The Influence of Climate Change and Foreign Direct Investment on Aquaculture: A Panel Data Approach for Top-Producing Countries

L.B.I. Dilakshi, N.G. Kariyawasam, S.R.A. Senevirathna, B.G.A. Vidumini, Y. Wickramasinghe*, K. Wisenthige and R. Jayathilaka

*SLIIT Business School, Sri Lanka Institute of Information Technology, Malabe, Sri Lanka, yamuna.w@sliit.lk

Abstract *- Aquaculture production is the major subdivision of the marine industry, indicating a critical sector in global food security and economic development. The objective of the current study is to discover the impact of Climate change and Foreign Direct Investments on Aquaculture Production in 10 major producers. According to the Food and Agriculture Organization, major aquaculture-producing nations are China, India, Bangladesh, Vietnam, Indonesia, Norway, Chile, Egypt, the Philippines, and South Korea. The panel regression model was implemented to quantify the influence of the variables on Aquaculture Production in major 10 aquacultures producers' gathered data from 1972 to 2022. To check the stability and stationery according to the major assumptions of the Ordinary Least Squared model, the Levin-Lin-Chu test, F-test, Breusch-Pagan Lagrange Multiplier test, and Hausman test were conceded from this study. Furthermore, the study was conducted to regulate the most relevant model among Pooled Ordinary Least Square, Fixed effect Model, and Random Effect Model. The findings from the descriptive statistics showed that the overall standard deviation specifies significant differences in Aquaculture Production across the preferred areas. Finally, the results shows that both climate change and Foreign Direct Investment has a significant positive impact on Aquaculture Production in top 10 producing nations.*

Keywords: Aquaculture Production, Carbon Dioxide Emission, Climate Change, Foreign Direct Investments, Panel Regression

I. INTRODUCTION

The global population is projected to reach 9.7 billion by 2050; the world is facing the daunting challenge of ensuring global food security. Aquaculture, the farming of aquatic organisms for human consumption has become a vital part of the global food security agenda by contributing to meeting the increasing demand for aquatic foods. With an average annual growth rate of 5.2% during the past 50 years, aquaculture has become the fastest growing food- producing sectors while sustainably contributing to alleviate hunger and poverty (Subasinghe et al, 2009). Beyond production, aquaculture significantly contributes to the world economy through export revenue and job creation.

However, the sector's growth is facing a significant challenge due to climate change. The exponential increase in atmospheric Carbon Dioxide (CO_2) is driving several climate change impacts, including ocean acidification, surface water temperature anomalies, rise in sea levels, unpredictable storms and longer droughts, which can directly and indirectly influence the growth and productivity of aquaculture (Maulu et al, 2021).

According to the study of Okeke-Ogbuafor et al (2024), they have interpreted Carbon Dioxide Emission (CDE) with Aquaculture Production (AP) as that AP is a solution for the uprising issues of food security and that it can also help in reducing CDE. On the other hand, when considering Foreign Direct Investment (FDI) net inflows, Sultana & Sadekin (2023), the study has enhanced that Bangladesh experiences negative

https://doi.org/10.54389/SRHZ4681

supremacy between FDI and the agricultural sector in the long run and no effects in the short run. All these sources provide clear grounds that CDE and FDI net inflows affect AP among the dominating giants of the industry.

The main objective of this study is to investigate the significant relationship between CDE and FDI on AP for five decades within 10 leading AP giants. As per further clarifications, the objectives are as follows.

1. Is there a significant impact of CDE on AP in 10 countries from 1972 - 2022?
2. Is there a significant impact of FDI on AP in 10 countries from 1972 - 2022?

Furthermore, this study is designed under nine sections. The introduction is the initiating section followed by the research problem, a detailed description of variables in the literature review, utilized methods, data analysis techniques, results and discussions, conclusions, and ultimately the references.

In recent years, food security has become a major issue all around the world. AP is a great solution towards this massive issue. According to the FAO (2022) report, China, India, Indonesia, Vietnam, Bangladesh, South Korea, Philippines, Norway, Egypt, and Chile account for a significant portion of global AP. Thus, these countries are at the forefront of the fight against hunger. While climate is considered a significant catalyst for aquaculture, quantitative analysis examining the impact of climate change in these nations is rather scarce. Further, since more than 50% of the production from these countries is farmed in a freshwater environment, which requires adequate infrastructure and technology in water circulation, climate resilience, and disease control, a significant amount of investment and access to capital is required. Despite its significant role in capital formation, knowledge and technology transfer impact of FDI on AP is largely unexplored. Thus, the current study intends to satisfy the existing gap by employing panel regression to examine the impact of climate change and FDI on AP in the top 10 producing nations. Findings of the study can be beneficial for stakeholders and policymakers to in formulating strategies to improve the efficiency, sustainability and climate resilience of AP to ensure future food security.

II. LITERATURE REVIEW

In line with the variables, as per the conformity of Jolly et al. (2023) AP production shows ups and downs in the long run and this study is plotted to investigate whether CDE along with the climate changes and FDI has an impact on AP.

A. Impact of CO_2 induced Climate Change on Aquaculture Production

According to the Paris Agreement and the standard carbon accounting methods used by the international community, China requisite account for the CO_2 emitted to the ether by mariculture activities. Under the recent policies in Chinese aquaculture 6.83 million tons of CO2 is emitted through wetland destruction in every year. From 1999 to 2008 past data according to the Chinese Harvest and the wetland destruction apparent that the net CO2 balance pulled from the atmosphere is 1.81-3.61 million tons (Meng & Feagin, 2019). The fossil fuel combustion, agricultural factors strongly impact for the global carbon (C) cycle that indicates different AP systems in India headed to increase in global temperature during the 20th century. In 2010 the distinctive pool of CO_2 at 390 ppm with a drastic increase of positive feedback through risks of conversions of wetland to other land uses (Adhikari et al, 2013). With the evidence of mangrove in Indonesia which provides

several important ecosystem services to humanity is generates significant CDE through the land use change in its ecosystem. According to the study about the Mahakam Delta, once among the largest mangrove forests in South Asia comprising 2% of Indonesia, the mean production rates of shrimp are dramatically lower than reported production of the traditional AP (Arifanti et al, 2019). Due to the Economic growth effects including industrialization, energy intensity and growing population release pollution and increase in CDE Vietnam was witnessed as an environmental determinant. As a result of this the world is experiencing climate change and global warming. The sector of construction industry producers' half of worldwide CDE and consumes 50% from global resources that includes 36% of total electricity usage in Vietnam. (Nguyen & Gray, 2016). As a result of Global warming and caused climate changes Greenhouse gasses (GHGs) emission can be concluded as a major concern in Bangladesh that contributes to emit 1.87% CO2 from country total (Islam et al, 2020). Bangladesh is subsidizing only 0.19%to the global CDE, expect to increase it by 15 times at 2050 (Ahmed et al, 2017).

According to the observation about marine environmental and carbonate factors investigated during year 2021, covering area of Jinhae-Geoje-Tongyeong Bay region of southeastern coast in Korea resulted that in October the largest CDE were observed in area of Tongyeong- Goseong which is coastal city in South Korea. The calculated CO2 emission in the commitment of seawater flux was acquired 1.4 -3.2 mmol m-2 d-1 during the months from July to October (Shim et al, 2021). Seaweed Aquaculture Beds (SAB) uses for the potential CO2 mitigation supports the production of seaweed and divers products of seaweeds by covering extensive coastal areas including the Asia- Pacific region. According to the Environmental Protection Agency (EPA) in 2014 assessed world – wide emissions of all major greenhouse gases reached nearly 46 * 109 t, with CO2 emissions during the period from 1990 to 2010. From 2003 to 2012 SABs production from major cultivated species of Undaria, Pyropia, Saccharina, and Saragassum covered roughly 74, 696 ha in the Republic of Korea. The total carbon assimilation is estimated as 23,624 t y-1, or 86,700 t CO2 y-1 during this time period. Mitigation of CDE indirectly can achieve for the uses of fossil fuels. Furthermore, As Food and Agriculture Organization outlined Seaweed aquaculture is a key player in the overall aquaculture industry, which harvested for utilization as a food, feed for aquaculture. During this process some of the CO2 released and it can store large amount of organic carbon in above- and below-ground biomass and can be used as bioenergy crops in future (Sondak et al, 2017). In Philippines mangrove forest is one of the 'blue carbon' ecosystem still lacking studies on the post-disturbance carbon stocks and rates of sequestration. This aspect can potentially subsidize carbon sequestration estimated at 180 Tg which is corresponding to ca. 661 Tg of avoided CDE (Salmo & Sev, 2019).

In accordance with the Norwegian study of (Ellingsen et al., 2009), they piloted a preliminary analysis on CDE and pinpointed reasons for considering CDE with AP of Salmon. The reasons circulated around getting a clear idea on the biggest challenge of global warming and the absence of well-grounded methodologies for computations. Also, in the study Ellingsen et al (2009), they have also highlighted the importance of developing a standard for evaluating CDE. The study of Jones et al (2022) has highlighted that 20% of CDE is due to usage of diesel oil in aquaculture industry but also the numbers are dropping due to utilizing natural gases instead of Diesel. Moreover, the report of Johansen (2022) addresses that 437 million of Norwegian Krone have spawned four tons of CDE from major aquaculture producers of Norway. As claimed by the study of (Yacout et al., 2016), Egypt ranks in the nineth place of world's fish production and is classified

as the first in African continent. As a matter of fact, Yacout et al (2016) highlight that two-third of African AP is dominated by Egypt. Their study revolves around semi-intensive and intensive production systems of Tilapia AP which determines that 960.7 Kg and 6126.1 Kg of CDE occur respectively. Yacout et al (2016) also brings out the global warming apprehensions caused due to CDE because of AP. According to the study of Kwakwa (2020), they have identified two indicators which include CDE to measure six production functions including AP of Egypt and they have identified that in the long run, there are significant effects on CDE fluctuations. Furthermore, a positive notable relationship was observed between CDE and AP in the study of (Kwakwa, 2020). Their study also focuses on the importance of implying policies regarding CDE and AP. According to the Chilean study of Mardones and Muñoz (2018), they have identified 34 sectors of disarticulated sectorial emissions of GHGs and CDE and Aquaculture is one of them. The study portraits the utilization of fuels results in 10,194 tons of CDE. Mardones & Muñoz (2018) depicts that tax rate due to CDE for agricultural sector is 0.09% and 0.01% of it is accumulated through AP of Chile. As per the book of Yáñez et al (2017), Chile holds 0.25% of CDE in a global basis. The review depicts that around the region of Patagonia in Chile is reserved for AP as it serves as a natural Carbon sink that absorbs CDE. Additionally, the study of Yevenes et al (2019) foregrounds on Chilean Mussel AP and outlines that CDE is a major disadvantage which creates negative impacts on calcified AP organisms.

B. Impact of FDI Inflows on Aquaculture Production

Aquaculture is one of the sectors under Agribusinesses that is allowed to connect with net inflows of FDI (Kumar & Bharti, 2015). FDI can be attracted through either an approach of production or service sector. China uses a production tactic while India endures a service approach towards uplifting the chances of FDI net inflows (Kumar & Bharti, 2015). In terms of FDI and FDI related policies, China is a gentle giant in agribusiness compared to India with a difference of 1137 FDI affiliate units for four consecutive years (Kumar & Bharti, 2015). As per current rankings of World Bank's Doing Business Index, China is in the 31st place while India is residing on 63rd place in global rankings. This provides a good foundation for FDI inflows as investors can lend their funds for a strong base (Kumar & Bharti, 2015). Indonesia is considered as one of the major manufacturing countries of aquatic commodities and one third of 99.9% of Asian Seaweed aquaculture produce is combined covered by China and Indonesia which is a great source of FDI net inflows in terms of shareholder involvement in aquaculture field governance (Jolly et al, 2023). In Tilapia farming, FDI net inflows even managed to enlighten the curiosity of Indonesian Private Sector (Kumar & Bharti, 2015). According to the Vietnam review of Leproux & Brooks (2004), FDI net inflows created 0.6% employment rate out of the total employment of Vietnam and 0.2% of it belonged to aquaculture, agriculture and forestry for nine years. With the gradual increase of policies and the need for agricultural and aquacultural produce, the employment rates skyrocketed for 25% with the help of FDI net inflows (Leproux & Brooks, 2004). As per 2019, out of the realized 6% of aquaculture and agriculture records of the Vietnam economy, 1% of them are displayed under FDI Diem & Thuy (2019) and as a matter of fact, 4.99% of the total agricultural firms are declared to be "FDI firms".

In compliance with the Bangladesh study of Sultana and Sadekin (2023), They have considered aquaculture as a subsector of agriculture. Although 12.09% of GDP is based on agriculture, it is considerably low in terms of FDI net inflows as the overall FDI

net inflows received by Bangladesh is significantly less than other countries which they have indicated as 0.53% of the total GDP (Sultana & Sadekin, 2023b). In conformity with Rahman et al (2024), FDI brings prosperity for developing countries like Bangladesh. Also, when analyzing quantitatively, Sultana and Sadekin (2023) has used Auto Regressive Distributed Lag (ARDL) methodology and found that FDI has an anti-impact on Agricultural sector of Bangladesh in the long run while no effect in the short run. There is a vertical integration or specialization between the small- scale producers and the large enterprises in aquaculture industry to encourage individual entrepreneurship with the technological elevation. According to the study about aquaculture governance commenced by various countries and regions evident that without alienation from nonetheless smallest producer, FDI brings all stakeholders to participate in the governance structure (Jolly et al., 2023).

At the beginning of 21st century, the leading countries namely Japan, Taiwan, and South Korea have long exported synthetic goods. For the high investment on infrastructure, during the period from 1995 to 2000 aquaculture and agriculture industries were focused as priority on export promotion based on foreign capital mainly relied on development aid from foreign governments (ODA) and direct investments from foreign business (FDI) (Viet, 2018). During the year of 1997, foreign direct investment into the Philippine were suffered by the economic crisis happened in regionally remains competitive in fresh and frozen shellfish, prepared and preserved fish, comes from the commercial fishing and aquaculture activities (Alburo, 1998). According to the study based on aquaculture and global food chain, from the global Neoliberalism happened in the late 1970s and early 1980s brings globalization agenda based on privatization motioned that aquaculture, large coastal commons and mangroves have to be privatized and with that Philippines have been relocated to make way for large infrastructure projects. With that FDI has repositioned jobs from high-income countries to labor- abundant economies, ultimate with a competitive downward decline in real wages in globally (Aquaculture and the globalized food chain, 1997).

According to the Norwegian study of Eiríksson (2015), they have indicated FDI as a technique to ensure the variegation of AP to minimize risks and improve profits to improve their strategic plans of economy. The study Eiríksson (2015) also highlights that political decision out shadows benefits accompanied by FDI on AP in Norway. As per the conformity of Jolly et al. (2023), Egypt is the leading AP giant of salmon in the African continent which covers a whopping 77% of total nationwide AP. The study Jolly et al. (2023) highlights the importance of FDI and discusses how FDI managed to uplift the trust in Private sector's interest in AP. In accordance with the study of Fløysand et al. (2010), Chile is the second largest Salmon AP of the global franchise. Fløysand et al. (2010) depicts that FDI brought out favorable circumstances including sustainability, expanded markets, food security and food safety. Furthermore, they illuminate that 65% of exports from twenty-six AP firms were facilitated through Chilean FDI inflows.

III. METHODOLOGY

The problem statement and relevant literature review enhanced the research objectives. To investigate the framework, panel regression analysis has been selected as the most sustainable methodological approach. The equation for general panel regression,

$$Y_{i,t} = \beta_0 + \beta_1 X1_{i,t} + \beta_2 X2_{i,t} + \varepsilon_{i,t} \quad (1)$$

The great quantities of economic models were considered stationarity tests, a foundational assumption. The results of panel data with stable unit roots have a risk of getting false regression results, meaning variables might show a statistically significant relationship, though there is not vice versa. Therefore, to avoid making false results, the Levin, Lin, and Chu (LLC) test was carried out to find the presence of a unit root in the data.

Investigating the simple linear model and checking the stability and stationarity of the data makes it more appropriate to convert to natural logarithmic format. Accordingly, AP, CDE and FDI were considered using a log and the equation is illustrated below,

$$\text{Ln } AP_{it} = \beta_0 + \beta_1 \ln CDE_{it} + \beta_2 \ln FDI_{it} + \varepsilon_{it} \quad (2)$$

Therefore, model specifications at aquaculture major producers such as China, India, Indonesia, Vietnam, Bangladesh, South Korea, Philippines, Norway, Egypt and Chile were analyzed to determine the most relevant model. The study conducted the analysis to determine the most relevant model among Pooled Ordinary Least Square (POLS), Fixed Effect (FE) Model or Random Effect (RA) Model. Despite the potential existence of this study heteroscedasticity, Least Square Estimation was utilized to estimate the linear model. Therefore, the robust estimator was used to conduct covariance in the study (Studenmund & Johnson, 2017). Heteroscedasticity, Least Square Estimation was utilized to estimate the linear model. Therefore, the robust estimator was used to conduct covariance in the study.

IV. DATA ANALYSIS AND DISCUSSION

The study employs panel data from 1972 to 2022 for the 10-leading aquaculture-producing nations, as determined by the The State of World Fisheries and Aquaculture (2022) report and their data sources. Aquaculture production is measured in production output in metric tons (MT). The climate change variable is proxied by per capita CDE which is measured in per capita emission in MT. FDI measures net inflow as a percentage of GDP. Table 5.1 Data for the variables are sourced from the World Bank. To handle the years with missing data, simple liner regression was employed, with both backward and forward predictions where applicable. Also, STATA (2017) software is used for data analysis to complete this study.

Table 1. Data Sources of Variables

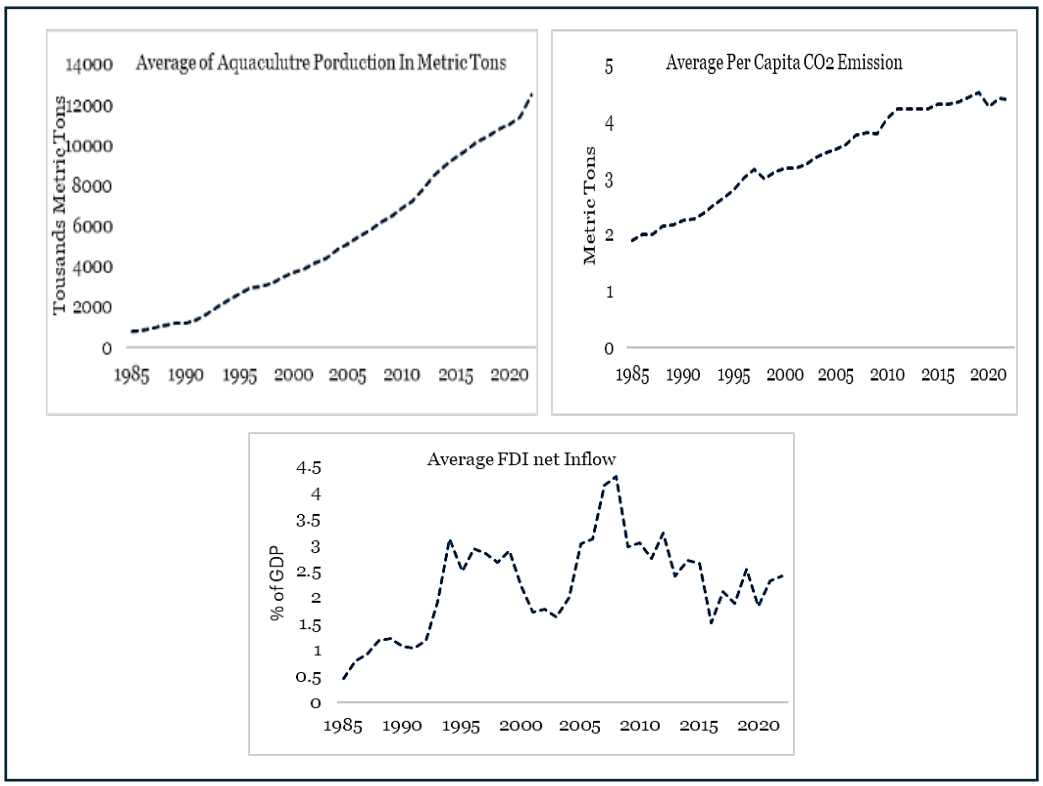
Variables	Definition	Measure	Source
AP	Aquaculture Production	Metric Tons (Mt)	World Bank
CDE	Carbon Dioxide Emission	Metric Tons (Per Capita)	World Bank
FDI	Foreign Direct Investment	Net Inflow Of (% Of GDP)	World Bank

Source: Authors' compilation.

During the period of 1985 to 2022 the Aquaculture production of 10 leading aquaculture producing countries exhibits an overall steady upward trend (Figure 1). The corresponding period exhibits an upward trend per capita CDE despite a brief decline in the year 2020. Thus, this depicts many of these countries are facing significant

environmental changes. Though FDI shows an overall upward trend it depicts significant volatility. After a sharp drop in 2008 and a continued decline, overall, the FDI seems to have recovered since 2017. Thus, this underscore further investigations are required to determine the causal relationship between AP, climate change and FDI.

Figure 1. Time Series Plot



Source: Authors' compilation.

Table 2 presents the descriptive statistics of top 10 aquaculture-producing nations during the period 1985 to 2022, which set the foundation for further analysis of the ready reference. The average AP of Top 10 producing nations observed to be 5,352,735 metric tons while the minimum value and maximum value were recorded as 7,497 and 78,500,000respectively. Overall, a standard deviation of 12,800,000 indicates that there is a significant difference in AP across the top 10 producing nations. China displays the highest mean AP of 36,900,000 MT during the studied period (1985- 2022) followed by Indonesia as the second largest producer with a mean AP of 5,545,421 MT. However, the data shows a substantial production discrepancy among the two leading producers, with China's production is almost seven times larger than Indonesia's production output. On the contrary, Egypt observed the Lowest mean AP (622,047 MT) among the top-producing countries.

Table 2. Descriptive Statistics

Country	Statistic	AP (MT)	CDE Per Capita (MT)	FDI (% of GDP)
Top 10 AP Nations	Observations	380	380	380
	Mean	5,352,735	3.36	2.23
	Minimum	7,497	0.11	-5.03
	Maximum	78,500,000	12.97	11.94
	Std. Deviation	12,800,000	3.40	2.32
Bangladesh	Observations	38	38	38
	Mean	1,077,356	0.29	0.52
	Minimum	123,811	0.11	-0.03
	Maximum	2,856,164	0.61	1.74
	Std. Deviation	866,949.70	0.16	0.51
Chile	Observations	38	38	38
	Mean	658,122	3.59	5.33
	Minimum	7,497	1.73	0.81
	Maximum	1,601,334	4.83	11.91
	Std. Deviation	488,888.80	0.96	2.80
China	Observations	38	38	38
	Mean	36,900,000	4.57	2.81
	Minimum	5,026,016	1.88	0.54
	Maximum	78,500,000	7.99	5.99
	Std. Deviation	22,000,000	2.22	1.51
Egypt	Observations	38	38	38
	Mean	622,047	1.93	2.38
	Minimum	41,846	1.28	-0.20
	Maximum	1,820,844	2.56	9.35
	Std. Deviation	578,996.30	0.43	2.08
India	Observations	38	38	38
	Mean	3,369,351	1.14	1.11
	Minimum	633,250	0.51	0.03
	Maximum	9,408,300	2.00	3.62
	Std. Deviation	2,433,536	0.46	0.88
Indonesia	Observations	38	38	38
	Mean	5,545,421	1.52	1.19
	Minimum	359,626	0.72	-2.76
	Maximum	19,000,000	2.65	2.92
	Std. Deviation	6,419,471	0.53	1.27
Philippines	Observations	38	38	38
	Mean	1,597,114	0.89	1.59
	Minimum	470,923	0.51	0.03
	Maximum	2,827,455	1.31	3.12
	Std. Deviation	778,337.60	0.21	0.81
South Korea	Observations	38	38	38
	Mean	1,304,021	9.60	0.83
	Minimum	667,883	4.09	0.21
	Maximum	2,783,470	12.97	2.16
	Std. Deviation	579,191.90	2.78	0.47
Vietnam	Observations	38	38	38

Mean	1,770,601	1.31	4.74
Minimum	127,449	0.27	0.00
Maximum	5,231,628	3.76	11.94
Std. Deviation	1,670,280	1.06	2.76

Source: Authors' compilation.

Accessing the per capita CDE, of the top 10 producers, the average per capita emission is 3.36 MT. The minimum value of per capita CDE is 0.11MT and the maximum is 12.97 MT with a standard deviation of 3.40. Among the studied sample of counties, the country with the highest per capita emission is South Korea with an average value of 9.60 MT whereas Bangladesh is the country with the lowest per capita emission with an average value of 0.29 MT from 1985 to 2022.

Regarding FDI of the 10 nations, the average value of FDI was observed as 2.23% of GDP with a minimum value of -5.03% and a maximum value of 11.94% of GDP. During the studied period, Chile was the country with the highest FDI inflow with an average inflow of 5.33% of GDP among the top 10 aquaculture-producing nations whereas Bangladesh is with the lowest FDI with an average inflow of 0.52% of GDP.

Table 3. Correlation Matrix

	lnAP	**lnCDE**	**lnFDI**
lnAP	1		
lnCDE	0.23	1	
lnFDI	0.23	0.44	1

Source: Authors' compilation.

Table 3 presents the correlation matrix of the studied variables. According to the results shown above, there is a positive correlation between AP with CDE and FDI. While existing literature states climate change has both positive and negative impacts on aquaculture Maulu et al (2021), the correlation of the current study further solidifies that climate change positively contributes to the AP being in the top 10 producers. The positive correlation between FDI and AP underscores that FDI can contribute to the growth of the sector by target investments, and infrastructure development and it can be an important conduit of technology and knowledge transfer. The correlation estimates are further examined by employing panel regression. Before the panel estimates the study conducted diagnostic tests to improve the reliability of the results. Thus, the Levin-Lin-Chu unit root test was applied to test the stationarity of the studied variables from 1972 to 2022. Results indicate that AP and FDI displayed nonstationary except FDI Therefore, all variables were transformed into natural logarithms to achieve stationarity. Additionally, the stability test was conducted, to address the potential model instability and heteroscedasticity. The results showed instability, due to one eigenvalue marginally surpassing the unit circle. However, due to its very small marginal deviation, while acknowledging the potential cautions the study proceeded.

To identify the correct model specification, the F-Test, Breusch-Pagan LM test, and Hausman test were performed. Table 4 exhibits the specification test results. According to the results below, the F test failed to reject the null hypothesis at a 1% significant level favoring the Fixed effect model. Breusch Pagan LM outcome also failed to reject the null hypothesis at a 1% significance level indicating that the Radom effect model is suitable for the studied countries. Finally, the Hausman test results which show

a significant chi-square statistic at a 5% significant level indicate the presence of time-invariant country-specific factors, therefore the study employed the panel fixed effect model over the panel random effect model after failing to reject the null hypothesis of the Hausman test.

Table 4. Specification Tests Results

Countries	Specification Tests		
	F test H0: POLS H1: Fixed Effect	Breusch Pagan LM Test H0: POLS H1: Random Effect	Hausman Test (Sigmamore) H0: POLS H1: Fixed Effect
Top 10 AP Nations	15.25*	3022.32*	15.65**

Note: *, ** and *** indicate significance at 1% ,5% and 10% levels, respectively.
Source: Authors' compilation.

Table 5 presents the Panel Fixed and Panel Random Effect Results for AP in the panel of top 10 aquaculture-producing nations. The panel fixed effect results show that CDE shows a strong positive impact at a 1% significant level, thus an increase in one MT per capita emission of CDE will result in a 1.84 MT increase in the total AP of the ten producers. Thus, this finding is supported by previous empirical studies (Bhuiyan et al., 2018; Munonye et al., 2024; Muniz & Del Rio ,2023) Further previous empirical studies underscore a positive effect of climate change on AP, according to Maulu et al (2021) many studies show biases towards exploring the negative impact of climate change on AP than positive ones which can be important for formulating adaptation strategies. Nevertheless, scholars like Collins et al (2020); Klinger et al (2017); Troell et al (2017) have highlighted, that the impact of climate change is rather heterogeneous, which implies effect of climate change on aquaculture can change based on factors like geographical location, economy, climate zones, cultivating systems, and cultured species. While ocean acidification and increasing temperature can be harmful for certain calcified organisms, they can also create favourable growth conditions for other species that are tolerant to high temperature and acidification.

Conversely, FDI shows a weak positive impact on AP with a 0.007 coefficient at a 5% significance level, indicating an increase of 1% in FDI inflow will increase AP of the top ten nations by 0.07 MT. thus, this underscores the significant role of FDI as a major catalyst for bringing capital for infrastructure enhancement, technology, and industrial progress Kayani et al (2023), while it has been recognized as a sustainable and profitable strategy in the agriculture and fisheries sector (Bhuiyan et al ,2018; Obekpa et al, 2020). The findings of the current study highlight that the productivity of the AP in top 10 producing nations depends on the infrastructure, technology, and expertise knowledge which can be better facilitated by directing FDI towards the sector. This finding can be particularly important for stakeholders and policy makers formulate policies and frameworks that leverage foreign capital effectively in support of local aquaculture systems.

Table 6. Panel Fixed and Panel Random Effect Results

Variables	All	
	LnAP	
	FE	RE

lnCDE	1.84*	1.78*
	(0.33)	(0.31)
lnFDI	0.07**	0.08**
	(0.05)	(0.05)
Constant	12.89*	12.88*
	(0.20)	(0.81)
N	365	365
No of Countries	10	10
No of years	37	37
R2 within	0.6576	0.6575
R2 Between	0.0018	0.0018
R2 Overall	0.0625	0.0629

Note: *, ** and *** indicate significance at 1% ,5% and 10% levels, respectively. FE denotes fixed effect and RE denotes rando effect. N indicates the number of observations in the panel. The parentheses represent the robust standard error.
Source: Authors' compilation.

V. CONCLUSION AND RECOMMENDATIONS

The main objective of this study is to assess the impact of climate change and FDI on AP of 10 leading aquaculture-producing nations over the period of 1972 – 2022. The study employed a panel fixed effect model, which controls unobserved heterogeneity across countries. The study precisely underlined two primary objectives: to examine the significance of CDE on AP and to assess the influence of FDI on AP. The results show that Bangladesh contains the lowest per capita CDE while Chile is the country with the highest FDI inflow. The results from panel-fixed and correlation had shown both climate change and FDI effect in the positive increase of AP. However, since the adjusted R-value is 7%, it indicates that while climate change and FDI play a significant role, the production disparity among the top 10 aquaculture-producing nations is not fully explained by these factors alone. Factors such as technological development and national polices might play a significant role in aquaculture development. Therefore, future studies exploring these aspects will be beneficial to gain a more comprehensive understanding of aquaculture production and trends in these leading nations.

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