the growth of aquaculture has increased greenhouse gas (GHG) emissions. Average GHG emissions from aquaculture were estimated at

Table 1: Panel data model

Aquaculture and fisheries production	Multiple linear regression	Regression of the pooled model	Fixed-effects regression	Random-effects regression
Constant	7.39063***	7.390633***		8.208148*
Temperature	−0.32096	−0.320955	1.03377	−0.083922
Rainfall	−0.52357	−0.523573	−0.18495	−0.222281
CO_2	0.82720***	0.827200***	0.24764	0.536905***

*,**,*** are the significance levels of 10%, 5% and 1% respectively

Table 2: Model selection tests

Test	Valor P
Lagrange FF multiplier tests for panel models	2.2E-16
F- test for individual and/or time effects	2.2E-16
Hausman test for panel models	0.08444

Developed by the authors of this research

2.12 kg CO_2e/kg of live weight of carp in India, 1.81 kg CO_2e/kg of live weight of Nile tilapia in Bangladesh, and 1.61 kg CO_2e/kg of live weight of striped catfish in Vietnam. In this sense, the authors assert that aquaculture products are considered the largest source of greenhouse gas emissions due to the production and transportation of raw materials, the use of energy in food plants, and the high rate of food conversion.

The results obtained coincide with the studies by Ghosh et al. (2014), who analyzed the contribution of marine fishing in Visakhapatnam in all stages of its life cycle to climate change during the 2010-2012 period, by determining the carbon footprint.

The pre-capture phase consisted of the construction and maintenance of boats and the supply of fishing gear; the collection phase included the collection of mechanized and motorized vessels, and the post-collection phase included the transport and processing of fish. The functional unit selected was 1 kg of marine fish to the consumer. The consumption of fuel and electricity was 0.48 l/kg and 0.255 kWh/kg of fish. The CO_2 emissions recorded were 0.382 kg C/kg and 1.404 kg CO_2/kg of fish.

Parker et al. (2018) presented another perspective and explained that CO_2 emissions come from the fuels used by the fisheries and aquaculture sectors. The authors estimated that fishing activities consumed 40 billion liters of fuel in 2011 and generated a total of 179 million tons of greenhouse gases, equivalent to CO_2.

Emissions from the global fishing industry grew by 28% between 1990 and 2011, with a small coincidental increase in production (average emissions per landed tons increased by 21%). The authors explain that the increase in emissions was mainly driven by increased catches of crustaceans that required excessive amounts of fuel.

Climate-related changes that affect ecological functions and the frequency, intensity, and location of extreme weather events include changes in temperature, rainfall, greenhouse gas emissions, sea levels, among others (Cochrane et al., 2009; FAO, 2016). A variety of impacts can be expected as a result of these changes, both direct and indirect, in fisheries and aquaculture. Scientific knowledge on the impact of individual climatic factors varies, and information on the combined effects of these factors is limited. This uncertainty complicates adaptation planning within the sector. Human agents, such as pollution, dam building, and unsustainable fishing, are exacerbating the damaging impacts of climate change.

There is evidence that climate change is modifying the distribution of marine species. Many species are migrating to the poles and deeper waters in search of ideal habitat conditions (e.g., oxygen levels). These migrations lead to changes in the interaction dynamics between species, trophic links and trophic networks. When migration is not possible, some aquatic species are prone to experience changes in size, reproductive cycles, and survival rates. The impacts, both positive and negative, will depend on the region and latitude. Certain commercial species are likely to move offshore and away from traditional fishing grounds, and new invasive species are likely to fill that gap. If these new species are suitable for human or animal consumption, new livelihood opportunities may arise in specific communities (FAO, 2016).

Despite the invasion of species tolerant to higher temperatures and changes in the chemical content of coastal waters, the productivity of ecosystems is likely to decline in most tropical and subtropical marine environments, seas, and lakes. The projected scenarios indicate higher productivity of capture fisheries in high-latitude systems but lower productivity in low- and mid-latitude systems. Coastal systems are particularly vulnerable to temperature increase, hypoxic zones, acidification, and extreme weather events (FAO, 2016).

6. CONCLUSION

The objective of this research work was to analyze the impact of climate change on aquaculture and fisheries production in Latin America during the 2014-2019 period. In this sense, a panel data model was applied, where the dependent variable was fisheries and aquaculture production measured in metric tons, and the variables representing climate change were temperature, rainfall, and carbon dioxide emissions.

The initial results showed that during the study period, aquaculture and fisheries production showed an increasing behavior, revealing an average growth rate of 5.2%, and registering its highest point in 2019 with a total production of 21.38 million metric tons. Concerning the average temperature, a fluctuating behavior was observed, showing a slight annual growth of 0.1%. On the other hand, rainfall also recorded the same volatile behavior as temperature, with an annual decrease of −0.6%. Finally, CO2 emissions evidenced a growing trend, whit an annual growth rate of 1.3%.

The scatter plots for the relationship between aquaculture and fisheries production and each climatic factor showed a negative relationship with the temperature and rainfall variables. However, a positive relationship with CO_2 emissions was observed, suggesting that as carbon dioxide emissions increase, aquaculture and fisheries production increases.

Finally, the application of a panel data model made it necessary to choose between the estimates of multiple linear regression, pooled data, fixed and random effects. The results of the Hausman test suggested the use of the random-effects model, which indicated that the signs found in the scatter plots were validated. In this sense, the interpretation of the coefficients indicates that in the face of an increase in the average temperature by 1%, fisheries and aquaculture production will decrease by −0.08%. Regarding rainfall, it is observed that an increase of 1% leads to a decrease in aquaculture and fisheries production of −0.22%. Finally, the 1% increase in CO_2 emissions implies an increase in fisheries and aquaculture production of 0.53%. Finally, it was observed that temperature and rainfall are not statistically significant.

Climate change may acutely affect the fisheries and aquaculture sector, causing a severe impact on post-harvest activities, processes that add value to the production, and fish distribution to local and national markets. There may be potential changes in the location and variability of supplies, and changes in the way to access other major inputs, such as energy and water for processing. All of these climate-induced changes will occur simultaneously as other global, regional, and national socio-economic pressures are exerted on natural resources. This will amplify the impacts on food security and nutrition, housing, and social stability (FAO, 2021).

To build resilience and sustain production in a changing climate, aquaculture producers must adapt to the options available in the short term while mitigating the effects by making the necessary adjustments to their long-term production practices. As time goes by, the aquaculture and fisheries sector keeps growing, and climate change becomes more evident. Ergo, the adoption of a holistic approach is necessary to project the effects of climate change on aquaculture and address these impacts. Consequently, mitigation and adaptation strategies would be more effective (FAO, 2016).

Some climate change adaptation strategies, including integrated aquaculture, the expansion of seafood production under coastal aquaculture, and mariculture, potentially increase fish production. Integrated rice and fish culture, integrated pond aquaculture-agriculture, and polyculture can increase fish production with reduced environmental impacts. Integrated shrimp and mangrove farming that respects the environment and is committed to mangrove restoration could contribute to blue carbon sequestration and mitigate climate change (De Silva and Soto, 2009).

Another strategy is the Integrated Multi-Trophic Aquaculture (IMTA), which is an ecosystem-based approach to growing fed fish (fish), organically extracted species (shellfish), and inorganically extracted species (algae) of different trophic levels in an integrated farm to create balanced systems for environmental sustainability. Furthermore, the expansion of mariculture on land and at sea could increase seafood production while reducing environmental impacts to climate change and promoting adaptation (Buck et al., 2018).

Recirculating Aquaculture Systems (RAS) are inland fish farms with closed containment farming systems where biofiltration is needed to purify water and remove toxic metabolic waste from fish. The RAS can be operated with fresh, brackish, or marine water, which will then be filtered, recycled, and discharged into fish tanks. By reusing water with the help of mechanical or biological filters, RAS can be expensive to install and operate but are environmentally friendly and highly productive (Ahmed and Turchini, 2021).

The proposed aquaculture strategies contribute significantly to global fish production, while positively affecting both environmental sustainability and adaptability to climate change. However, institutional support with technical and financial assistance is needed to implement these strategies.

Key parties, including international agencies, researchers, policymakers, governmental and non-governmental organizations, and fish farming communities, must collaborate in the implementation of these strategies. Social, economic, and ecological challenges must also be identified and addressed to facilitate proposed adaptation strategies. Empirical research is needed to understand the interrelated processes of increasing aquaculture productivity, environmental sustainability, and adaptability to climate change.

6.1. Study Limitations

Within the limitation of the study, it can be said that climatic factors such as CO2 emissions caused by the aquaculture and the fisheries industries have not been found. This would allow identifying the impact caused by global warming more accurately. Furthermore, another limitation is that Latin American countries have not conducted studies on the variables analyzed at the individual level.

6.2. Future Lines of Research

It is expected that future research will analyze other climatic factors such as cyclones, droughts, floods, ocean acidification, salinity, and sea-level rise, conductive to establish how this affects aquaculture fish production, with the aim of having a global view on how climate change affects the fishing sector.

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