Thesis for the Degree of Master of Fisheries Science

A Bioeconomic Assessment of Venezuela's Tuna Fishery in the Eastern Pacific Ocean

By

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동태평양에서의 베네수엘라 참치어업에 대한 생물경제학적 평가

Advisor: Prof. PYO Hee-Dong

by

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A dissertation

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Table of Contents

Chapter 3. Materials and Methods

Chapter 4. Results and Discussion

Chapter 5. Conclusions

List of Figures

List of Tables

List of Acronyms

AIDCP: Agreement on the International Dolphin Conservation Program

CPUE: Catch per unit effort

CYP: Clarke, Yoshimoto and Pooley

DMLs: Dolphin mortality limits

DW: Durbin-Watson

EPO: Eastern Pacific Ocean

IATTC: Inter-American Tropical Tuna Commission

KOICA: Korea International Cooperation Agency

MEY: Maximum economic yield

MSY: Maximum sustainable yield

OAE: Open access equilibrium

OLS: Ordinary least square

RFMOs: Regional Fisheries Management Organizations

TR: Total revenue

TC: Total cost

UNCLOS: The United Nations Convention on the Law of the Sea

WH: Walter and Hilborn

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Abstract

The fishing activity of Venezuela is mainly focused on the production of two marine fisheries such as tuna and sardine, amount to approximately 54% of total national catches, being the first item of artisanal origin and the second object of industrial offshore fishing, both generate an important level of employment and industrial movement within the sector. Venezuela became a full-member of the Inter-American Tropical Tuna Commission (IATTC) in 1992. This, helped the country establish a solid fishing fleet operating in the Eastern Pacific Ocean (EPO). The present study performs an assessment of Venezuela's tuna fishery in the EPO. By the bioeconomic model, the study analyses fishing data (catch and effort) for last 26 years (1993-2018), employing one of the exponential growth model in surplus production model: Clarke, Yoshimoto and Pooley

(CPY). The results of the model show that the fishing effort (associated to boat size) and the catch should be reduced by 34 % and 24 %, respectively, in order to harvest fisheries resources of the EPO and maintain economic profitability. Determining accuracy of the model Theil's U-statistics is estimated to be 0.64, which implies that estimated catches of the model and actual catches represent quite similar. Therefore, it is necessary to implement effective management measures and policies, to evaluate how to reduce the fishing effort and catch.

Keywords: Venezuela's tuna fishery, Maximum sustainable yield (MSY); Maximum economic yield (MEY); Surplus production model; Clarke, Yoshimoto and Pooley (CYP) model.

Chapter 1. Introduction

1. Background

The Bolivarian Republic of Venezuela, being a country with a long fishing tradition, has developed over time, the fishing activity of industry type or fishing exercised by vessels which operate not only in the Exclusive Economic Zone, also on the high seas (FAO, 2005).

The national industrial fishing is related to the capture of highly migratory or straddling species, such as tuna. However, there is also a fleet of vessels called polyvalent, which use more fishing gear and generate a varied species catch. This last fleet is constituted in greater degree by boats that were used in principle in the fishing on drag, activity nowadays prohibited to industrial level by the Law of Fisheries and Aquaculture, and operation inside the Exclusive Economic Zone of the country, with discharge in the provinces of Sucre and Falcon (FAO, 2005).

The national production corresponding to 2017 was 240,890 tons, of which 77% came from artisanal fishing, 15% from industrial fishing and 8% from aquaculture. The fishing activity in Venezuela is mainly focused on the production of two marine fisheries (i.e. tuna and sardine), amount to approximately 54% of total national catches, being the first item artisanal origin and the second object industrial offshore fishing, both generate an important level of employment and industrial movement within the sector. In addition to taking the above into account, the rest of the production is geared towards obtaining a high volume of other species from mainly artisanal maritime fisheries, also observing a growing trend in the cultivation of aquaculture items, such as marine shrimp, native species such as cachama *(Colossoma macropomum)*, as well as certain mollusks such as pepitone *(Arca zebra)*, of which there is a high potential in natural banks (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

The total production of Venezuela's fisheries sector (2017) and statically data by each sector from 2012 to 2017 are shown in Fig.1 and Table 1.

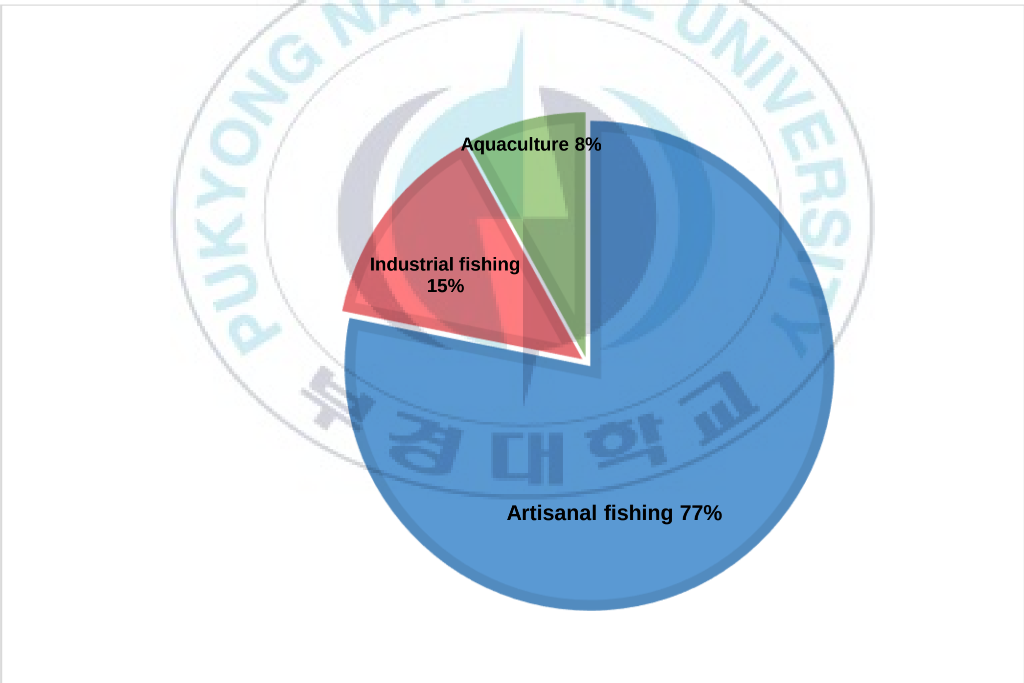

Fig. 1 Total production of Venezuela's fisheries sector 2017.

Table 1. 2012-2017 production by fishery type in Venezuela (tons).

Year	Capture fishery		Aquaculture		Total
	Marine	Inland	Marine	Inland	
2012	192,525	42,700	19,580	6,514	235,225
2013	182,173	29,577	20,558	7,259	239,567
2014	163,766	31,000	22,501	8,250	252,345
2015	186,611	32,000	13,628	5,283	255,645
2016	201,389	22,000	21,469	4,528	249,382
2017	194,570	27,401	13,586	5,333	240,890

Venezuela's tuna industry has two starting points: (1) in the 1960's with the incorporation of canned tuna production lines; and (2) in the 1980's with a tuna purse seine fleet or tuna purse-seiners. Due to the versatility of this species, the high level of acceptance by the domestic market, and the intense commercialization at international level, Venezuela became then a full member of both the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Inter-American Tropical Tuna Commission (IATTC) since 1975 and 1992, respectively (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2016).

Venezuela is a member to the Geneva Conventions of 1958, and in that sense has defined its maritime spaces established in the National Constitution (1999) and the Law of Aquatic Spaces (2014). Venezuela is not part of the United Nations Convention on the Law of the Sea (UNCLOS) of 1982.

Yellowfin tuna is the main fishing resource of the Venezuelan fleet, highly valued for its commercialization characteristics, although the product offering of the fleet also extends to other tuna species, such as skipjack and bigeye among others.

It is necessary to point out that the country not only participates as a member of the IATTC in the Eastern Pacific Ocean (EPO), but also is a member in that area of the Agreement on the International Dolphin Conservation Program (AIDCP), which constitutes the multilateral instrument, that lays the foundations for the protection of the populations of these marine mammals in that fishing area.

2. Aim of research

Venezuela has a territorial extension of 916,445 Km²; 710,600 Km² of maritime and insular territory and 4,262 kilometers of the continental and insular coast (Morales Paúl, 1981; Sánchez, 1989, López, 1999).

Venezuela is one of the most important fishing countries of the Caribbean-Atlantic area. In its great territorial extension, it possesses, fisheries resources that are characterized by their high diversity and potential. In addition to commercial extractive activity, marine and continental aquaculture has been developed as an alternative to reduce pressure on natural banks.

The national fishing sector has a great relevance for the Venezuelan economy. This is mainly due to the great variety and diversity of hydrobiological resources that make it up. This sector as a whole has a participation in the Gross Domestic Product (GDP) of 0.7% and in conjunction with agriculture. It contributes 5.2% to the GDP of the country (2017). It is estimated that approximately 94,921 people work in the sector, both at the primary and industrial level (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

The present study performs an assessment of Venezuela's tuna fishery in the EPO. Using the bioeconomic model, the study analyses fishing data (catch and effort) for last 26 years (1993-2018) by employing one of the exponential growth model in surplus production model: Clarke, Yoshimoto and Pooley (CPY).

Finally, this research constitutes an academic contribution in the fishing field, which represents an important issue that must be considering in the strategic lines of the National Development Plan of Venezuela.

3. Objectives

Based on the previous information, the objectives of this research are the next:

1. To identify the best applicable surplus production model for the fishing activity of tuna based on catch per unit effort (CPUE).
2. To determine the maximum sustainable yield (MSY), maximum economic yield (MEY) and open access equilibrium (OAE) from the fishing activity of tuna, considering the biological parameters intrinsic growth rate (r), catchability coefficient (q) and carrying capacity (k), and economic parameters price (p) and cost (v).
3. To analyze the decisions about guarantee, preservation and sustainability of fishery resources and increase the economic benefits in the research area.

Chapter 2. General Overview

1. The Pacific Ocean

The Pacific Ocean is the body of salt water, extending from the Antarctic region in the south to the Arctic in the north and lying between the continents of Asia and Australia on the west and North and South America on the east (Morgan, Bardash and Cotter, 2018).

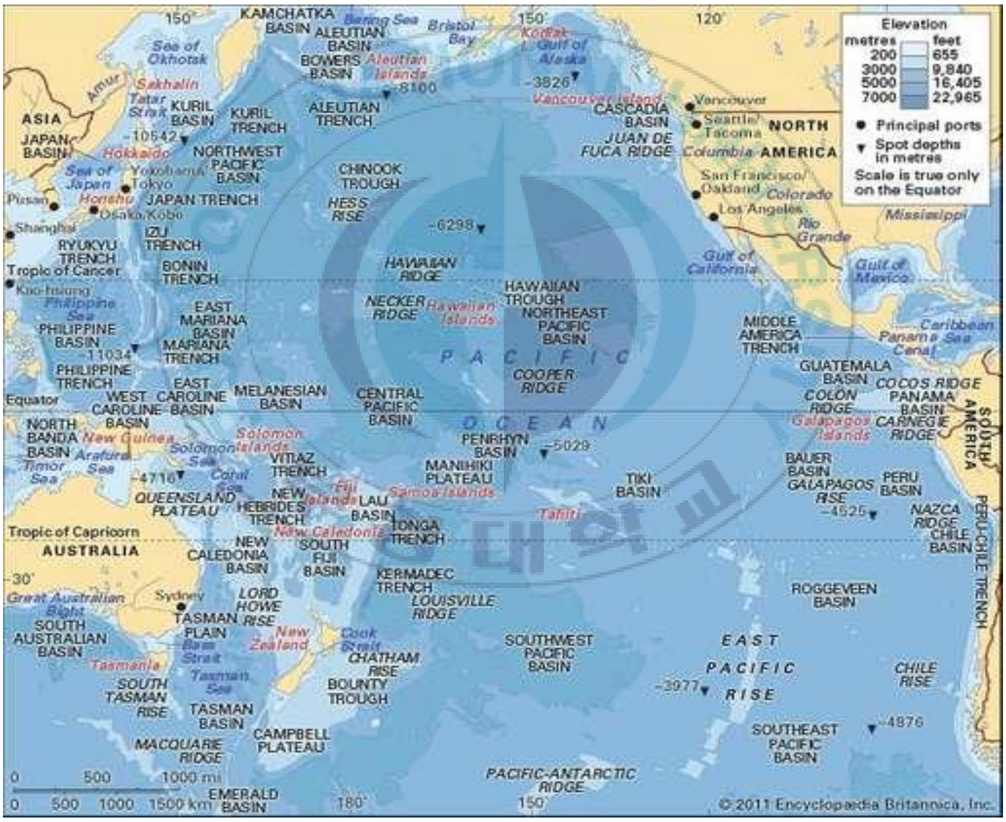

Fig. 2 The Pacific Ocean.

Of the three oceans that extend northward from the Antarctic continent, the Pacific Ocean is by far the largest, occupying about a third of the surface of the globe, its area, excluding adjacent seas, encompasses about 165,25 million km^2. It has double the area and more than double the water volume of the Atlantic Ocean—the next largest division of the hydrosphere—and its area more than exceeds that of the whole land surface of the globe. The Pacific Ocean stretches from the shores of Antarctica to the Bering Strait through 135° of latitude, some 15,500 km, its greatest longitudinal extent measures some 19,300 km along latitude 5° N, between the coasts of Colombia in South America and the Malay Peninsula in Asia. The mean depth of the Pacific (excluding adjacent seas) is 14,040 feet (4,280 meters), and its greatest known depth is 36,201 feet (11,034 meters)—in Mariana Trench—also the greatest depth found in any ocean (Morgan, Bardash and Cotter, 2018).

1.1 Physiography

The Pacific basin may conveniently be divided into three major physiographic regions: the eastern, western, and central regions (Morgan, Bardash and Cotter, 2018).

Eastern region: the eastern pacific region, which extends southward from Alaska to Tierra del Fuego, is relatively narrow and is associated with the American Cordillera System of almost unbroken mountain chains, the coastal ranges of which rise steeply from the western shores of North and South America. The continental shelf, which runs parallel to it, is narrow, while the adjacent continental slope is very steep. Significant oceanic trenches in this region are the Middle America Trench in the north Pacific and the Peru-Chile Trench in the south Pacific. The principal species of tuna in the EPO are: yellowfin, *Thunnus albacares*, bigeye, *T. obesus*, skipjack, *Katsuwonus pelamis*, Pacific bluefin, *Thunnus orientalis*, and albacore, *T. alalunga*. The first three are tropical species, while the other two inhabit temperate waters (Bayliff, 2016).

The greatest catches of tuna are taken by purse seines—large nets that encircle entire schools of fish. Yellowfin, bigeye, skipjack, and bluefin are caught mainly by purse seines. Longlines consist of a mainline—about 60 nautical miles long if deployed in the open ocean—and branch lines, each with a baited hook at the end of it. Longlines catch yellowfin, bigeye, bluefin, and albacore. Trolling is conducted from a relatively small vessel that tows lines, each with an artificial lure at the end of it, through the water. Trolling vessels catch mainly albacore. Nearly all the purse seiners and trolleys that fish in the EPO are registered in nations of the western hemisphere, while nearly all the longline vessels are registered in far eastern nations (Bayliff, 2016).

Tuna vessels stay at sea for weeks or months at a time, so their catches must be frozen at sea. The catches of longline vessels are nearly always sold fresh, so they must be handled with great care and frozen at very low temperatures. Purse-seine vessels catch large amounts of fish—sometimes 100 or more tons in a single day—so, it is not often feasible to handle the fish as carefully as longline-caught fish. These fish are nearly always canned.

In the EPO, the catches of yellowfin and skipjack are greatest, followed by those of bigeye, albacore, and bluefin in that order.

Western region: the seaward boundary of the western pacific region is marked by a broken line of oceanic trenches, extending from the Aleutian Trench in the north through the Kuril and Japan trenches and southward to the Tonga and Kermadec trenches, terminating close to the northeast of North Island, New Zealand. Its structure is more complex than that of the eastern region. Characteristically associated with the ocean trenches of the western region are festoons of either peninsulas or islands or both. The islands, which include those of Japan as well as numerous smaller islands, represent the upper parts of mountain systems that rise abruptly from the deep ocean floor. The island clusters of the western pacific form the boundaries of the several wide and deep continental seas of the region.

Central region: the central pacific region lies between the boundaries of the eastern and western regions. The largest and the most geologically stable of the structural provinces of the Earth's crust, it is characterized by expansive areas of low relief, lying at a general depth of about 4,600 meters below the surface.

1.2 Biological resources

The Pacific Ocean has the most varied array of plants (algae) and animals of the world's oceans. The circumglobal mixing of water in the southern and, to a much more limited extent, northern polar reaches of the Pacific permits the intermingling of flora and fauna from the oceanic regions, while temperate and tropical surface waters of the Pacific are more likely to have indigenous biotas. On the rocky cold-water coasts of North and South America, for example, are found vast forest like kelp beds made up of brown algae of the genus *Laminaria*, with individual plants often reaching heights of 100 feet (30 meters) or more. They harbour a rich animal complement of invertebrates and fishes approaching a fauna variety that vies with that of tropical rainforests. Where up welling and other current conditions add nutrients to the offshore surface waters of these same reaches of the Pacific, dense concentrations of plankton-feeding fishes thrive, predominantly those of the herring family and its relatives. Examples include the Japanese sardine and the Peruvian anchovy, both of which are among the largest single-species fishing catches in the world (Morgan, Bardash and Cotter, 2018).

In the north Pacific, circulation patterns and runoff from the land create conditions in which demersal, or bottom-living, species abound. The north Pacific hake and the Alaska pollock are prominent examples. Salmon likewise thrive in the north Pacific, proliferating there in five species of the genus *Oncorhynchus*, as compared with the single species, *Salmo salar*, of the Atlantic (Morgan, Bardash and Cotter, 2018).

In the warm tropical region—roughly between the North and South Equatorial Current systems—the wealth of marine animals especially increases dramatically. The variety of animal life is greater in the western Pacific, where the warm monsoonal climate and variegated landforms have promoted evolution of the unique Indo-Pacific marine forms.

The western Pacific also has the richest and most extensive coral reefs of any ocean, with some six times more species of fish associated with them than with the coral reefs of the Caribbean Sea in the Atlantic. The tropical sea passages between the Pacific and the Indian oceans have also given the latter ocean a rich reef fauna; Indo-Pacific mollusks have reached copious evolutionary diversification, with the giant clam, *Tridacna gigas*, a spectacular example. Another example of the Pacific's richness in species is found among the tunas: six species (one of them endemic) roam the tropical reaches of the Pacific, furnishing more than half of the world's tuna catch (Morgan, Bardash and Cotter, 2018).

Whales are a prominent and spectacular component of the Pacific marine biota. The habits of many species include regular long-distance migrations from cold-water feeding to warm-water breeding and calving grounds, thus predisposing them to global distribution (Morgan, Bardash and Cotter, 2018).

1.3 Trade and transportation

Since the mid-20th century, there has been remarkable growth in trade between western Pacific rim—most notably China, Japan, Korea, and Taiwan—and North America, particularly the United States. Trade has also expanded between North America and Southeast Asian countries as Singapore, Thailand, Malaysia, the Philippines, and, to a lesser degree, Indonesia; in the western Pacific, trade has increased between Japan and Korea in the north, and between Australia and Southeast Asia in the south. In addition, trade patterns in the United States have shifted, with pacific countries now accounting for a major portion of overall trade. In the United States, Los Angeles has surpassed New York City as the port with the country's largest trade volume in terms of value, and the nearby port of Long Beach has also become a major hub of international trade (Morgan, Bardash and Cotter, 2018).

Thus, the Pacific Ocean supports some of the world's most important trade routes. Most of the exports moving from west to east and from north to south are high-value-added manufactured goods. Conversely, most of the exports moving from east to west and from south to north are raw materials and light manufactures (Morgan, Bardash and Cotter, 2018).

2. Inter-American Tropical Tuna Commission

The Inter-American Tropical Tuna Commission (IATTC) operates under the authority and direction of a convention originally entered into by Costa Rica and the United States of America (USA). The Convention, which came into force in 1950, is open to adherence by other governments whose nationals fish for tropical tuna and tuna-like species in the EPO. Under this provision Panama adhered in 1953, Ecuador in 1961, Mexico in 1964, Canada in 1968, Japan in 1970, France and Nicaragua in 1973, Vanuatu in 1990, Venezuela in 1992, El Salvador in 1997, Guatemala in 2000, Peru in 2002, Spain in 2003, Korea in 2005, and Colombia in 2007. Canada withdrew from the IATTC in 1984. The Convention states that the IATTC staff is to "make investigations concerning the abundance, biology, biometry, and ecology of yellowfin and skipjack tuna in the waters of the EPO fished by the nationals of the High Contracting Parties, and the kinds of fishes commonly used as bait in the tuna fisheries and of other kinds of fish taken by tuna fishing vessels; and the effects of natural factors and human activities on the abundance of the populations of fishes supporting all of these fisheries" (IATTC, 2019). Further, it is to "recommend from time to time, on the basis of scientific investigations, proposals for joint action by the High Contracting Parties designed to keep the populations of fishes covered by this Convention at those levels of abundance which will permit the maximum sustained catch" (IATTC, 2019).

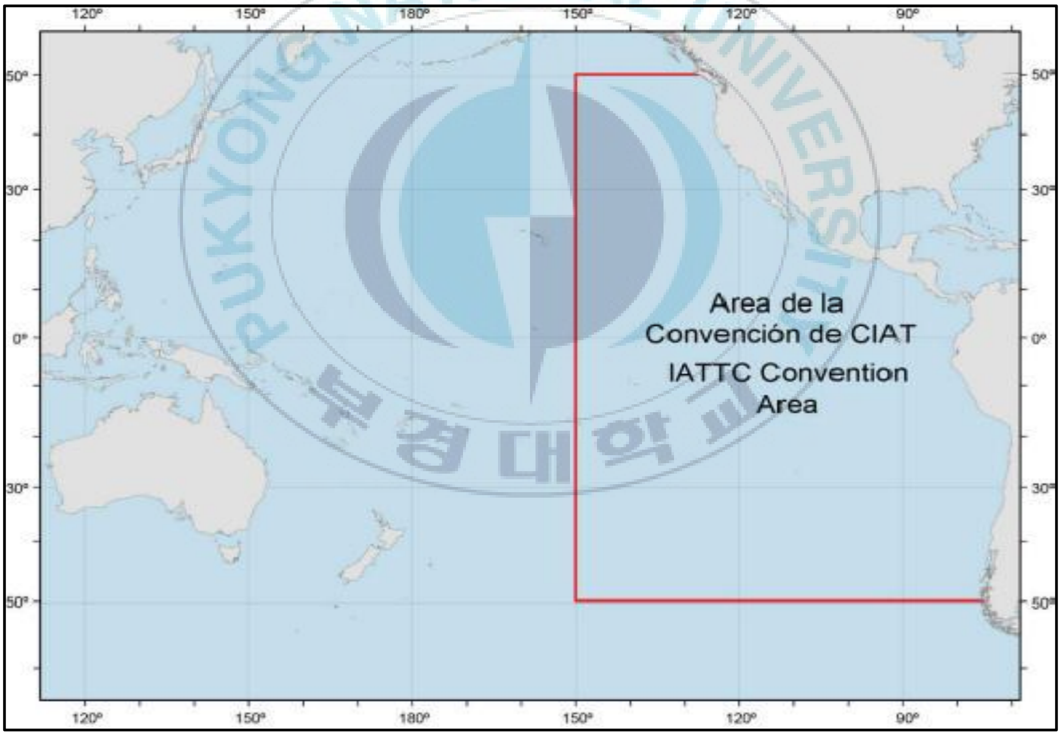

Fig. 3 The Pacific Ocean and IATTC Convention area.

Fig. 4 Bolivarian Republic of Venezuela.

Each member of the IATTC is represented by up to Commissioners, appointed by the respective government. The IATTC also has significant responsibilities for the implementation of the International Dolphin Conservation Program (IDCP), and provides the Secretariat for that program.

The main obligations of the IATTC are: (1) to study biology of tuna, baitfish, and other types of fish caught by tuna vessels in the EPO and the effects on them of fishing and natural factors and (2) recommend appropriate measures conservation, when appropriate, to allow fish stocks to be maintained at levels that provide maximum sustainable catches (IATTC, 2019).

In 1976, the obligations of the IATTC were extended to cover the problems caused by the tuna-dolphin relationship in the EPO. It was agreed that the objectives would be "to maintain a high level of production tuna and sustain the population of dolphins at levels or levels that guarantee their survival perpetuity, working as soon as possible to avoid unnecessary death or carelessness of dolphins" (Bayliff, 2003).

2.1 Objectives

The objective of the Inter-American Tropical Tuna Commission (IATTC) is to ensure long-term conservation and sustainable use of tuna and other species of fish taken by fishing vessels in the EPO, in accordance with the relevant rules of international law (IATTC, 2019).

2.2 The area of competence

The IATTC area of application comprises the area of the Pacific Ocean bounded by the coastline of North, Central, and South America and by the following lines: the 50°N parallel from the coast of North America to its intersection with the 150°W meridian; 150°W meridian to its intersection with the 50°S parallel; and the 50°S parallel to its intersection with the coast of South America (FAO, 2019).

2.3 Headquarters and Regional Offices

The rules of procedures of the IATTC provide that its headquarters (that is, the place where its staff is located) is in San Diego, California, United States. Currently, it has Regional Offices in Ensenada and Mazatlan (Mexico): Mayaguez, (Puerto Rico); Panama and Bahia of Achotines (Republic of Panama); Las Playas y Manta (Ecuador) and Cumana (Venezuela). In several moments in the history of the IATTC staff members were also assigned to San Pedro, California (United States); Puntarenas (Costa Rica), Taboga (Republic of Panama); Guayaquil (Ecuador); Paita and Coishco (Peru); Pago Pago (Eastern Samoa), and various places in Japan (Bayliff, 2003).

2.4 The Agreement on the International Dolphin Conservation Program

The Agreement on the International Dolphin Conservation Program (AIDCP) is a legally-binding multilateral agreement which entered into force in February 1999. The IATTC's responsibilities were broadened in 1976 to address the problems arising from the incidental mortality in purse seines of dolphins that associate with yellowfin tuna in the EPO. The Commission agreed that it "should strive to maintain a high level of tuna production and also to maintain dolphin stocks at or above levels that assure their survival in perpetuity, with every reasonable effort being made to avoid needless or careless killing of dolphins" (Bayliff, 2003).

The principal responsibilities of the IATTC's Tuna-Dolphin Program are: (1) to monitor the abundance of dolphins and their mortality incidental to purse-seine fishing in the EPO; (2) to study the causes of mortality of dolphins during fishing operations and promote the use of fishing techniques and equipment that minimize these mortalities; (3) to study the effects of different modes of fishing on the various fish and other animals of the pelagic ecosystem and (4) to provide information to a Secretariat for the International Dolphin Conservation Program (Bayliff, 2003).

This agreement introduced such novel and effective measures as Dolphin Mortality Limits (DMLs) for individual vessels and the International Review Panel to monitor the performance and compliance of the fishing fleet. On May 21th 1998, the Agreement on the International Dolphin Conservation Program (AIDCP), which built on and formalized the provisions of the 1992 La Jolla Agreement, was signed, and it entered into force on February 15th 1999. In 2010, Costa Rica, Ecuador, El Salvador, the European Union, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, the United States, Vanuatu, and Venezuela were Parties to this agreement, and Bolivia and Colombia were applying it provisionally (IATTC, 2019).

This agreement established Stock Mortality Limits, which are similar to DMLs except that (1) they apply to all vessels combined, rather than to individual vessels, and (2) they apply to individual stocks of dolphins, rather than to all stocks of dolphins combined. The IATTC provides the Secretariat for the International Dolphin Conservation Program (IDCP) and its various working groups and panels and coordinates the On-Board Observer Program and the Tuna Tracking and Verification System (IATTC, 2019).

2.5 Venezuela and the Inter-American Tropical Tuna Commission

The Inter-American Tropical Tuna Commission (IATTC) was established by an International Convention in 1949. This Convention was ratified by Venezuela in 1992.

The activate participation of Venezuela as a full member, is based on the need for defense and promotion of the country's interests in the tuna fishery that takes place in the EPO, every time the decisions taken within this Commission are the mandatory compliance of the Members. Currently, Venezuela's fishing activity in the EPO is carried out through privately owned vessels, which are granted the respective concession for fishing activity.

The National Observer Program of Venezuela (PNOV) provides trainers to observers and captains employed in tuna vessels on the techniques used in tuna fishing on dolphins in the EPO.

Venezuela's fleet in the EPO is composed for 24 vessels (purse seiners). Purse seiners use nets up to 1 kilometer in length, which have a significant vertical area of influence. They have a range of autonomy of up to 60-70 days of fishing and use equipment to detect schools, echo sounders and thermographs, support helicopters, as well as powerful hydraulic systems to complete the fishing task, therefore, they employ specialized equipment to reduce the mortality of these mammals in accordance with the provisions of the AIDCP. The contribution of production to Venezuelan fishing gears in the EPO varies between 5% and 15% (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

The national government supply a concession to the private sector, who operate Venezuela's fleet in the EPO.

3. Fisheries activity in Venezuela

Approximately, between 80 and 85% of the national production of tuna is generated by tuna fishing carried out in the EPO with the purse seiners. This is due in large part to the high yields traditionally maintained by the area, which is one of the main fishing grounds around the world (FAO, 2003). The rest of the national tuna fishery corresponds to the Atlantic Ocean and Caribbean Sea, an area where, in addition to the purse seine, two additional gears are used, such as longlines and sugarcane (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

In this large territorial area, Venezuela has, both in its marine and river environments fishery resources that are characterized by their high diversity and potentiality, on which commercial holdings of increasing importance have been developed over the last 50 years (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

In contrast to other Latin American countries, the artisanal marine fishing in Venezuela contributes a significant part of the total catches of the sector. This is largely due to the management of the sardine resource, whose fishery is limited by law to artisanal fishermen (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

Inland fisheries have a lower relative importance in comparison with maritime or industrial artisanal fishing, contributing to historical maximum of just 12% to the total national production (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

Respect to the total number of catches reported by different fisheries, the artisanal marine subsector contributes up to 70% of the total catches, in the highest proportion constituted by those corresponding to the sardine resource. The rest of the report corresponds to the different species from multi-species maritime fisheries and nonobjective species from trawl fisheries. The tuna industrial sub sector contributes about 26% of the total, with the largest proportion of the catches in the EPO, an area which Venezuela maintains the third purse seine fleet. The trawl industry, on the other hand, generates only 3% of the production, concentrating its activities in the Gulf of Venezuela, the Sad Gulf, the Unare Platform, the north coast of Sucre Province, the northwest of Margarita island, the Gulf of Paria and Atlantic Area, facing the Orinoco River Delta (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2018).

Unlike the artisanal sector in other countries, that of Venezuela is extremely important in the supply of fish to the national market. As described above, it is largely due to the restriction of access to the sardine fishery which is limited to purely artisanal extraction activities. Other important fisheries are focused on pepitone *(Arca zebra)*, whose extractive activity has generated up to 10% of production, in addition to curb, carite (*Scomberomorus cavalla)*, snapper, catfish, horse mackerel and crabs. The artisanal maritime fishing sector has achieved great importance, not only in terms of its participation in the total production of the country, but also for its contribution to employment in regions with less economic development.

3.1 Fish consumption per capita

In Venezuela, the demand is mainly focused on the segment of fresh / frozen products with 61%, following that of canned with 33% and dry / salted with 6%. The consumption of fish is not the highest compared to that of other products of different origin that make up the basic basket established by Venezuelan government (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2015). The trend of fish consumption per capita during the period 1994-2015 is shown in the Fig. 5.

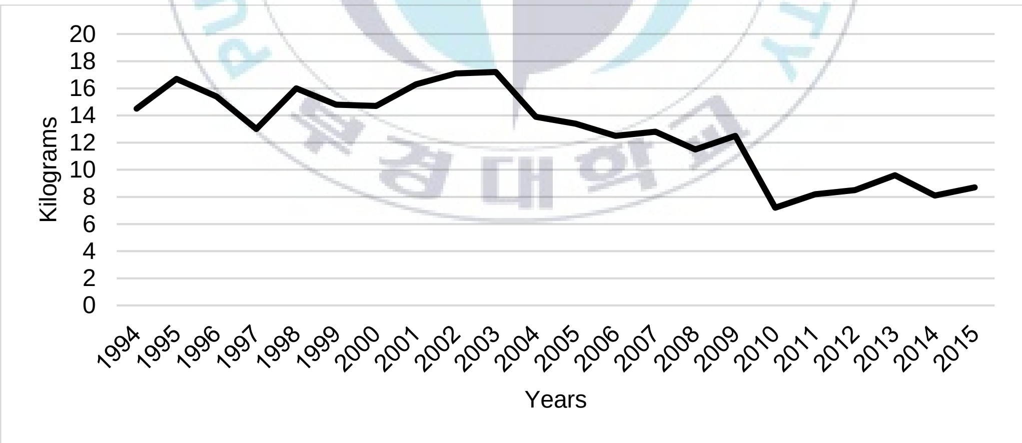

Fig. 5 Fish consumption per capita in Venezuela 1994-2015.

3.2 Exports

Exports of Venezuelan fish and aquaculture products accounted for around 13,913.58 tons in 2017, of which the main species sold were: shrimp (*Litopeneaus Vannamei*), blue crab (*Callinectis Sapidus*), Tajali or swordfish (*Trichiurus lepturus*), pargo (*Lutjanus sp.*), curbina del lago (*Cynoscion acoupa*), and others. Main markets are: France, Vietnam, United States and Spain (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

3.3 Imports

Pangaso (*Pangasianodon hypophthalmus*) salmon, fishmeal and others. The countries with the largest share in imports are: Peru, Ecuador, China and Chile (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2017).

Chapter 3. Materials and Methods

1. Surplus production model

Pascoe (1995), indicates that the assumption of all surplus production model is that the biomass next year B_{t+1}, is determined by the biomass this year, B_t, the growth in biomass over the year, G_t, and the level of catch, C_t

$$B_{t+1} = B_t + G_t - C_t \quad (1)$$

If the sum of the recruitment and growth is larger than the sum of catch and natural mortality, a stock increases in abundance; if the losses exceed the additions, the stock declines.

For a stock to remain at a given level of biomass (new biomass = old biomass), the fishery removal (catch) should not be larger than the surplus production of the stock. To rebuild a stock, catch must be lower than the surplus production.

These types of models are attractive in stock assessment in that not only do they have biological soundness but also require minimal amounts of data. The basic set of data required for surplus production models is a time series of catch and fishing effort.

Surplus production models are derived from catch and effort data. Most studies involving the estimation of surplus production models fall into two categories: (1) logistic growth models and (2) exponential growth curves. The main difference between the logistic and exponential growth curve is that the former is symmetrical while the latter is asymmetrical (Pascoe, 1995).

The Schaefer (1957), Schnute (1977) and Walter and Hilborn (1976) models have logistic yield-effort relationship (logistic growth model), while, the Fox (1970) and Clark Yoshimoto and Pooley (1992) models are following exponential yield-effort relationship (exponential growth model). They consist of three distinctly different production (i.e. yield and effort) relationship: The Schaefer, Schnute and Walter and Hilborn models have a parabolic or logistic relationship; the Fox and Clark, Yoshimoto and Pooley models follow a Gompertz curve (Pascoe, 1995).

The five models relate stock size, fishing effort, and yield to one another. Stock size adjusts to different levels of effort, and sustainable yield is a result of applied effort.

The Schaefer, Schnute, WH, Fox, and CYP models show the equation for estimating surplus production in the Table 2.

Table 2. Estimating equation for surplus production model.

Function type	Model	Data formulation
Logistic function	Schaefer	$(\overline{U}_{t+1} - \overline{U}_{t-1})/(2\overline{U}_{t}) = r - (r/(qk)))(\overline{U}_{t}) - q(\overline{E})$
	Schnute	$\ln(\overline{U}_{t+1}/\overline{U}_{t}) = r - (r/(qk))(\overline{U}_{t}+\overline{U}_{t+1})/2 - q(\overline{E}_{t}+\overline{E}_{t+1})/2$
	WH	$(\overline{U}_{t+1}/\overline{U}_{t}) - 1 = r - (r/(qk))(\overline{U}_{t}) - qE_{t}$
Exponential function	Fox	$(\overline{U}_{t+1} - \overline{U}_{t-1})/(2\overline{U}_{t}) = (r - \ln(qk)) - r\ln(\overline{U}_{t}) - q\overline{E}_{t}$
	CYP	$\ln(\overline{U}_{t+1}) = (2r/(2+r))\ln(qk)) + ((2-r)/(2+r))\ln(\overline{U}_{t}) - (q/(2+r))(\overline{E}_{t}+\overline{E}_{t+1})$

The basis of the logistic growth model was proposed as population model in 1838 by P.F. Verhults. This model was used like the basis for one of the commonly surplus production models, produced by Schaefer (1954, 1957).

The surplus growth of the population was assumed by Schaefer to be logistic, and given by:

$$G_t = r\,B_t\,(1 - B_t/k) \qquad (2)$$

where r is the intrinsic growth rate and k is the carrying capacity of the environment. Hence, when $B = k$, growth is zero. From the first order condition, growth is maximized at k/2 (Pascoe, 2005).

Implicit in the growth function give in equation (2) are two important assumptions. First, the age structure does not affect the rate of growth of the population, a second assumption of the model is that changes in the population happen immediately. Other key assumption of the Schaefer model is that catch per unit of effort is proportional to the stock biomass, given by (Pascoe, 2005):

$$U_t = q\,B_t \qquad (3)$$

where U_t is the catch per unit of effort and q is the catchability coefficient. Catch is equal to the catch per unit of effort times the level of effort:

$$C_t = q\,B_t E_t \qquad (4)$$

where E_t, is the level of fishing effort.

In equilibrium, the catch is equal to the growth rate, for that reason, $B_{t+1} = B_t$ Equating equations (2) and (4) and dropping subscripts gives (Pascoe, 2005):

$$qBE = rB\,(1 - B/k) \tag{5}$$

which can be rewritten as:

$$B = k\,(1 - qE/r) \tag{6}$$

Substituting equation (6) into equation (4), an expression can be derived relating the sustainable level of catch to the level of effort:

$$C = qkE\,(1 - qE/r) \tag{7}$$

or $$C = \alpha E - \beta E^2 \tag{8}$$

where $\alpha = qk$ and $\beta = q^2k/r$

The effort level is give rise into the maximum sustainable yield (MSY), in this way, E_{msy}, could be estimated by setting the first order derived, dC/dE, to zero:

$$\frac{dC}{dE} = \alpha - 2\beta E = 0 \tag{9}$$

$$E_{msy} = \frac{r}{2q} \tag{10}$$

C_{msy} is determined by substituting equation (10) into equation (7), by:

$$C_{msy} = q\,(\frac{r}{2q})\,k\,(1 - \frac{q}{r}\,\frac{r}{2q})$$

$C_{msy} = \frac{kr}{2}\left(\frac{1}{2}\right)$

$C_{msy} = \frac{kr}{4}$ (11)

1.1 Schaefer model

Schaefer model is a simple, useful and convenient method for assessing fish stocks. According to this model, in equilibrium the growth in the population, is equal to the catch. However, when the catch is either greater or less than the growth in the population, the change in population is the difference between the sustainable level of catch at a given population biomass, C_e, and actual catch, C. This can be formulated as (Pascoe, 2005):

$\Delta B = C_e - C$ (12)

From equation (2), the equilibrium catch can be expressed as a function of the mean biomass:

$C_e = a\overline{B}\ (k-\overline{B})$ (13)

where $a = r/k$ and $\overline{B}$ is the mean biomass during the year.

From equation (3), it follows that:

$\overline{U} = q\,\overline{B}$ (14)

where U is the mean catch per unit of effort over the year, and

$\Delta U = q\ \Delta B$ (15)

where ΔU is the change in catch per unit of effort over the year. Rearranging equations (14) and substituting for ΔB in equation (13) results in:

$$C_e = C + \Delta U/q \tag{16}$$

rearranging equation (14) and substituting for $\overline{B}$ in equation (13) results in:

$$C_e = a\overline{U}(k/q - \overline{U}) \tag{17}$$

equations (16) and (17) results in:

$$C + \Delta U/q = a\overline{U}\,(k/q - \overline{U}) \tag{18}$$

it can be arranged to get:

$$\frac{\Delta U}{\overline{U}} = aq\,(k/q - \overline{U} - q\,C/\overline{U}) \tag{19}$$

a finite approximation of ΔU is given by:

$$\Delta U \approx \frac{\overline{U}_{t+1} - \overline{U}_{t-1}}{2} \tag{20}$$

substituting equation (20) into equation (19) and substituting $a = r/k$ results in:

$$\frac{\overline{U}_{t+1} - \overline{U}_{t-1}}{2\overline{U}_t} = r - \frac{r}{qk}\,\overline{U}_t - q\overline{E}_t \tag{21}$$

where $\overline{E}$ is the effort divided by the mean of catch per unit of effort, $\overline{U}$.

1.2 Schnute model

Schnute model suggested an alternative approximation system based on integration rather than average. Following Schnute equation can be specified as (Pascoe, 1995).

$$\frac{1}{U}\frac{dU}{d_t} = r - \frac{r}{qk}\mathrm{U} - qE \tag{22}$$

Integrating this equation from *t* to *t+1* results in a modified dependent variable, as given by:

$$\ln\left[\frac{U_{t+1}}{U_t}\right] = r - \frac{r}{qk}\overline{U}_t - q\overline{E}_t \tag{23}$$

The quantity $ln(U_{t+1}/U_t)$ is usually not know as it involves the instantaneous values of U_t at the start of each year. However, an approximation of equation (23) can be derived by adding equation (23) for year *t* to itself for year t_{+1}, and divided by 2

$$\ln\left[\frac{\sqrt{U_{t+1}\,U_{t+2}}}{U_t\,U_{t+1}}\right] = r - \frac{r}{qk}\left[\frac{\overline{U}_t + \overline{U}_{t+1}}{2}\right] - q\left[\frac{\overline{E}_t + \overline{E}_{t+1}}{2}\right] \tag{24}$$

The left side of equation (24) can be simplified assuming that the mean catch per unit of effort over a year is approximately the geometric mean of the values at the beginning and the end of each year. That is:

$$\overline{U}_t \cong \sqrt{U_t\,U_{t+1}} \tag{25}$$

Incorporating equation 25 into equation 24 results in:

$$\ln\left(\frac{\overline{U}_{t+1}}{\overline{U}_t}\right) = r - \frac{r}{qk}\left(\frac{\overline{U}_t + \overline{U}_{t+1}}{2}\right) - q\left(\frac{\overline{E}_t + \overline{E}_{t+1}}{2}\right) \tag{26}$$

1.3 Walters and Hilborn model

The difference equation method developed by Walters and Hilborn is relatively simpler than that developed by Schnute. The population dynamics assumption in equation $B_{t+1=} B_t + G_t – C_t$ (1) can be re specified as (Pascoe, 1995).

$$B_{t+1=} B_t + r B_t (1 - B_t/k) - qE_t B_t \quad (27)$$

from this,

$$\frac{B_{t+1}}{B_t} = 1 + r (1- B_t/k) - qE_t \quad (28)$$

assuming $B_t = \overline{U}_t /q$, equation (28) can be re specified as:

$$\frac{\overline{U}_{t+1}}{\overline{U}_t} = 1 + r (1- \overline{U}_t/qk) - qE_t \quad (29)$$

which can be rearranged to give:

$$\frac{\overline{U}_{t+1}}{\overline{U}_t} -1 = r- \frac{r}{qk} \overline{U}_t -qE_t \quad (30)$$

An alternative to the logistic growth curve assumed in the Schaefer model is an exponential growth model based on the Gompertz growth function, given by (Pascoe, 1995):

$$G= rB \ln (k/B) \quad (31)$$

Fox model is one of the exponential model in surplus production model, is based on such a growth assumption. This model is very similar to Schaefer method, due to the sustainable yield is equal to the growth of the population, given by: (Pascoe, 1995).

$$C_e = rB \ln (k/B) \quad (32)$$

Assuming that catch per unit of effort is proportion to the biomass, (equation 3), equation (32) can be re specified as:

$$C_e = \frac{r\overline{U}}{q} \left[\ln \left(\frac{U_\infty}{q}\right) - \ln \left(\frac{\overline{U}}{q}\right)\right] \tag{33}$$

where U_∞ is the catch per unit of effort that would occur if the stock was at an unexploited level ($U_\infty = qk$) and $\overline{U}$ is, the mean catch per unit of effort. Expanding out the right hand side results in the cancellation of the *ln(q)* terms so that equation (20) can be simplified as:

$$C_e = \frac{r\overline{U}}{q} \left[\ln U_\infty - \ln \overline{U}\right] \tag{34}$$

Dividing equation (34) through by $\overline{U}$ results in:

$$E = \frac{r}{q} \left[\ln_\infty - \ln \overline{U}\right] \tag{35}$$

where *E* is, the level of effort expended in the fishery. This can be rearranged to produce:

$$\ln \overline{U} = \ln U_\infty - (q/r)\, E \tag{36}$$

Exponentiating equation (36), the mean catch per unit effort in the Fox model can be expressed as:

$$\overline{U} = U_\infty\, e^{-(q/r)E} \tag{37}$$

and hence catch can be expressed as:

$$C = U_\infty\, E\, e^{-(q/r)E} \tag{38}$$

or

$$C = qkE\, e^{-(q/r)E} \tag{39}$$

The effort level of the maximum catch in the Fox model is given by:

$$\frac{dC}{dE} = qke^{-(q/r)E}\,(1-\frac{q}{r}E) = 0 \qquad (40)$$

distributing both side by $qke^{-(q/r)E}$ and solving the equation for E gives:

$$E_{msy} = \frac{r}{q} \qquad (41)$$

1.4 Fox model

The development of the Fox method is similar to that of the Schaefer method. This model chose to use the effort averaging method. By replacing equation (33) with equation (17) and following the derivation of the Schaefer model, equation (19) can be restated as (Pascoe, 1995):

$$\frac{\Delta U}{\overline{U}} = r\ln(qk) - r\ln(\overline{U}) - q\overline{E} \qquad (42)$$

Fox model used the finite approximation of ΔU given in equation (20) resulting in:

$$\frac{\overline{U}_{t+1} - \overline{U}_{t-1}}{2\overline{U}_t} = r\ln(qk) - r\ln(\overline{U}_t) - q\overline{E}_t \qquad (43)$$

1.5 Clarke, Yoshimoto and Pooley model

This model developed an integrated version of the Fox model along similar lines as employed by Schnute when developing the integrated version of the logistic model. Following CYP model, equation (42) can be redefined as (Pascoe, 1995):

$$\frac{1}{U}\frac{dU}{dt} = r\ln(qk) - r\ln(U) - qE \qquad (44)$$

which can be integrated over a year to produce:

$$\ln\left[\frac{U_{t+1}}{U_t}\right] = r\ln(qk) - r\ln(\overline{U}) - q\overline{E} \quad (45)$$

Following the same procedure as used by Schnute, an approximation for equation (45) is derived by adding equation (45) for time t to itself for time $t+1$. Assuming the approximation given in the equation (25), the resulting equation can be specified as:

$$\ln(\overline{U}_{t+1}) - \ln(\overline{U}_t) = 2r\ln(qk) - r(\ln(\overline{U}_t) + \ln(\overline{U}_{t+1})) - q(\overline{E}_t + \overline{E}_{t+1}) \quad (46)$$

solving this algebraically for ln (U_{t+1}), gives:

$$\ln(\overline{U}_{t+1}) = \frac{2r}{2+r}\ln(qk) + \frac{2-r}{2+r}\ln(\overline{U}_t) - \frac{q}{2+r}(\overline{E}_t + \overline{E}_{t+1}) \quad (47)$$

2. Maximum sustainable yield (MSY)

According to the European Common Fisheries Policy the maximum sustainable yield is “the highest theoretical equilibrium yield that can be continuously taken on average from a stock under existing average environmental conditions with-out significantly affecting the reproduction process” (Kempf, et al., 2016).

The maximum sustainable yield (MSY) is typically defined on the basis of a given age-specific fishing mortality. For any given fishery, this mortality is achieved through gear selectivity. In a multigear fishery it results from a combination of the selectivity of each gear and the relative efforts allotted to gears; different gears may produce different levels of MSY (Maunder and Harley, 2006).

The equations for estimating MSY in surplus production model are shown in the Table 3.

Table 3. Equations for estimating MSY, logistic and exponential models.

	Equation	Logistic growth models	Exponential growth models
MSY	Effort (E_{msy})	$r/2q$	r/q
	Catch (C_{msy})	$kr/4$	$qkE_{msy}\ e^{-(q/r)Emsy}$
	Biomass (B_{msy})	$k(1\text{-}qE_{msy}/r)$	$k\ e^{-(q/r)Emsy}$

3. Maximum economic yield (MEY)

Maximum economic yield (MEY) in a fishery can be defined as the point at which the sustainable fishing effort level and catches in the fishery entail maximum profits or as the greatest difference between total revenues and total costs of fishing (Pascoe, Thebaud and Vieira, 20014). In most cases, this scenario results in yields and effort levels that are less than at maximum sustainable yield (MSY) and in stock biomass levels greater than at MSY (Narayanakumar, 2017).

In order to estimated MEY (logistic growth model), the steps are the next (Lotfy, 2019):

$NP = TR\text{-}TC$

$NP = PC – vE$

$NP= P\ (qkE – e\ ^{2}q^{2}k/r) – vE$

$NP = PqkE\text{-}\ PE^{2}q^{2}k/r – vE$ (48)

here, E, at the maximum economic yield, $E_{mey,}$ it can be observed by:

$\frac{d\pi}{dE} = Pqk - 2PEq^2k/r - v = 0$

$2PEq^2k/r = Pqk - v$

$$E_{mey} = \frac{Pqk - v}{2Pq^2k/r} = \frac{Pqk - v}{2Pq^2k/r} - \frac{v}{2Pq^2k/r} = \frac{qk - v/p}{2Pq^2k/r} \quad (49)$$

Equally, in the Gordon-Schaefer bioeconomic model, total revenue (TR) in the Fox model can be defined as a fishing effort function by reproducing equation (39) adding price.

In order to estimated MEY (exponential growth model), the steps are the next (Lotfy, 2019):

$$TR = pqkE\, e^{-(q/r)\,E} \quad (50)$$

Total cost (TC) is derivate as a function of effort

$$TC = vE \quad (51)$$

The total rent or maximum net profit (NP) is assumed by subtracting equation (51) to equation (50)

$$NP = pqkE\, e^{-(q/r)\,E} - vE \quad (52)$$

The level of effort that turn out the maximum economic yield, E_{mey}, it able to found using the first order condition for profit maximization.

$$\frac{d\pi}{dE} = pqke^{-(q/r)E}\,(1 - \frac{q}{r}E) - v = 0 \quad (53)$$

E_{mey} cannot be explicated as a function of the model parameters, for the exponential function as compare to the associated equation in the Gordon-Schafer model. The relation can be express as a follow:

$$E_{mey} = \frac{r}{q}\,[\,1 - \frac{v}{pqk}\, e^{(q/r)\,Emey}\,] \quad (54)$$

For estimating effort, catch and biomass of MEY in the logistic and exponential models are shown in the Table 4.

Table 4. Equations for estimating MEY, logistic and exponential models.

	Equation	Logistic growth models	Exponential growth models
MEY	Effort (E_{mey})	$r(1-v/(pqk))/(2q)$	$r/q[1-(v/pqk)e^{(q/r)Emey}]$
	Catch (C_{mey})	$(kr/4)[1-(v/(pqk))^2]$	$qkE_{mey}/e^{(Emeyq/r)}$
	Biomass (B_{mey})	$C_{mey}/(qE_{mey})$	$C_{mey}/(qE_{mey})$

4. Fishing in open access equilibrium (OAE)

Open access equilibrium (OAE) occurs when all of the excess profits or economic rent that attracts new entrants to a developing fishery have been dissipated in the costs associated with the additional fishing effort. The fishery is no longer attractive to new entrants. Usually occurs when fishing effort is higher than that which will obtain the greatest yield from a fishery and all rents have been dissipated, such that NP=0. As with the Gordon-Schaefer model, the effort level in open access equilibrium could be estimated by setting equation (48) to zero, giving (Lotfy, 2019):

$TR\text{-}TC=0$

$PqkE\text{-}PE^2q^2k/r - vE = 0$

$Pqk - PE^2 q^2k/r - v = 0$

$PEq^2k/r = Pqk - v$

$$E_{oae} = \frac{\alpha - v/p}{\beta} = r(1- v)/(pkq)/q \qquad (55)$$

The OAE, through the Gordon-Schaefer model, the effort level on open access equilibrium possibly be appraised by setting equation (52) to zero, given by (Lotfy, 2019):

$$pqke^{-(q/r)E} = v \qquad (56)$$

resolving equation for E as:

$$E_{oae} = \frac{r}{q}\,[\ln(pqk) - \ln(v)] \qquad (57)$$

The equations for estimating effort, catch and biomass of OAE in the logistic and exponential models are shown in the Table 5.

Table 5. Equations for estimating OAE, logistic and exponential models.

	Equation	Logistic growth models	Exponential growth models
OAE	Effort E_{oae}	$r(1-v/(pqk))/q$	$r/q[\ln(pqk)-\ln(v)]$
	Catch C_{oae}	$qkE_{oae}(1-qE_{oae}/r)$	$qkE_{oae}\, e^{-(q/r)Eoae}$
	Biomass B_{oae}	$ke^{-(q/r)Eoae}$	$k(1-qE_{oae}/r)$

5. Catch and fishing effort data

The level of production in a fishery is assumed to be a function of the level of fishing effort and stock abundance. Due to defining an appropriate effort index it difficult as not all factor of production can be readily quantifiable, instead, fishing effort is usually expressed in terms of some measurable feature of the fishery, such as days or hours fished, horse power, boat size, number of vessels and others (Pascoe, 1998).

Data on catch and effort were provided by Instituto Socialista de la Pesca y Acuicultura (INSOPESCA) of Venezuela and the Inter-American Tropical Tuna Commission (IATTC).

To analyze stock assessment, the catch in the EPO were expressed of the total production in tons, while the effort was expressed by the boat size (meters) of vessels for the last 26 years (1993-2018). The effort data provided by INSOPESCA and IATTC included horsepower and fishing days too (this category is available from 2000).

In order to estimate independent and dependent variables for surplus production model (logistic and exponential), a regression analysis is applied. Regression analysis is a method to examine a linear relationship between two variables. This analysis provides information by expressing the linear relationship between two variables in the form of an equation. Using this equation, it is possible to estimate the value of the dependent variable Y_i bases on selected values of the independent variables X_i (Lind, Marchal and Wathen, 2018).

Considering catch and effort data, catch per unit effort (CPUE) was calculated. The values obtained from regression analysis of the data corresponding to fishing effort as a boat size of vessels, specifically, coefficients and P-value (with 90% significant level), applying CYP model were significant. The results obtained from regression analysis of data corresponding to fishing effort associated to number of vessels and horsepower were not significant. Due to the lack of data, the effort expressed as a days fished was not consider for analysis stock assessment. Catch, effort and CPUE data of tuna in the EPO from 1993 to 2018 period (26 years) are shown in Table 6.

Table 6. 1993-2018 catch and effort data of Venezuela in the Eastern Pacific Ocean.

Year	Catch (ton)	Effort as boat size (meters)	CPUE (boat size)	Effort as number of vessels	CPUE (No. of vessels)	Effort as days fished	CPUE (days fished)
1993	51,197	1,036.80	49.38	16	3,199.81	-	-
1994	48,548	972.00	49.95	15	3,236.53	-	-
1995	54,608	1,036.80	52.67	16	3,413.00	-	-
1996	67,682	1,036.80	65.28	16	4,230.13	-	-
1997	67,049	1,036.80	64.67	16	4,190.56	-	-
1998	68,722	1,036.80	66.28	16	4,295.13	-	-
1999	71,999	1,090.13	66.05	17	4,235.24	-	-
2000	74,968	1,538.66	48.72	24	3,123.67	4,236	17.70
2001	112,304	1,410.75	79.61	22	5,104.73	2,443	45.97
2002	125,534	1,648.80	76.14	26	4,828.23	1,776	70.68
2003	103,571	1,731.38	59.82	27	3,835.96	3,642	28.44
2004	72,272	1,539.00	46.96	24	3,011.33	1,266	57.09
2005	60,194	1,499.83	40.13	23	2,617.13	1,276	47.17
2006	48,463	1,410.75	34.35	22	2,202.86	1,011	47.94
2007	46,311	1,470.75	31.49	22	2,105.05	1,222	37.90
2008	52,131	1,410.75	36.95	21	2,482.43	1,167	44.67
2009	52,247	1,410.75	37.03	22	2,374.86	965	54.14
2010	36,784	1,090.00	33.75	17	2,163.76	1,059	34.73
2011	46,229	1,166.40	39.63	18	2,568.28	864	53.51
2012	44,747	1,090.00	41.05	17	2,632.18	885	50.56
2013	43,576	972.00	44.83	15	2,905.07	465	93.71
2014	37,464	907.20	41.30	14	2,676.00	942	39.77
2015	35,042	833.63	42.04	13	2,695.54	312	112.31
2016	32,912	907.20	36.28	14	2,350.86	527	62.45
2017	24,402	833.63	29.27	13	1,877.08	339	71.98
2018	26,043	907.20	28.71	14	1,860.21	580	44.90

6. Economic data

The fish prices and the fishing costs are considered two essential keys that can make of economic conditions in a fishery. The change in per capita can have insignificant impact on the financial capability of vessels operating in a fishery and the return from the utilization of fisheries stocks. These (p, v) are stated in real term (US$) (Putasa, 2018).

6.1 Price

Quantities supplied of tuna are one of the factors in establishing the international price of tuna. The kite or skipjack tuna (landed in Bangkok, Thailand) is the reference product for establishing the international price (Bangkok tuna price index), about 64% of the landing levels are extracted from the EPO. A large percentage of the catch is landed in Thailand, due to the huge processing capacity it has (Mendoza, 2003).

According to the internal policies in Venezuela, the tuna price is calculated considering the Bangkok tuna price index (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2018). Real US$ price for tuna followed a similarly steady trend over time (US Inflation Calculator, 2019). The nominal and real price trends for yellowfin tuna are presented in Fig. 6.

The average price of tuna for the last 14 years was estimated US$1,673.33 per ton. The reason for considering a period of 14 years (from 2005 to 2018) was due to the information respect to operating cost has as reference the year 2005, being the based year

2018 (Annual report Ministry of People's Power for Fisheries and Aquaculture of Venezuela, 2018).

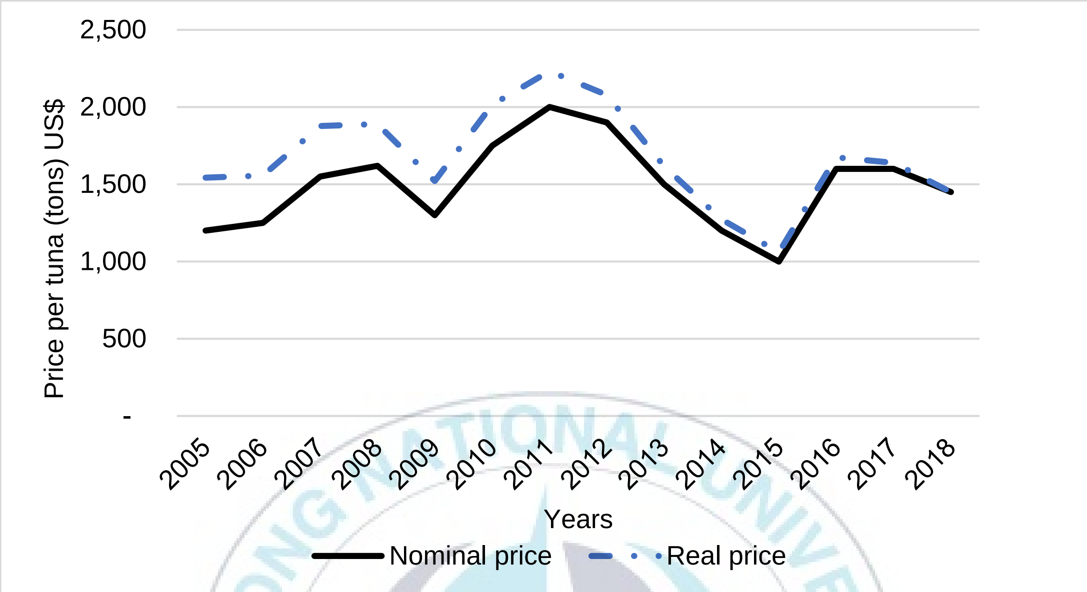

Fig. 6 Real and nominal price of tuna (US$) 2005-2018.

6.2 Cost of effort

The cost of effort for the bioeconomic model can be estimated in two ways: average fleet cost, which combine the costs from the vessels classes comprising the fleet, or optimal cost, which are derived from the vessel class (Clarke, R., Yoshimoto, S., Pooley, S. 1992).

The Venezuelan fleet operating in the EPO is purse seine vessel class and the data was provided by the Ministry of People's Power for Fisheries and Aquaculture and researches from Venezuelan universities (Solari, 2005).

For this research it was considered that unit cost data are a function of catch, no effort, that is:

*w= total cost/catch = total cost /(CPUE*effort)* (58)

which mean a marginal cost of effort, *v= w*CPUE=wqB* (59)

which is apply in the analysis of MSY, MEY and OAE respectively (Pyo, 2001).

The number of days per trip were around 69 days. Once the number of days per trip was obtained, the operating costs for each vessel per trip were calculated. The real operating costs (US$ 707,162.57) include costs for fuel, oil, food, stock replacement, stock maintenance, taxes and labor cost. The amount US$ 707,162.57 covers all the necessary costs for each vessel to carry out its fishing work successfully.

The average fishing days per year is 1,314.58 days. This value was obtained from the sum of the measures of the total of the vessels that carried out fishing work per year. The period 2000-2018 was analyzed, because official data was not available for the period 1993-1999.

The average fishing effort associated to boat size was calculated, during the period 2000-2018, the result being 1,251.51 meters. The period 2000-2018 was taken with the objective of maintaining the uniformity of the fishing data.

Subsequently, the number of trip per year per vessel was determined, resulting from dividing the average days fished per year (1,314.58 days) by the value of the days per trip per vessel (69 days). The average of total catch and the effort associated to: boat size, number of vessels and days fished and CPUE from 2000 to 2018, are shown in the Table 7.

Table 7. 2000-2008 average value catch and fishing effort.

Item	Average
Catch (tons)	56,589
Effort as days fished	1,314.57
Effort as boat size (meters)	1,251.50
Effort as number of vessels	19.368
CPUE (effort as a boat size)	43.58

The number of trips per year was calculated dividing the average of days fished per year (1,314.57) by the number of days per trip (69), results in (19.05), then, the annual operating costs were determined, as a result of multiplying the real operating cost per vessel per trip (US$ 707,162.57) by the number of trips per year per vessels (19.05), the real annual operating cost was calculated at US$ 13,472,779.30.

Cost per unit of catch (w) was calculated as result to divide annual total operating cost (US$ 13,472,779.30) between the catch average (56,589.16 tons), subsequently, the unit cost per unit of catch is US$ 232.750.

Therefore, the cost of effort, *v*, was obtained as result to divided the annual operating cost (US$ 13,472,779.30) by the average fishing effort (1,251.50 meters). The cost of effort is US$ 10,765.22.

The fishing cost details is shown in the Table 8.

Table 8. Venezuela's tuna fishing cost in the Eastern Pacific Ocean.

Item	Total cost (US$)	Total cost (US$)
	Nominal	Real
Annual total operating cost	10,478,536.23	13,472,779.30
Operating cost per trip per vessel	550,000	707,162.57
v (measure cost of effort)	8,372.71	10,765.22

Chapter 4. Results and Discussion

1. Catch per unit effort

According to the data analyzed during the period 1993-2018, in 2001, 2002 and 2003, the data registered highest catch: 112,304 tons, 125,534 tons and 103,571 tons respectively, associated to fishing effort: 1,410.75 meters; 1,648.80 meters and 1,731.38 meters respectively. In 2004 total catch decreased significantly (from 103,571 tons to 72,272 tons), then, in 2008 and 2009 the catch increased again (52,131 tons and 52,247 tons). The lowest level of total catch was registered in 2017 (24,402 tons). The average corresponding to total catch is 56,589 tons.

In the same way, the highest fishing effort was registered in 2003 (1,731.38 meters) with total catch 103,571 tons, while the lowest fishing effort was registered in 2015 and 2017 (833.63 meters) associated to total catch 35,042 tons and 24,402 tons respectively. The total average of fishing effort corresponding to 1,251.51 meters. Since 2003, total annual catch has been decreasing in the same trend that fishing effort associated to boat size (Fig. 7).

Respect to CPUE, the highest CPUE was registered in 2001 (79.61) with total catch 112,304 tons, while the lowest CPUE was registered in 2018 (28.71) associated to total catch 26,043 tons respectively. The total average of CPUE corresponding to 43.58. Since

2003, total annual catch and CPUE has been decreasing in the same trend. According to results, the relationship between effort (associated to boat size) and CPUE is inversely proportional, it means, when the effort increases, the CPUE decreases and vice versa (Fig. 8).

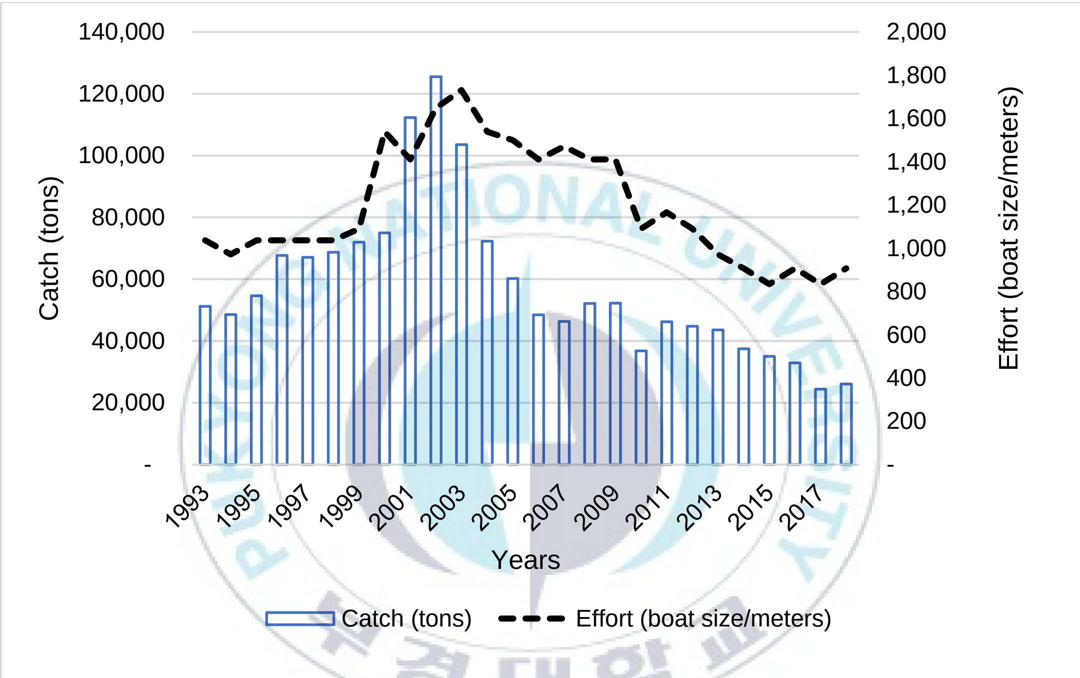

Fig. 7 Annual catch considering effort as boat size 1993-2018.

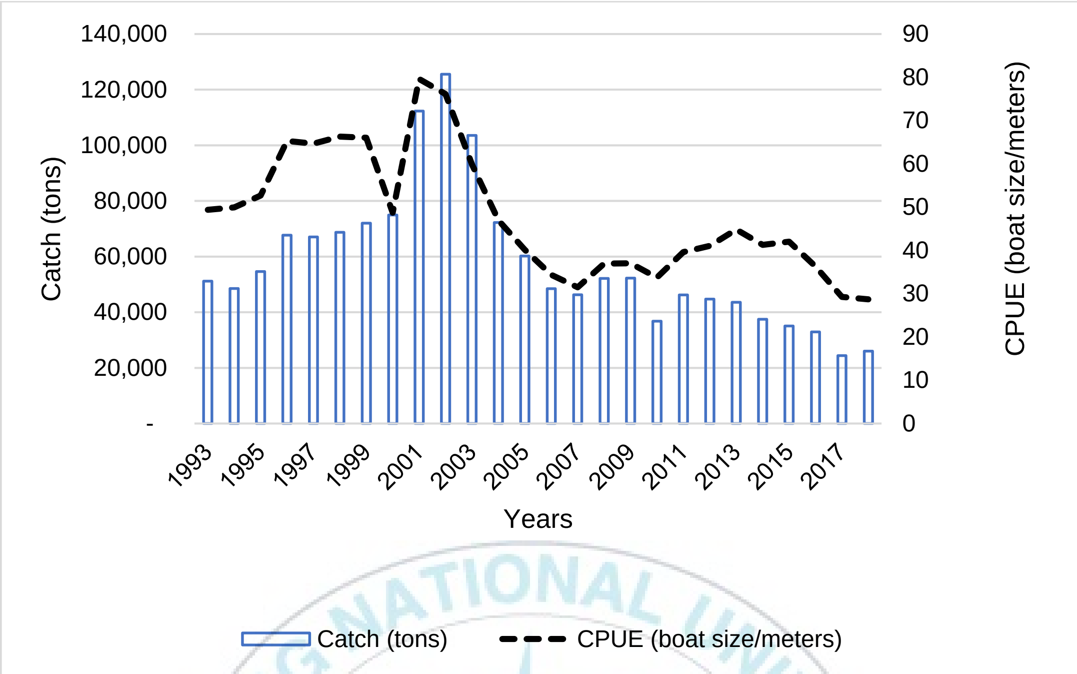

Fig. 8 CPUE considering as boat size 1993-2018.

In general, during 2001-2003, the effort and catch increased due to management policies implemented by the national government relative to support the development of fisheries activity. Nevertheless, since 2004 the number of vessels have been decreasing in the same trend to total catch and fishing effort. Nowadays, the total operating vessels is 14 (the Venezuelan fleet operating in the EPO is composed by 24 vessels). This situation is due to the highest amount for maintenance and operating cost.

2. Annual catch of Venezuela 1993-2018

The trend to annual catches (1993-2018) has been decreasing from 2003, in comparison with annual estimated catch by the same period. According to calculates the trend has important differences. The results of annual catch (1993-2018) are shown in the Fig. 9.

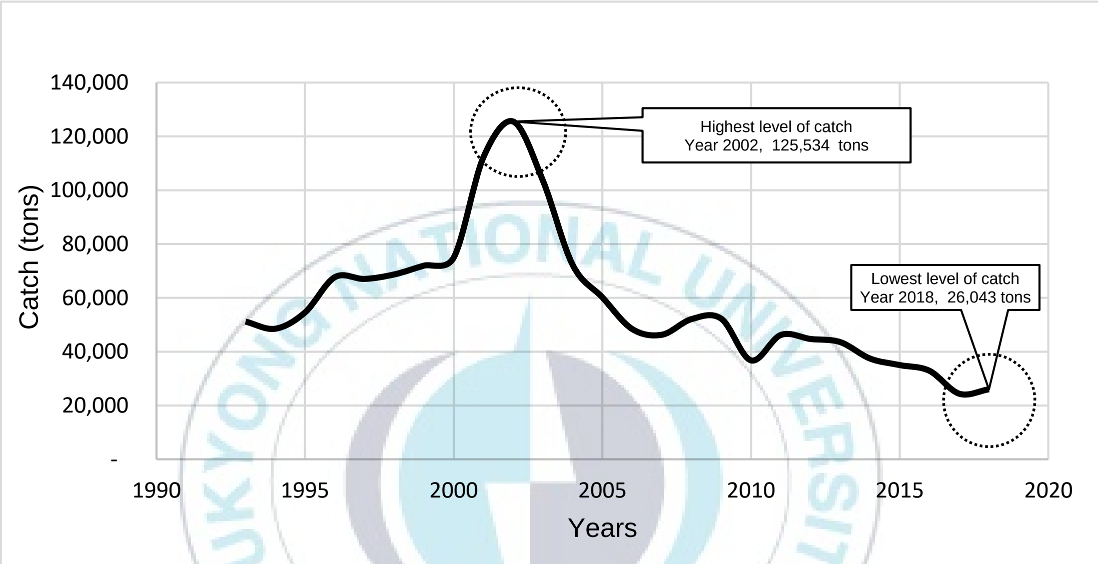

Fig. 9 Annual catch of Venezuela1993-2018.

3. Estimates of surplus production model

The study analyses fishing data (catch and effort) for last 26 years (1993-2018). Each of the model examined (Schaefer, Schnute, WH, Fox and CYP) were applied to estimated biological coefficients. The surplus production model was estimated using regression analysis in Excel program and ordinary least square method (OLS). The regression analysis results of five models are shown in the Table 9.

Table 9. Estimated equations and statistic.

Model	Independent Variables	Values of Parameters Estimated	P-value	Standard Error	R-square	Adjusted R-square	D-W statistic	VIF
Schaefer	Constant	0.028485467	0.828415	0.129800888	0.063862257	-0.025293	1.065437	1.04
	CPUE size	0.001359972	0.446121	0.001751448				
	Total size	-9.61251E-05	0.310573	9.25077E-05				
Schnute	Constant	0.2594183	0.007	0.082369	0.6063	0.5538	1.97411	1.04
	(U+U1)/2	0.00063	0.585	0.0011292				
	(E+E1)/2	-0.0002795	0.000	0.0000584				
Walters and Hilborn	Constant	0.183682	0.155	0.1242097	0.1639	0.0803	1.673048	1.04
	CPUE size	-0.0024208	0.162	0.0016665				
	Total size	-0.0000938	0.314	0.0000908				
Fox	Constant	-0.167864167	0.625364	0.33874951	0.063477373	-0.0257153	1.065768	1.03
	LN (U)	0.067929771	0.449442	0.088135041				
	Total size	-9.49736E-05	0.315112	9.22824E-05				
CYP	Constant	0.709742309	0.033154	0.308982626	0.851732812	0.83612574	1.948392	1.07
	LN (U)	0.857569188	2.71E-09	0.082317762				
	E+E1	-8.60793E-05	0.077281	4.60839E-05				

All models, with the exception of the CYP, have not coefficients with the proper signs and P-value statistically significance at 10% level. The Durbin-Watson test for autocorrelation and the multicollinearity test (VIF) were applied, the results show negative results for autocorrelation and multicollinearity in the five models. R-square or Adjusted

R-square for CYP model show higher than those other models, representing higher explanation power.

The CYP model was the most appropriate model to describe the biological coefficients, with R-Square = 0.851732812; D-W value = 1.948392 (no autocorrelation); 22 observations and VIF = 1.07 (no multicollinearity). The *P*-values shows statistically significance at 10% level for coefficients in CYP model.

The biological coefficients *r, q* and *k* were estimated by surplus production model. The results of the regression analysis of this models were evaluated, and CYP obtained next results: *r*= 0.153386001; *q*=0.000185362; *k*=786,214.05 respectively. The five model in surplus production model estimated *r, q* and *k* are shown in Table 10.

Table 10. Biological parameters estimated in surplus production model.

Parameter	Schaefer	Schnute	WH	FOX	CYP
r	0.028485467	0.027312512	0.18368203	-0.067929771	0.153386001
q	9.61E-05	2.80E-04	9.38E-05	9.50E-05	0.000185362
k	1.05106E+27	3,175,787.32	604,355.03	124,490.49	786,214.05

4. Estimated catch of Venezuela 1993-2018

In order to calculate estimated catch 1993-2018, it was applied the formula (39), according to exponential model. This result was compare with the actual catch data in the same period (1993-2018). The Fig. 10 shows the relationship between actual catch and estimated catch 1993-2018 of Venezuela’s tuna fishery in the EPO.

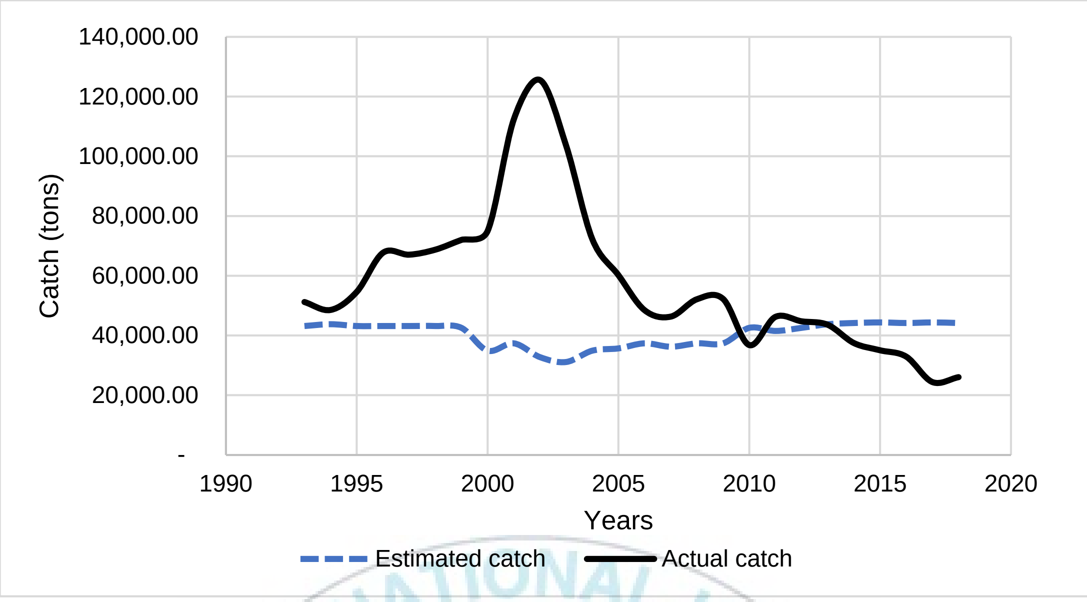

Fig. 10 Actual catch and estimated catch 1993-2018.

5. Theil's *U*- statistic

A popular criterion used in the Theil's *U*- statistic which metric is designed as follows:

$$U = \sqrt{\frac{\sum_{t=1}^{n-1}\left(\frac{\hat{Y}_{t+1} - Y_{t+1}}{Y_t}\right)^2}{\sum_{t=1}^{n-1}\left(\frac{Y_{t+1} - Y_t}{Y_t}\right)^2}} \quad (60)$$

Theil's *U*- statistic is a measure of the degree to which one-time series $(\hat{y})$ differs from another (y). A Theil's *U*- statistic of one implies that the model under consideration and the benchmark model are equally (in) accurate, while the value of less than one implies that the model is superior to the benchmark and vice versa of U>1 (Tendaupenyu and Pyo, 2017).

Determining accuracy of the model Theil's U-statistics is estimated to be 0.64 which implies that estimated catch of the model and annual catch 1993-2018 are represent quite similar (Fig. 10).

6. Estimates of bioeconomic model

A bioeconomic model provides a framework for simultaneously considering breeding, management, and production decisions.

The purpose in managing fisheries is to ensure that the resource is exploited in an optimal level. According to this, there are two targets as the goal of managing fisheries, maximum sustainable yield (MSY) and the maximum economic yield (MEY). The MEY is associated to lower catch level and a higher stock level than the MSY in order to achieve the conservation of fish resources (Pascoe, 1995).

Biological models usually provide an estimate of the MSY and the level of effort associated with that yield. In the bioeconomic model, both the revenue from and cost of harvesting the stock are taken into consideration when estimating the optimal yield, and also provide a means of combining what is known about the biology and the fleet into a single framework for policy analysis. The development of a bioeconomic model is a multidisciplinary task, involving input from biologists, economist, fishery managers and commercial operators (Pascoe, 1995).

It is possible to insert two broad categories in the bioeconomic models: equilibrium models and dynamic models. The equilibrium models provide an indication of long term levels of catch and economic profits according to fishing effort. For the other hand, dynamic models provide an indication of the shorter term effects of changes in fishing effort and economics profits (Pascoe, 1995).

CYP model estimates the MSY and MEY. The results of the model show that MSY and effort for MSY be 44,364.14 tons and 827.49 meters of vessel size (equivalently about 13 vessels). Additionally, the results show that MEY and effort for MEY be 44,087.38 tons and 738.34 meters of vessel size (equivalently about 11 vessels), respectively. For OAE, the result show that OAE and effort for OAE be 16,611.17 tons and 2, 581.01 meters (equivalently about 40 vessels). The values for MSY, MEY and OAE were compared with the average of total catch and the effort associated to: boat size, number of vessels and days fished and CPUE from 2000 to 2018 (Table 7).

According to results, the Venezuela's tuna fishery in the EPO shows over using of effort and over catch, nevertheless, the CPUE must be higher than the average from 2000-2018 (Table 11).

Table 11. Results MSY, MEY and OAE.

Model	Fisheries level	Effort (boat size)	No. vessels	Catch (tons)	CPUE
CYP	MSY	827.49	13	44,364.14	53.61
	MEY	738.34	11	44,087.38	59.71
	OAE	2,582.01	40	16,611.17	6.4

The sustainable yield curve for CYP model 1993-2018 is shown in Fig. 11.

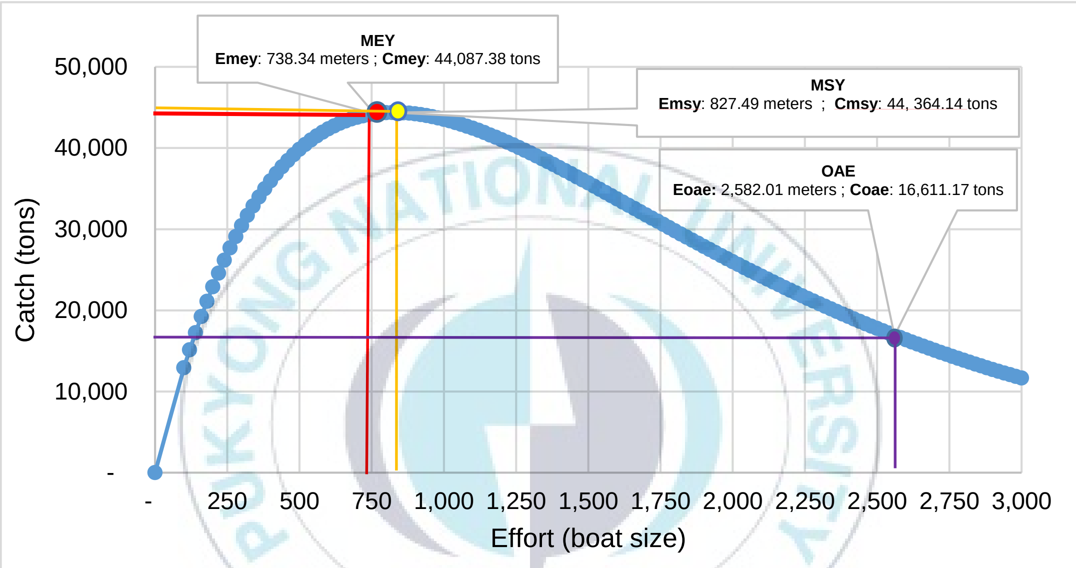

Fig. 11 Curve of estimated yield-effort relationship in CYP model.

The results of MSY and MEY are quite similar, due to the location of total cost function.

In order to obtain the MEY with the maximum net profit (NP), is necessary to subtract the total cost (TC) from the total revenue (TR). The annual total revenue for

Venezuela's tuna fishery in the EPO was estimated by multiplying the average producer price by the catches (Yun and Nam, 2017). Total cost (TC) was estimated by multiplying constant marginal cost of effort (*v)* by the fishing effort.

To achieve US$ 65,824,343.04 of maximum net profit (NP), the fishing effort at the level (E_{mey}) has to maintain 738.34 meters (boat size), with an estimated C_{mey} 44,087.38 tons. The results come from the total revenue (TR) US$ 73,772,735.58 subtracted from the total cost (TC) US$ 7,948,392.53. The results are shown in the Table 12.

Table 12. The condition of fisheries economic at MSY, MEY and OAE level.

Model	Fisheries level	Effort (boat size)	Catch (tons)	Biomass	TR (US$)	TC (US$)	NP (US$)
CYP	MSY	827.49	44,364.14	289,231.99	74,235,846.39	8,908,111.90	65,327,734.49
	MEY	738.34	44,087.38	322,135.20	73,772,735.58	7,948,392.53	65,824,343.04
	OAE	2,582.01	16,611.17	- 1,666,992.61	27,795,969.10	27,795,969.10	0

By increasing the effort level to 2,582.01 meters, at OAE, the operation of total cost will increase until US$ 27,795,969.10. Applying the equation TR-TC, the maximum net profit was found to be zero. This condition is shown in Fig. 12

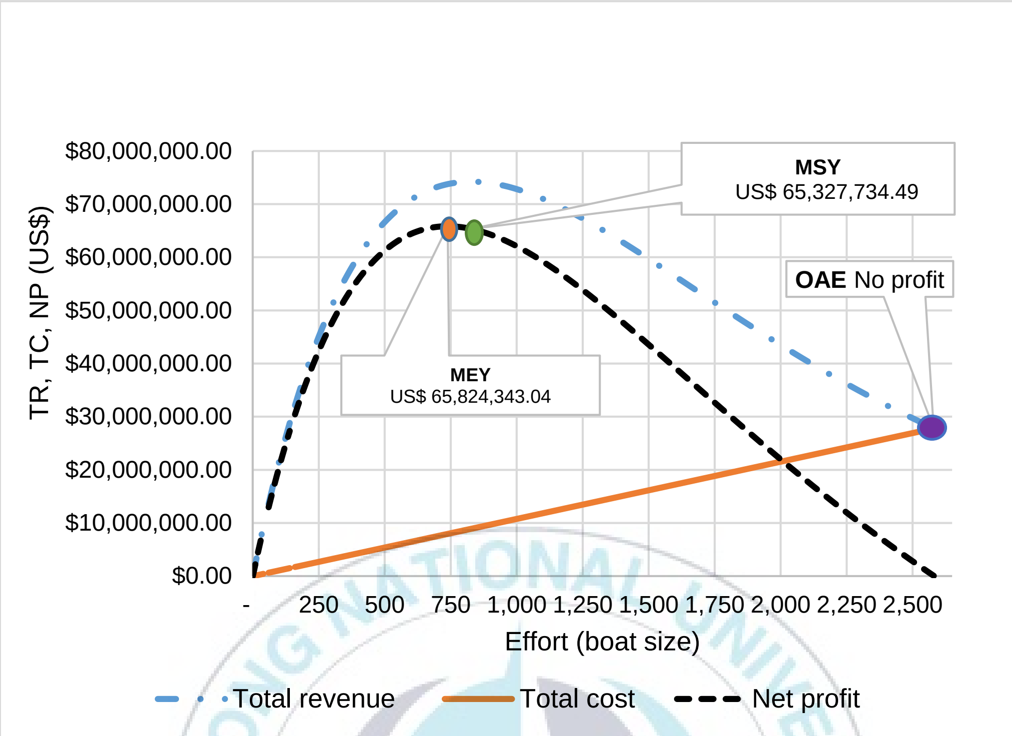

Fig. 12 Curves of total revenue (TR), total cost (TC) and maximum net profit (NP).

Chapter 5. Conclusions

The contribution of fish production in Venezuela from offshore fishing in the EPO is approximately 10%, furthermore, between 80 and 85% of the national production of tuna is generated by tuna fishing carried out in the EPO with the purse seiners.

Despite the enormous potential that Venezuela has in the fishing sector, there are still limitations that prevent its full development.

The commercialization of fishery products constitutes the main problem that blocks the growth of the fishing sector, since fishermen depend very significantly on intermediaries, in many cases they do not have an adequate infrastructure to refrigerate the product, being obliged to sell the product at the price capture at low prices.

The trade of fishery products is carried out through several levels of intermediation, mainly for fresh consumption, those communities that do not have access to means of transport deliver their production to the caverns, in some cases boaters when there are no roads, who transport the product to the wholesale centers that communicate with the local markets by land.

By the bioeconomic model, the study analyses fishing data (catch and effort) for last 26 years (1993-2018), in order to analyse the Venezuela's tuna fishery in the EPO.

The surplus production model allows to estimate the optimum level of effort and catch that produces the MSY and MEY without affecting the biomass stock and economic profit.

Five models (Schaefer, Schnute, WH, Fox and CYP) were applied to determine the biological parameter *r, q, k* and economic situation of Venezuela's tuna fishery in the EPO. According to statistical results, the CYP model development by Clarke, Yoshimoto and Pooley in 1992 was identified as the best model and was applied to describe the state of Venezuela's tuna fishery in the EPO.

The CYP model estimates the MSY, MEY and OAE. MSY and effort for MSY were calculated as 44,364.14 tons and 827.49 meters (equivalently 13 vessels); MEY and effort for MEY were calculated as 44,087.38 tons and 738.34 meters (equivalently 11 vessels); finally, OAE and effort for OAE were calculated as 16,611.17 tons and 2,581.01 meters respectively (equivalently 40 vessels).

Determining accuracy of the CYP model Theil's U-statistics was estimated at 0.70 which implies that estimated catches of the model and actual catches are equally accurate.

The results of the analysis indicate the fishing effort (associated to boat of size) has a similar trend to catch and the biomass is considerably higher, that means Venezuelan management policies relative to reduce fishing mortality and to harvest fisheries resources of the EPO, have been successful.

Even though effort and catch have been declining since 2002 as a result of increasing operating cost, the tuna catch had exceeded MSY and MEY level. Consequently, in order to achieve MEY, MSY and NP, the effort and catch should be reduced by 34 % and 24 %, respectively.

Maintaining MSY and MEY is one of the main objective stated in the conventions of most of Regional Fisheries Management Organizations (RFMOs) including the Inter-American Tropical Tuna Commission (IATTC). Consequently, it is strongly recommended to implement fisheries management policies for decreasing the fishing effort.

The Venezuelan fleet in the EPO is composed by 24, nevertheless, the number of vessels have been decreasing since 2004 (nowadays 14 vessels are operating). In this way, according to results of the model, the number of vessels must be reduced (approximately 11 vessels). This decision could imply unemployment situation, in addition, considering that national government supply a concession to the private sector who operate the Venezuela's fleet in the EPO, it is highly recommended to implement workshop season, in the order to evaluate how avoid negative consequences for fishermen, in this case, it is possible to offer job vacancies in the national fishing industry. The management measures for decreasing fishing effort and subsequently the total catch, must be compatible with each other, that is, the totality of the areas where the activities are carried out, such as the different jurisdictions and management plans.

In estimated surplus production model, it was assumed as static model which provide valuable information to fisheries managers about the long term potential of a fishery and the sustainable levels of catch and profit for given levels of effort. Nevertheless, this static model neglects the change in the stock biomass overtime. Therefore, the further study should be extended to dynamic model which is concerned with the size of the harvestable biomass each year (population dynamics) and the size of the fleet and the level of effort (effort dynamics).

These two components are interlinked in the dynamic models, it means the size of the biomass in any one year is determined by the level of recruitment, natural mortality, growth and the level of fishing, by the other hand, the size of the fleet and the level of effort is largely a function of the profitability of the fleet, which in turn is a function of process, catch levels and the costs of fishing.

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