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Research Article

Industrial Marine Fishing in the Face of Climate Change in Peru

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Peru's industrial fishery centers on the Peruvian anchoveta (*Engraulis ringens*), which is highly productive due to the marine conditions of the Humboldt Current. However, like elsewhere, the country's marine fishing industry is linked to climate change. The objective of this study is to analyze the relationship between industrial marine fishing and climate change in Peru. Correlation and linear regression methods were used. A key variable of climate change is the sea surface temperature (SST). The study found that in Peru during 1997-2020, the higher the SST, the lower the industrial fishing catch ($\alpha = 5\%$). There is also evidence of an inverse correlation between sea level and industrial catch; i.e., sea level rise would alter marine ecosystems. A positive correlation between landings of industrial marine fishing and exports for nonfood purposes was corroborated, especially fishmeal. The study concludes that the industrial Peruvian anchoveta catch is negatively affected by SST, fishing effort (search time in hours), and catch per unit of effort (CPUE). For the sustainability of Peru's industrial fishery, climate change adaptation measures, such as a reduction of fishing effort and research on alternative production of fishmeal with unmodified natural inputs without or in combination with anchoveta, should be implemented. For the future, a change in fishing policies is required that replaces anchoveta for fishmeal with a warm-water marine species during strong El Niño events.

1. Introduction

Although the Humboldt Current System (HCS) is the fundamental cause of the high productivity of Peru's sea resources, the country's industrial marine fishing economy is coming under increased threat from climate change factors that limit the sustainability of traditional fishmeal and fish oil exports, composed almost entirely of the Peruvian anchoveta. Indeed, of all marine fish landed in Peru in 2022, the Peruvian anchoveta catch predominated, accounting for 86.7% of all landings. The majority came from the north region, where 2.3 million tons were caught. Nonfood uses include catches from industrial marine fisheries to manufacture fishmeal and fish oil, with a predominance of anchoveta catches above 95% in the 1997-2020 study period and 99.9% from 2003 onwards.

The Peruvian anchoveta's migratory behavior from its cold coastal water (CCW) habitat has allowed the species to remain in the marine ecosystem of the Humboldt Current System. The anchoveta's distribution tends to be favored by CCW that varied according to the season. For instance, in the spring of 2019, the anchoveta was found in temperatures below 22.1°C, and in the winter of 2020, they were found at temperatures lower than 17.2°C. In addition, the anchoveta was always found in salinities below 35.2 ppt (parts per thousand) [1].

During the decades since 1980, the coastal ecosystem of the eastern Peruvian-Chilean upwelling boundary system has been disturbed by occasional occurrences of extreme ocean temperatures or marine heat waves (MHW) [2]. Longer and more intense El Niño events related to marine MHW in the global ocean tend to overshadow shorter-duration MHWs, which are significantly more common in the region. Analyzing sea surface temperature data from 1982 to 2019, Pietri et al. [2] found that long-lived MHWs (>100 days) preferentially affect the coastal zone north of 15°S but have decreased in both occurrence and intensity over the past four decades. On the other hand, shorter events, which represent more than 90% of all observed MHWs, are more common south of 15°S and show an increase in their thermal impact as well as in the number of days affected—with ranges from 30 to 100 days becoming increasingly frequent. Anchoveta populations are known to be influenced by periodic El Niño weather events [3]. In Peru, the 2017 El Niño event reduced anchoveta landings.

Peru's anchoveta fishery is subject to a complex regulatory system marked by two different regimes: one for the north-central marine region and another for the south [4]. The landing of anchoveta for nonfood purposes (that is, for the meal and oil industries (known in Peru as the catch for "indirect human consumption")) decreased by 21.8% in 2022 from 2021 (Table 1). Similarly, in 2019, landings were affected by the warm Kelvin wave [5]. The fishing effort of Peru's industrial purse-seine fleet in the extraction of anchoveta in the north-central region was likewise higher during the second season of 2020 than in the previous season; consequently, the catch per unit of effort (CPUE) was lower [6].

De la Puente et al. [7] reconstructed small-scale fishing effort over time, from 1950 to 2018, and found that effort increased considerably, and at a much faster rate than catches, since 2006 in particular. The decline in catches is due to variability in oceanographic conditions. The combined effect of these trends resulted in significant declines in catch per unit effort, income per unit effort, and fishers' earnings relative to Peru's minimum wage, indicating that the increasing fishing effort is unsustainable and wasteful [7].

To obtain the value of the anchoveta fishery in northern Chile and southern Peru, Chávez et al. [8] calculated the final (export) value per landed ton based on the export price of fishmeal together with the amount of exported fishmeal that is produced by processing landed anchoveta. The estimated added value per ton of that landed in northern Chile was US$317/ton, while in southern Peru, it was around US$258/ton.

In 2020, 54.5% of the total value exported by the Peruvian fishing sector came from the foreign exchange earnings from shipments of fishmeal and fish oil of US$ 1,562 million, mainly to the Asian market as an input for its aquaculture industry. For Peru in 2020, foreign exchange for fishmeal per MT (US$1,195,600 thousand/873.5 thousand MT) was US$1,369 per ton [9]. Globally, each year, 15 million tons of fish landings are bound for the production of fish oil and fishmeal, most of which comes from whole fish. In the production process, 100 kilograms of raw material produces around 21 kilograms of fishmeal and 3-6 kilograms of fish oil [3]. Peru is among the countries with the largest fishmeal industries, alongside Iceland, Denmark, Chile, Norway, and South Africa [3].

But in Peru and Latin America in general, even though the ocean makes a substantial contribution to GDP, the full potential of the blue economy has yet to be realized. The Peruvian coast stretches for 3,000 kilometers from Ecuador in the north to Chile in the south, encompassing diverse ecosystems including coastal wetlands, bays, and hundreds of islands and capes [10]. Two species of small pelagic fish inhabit the southern coast of Chile and Peru, the anchoveta (*Engraulis ringens*) and the sardine (*Strangomera bentincki*), which are important species in terms of their ecological interactions and their economic value [11].

Table 1: Landings of hydrobiological resources, Peru, 2021-2022 (thousand MT).

Use	2021	2022	Var. % 2022/2021
Total	6,641.0	5,436.7	-18.1
Food purposes	1,470.8	1,396.1	-5.1
Nonfood purposes	5,170.2	4,040.7	-21.8
Anchoveta	5,170.2	4,040.7	-21.8
Other species	0.0	0.0	0.0

Source: Anuario estadístico de pesca y acuicultura 2022.

Small pelagic fish (SPF) play extremely important ecological roles in marine ecosystems, constitute some of the most economically valuable fishery resources, and play a critical role in global food security. Because of their short generation times and their close coupling with lower trophic levels, SPF population exhibit pronounced boom-and-bust dynamics that are intimately linked to climate variability [12]. Atmospheric and oceanographic processes such as global climate change can affect spawning conditions, fish populations, and coastal communities [13]. Moreover, greenhouse gas (GHG) emissions and industrial fishing have increased in parallel since about 1850, and both are processes whereby human activity affects SPF [14]. The anchoveta fishery exhibits diverse socioeconomic and environmental telecouplings and interactions across distances [15].

The net negative impacts of extremely high temperatures on fish stocks are expected to include disruption to fisheries' socioecological systems, particularly in climate-vulnerable areas, leading to increasing losses in fishing income and livelihoods in most maritime countries [16]. Therefore, Ojea et al. [17] consider social and institutional factors to improve climate change adaptation in fisheries. In 2020, of the total global fisheries catch of 90.3 million tons, 78.8 million tons came from marine waters, 4% less than in the previous three years. Of these marine catches, finfish accounted for 85%, and anchoveta was once again the main species caught [18]. The Peruvian anchoveta, of global importance, is also one of the most exposed to variability and climate change. Salvatteci et al. [19] reconstructed the oceanographic conditions of the global warm period during the last interglacial period between 116,000 and 130,000 years ago, using sediments from the North Humboldt Current System off the coast of Peru—a productivity hotspot for small pelagic fish. In contrast to the current conditions in which anchoveta predominate, the last interglacial period was characterized by far smaller species (mesopelagic and gobies) and a very low abundance of anchoveta. This indicates the threat that global warming poses to the world fish supply [19].

With regard to the main trophic pathways that lead to high landings of anchoveta, Massing et al. [20] found that five species explain the high trophic transfer efficiency (TTE) of the northern HCS, and that zooplankton species, especially copepods and euphausiids, are essential food sources for anchoveta and sardine.

This study is relevant because the Peruvian anchoveta is one of the most productive species in the world due to the marine conditions of the Humboldt Current, and industrial fishing for fishmeal and fish oil exports has made Peru the largest global producer of fishmeal, but both are threatened by climate change. And as well as being the basis of the Peruvian fishing industry, anchoveta is essential to the food chain and plays a key role in the Peruvian marine ecosystem [21]. In addition, Peru's blue economy promotes economic growth [22, 23] and UN Sustainable Development Goal 14 to sustainably conserve and use the oceans, seas, and marine resources. The main objectives of the present study are to analyze the relationship between the industrial fishing marine economy and climate change in Peru and to estimate the relationship between the sea surface temperature and the industrial anchoveta catch. In Peru, industrial fishing for indirect human consumption (nonfood uses) consists of marine fishery catches to manufacture fishmeal and fish oil, but according to Peruvian official data, 99.9% of annual catches for this industry correspond to the anchoveta species. The hypotheses we address in this study are that the Peruvian anchoveta industrial marine fishery is affected by climate change; particularly, industrial anchoveta landing is negatively affected by SST.

2. Methods

This study considers industrial marine fishing in a context of climate change in Peru over the period 1997-2020. The universe is comprised by the landings of industrial fishing for fishmeal and fish oil exports. The sample is the landing of anchoveta industrial fishing for fishmeal exports from 1997 to 2020 ($n = 24$). The unit of analysis is anchoveta industrial fishery landing per metric ton.

The study area covers the Peruvian coast from the port of Talara (latitude 04°34′30″, longitude 81°16′57″) to Matarani (17°00′03″ S, 72°06′31″ W), with particular emphasis on the north-central region where the greatest anchoveta biomass is concentrated, from the port of Talara to Pisco (13°49′10″ S, 6°15′07″ W) (Figure 1).

2.1. Data Collection. Our data sources were the Peruvian Ministry of Production (PRODUCE), the Marine Institute of Peru (IMARPE), the Central Reserve Bank of Peru (BCRP), and the National Institute of Statistics and Informatics (INEI). The data collected comes from PRODUCE fishing yearbooks, IMARPE bulletins, and the Central Reserve Bank of Peru (BCRP). We also gained access to public information on fishing effort from IMARPE. Specifically, the data pertained to economic and climatic factors, industrial fish landings, industrial fish exports, measures of fishing effort, and SST.

The data related to the fishing effort and CPUE of the industrial purse-seine fleet and on the north-central anchoveta fishing seasons from 1998-I to 2019-II were provided by IMARPE in July 2022, based on information availability. This included information on number of trips and trip duration, search time in hours, number of sets per trip, and catch per trip. IMARPE informed us that for the years 2020-I to 2021-II, no observations were made due to the COVID-19 pandemic. Therefore, for 2020, we obtained our information on fishing effort (trip duration in hours, number of sets per trip) from the bulletin of IMARPE [24] "Situación del stock norte-centro de la anchoveta peruana (*Engraulis ringens*)" (Season 2020-II).

2.2. Procedure. First, we investigated the characteristics of Peru's industrial marine anchoveta fishery. Second, we collected data on fish landings for fish oil and fishmeal exports for the study period 1997-2020. Third, we collected data on climate change, such as SST, in order to determine its relationship with industrial fishing. Then, we applied correlation and linear regression methods, the latter to measure the effect of climate change on anchoveta fisheries, using the SPSS v.26 software, and finally, we analyzed the findings.

3. Results and Discussion

The Humboldt Current System is highly productive, accounting for more than 15% of the world's annual fish catch, but is also affected by climate variability and change. Peru harvests around 4 million metric tons of fish per year [25], but increasing SSTs are causing a decrease in plankton levels such that catch reductions are forecast by 2050, threatening food security.

In our study period, 1997-2020, Peru's average industrial fishing catch was 5.6 million metric tons, and the average annual catch of Peruvian anchoveta for fishmeal was 5.4 million tons (Figure 2). Entire industrial fishing (nonfood purposes) is oriented towards the production of fishmeal and fish oil.

Before 2003, the catch of marine resources for nonfood purposes overall exceeded the landings of anchoveta specifically for fishmeal, and then in the subsequent years, the catch of anchoveta for fishmeal was practically equivalent to the overall catch for nonfood use (Figure 2). Since 2003, PRODUCE has carried out increased inspections of the holding capacity of fishing vessels according to the industrial fishing permit for anchoveta (*Engraulis ringens*) and white anchoveta (*Anchoa nasus*), restricting fishing of other species for nonfood uses. Law 1084 on maximum catch limits per vessel for industrial fishing, in force since 2008, improved the sustainable management of anchoveta. This shows that the vast majority of Peru's total industrial catch is intended for fishmeal and fish oil exports. According to Figure 2, the 1998 El Niño phenomenon abruptly reduced the anchoveta catch by 80% compared to the previous year, and as a result, other species such as sardines were used for fishmeal production, which in turn affected the sustainability of sardines. The following drops in catches are also explained by the increase in seawater surface temperature (El Niño phenomenon of strong intensity in 2016 and

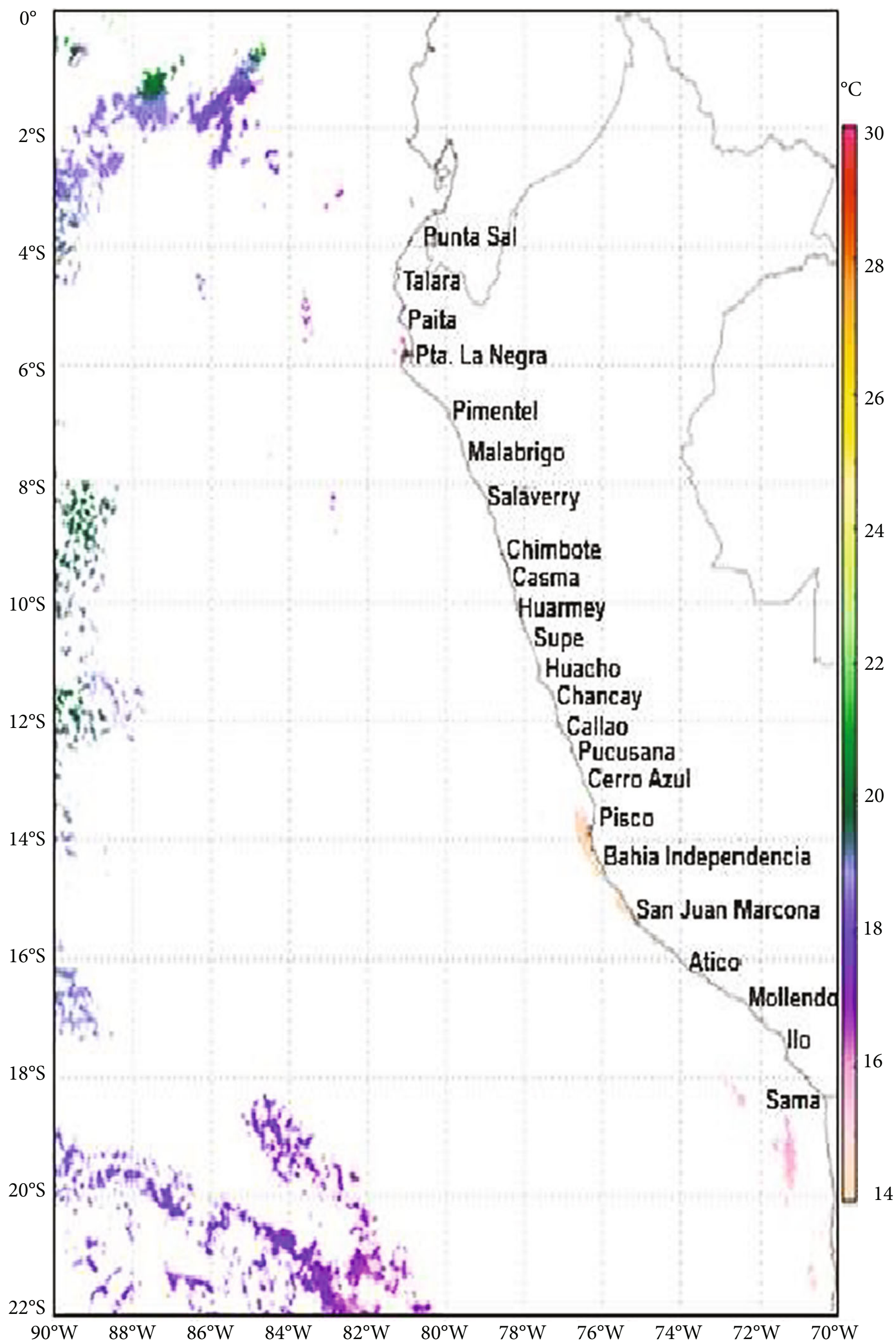

Figure 1: Peruvian industrial anchoveta fishing sites and the SST (°C), Peru. Source: IMARPE (2022). Satellite Tracking System—SISESAT.

2017) and the closure for biomass regeneration in 2014. In general, there is a decreasing trend in anchoveta landings for nonfood uses and fishmeal mainly due to climate change.

In a short referential survey administered to employees of a fishmeal and fish oil producer (Exalmar S.A.A.) in June 2022, they said every time a climatic phenomenon occurs (such as "El Niño" in 1982-1983, 1997-1998, 2015-2016, and 2017), the fishing company is subject to lower fishing quotas and shorter fishing seasons. This causes variations in biomass, affects product quality, drives up costs, and pushes down exports and earnings. They also argued that there was no anchoveta fishing in the 2014-II season in the north-central area, while the 2019-II season in that same area ended early.

One of the key variables with which to understand the effects of climate change is ocean temperature [26]. There is an indirect relationship between the anchoveta catch and the SST. When the SST increases, landings of anchoveta for fishmeal decrease in the study period 1997-2020 (Figure 3). For example, in 1997-1998, when SSTs of 22.8-22.5°C were recorded at the Chimbote weather station (North), Peruvian anchoveta landings fell to 1.2 million

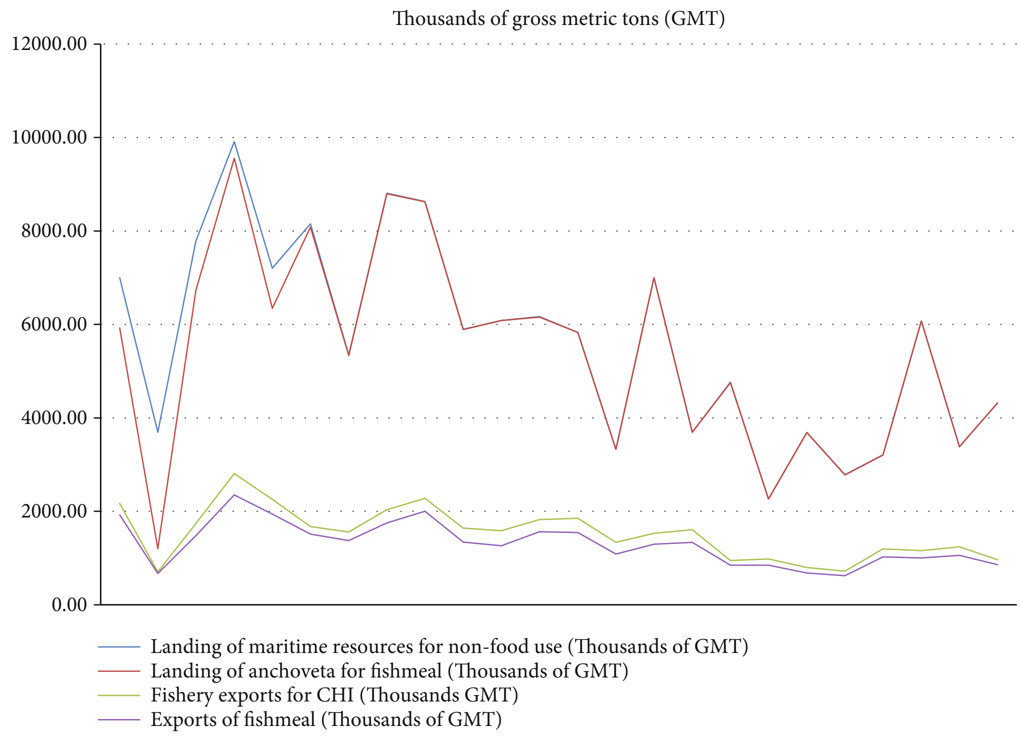

Figure 2: Industrial marine fishery landings and exports, Peru, 1997-2020. Source: Produce [5]. Compiled by authors.

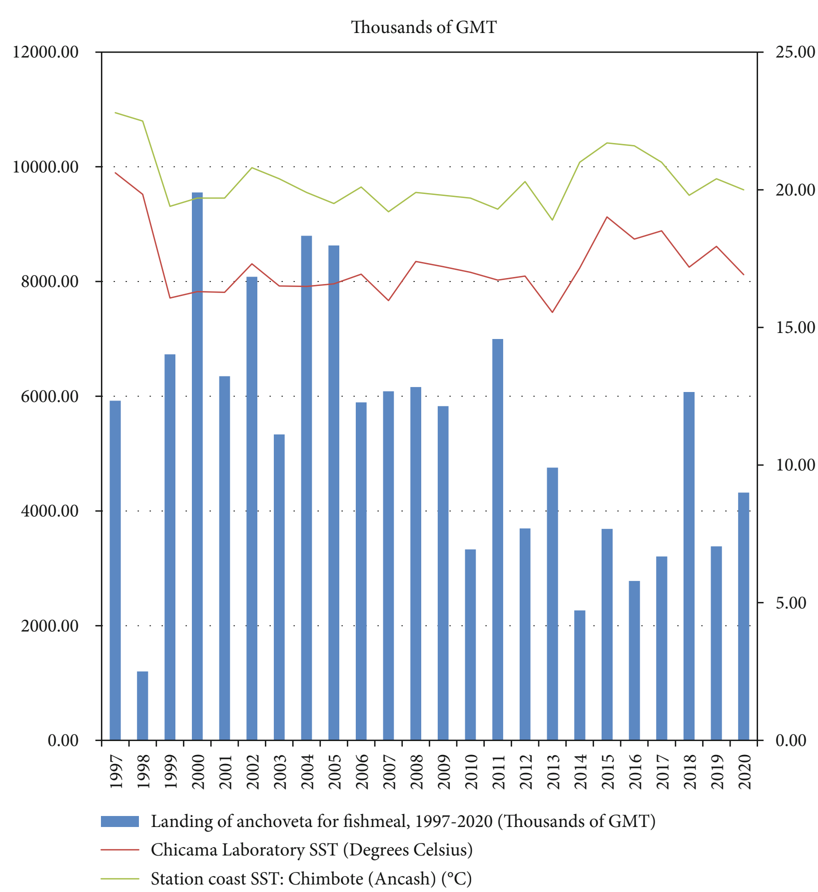

Figure 3: Anchoveta fishing for fishmeal and SST (in main ports), 1997-2020. Source: INEI: Anuario de estadísticas ambientales 2007, 2017, and 2021. Compiled by authors.

Table 2: Correlations: anchoveta landings, fishmeal exports, effort, and climatic factors (SST, sea level), Peru, 1997-2020.

		Fishery exports for nonfood purposes (thousands of GMT)	Exports of fishmeal (thousands of GMT)	SST, Chicama regional laboratory (°C)	Average coastal SST by Chimbote weather station (Ancash) (°C)	Annual average sea level, monitoring station, central zone-Chimbote (meters)	Fishing effort: trip_ duration (h)	Average fishing effort: search time (h)	Fishing effort: no. of sets per trip	CPUE: capture/ trip
Landing of anchoveta for fishmeal, (thousands of gross metric tons)	Corr. Pearson	0.822**	0.827**	-0.469*	-0.500*	-0.207	-0.469*	-0.670**	0.168	0.212
	Sig. (bilateral)	0.000	0.000	0.021	0.013	0.331	0.021	0.000	0.434	0.331
	N	24	24	24	24	24	24	24	24	24
Fishery exports for nonfood purposes (thousands of GMT)	Corr. Pearson	1	0.996**	-0.296	-0.325	-0.128	-0.423*	-0.490*	0.014	-0.048
	Sig. (bilateral)		0.000	0.160	0.122	0.552	0.040	0.018	0.949	0.829
	N		24	24	24	24	24	24	24	24
Exports of fishmeal (thousands of GMT)	Corr. Pearson		1	-0.262	-0.284	-0.089	-0.432*	-0.488*	-0.031	-0.088
	Sig. (bilateral)			0.217	0.179	0.679	0.035	0.018	0.887	0.691
	N			24	24	24	24	24	24	24
Sea surface temperature (SST), Chicama regional laboratory (°C)	Corr. Pearson			1	0.926**	0.757**	-0.017	0.301	-0.466*	-0.357
	Sig. (bilateral)				0.000	0.000	0.936	0.163	0.022	0.094
	N				24	24	24	24	24	24
Average coastal SST, Chimbote weather station (Ancash) (°C) 1997-2020	Corr. Pearson				1	0.745**	0.175	0.439*	-0.408*	-0.592**
	Sig. (bilateral)					0.000	0.413	0.036	0.048	0.003
	N					24	24	24	24	24
Annual average sea level, Chimbote weather station, central zone (meters)	Corr. Pearson					1	-0.191	0.106	-0.426*	-0.262
	Sig. (bilateral)						0.372	0.631	0.038	0.228
	N						24	24	24	24

Table 2: Continued.

		Fishery exports for nonfood purposes (thousands of GMT)	Exports of fishmeal (thousands of GMT)	SST, Chicama regional laboratory (°C)	Average coastal SST by Chimbote weather station (Ancash) (°C)	Annual average sea level, monitoring station, central zone-Chimbote (meters)	Fishing effort: trip_ duration (h)	Average fishing effort: search time (h)	Fishing effort: no. of sets per trip	CPUE: capture/ trip
Trip_duration (h) average	Corr. Pearson						1	0.851**	0.468*	-0.417*
	Sig. (bilateral)							0.000	0.021	0.048
	N							24	24	24
Search time (h)	Corr. Pearson							1	0.255	-0.504*
	Sig. (bilateral)								0.240	0.014
	N								24	24
No. of sets per trip	Corr. Pearson								1	0.140
	Sig. (bilateral)									0.523
	N									24

**$p < 0.01$. *$p < 0.05$.

Table 3: Regression of industrial marine fishery landings based on fishing effort and SST, Peru, 1997-2020.

Model		Coefficients[a] Nonstandardized coefficients B	Error tip.	Typified coefficients Beta	t	Sig.
1	(Constant)	34702.744	9037.846		3.840	0.001
	Coastal SST, Chimbote weather station (Ancash) 1997-2020 (°C) average	-959.509	395.126	-0.449	-2.428	0.025
	Fishing effort: search time (h)	-864.073	221.942	-0.671	-3.893	0.001
	CPUE: catch/trip	-52.611	25.796	-0.392	-2.039	0.056

[a]Dependent variable: landings of anchoveta for fishmeal, 1997-2020 (thousands GMT). Dw = 1.834, $R^2 = 0.772$. The Durbin-Watson test is around 2 (Dw = 2 indicates no autocorrelation), so the regression is reliable. The coefficient of determination (R-squared) means that the independent variables SST, search time, and CPUE have a 77.2% influence on the dependent variable landings of anchoveta for fishmeal.

Table 4: Contribution of anchoveta catch to fishmeal exports, 1997-2020.

Model		Coefficients[a] Nonstandardized coefficients B	Error tip.	Typified coefficients Beta	t	Sig.
1	(Constant)	360.117	147.520		2.441	0.023
	Anchoveta landings for fishmeal, 1997-2020 (thousands GMT)	0.176	0.026	0.827	6.911	0.000

[a]Dependent variable: exports of fishmeal (thousands GMT). Dw = 2.238, $R^2 = 0.827$. The Durbin-Watson test measures the autocorrelation of the errors and should be around 2 for the regression to be reliable (Dw = 2 indicates no autocorrelation). The coefficient of determination (R-squared) measures the percentage that the exogenous variable explains the endogenous variable.

metric tons. In addition, there is a downward trend in the volume of fishing. An explanatory variable for the decrease in fishing is the SST (Tables 2 and 3).

In the analysis period 1997-2020, there is a positive correlation between industrial marine fishing measured by landings in gross metric tons and the volume of exports for nonfood purposes, especially anchoveta meal. We found a strong negative relationship between the volume of industrial fishing and the sea surface temperature at the 5% level of significance (Table 2), which could be considered a stylized fact. Another climatic variable is the sea level in meters; although we found no strong correlation between industrial fishing landings and sea level, there is clearly a negative relationship since the higher the sea level, the lower the volume of catches (Table 2), which is evidenced by the high direct correlations between SST and sea level ($\alpha = 1\%$)—that is, rising seawater temperature causes an increase in sea level. Therefore, sea level rise would alter marine ecosystems.

The fishing effort variable is represented by three alternative indicators, provided by IMARPE: average trip duration in hours, search time in hours, and number of sets per trip. Catch per unit effort (CPUE) measured by catch per trip was also used to compare with average trip duration and search time in hours and to investigate its association with anchoveta landings. We found a significant inverse relationship between anchovy landings and the effort indicators of trip duration and search time in hours, at the 5% level of significance. Regarding the relationship between the SST climatic factor and the catch per unit of effort, there is a negative correlation at the 10% level of significance, which means that the higher the temperature of the seawater surface, the lower the catch per trip (Table 2).

Table 2 also shows a positive correlation between SST and fishing effort through search time in hours by the industrial purse-seine fleet, in the north-central anchoveta fishing season 1997-2020.

Table 4 illustrates the significant contribution ($\alpha = 1\%$) of the anchoveta catch volume that goes into Peruvian fishmeal exports, in which the determination coefficient is 82.7% (fishmeal exports are 82.7% explained by anchoveta landings).

In this study, we find that the anchoveta catch for the industry is negatively affected by SST, fishing effort (in terms of search time in hours), and CPUE (Table 3).

The ocean has warmed steadily since 2005, marking a continuation of the multidecade warming trends assessed by the Intergovernmental Panel on Climate Change. The warming of seawater is caused by anthropogenic activities and has been reliably confirmed by improved ocean temperature measurements over the past decade [27]. In turn, the increase in SST has repercussions for marine fishing activities—not least a decrease in the industrial catch for the Peruvian case. Anchoveta plays a relevant role in the marine ecosystem [21] and is economically valuable [11]. In Peru, high SSTs were found to reduce anchoveta landings, and we agree with Cheung et al. [16] who predicted that higher temperatures cause losses in fishing revenues in maritime countries. Also, the Peruvian anchoveta scarcity in the face of increased SST and climate change is reinforced by Castillo et al. [28] who after the 1997-1998 El Niño phenomenon corroborated high anchoveta volumes.

In Peru, De la Puente et al. [7] found that from 1950 to 2018, small-scale fishing efforts had increased at a much faster rate than catches and that overfishing would be unsustainable. Comparatively, in the study period 1997-2020, the industrial fishing effort exhibited a greater increase than the total anchoveta catch for fishmeal. Accordingly, in the present study, we found that greater effort measured by trip duration in average hours is related to a lower catch for the fishmeal industry. Likewise, catch per unit effort was lower in relation to average trip duration and search time.

According to Porreca [29], using data for the western and Central Pacific tuna fisheries, the fishery biomass is a function of the SST. Similarly, we find that Peru's total industrial catch is influenced by this metric. To save the oceans, we agree with the FAO [18] about the need to strengthen, organize, and urgently implement adaptation measures for marine fishing in the face of climate change to achieve SDG 14 by 2030.

To avoid the collapse of the productive system due to ecosystem changes, there must be continuous efforts at species diversification for the fishmeal industry as well as the development of a market for warm-water species within a multispecies management system [30]. In light of the findings presented in Table 2, one climate change adaptation measure could be a reduction of fishing effort to decouple it from the correlation with the SST. Another adaptation measure is research on alternative fishmeal production with natural, non-GM inputs, without or in combination with anchoveta.

4. Conclusion

The considerable productivity of Peru's sea resources, particularly the industrial Peruvian anchoveta fishery, is favored by the cold water conditions of the Humboldt Current. But marine fishing is also affected by climate variability and change. A factor in climate change is the sea surface temperature; for instance, in Peru during 1997-2020, higher SSTs meant a decrease in the industrial fishing catch, validating our hypothesis. Accordingly, there is a downward trend in the volume of fishing. However, from 1997 to 2020, the average annual industrial catch was 5.6 million metric tons, of which Peruvian anchoveta for fishmeal comprised 5.4 million tons. This trend is exacerbated by El Niño events and the SST rises they precipitate.

For the annual period 1997-2020, a positive correlation was found between industrial marine fishing landings and exports for nonfood purposes, especially anchoveta meal. There are indications that the climatic variable of sea level is inversely related to industrial fishing catch, evidenced by the significant positive correlation between SST and sea level.

Moreover, a significant inverse relationship was found between anchoveta landings and fishing effort as measured by trip duration and search time in hours. There is also a negative correlation between SST and catch per unit of effort (measured by catch per trip). From the application of the multiple regression model, we found that the industrial capture of anchoveta is negatively influenced by SST, fishing effort (search time in hours), and CPUE.

The path for future studies is to continue investigating nutrient-producing warm-water fish varieties with similar characteristics to anchoveta and fishery policies that allow the use of fish substitutes to anchoveta for fishmeal and fish oil production. Furthermore, it is necessary to collect climate change adaptation proposals which include cost-benefit estimates to cope with the anchoveta reduction for fishmeal due to warmer oceans.

Data Availability

Data supporting this study are included within the article.

Conflicts of Interest

The authors declare no competing interests.

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