Impact of Carbon Dioxide Concentration on ASEAN Capture Fishery and Aquaculture Production

GOH JING YU

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature :

Name : Goh Jing Yu

ID No. : 1901592

Date : 18/05/2024

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"Impact of Carbon Dioxide Concentration on ASEAN Capture Fishery and Aquaculture Production"** was prepared by **Goh Jing Yu** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours at Universiti Tunku Abdul Rahman.

Approved by,

Signature	:	
Supervisor	:	Ir. Dr. Ling Lloyd
Date	:	18/05/2024

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ABSTRACT

Fisheries production refers to the number of aquatic species captured or cultivated for human use. It can be categorized into two types: capture fishery and aquaculture. The ASEAN region has significantly contributed to fisheries products, with the 10 ASEAN countries collectively accounting for a quarter of the world's fish production. However, due to the rise in atmospheric carbon dioxide levels, extreme climate events have become more frequent compared to the past. These changes will severely impact fish populations and their habitats, ultimately disrupting the aquatic ecosystem. Hence, this research compares both production yields while considering the annual average global atmospheric carbon dioxide concentration. By referring to open-source data from National Oceanic and Atmospheric Administration (NOAA), World Bank, ASEAN Secretariat and International Monetary Fund (IMF), trend analysis can be performed to study impact of carbon dioxide concentration on ASEAN capture fishery and aquaculture production. Moreover, statistical model can be processed using IBM SPSS Statistics software with the data obtained, which is then utilized to predict the ASEAN capture fishery and aquaculture production. The results show the ASEAN capture fishery and aquaculture production models has an adjusted R squared value of above 0.9 which indicates a strong correlation with annual average global atmospheric carbon dioxide concentration. Furthermore, the standard error of estimate for ASEAN capture fishery exponential model is 0.055 tonnes while ASEAN aquaculture power model is 0.192 tonnes. Most importantly, each model has a p-Value less than 0.001 which means the models are statistically significant at confidence interval of 99%. The overall forecasting result of ASEAN capture fishery and aquaculture production shows an increase as the annual average global atmospheric carbon dioxide concentration increases with year. The upper bound predicted ASEAN capture fishery production yield is from logarithmic model with 19,798,511.18 tonnes, while the lower bound predicted production yield is from linear model with 18,082,735.22 tonnes. For ASEAN aquaculture production yield, the upper bound predicted is from power model with 51,061,322.27 tonnes, while the lower bound predicted production yield is from linear model with 30,204,252.63 tonnes.

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LIST OF SYMBOLS / ABBREVIATIONS

CO_2	Carbon Dioxide
t	Tonnes
ppm	micromol/mol
r	Correlation Coefficient
R^2	Coefficient of Determination
α	Level of Confidence
p	Probability
c	Annual Average Global Atmospheric Carbon Dioxide Levels
y	Year
f	Capture Fishery Production
a	Aquaculture Production

FAO	Food and Agriculture Organization
ASEAN	Association of Southeast Asian Nations
IMF	International Monetary Fund
NOAA	National Oceanic and Atmospheric Administration
USD	United States dollar
SEA	Southeast Asia
ADB	Asian Development Bank
SEE	Standard Error of the Estimate
NSE	Nash-Sutcliffe Efficiency
KGE	Kling-Gupta Efficiency
BCa	Bias-corrected and accelerated
CI	Confidence Intervals
ESG	Environmental, Social and Governance
SDGs	Sustainable Development Goals

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Fisheries production refers to the number of aquatic species captured or cultivated for human use. It can be categorized into two types which are capture fisheries and aquaculture. The term “capture fishery” refers to both marine and inland water capture fisheries. According to Food and Agriculture Organization (FAO), the global capture fishery production in 2020 was 90.3 million tonnes. In comparison to the previous three years, it has decreased 4% in terms of production (FAO, 2022). The ASEAN region has been a crucial contributor of fisheries products. Together, the 10 ASEAN countries made up a quarter of the world’s fish production. Indonesia, Thailand, Vietnam, and the Philippines, Myanmar and Malaysia are among the top fifteen largest marine capture fisheries producers globally, and they are all from ASEAN (ASEAN CDS, 2017).

In Malaysia, the total fisheries production in 2021 was about 1.75 million tonnes, of which 76% was from capture fisheries and 24% was from aquaculture. This shown a production decreased by 2.1%, a decrease from 1.79 million tonnes in 2020 (Department of Fisheries Malaysia, 2022). This may be due to the COVID-19 pandemic during 2020 disrupting the fishing operations for marine and inland capture. However, this factor is considered to be a short-term effect, the world will eventually go back to its norm as time goes on. Other factors that can cause a huge impact on the fisheries production and habitats long-terms are sea surface temperature, water depths, oxygen level, dissolved minerals, etc. (Gebrekiros, 2016).

It’s notable nowadays in news and articles that climate events such as El Niño not only causes drought and heavy rainfall but also brings marine heatwave, which are periods of extreme warm ocean temperatures at the surface or along the seafloor that heavily harms the ocean ecosystems. As climate change persists, the frequency of marine heatwaves increases steadily and tends to be more frequent when El Niño comes. Marine heatwave can be more intense along the seabed than those at the surface, this will severely affect the fish population and their habitats (Conrad, 2023).

In spite of that, when looking at a larger perspective, the main culprit that triggers climate change and events is none other than carbon dioxide (CO_2). There are many studies on the relationship between the rising temperatures due to CO_2 emission and fisheries production, but there is another major effect caused by the elevated concentration levels of dissolved CO_2 as well called ocean acidification. Around 30% of CO_2 released into the atmosphere are absorbed by the ocean. Human activities such as burning fuels in vehicles and clearing forests increase the CO_2 in the atmosphere, which leads to more CO_2 being absorbed by the ocean (NOAA, 2020). This will lower the pH value in the ocean ultimately increasing the acidity of ocean and disrupting the ocean's ecosystem.

1.2 Importance of the Study

CO_2 are the main cause of many climate events, the capture fishery and aquaculture production are in a dire state as the CO_2 concentration in the atmosphere increases. As the ASEAN countries made up a quarter of the global fish production, this study assess the impact of annual average global atmospheric carbon dioxide concentration on capture fishery and aquaculture production in the ASEAN region.

By referring to National Oceanic and Atmospheric Administration (NOAA), World Bank, The ASEAN Secretariat, and International Monetary Fund (IMF), accurate data are collected to use for this research. Subsequently, multiple models are created to predict the capture fishery and aquaculture production yield of ASEAN using IBM SPSS Statistics software. This will provide a better understanding about the correlation between atmospheric carbon dioxide levels with capture fishery and aquaculture production in the ASEAN region.

1.3 Problem Statement

The global atmospheric carbon dioxide concentration is increasing each year causing effects such as climate change by trapping heat, changing the ocean chemistry and affecting the terrestrial and oceanic ecosystems. The fisheries are one of the many species that is severely affected by the effects of rising atmospheric carbon dioxide concentration. To make matters more serious, as fishing technologies advanced throughout the years, the rate of fishing in the ASEAN region has amplify as well resulting in reduction of fish populations. Given capture fishery production is affected by the rise of global atmospheric carbon dioxide concentration, but the aquaculture production may have lesser impact in contrast to the capture fishery production. Hence, this research compares both productions yield while considering the global atmospheric carbon dioxide concentration. From this study, government and researcher can gain insight on the trends of both productions to decide which developments should they improve or focus on to acquire the most benefits.

1.4 Aim and Objectives

The aim of this study is to determine the correlation between annual average global atmospheric carbon dioxide concentration with capture fishery and aquaculture production in the ASEAN region and create multiple models to predict the capture fishery and aquaculture production using IBM SPSS Statistics software. The objectives of this study are:

1. To compare both capture fishery and aquaculture production trend of ASEAN countries.
2. To analyse the correlation between annual average global atmospheric carbon dioxide concentration with ASEAN capture fishery and aquaculture production.
3. To apply statistical models and predict the ASEAN capture fishery and aquaculture production.

1.5 Scope and Limitation of Study

Analysing the correlation between annual average global atmospheric carbon dioxide concentration with capture fishery and aquaculture production followed up with the trend prediction of fisheries production is the main scope of the study. The data is also used to construct multiple predictive models. As for the limitation of this study, the study is heavily dependent on open data sources, the quality and availability of data is pre-determined from the sources obtained.

1.6 Contribution of the Study

Given that ASEAN contributes to a quarter of global fishery production, maintaining its sustainability is of utmost importance. As global CO_2 levels rise due to human activities, the Earth's climate undergoes significant changes. Elevated CO_2 levels can lead to ocean acidification, which directly impacts fish growth, reproduction, and survival. Such disruptions in fish populations can significantly affect the sustainability of capture fisheries in ASEAN. Healthy fisheries and aquaculture systems rely on stable and balanced ecosystems. Unfortunately, elevated CO_2 levels can disrupt marine ecosystems, resulting in changes in species composition, food web dynamics, and habitat availability. Studying these impacts is crucial for effective management and conservation of marine biodiversity. Furthermore, ASEAN countries heavily depend on fisheries and aquaculture for food security, livelihoods, and economic growth. Understanding how CO_2 affects these sectors is essential for informed decision-making. Therefore, conducting this study provides valuable insights for governments and other relevant parties, allowing better planning and strategic development for the ASEAN fishery industry.

1.7 Outline of the Report

Chapter 1 of the report presents an overview of the study. The subsequent chapter reviews existing literature related to global CO_2 level and their impact on ASEAN fisheries and aquaculture. Chapter 3 provides a detailed description of the applied methodology. Chapter 4 will delve into the analysis and discussion of the study's findings. Lastly, Chapter 5 concludes the study and offer recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Numerous studies have explored the impacts of climate change on capture fishery and aquaculture production but relatively few have specifically examined the influence of the global atmospheric carbon dioxide concentration. Carbon dioxide significantly contributes to driving climate change in general, hence why countries around the world are gravitating towards minimizing its overall carbon dioxide emissions. As the global carbon dioxide concentration rises, it will damage the natural habitats of marine and freshwater ecosystems across the globe ultimately affecting fishery production of countries. Since the beginning of the industrial era, CO_2 concentrations have increased by 40% due to the emissions from fossil fuels as well as emissions related to net land use change. Therefore, it is almost certain that the main factor causing the warming of earth is human activities since the mid-20th century. In fact, the ocean has absorbed approximately 93% of the additional heat generated by human activities. Additionally, the global mean sea level has also increased by 0.19 meter from 1901 to 2010. Global warming is causing substantial changes in the aquatic systems that facilitates fisheries and aquaculture while predictions show that these changes will only intensify in the coming years (Barange et al., 2018).

2.2 World’s Fisheries Production

According to FAO (2020), the fish production around the world in 2018 is speculated to have reached approximately 179 million tonnes as shown in Figure 2.1, with a combined initial sales value of 401 billion USD where 82 million tonnes that is worth about 250 billion USD were produced through aquaculture. Human consumption globally takes up roughly 156 million tonnes which translates to an average yearly supply of 20.5 kg per capita. Likewise, aquaculture contributed to 46% of the total production and supplied 52% of fish consumed by humans. China still remained as the world’s leading fish producer, contributing 35% to the global fish production in 2018. With the exception of

China, Asia accounted for 34% of global production in 2018, followed after by America, Europe, Africa and Oceania. The total fish production is observed to be increasing across every continent over the past few decades, except for Europe, where it experienced a progressive decline since the late 1980s, though there has been a slight recovery in recent years. America also witnessed fluctuations in production since the mid-90s, primarily attributed to variations in anchoveta catches. Meanwhile, Africa and Asia have seen their fish production nearly double in the last two decades as shown in Figure 2.2.

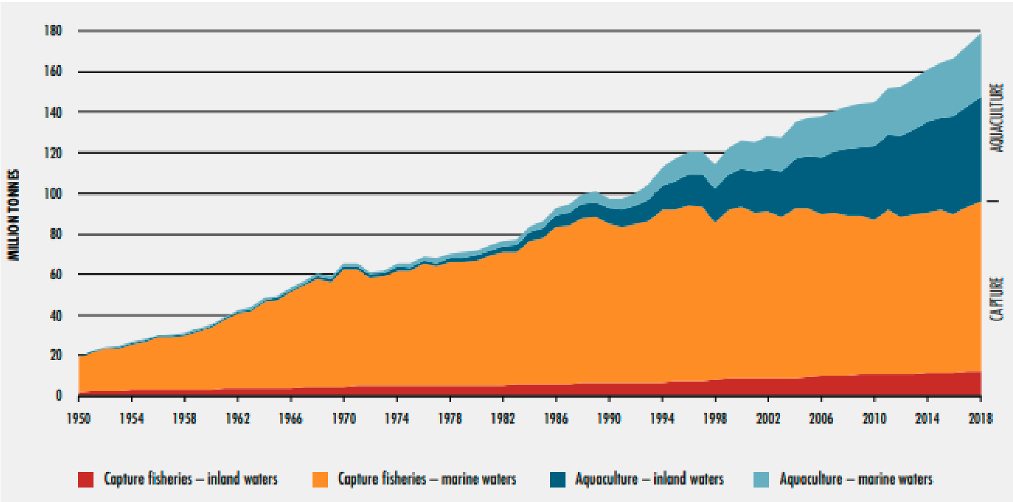

Figure 2.1: Global Capture Fishery and Aquaculture Production (FAO, 2020).

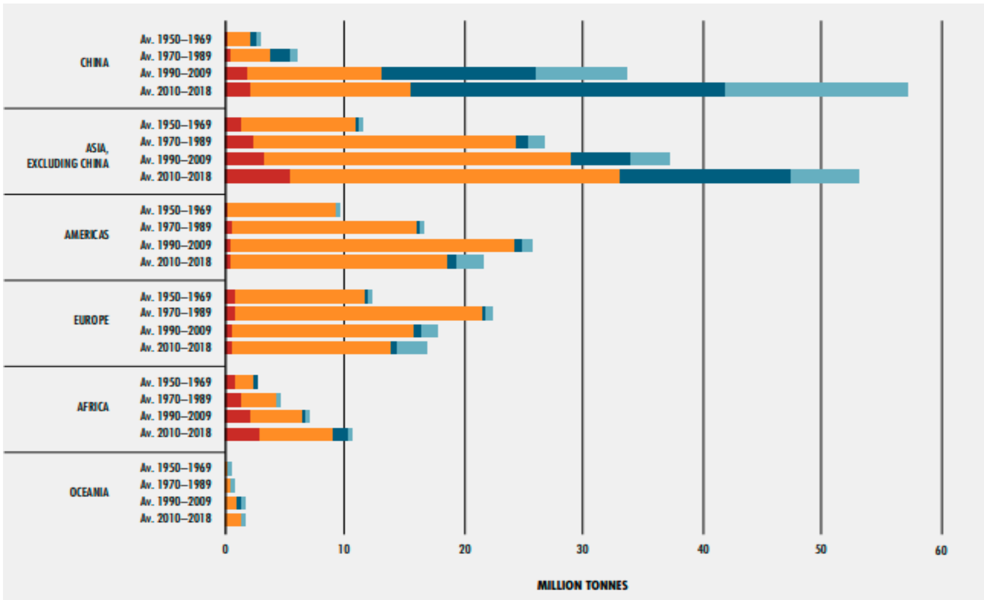

Figure 2.2: Global Fishery and Aquaculture Production Regional Contribution (FAO, 2020).

2.3 Climate Change on Southeast Asia

According to geological studies, the global temperature has changed significantly over the past couple million years and these changes shown to have been concur with the observable shifts in atmospheric CO_2 level. A positive correlation between warm climates and high CO_2 is suggested by the geological record. However, this correlation is imperfect, suggesting that other factors have also been significant in determining climate such as the expansion of polar ice sheets, which serve as reflective surfaces and provide additional cooling while reducing the impact of rising atmospheric CO_2 (Sriskanthan & Funge-Smith, 2011). Moreover, the shifts in atmospheric CO_2 levels are shown to have a direct influence on the potential catches. In line with changes in species composition and habitat loss, climatic changes may cause a severe geographical shift in the world's catch potential. This will have an effect on important factors that affect how productive fisheries systems are, such as thermal change effects on planktonic productivity. In a prediction evaluating the world's catch potential of 1066 marine species between 2005 and 2055, Cheung et al. (2009) described a climate scenario where if the CO_2 concentrations (720 *ppm*) in 2100 are in the high range end, there could be huge latitudinal shifts in catch, with high-latitude locations likely to experience an increase of catch potential which is about 30 to 70% while tropical countries in Asia and elsewhere experiencing a loss in catch potential of up to 40%.

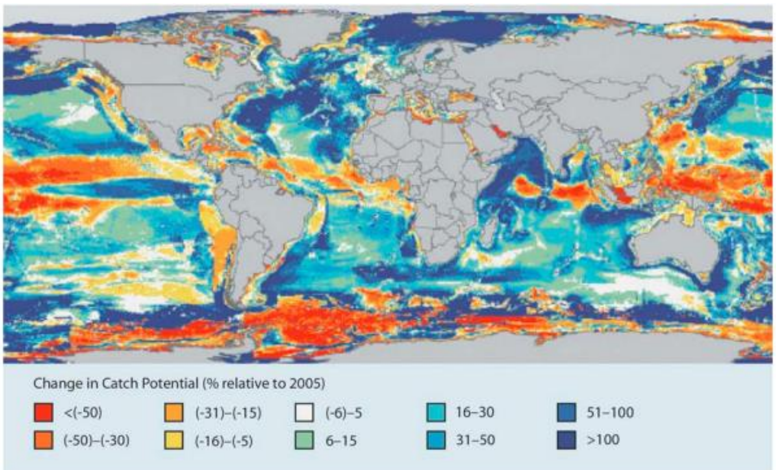

Figure 2.3: Change in Maximum Marine Catch Potential if CO_2 Concentrations is 720 *ppm* in Year 2100 (Sriskanthan & Funge-Smith, 2011).

Southeast Asia (SEA) is one of the regions that stand out as most susceptible to the consequences of a shifting climate. A substantial number of its inhabitants continue to live in dire poverty and work in industries highly vulnerable to climate-related shifts. If this issue is left unaddressed, the 2009 report titled “Economics of Climate Change in Southeast Asia: A Regional Review” by Asian Development Bank (ADB) predict that climate change could lead to a loss equivalent to approximately 6.7% of the region's combined annual gross domestic product by the year 2100 (ADB, 2009). SEA is gradually heading towards a direction that could position itself as a significant future contributor to global warming. CO_2 emissions in the SEA region have experienced a more drastic increase than in any other part of the world in recent decades as seen in Figure 2.4. Besides, SEA has policies that encourage high emissions and technical inefficiencies, including large subsidies for fossil fuels. When paired with several countries fastest growing economies, the world is heading towards a substantial emissions growth in the near future. This rapid escalation conflicts with the established international scientific consensus on the allowable level of global warming to avoid catastrophic dangers (ADB, 2015).

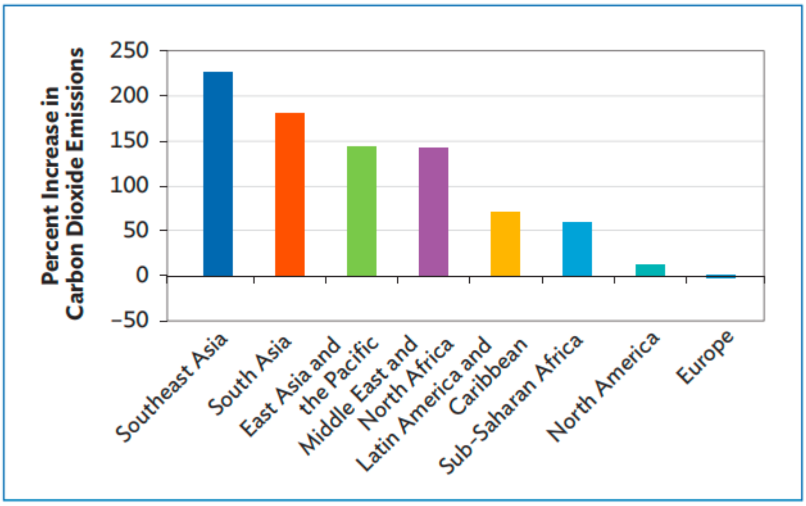

Figure 2.4: Rise of Global CO_2 Emissions Between 1990 – 2010 (ADB, 2015).

In alignment with the Fifth Assessment Report from the Intergovernmental Panel regarding Climate Change, some region in SEA have been observed to have a pattern of increasing mean temperatures by approximately 0.14°C to 0.20°C each decade since the 1960s, resulting in more frequent hot days and warm nights. Furthermore, changes in precipitation patterns are also becoming more evident, though these trends exhibit considerable geographic and seasonal variations. The rainfall on days with extreme precipitation have been rising by 10 millimetres per decade, while the annual total of rainfall on wet days have been increasing by 22 millimetres per decade. Moreover, the percentage of rainfall during the rainy and dry seasons in the region increased overall between 1955 and 2005 while the rise in relative sea levels in the Western Pacific Ocean has surpassed the global average threefold from 1993 to 2012 (ADB, 2015).

Unambiguous and convincing scientific evidence exists that the climate system is warming. Since the 1950s, there has been a rise in both the frequency and intensity of extreme occurrences, including high temperatures, heavy rains, typhoons, and other storms (Lebata-Ramos, 2017). Southeast Asia is not exempt from the impacts of climate change and among those affected by its consequences, the Philippines stands out as the nation most at risk in experiencing these global changes in SEA as shown in Figure 2.5 (Yusuf & Francisco, 2009).

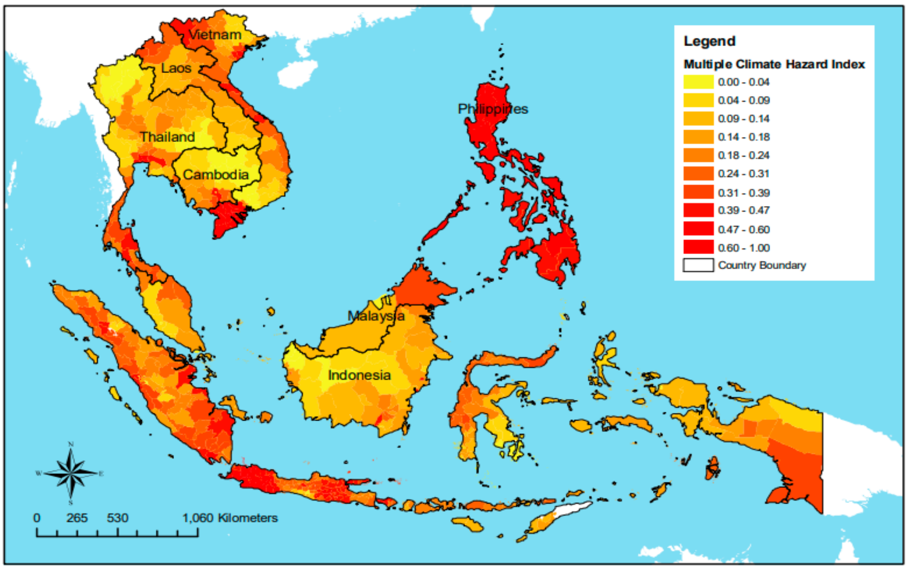

Figure 2.5: Southeast Asia Climate Change Vulnerability Map (Yusuf & Francisco, 2009).

2.4 CO_2 Level and Climate Change Affecting ASEAN Fisheries and Aquaculture

One research shows some countries in ASEAN have shown a decrease in the outputs of marine capture fishery production. The countries include Brunei Darussalam, Malaysia, the Philippines, Singapore, and Thailand. It is also predicted that the other ASEAN countries will show a decline as well in the future unless appropriate management measures and limited target catches is implemented from the respective governments implemented with strong monitoring and enforcement (FAO, 2014). According to Badjeck et al. (2010), there are multiple ways that climate change can affect the fisheries. The marine and freshwater ecosystems, along with resident fish populations are substantially affected by factors such as water temperature discrepancy, precipitation and variables of oceanographic, velocity of wind, action of wave and rising sea level. These ecological and biological changes directly impact people whose livelihoods depend on these ecosystems. Additionally, extreme weather condition can interfere with land-based infrastructure and fishing activities while fishery yield fluctuation and other natural resource availability may affect the livelihoods plans and outcomes of fishing communities.

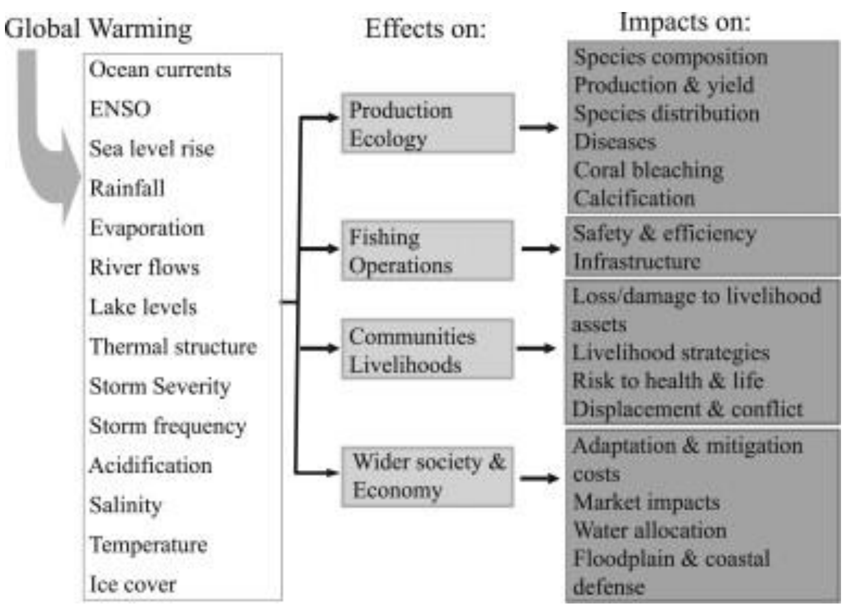

Figure 2.6: Climate Change Impact Pathway in Fisheries and Aquaculture (Badjeck et al., 2010).

Komatsu (2013) states that the fisheries industry is highly susceptible to the effects of climate change on a worldwide scale. Ocean acidification and a rise in water temperature are directly attributed to CO_2 emissions, which also induce a decrease in ocean pH. Both of these consequences have the potential to alter the ocean ecology, including fish habitats and behaviours. In spite of efforts have been to explain how climate change affects the ocean, there is still much that is unclear. The general consensus is that it will result in a decline in fisheries production. More fish will migrate to a higher latitude in the tropical regions as temperatures increase, whereas phytoplankton primary output will fall. Following that, there will be a reduction in the output of the higher ecological niches, including fishery resources. While the future productivity of some fish, including salmon and saury can be predicted using models but as they decrease in size and weight, the fishery production yield is subjected to lowered as well. Besides that, acidification will also destroy marine ecosystems, especially nursery sites and harming the coral reefs. Another concern is the increasing temperatures impact on intensive facilities and ponds which are usually situated in shallow waters, making aquaculture another vulnerable industry. In fact, the problem of Early Mortality Syndrome is seemingly caused by the warmer water. Therefore, the water bodies in aquaculture zones are sensitive to climate change.

Another similar research from Brander (2010) said that there is increasing evidence of human-induced climate change affecting marine ecosystems. However, it is important to analyse this evidence within the context of natural climate cycles and variability which have historically influenced fluctuations in fisheries. Various chemical and physical factors such as temperature, winds, salinity, oxygen levels, pH have both direct and indirect impacts on fisheries. Specifically, climate change directly affects fish stocks by altering their growth, reproductive capabilities, mortality rates and distribution patterns through changes in physiology and behaviour. As for indirect effects, it alters the productivity, structure and composition of the aquatic ecosystems that fish depend on for their survival. Despite the lack a thorough understanding about how climatic and environmental elements impact fish on individual, population, and ecosystem scales, observable changes at these levels can already be attributed to climatic variability and climate change. Notably, shifts in the distribution of fish and plankton are especially apparent since they occur more quickly than changes in terrestrial fauna and plants.

Similarly, research by De Silva and Soto (2009) also said that aquaculture operations will be affected by climate change through both direct and indirect means. As mentioned in previous study, indirect impact pertains to related problems like feed supply and trade while immediate physical, physiological, and ecological effects are considered as direct impacts. Water temperatures shift, patterns of monsoon, action of current and wave, serious climatic events are only a few of the direct impact of altered environmental conditions at the site level (De Silva & Soto 2009). The types of species utilized in aquaculture will encounter similar constraints as those preferred in traditional fishing practices. Factors such as temperature and salinity can affect their physiological functions, which may necessitate adjustments in the best locations and cultivation methods for various species. It is highly likely that fish species will face physiological limitations caused by decreased oxygen transport to their tissues at elevated temperatures, and this is expected to drastically hamper the aquaculture activities. Furthermore, disease outbreaks, invasions by invasive species, and toxic algal blooms could all become more frequent as a result of warming temperature (Barange & Perry, 2009).

Another research by Ishimatsu et al. (2015) also states that elevated levels of CO_2 in water will indirectly affect the fishes by impacting the aquatic environment. This includes rising water temperatures and altering the structure and functioning of ecosystems. Over the span of 100 to 200 years, shallow-water fish species will experience more pronounced effects from atmospheric CO_2 diffusion, while deep-sea species may encounter high CO_2 concentration if CO_2 is intentionally introduced into the deep sea with purpose of mitigating the rapid rise in atmospheric CO_2concentrations. Therefore, another possible risk to the future global population is the probable decrease of fish resources caused by high CO_2 circumstances brought on by atmospheric CO_2 diffusing into surface waters or by direct CO_2 injection into the deep sea. In comparison to terrestrial animals, aquatic animals are more vulnerable to the increased environmental CO_2 levels due to the dissimilarity in CO_2 partial pressure between the body fluids of water-breathing animals and their surrounding environment is a lot smaller than in terrestrial animals.

Research from Yazdi and Shakouri (2010) states that accumulation of CO_2 and other greenhouse gases are altering Earth's climate, oceans, coasts, and freshwater ecosystems, which has an impact on fisheries and aquaculture. These changes extend to alterations in air and sea surface temperatures, precipitation patterns, sea levels, ocean acidity, wind behaviour and the intensity of tropical cyclones. As a result of these transformations, individuals involved in fishing and coastal living will face significant impacts including less secure livelihoods, alterations in the availability and quality of fish as a food source as well as heightened risks to their well-being and safety. Numerous communities reliant on fisheries had to endure precarious and vulnerable living conditions due to poverty, inadequate social services and essential infrastructure deficiencies. Their vulnerability is compounded to a greater extent by the overexploitation of fishery resources and the deterioration of ecosystems. In many developing nations and small island states, the climate change effects on food security and livelihoods are significant while the aquatic habitats are being drastically impacted by increased ocean temperature and ocean acidification. Notably, climate change will influence the oceans' ability to absorb and retain carbon. Coastal fishing communities face immediate challenges from rising sea levels, placing them at the forefront of climate change impacts. Meanwhile, inland fisheries and aquaculture are impacted by the shifting rainfall patterns and water usage.

Likewise, the increasing concentrations of atmospheric CO_2 is causing the ocean's average sea-surface temperature and the dissolved CO_2 to rise (Munday, McCormick and Nilsson, 2012). A large number of coral reef fishes appear to inhabit environments close to their optimum temperature range, whereas for some of them even a slight increase in temperature (2–4°C) can result in significant reductions in their aerobic capacity. This reduced ability to utilize oxygen may impact the long-term viability of populations since less energy can be allocated to activities like reproduction and feeding. The anticipated rise in partial pressure of carbon dioxide and the associated ocean acidification can also impact the aerobic capacity of coral reef fish. However, considering variation among species, some may experience a decrease and others an increase in aerobic CO_2 capacity level in the near future. Similar to the effects of temperature, excessive CO_2 can cause transgenerational alterations that might offset the influence of high CO_2 on the development and survival of reef fish. Unexpectedly, researchers found that increased CO_2 level has a significant impact on a variety of reef fish behaviour and sensory responses, which has an impact on the timing of settlement, habitat choice, predator avoidance, and individual fitness (Munday, McCormick and Nilsson, 2012).

Viewing in a different perspective, fisheries and aquaculture is not only a victim of climate change but also a leading contributor of greenhouse gases too. Global greenhouse gas emissions are produced from fisheries and aquaculture activities such as fish capture or cultivation, processing, transportation, and storage. Moreover, there exists a variety of fisheries vessels with diverse fuel requirements. These range vary from small, low-power engines to huge fish factory ship-style vessels. Fuel efficiency can be defined as the proportion of revenue spent on fuel and this varies significantly between developed and developing-country fisheries. In developing countries, up to 50% of their total catch revenue may be allocated to fuel costs (Daw et al., 2009). Some of this inefficiency is caused by policies in fisheries management that foster a “race to fish”. This pertains to regulation that unintentionally encourages the usage of more potent fishing equipment, which can swiftly result in overfishing. To catch an equivalent number of fish as in the past, vessels must venture further or into deeper waters and expend additional resources. Furthermore, the primary source of emissions in the fisheries industry aside from fuel emissions from fishing vessels is the product transportation. Notably, when travelling from one country to another country's markets, goods are often transported via goods on ships or plane. Since high-value species like tuna exported from Japan are more likely to be carried by air, their transport emissions are relatively high (Daw et al., 2009).

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Study Area

The 10 ASEAN countries consist of Myanmar, Laos (LAO PDR), Thailand, Cambodia, Vietnam, Philippines, Brunei, Malaysia, Indonesia, and Singapore. Its collective population amount to 662 million with a combined gross domestic product valued at 3.2 trillion USD (CFR.org Editors, 2021). The ASEAN countries is responsible for a quarter of the world's total fishery production.

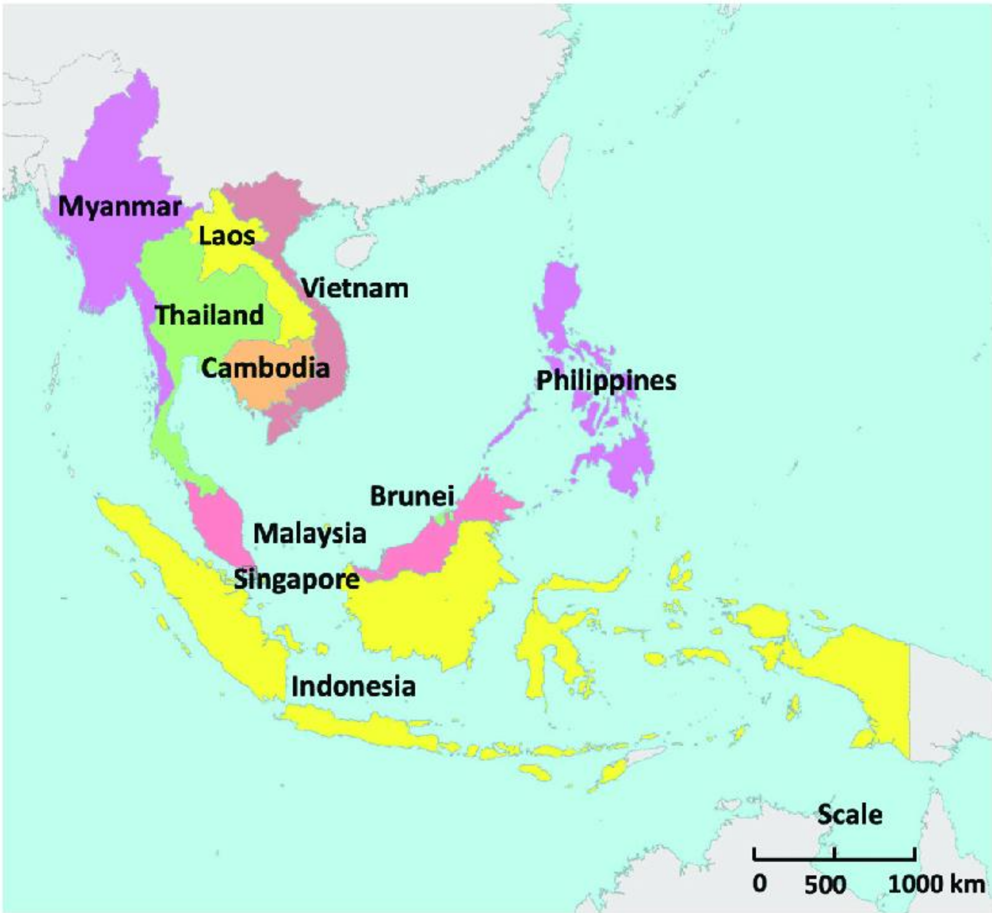

Figure 3.1: Map of ASEAN Countries (Lau et al., 2022).

3.2 Methodology Flowchart

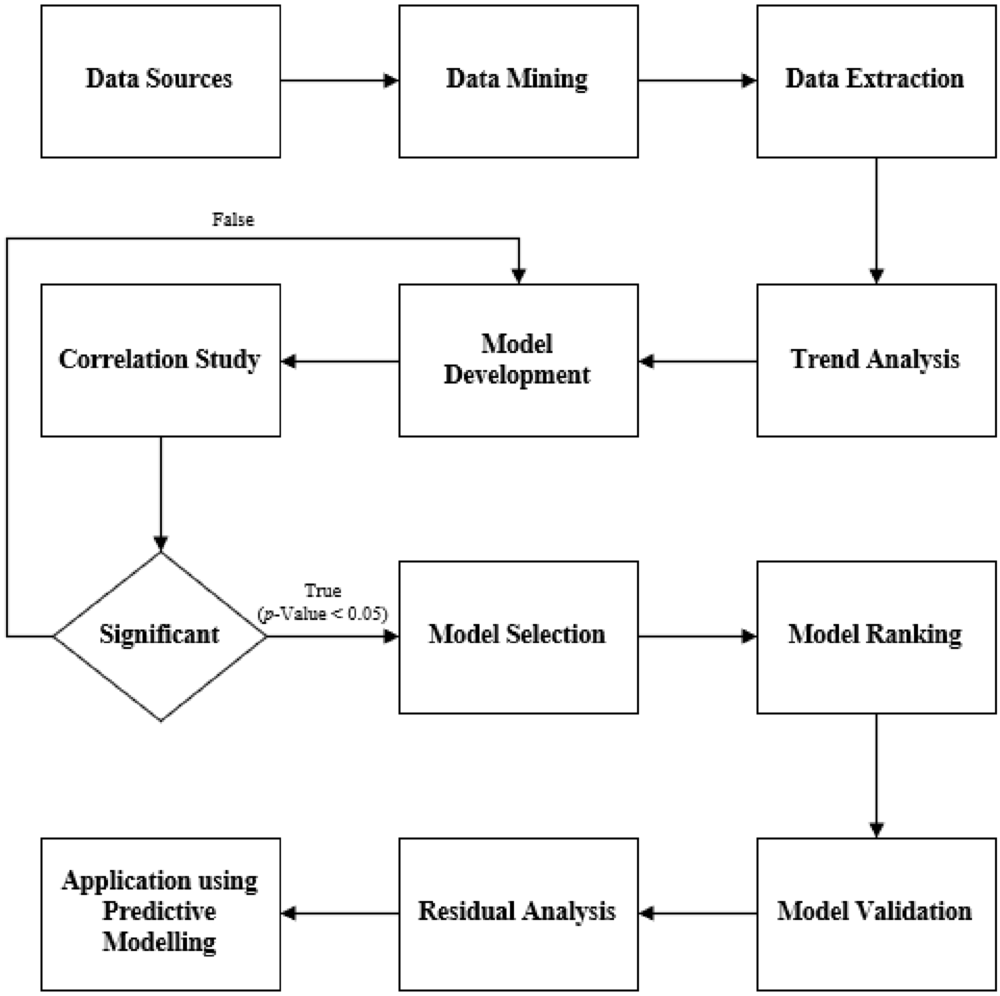

Figure 3.2: Methodology Flowchart.

3.3 Data Sources

A data source is a necessary foundation needed before developing and conducting predictive modelling. In the initial stage, a reliable data sources are identified to find a relevant dataset. For this research, World Bank, the ASEAN Secretariat, International Monetary Fund and National Oceanic and Atmospheric Administration are the data sources used to find the most appropriate and accurate data archive.

3.4 Data Mining

The dataset of capture fishery and aquaculture production was obtained from the World Bank Open Data source with production yield expressed in tonnes (*t*) while the ASEAN population dataset was obtained from The ASEAN

Secretariat and International Monetary Fund. As for the atmospheric carbon dioxide levels data, it was obtained from NOAA's Global Monitoring Lab at Mauna Loa Observatory in Hawaii with CO_2 represented as a mole fraction in dry air, measured in micromoles per mole, abbreviated as *ppm*. The range of data used for this research is 31 years which can be separate into two categories, early 31 years (1960 – 1990) and recent 31 years (1991 – 2021).

3.5 Data Extraction

The dataset of annual average global atmospheric carbon dioxide concentration, capture fishery and aquaculture production of ASEAN countries as well as ASEAN population are extracted to an excel spreadsheet. The data is then sort out column by column based on the ASEAN countries.

3.6 Trend Analysis

Across ASEAN countries, variations in capture fishery and aquaculture production trends arise due to differing national strategies and priorities. This analysis sheds light on the overall trajectory that ASEAN's capture fishery and aquaculture production has followed in recent years. The comparison was made by plotting graphs using data from the World Bank to assess capture fishery and aquaculture production yields. This study also shows how prevalent capture fishery and aquaculture sector are to each ASEAN country.

3.7 Model Development

To create a model, IBM SPSS Statistic v26.0 is used to develop the skeleton of the model. The data mined and extracted from the data source organized in the excel spreadsheet are opened inside IBM SPSS Statistic software. By selecting the function 'Analyze' followed by 'Regression' to 'Curve Estimation', both dependent and independent variable of the data are selected and subsequently various model options are selected for generation. After all inputs are completed, the output will generate a Variable Processing and Model Summary. At the same time, Microsoft Excel is used to cross check the model produced by IBM SPSS Statistic v26.0.

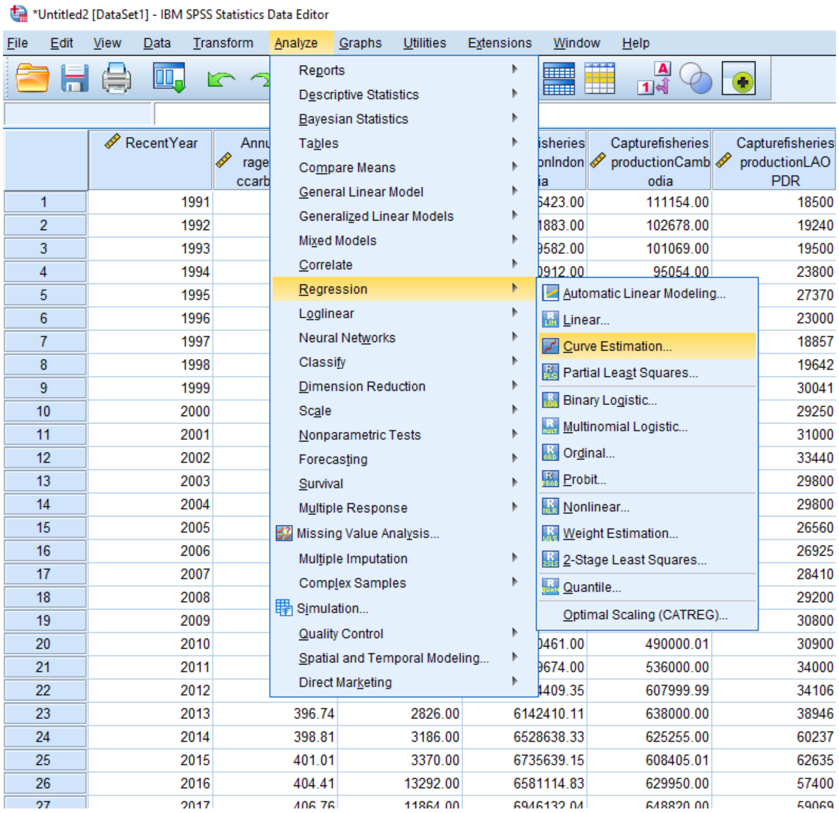

Figure 3.3: 'Analyze' Function in IBM SPSS Statistic v26.0.

3.8 Correlation Study

The Correlation Study was conducted after inputting the data set into IBM SPSS Statistics v26.0 to generate a Model Summary. The dependent variable will be the capture fishery and aquaculture production of each ASEAN country while the independent variable is the annual average global atmospheric carbon dioxide concentration. Additionally, the 3 important components in a Correlation study includes the statistical significance, adjusted correlation coefficient and standard error of the estimate. Generally, to conduct a strong statistical analysis, the minimum sample size used should be at least 30. According to Ganti (2023), a sample size of 30 or greater is quite common in statistical study as it is considered adequate for Central Limit Theorem to hold. A sample size of 30 frequently widens the population data set's confidence interval to the point where comments contradicting your findings are justified. The likelihood that your sample will be representative of your population set increases with sample size (Ganti, 2023). In this study the sample size for the correlation analysis is 31 years.

3.8.1 Statistical Significance

In a study, the statistical significance is a probability measurement of the null hypothesis being true in contrast to the uncertainty acceptable level regarding the true answer (Tenny & Abdelgawad, 2022). Some level of confidence or significance level must be settled on when disproving a hypothesis. The level of confidence is denoted as the Greek letter alpha (α) and is describe as the probability of willingness to be incorrect for a research. Generally, a significant research would need to be correct about their results 95% of the time, or in another point of view the research is willing to be incorrect 5% of the time. Thus, this implies that the alpha value of this research study will be set at a benchmark of 0.05. Next step is to perform a statistical analysis of the outcome to acquire a probability value (p-value). The probability that a statistical summary of the data would match or exceed its observed value based on a specific statistical model is known as a "p-value”. If the data analysis's p-value is smaller than the set alpha, it implies there is statistical significance for the study (Tenny & Abdelgawad, 2022). For this study, if the atmospheric carbon dioxide levels is shown to have an impact on capture fishery and aquaculture production in the ASEAN region after running a proper statistical analysis with a p-value lower or equal than the alpha value, this will conclude the study to be statistically significant.

3.8.2 Correlation coefficient

In statistics and modelling, the correlation coefficient (r) is a measurement of strength of the linear correlation between two variables, it can have an interval between +1 and −1 (Ratner, 2009). While the coefficient of determination (R^2) is generally regard as the ‘variation percentage shared between the two variables’. R^2 tends to optimistically predict the linear regression fit, as it increases with the inclusion of more factors in the model (IBM, 2023). In addition, an adjustment can be done to R^2 due to the individual shapes of the dependant and independent data. Hence, the actual correlation coefficient falls within the closed interval of [−0.99, +0.90] and the adjusted correlation coefficient can be determined. The adjusted correlation coefficient also known as adjusted R^2 calculated by dividing the original correlation coefficient by the recalibrated correlation coefficient (Ratner, 2009). In general, adjusted R^2 has a more precise view of the correlation between 2 variables because of its nature in seeking to correct the overestimation of R^2, making it always less than or equal to the R^2 value (IBM, 2023). Therefore, adjusted R^2 is studied and observed to determine the correlation between the two variables for this research.

Table 3.1: Correlation Coefficient Interpretation (Ratner, 2009).

Correlation Coefficient	Range	Relationship
r / R^2/ adjusted R^2	0 – 0.3 (0 – -0.3)	Weak
	0.3 – 0.7 (-0.3 – -0.7)	Moderate
	0.7 – 1.0 (-0.7 – -1.0)	Strong

3.8.3 Standard Error of the Estimate

An error or residual can be referred as the contrast between the observed value and predicted value of dependant variable which is derived from the multiple regression model. The Standard Error of the Estimate (SEE) is an evaluation of standard deviation of the errors within a regression model. It measures the average deviation of the error as well as the disparities between the predicted y-value by multiple regression model and the sample's y-value (Watts, 2022). The SEE value indicates on an average magnitude by which the dependent variable deviates from the predictions made by the regression model based on the independent variables. In other words, it measures how closely the regression model's predictions matches the actual data. SEE is used to assess the regression model's accuracy and is frequently associated with the residual errors in a model. Notably, the units of the Standard Error of the Estimate are the same with those of the dependent variable (Watts, 2022). The SEE formula is written as follows:

$$SEE = \sqrt{\frac{\sum(x_i - \bar{x})}{n-2}} \tag{3.1}$$

where

x_i = Data values

$\bar{x}$ = Mean value

n = Sample size

3.9 Model Selection

After the output is displayed, there are three steps in priorities when it comes to selecting an appropriate model for research. The first priority is to identify the *p*-Value of the models which does not exceed 0.05 as any model's *p*-value exceeding 0.05 is deemed to be statistically insignificant. Next priority will be choosing the highest adjusted R^2 value amongst the models. Reason being a high adjusted R^2 value implies a strong correlation between both variables. In a case where multiple models have the same adjusted R^2 value, the last component will be compared which is the SEE value. In general, a low SEE value is desirable as it shows model has a high accuracy. The closer the SEE value is to 0, the higher the precision of the model can make a prediction. In short, the model with a *p*-value not exceeding 0.05, highest adjusted R^2 value and lowest SEE value will the first ranked model.

3.10 Model Ranking

Due to each ASEAN country has its own capture fishery and aquaculture production dataset, the types of models being develop for a specific country may not be the same as other countries. Hence, the top three ranking of models for each country is presented to compare with other countries.

3.11 Model Validation

Model validation is a crucial step in the process of developing predictive or statistical models. A newly developed model is not perfect; thus, a test must be conducted to check the validity of a model. A model's validity can be determined with its biasness. Both Nash-Sutcliffe efficiency (NSE) and Kling-Gupta efficiency (KGE) are widely used to evaluate the biasness and prediction accuracy of hydrological models. The value of both efficiency ranges from $-\infty$ to 1.0 where the closer the efficiency is to 1.0 the more unbiased and accurate the model is.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(x_{predicted} - x_{observed})^2}{\sum_{i=1}^{n}(x_{observed} - x_{mean})^2} \qquad (3.2)$$

$$KGE = 1 - \sqrt{(r-1)^2 + (\frac{\sigma_s}{\sigma_o} - 1)^2 + (\frac{\mu_s}{\mu_o} - 1)^2} \qquad (3.3)$$

$$BIAS = \frac{\sum_{i=1}^{n}(x_{predicted} - x_{observed})}{n} \qquad (3.4)$$

where

r = Correlation coefficient

σ_s = Standard deviation of the simulation

σ_o = Standard deviation of the observation

μ_s = Mean of simulation

μ_o = Mean of observation

3.12 Residual Analysis

Residual analysis uses data from the predicted data subtracting the observed data and it is performed to further test the stability of model. By utilizing the function ‘Analyze’ followed by ‘Descriptive Statistisc’ to ‘Explore’ in IBM SPSS Statistic v26.0, the user can perform bootstrapping. The setting of bootstrapping used in this analysis is 2000 number of samples and Bias-corrected and accelerated (BCa) of 99% Confidence Intervals (CI). The choice of a 99% CI is to be more conservative in the estimation. Compared to a lower confidence interval like 95% CI, it captures more uncertainty but provides greater confidence in the coverage of the true parameter. Moreover, a moving window time series forecasting validation is implemented in the residual analysis of CO_2 concentration as well as ASEAN capture fishery and aquaculture production with the same setting to assess whether the output results remain consistent in each timeframe.

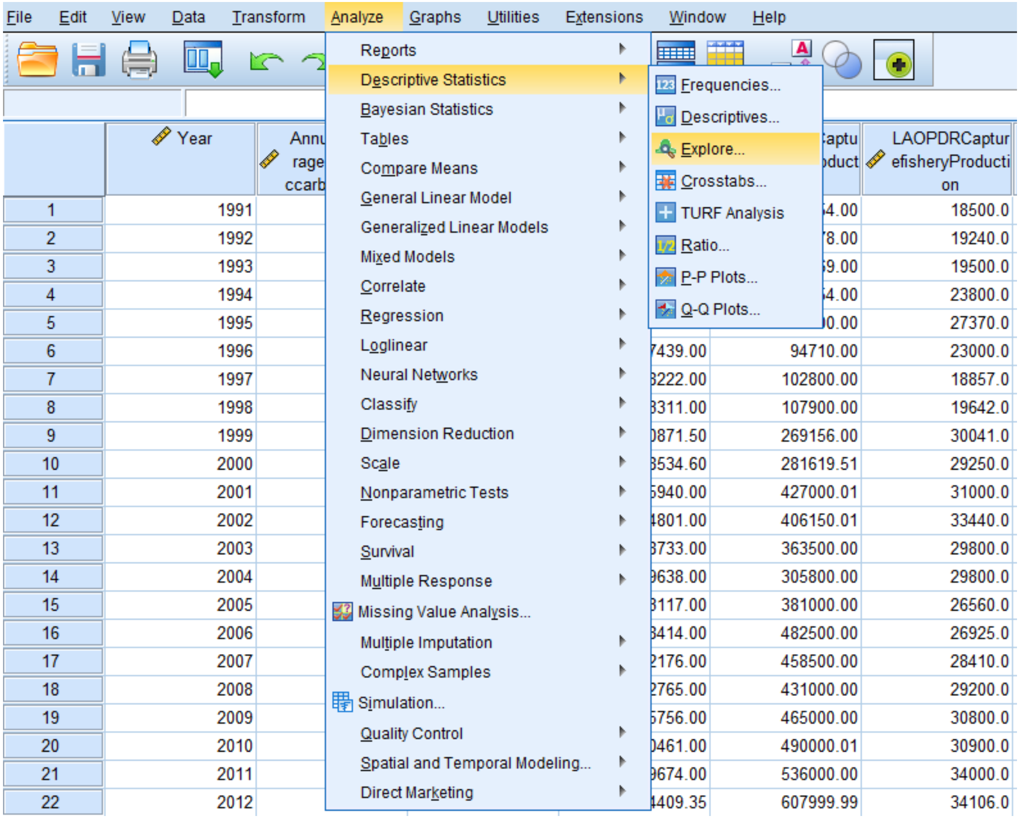

Figure 3.4: Bootstrap in 'Analyze' Function in IBM SPSS Statistic v26.0.

3.13 Application using Predictive Modelling

The predictive modelling process involves forecasting ASEAN capture fishery and aquaculture production in terms of annual average global atmospheric carbon dioxide concentration. Using the model, graph was plotted to analyse the trends of fishery production by year. Individually, the countries may subject to have multiple variation of model from each other as the adjusted correlation coefficient and statistical significance determines the suitability of various model. With that, the prediction model can be applied to the ASEAN Environmental, Social and Governance (ESG) principle and Sustainable Development Goals (SDGs). This application can be further supported by analysing the population as well as forecasted results of capture fishery and aquaculture production in ASEAN. With the ability to forecast the ASEAN capture fishery and aquaculture production, government and other relevant parties can strategically invest and plan their course of action in the fishery sector.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

To study the correlation between annual average global atmospheric carbon dioxide concentration with capture fishery and aquaculture production in the ASEAN region, it is crucial to comprehend the ASEAN fisheries status. In the recent 31 years (1991 - 2021), Indonesia has been the leading country when it comes to fisheries production within ASEAN, followed by Thailand and Vietnam. Table 4.1 shows the total capture fishery production for each ASEAN country in the recent 31 years.

Table 4.1: Total Capture Fishery Production of ASEAN from 1991 to 2021 (WORLD BANK, 2023).

Rank	ASEAN country	Total Capture fishery production (*t*)
1	Indonesia	157,238,914.50
2	Thailand	71,669,565.36
3	Vietnam	64,921,236.22
4	Philippines	64,318,206.02
5	Myanmar	46,206,760.00
6	Malaysia	40,516,980.09
7	Cambodia	12,175,175.55
8	LAO PDR	1,138,638.00
9	Brunei	153,635.43
10	Singapore	127,846.34

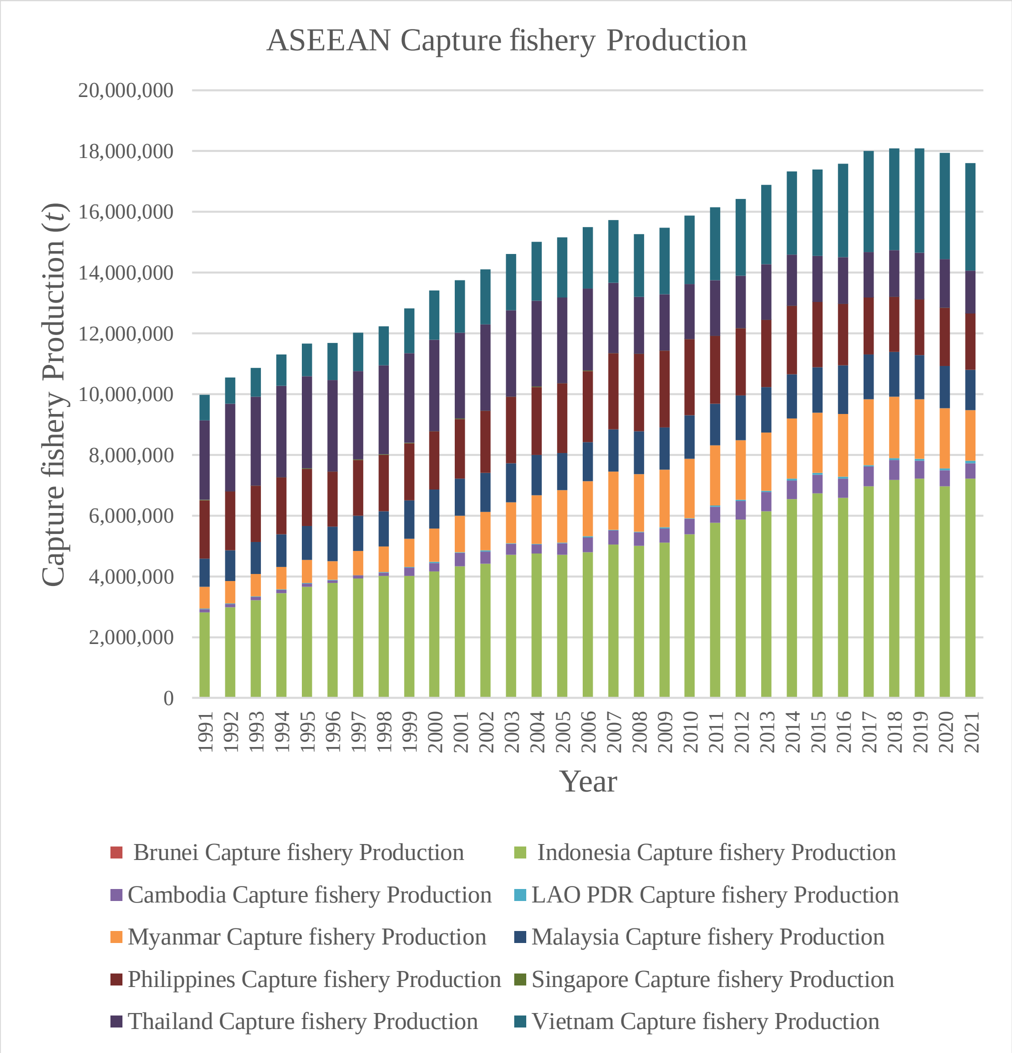

Figure 4.1: Capture Fishery Production of ASEAN from 1991 to 2021 (WORLD BANK, 2023).

As for the aquaculture production of ASEAN region, its practice started blooming in the early 80s. Fish, shellfish, algae, and other species are bred, raised, and harvested through aquaculture in many kinds of aquatic habitats. Advancements in technology have enabled the cultivation of food in open ocean and coastal marine areas to meet the growing demand for seafood. Aquaculture serves multiple purposes including food production, replenishing wild fish stocks, habitat rehabilitation and the conservation of threatened and endangered species (NOAA, 2023). Despite that, some countries have a late start in its aquaculture sector compared to other ASEAN countries namely, Brunei, Cambodia, LAO PDR and Singapore. Table 4.2 shows the aquaculture production for each ASEAN country in the recent 31 years.

Table 4.2: Total Aquaculture Production of ASEAN from 1991 to 2021 (WORLD BANK, 2023).

Rank	ASEAN country	Total aquaculture production (*t*)
1	Indonesia	188,822,153.70
2	Vietnam	61,171,196.45
3	Philippines	54,435,878.86
4	Thailand	28,567,232.96
5	Myanmar	16,541,547.92
6	Malaysia	9,235,475.64
7	Cambodia	2,666,889.00
8	LAO PDR	2,042,141.50
9	Singapore	142,508.32
10	Brunei	21,427.79

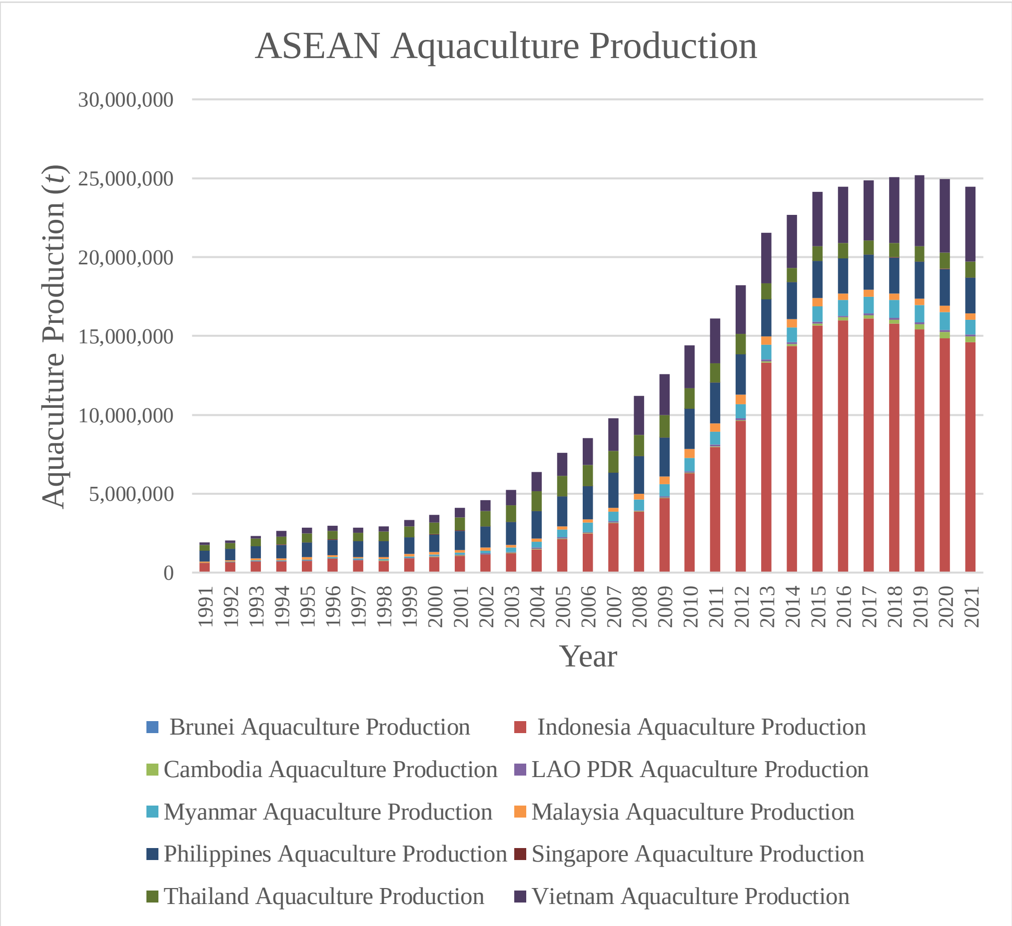

Figure 4.2: Aquaculture Production of ASEAN from 1991 to 2021 (WORLD BANK, 2023).

Indonesia is also the leading country in terms of aquaculture production followed by Vietnam and Philippines. From both total production data, some countries seem to have a higher production yield on the aquaculture sector compared to the capture fishery sector which includes Indonesia, LAO PDR and Singapore.

4.2 ASEAN Capture Fishery and Aquaculture Production Trend Analysis

Each country in the ASEAN region has its own strategies in the fishery and aquaculture sector, hence the production trend may differ from one another. Other factors such as location, overfishing and manpower may affect the production yield as well. This section analyses the production trend of capture fishery and aquaculture of all ASEAN country and ASEAN as a whole.

4.2.1 Indonesia

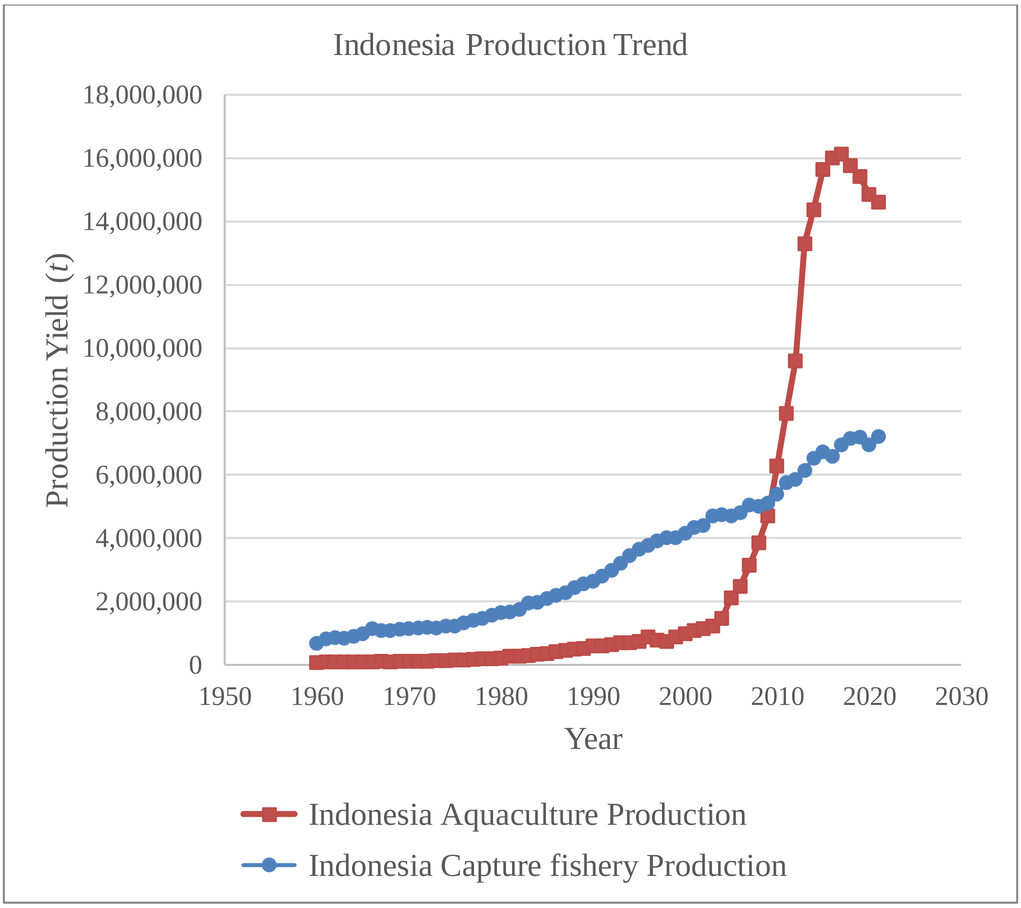

Figure 4.3: Indonesia Production Trend (1960 – 2021).

Indonesia having highest amount of capture fishery and aquaculture production stands out as a powerhouse in fisheries within the ASEAN region. Over the past years, Indonesia's capture fishery sector has steadily risen, reflecting a positive trend. Conversely, Indonesia's aquaculture production has experienced a remarkable surge. By 2010, it had already surpassed the capture fishery production by an impressive 887,463.49 tonnes. The peak came in 2017, with a staggering 16,118,238 tonnes produced. Unfortunately, the aquaculture sector faced a downturn in 2018, and this decline has persisted. Despite the aquaculture sector's decline, its 2021 production yield remains twice that of capture fishery.

4.2.2 Thailand

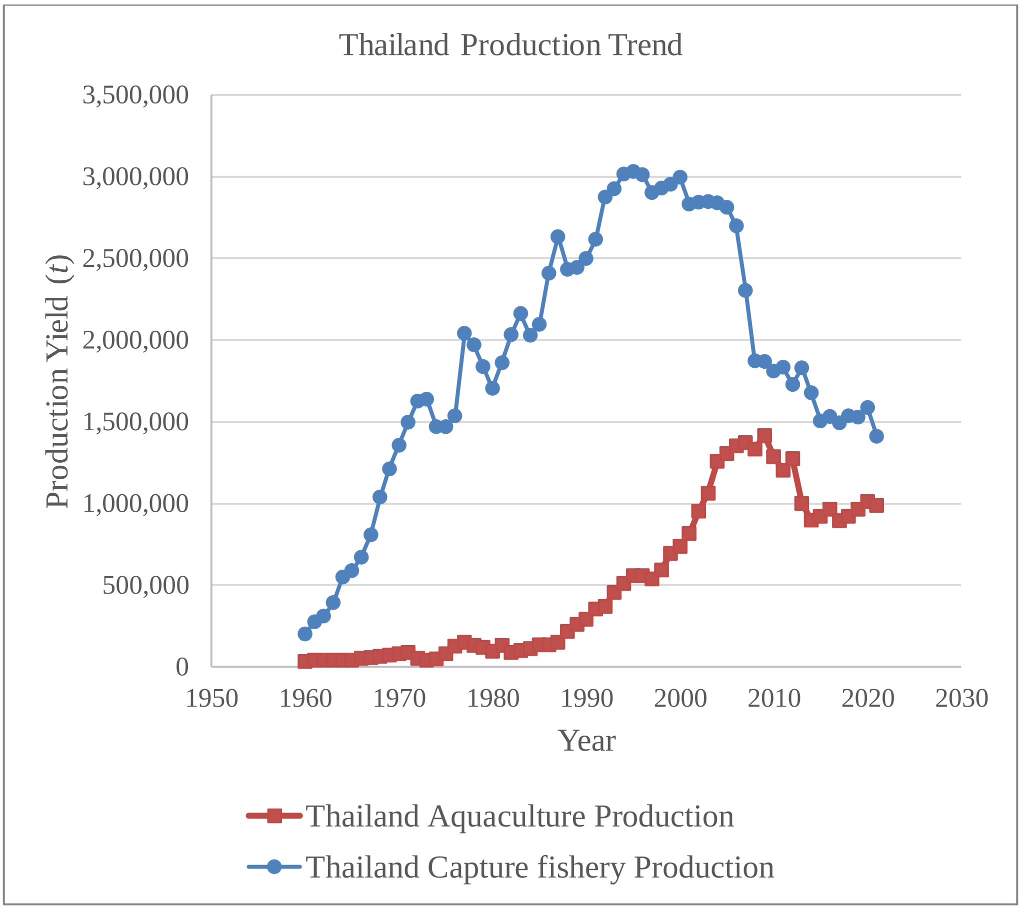

Figure 4.4: Thailand Production Trend (1960 – 2021).

Thailand ranks second in overall capture fishery production within the past year. In 1996, Thailand achieved its highest production yield, reaching an impressive 3,013,961 tonnes. However, over the years, a downward trend emerged. By 2008, production had declined to 1,873,432 tonnes, marking a substantial drop over a span of 12 years. This decline persisted, reaching 1,412,123.25 tonnes in 2021. While Thailand's aquaculture production doesn't shine as brightly as its fishery counterpart, it has shown resilience. Despite facing challenges since 2009, aquaculture production has been on a slow rise, particularly since 2017. If this downward trajectory of the fishery sector continues, aquaculture might even surpass capture fishery production in the near future.

4.2.3 Vietnam

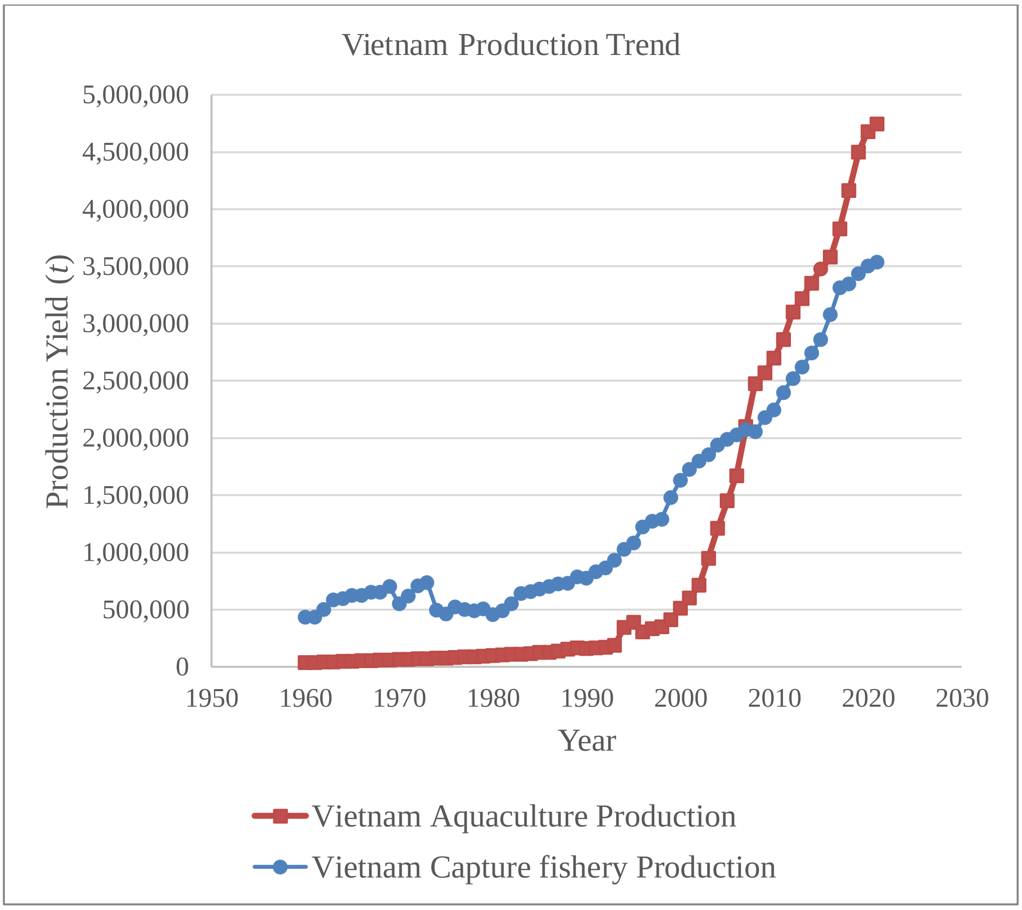

Figure 4.5: Vietnam Production Trend (1960 – 2021).

Vietnam is another prominent country with substantial growth in capture fishery and Aquaculture production. Both sectors have been experiencing an uptrend in terms of production yield. Notably, the aquaculture sector witnessed a remarkable growth surpassing capture fishery in 2008. In 2021, Vietnam achieved an impressive production yield of 4,749,273.83 tonnes from aquaculture alone. As for capture fishery sector, it shows a steady increase throughout the year with a production yield of 3,540,250.15 tonnes in 2021.

4.2.4 Philippines

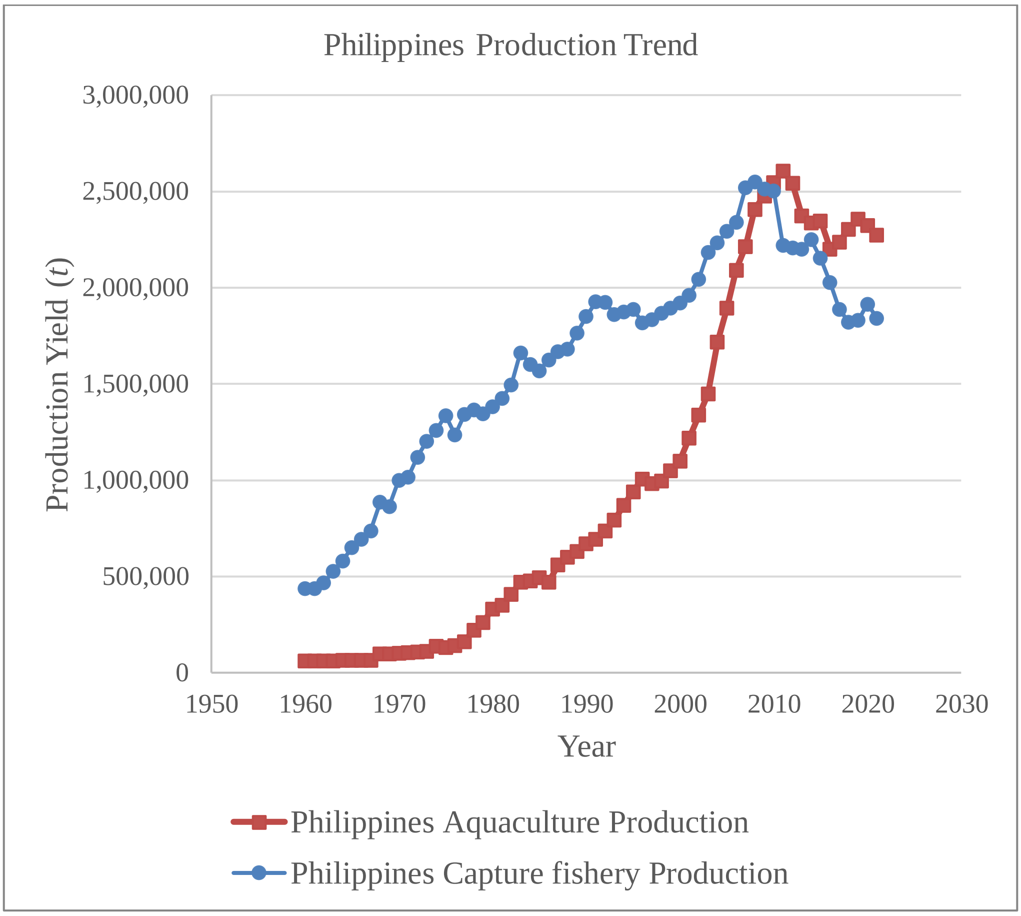

Figure 4.6: Philippines Production Trend (1960 – 2021).

Philippines also plays a major part in the ASEAN fishing industry. In 2008, the country achieved a peak capture fishery production of 2,550,700 tonnes. However, its production yield has been declining ever since with the latest data from 2021 indicates a capture fishery production of 1,842,066.89 tonnes. On the other hand, the aquaculture sector witnessed robust growth over the years and even overtaking the capture fishery production in 2010. Although it experienced a downturn since 2011, it remains resilient compared to the capture fishery sector with a production yield of 2,272,527.53 tonnes in 2021.

4.2.5 Myanmar

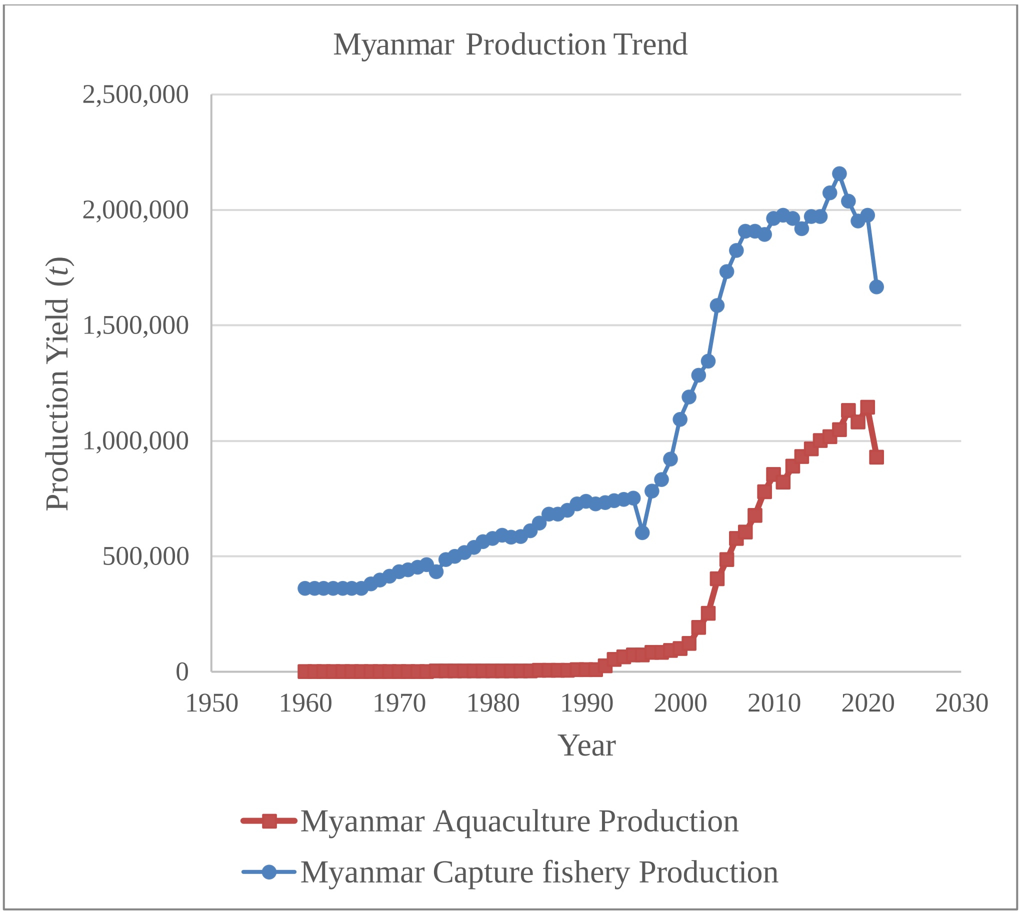

Figure 4.7: Myanmar Production Trend (1960 – 2021).

Myanmar's fishery and aquaculture sector has witnessed significant developments in the past year. In the early 2000s, its capture fishery production had a spike and reaches a peak of 2,155,440 tonnes in 2017. However, the production faced a downturn ever since, having a production yield of 1,665,740 tonnes in 2021. On the other hand, Myanmar's aquaculture sector has followed a more consistent upward trajectory. In 2020, it achieved an all-time high of 1,145,108 tonnes but witnessed a decline in production yield the following year.

4.2.6 Malaysia

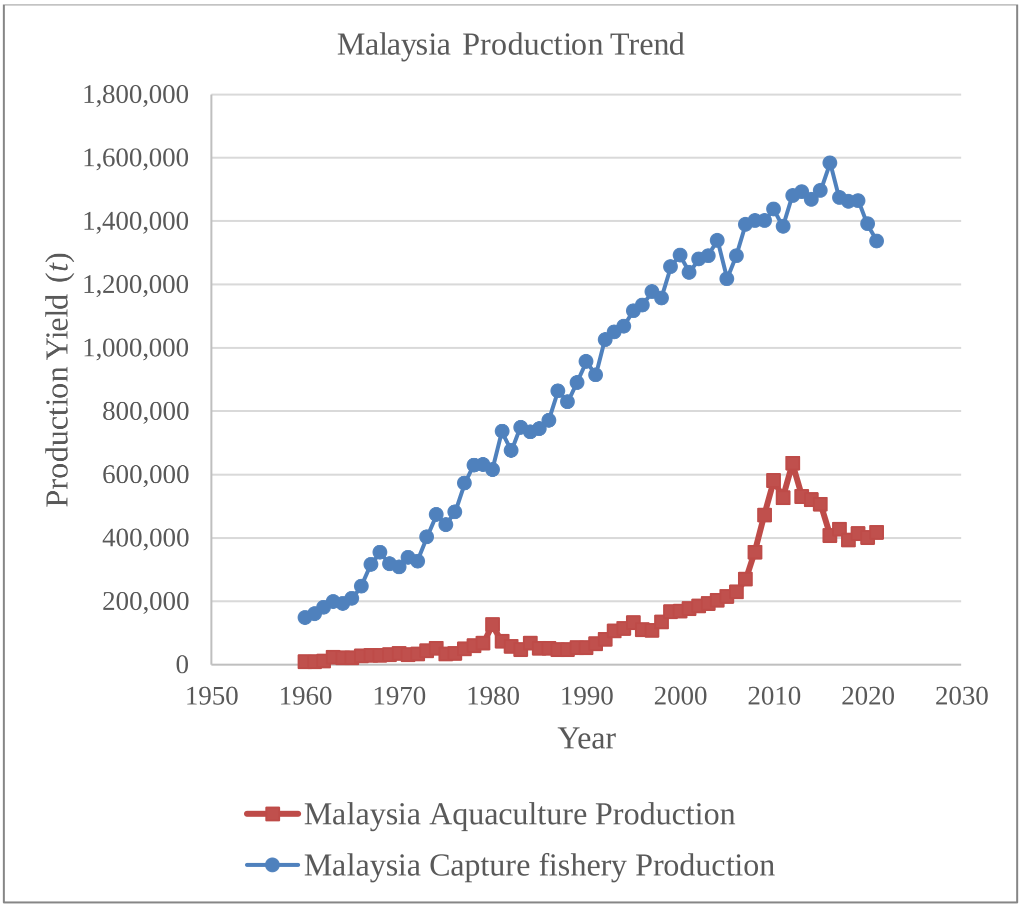

Figure 4.8: Malaysia Production Trend (1960 – 2021).

Malaysia holds the 6th position in overall capture fishery and aquaculture production within the ASEAN region. In terms of production yield, its capture fishery sector seems to be more prominent compared to the aquaculture sector. In recent years, capture fishery production followed an upward trajectory, reaching a peak of 1,584,371.02 tonnes in 2016. However, it has experienced a decline in production yield in the following years. Similarly, the aquaculture sector also witnessed growth in production yield. However, starting from 2013, its production has been on a downward trend. Currently, it maintains a consistent production range of approximately 400,000 tonnes over the past five years.

4.2.7 Cambodia

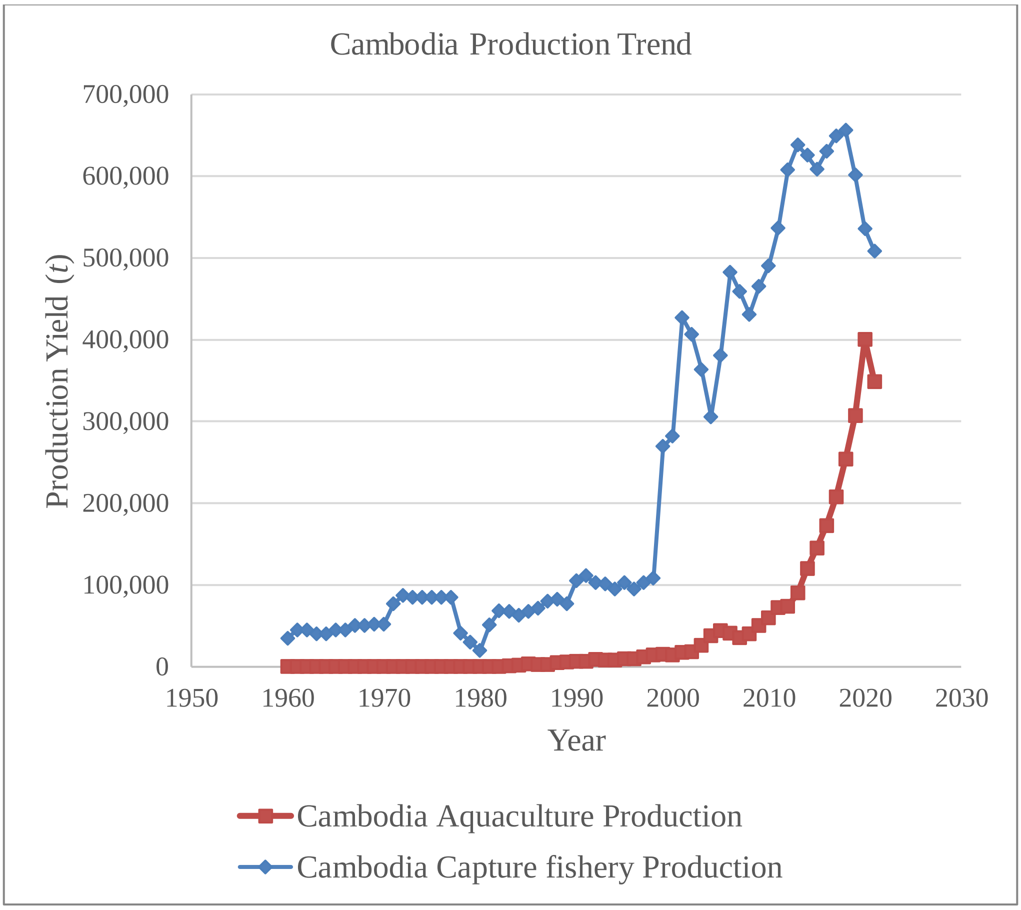

Figure 4.9: Cambodia Production Trend (1960 – 2021).

The Cambodia's capture fishery sector experienced significant growth during the early 2000s, but it has also exhibited a fluctuating pattern of highs and lows throughout the year. Despite reaching its peak production yield of 656,105.01 tonnes in 2018, the trajectory of production yield has been on a downward trend ever since. In contrast, the aquaculture production has consistently shown an upward trajectory over the past year when compared to capture fishery production. While reaching a record high of 400,400 tonnes in 2020, it experienced a decline of 52,050 tonnes in 2021.

4.2.8 LAO PDR

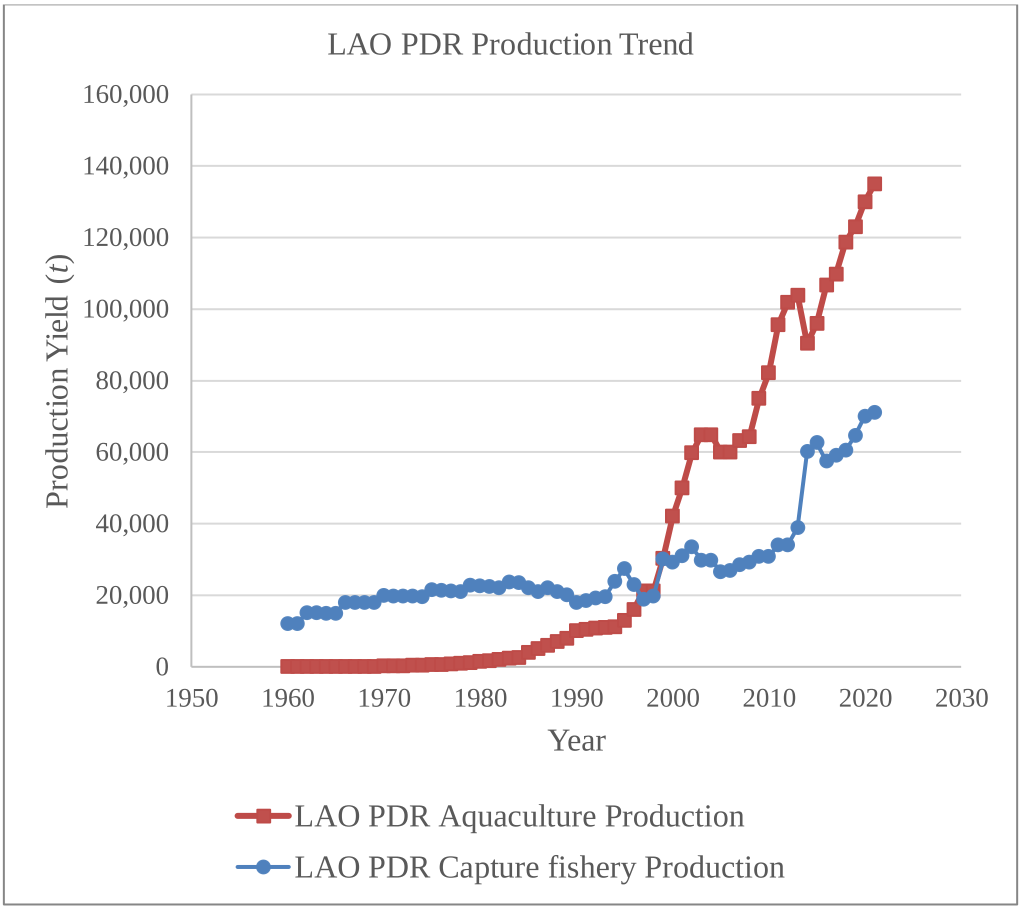

Figure 4.10: Lao PDR Production Trend (1960 – 2021).

As the sole landlocked nation in Southeast Asia, Lao PDR faces a disadvantage in marine capture fishery compared to its ASEAN compared to other ASEAN countries. Its capture fishery production primarily consists of inland fisheries has displayed a steady upward trend in recent years. On the other hand, its aquaculture sector plays a pivotal role in Lao PDR's fisheries industries, surpassing capture fisheries production by 12,816 tonnes in 2000. Since then, the aquaculture production continues to rise steadily with each passing year.

4.2.9 Brunei

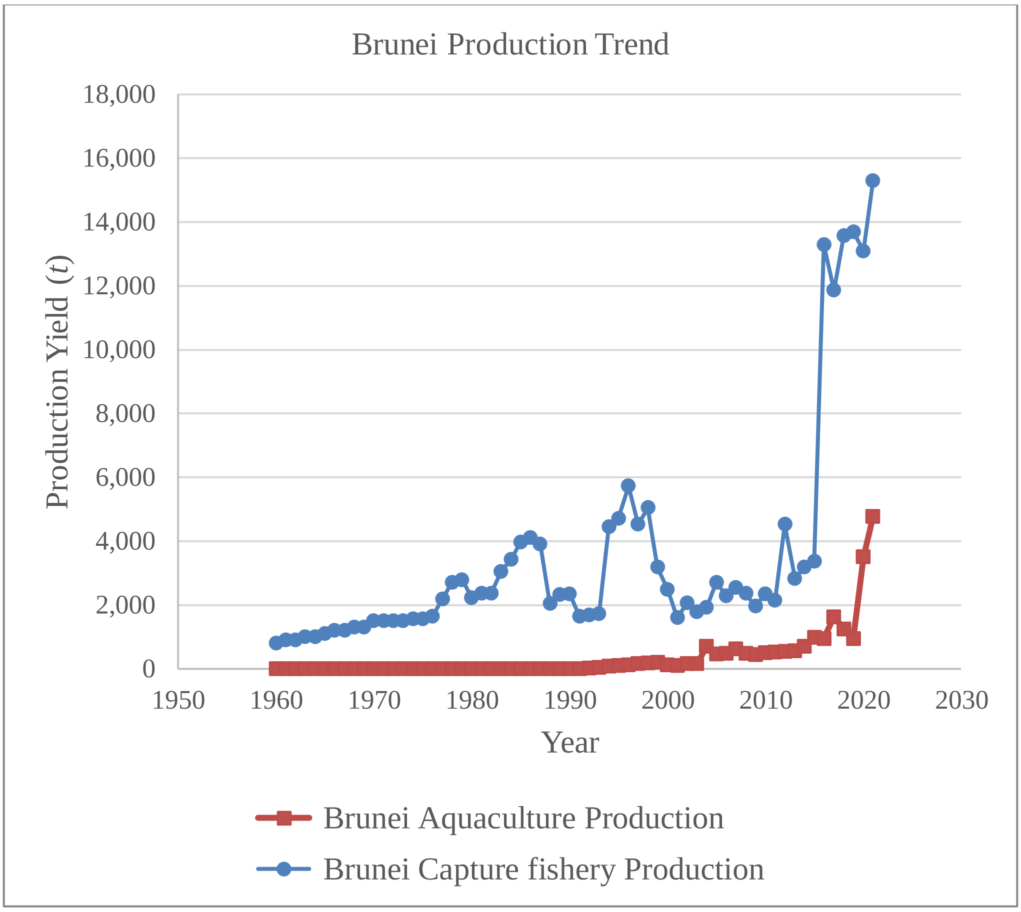

Figure 4.11: Brunei Production Trend (1960 – 2021).

The capture fishery sector in Brunei has experienced production yield fluctuations over the past decades, yet it has maintained an overall upward trajectory. In 2016, the production yield witnessed a significant spike compared to the previous year. The production growth persisted, reaching a record high of 15,295 tonnes in 2021. In contrast, the aquaculture sector began its development in the late 1990s and has been gradually growing. Notably, it has experienced a spike in production growth in 2020 and the production continues to move in an upward trend.

4.2.10 Singapore

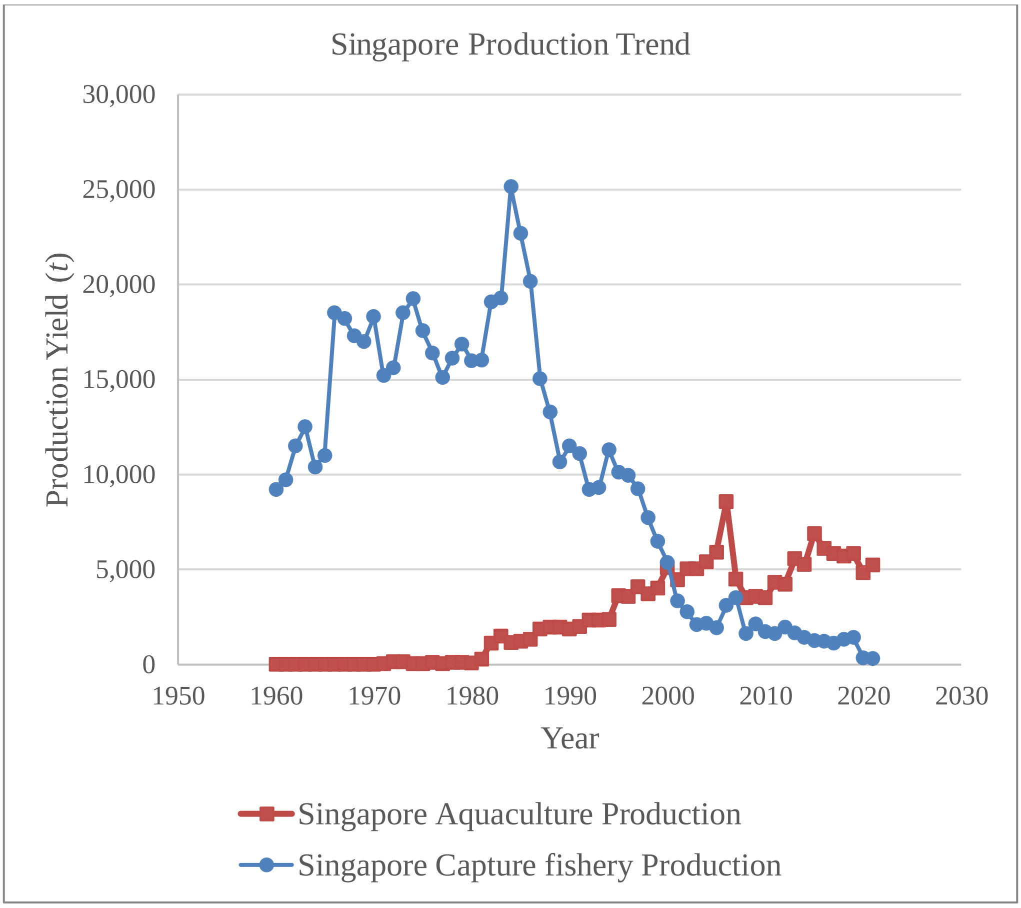

Figure 4.12: Singapore Production Trend (1960 – 2021).

Singapore ranks last in terms of production yield in comparison to other ASEAN countries. As a small country, it is well verse in its trading economy than production. Nevertheless, its aquaculture sector has been steadily growing in the past year and even manage to overtake the capture fishery production in 2001. Even though it has experienced a drop in 2007, the aquaculture production shows an upward trend in the recent years. Meanwhile, the capture fishery has witnessed a continuous plunge since 1984 and the downward trend continues to persist for the past decades.

4.2.11 ASEAN

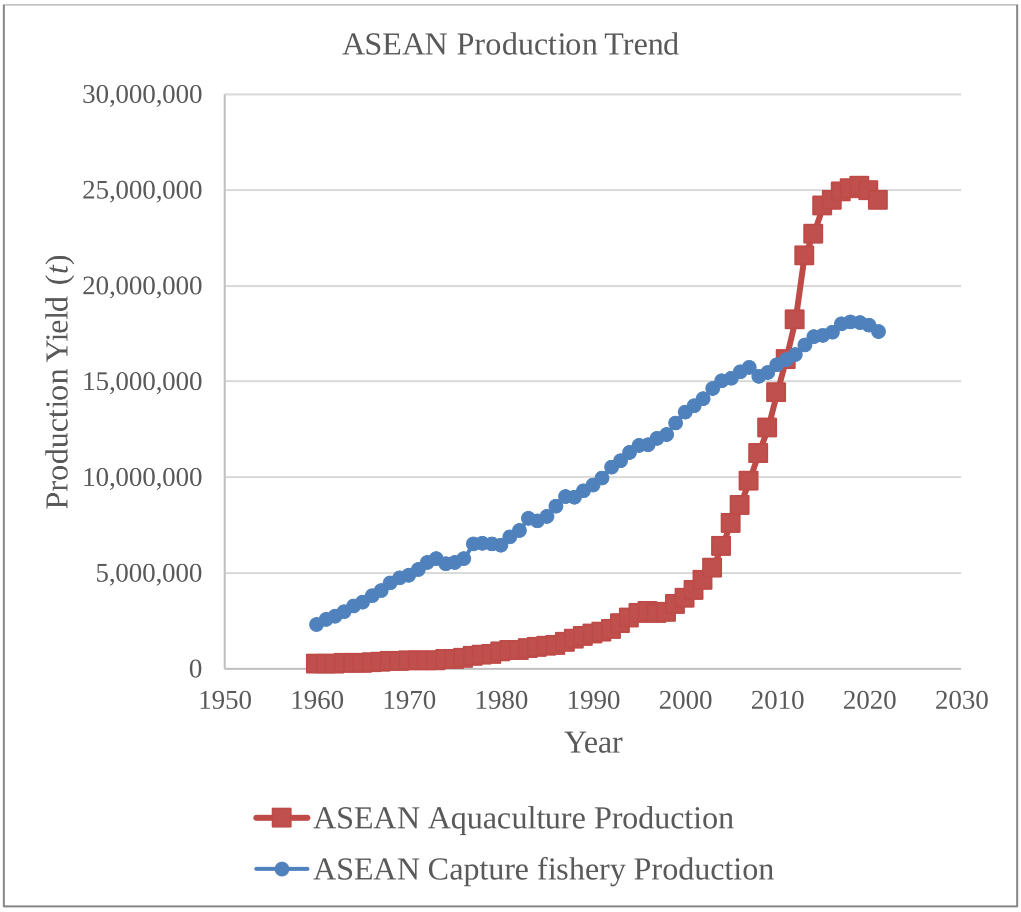

Figure 4.13: ASEAN Production Trend (1960 – 2021).

Over the past decade, the production from capture fisheries and aquaculture in ASEAN countries has seen significant growth. Notably, ASEAN's aquaculture production has surpassed that of capture fishery by 1,808,363.09 tonnes in 2012. While ASEAN's capture fishery production experienced a steady increase over the past decade, it has been on a downward trend since 2019, reaching a production yield of 17,598,941.37 tonnes in 2021. Similarly, ASEAN's aquaculture production has also witnessed a decline since 2020, reaching a production yield of 24,457,797.72 tonnes in 2021.

4.3 Summary of ASEAN Trend Analysis

From the conducted data analysis, it can be seen that the capture fishery production from six out of the 10 ASEAN countries witnessed an overall down trend of production yield. The countries include Thailand, Philippines, Myanmar, Malaysia, Cambodia and Singapore. As for the aquaculture production, five out of the 10 ASEAN countries experienced an overall downward trajectory in production yield. These countries are Indonesia, Thailand, Philippines, Malaysia and Singapore. In terms of ASEAN's total capture fishery and aquaculture production, both yields continued to drop as the year progressed.

4.4 Correlation of Annual Average Global Atmospheric Carbon Dioxide Concentration with Years

To predict the future atmospheric carbon dioxide levels, a model is needed. Using the atmospheric carbon dioxide levels data obtained through NOAA (2023), the atmospheric carbon dioxide levels was selected as the dependent variable in IBM SPSS Statistic v26.0. The correlation between the years and carbon dioxide concentration was then analysed and the top 3 model were ranked. The independent variable which is year is denoted as *y* while dependent variable atmospheric carbon dioxide levels denote as *c*.

Table 4.3: Annual Average Global Atmospheric Carbon Dioxide Concentration Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Power	$c = 1.159E - 33y^{10.756}$	0.9966	0.0028	<0.001
2	Growth	$c = e^{(-4.810+0.005y)}$	0.9968	0.0027	<0.001
3	Exponential	$c = 0.008e^{0.005y}$	0.9968	0.0027	<0.001

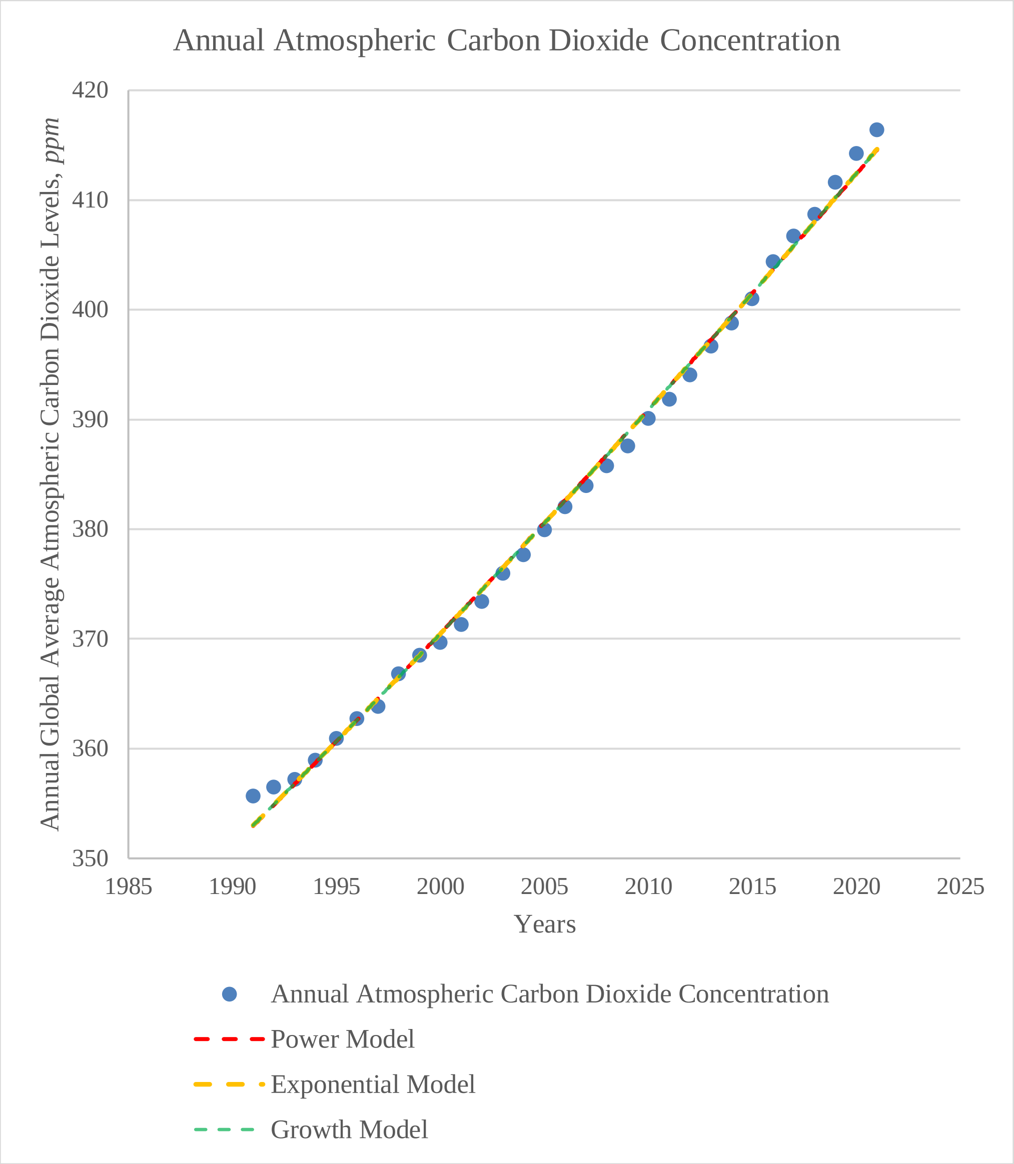

Figure 4.14: Annual Average Global Atmospheric Carbon Dioxide Concentration Model (1991 – 2021).

4.5 Correlation of Capture fishery and Aquaculture with Annual Average Global Atmospheric Carbon Dioxide Concentration

Using the atmospheric carbon dioxide levels data obtained through NOAA (2023), the atmospheric carbon dioxide levels were selected as the independent variable in IBM SPSS Statistic v26.0. The correlation between the fishery production and carbon dioxide concentration was then processed and the top 3 model were listed accordingly for each ASEAN countries and ASEAN as a whole. The dependent variables, capture fishery and aquaculture production are denoted as *f* and *a* while independent variable atmospheric carbon dioxide level is denoted as *c*.

4.5.1 Indonesia

Early years (1960 – 1990) capture fishery model: Power, Exponential and Quadratic.

Table 4.4: Indonesia Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SSE	p-Value
1	Power	$f = 1.305E-20c^{10.318}$	0.972	0.061	<0.001
2	Exponential	$f = 47.946e^{0.031c}$	0.972	0.062	<0.01
3	Quadratic	$f = 675.245c^2 - 405819.193c + 61644707.15$	0.987	63427	<0.001

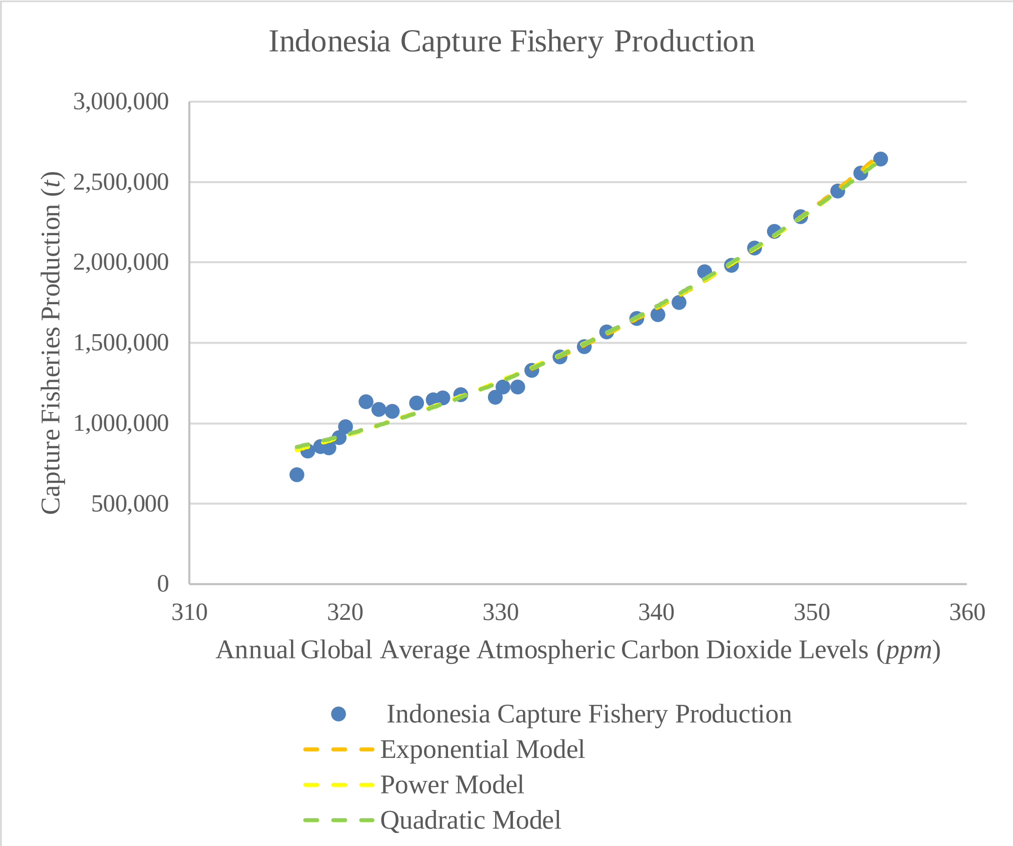

Figure 4.15: Indonesia Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Exponential, Logarithmic and Linear.

Table 4.5: Indonesia Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Exponential	$f = 19610.018e^{0.014c}$	0.960	0.055	<0.001
2	Logarithmic	$f = 27492132.370\ ln(c) - 158422270.25$	0.980	193766	<0.001
3	Linear	$f = 71556.601c - 22336055.82$	0.979	194555	<0.001

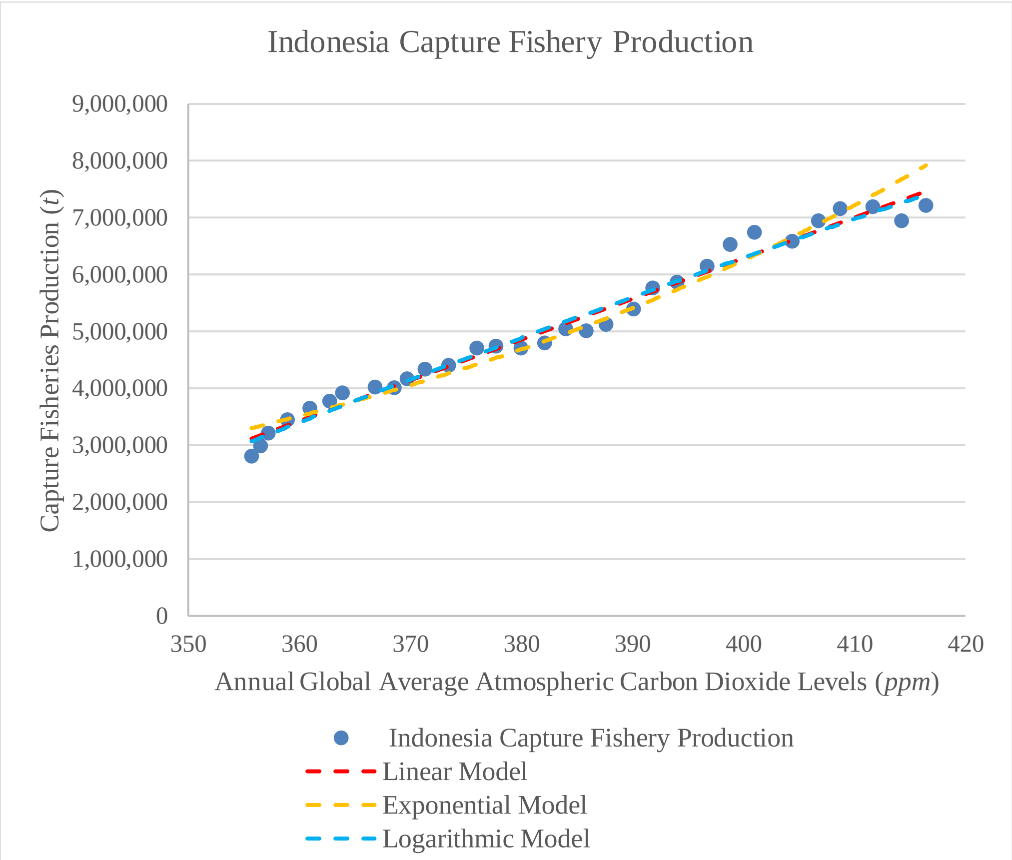

Figure 4.16: Indonesia Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Exponential, Power and Quadratic.

Table 4.6: Indonesia Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Exponential	$a = 0.004e^{0.053c}$	0.985	0.075	<0.02
2	Power	$a = 3.883E - 40c^{17.706}$	0.982	0.083	<0.001
3	Quadratic	$a = 405.549c^2 - 259493.276c + 41602633.73$	0.995	10125	<0.001

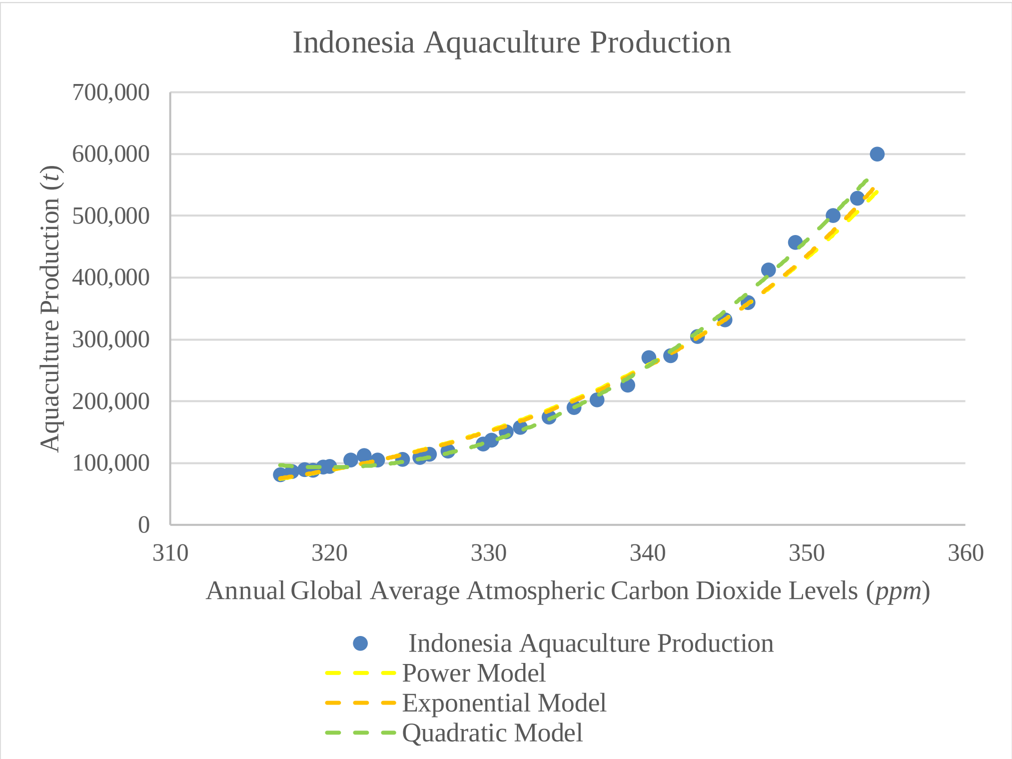

Figure 4.17: Indonesia Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Power, Growth and Quadratic.

Table 4.7: Indonesia Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$a = 7.235E-60c^{25.408}$	0.938	0.318	<0.001
2	Growth	$a = e^{(0.066c-10.395)}$	0.937	0.320	<0.001
3	Quadratic	$a = 4007.247c^2 - 2774683.714c + 479602551.56$	0.888	2098924	<0.02

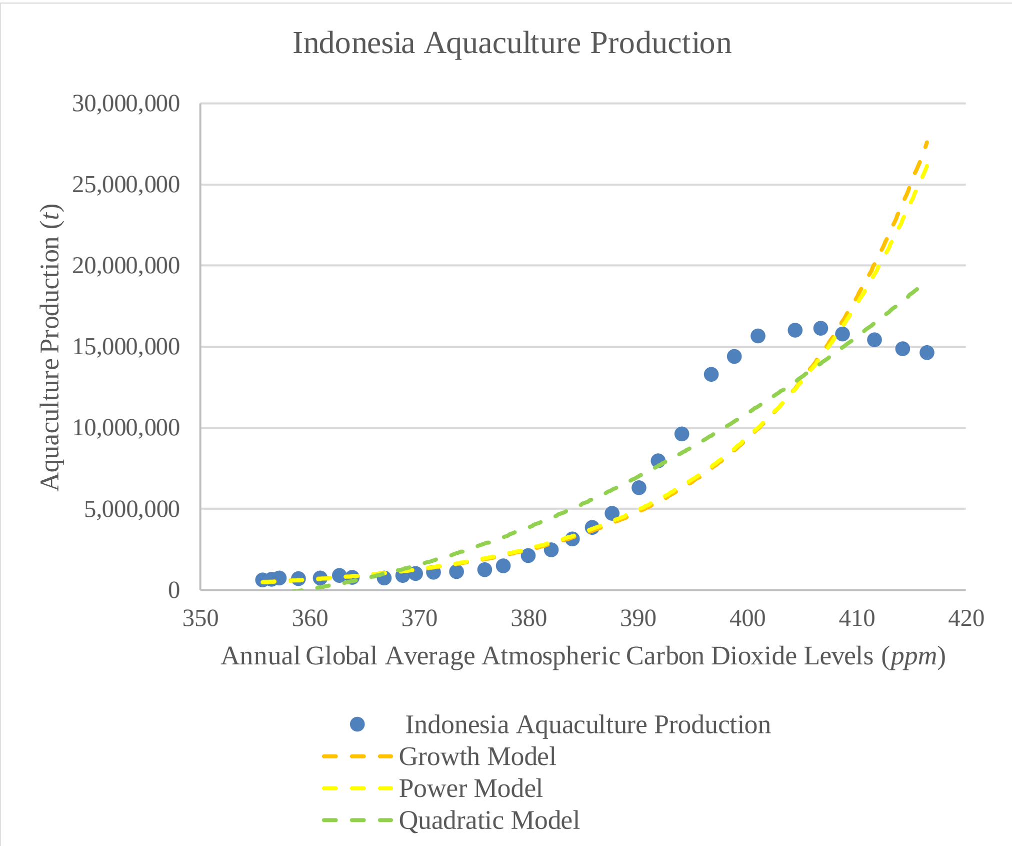

Figure 4.18: Indonesia Aquaculture Models (1991 – 2021).

4.5.2 Thailand

Early years (1960 – 1990) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.8: Thailand Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = -1518.672c^2 + 1075973.118c - 188182862.51$	0.944	173210	<0.001
2	Logarithmic	$f = 19817693.845\ln(c) - 113581907.89$	0.893	239806	<0.001
3	Linear	$f = 59018.895c - 18143021.25$	0.886	247339	<0.001

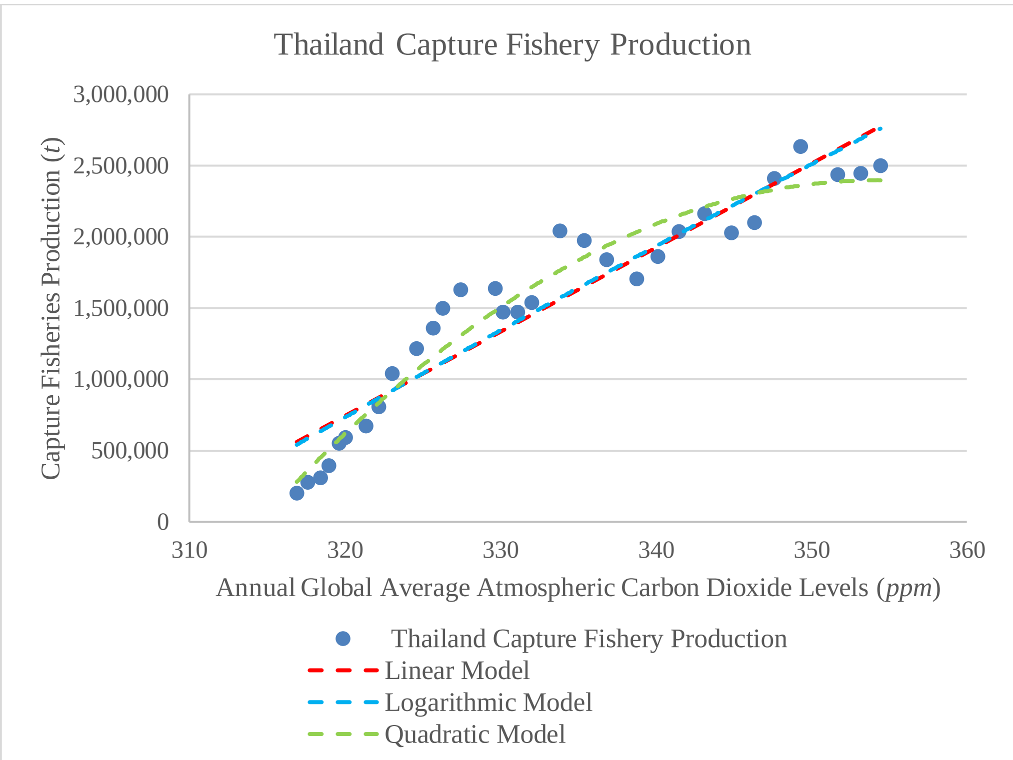

Figure 4.19: Thailand Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Exponential, Linear and Logarithmic.

Table 4.9: Thailand Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Exponential	$f = 516778969.1e^{-0.014c}$	0.861	0.107	<0.02
2	Linear	$f = -30822.353c + 14117787.53$	0.848	243642	<0.001
3	Logarithmic	$f = -11821496.3\, ln(c) + 72613836.54$	0.846	245968	<0.001

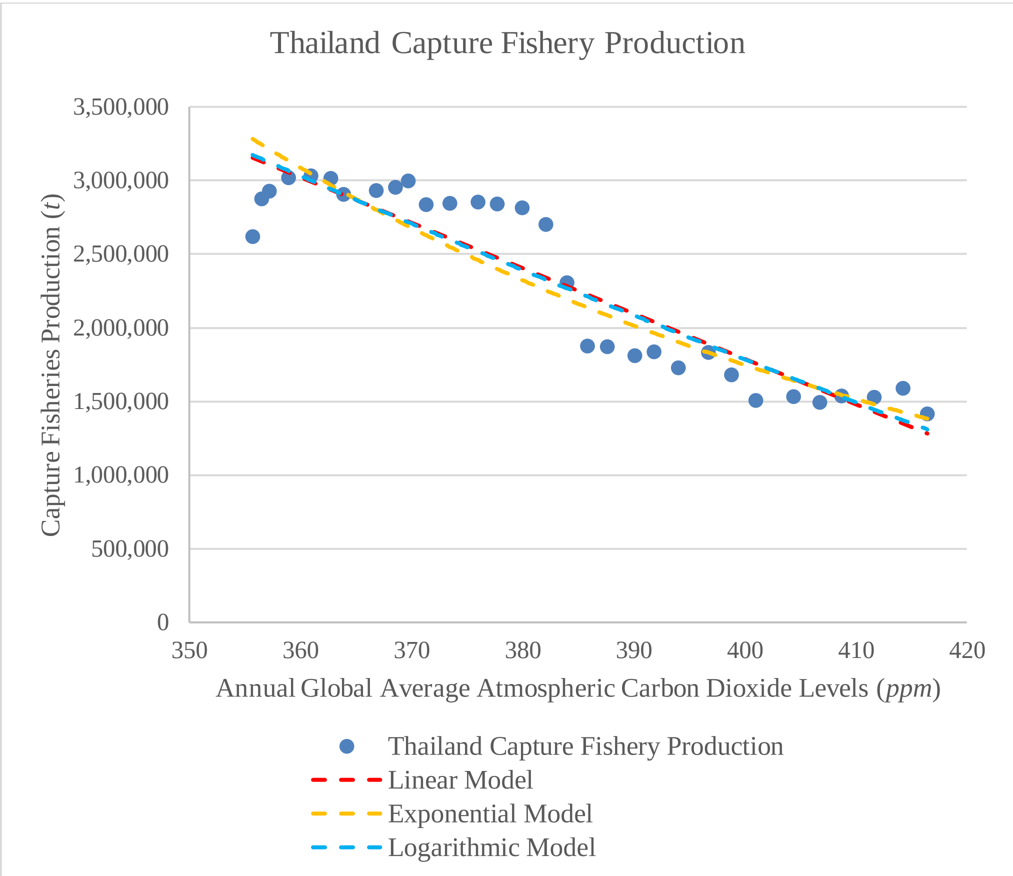

Figure 4.20: Thailand Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Power, Growth and Quadratic.

Table 4.10: Thailand Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Power	$a = 1.912E - 34c^{15.322}$	0.8005	0.2669	<0.001
2	Growth	$a = e^{(0.046c-3.906)}$	0.8001	0.2671	<0.01
3	Quadratic	$a = 134.917c^2 - 85616.354c + 13632064.44$	0.783	30048	<0.02

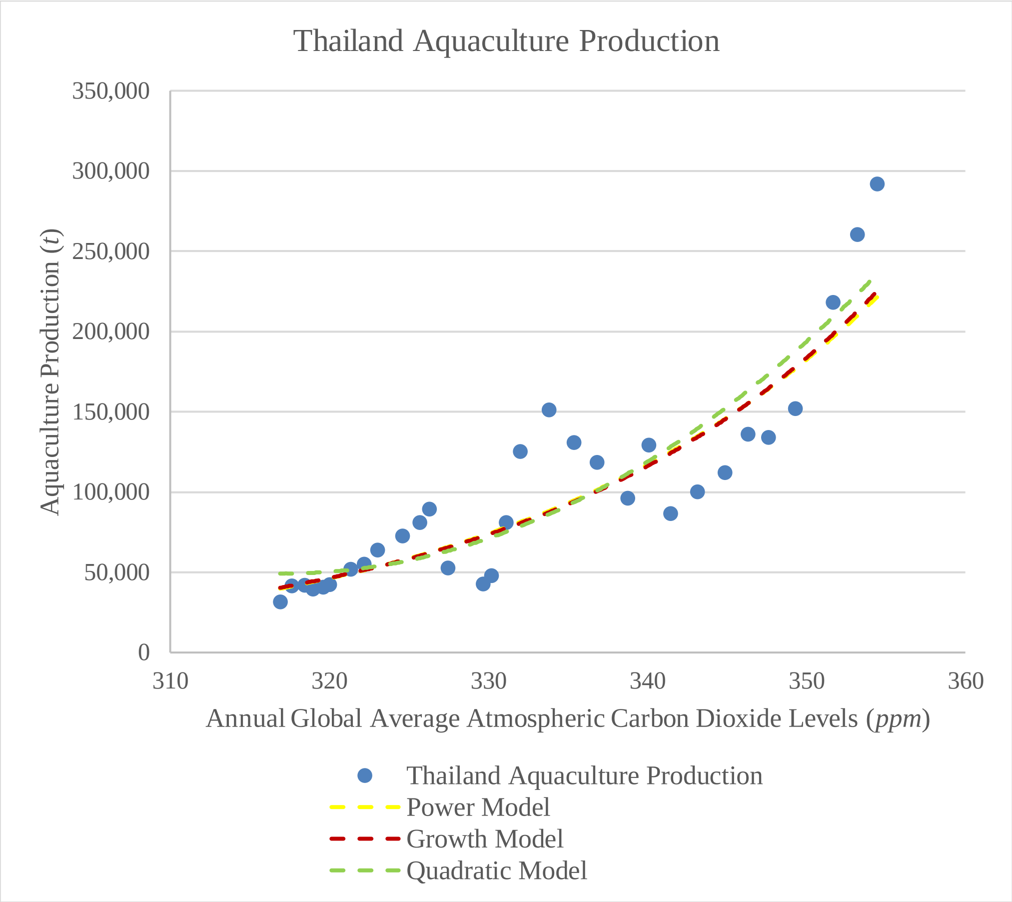

Figure 4.21: Thailand Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Quadratic, Growth, Logarithmic.

Table 4.11: Thailand Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$a = -707.361c^2 + 554068.903c - 107284298.961$	0.778	150741	<0.001
2	Growth	$a = e^{(8.421+0.014c)}$	0.397	0.309	<0.001
3	Logarithmic	$a = 3820936.209ln(c) - 21801414.7$	0.318	264146	<0.01

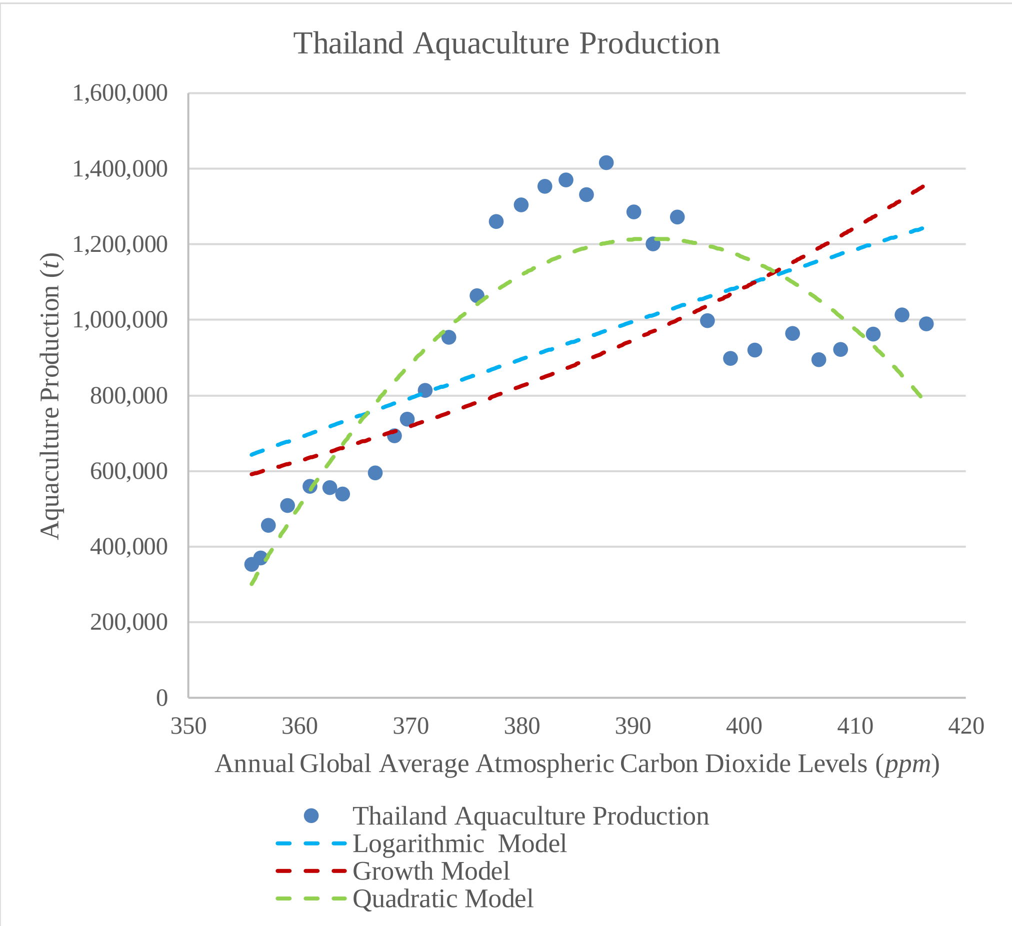

Figure 4.22: Thailand Aquaculture Models (1991 – 2021).

4.5.3 Vietnam

Early years (1960 – 1990) capture fishery model: Quadratic, Logarithmic and Growth.

Table 4.12: Vietnam Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = 313.057c^2 - 205449.925c + 34260327.45$	0.284	89620	<0.04
2	Logarithmic	$f = 1384547.684\ln(c) - 7439109.135$	0.182	95796	<0.02
3	Growth	$f = e^{(11.049+0.007c)}$	0.166	0.164	<0.02

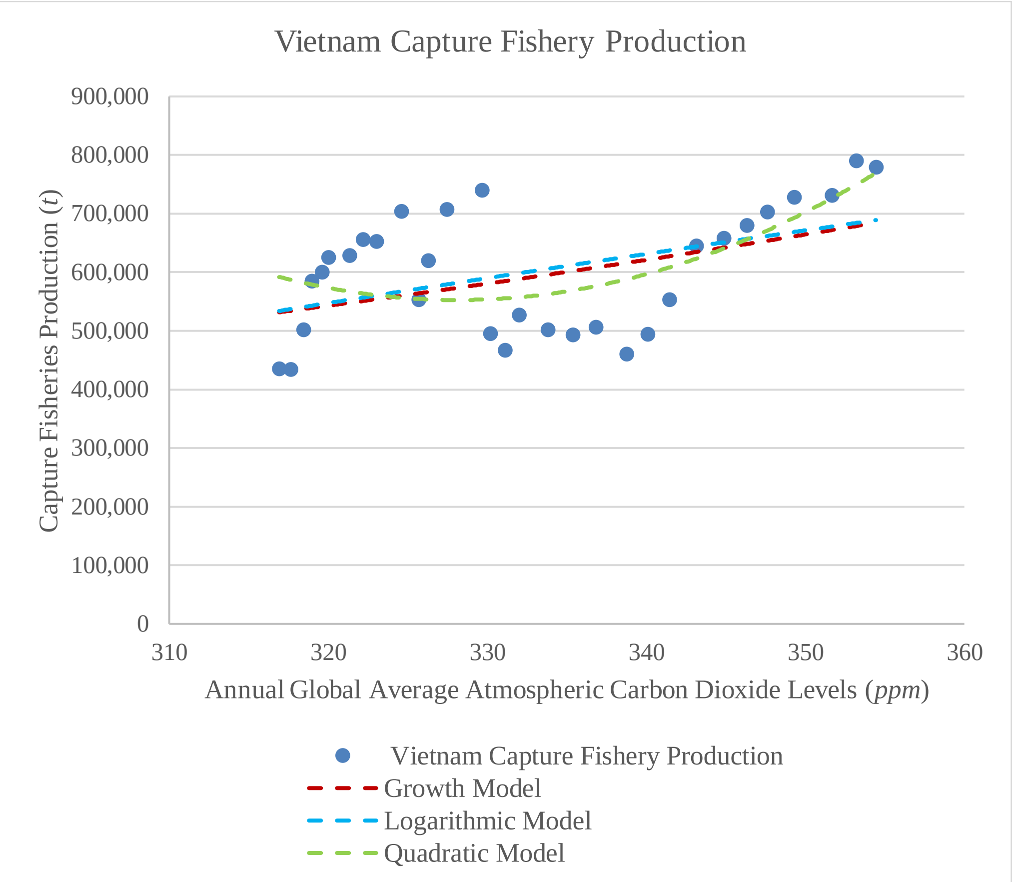

Figure 4.23: Vietnam Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Power, Linear and Logarithmic.

Table 4.13: Vietnam Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Power	$f = 5.827E - 17c^{8.719}$	0.956	0.091	<0.001
2	Linear	$f = 44470.080c - 14939112.7$	0.989	88432	<0.001
3	Logarithmic	$f = 17074154.09ln(c) - 99445004.6$	0.988	93029	<0.001

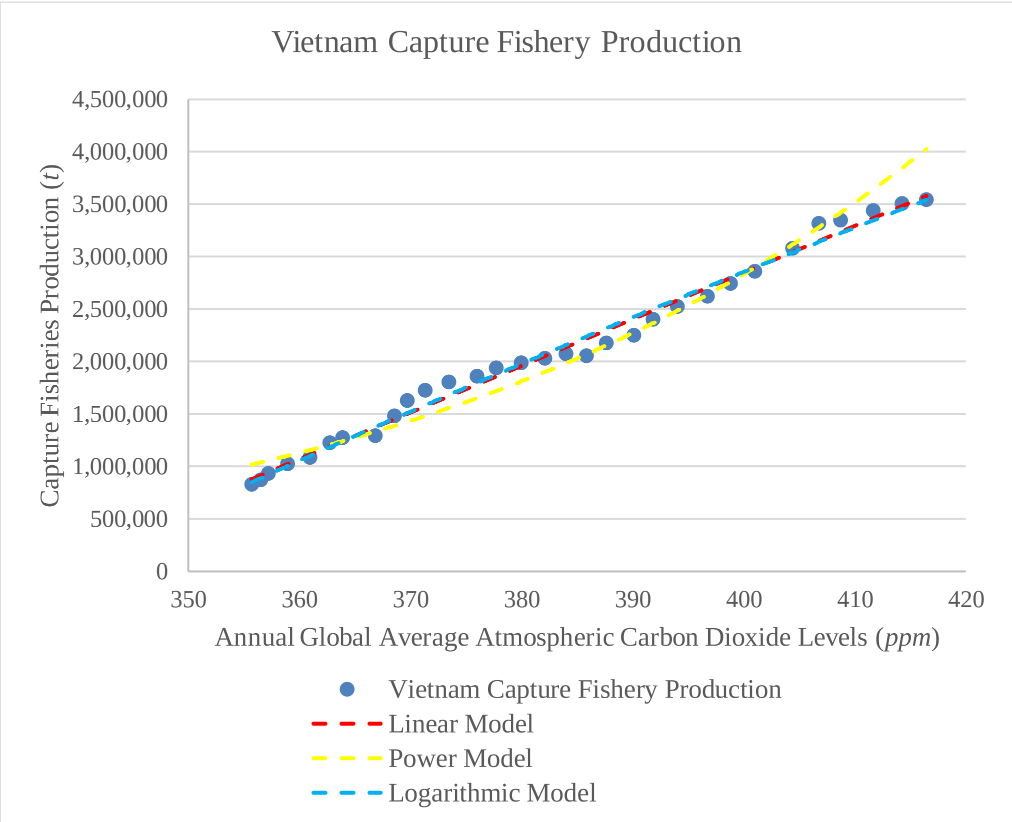

Figure 4.24: Vietnam Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Power, Quadratic and Linear.

Table 4.14: Vietnam Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$a = 3.098E - 26c^{12.059}$	0.980	0.060	<0.001
2	Quadratic	$a = 29.809c^2 - 16827.773c + 2381903.361$	0.992	3315	<0.001
3	Linear	$a = 3133.336c - 955694.159$	0.983	4798	<0.001

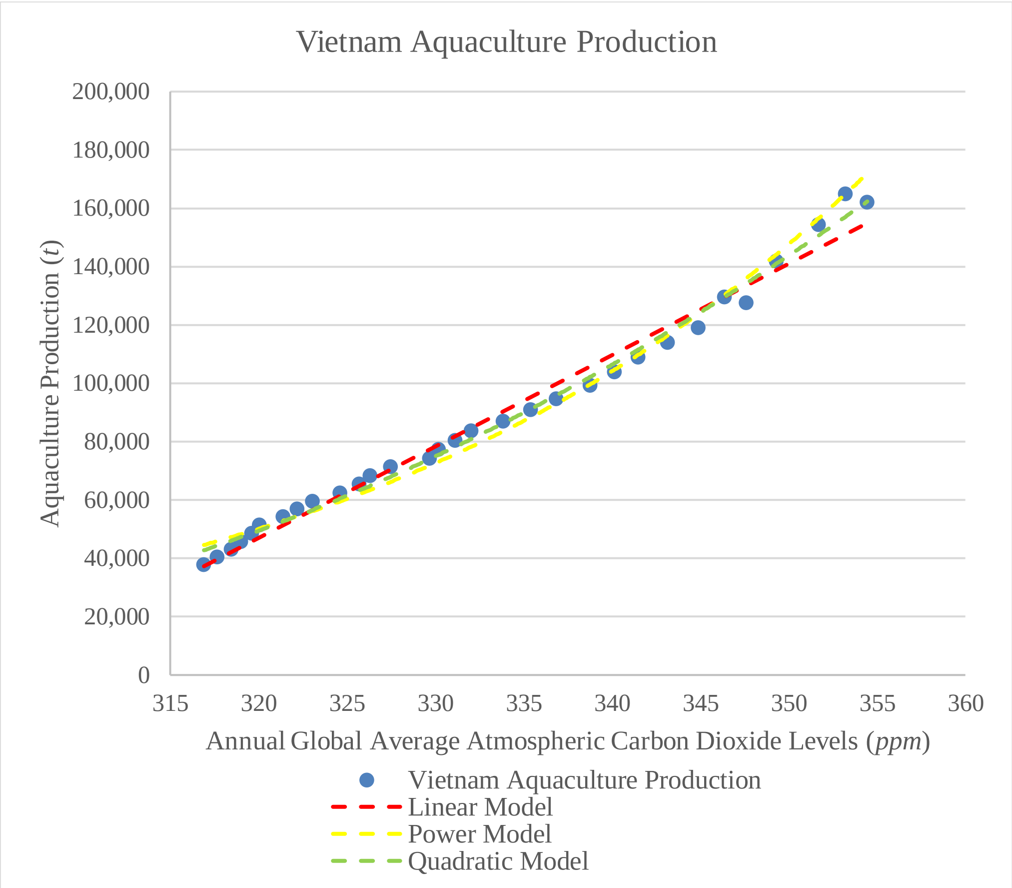

Figure 4.25: Vietnam Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Power, Linear and Logarithmic.

Table 4.15: Vietnam Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$a = 4.236E - 52c^{22.247}$	0.926	0.307	<0.001
2	Linear	$a = 82599.445c - 29664747.6$	0.970	270410	<0.001
3	Logarithmic	$a = 31671137.49ln(c) - 186373587$	0.967	287525	<0.001

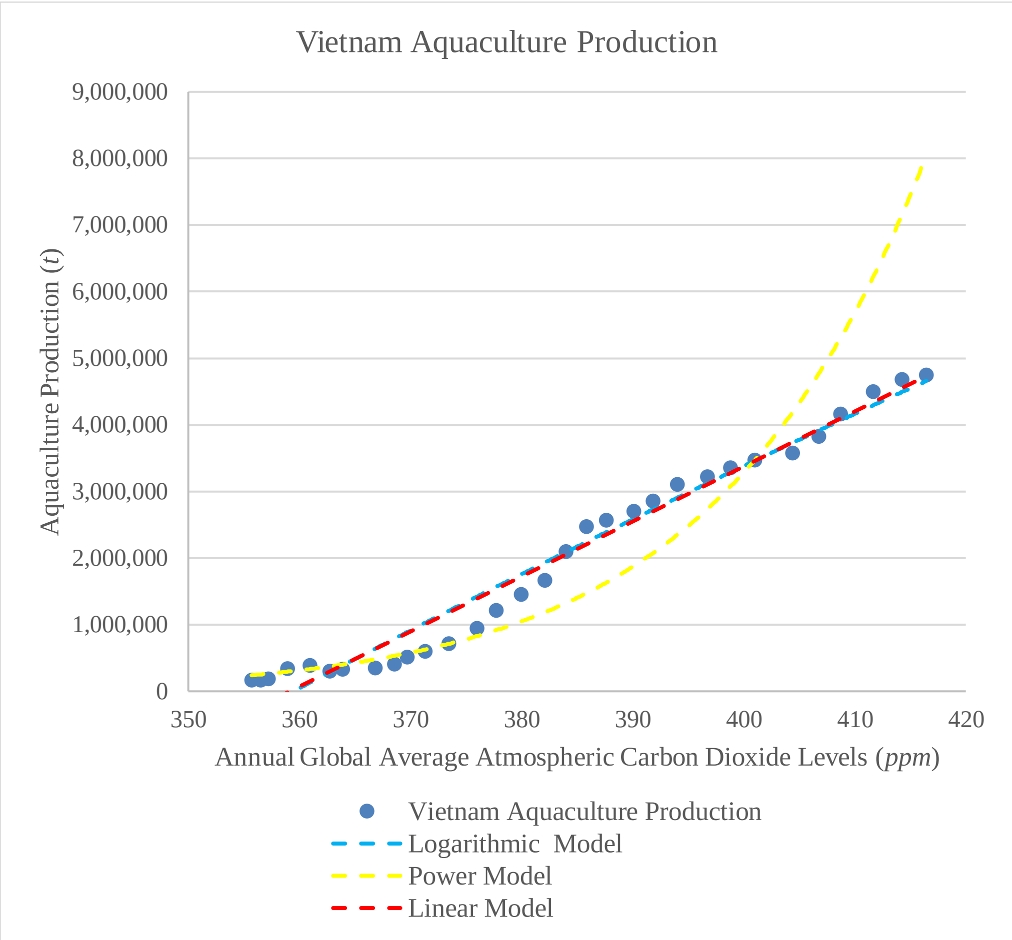

Figure 4.26: Vietnam Aquaculture Models (1991 – 2021).

4.5.4 Philippines

Early years (1960 – 1990) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.16: Philippines Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$f = -863.456c^2 + 614053.585c - 107447368$	0.978	64591	<0.001
2	Logarithmic	$f = 12036291.67\ln(c) - 68731400.5$	0.931	114800	<0.001
3	Linear	$f = 35854.255c - 10769543.6$	0.924	120167	<0.001

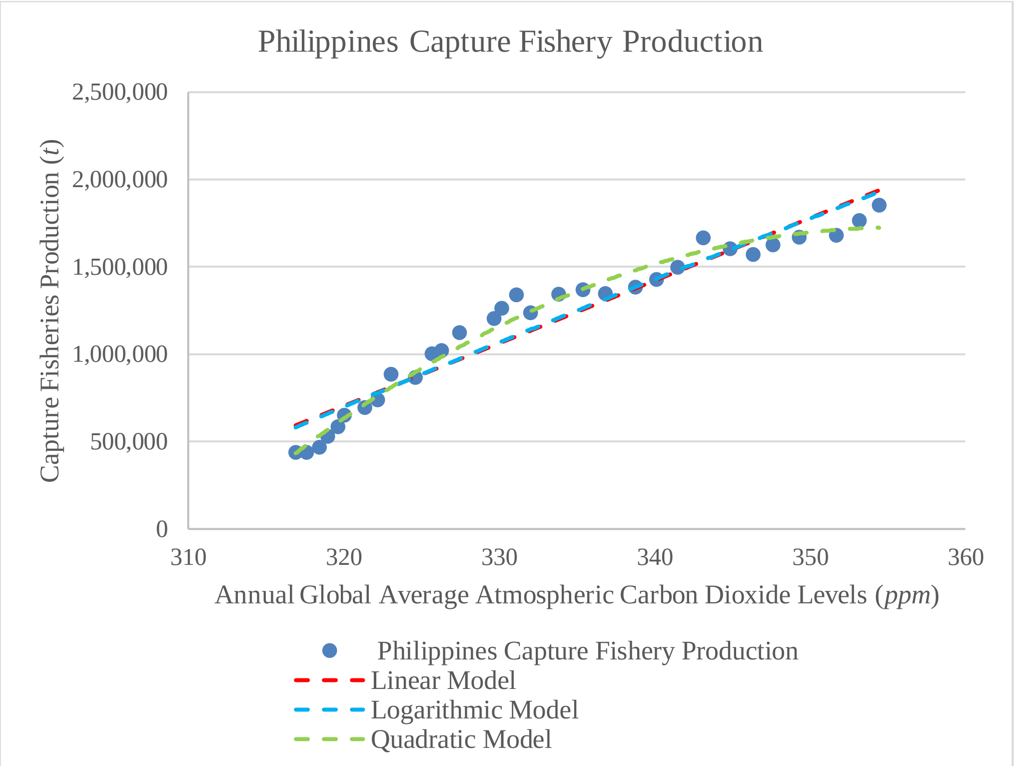

Figure 4.27: Philippines Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Quadratic.

Table 4.17: Philippines Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = -598.201c^2 + 462554.881c - 87130569.9$	0.613	147673	<0.001

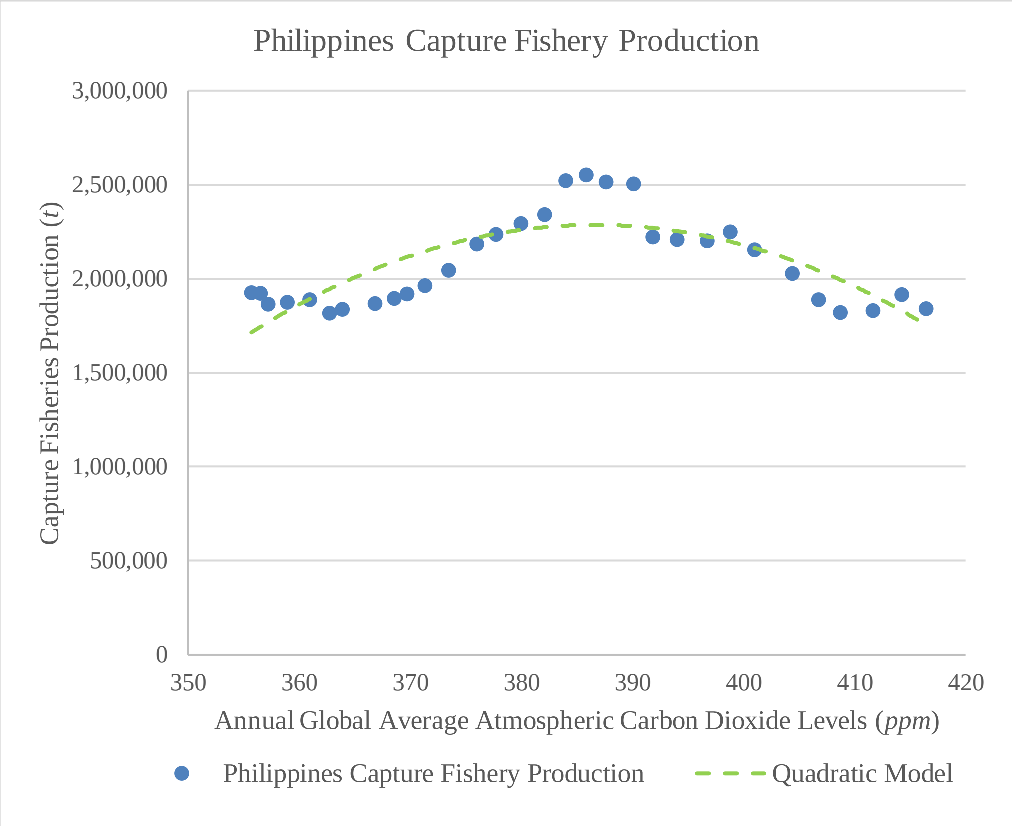

Figure 4.28: Philippines Capture Fishery Model (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Power, Growth and Quadratic.

Table 4.18: Philippines Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Power	$a = 1.229E - 56c^{24.246}$	0.975	0.135	<0.001
2	Growth	$a = e^{(-12.051+0.072c)}$	0.974	0.138	<0.001
3	Quadratic	$a = 371.312c^2 - 231851.184c + 36230341.63$	0.978	30190	<0.001

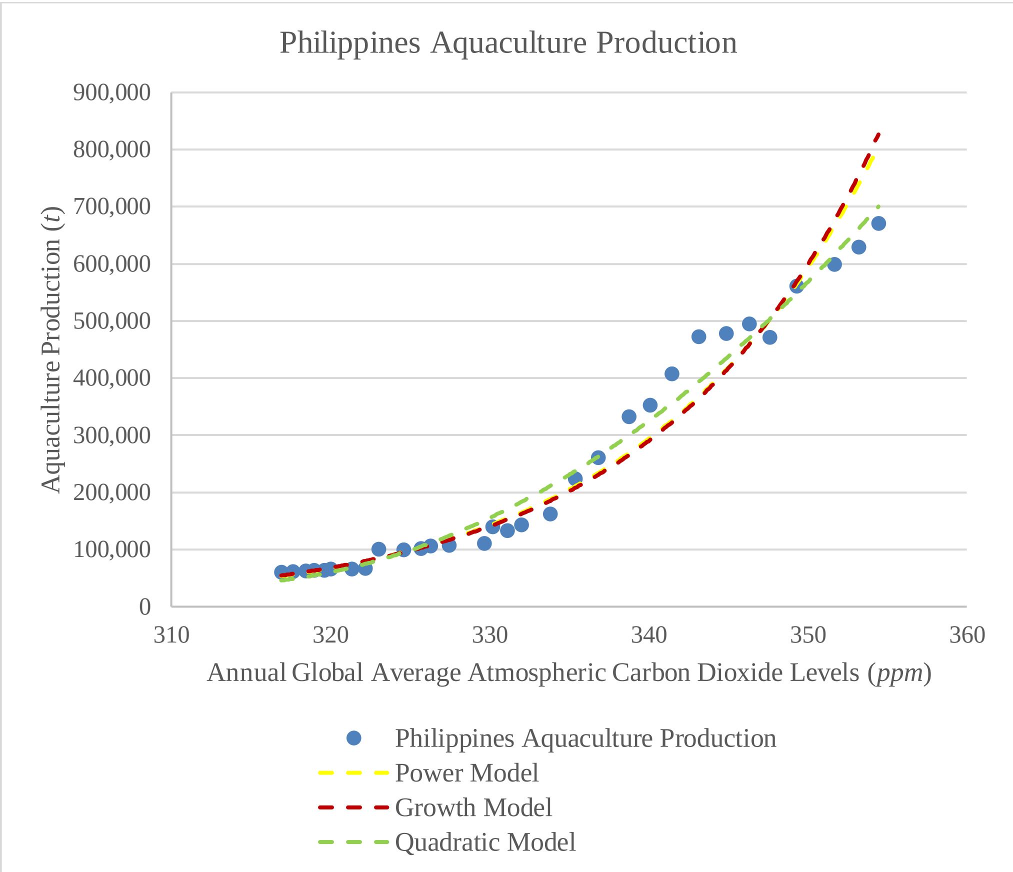

Figure 4.29: Philippines Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Quadratic, Power and Logarithmic.

Table 4.19: Philippines Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$a = -797.602c^2 + 645672.273c - 128266400$	0.904	209844	<0.001
2	Power	$a = 1.127E - 15c^{8.191}$	0.793	0.204	<0.001
3	Logarithmic	$a = 12340833.25ln(c) - 71634392.5$	0.784	315091	<0.001

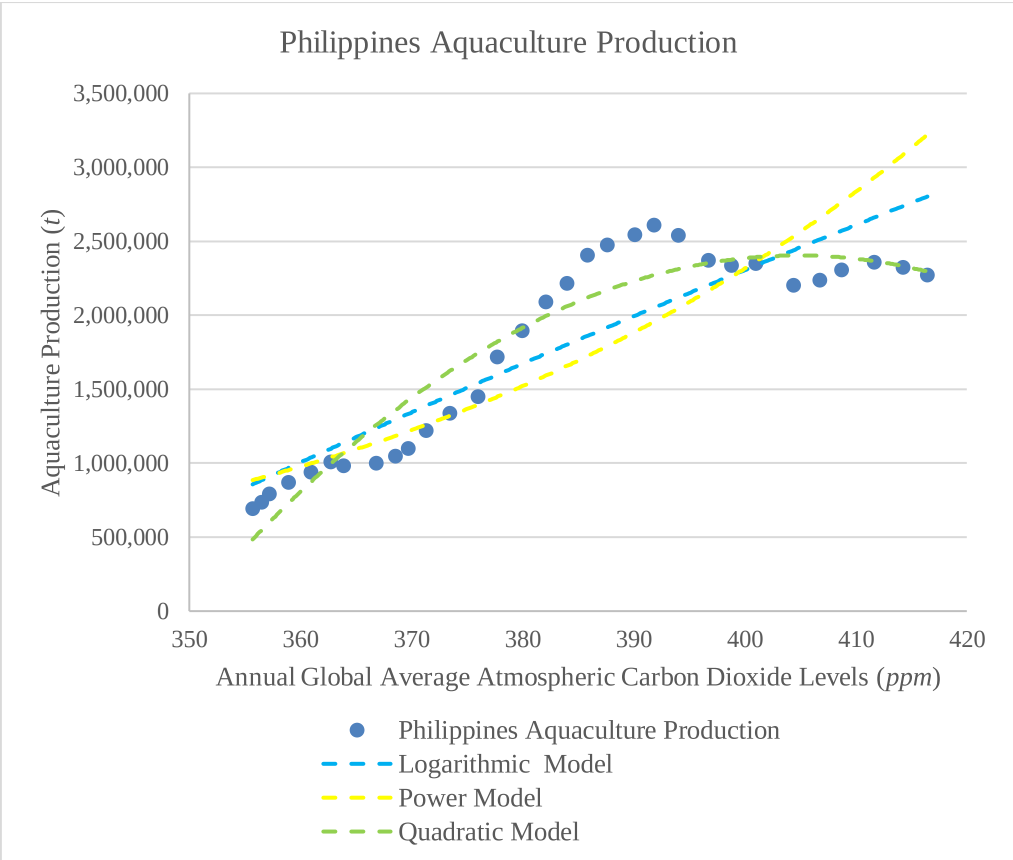

Figure 4.30: Philippines Aquaculture Models (1991 – 2021).

4.5.5 Myanmar

Early years (1960 – 1990) capture fishery model: Power, Linear and Logarithmic.

Table 4.20: Myanmar Capture Fishery Model Ranking (1960 – 1990)

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$f = 1.742E - 12c^{6.918}$	0.982	0.033	<0.001
2	Linear	$f = 10539.024c - 3004763.388$	0.986	14730	<0.001
3	Logarithmic	$f = 3523955.369\ln(c) - 19960803.8$	0.985	15281	<0.001

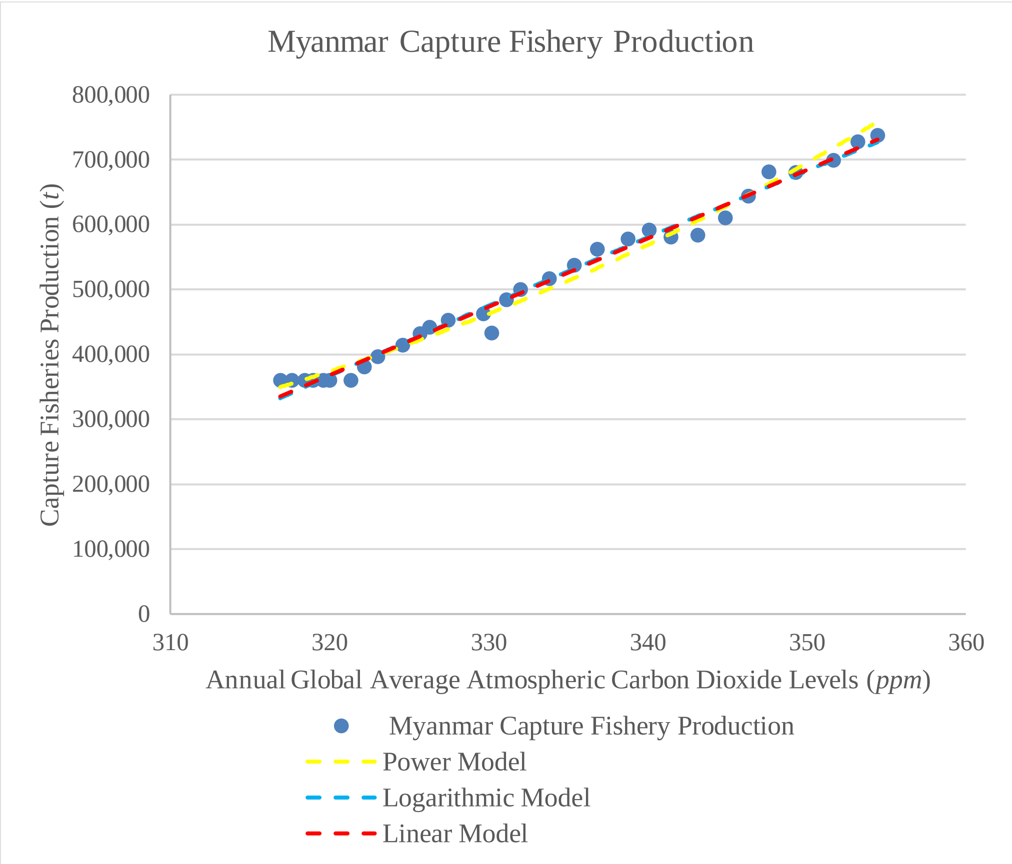

Figure 4.31: Myanmar Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.21: Myanmar Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = -648.031c^2 + 524310.949c - 104041640$	0.922	150668	<0.001
2	Logarithmic	$f = 9918629.918ln(c) - 57495112.1$	0.796	243795	<0.001
3	Linear	$f = 25598.199c - 8314321.106$	0.782	252105	<0.001

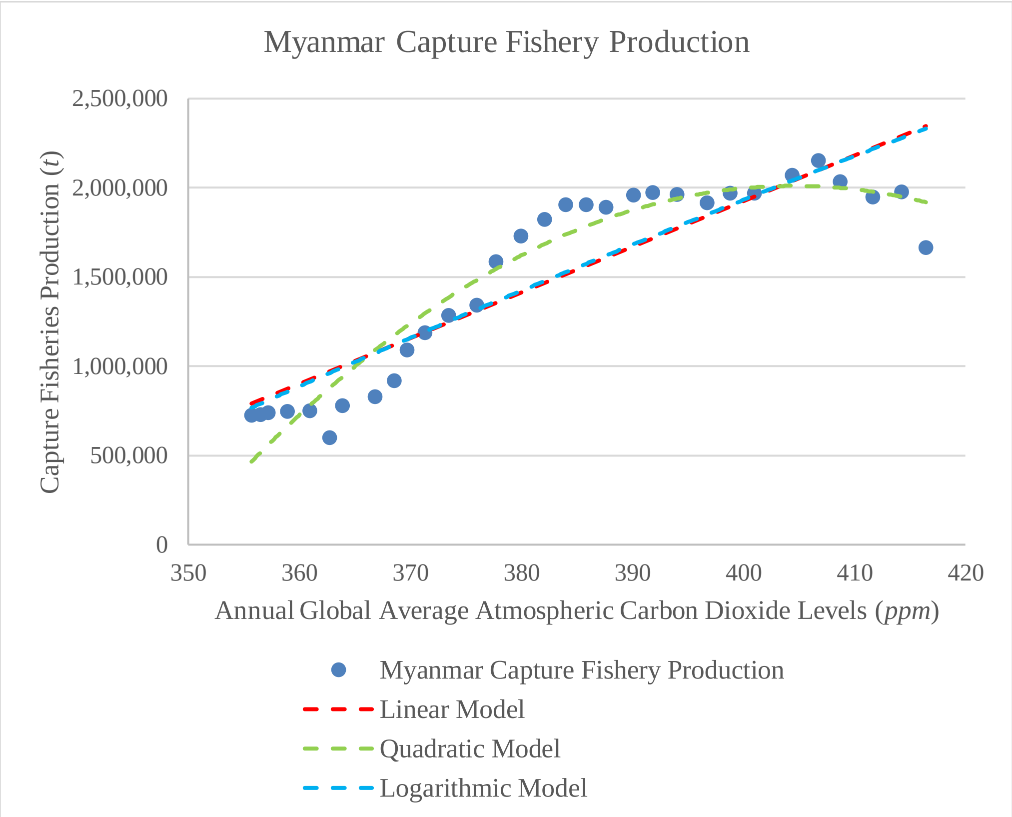

Figure 4.32: Myanmar Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Quadratic, Linear and Logarithmic.

Table 4.22: Myanmar Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$a = 3.777c^2 - 2347.141c + 364592.867$	0.991	212	<0.001
2	Linear	$a = 181.915c - 58278.101$	0.949	492	<0.001
3	Logarithmic	$a = 60667.415ln(c) - 350029.121$	0.943	522	<0.001

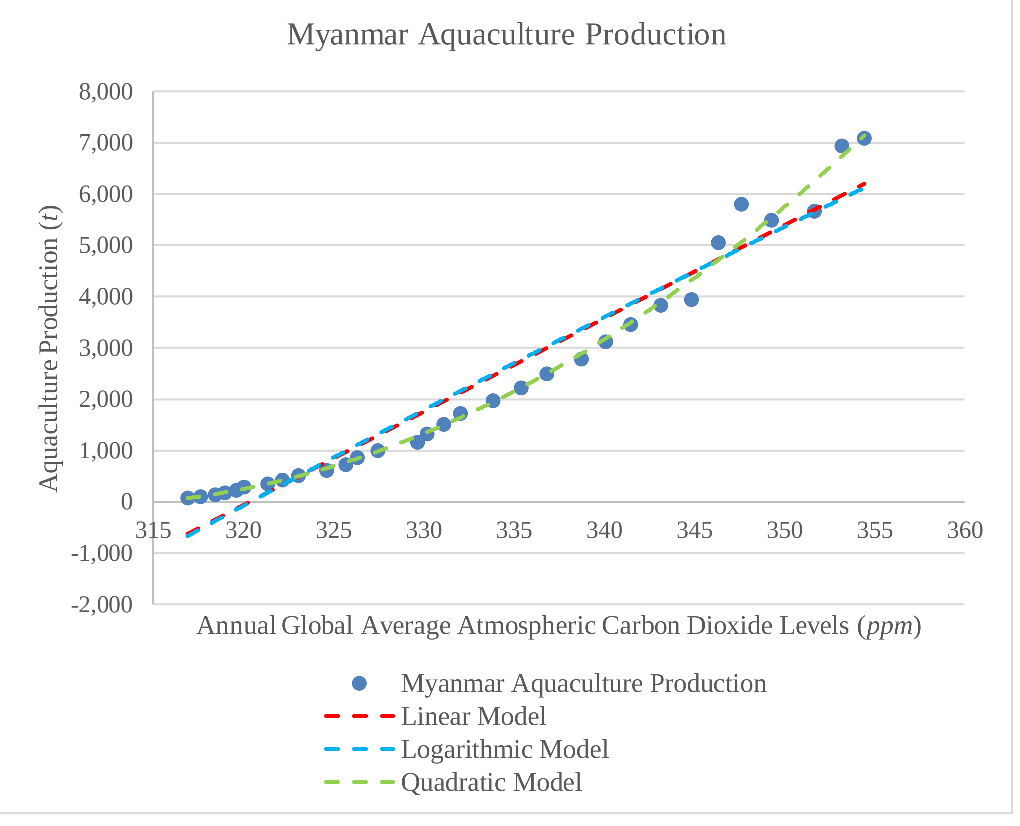

Figure 4.33: Myanmar Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Logarithmic, Linear and Power.

Table 4.23: Myanmar Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Logarithmic	$a = 8272388.198 ln(c) - 48661927.8$	0.932	108618	<0.001
2	Linear	$a = 21503.808c - 7702991.501$	0.930	110715	<0.001
3	Power	$a = 8.050E - 61c^{25.386}$	0.837	0.546	<0.001

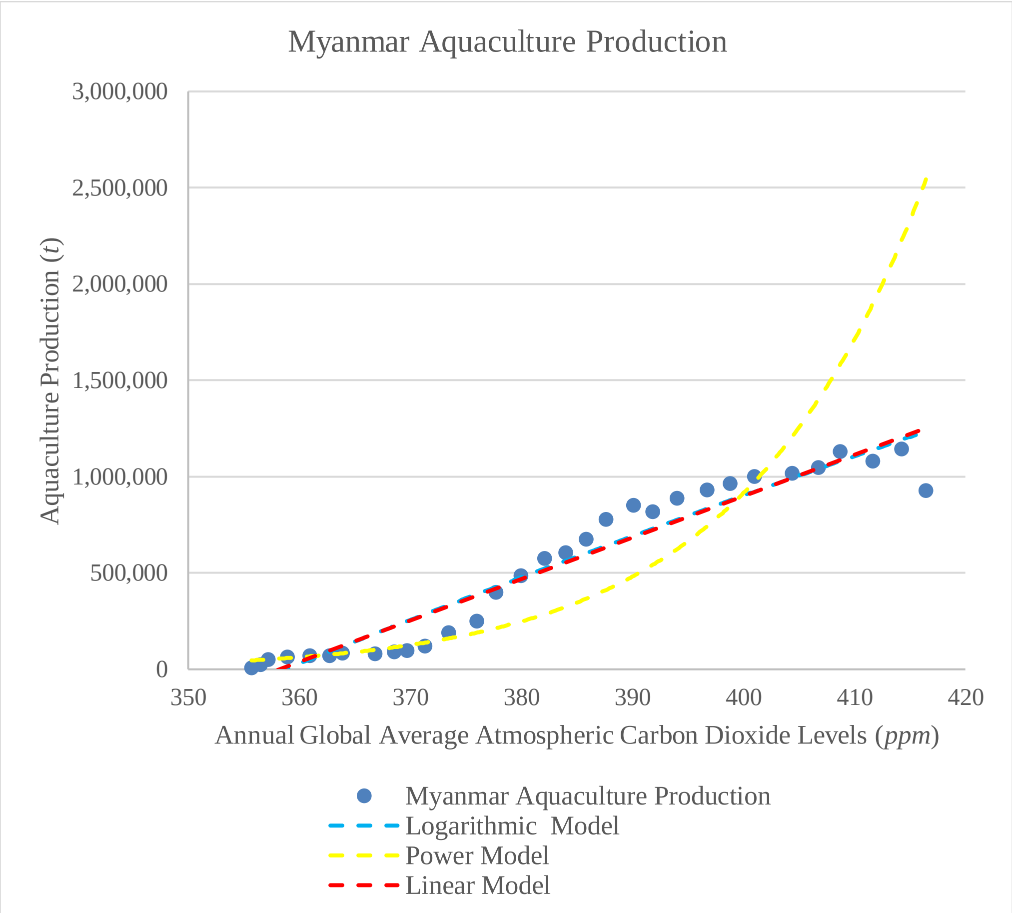

Figure 4.34: Myanmar Aquaculture Models (1991 – 2021).

4.5.6 Malaysia

Early years (1960 – 1990) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.24: Malaysia Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$f = -126.363c^2 + 105632.706c - 20646555.6$	0.978	36742	<0.04
2	Logarithmic	$f = 7036250.396ln(c) - 40363237.7$	0.977	37818	<0.001
3	Linear	$f = 21016.031c - 6498223.528$	0.975	39070	<0.001

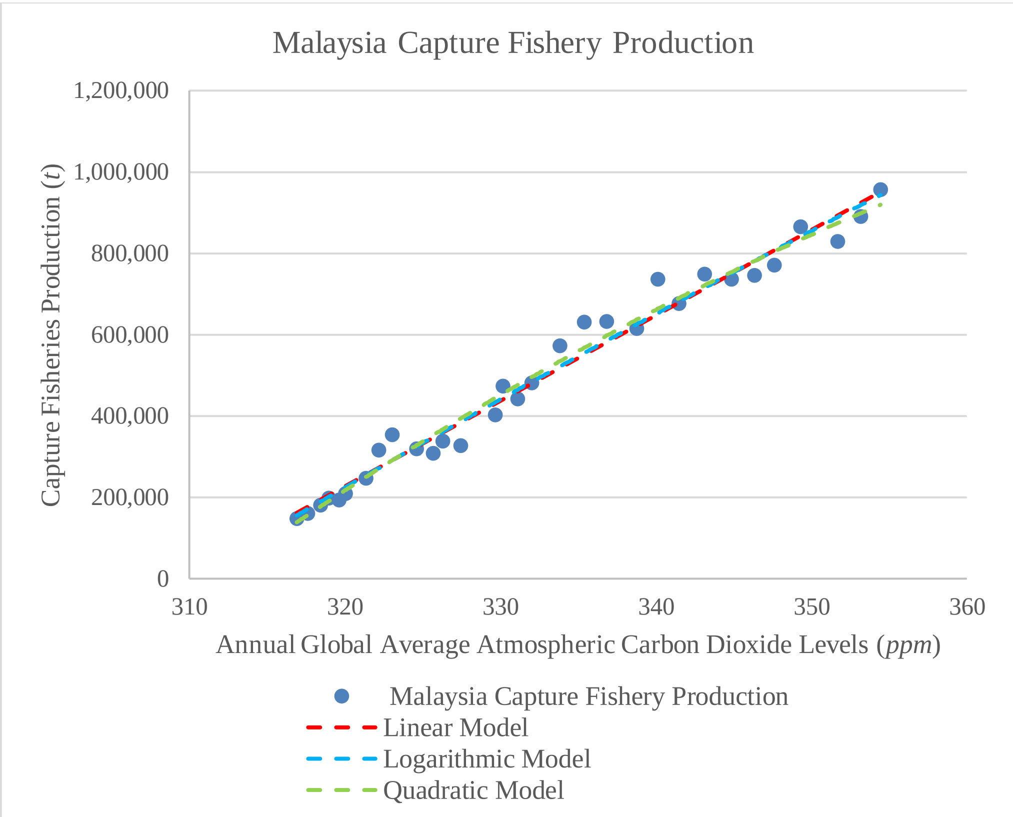

Figure 4.35: Malaysia Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.25: Malaysia Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$f = -214.899c^2 + 172987.031c - 33350723.5$	0.904	51068	<0.001
2	Logarithmic	$f = 2949759.362ln(c) - 16235088.9$	0.754	81771	<0.001
3	Linear	$f = 7604.479c - 1605739.424$	0.739	84244	<0.001

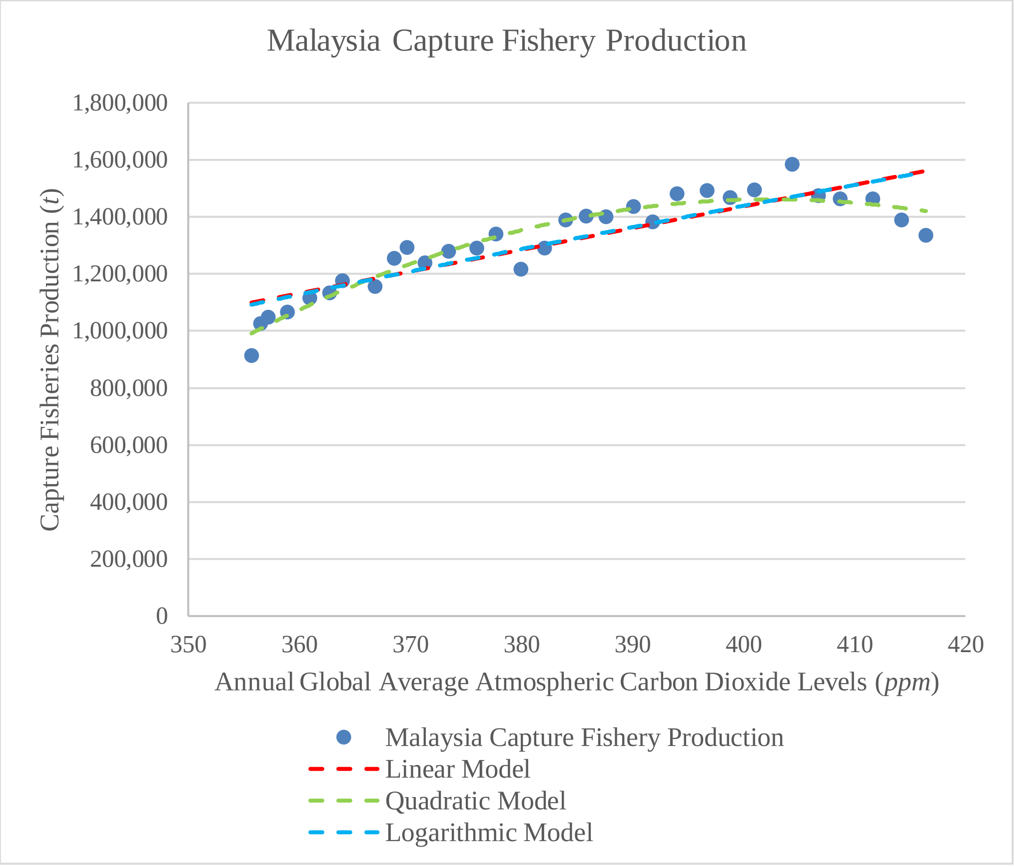

Figure 4.36: Malaysia Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Quadratic, Power and Logarithmic.

Table 4.26: Malaysia Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$a = -88.999c^2 + 60888.552c - 10352587.2$	0.599	14679	<0.01
2	Power	$a = 7.822E - 30c^{13.348}$	0.547	0.419	<0.001
3	Logarithmic	$a = 436559.523ln(c) - 2492833.859$	0.416	17718	<0.001

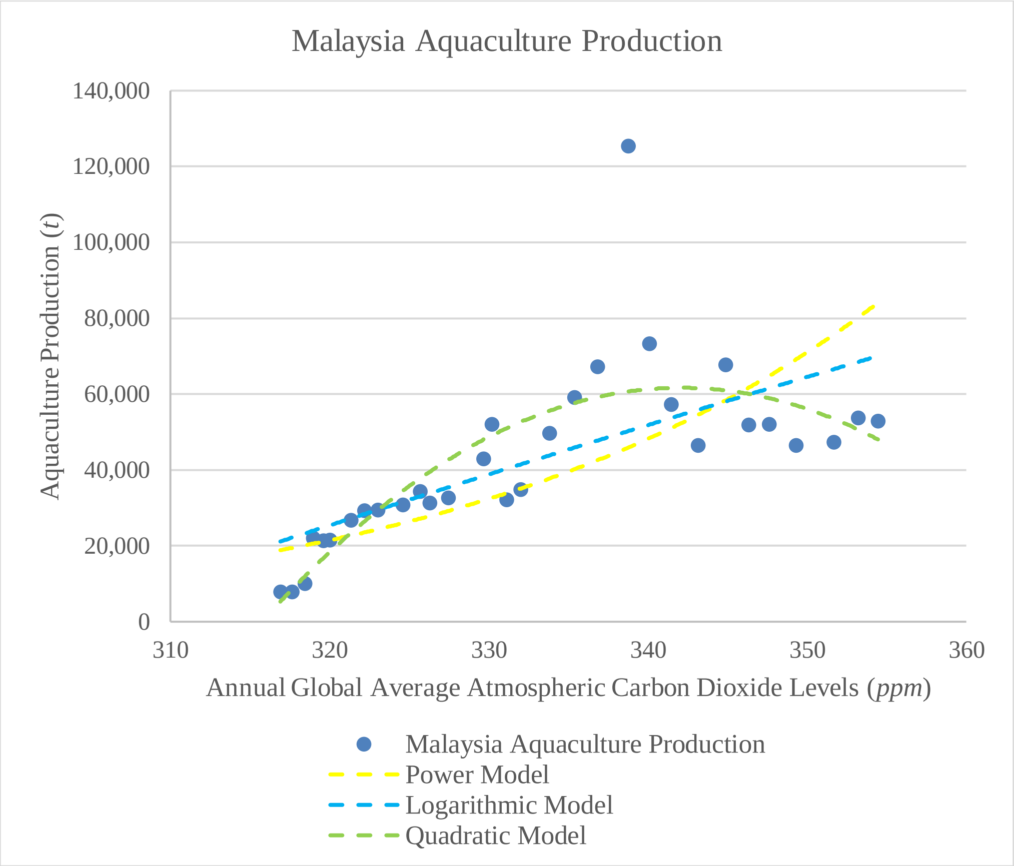

Figure 4.37: Malaysia Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Power, Quadratic and Logarithmic.

Table 4.27: Malaysia Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$a = 1.543E - 26c^{12.081}$	0.791	0.302	<0.001
2	Quadratic	$a = -155.546c^2 + 127326.096c - 25598399.1$	0.745	87321	<0.01
3	Logarithmic	$a = 2947541.462ln(c) - 17230979.9$	0.683	97336	<0.001

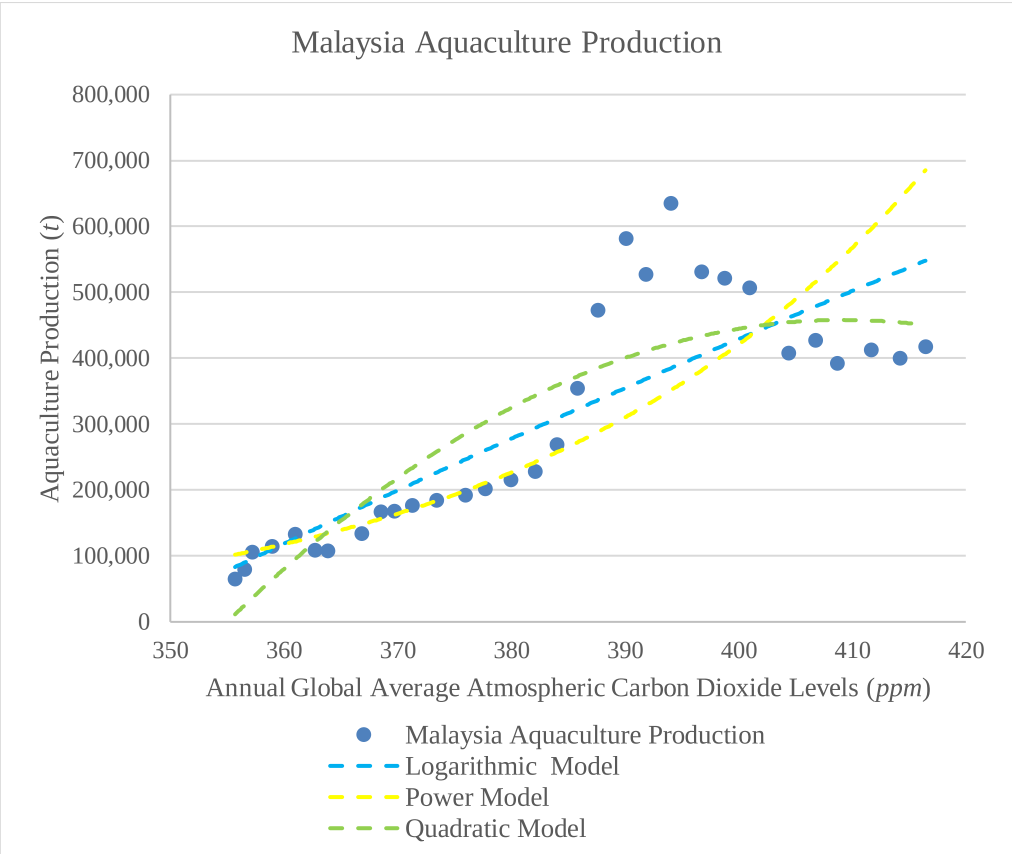

Figure 4.38: Malaysia Aquaculture Models (1991 – 2021).

4.5.7 Cambodia

Early years (1960 – 1990) capture fishery model: Logarithmic, Linear and Growth.

Table 4.28: Cambodia Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Logarithmic	$f = 297987.241ln(c) - 1668953.312$	0.223	18437	<0.01
2	Linear	$f = 889.701c - 234648.899$	0.2225	18444	<0.03
3	Growth	$f = e^{(6.261+0.014c)}$	0.161	0.348	<0.02

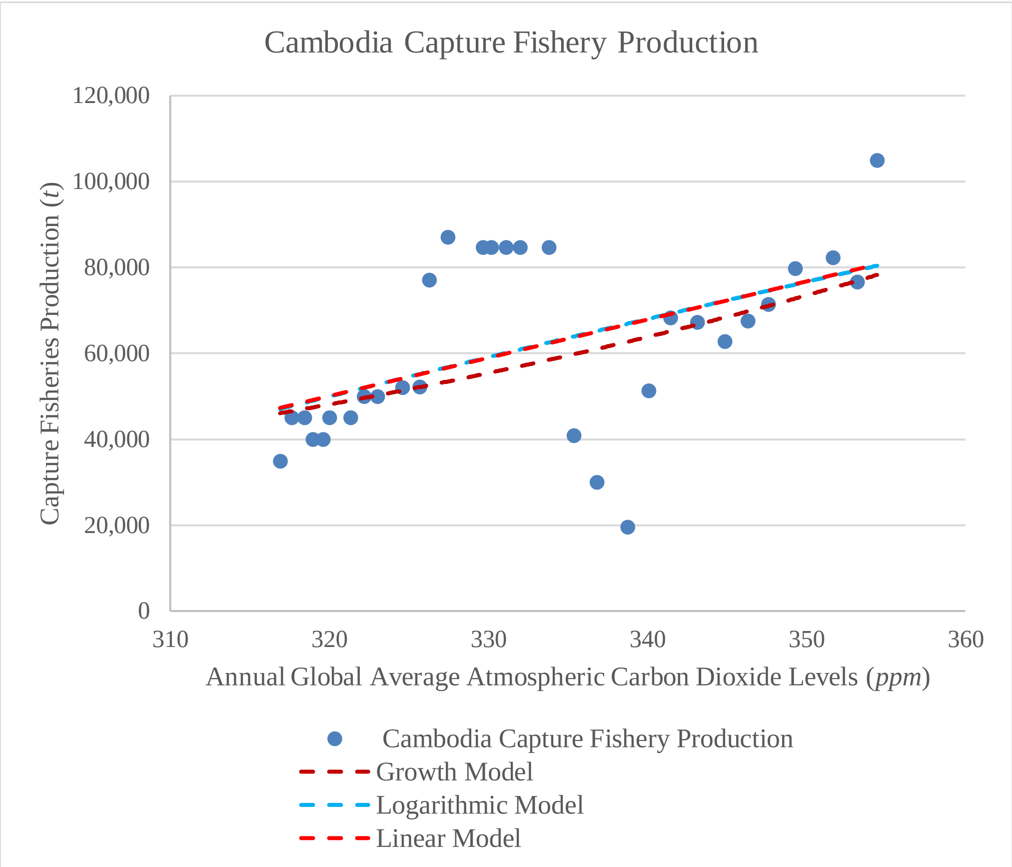

Figure 4.39: Cambodia Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.29: Cambodia Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = -192.011c^2 + 157617.871c - 31743869.9$	0.907	61804	<0.001
2	Logarithmic	$f = 3808727.368ln(c) - 22257585.3$	0.833	82937	<0.001
3	Linear	$f = 9849.536c - 3379913.857$	0.822	85695	<0.001

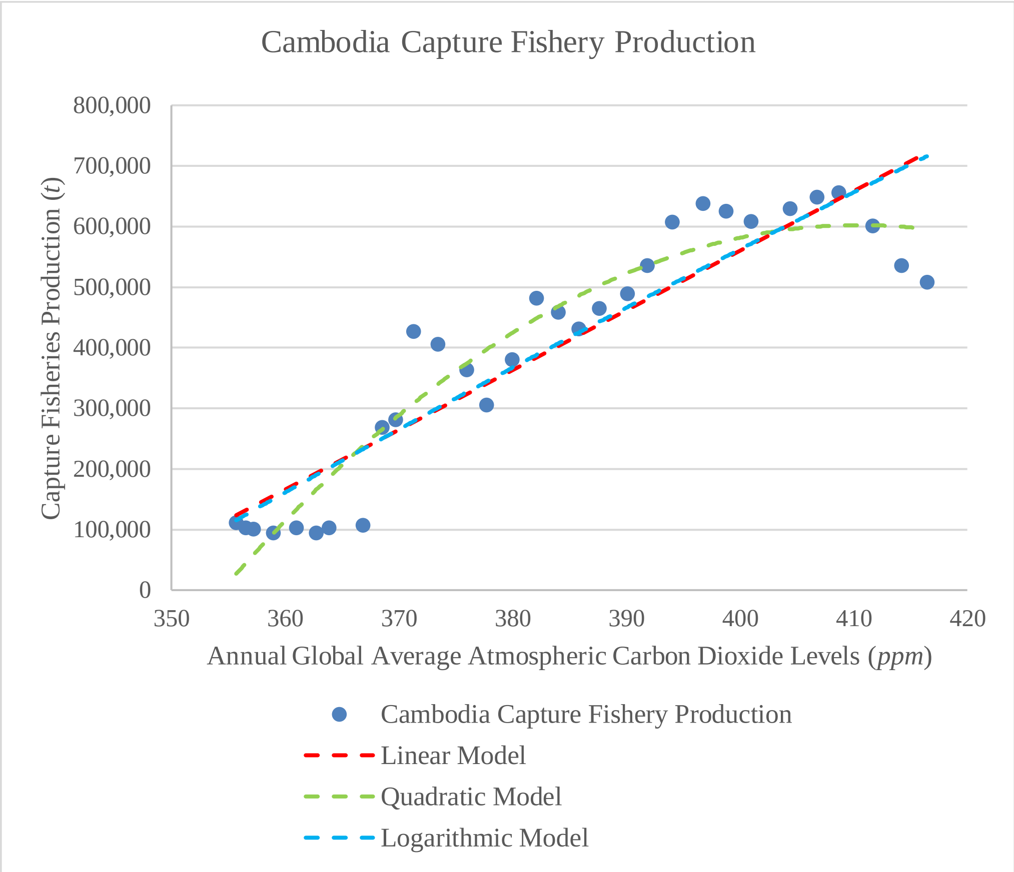

Figure 4.40: Cambodia Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Quadratic, Linear and Logarithmic.

Table 4.30: Cambodia Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$a = 8.436c^2 - 5531.767c + 90636$	0.927	474	<0.001
2	Linear	$a = 117.412c - 38203.095$	0.605	1100	<0.001
3	Logarithmic	$a = 38865.283 ln(c) - 224816.786$	0.591	1119	<0.001

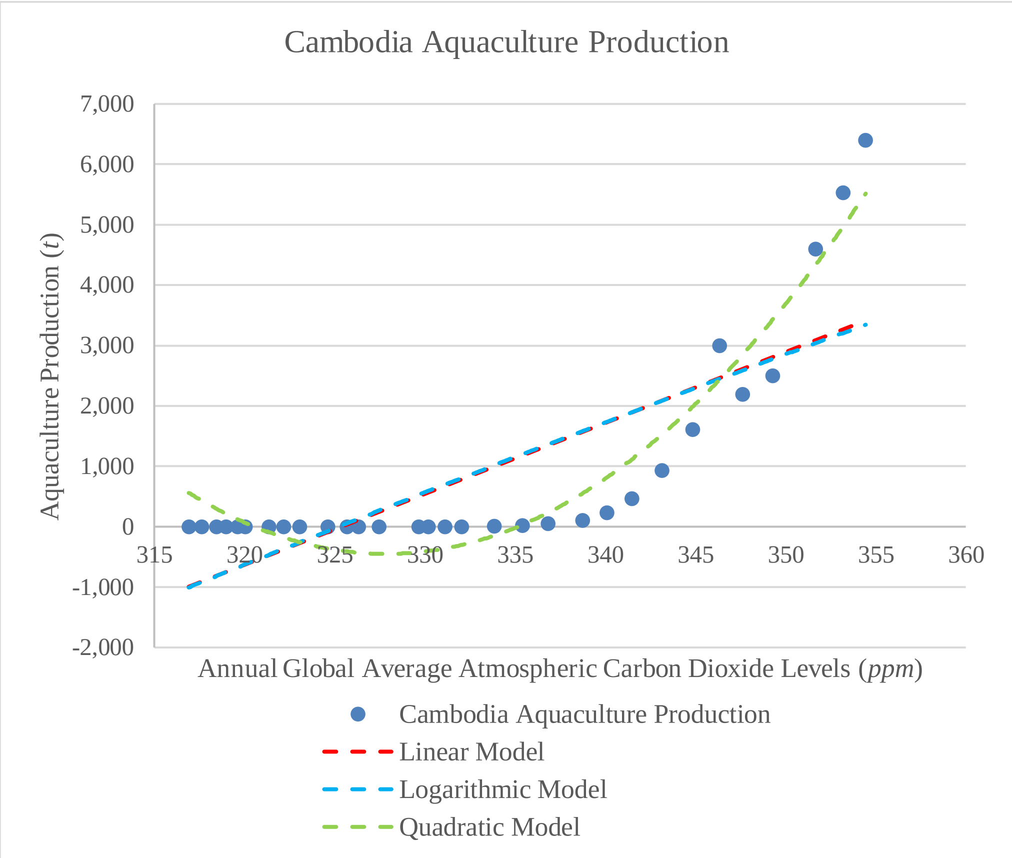

Figure 4.41: Cambodia Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) Aquaculture model: Exponential, Power and Quadratic.

Table 4.31: Cambodia Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Exponential	$a = 3.032E - 7e^{0.067c}$	0.989	0.130	<0.05
2	Power	$a = 1.926E - 62c^{25.681}$	0.987	0.142	<0.001
3	Quadratic	$a = 160.787c^2 - 118713.833c + 21912796.12$	0.958	22253	<0.001

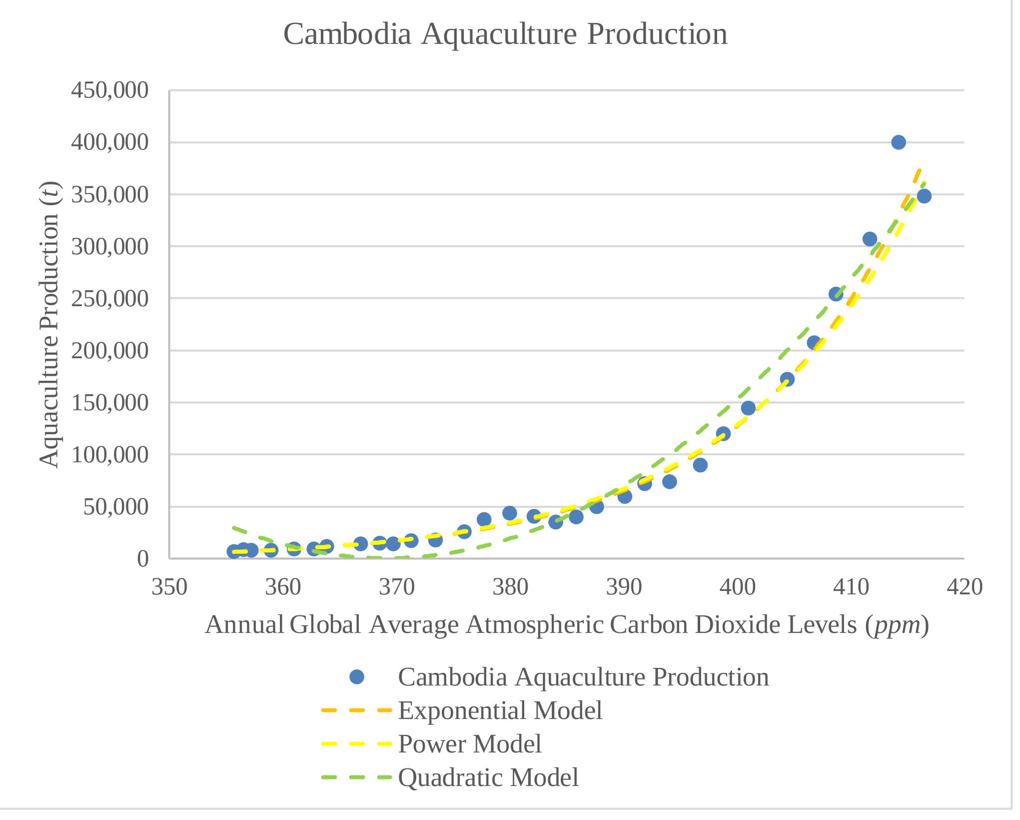

Figure 4.42: Cambodia Aquaculture Models (1991 – 2021).

4.5.8 LAO PDR

Early years (1960 – 1990) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.32: LAO PDR Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = -17.607c^2 + 11985.923c - 2017158.695$	0.926	866	<0.001
2	Logarithmic	$f = 66261.089 ln(c) - 365453.246$	0.515	2216	<0.001
3	Linear	$f = 195.503c - 45741.335$	0.501	2248	<0.001

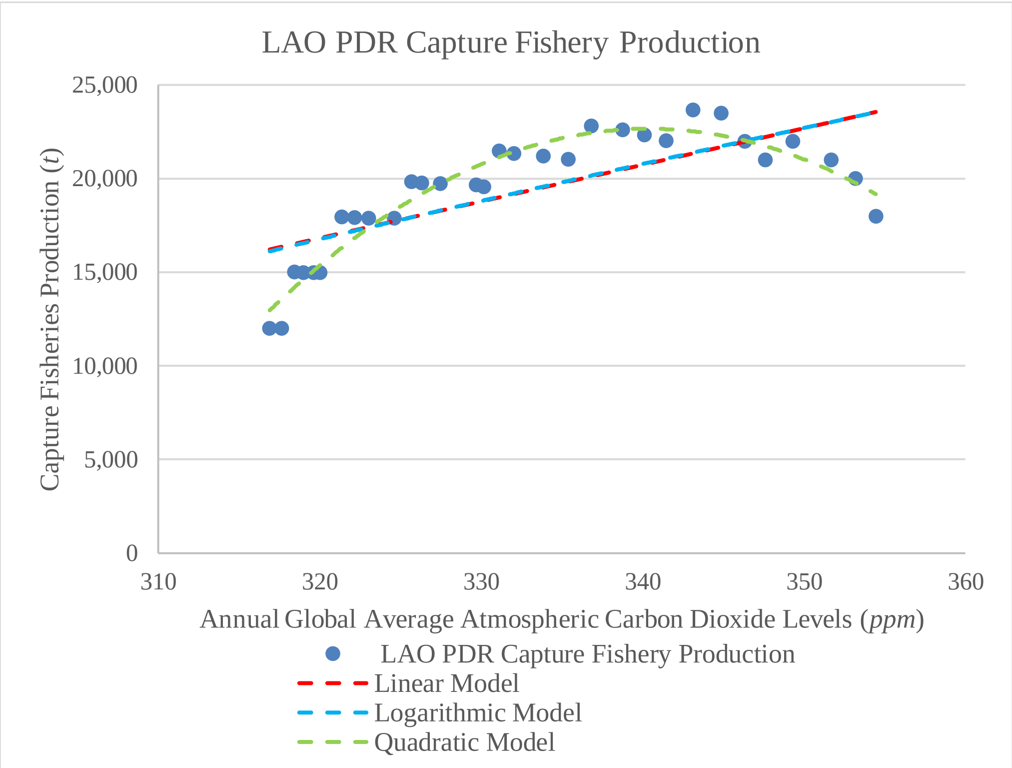

Figure 4.43: LAO PDR Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Growth, Power and Quadratic.

Table 4.33: LAO PDR Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Growth	$f = e^{(2.437+0.021c)}$	0.852	0.163	<0.001
2	Power	$f = 8.303E - 17c^{7.979}$	0.845	0.166	<0.001
3	Quadratic	$f = 15.427c^2 - 11064.958c + 2006309.059$	0.892	5518	<0.001

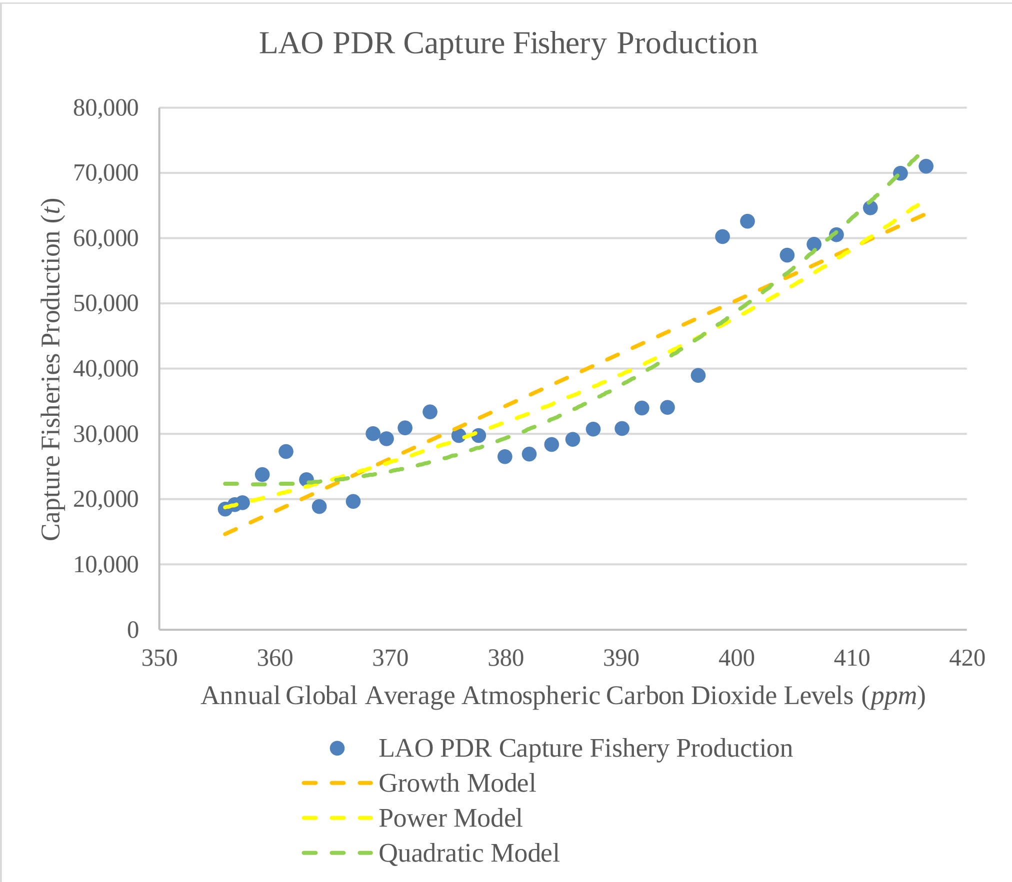

Figure 4.44: LAO PDR Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Quadratic, Linear and Logarithmic.

Table 4.34: LAO PDR Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$a = 10.513x^2 - 6841.210c + 1112788.046$	0.966	492	<0.001
2	Linear	$a = 198.461c - 64280.158$	0.751	1333	<0.001
3	Logarithmic	$a = 65875.368ln(c) - 380766.979$	0.738	1365	<0.001

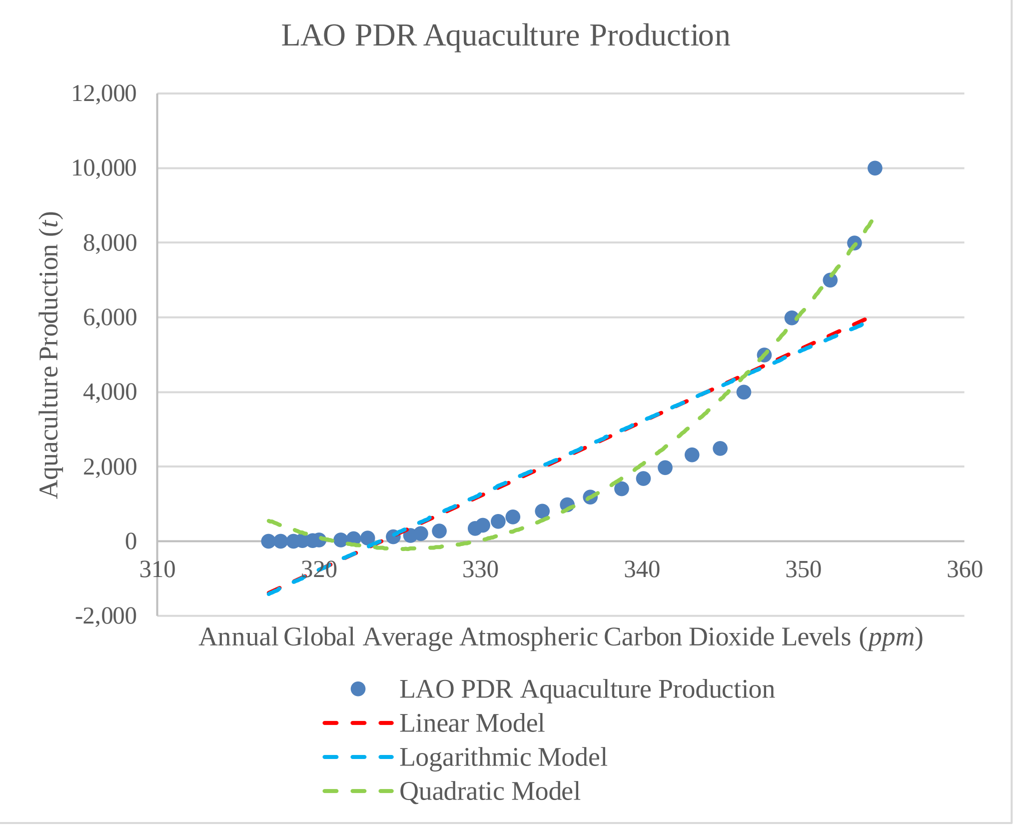

Figure 4.45: LAO PDR Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) aquaculture model: Logarithmic, Linear and Power.

Table 4.35: LAO PDR Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Logarithmic	$a = 803328.517 ln(c) - 4711483.571$	0.969	7063	<0.001
2	Linear	$a = 2089.135c - 734324.672$	0.967	7269	<0.001
3	Power	$a = 6.150E - 38c^{16.227}$	0.857	0.323	<0.001

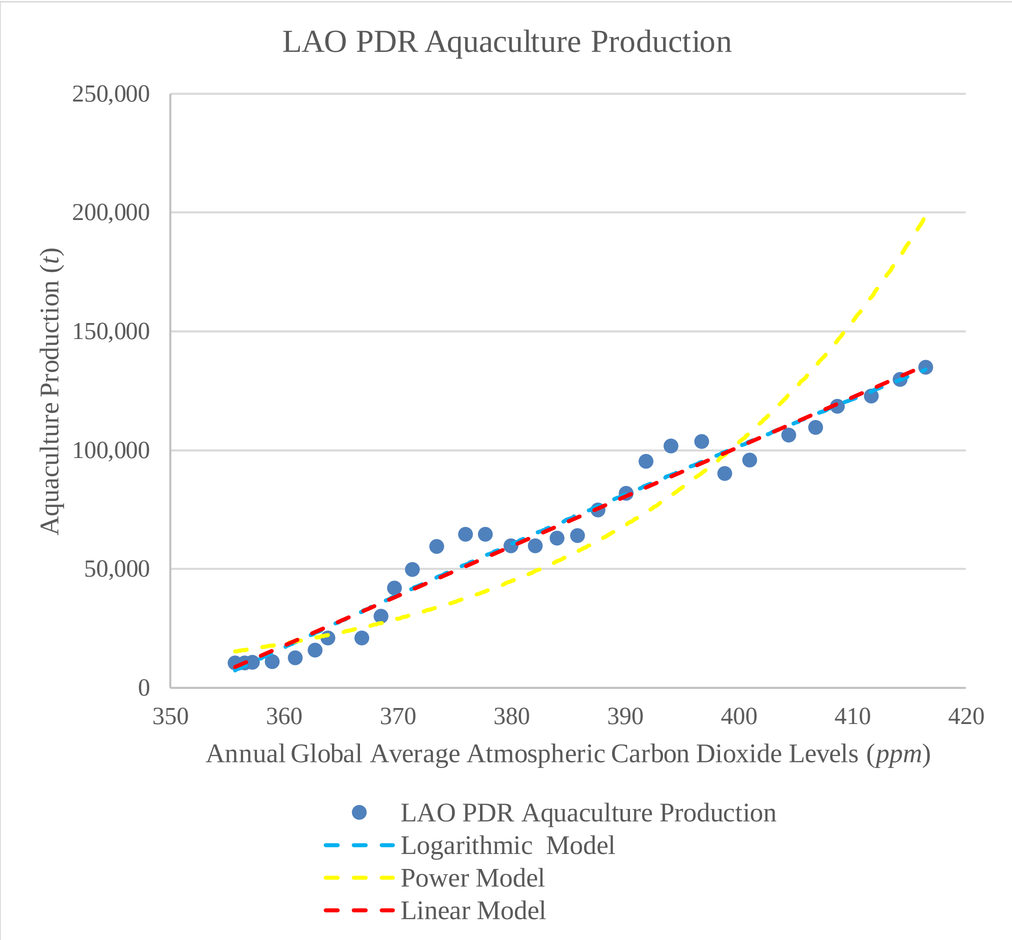

Figure 4.46: LAO PDR Aquaculture Models (1991 – 2021).

4.5.9 Brunei

Early years (1960 – 1990) capture fishery model: Power, Growth and Logarithmic.

Table 4.36: Brunei Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Power	$f = 1.638E-27c^{11.908}$	0.783	0.219	<0.001
2	Growth	$f = e^{(-4.313+0.035c)}$	0.775	0.223	<0.01
3	Logarithmic	$f = 22662.215ln(c) - 129633.779$	0.684	536	<0.001

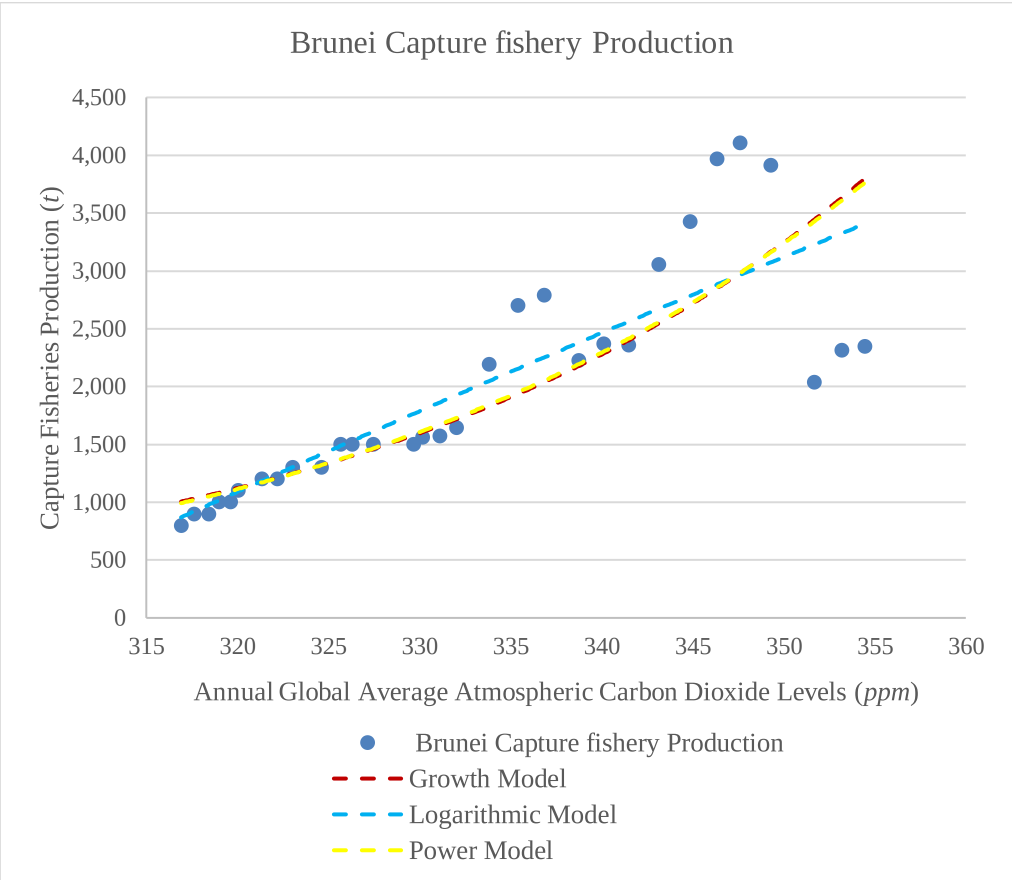

Figure 4.47: Brunei Capture Fishery Models (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Quadratic, Linear and Logarithmic.

Table 4.37: Brunei Capture Fishery Model Ranking (1991 – 2021)

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Quadratic	$f = 8.086c^2 - 6061.994c + 1137813.317$	0.779	2066	<0.001
2	Linear	$f = 160.850c - 56654.128$	0.452	3257	<0.001
3	Logarithmic	$f = 60691.823ln(c) - 355975.600$	0.435	3307	<0.001

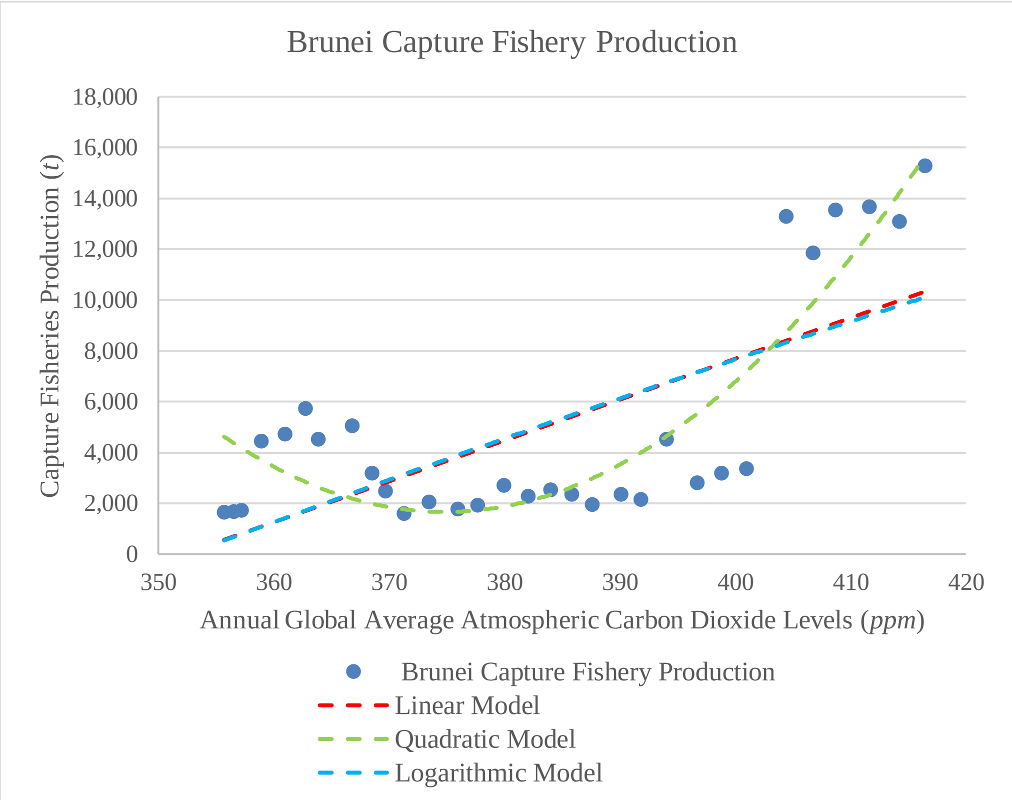

Figure 4.48: Brunei Capture Fishery Models (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Quadratic, Linear and Logarithmic.

Table 4.38: Brunei Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$a = 0.006c^2 - 3.816c + 628.779$	0.607	0.754	<0.001
2	Linear	$a = 0.058c - 18.956$	0.297	1.008	<0.01
3	Logarithmic	$a = 19.153ln(c) - 110.841$	0.288	1.015	<0.01

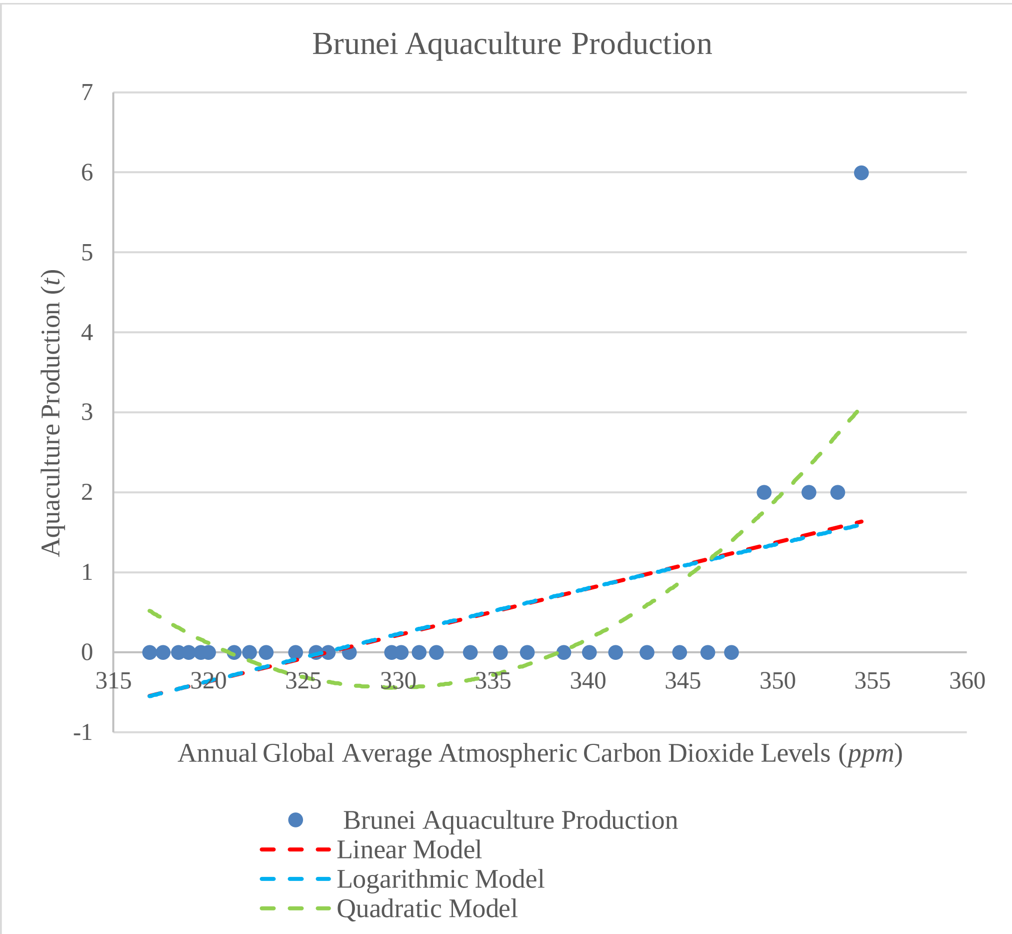

Figure 4.49: Brunei Aquaculture Models (1960 – 1990).

Recent years (1991 – 2021) aquaculture model: Power, Exponential and Quadratic.

Table 4.39: Brunei Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$a = 1.364E - 72c^{28.780}$	0.733	0.844	<0.001
2	Exponential	$a = 1.163E - 10e^{0.075c}$	0.725	0.855	<0.001
3	Quadratic	$a = 1.415c^2 - 1049.643c + 194679.687$	0.695	558.452	<0.001

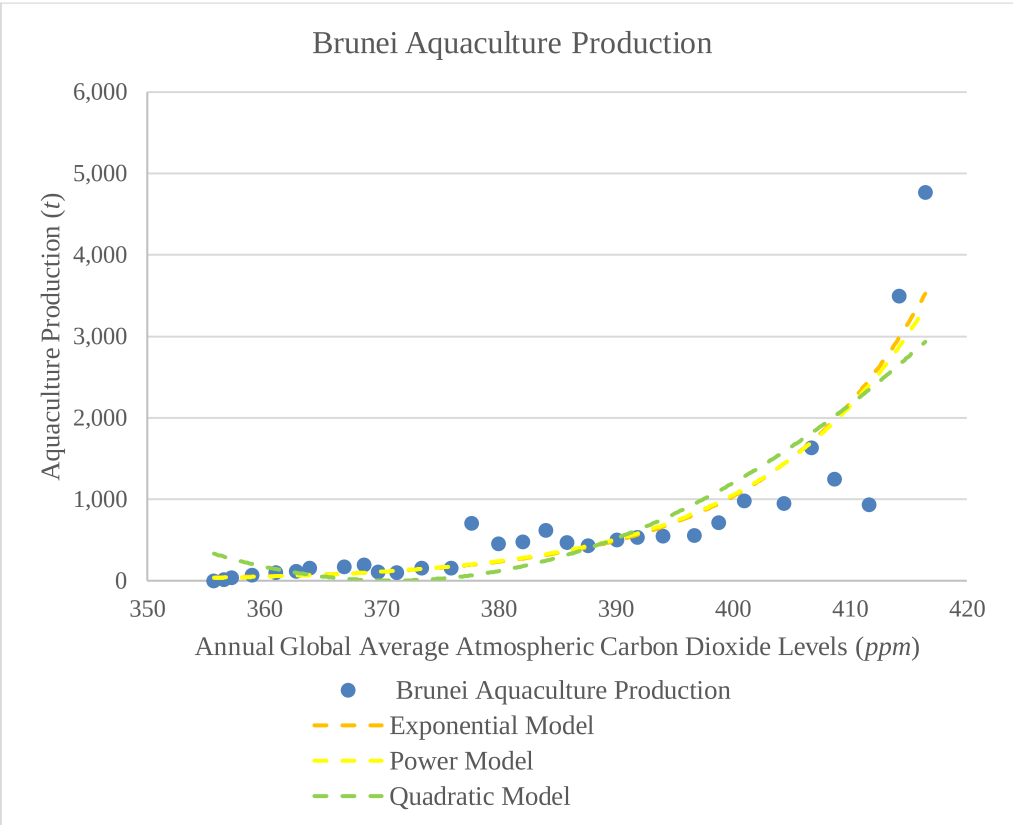

Figure 4.50: Brunei Aquaculture Models (1991 – 2021).

4.5.10 Singapore

Early years (1960 – 1990) capture fishery model: Quadratic.

Table 4.40: Singapore Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$y = -20.722x^2 + 13974.745x - 2337092.980$	0.452	2829	<0.001

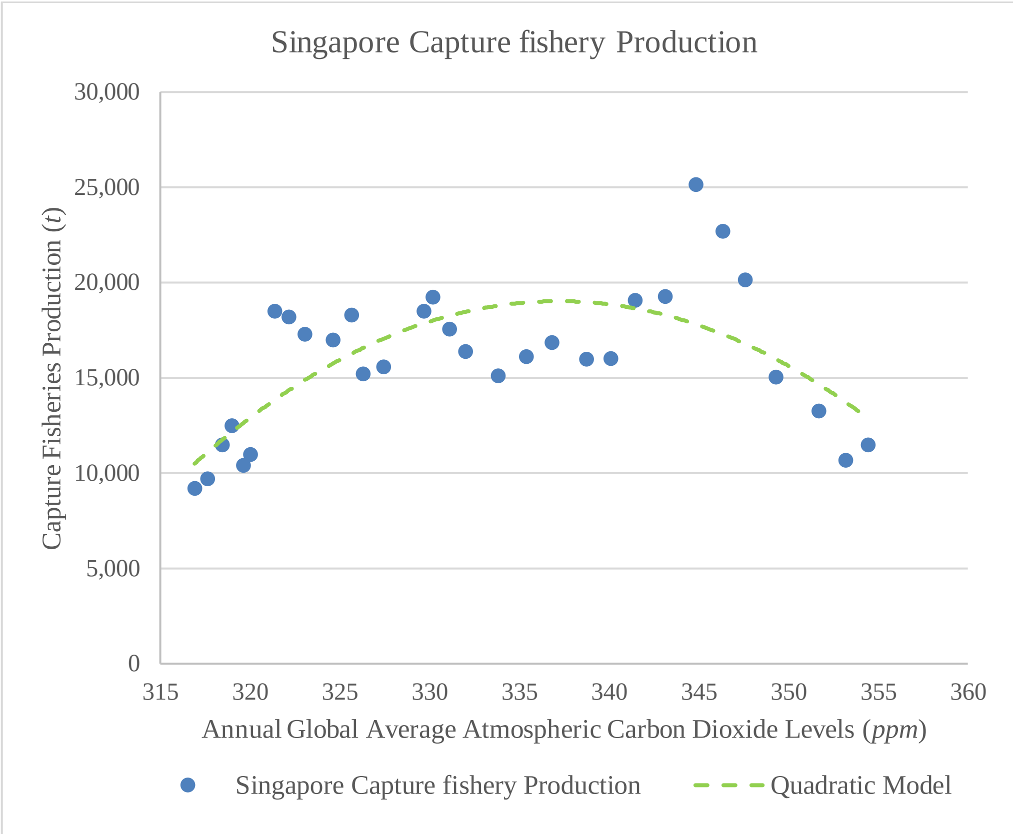

Figure 4.51: Singapore Capture Fishery Model (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Growth, Quadratic and Logarithmic.

Table 4.41: Singapore Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Growth	$f = e^{(26.387-0.048c)}$	0.872	0.346	<0.001
2	Quadratic	$f = 4.635c^2 - 3734.532c + 753003.294$	0.900	1147	<0.001
3	Logarithmic	$f = -65036.341ln(c) + 390892.317$	0.757	1789	<0.001

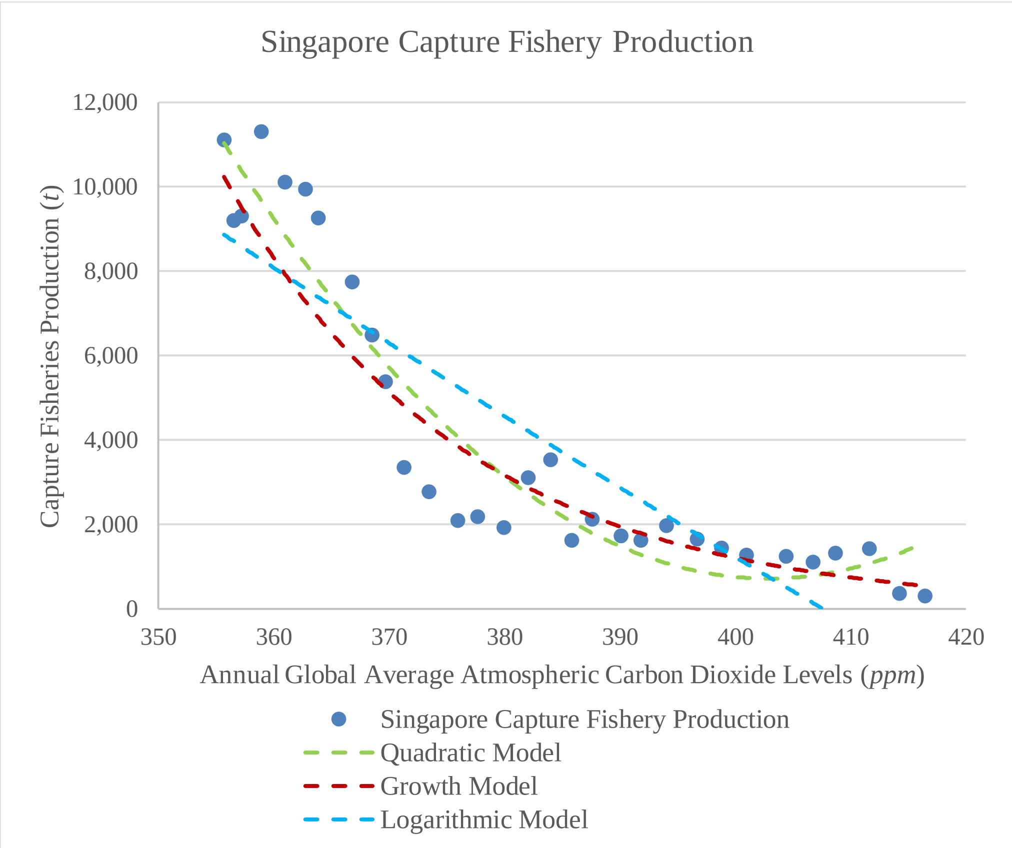

Figure 4.52: Singapore Capture Fishery Model (1991 – 2021).

Early years (1960 – 1990) Aquaculture model: Quadratic, Linear and Logarithmic.

Table 4.42: Singapore Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$a = 2.346c^2 - 1516.692c + 245134.819$	0.910	216	<0.001
2	Linear	$a = 53.991c - 17491.275$	0.765	349	<0.001
3	Logarithmic	$a = 17945.455ln(c) - 103731.193$	0.755	356	<0.001

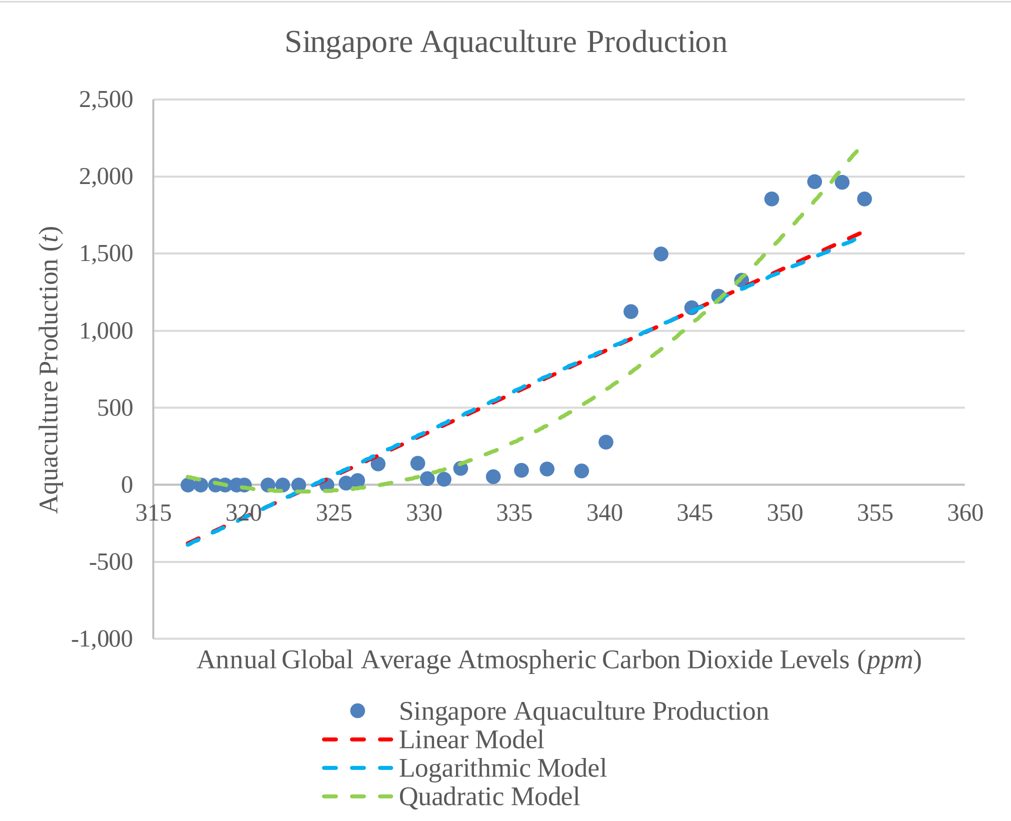

Figure 4.53: Singapore Aquaculture Model (1960 – 1990).

Recent years (1991 – 2021) aquaculture model: Growth, Quadratic and Logarithmic.

Table 4.43: Singapore Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Growth	$f = e^{(3.884+0.012c)}$	0.413	0.256	<0.001
2	Quadratic	$f = -1.490c^2 + 1193.393c - 233348.103$	0.437	1074	<0.03
3	Logarithmic	$f = 18044.762ln(c) - 102714.360$	0.358	1147	<0.001

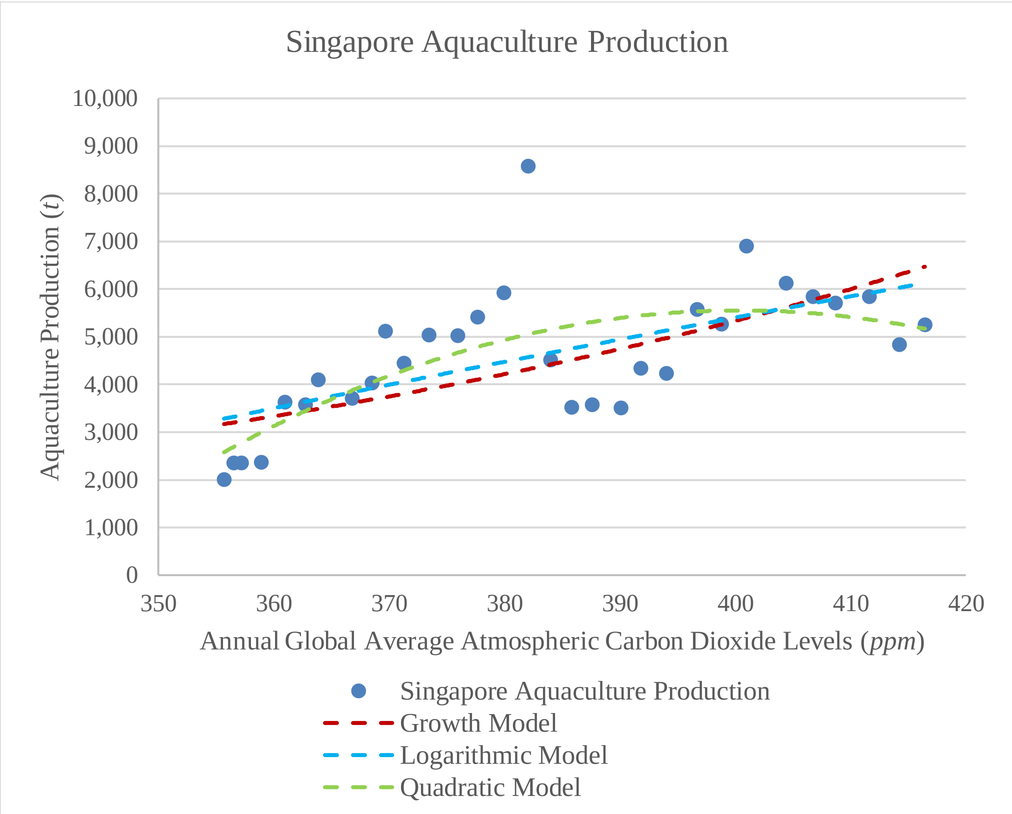

Figure 4.54: Singapore Aquaculture Model (1991 – 2021).

4.5.11 ASEAN

Early years (1960 – 1990) capture fishery model: Quadratic, Logarithmic and Linear.

Table 4.44: ASEAN Capture Fishery Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Quadratic	$f = -1536.538c^2 + 1207129.103c - 225524981$	0.979	303540	<0.01
2	Logarithmic	$f = 59690669.4ln(c) - 340796746$	0.975	333543	<0.001
3	Linear	$f = 178211.345c - 53484777.2$	0.973	349186	<0.001

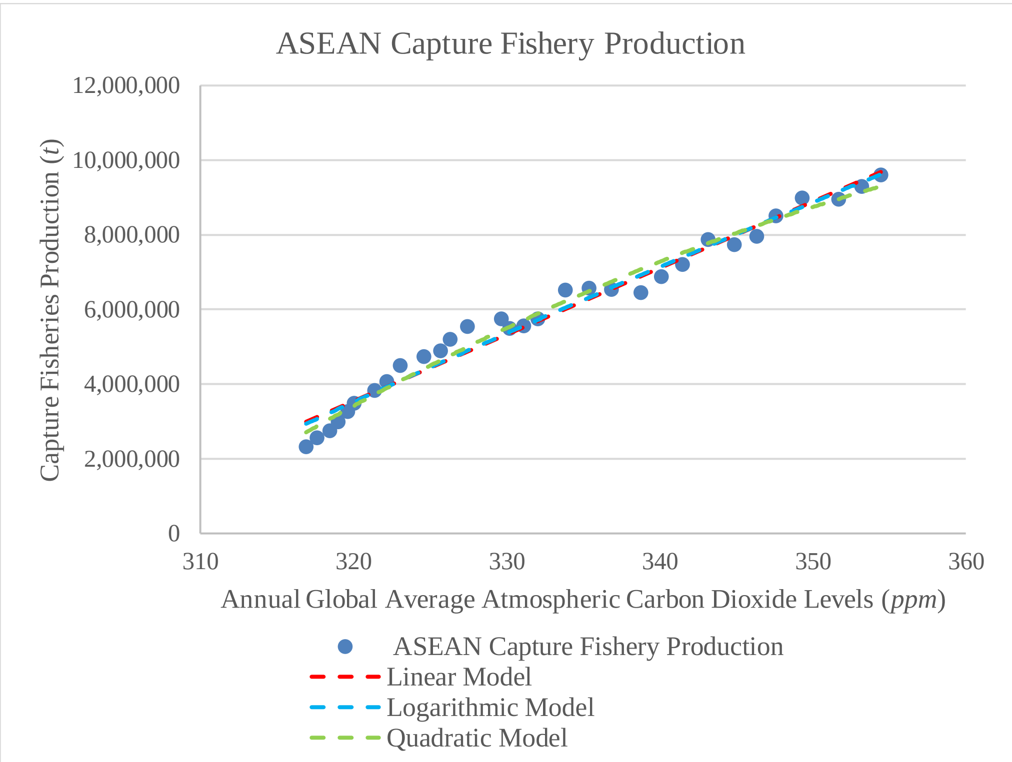

Figure 4.55: ASEAN Capture Fishery Model (1960 – 1990).

Recent years (1991 – 2021) capture fishery model: Exponential, Quadratic and Logarithmic.

Table 4.45: ASEAN Capture Fishery Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Exponential	$f = 431992.578e^{0.009c}$	0.907	0.055	<0.001
2	Quadratic	$f = -1749.949c^2 + 1477975.838c - 293985290$	0.987	292720	<0.001
3	Logarithmic	$f = 50647459.35ln(c) - 286408940$	0.949	574446	<0.001

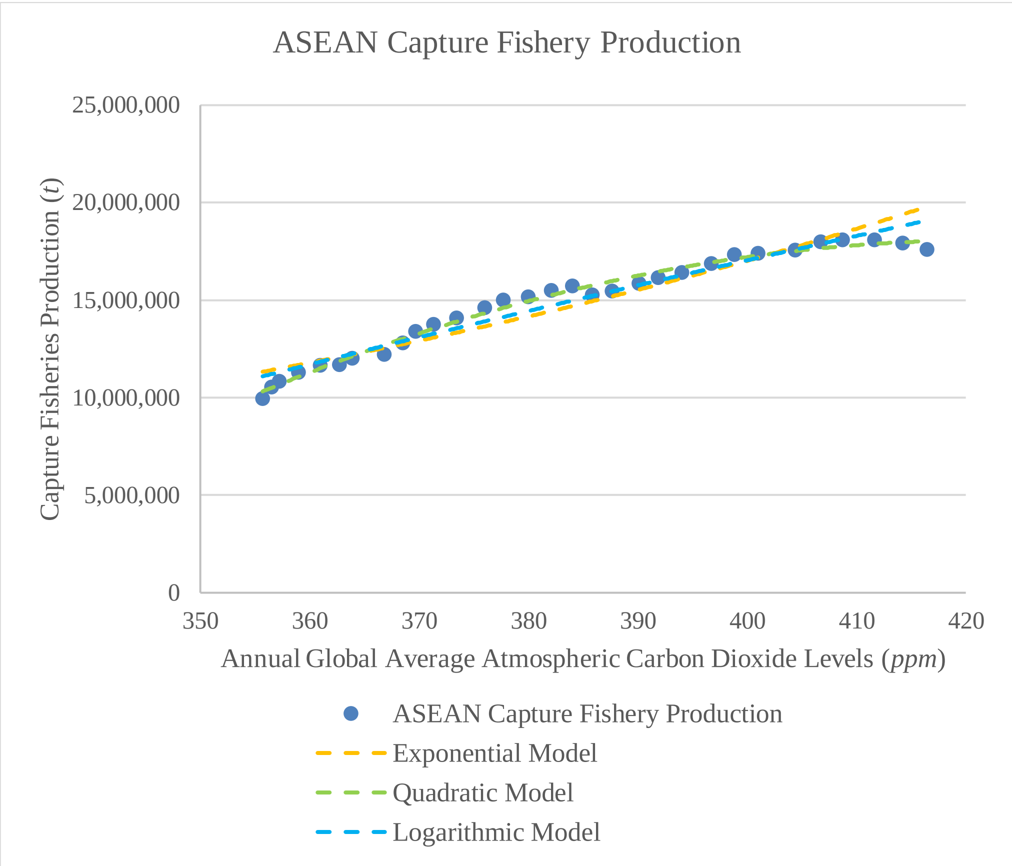

Figure 4.56: ASEAN Capture Fishery Model (1991 – 2021).

Early years (1960 – 1990) aquaculture model: Power, Exponential and Quadratic.

Table 4.46: ASEAN Aquaculture Model Ranking (1960 – 1990).

Rank	Model Type	Model	Adj. R^2	SEE	p-Value
1	Power	$a = 7.705E-42c^{18.582}$	0.992	0.059	<0.001
2	Exponential	$a = 0.005e^{0.056c}$	0.991	0.062	<0.01
3	Quadratic	$a = 877.665c^2 - 549140.661c + 186123868.48$	0.995	34081	<0.001

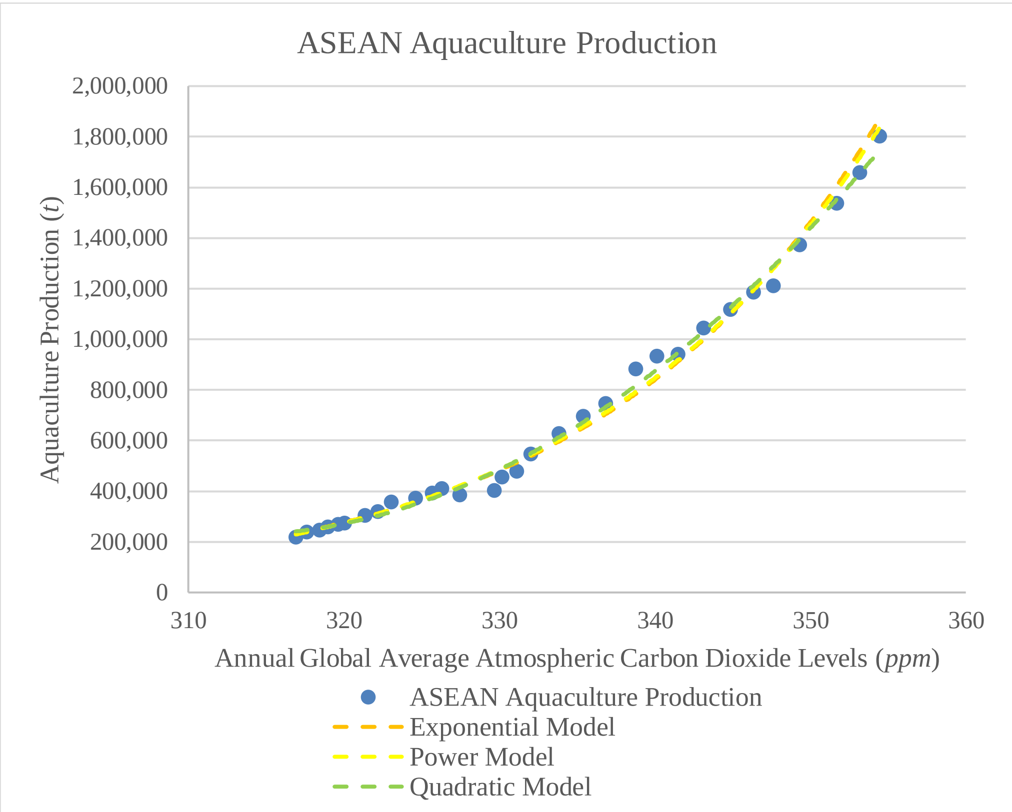

Figure 4.57: ASEAN Aquaculture Model (1960 – 1990).

Recent years (1991 – 2021) aquaculture model: Power, Growth and Linear.

Table 4.47: ASEAN Aquaculture Model Ranking (1991 – 2021).

Rank	Model Type	Model	Adj. R^2	SEE	*p*-Value
1	Power	$a = 5.225E - 42c^{18.658}$	0.958	0.192	<0.001
2	Growth	$a = e^{(-2.645+0.048c)}$	0.952	0.204	<0.01
3	Linear	$a = 469692.774c - 168175590$	0.933	2351874	<0.001

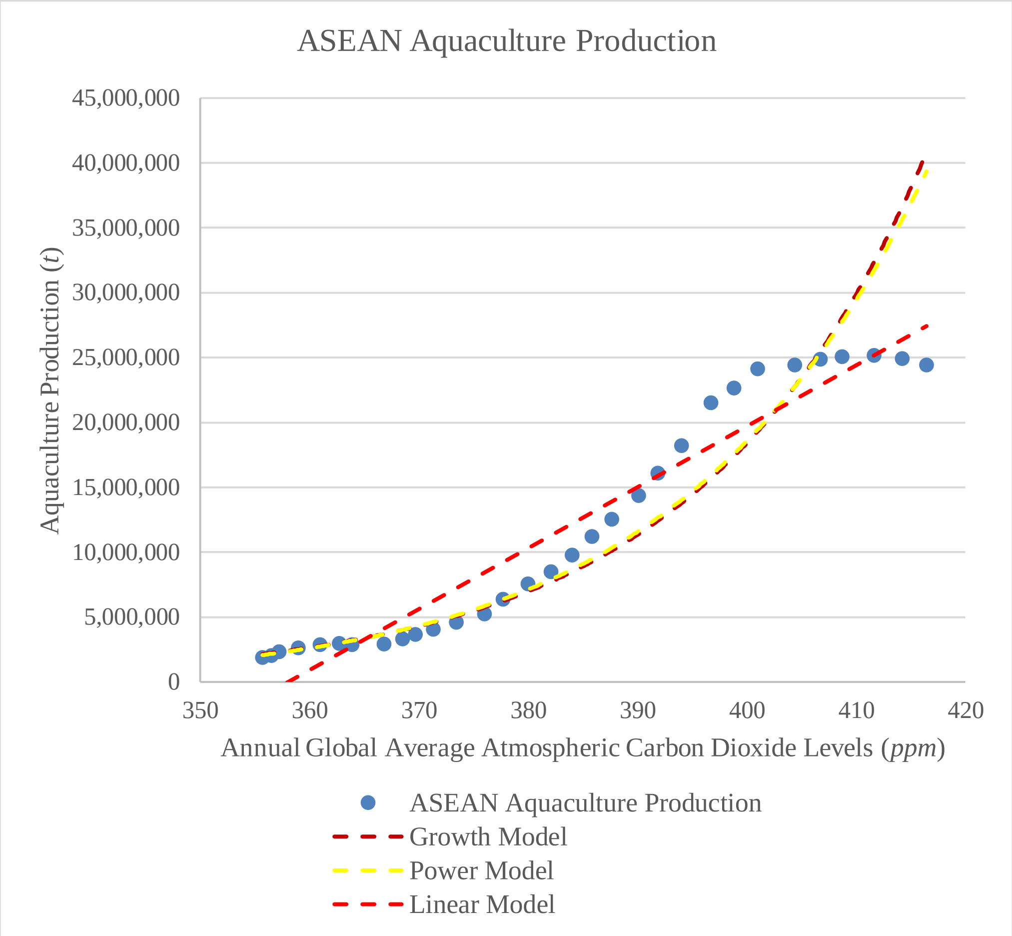

Figure 4.58: ASEAN Aquaculture Model (1991 – 2021).

4.6 Model Validation

Both Nash-Sutcliffe Efficiency (NSE) and Kling-Gupta efficiency was used for the validation of models. Moreover, biasness of the models was tested as well to compare its discrepancy between the model's expected value and the actual value of the parameter it aims to predict.

4.6.1 Annual Atmospheric Carbon Dioxide Concentration

Table 4.48: Annual Average Global Atmospheric Carbon Dioxide Concentration (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Power	$c = 1.159E - 33y^{10.756}$	0.994	0	1.038
Growth	$c = e^{(-4.810+0.005y)}$	-114.321	-0.126	-198
Exponential	$c = 0.008e^{0.005y}$	-118.268	-0.130	-201

4.6.2 Indonesia

Table 4.49: Indonesia Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Logarithmic	$f = 27492132.370\ln(c) - 158422270.25$	0.980	0.986	0.002
Linear	$f = 71556.601c - 22336055.82$	0.980	0.986	-0.148
Exponential	$f = 19610.018e^{0.014c}$	0.633	0.791	-747297

Table 4.50: Indonesia Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Power	$a = 7.235E - 60c^{25.408}$	0.707	0.824	-69856
Growth	$a = e^{(0.066c-10.395)}$	0.680	0.813	-238298
Quadratic	$a = 4007.247c^2 - 2774683.714c + 479602551.56$	0.895	0.924	31.320

4.6.3 Thailand

Table 4.51: Thailand Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Exponential	$f = 516778969.1e^{-0.014c}$	0.718	0.876	191920
Linear	$f = -30822.353c + 14117787.53$	0.854	0.892	0.081
Logarithmic	$f = -11821496.3\, ln(c) + 72613836.54$	0.851	0.890	-0.003

Table 4.52: Thailand Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$a = -707.361c^2 + 554068.903c - 107284298.961$	0.793	0.845	-43.342
Growth	$a = e^{(8.421+0.014c)}$	0.050	0.455	80077
Logarithmic	$a = 3820936.209ln(c) - 21801414.7$	0.340	0.411	-0.002

4.6.4 Vietnam

Table 4.53: Vietnam Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Linear	$f = 44470.080c - 14939112.7$	0.989	0.992	-0.107
Logarithmic	$f = 17074154.09ln(c) - 99445004.6$	0.988	0.992	-0.002
Power	$f = 5.827E - 17c^{8.719}$	0.961	0.921	6618

Table 4.54: Vietnam Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Linear	$a = 82599.445c - 29664747.6$	0.971	0.980	0.142
Logarithmic	$a = 31671137.49ln(c) - 186373587$	0.968	0.977	0.000
Power	$a = 4.236E - 52c^{22.247}$	0.631	0.603	109525

4.6.5 Philippines

Table 4.55: Philippines Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = -598.201c^2 + 462554.881c - 87130569.9$	0.639	0.716	71.973

Table 4.56: Philippines Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$a = -797.602c^2 + 645672.273c - 128266400$	0.910	0.935	39.972
Power	$a = 1.127E - 15c^{8.191}$	0.613	0.810	-15206
Logarithmic	$a = 12340833.25ln(c) - 71634392.5$	0.791	0.844	0.002

4.6.6 Myanmar

Table 4.57: Myanmar Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = -648.031c^2 + 524310.949c - 104041640$	0.927	0.948	25.920
Logarithmic	$f = 9918629.918ln(c) - 57495112.1$	0.803	0.853	-0.002
Linear	$f = 25598.199c - 8314321.106$	0.790	0.842	-0.103

Table 4.58: Myanmar Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Logarithmic	$a = 8272388.198ln(c) - 48661927.8$	0.935	0.953	0.001
Linear	$a = 21503.808c - 7702991.501$	0.932	0.951	-0.116
Power	$a = 8.050E - 61c^{25.386}$	-0.076	0.318	53553

4.6.7 Malaysia

Table 4.59: Malaysia Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = -214.899c^2 + 172987.031c - 33350723.5$	0.865	0.870	-10545
Logarithmic	$f = 2949759.362ln(c) - 16235088.9$	0.833	0.797	-10597
Linear	$f = 7604.479c - 1605739.424$	0.823	0.788	-10597

Table 4.60: Malaysia Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Power	$a = 1.543E - 26c^{12.081}$	0.465	0.731	-7591
Quadratic	$a = -155.546c^2 + 127326.096c - 25598399.1$	0.762	0.820	-41.278
Logarithmic	$a = 2947541.462ln(c) - 17230979.9$	0.693	0.763	0

4.6.8 Cambodia

Table 4.61: Cambodia Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = -192.011c^2 + 157617.871c - 31743869.9$	0.914	0.938	45.436
Logarithmic	$f = 3808727.368ln(c) - 22257585.3$	0.839	0.881	-0.001
Linear	$f = 9849.536c - 3379913.857$	0.828	0.873	-0.036

Table 4.62: Cambodia Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Exponential	$a = 3.032E - 7e^{0.067c}$	0.979	0.969	740
Power	$a = 1.926E - 62c^{25.681}$	0.969	0.887	-3648
Quadratic	$a = 160.787c^2 - 118713.833c + 21912796.12$	0.961	0.972	-59.716

4.6.9 LAO PDR

Table 4.63: LAO PDR Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = 15.427c^2 - 11064.958c + 2006309.059$	0.899	0.926	-53.165
Growth	$f = e^{(2.437+0.021c)}$	0.872	0.892	1693
Power	$f = 8.303E - 17c^{7.979}$	0.869	0.837	-522

Table 4.64: LAO PDR Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Logarithmic	$a = 803328.517ln(c) - 4711483.571$	0.970	0.978	0
Linear	$a = 2089.135c - 734324.672$	0.968	0.977	-0.173
Power	$a = 6.150E - 38c^{16.227}$	0.687	0.665	1351

4.6.10 Brunei

Table 4.65: Brunei Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = 8.086c^2 - 6061.994c + 1137813.317$	0.794	0.846	-1.553
Linear	$f = 160.850c - 56654.128$	0.470	0.556	0.162
Logarithmic	$f = 60691.823ln(c) - 355975.600$	0.454	0.538	0.001

Table 4.66: Brunei Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Power	$a = 1.364E - 72c^{28.780}$	0.806	0.847	-1.206
Exponential	$a = 1.163E - 10e^{0.075c}$	0.756	0.743	147
Quadratic	$a = 1.415c^2 - 1049.643c + 194679.687$	0.715	0.781	23.018

4.6.11 Singapore

Table 4.67: Singapore Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$f = 4.635c^2 - 3734.532c + 753003.294$	0.907	0.932	30.022
Growth	$f = e^{(26.387-0.048c)}$	0.905	0.895	104
Logarithmic	$f = -65036.341ln(c) + 390892.317$	0.765	0.823	0.003

Table 4.68: Singapore Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Quadratic	$a = -1.490c^2 + 1193.393c - 233348.103$	0.473	0.562	51.872
Growth	$a = e^{(3.884+0.012c)}$	0.226	0.520	343
Logarithmic	$a = 18044.762ln(c) - 102714.360$	0.379	0.457	-0.002

4.6.12 ASEAN

Table 4.69: ASEAN Capture Fishery (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Exponential	$f = 431992.578e^{0.009c}$	0.736	0.889	-1028546
Quadratic	$f = -1749.949c^2 + 1477975.838c - 293985290$	0.988	0.991	21.278
Logarithmic	$f = 50647459.35ln(c) - 286408940$	0.950	0.965	0

Table 4.70: ASEAN Aquaculture (1991 – 2021) Model Validation.

Model Type	Model	NSE	KGE	Bias
Power	$a = 5.225E - 42c^{18.658}$	0.793	0.818	145630
Growth	$a = e^{(-2.645+0.048c)}$	0.795	0.834	-1665094
Linear	$a = 469692.774c - 168175590$	0.936	0.954	-0.159

4.7 Residual Analysis

Residual analysis is used to further validates the model's stability. By using the predicted data from models and observed data from data sources, residual analysis was performed. A sample size of 2000 and Bias-corrected and accelerated (BCa) of 99% Confidence Intervals (CI) was used to be more conservative in the estimation and provide greater confidence in the coverage of the true parameter.

4.7.1 Annual Atmospheric Carbon Dioxide Concentration

Table 4.71: Annual Average Global Atmospheric Carbon Dioxide Concentration Power Model with Residual Analysis Summary using 2000 bootstrap sample and Confidence Interval Level of 99%.

Dependant Variable	Annual global average atmospheric carbon dioxide levels (*ppm*)
Predictor	Year
Modelled Period	1991–2021 (N=31)
Forecasted Period	2021–2024 (N=3)
Model	Power
Adjusted R^2	0.996614
SEE	0.002841
p-Value	<0.001
Residual Sum of Squares (RSS)	67.4532939
Residual Skewness	-0.973
Residual Range	4.033
Residual Mean	1.038
BCa 99% CI	[0.372, 1.569]
Residual Standard Deviation	1.065
BCa 99% CI	[0.748, 1.316]
Residual Variance	1.134
BCa 99% CI	[0.548, 1.768]

Table 4.72: Annual Average Global Atmospheric Carbon Dioxide Concentration Power Model Moving Window Validation with Residual Analysis Summary using 2000 bootstrap sample and Confidence Interval Level of 99%.

Modelled Period	1991–2015	1992–2016	1993–2017	1994–2018	1995–2019	1996–2020	1997–2021
Model	Power	Power	Power	Power	Power	Power	Power
Adjusted R^2	0.998	0.998	0.998	0.998	0.998	0.998	0.998
SSE	0.002	0.002	0.002	0.002	0.002	0.002	0.002
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Residual Skewness	-1.934	-1.214	-0.643	-0.663	-0.928	-1.141	-1.112
Residual Range	4.033	2.957	2.093	2.093	2.632	3.015	3.018
Residual Mean	1.331	1.416	1.45	1.443	1.399	1.341	1.276
BCa 99% CI	[0.803, 1.718]	[1.023, 1.732]	[1.128, 1.738]	[1.127, 1.741]	[1.073, 1.698]	[0.932, 1.698]	[0.809, 1.672]
Residual Standard Deviation	0.948	0.726	0.635	0.647	0.731	0.839	0.936
BCa 99% CI	[0.449, 1.384]	[0.468, 0.982]	[0.462, 0.753]	[0.459, 0.767]	[0.498, 0.887]	[0.503, 1.087]	[0.574, 1.170]
Residual Variance	0.899	0.527	0.404	0.418	0.535	0.705	0.877
BCa 99% CI	[0.185, 2.004]	[0.212, 0.977]	[0.211, 0.569]	[0.206, 0.593]	[0.236, 0.796]	[0.234, 1.193]	[0.309, 1.397]

4.7.2 ASEAN Capture fishery and Aquaculture

Table 4.73: ASEAN Capture Fishery Exponential Model with Residual Analysis Summary using 2000 bootstrap sample and Confidence Interval Level of 99%.

Dependant Variable	Capture Fishery Production (*t*)
Predictor	Annual global average atmospheric carbon dioxide levels (ppm)
Modelled Period	1991–2021 (N=31)
Forecasted Period	2021–2024 (N=3)
Model	Exponential
Adjusted R^2	0.907
SSE	0.055
p-Value	<0.001
Residual Sum of Squares (RSS)	5.09898E+13
Residual Skewness	0.679
Residual Range	2819291.21
Residual Median	-1326941.52
(BCa 99% CI)	[-1532510.11, -528250.223]
Residual Standard Deviation	778773.5784
(BCa 99% CI)	[568400.6218, 934720.9440]
Residual Variance	6.065E+11
(BCa 99% CI)	[3.188E+11, 8.775E+11]

Table 4.74: ASEAN Capture Fishery Exponential Model Moving Window Validation with Residual Analysis Summary using 2000 bootstrap sample and Confidence Interval Level of 99%.

Modelled Period	1991–2015	1992–2016	1993–2017	1994–2018	1995–2019	1996–2020	1997–2021
Model	Exponential	Exponential	Exponential	Exponential	Exponential	Exponential	Exponential
Adjusted R^2	0.936	0.94	0.941	0.94	0.933	0.919	0.902
SSE	0.042	0.036	0.037	0.036	0.036	0.038	0.039
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Residual Skewness	0.791	0.597	0.518	0.398	0.35	0.648	1.303
Residual Range	2729983.357	2238353.528	1989450.805	1708461.123	1698196.015	2118656.355	2819291.21
Residual Median	-1414839.26	-1414839.26	-1414839.26	-1414839.26	-1414839.26	-1414839.26	-1414839.26
BCa 99% CI	[−1653547.81, -536220.96]	[-1684719.08, -603333.68]	[-1653547.81, -914824.577]	[-1539652.89, -1125022.30]	[-1653547.81, -990679.322]	[-1681252.59, -990679.322]	[-1539652.89, -1125022.30]

Residual Standard Deviation	744066.6639	643296.5055	576108.1421	525190.7835	514707.4121	561309.5857	671038.9026
BCa 99% CI	[511601.3448, 901003.8069]	[460975.3634, 761388.6926]	[417694.8138, 676660.4671]	[394702.5642, 615247.8908]	[392007.0403, 598781.6553]	[381788.0136, 691231.0715]	[382599.1589,903550.1795]
Residual Variance	5.536E+11	4.138E+11	3.319E+11	2.758E+11	2.649E+11	3.151E+11	4.503E+11
BCa 99% CI	[2.554E+11, 8.203E+11]	[2.060E+11, 5.860E+11]	[1.733E+11, 4.624E+11]	[1.542E+11, 3.824E+11]	[1.519E+11, 3.638E+11]	[1.417E+11, 4.873E+11]	[1.368E+11, 8.392E+11]

Table 4.75: ASEAN Aquaculture Power Model with Residual Analysis Summary using 2000 bootstrap sample and Confidence Interval Level of 99%.

Dependant Variable	Aquaculture Production (*t*)
Predictor	Annual global average atmospheric carbon dioxide levels (*ppm*)
Modelled Period	1991–2021 (N=31)
Forecasted Period	2021–2024 (N=3)
Model	Power
Adjusted R^2	0.958
SSE	0.192
p-Value	<0.001
Residual Sum of Squares (RSS)	5.15054E+14
Residual Skewness	1.958
Residual Range	20466418.66
Residual Median	-24426.8836
(BCa 99% CI)	[-639034.302, 415999.0932]
Residual Standard Deviation	4140838.006
(BCa 99% CI)	[2013225.044, 5743523.057]
Residual Variance	1.715E+13
(BCa 99% CI)	[3.887E+12, 3.383E+13]

Table 4.76: ASEAN Aquaculture Power Model Moving Window Validation with Residual Analysis Summary using 2000 bootstrap sample and Confidence Interval Level of 99%.

Modelled Period	1991–2015	1992–2016	1993–2017	1994–2018	1995–2019	1996–2020	1997–2021
Model	Power	Power	Power	Power	Power	Power	Power
Adjusted R^2	0.984	0.982	0.978	0.973	0.964	0.948	0.927
SSE	0.105	0.112	0.123	0.136	0.157	0.185	0.214
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Residual Skewness	-1.114	-1.029	-1.024	-0.769	0.316	1.328	1.755
Residual Range	6403571.503	6403571.503	6403571.503	8279871.201	12123798.61	16268618.59	20466418.66
Residual Median	-137749.185	-171541.431	-171541.431	-171541.431	-137749.185	-24426.8836	-24426.8836
BCa 99% CI	[-1281687.28, 156925.0692]	[-1752589.29, 22432.56483]	[-1752589.29, 303422.2077]	[-1752589.29, 303422.2077]	[-1752589.29, 415999.0932]	[-1752589.29, 532611.116]	[-1752589.29, 533214.3255]
Residual Standard Deviation	2034266.203	2019163.227	2028435.03	2158139.89	2631841.533	3487424.824	4628295.186

BCa 99% CI	[1239458.959, 2496077.269]	[1336997.555, 2427228.846]	[1362653.054, 2430538.448]	[1497784.979, 2606093.204]	[1740828.81, 3494545.528]	[1915150.648, 4898011.372]	[2122454.021, 6581457.104]
Residual Variance	4.138E+12	4.077E+12	4.115E+12	4.658E+12	6.927E+12	1.216E+13	2.142E+13
BCa 99% CI	[1.507E+12, 6.266E+12]	[1.701E+12, 5.976E+12]	[1.775E+12, 5.973E+12]	[2.203E+12, 6.894E+12]	[2.981E+12, 1.239E+13]	[3.538E+12, 2.525E+13]	[4.157E+12, 4.519E+13]

4.8 Forecasted Results

Due to the limitations of available open-source data, the most recent ASEAN capture fishery and aquaculture production data extends only up to 2021. For an accurate forecasting, only 5% to 10% relative to the analysed sample size is considered for output prediction. Hence, the models will predict the atmospheric carbon dioxide levels and ASEAN production yield for year 2022 to 2024.

Table 4.77: Forecasted Annual Global Average Atmospheric Carbon Dioxide Levels using Power Model (2022 – 2024).

Model	Year	Predicted Annual Global Average Atmospheric Carbon Dioxide Levels (*ppm*)
Power	2022	417.89
Power	2023	420.12
Power	2024	422.36

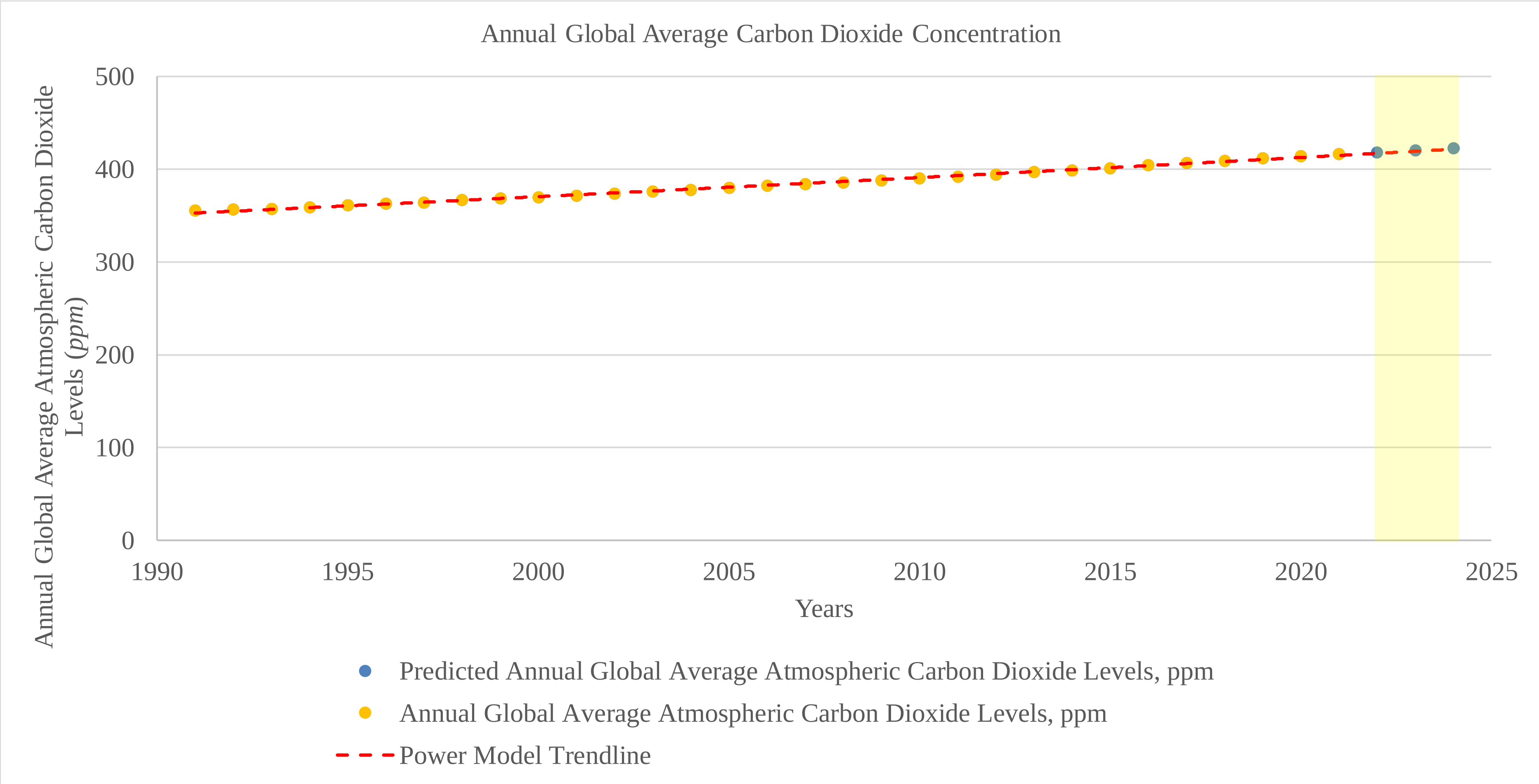

Figure 4.59: Annual Global Average Carbon Dioxide Concentration projected to 2024.

Table 4.78: Forecasted ASEAN Capture Fishery Production using Exponential Model (2022 – 2024).

Model	Year	Predicted ASEAN Capture Fishery Production (*t*)
Exponential	2022	18,572,715.84
	2023	18,948,954.33
	2024	19,334,688.93
Logarithmic	2022	19,259,940.62
	2023	19,529,292.46
	2024	19,798,511.18
Linear	2022	18,048,899.66
	2023	18,074,508.09
	2024	18,082,735.22

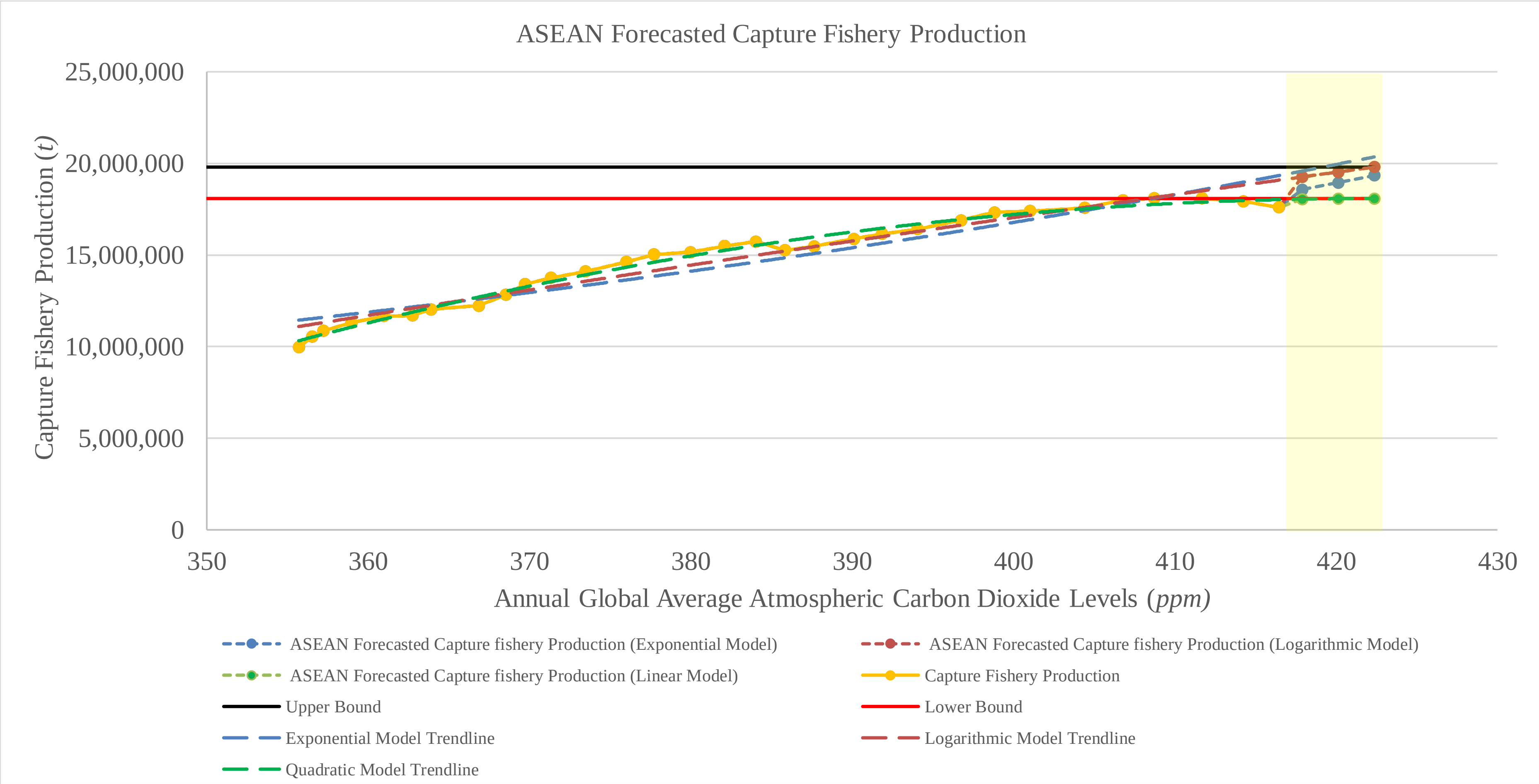

Figure 4.60: ASEAN Forecasted Capture Fishery Production projected to 2024.

Table 4.79: Forecasted ASEAN Aquaculture Production using Power Model (2022 – 2024).

Model	Year	Predicted ASEAN Aquaculture Production (*t*)
Power	2022	41,872,257.16
	2023	46,240,216.95
	2024	51,061,322.27
Growth	2022	36,538,702.00
	2023	40,663,576.06
	2024	45,277,514.91
Linear	2022	28,105,914.63
	2023	29,152,553.80
	2024	30,204,252.63

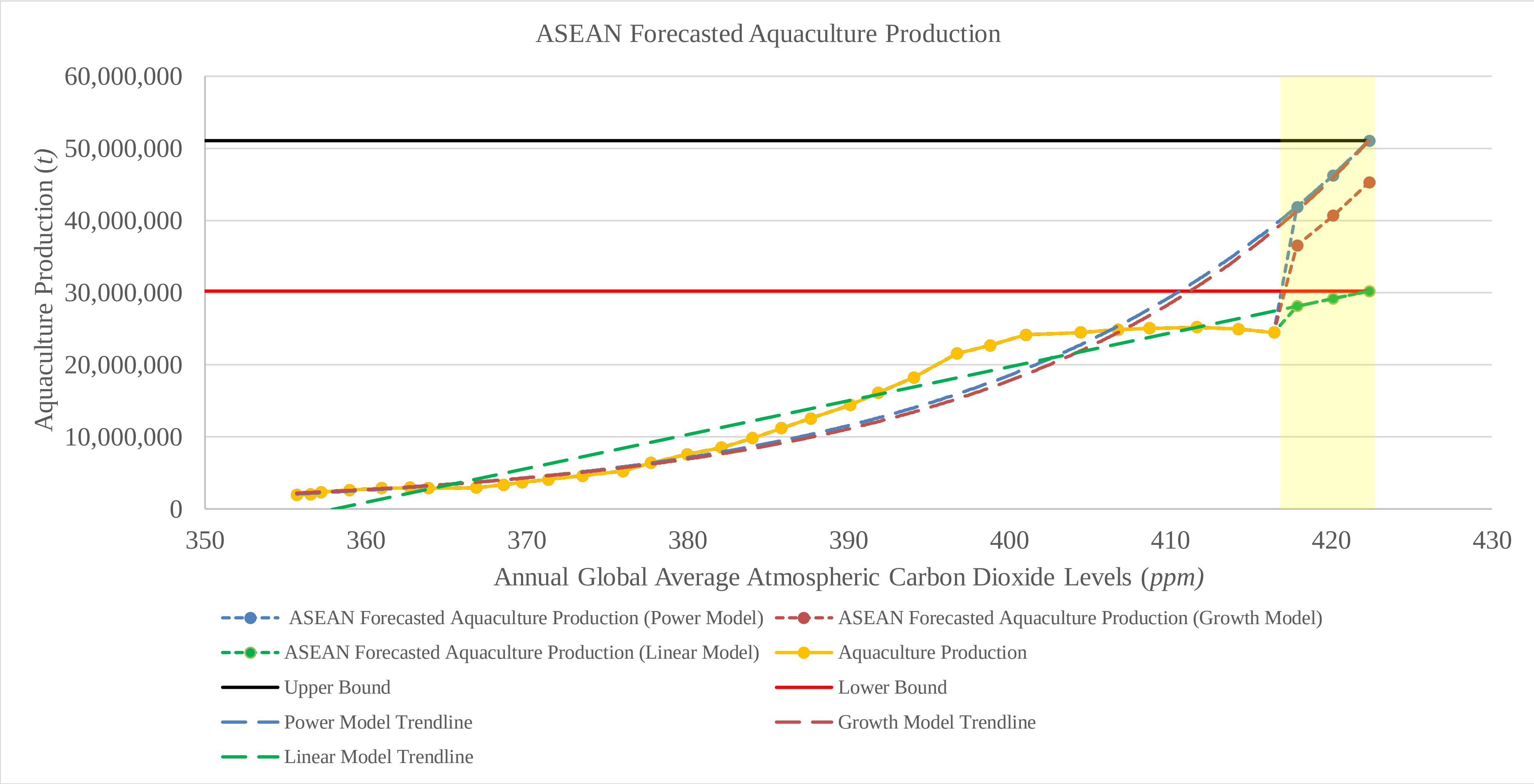

Figure 4.61: ASEAN Forecasted Aquaculture Production projected to 2024.

4.9 Predictive Ability of Models

4.9.1 Annual Average Global Atmospheric Carbon Dioxide Concentration Model

The atmospheric carbon dioxide levels display a strong correlation with years, all of its models are statistically significant at $\alpha = 0.01$ confidence interval and has an adjusted R^2 value of above 0.99 as well as a SEE value lesser than 0.0003*ppm*. The atmospheric carbon dioxide levels power model is deemed to be the first ranked model due to it having a NSE and KGE value of 0.994 and 0 respectively (as shown in Table 4.48) while also having the lowest bias value of 1.038 ppm compared to other models. Its high adjusted R^2 value and low SEE value indicates the model is highly accurate. Furthermore, the power model's NSE and KGE value are within a well performance range and has a low bias value, but it may have a tendency to overpredict by a small margin. Although the other two have a higher adjusted R^2 and lower SEE values, the discrepancy of the values between the models is only by 0.000211 and 0.00009 respectively (as shown in Table 4.3), which in this case the priority goes to which models has the lowest bias value. In the time series forecasting validation test, seven different models were employed within a moving window time frame of 25 years. The proposed power model consistently demonstrate stability, as evidenced by the adjusted R^2 values remaining constant at 0.998 (as shown in Table 4.72). Additionally, the residuals of power model exhibit a mean with 99% confidence intervals that ranges within positive values, indicating a tendency to overpredict.

4.9.2 ASEAN Capture Fishery and Aquaculture Production Model

The ASEAN capture fishery and aquaculture production also shows a strong correlation with annual average global atmospheric carbon dioxide concentration. Both of its first ranking model in Table 4.45 and 4.47 has an adjusted R^2 value of above 0.9. Moreover, the Standard Error of Estimate for ASEAN exponential capture fishery model is 0.055 tonnes while ASEAN power aquaculture model is 0.192 tonnes. Most importantly, each model has a *p*-Value less than 0.001 which means the models are statistically significant at confidence interval of 99%. In terms of model validation, the NSE and KGE values for ASEAN capture fishery production exponential model are 0.736 and 0.889, respectively. These values suggest that the model performs well overall. However, there is a bias of -1,028,545.841 tonnes, indicating the model has a tendency to underpredict. As for ASEAN aquaculture production power model, its NSE and KGE values are 0.793 and 0.818 which shows the model has a good performance as well. Nevertheless, the power model has a bias of 145,629.856 tonnes, indicating a tendency to overpredict. Ideally, the first ranked model is statistically significant at $\alpha = 0.05$ confidence interval with the highest adjusted R^2, lowest SEE, lowest bias value and a NSE or KGE value closes to 1. Even though other models seem to have a higher NSE and KGE values as well as lower bias value, the SEE is prioritized rather than the bias value. The reason being the lower the SEE value of a model has, the higher the model's accuracy of prediction will be.

In the time series forecasting validation test for ASEAN capture fishery production exponential model, seven different models were employed within a moving window time frame of 25 years. The suggested exponential model consistently showcases stability as shown in Table 4.74 with its adjusted R^2 values ranging from 0.941 to 0.902. Furthermore, the residuals of exponential model reveal a median within a 99% confidence interval that spans within negative values, suggesting a tendency to underpredict. Similarly, the time series forecasting validation test for ASEAN aquaculture production power model also employed seven different models within 25 years moving window time frame. The proposed power model consistently demonstrates stability, as evidenced by the adjusted R^2 values ranging from 0.984 to 0.927 (as shown in

Table 4.76). Additionally, the residuals of power model exhibit a median with 99% confidence that spans across zero, affirming the forecasting capability and stability of the proposed model.

4.10 Forecasting ASEAN Capture fishery and Aquaculture Production

There are many uncertainties and factors that can affect the ASEAN Capture fishery and Aquaculture production yield. Extended forecast horizons introduce greater uncertainty, leading to reduced prediction accuracy as you project further into the future (FasterCapital, 2023). To increase the accuracy of prediction, the forecasting period is determined using 5-10% of the analysed data period, thus the forecasted period is three years from the analysed data period. Due to the limitations of available open-source data, the most recent ASEAN capture fishery and aquaculture production data only extends up to 2021. Hence, the model will predict the production yield from the year 2022 to 2024 (highlighted area). The overall forecasting result of ASEAN capture fishery production shows an increase as the carbon dioxide concentration increases with years. Each ASEAN capture fishery production model predicts a slow and steady upward trend of production yield (Figure 4.60). Comparing all three model, the upper bound predicted production yield is from logarithmic model with 19,798,511.18 tonnes, while the lower bound predicted production yield is from linear model with 18,082,735.22 tonnes.

As for the forecasting result of ASEAN aquaculture production, it shows an increase as the carbon dioxide concentration increases with years too. Each ASEAN aquaculture production model predicts the production yield to rise significantly (Figure 4.61). In comparison to each ASEAN aquaculture production model, the upper bound predicted production yield is from power model with 51,061,322.27 tonnes, while the lower bound predicted production yield is from linear model with 30,204,252.63 tonnes. Even though power model is rank first among the aquaculture model, its output prediction doesn't seem realistic when compared to the past year's production yield data. This may cause by the nature and biasness of a power model.

4.11 Application using Prediction Model

4.11.1 ASEAN Capture Fishery and Aquaculture Production for ASEAN Population from 2012 to 2024

The ASEAN Capture Fishery and Aquaculture Production is predicted using the linear model. This model provides the lower bound prediction of production yield, representing the minimum expected production yield in the future through predictive modelling. Subsequently, leveraging data from Appendix A, the ASEAN Capture Fishery and Aquaculture Consumption Availability per Capita can be calculated. The shaded area in Figure 4.62 shows the predicted results from 2022 to 2024.

Table 4.80: ASEAN Capture Fishery and Aquaculture Production Yield per Capita.

Year	ASEAN Capture Fishery Production (*t*)	ASEAN Aquaculture Production (*t*)	ASEAN Capture Fishery Consumption Availability per Capita (kg/capita)	ASEAN Aquaculture Consumption Availability per Capita (kg/capita)
2012	16,414,489.94	18,222,853.03	27.14	30.13
2013	16,892,687.19	21,555,514.69	27.58	35.19
2014	17,327,732.37	22,668,349.38	27.92	36.53
2015	17,398,872.22	24,149,382.38	27.70	38.45
2016	17,575,312.67	24,460,074.71	27.67	38.50
2017	17,993,310.78	24,883,921.13	28.01	38.74
2018	18,091,614.12	25,063,683.56	27.90	38.65
2019	18,087,715.36	25,179,457.65	27.72	38.59
2020	17,938,535.16	24,945,714.67	27.23	37.86
2021	17,598,941.37	24,457,797.72	26.51	36.84
2022	18,048,899.66*	28,105,914.63*	26.87*	41.84*
2023	18,074,508.09*	29,152,553.80*	26.66*	43.00*
2024	18,082,735.22*	30,204,252.63*	26.45*	44.17*

* Predicted results.

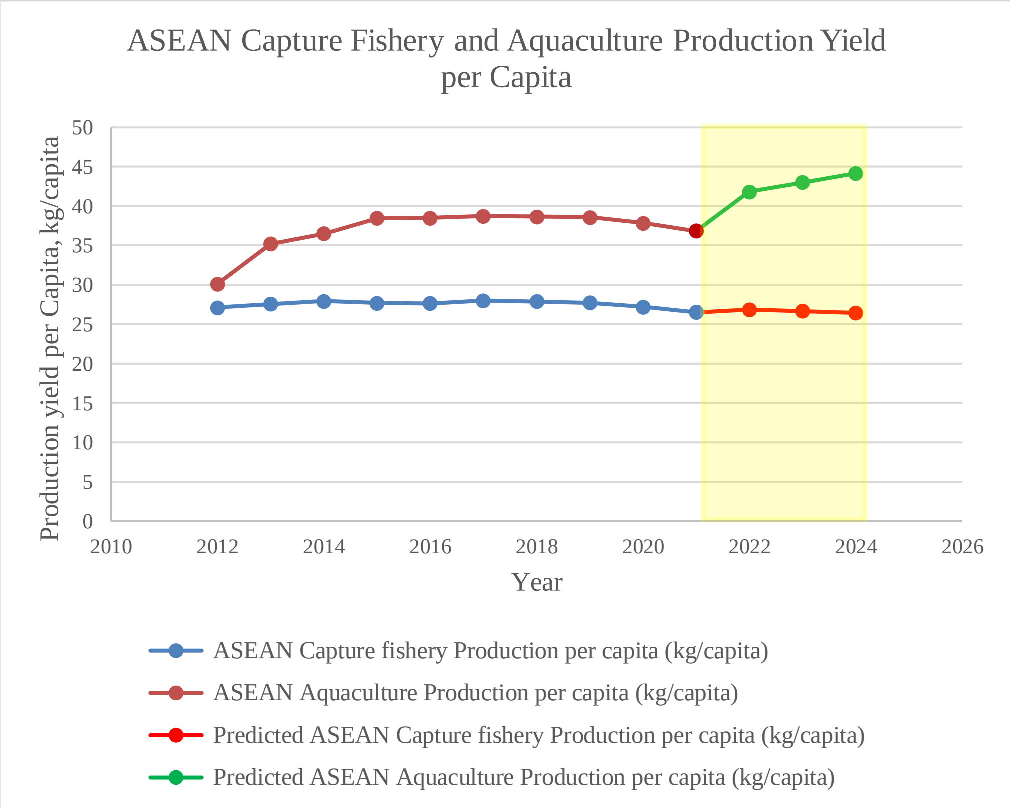

Figure 4.62: ASEAN Capture Fishery and Aquaculture Production Yield per Capita.

4.11.2 ASEAN Environmental, Social, and Governance

Environmental, Social, and Governance (ESG) standards are crucial for evaluating the ethical and sustainability implications of investments across industries, such as fisheries in ASEAN. Considering ESG factors is essential for ensuring the enduring sustainability and prosperity of fisheries enterprises. There are a few instances of how this study can be apply in the ESG principles for fisheries sector.

Since the predicted results in Table 4.80 show the ASEAN Capture Fishery Consumption Availability per Capita are in scarcity, this suggests that fisheries firms should emphasize on environmental responsibility by integrating sustainable fishing methods. This involves observing catch quotas, preventing overfishing, and embracing fishing approaches that minimize incidental catch and safeguard fragile habitats. Introducing strategies to address climate change effects, like curbing greenhouse gas emissions from fishing vessels can enhance the sector's environmental sustainability as well (Malaysian Green Technology And Climate Change Corporation, 2023).

Moreover, ESG standards extend to social responsibility in the fisheries industry. With the aquaculture production showing a prosperous result in Figure 4.62 for the foreseeable future, fisherman and local communities may consider venturing into this sector. Consequently, this could drive government to be involved in the aquaculture industry as more people brings attention to it. The authorities will then ensure equitable labour practices, the rights of fishing communities, and even foster the community’s welfare. This objective can be accomplished by offering comprehensive safety training for fishermen, advocating for gender equality and inclusivity, and setting up systems for transparent and equitable compensation. Active involvement with local communities and backing initiatives that bolster their social and economic progress further underscores social responsibility (Malaysian Green Technology And Climate Change Corporation, 2023).

Good governance practices are fundamental for the sustainable administration of fisheries. As shown in Figure 4.13, the trend of ASEAN capture fishery and aquaculture production has been declining in recent years. This is an indication where proper governance is needed in the capture fishery and aquaculture farming industry. Without a good governance, the fishery production will eventually succumb to the rise of population which causes the fishery sector to be unsustainable. To counter this issue, relevant parties should encompass transparent decision-making mechanisms, robust regulatory structures and cooperation among stakeholders. Fisheries enterprises can elevate their governance standards by integrating traceability systems to verify the legality and source of their seafood items. Furthermore, embracing top-notch methods in data gathering and exchange can enhance the precision of stock evaluations and facilitate well-informed decision-making (Malaysian Green Technology And Climate Change Corporation, 2023).

4.11.3 ASEAN Sustainable Development Goals

ASEAN actively coordinates its endeavours with the United Nations Sustainable Development Goals (SDGs) to nurture a sustainable future for the region. This research emphasizes on various SDGs such as No Poverty, Zero Hunger, Responsible Consumption and Production, Climate Action and Life Below Water. Realistically, capture fishery and aquaculture production are not only use for domestic human consumption but also exports of goods and cosmetics as well. For analysis purposes, the research assumes the productions are used for domestic human consumption. According to dataset from Appendix A, the population of ASEAN is rising steadily by each year, while the ASEAN capture fishery and aquaculture production has been on a down trend in the recent year. The supply and demand of these production will ultimately reach a critical point of scarcity if left unsolved. To balance this issue, ASEAN should focus on increasing the production yield for the population.

Goal 1: No Poverty

The 2022 ASEAN SDG Snapshot Report (2022) reveals that the ASEAN region experienced heightened vulnerability to climate-induced calamities in 2020 compared to 2016. This is evident from the rising average population affected by such disasters. A critical dimension of poverty is vulnerability, it becomes particularly pronounced in regions that frequently encounter these calamities. Notably, this vulnerability affects not only the poor but also non-poor individuals, who can easily slip into poverty when disaster strikes. The rise of sea levels is an example of a widespread and critical climate concern, which lead to heightened storm surges, flooding, and detrimental impacts on coastal regions (National Geographic Society, 2023). According to the 2021 ASEAN State of Climate Change Report, approximately 77% of the ASEAN region's population resides in coastal areas. These regions are home to major cities and critical ports that contribute significantly to the region's prosperity (ASEAN Secretariat, 2021). However, the IPCC issued a report in 2022 stating that Southeast Asia faces grave threats from the rising of sea levels. Due to unavoidable flooding caused by sea level rise, the region is at high risk of losing vital infrastructure and low-lying coastal settlements (Bhandari, 2023). This will lead the majority to be vulnerable to poverty, especially for coastal fishery habitant and workers. According to Subasinghe (2003), aquaculture stands out as one of the swiftest expanding sectors in global food production, renowned for its substantial role in reducing poverty, enhancing food security, and income generation. It also serves as a crucial source of employment, cash flow, and foreign exchange, particularly with developing nations contributing more than 90% of the world's total output. With strategic integration in the aquaculture sector, it offers relatively low-risk opportunities for rural development and demonstrates versatile applications in both inland and coastal regions. The predicted results of this studies further support the potential of aquaculture in ASEAN, and it may have a beneficial chain effect if careful planning and investment is poured into the aquaculture sector.

Goal 2: Zero Hunger

The objective of Goal 2 in SDG is to end hunger, attain food security, and promote agricultural sustainability. In reference to the 2022 ASEAN SDG Snapshot Report, an average of 25.4% of children under the age of 5 experienced stunted growth in 2020. While almost half of ASEAN countries such as Malaysia, Thailand, and Indonesia, encountered a worsening malnutrition issue, others like Myanmar, Vietnam, Cambodia and Philippines demonstrated certain advancements in 2020 when compared to their status in 2016. Due to this reason, the change in the regional average is not as drastic. However, concerted efforts are necessary to significantly enhance the children’s nutritional status in the region (The 2022 ASEAN SDG Snapshot Report, 2022). A sustainable solution to solve children hunger issue could be the practice of aquaculture. Table 4.80 shows the predicted ASEAN capture fishery consumption availability per capita decreases as population rises while aquaculture consumption availability per capita is able to resist demand from the rise of population. Moreover, aquaculture provides variety of option such as marine fish, inland fish, shellfish, seaweed, etc. Fish being a low-fat high quality protein sources contains abundance of omega-3 fatty acids and various vitamins. Additionally, fish provides important minerals, including calcium, phosphorus, potassium, iodine and many more. The American Heart Association recommends including fish in a balanced diet at least twice weekly to maintain a good health (Washington State Department of Health, 2023).

Goal 12: Responsible Consumption and Production

To achieve a Responsible Consumption and Production, a sustainable source of production is needed. As shown in Table 4.80, the predicted ASEAN Capture fishery Production available to a person for consumption within the region in 2024 is 26.45 kg/capita while the predicted ASEAN Aquaculture Production consumption per capita is 44.17 kg/capita. Compared to the production yield in 2021, ASEAN Capture fishery consumption per capita dropped 0.06 kg/capita or 0.23% whereas the Aquaculture consumption per capita increased 7.33 kg/capita or 19.9%. Target 12.2 of Goal 12: Responsible Consumption and Production are to work towards on achieving a sustainable stewardship and efficient utilization of natural resources by 2030 (THE GLOBAL GOALS, 2024). Fisheries being one of the natural resources widely for human consumption are showing symptoms of scarcity as the years go by, both capture fishery and aquaculture sector should start brainstorming to maintain a sustainable production of fisheries.

Goal 13: Climate Action

The capture fishery sector predominantly operates at sea, but the carbon emission contributed by the fishing vessel must be addressed. Fishing vessels are primarily powered by fossil fuels like marine diesel, contribute approximately 0.1% to 0.5% of global carbon emissions which amounts to 159 million tons annually. Notably, these emissions constitute around 4% of the total carbon emissions arising from global food production (UNCTAD, 2024). Moreover, by shifting towards eco-friendly diets sourced from the sea, such as seafood and seaweeds, has the potential to account for 2% of the necessary emission cuts to adhere to the 1.5°C target by 2050. When comparing the environmental impact, farmed salmon contributes significantly less carbon than the beef industry and the pressure on environment related to feeding and growing stock is also significantly lower in seafood production than in other sectors (ASC International, 2024). If aquaculture were to meet the world's additional protein requirements in 2050 instead of agriculture, it could save a staggering 729 to 747 million land hectares according to study done by Froehlich et al. (2018). In comparison to the forecasted results in Figure 4.60 and Figure 4.61, the ASEAN aquaculture production with the rise global carbon dioxide concentrations indicates that it has more resilience against climate issue compared to the capture fishery production.

Goal 14: Life Below Water

Aside from climate events having a negative impact on fisheries and ocean's ecosystem, humans are also responsible for drying up the ocean resources since the industrial revolution. The decline in aquatic life is primarily attributed to overfishing, ocean acidification, and pollution caused by human activities. Target 14.3 of Goal 14: Life Below Water seeks to mitigate and counteract the effects of ocean acidification by fostering scientific collaboration across various levels (THE GLOBAL GOALS, 2024). Due to the prevalent use of diesel or other types of bunker fuel or heavy fuel oil in most fishing vessels, they contain more contaminants than regular fuel, thus contributing to more pollution (UNCTAD, 2024). A recent controversial news about pollution affecting the fishing industry is the treated radioactive water releasing into the Pacific Ocean from Fukushima Daiichi nuclear power plant in August 2023. Due to this incident, the import of Japanese seafood products has been suspended by China for an indefinite period (AFM Editorial Office, 2023). It has been a debate between two sides: Japan reassures the safety of treated wastewater, which contains the radioactive isotope tritium and potentially other radioactive traces. Meanwhile, neighbouring countries and experts argues the release of the treated water is an environmental risk with potential consequences spanning generations and may even impact the ecosystems as far as North America (Blume, 2023). The Kewalo Marine Laboratory's director at University of Hawaii, Robert Richmond, states that "Anything released into the ocean off of Fukushima is not going to stay in one place" (Blume, 2023). Not only that, but Richmond also emphasized on the phytoplankton which are the foundation of food chain for the marine ecosystem is able to capture a harmful radioactive isotope called radionuclides from the Fukushima cooling water and spread it across the Pacific Ocean. When consumed, these isotopes have the potential to build up in various invertebrates, fish, marine mammals, and even humans (Blume, 2023). Hence, aquaculture practice is shown to be a sustainable alternative for consumption and a promising method to protect endangered marine life.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The purpose of this study is to predict the ASEAN capture fishery and aquaculture production using atmospheric carbon dioxide concentration. Using data sources from NOAA and the World Bank, a statistical analysis is performed to create a model for ASEAN and its countries. From IBM SPSS Statistics v26.0, the analysis reveals a strong correlation between atmospheric carbon dioxide concentration with ASEAN capture fishery and aquaculture production. Statistically, the best model to forecast the annual average global atmospheric carbon dioxide concentration using year as its independent variable is the power model, while for ASEAN capture fishery and aquaculture production using atmospheric carbon dioxide levels as its independent variable would be exponential model and power model respectively. However, it is still important to compare the output results with the second and third ranked model as the results may differ due to its nature and biasness. Moreover, the trend analysis and forecasted production results have shown that aquaculture is a more sustainable option than capture fishery. With the ever-growing number of populations, the production yield needed to sustain the people will need to grow significantly as well. In fact, the supply of aquaculture far outweighs that of capture fishery causing the capture fishery to become less affordable as its demand rises. This study gives government or any relevant parties more insight about statistical modelling and its application of models for ESG and SDGs studies as well as predicting the future fishery economy.

5.2 Recommendations

In terms of production that is easier to control by humans, aquaculture sector is a much more promising option than the capture fishery sector. The benefits of advancing the aquaculture sector far outweighs that of capture fishery sector. Although statistics shows there is an increase of capture fishery production with the rise of atmospheric carbon dioxide concentration, the capture fishery production is still negatively impacted by climate issue such as rise of sea temperatures and ocean acidification. To make matters worse, climate event such as El Niño tends to increase the rate of carbon dioxide entering the atmosphere as well as trigger extreme weather events globally, ultimately disrupting the activities of fishing vessels (NOAA RESEARCH, 2019). The pollution inflicted upon the ocean by human activities remains a challenging and costly issue to tackle too.

Likewise, the statistical model also shows a rise of aquaculture production with the increase of atmospheric carbon dioxide concentration. While aquaculture faces its own environmental and management challenges, it remains a more sustainable alternative compared to capture fisheries. Since aquaculture involves cultivating aquatic life in a controlled environment, its facilities allow for precise control over water quality, feeding, and disease prevention. This approach minimizes environmental impact and promotes healthier fish. Additionally, aquaculture also generate more employment opportunities which boost the country's gross domestic product and contributes to local economies. It reduces the necessity for long-distance fishing expeditions, resulting in fuel cost savings and decreased carbon emissions. Above all, with the global population increasing annually, aquaculture assumes a pivotal role in satisfying the escalating need for protein-rich seafood. It acts as a complementary force alongside conventional capture fisheries, effectively contributing to the solution of food security challenges.

This study considers only the atmospheric carbon dioxide levels as an independent variable to forecast ASEAN capture fishery and aquaculture production. The model can be further improved using other relevant factors as a variable, this includes water temperature, salinity of water, sea levels, etc.

REFERENCES

ADB. 2009. The Economics of Climate Change in Southeast Asia: A Regional Review. Available at: https://www.adb.org/sites/default/files/publication/29657/economics-climate-change-se-asia.pdf [Accessed 15 September 2023]

ADB. 2015. The Economics of Climate Change in Southeast Asia: A Regional Review. Available at: https://www.adb.org/sites/default/files/publication/178615/sea-economics-global-climate-stabilization.pdf [Accessed 15 September 2023]

AFM Editorial Office. 2023. Japan's fishing industry under pressure after Fukushima water release. Available at: https://asiafundmanagers.com/us/japans-fishing-industry-under-pressure-after-fukushima-water-release/ [Accessed 21 February 2024]

ASC International. 2024. Aquaculture & climate change. [online] Available at: https://asc-aqua.org/learn-about-seafood-farming/aquaculture-climate-change/. [Accessed 7 April 2024]

ASEAN CDS. 2017. ASEAN CATCH DOCUMENTATION SCHEME FOR MARINE CAPTURE FISHERIES. Available at: https://asean.org/wp-content/uploads/2012/05/16.-ASEAN-Catch-Documentation-Scheme.pdf [Accessed 3 August 2023]

ASEAN Secretariat. 2021. ASEAN State of Climate Change Report. [online] Available at: https://asean.org/wp-content/uploads/2021/10/ASCCR-e-publication-Correction_8-June.pdf. [Accessed 16 January 2024]

ASEAN Secretariat. 2022. ASEAN STATISTICAL YEARBOOK 2022. Available at: https://www.aseanstats.org/wp-content/uploads/2023/04/ASYB_2022_423.pdf [Accessed 16 January 2024]

ASEAN Secretariat. 2023. ASEAN STATISTICAL YEARBOOK 2023. [online] Available at: https://asean.org/wp-content/uploads/2023/12/ASEAN-Statistical-Yearbook-2023.pdf [Accessed 7 March 2024]

Badjeck, M-C., Allison, E. Halls, A. & Dulvy, N. 2010. Impacts of climate variability and change on fishery-based livelihoods. *Marine Policy*, 34: 375–383. Available at: https://doi.org/10.1016/j.marpol.2009.08.007. [Accessed 11 September 2023]

Barange, M., & Perry, R.I. 2009. Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. *FAO Fisheries Technical Paper,* 530, 07–95. Available at: https://www.researchgate.net/publication/286785678_Physical_and_ecological _impacts_of_climate_change_relevant_to_marine_and_inland_capture_fisheries_and_aquaculture [Accessed 15 September 2023]

Barange, M., Tarûb Bahri, Beveridge, M.C.M., Cochrane, K.L., S Funge Smith, Poulain, F. and Food And Agriculture Organization Of The United Nations 2018. *Impacts of climate change on fisheries and aquaculture : synthesis of current knowledge, adaptation and mitigation options*. Rome: Food And Agriculture Organization Of The United Nations. Available at: https://www.fao.org/3/i9705en/i9705en.pdf [Accessed 15 September 2023]

Bhandari, S.R. 2023. Asian cities at increased exposure to rising sea levels, study says. [online] Available at: https://www.rfa.org/english/news/environment/sea-level-rise-03092023053115.html#:~:text=Massive%20risk%20for%20Southeast%20Asia&text=Last%20year%2C%20the%20Intergovernmental%20Panel,by%20unavoidable%20sea%20level%20rise. [Accessed 3 April 2024]

Blume, M. M. L. 2023. Japan releases nuclear wastewater into the Pacific. How worried should we be? Available at: https://www.nationalgeographic.com/premium/article/fukushima-japan-nuclear-wastewater-pacific-ocean#:~:text=Japan%20has%20started%20releasing%20wastewater,earthquake%20over%20a%20decade%20ago. [Accessed 21 February 2024]

Brander, K. 2010. Impacts of climate change on fisheries. *Journal of Marine Systems*, 79: 389–402. Available at: https://doi.org/10.1016/j.jmarsys.2008.12.015. [Accessed 11 September 2023]

CFR.org Editors. 2021. What Is ASEAN? Available at: https://www.cfr.org/backgrounder/what-asean#:~:text=It%20is%20an%20intergovernmental%20organization,promoting%20economic%20integration%20among%20members. [Accessed 11 August 2023]

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., Zeller, D. & Pauly, D. 2009. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*. doi: 10.1111/j.1365-2486.2009.01995.x [Accessed 14 September 2023]

Conrad, M. 2023. How Does El Niño Affect Fisheries?. Available at: https://oceanconservancy.org/blog/2023/06/13/how-el-nino-affect-fisheries/ [Accessed 3 August 2023]

Daw, T., Adger, W.N., Brown, K. & Badjeck, M.-C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto & T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. *FAO Fisheries and Aquaculture Technical Paper.* No. 530. Rome, FAO. pp. 107–

150. Available at: https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/1339/WF_2545.pdf?sequence=1 [Accessed 11 September 2023]

Department of Fisheries Malaysia. 2022. FISHERIES INDUSTRY SCENARIO. Available at: https://www.dof.gov.my/en/corporate-info/introduction/fisheries-industry-scenario/ [Accessed 3 August 2023]

De Silva, S.S. & Soto, D. 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. *FAO Fisheries Technical Paper*, 537, 137–215. Available at: https://www.researchgate.net/publication/255578835_Climate_change_and_aquaclture_Potential_impacts_adaptation_and_mitigation [Accessed 14 September 2023]

FAO. 2014, 'Climate Change Adaptation in Fisheries and Aquaculture: Compilation of Initial Examples', *FAO Fisheries and Aquaculture Circular*, No. 1088, Rome: United Nations Food and Agriculture Organization. Available at: https://www.uncclearn.org/wp-content/uploads/library/fao195.pdf [Accessed 11 September 2023]

FAO. 2020. The State of World Fisheries and Aquaculture 2020. *Sustainability in action*. Rome. Available at: https://doi.org/10.4060/ca9229en [Accessed 15 September 2023]

FAO. 2022. THE STATE OF WORLD FISHERIES AND AQUACULTURE 2022. Available at: https://www.fao.org/3/cc0461en/online/sofia/2022/capture-fisheries-production.html#:~:text=In%202020%2C%20global%20capture%20fisheries,of%20the%20previous%20three%20years. [Accessed 3 August 2023]

FasterCapital. 2023. Forecast horizon: Evaluating the Influence of Forecast Horizon on Accuracy Measurements. [online] Available at: https://fastercapital.com/content/Forecast-horizon--Evaluating-the-Influence-of-Forecast-Horizon-on-Accuracy-Measurements.html#:~:text=Short%2Dterm%20forecasts%20tend%20to [Accessed 7 March 2024]

Froehlich, H. E., Runge, C. A., Gentry, R. R., Gaines, S. D., & Halpern, B. S. 2018. Comparative terrestrial feed and land use of an aquaculture-dominant world. Proceedings of the National Academy of Sciences, 115(20), 5295–5300. Available at: https://doi.org/10.1073/pnas.1801692115 [Accessed 4 April 2024]

Ganti, A. 2023. What Is the Central Limit Theorem (CLT)? [online] Investopedia. Available at: https://www.investopedia.com/terms/c/central_limit_theorem.asp#:~:text=A%20sample%20size%20of%2030. [Accessed 17 September 2023]

Gebrekiros, S.T. 2016. Factors Affecting Stream Fish Community Composition and Habitat Suitability. *J Aquac Mar Biol* 4(2): 00076. Available at: https://medcraveonline.com/JAMB/factors-affecting-stream-fish-community-composition-and-habitat-suitability.html#:~:text=A%20fish's%20habitat%20includes%20all,other%20substances)%20in%20their%20environment. [Accessed 3 August 2023]

IBM. 2023. Adjusted R squared. Available at: https://www.ibm.com/docs/fi/cognos-analytics/11.1.0?topic=terms-adjusted-r-squared [Accessed 11 August 2023]

International Monetary Fund. 2024. Population. [online] Available at: https://www.imf.org/external/datamapper/LP@WEO/VNM/IDN/PHL/MMR/MYS/KHM/LAO/THA/SGP/BRN [Accessed 7 March 2024]

Ishimatsu, A., Hayashi, M., Lee, K., Kikkawa, T., Kita, J. 2005. Physiological effects on fishes in a high-CO2 world. *Journal of Geophysical Research*, 110(C9). doi:https://doi.org/10.1029/2004jc002564. [Accessed 15 September 2023]

Komatsu, M. 2013. Special Study on Sustainable Fisheries Management and International Trade in the Southeast Asia and Pacific Region. ADBI Working Paper 438. Tokyo: Asian Development Bank Institute. Available at: http://www.adbi.org/workingpaper/2013/10/16/5913.sustainable.fisheries.mngt.international.trade/ [Accessed 15 September 2023]

Lau, H. C., Zhang, K., Bokka H. K. & Ramakrishna, S. 2022. A Review of the Status of Fossil and Renewable Energies in Southeast Asia and Its Implications on the Decarbonization of ASEAN. *Energies*. 15. 2152. 10.3390/en15062152. Available at: https://www.researchgate.net/figure/Map-of-ASEAN-countries_fig1_359291255 [Accessed 11 August 2023]

Lebata-Ramos, Ma. J. H. 2017. Issues and challenges in sustainable development of fisheries of the Southeast Asian Region: Aquaculture development: Addressing concerns due to intensification of aquaculture and climate change. In The Southeast Asian State of Fisheries and Aquaculture 2017 (pp. 126-131). Bangkok, Thailand: Secretariat, Southeast Asian Fisheries Development Center. Available at: http://hdl.handle.net/20.500.12066/6204 [Accessed 15 September 2023]

Malaysian Green Technology And Climate Change Corporation. 2023. GREEN PRACTICES GUIDELINE FOR FISHERIES SECTOR (AQUACULTURE). Available at: https://www.mgtc.gov.my/wp-content/uploads/2023/08/4-MGTC-GG_2023_Fisheries_Single_040823_Rv1.pdf [Accessed 12 Apr. 2024].

Munday, P.L., McCormick, M.I. & Nilsson, G.E. 2012. Impact of global warming and rising CO2 levels on coral reef fishes: what hope for the future? *Journal of Experimental Biology*, 215(22), pp.3865–3873. doi:https://doi.org/10.1242/jeb.074765. [Accessed 15 September 2023]

National Geographic Society. 2023. Sea Level Rise | National Geographic Society. [online] education.nationalgeographic.org. Available at: https://education.nationalgeographic.org/resource/sea-level-rise/. [Accessed 3 April 2024]

NOAA. 2020. Ocean acidification. Available at: https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification [Accessed 4 August 2023]

NOAA. 2023. What is aquaculture? Available at: https://oceanservice.noaa.gov/facts/aquaculture.html [Accessed 13 August 2023]

NOAA. 2023. Annual Average Carbon Dioxide. Available at: https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_annmean_mlo.txt [Accessed 31 October 2023]

NOAA RESEARCH. 2019. Surprisingly large carbon uptake by North American biosphere during El Niños. Available at: https://research.noaa.gov/2019/06/05/surprisingly-large-carbon-uptake-by-north-american-biosphere-during-el-ninos/#:~:text=Scientists%20have%20long%20known%20that,2%20emitted%20by%20tropical%20ecosystems. [Accessed 18 February 2024]

Ratner, B. 2009. The correlation coefficient: Its values range between +1/−1, or do they?. *Journal of Targeting, Measurement, and Analysis for Marketing*. 17, 139–142. Available at: https://doi.org/10.1057/jt.2009.5 [Accessed 11 August 2023]

Sriskanthan, G. & Funge-Smith, S. J. (2011). The potential impact of climate change on fisheries and aquaculture in the Asian region. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2011/16, 41 pp. Available at: https://www.fao.org/3/ba0083e/ba0083e.pdf [Accessed 11 September 2023]

Subasinghe, R.P. 2023. An Outlook for Aquaculture Development: Major Issues, Opportunities and Challenges. [online] Available at: https://www.fao.org/3/y4490E/y4490E02.pdf. [Accessed 4 April 2024]

Tenny S, Abdelgawad I. Statistical Significance. 2022. In: StatPearls [online]. *Treasure Island (FL): StatPearls Publishing*; 2023 Jan-. Available at: https://www.ncbi.nlm.nih.gov/books/NBK459346/ [Accessed 13 August 2023]

The 2022 ASEAN SDG Snapshot Report. 2022. Available at: https://www.aseanstats.org/wp-content/uploads/2022/11/The-2022-ASEAN-SDG-Snapshot-Report-b.pdf. [Accessed 3 April 2024]

THE GLOBAL GOALS. 2024. Goal 12: Responsible Consumption and Production. Available at: https://www.globalgoals.org/goals/12-responsible-consumption-and-production/ [Accessed 18 February 2024]

THE GLOBAL GOALS. 2024. Goal 14: Life Below Water. Available at: https://www.globalgoals.org/goals/14-life-below-water/ [Accessed 18 February 2024]

UNCTAD. 2024. Energy transition of fishing fleets: Opportunities and challenges for developing countries. Available at: https://unctad.org/publication/energy-transition-fishing-fleets-opportunities-and-challenges-developing-countries [Accessed 18 February 2024]

Washington State Department of Health. 2023. Health Benefits of Fish | DOH. [online] doh.wa.gov. Available at: https://doh.wa.gov/community-and-environment/food/fish/health-benefits#:~:text=Fish%20is%20filled%20with%20omega. [Accessed 3 April 2024]

Watts, V. 2022. 13.3 STANDARD ERROR OF THE ESTIMATE. – Introduction to Statistics. Available at: https://ecampusontario.pressbooks.pub/introstats/chapter/13-3-standard-error-of-the-estimate/ [Accessed 11 September 2023]

WORLD BANK. 2023. Capture fisheries production (metric tons). Available at: https://data.worldbank.org/indicator/ER.FSH.CAPT.MT [Accessed 31 October 2023]

WORLD BANK. 2023. Aquaculture production (metric tons). Available at: https://data.worldbank.org/indicator/ER.FSH.AQUA.MT [Accessed 31 October 2023]

Yazdi, S. khoshnevis and Shakouri, B. 2010. The Effects of Climate Change on Aquaculture. International Journal of Environmental Science and Development, pp.378–382. doi:https://doi.org/10.7763/ijesd.2010.v1.73. [Accessed 15 September 2023]

Yusuf, A.A. and Francisco, H. 2009. Climate change vulnerability mapping for Southeast Asia. idl-bnc-idrc.dspacedirect.org. [online] Available at: http://hdl.handle.net/10625/46380 [Accessed 15 September 2023]

APPENDICES

APPENDIX A: ASEAN Population (2012 – 2024).

Source	Year	Population
(ASEAN Secretariat, 2022)	2012	604,775,800
(ASEAN Secretariat, 2022)	2013	612,484,300
(ASEAN Secretariat, 2022)	2014	620,574,000
(ASEAN Secretariat, 2022)	2015	628,061,700
(ASEAN Secretariat, 2022)	2016	635,260,800
(ASEAN Secretariat, 2022)	2017	642,278,600
(ASEAN Secretariat, 2022)	2018	648,454,700
(ASEAN Secretariat, 2022)	2019	652,469,000
(ASEAN Secretariat, 2022)	2020	658,878,800
(ASEAN Secretariat, 2022)	2021	663,850,300
(ASEAN Secretariat, 2023)	2022	671,680,700
(International Monetary Fund, 2024)	2023	678,006,000
(International Monetary Fund, 2024)	2024	683,785,000