Thesis for the Degree of Master of Fisheries Science

Bioeconomic Analysis of the Yellowfin Tuna (*Thunnus albacares*) Longline Fishery in Western and Central Pacific Ocean

by

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태평양 중서부의 연승어업 황다랑어에 대한 생물경제 분석

Advisor: Prof. NAM Jong-Oh

by

Marezo Alfathoni Putasa

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List of Acronyms

ABT	:	Albacore Tuna
BET	:	Bigeye Tuna
CMM	:	Conservation and Management Measures
CNM	:	Cooperating Non-Member
CPUE	:	Catch Per Unit Effort
CY&P	:	Clarke, Yoshimoto, & Pooley
DW	:	Durbin-Watson
FAC	:	Finance and Administrative Committee
FAO	:	Food and Agriculture Organization
FFA	:	Forum Fisheries Agency
IATTC	:	Inter-American Tropical Tuna Commission
IUU	:	Illegal, Unreported and Unregulated fishing
JPY	:	Japanese Yen
KOICA	:	Korea International Cooperation Agency
MEY	:	Maximum Economic Yield
MSE	:	Mean Square Error
MSY	:	Maximum Sustainable Yield
NC	:	Northern Committee

NP	:	Net Profit
OAE	:	Open Access Equilibrium
OLS	:	Ordinary Least Square
PIFSC	:	Pacific Islands Fisheries Science Center
PKNU	:	Pukyong National University
RFMOs	:	Regional Fisheries Management Organizations
SC	:	The Scientific Committee
SY	:	Sustainable Yield
STR	:	Sustainable Total Revenue
TC	:	Total Cost
TCC	:	The Technical and Compliance Committee
UN	:	The United Nations
UNCLOS	:	The United Nations Convention on the Law of the Sea
UNDP	:	United Nations Development Program
WH	:	Walter & Hilborn
WCFO	:	Western and Central Pacific Ocean
WCPFC	:	Western and Central Pacific Fisheries Commission
WWF		World Wildlife Fund
YFT	:	Yellowfin Tuna

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Abstract

This research analyzes the stock assessment of yellowfin tuna caught by longline in western and central Pacific Ocean. Time series data catch and effort of yellowfin tuna were used to determine biological coefficients using surplus production model. The five surplus production models were tested for the fishery. The CY&P model which is an exponential growth model, appears as the best model to estimates MSY and fishing effort for MSY (E_{MSY}). Using price and cost data, the MEY and fishing effort for MEY (E_{MEY}) and also fishing effort for OAE (E_{OAE}) were obtained by the bioeconomic model.

The analysis showed the actual catch of yellowfin tuna lies around the MSY. Even though the present fishing mortality had exceeded above the MSY, the present efforts however were still below the effort MSY level, indicating a recovered fish stock. In order to get sustainable maximum rent, the current effort level should be reduced to E_{MEY} level with some management tools such as implementing closure for the fisheries and capacity limit through effort reduction.

Keywords: Yellowfin tuna, Longline fisheries, Surplus production model, CY&P model, MSY, MEY, OAE.

Chapter I. Introduction

1.1. Background

Oceanic tunas are designated as highly migratory species under UNCLOS as they are widely dispersed all over the Pacific Ocean, the Atlantic Ocean, and others from approximately 600N to 600S. Their effective conservation and management is complicated by their migratory/highly mobile nature and the many nations and regions involved in their harvest; hence sustainable management requires cooperation among nations, either directly or through international organizations. Article 64 of UNCLOS underscored the importance of multilateral cooperation for long term and sustainable management of the region's marine resource and the protection and conservation of its ecosystems. The more recent UN Fish Stock Agreement additionally requires that management of these stocks is undertaken by regional of sub-regional fisheries organization (RFMOs). The Western and Central Pacific Fisheries Commission (WCPFC) was entered into force in 2004 as the relevant RFMO in Western and Central Pacific Ocean (WCPO) (UNDP, 2014).

The Pacific Ocean produces approximately 72 percent of global tuna catch, while Indian Ocean and Atlantic Ocean respectively at 18 percent and 10 percent an average during

2012-2014 (FFA, 2015). The WCPO region contributes 58 percent of the harvested tuna species that are commercially viable such as albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), and yellowfin (*Thunnus albacares*). These WCPO tuna resources collectively form the basis of one of the world's largest and most valuable fisheries (Virdin J. et al. 2015). However, the sustainable fishing of shared tuna stock in the world faces a number of threats such as the high demand in fish, population and export, which have substantially increase fishing pressure on marine fishery resource in the past two decades. Tuna fisheries are also threatened by Illegal, Unreported and Unregulated fishing (IUU), compounded by ineffective surveillance and monitoring, and incomplete reporting (UNDP, 2014).

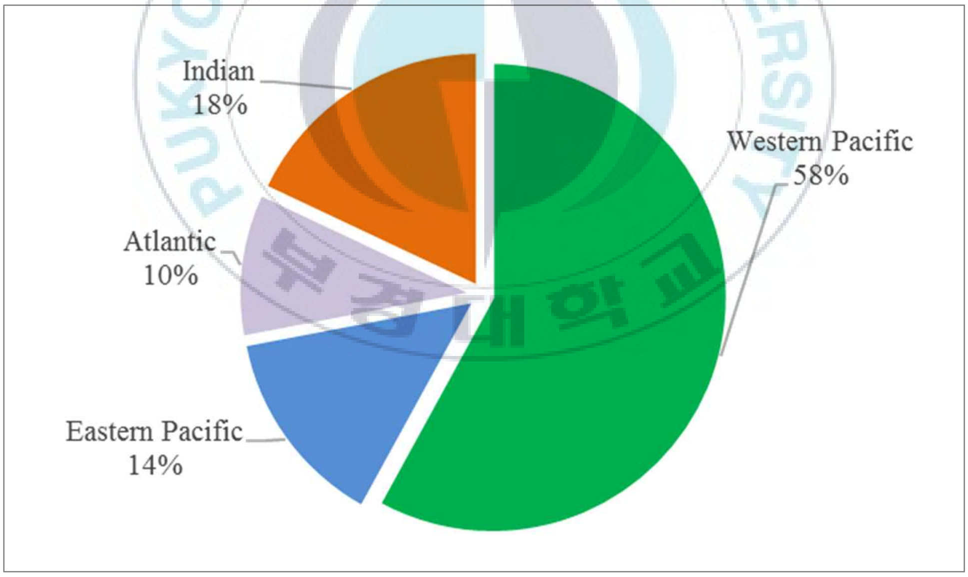

Fig. 1. Global tuna catches by ocean, 2012 – 2014.

Yellowfin is a crucial part of tuna fisheries and one of the most important sashimi-grade species in the WCPO as they are caught with a various gear types with the longline fishery taking most of the adult fish. Harley et al. (2015) stated that longline catch has increased in 2014 by 25 percent from 2013 and this has contributed to the fishing mortality of yellowfin tuna in recent years with increase in catch estimated to reach or go beyond 13 percent of the Maximum Sustainable Yield (MSY). There has been a gradual decline of both biomass and recruitment during the period of the longline fishery with approximately 38 percent of the current spawning biomass reaching the predicted level without any fishing activity. In order to reduce fishing mortality in the WCPO region, WCPFC has considered management measures such as recommending to prevent the increase in catch of yellowfin from 2012 levels which would exceeded the MSY.

Fisheries resources must be understood as limited and dynamic population. Prior to the implementation of fisheries management measures, analysis of the overexploitation of limited resources both biologically and economically should be considered. Pascoe (1995) added that fisheries might be characterized as the connection between the biological (resources) and the economic model of the fishing activity.

Fisheries management is needed to promote sustainable fisheries. Fisheries management may be characterized as part of the government of fisheries. An ideal of fisheries governance might involve government working with industry and other stakeholder to manage fisheries such that they are sustainable and profitable (Barclay et al. 2007). There is no clear and generally accepted definition of fisheries management. However, according to FAO (1997), fisheries management is the integrated process which govern fisheries activities in order to ensure the continued productivity of the resources and the accomplishment of the other fisheries objectives.

Bioeconomic models are a multidisciplinary task, which involve input from biologist, economist, fisheries managers and commercial operators. It provides a focus for collaboration between the different groups, and improves the understanding of the fishery for all concerned. Catch (quota system), effort (input control), and cost (tax system) can be managed by incorporating into the bioeconomic model. Bioeconomic analysis can be a useful tool to determine changes in the tuna stock and economic value that will result from given fishing mortality rates. Thus, it is necessary to study stock assessment in order to obtain data and information as the determination of fisheries management.

1.2. Purpose of Research

This research is focused on tuna longline fishery that harvest yellowfin tuna (*Thunnus albacares*) in the Western and Central Pacific Ocean (WCPO) with the purpose to analyze both the biological and economical condition using bioeconomic model in order to obtain results on Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and

Open Access Equilibrium (OAE) level. This research will further explain in detail the following.

1. Determine the best fit Surplus Production Model which can be applied in yellowfin tuna longline fisheries;
2. Determine the effort and catch at MSY in estimating biological parameters; intrinsic growth rate, catchability coefficient and carrying capacity;
3. Determine the effort levels at MEY, that gives the maximum rent, and at OAE using the economic parameters, price and cost;
4. Identify possible management implications from the fisheries ecological and economic conditions in the research area.

1.3. Framework of research

The conceptual framework of this research is based on the existence tuna species in Western and Central Pacific Ocean (WCPO). This region/ocean provides almost 58 percent of global tuna species such as bigeye, albacore, yellowfin, bluefin, skipjack tuna caught by three main types of tuna fishing gears in the likes of purse seine, longline and pole and line. In this research, focus species is yellowfin tuna that caught by longline.

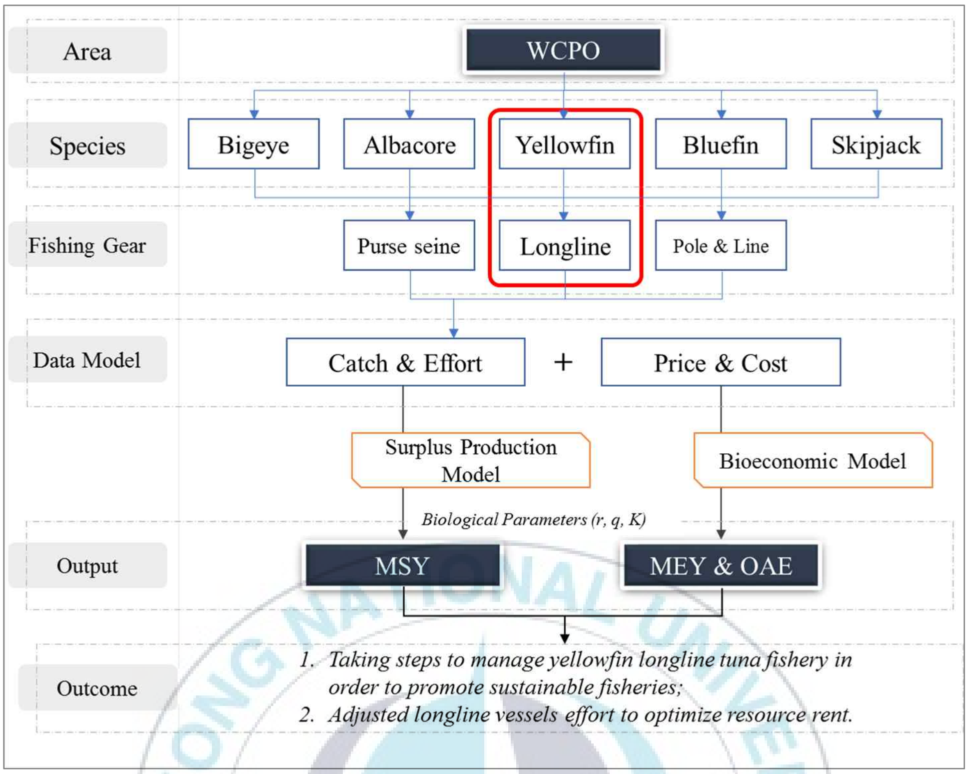

Fig. 2. Conceptual framework of research approach.

Chapter II. Western and Central Pacific Ocean (WCPO) Tuna Longline Fishery

2.1. Western and Central Pacific Fisheries Commission (WCPFC)

The Convention that mentioned in Article 9, established the Western and Central Pacific Fisheries Commission (WCPFC) which signed in 2000 and entered into force on 19 June 2004 in order to ensure through effective management, the long-term conservation and sustainable use of the highly migratory fish stocks of the Western and Central Pacific Ocean (WCPO) in accordance with the 1982 Convention and Agreement (WCPFC, 2010). Moreover, the Convention determines each TAC or total allowable effort within the Convention Area (Parris and Grafton, 2006).

The Commission develops conservation and management measures (CMMs) and resolution. CMMs describe binding decisions relating to CMMs, while resolutions describe non-binding statement and recommendation. Both CMMs and resolutions are addressed to members of the Commission and Cooperating non-member (WCPFC, 2010). Since 1999, a number of resolution and CMMs were developed to mitigate the overfishing of bigeye and yellowfin tuna and to limit the growth of fishing capacity in the WCPO (WCPFC, 2016). One of the CMMs related to yellowfin tuna that as mentioned in CMM 2016-01 about CMM for bigeye, yellowfin and skipjack tuna in the WCPO, the fishing mortality rate of yellowfin tuna is not greater than fishing mortality in MSY level, C_{MSY}, i.e. $C/C_{MSY} \leq 1$.

The Scientific Committee (SC), the Technical and Compliance Committee (TCC), the Northern Committee (NC), and the Finance and Administrative Committee (FAC) are four subsidiary bodies that supports the Commission. Expert fisheries scientists are used by the SC to ensure that best scientific information is available in considering appropriate CMMs. The TCC makes recommendations to the Commission with respect to encouraging, improving, and enforcing by members with the decisions of the Commission. The NC gives recommendation on species found north of 20 degrees north. The FAC gives recommendation on the Commissions budged (WCPFC, 2010).

As stated in Article 3 of the WCPFC Convention (2000), the responsible area of the Commission covers all waters of the Pacific Ocean bounded to the East and to the South as shown in Figure 3.

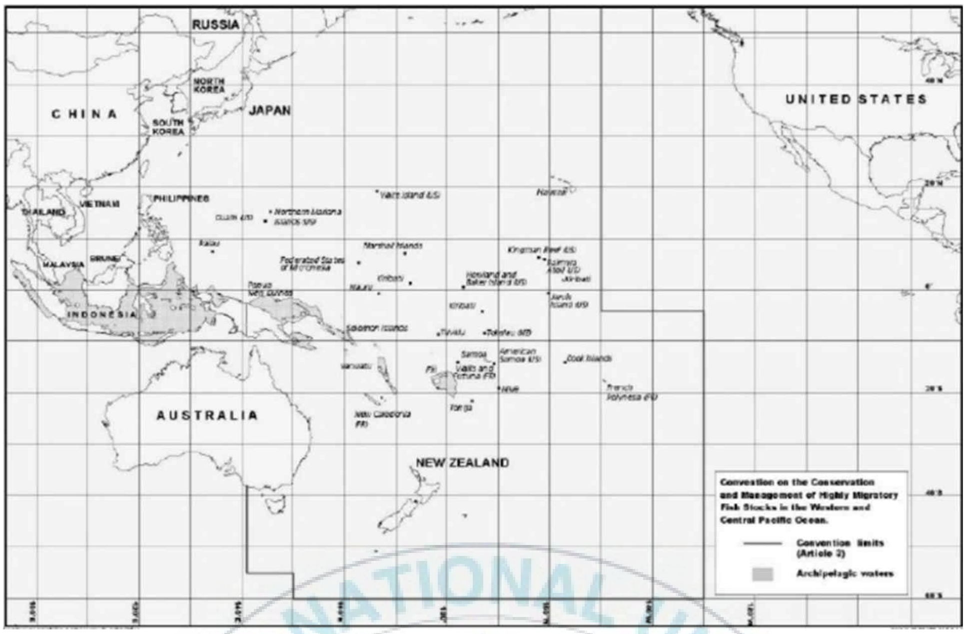

Fig. 3. WCPFC Convention area.

Approximately 20 percent of the Earth's surface lies within the Convention area. The Convention Area overlaps the Inter-American Tropical Tuna Commission (IATTC) area of competence even though the western boundary nationally extends to the east Asian seaboard. The southern boundary extends to 60 degrees south and the northern boundary extends to Alaska and the Bering Sea (WCPFC, 2010).

Included in the Commission are twenty-seven member countries, seven participating territory countries and seven cooperating non-member countries. The Commission members are as follows.

1. Australia,
2. China,
3. Canada,
4. Cook Islands,
5. European Union,
6. Federated States of Micronesia,
7. Fiji,
8. France,
9. Indonesia,
10. Japan,
11. Kiribati,
12. Republic of Korea,
13. Republic of Marshall Island,
14. Nauru,
15. New Zealand,
16. Niue,
17. Palau,
18. Papua,
19. New Guinea,
20. Philippines,
21. Samoa,
22. Salomon Islands,
23. Chinese Taipei,
24. Tonga,
25. Tuvalu,
26. United States of America,
27. Vanuatu.

The Participating Territory Countries that also have rights at the commission meeting consist of the following.

1. American Samoa,
2. Commonwealth of Northern Mariana Islands,
3. French Polynesia,
4. Guam,
5. New Caledonia,
6. Tokelau,
7. Wallis and Futuna.

Cooperating Non-Member (CNM) Countries that have fishing interest in the region but do not sign the WCPFC Convention consist of the following.

1. Ecuador,
2. El Salvador,
3. Mexico,
4. Panama,
5. Liberia,
6. Thailand,
7. Vietnam.

CNM status is a clever mechanism to address issues of non-members and provides a middle ground between international obligations and concerns of WCPFC members to close 'full' fisheries to new entrants. Although still non-parties, CNM commitment to abide by WCPFC means they effectively carry same obligation as member, without all right such as participation in decision making.

In order to ensure the long-term sustainability of highly migratory fish stock in the convention area, each member country within the commission adopts management measures to effectively conserve and manage stocks at levels that would produce MSY. Each member also takes measures to ensure that its national and fishing vessels owned or controlled by its nationals fishing in Convention Area, comply with the provisions of this Convention. In addition, each member shall collect and share complete and accurate data concerning fishing activities on such as vessel position, fish target or non-target and fishing effort (WCPFC, 2000).

Moreover, Suspita (2013) compared each RFMO allocation system and stated that WCPFC determines and negotiates its allocation decisions in using data various data including stock assessment, time series catch data, aspiration of developing countries and by catch production. Included in this decision is the permitting smaller fleets to expand within a development plan submitted to Commission. The Commission gives reduction in quotas of catch as a result of non-compliance issues from Illegal Unregulated and Unreported (IUU) fishing activity.

2.2. Yellowfin Tuna (*Thunnus albacares*) Longline Fishery Catch Status

Yellowfin tuna (*Thunnus albacares*) are found throughout the tropical and temperate Pacific Ocean. The majority catch tends to be taken in tropical areas, especially in the western parts of region, with smaller amounts in seasonal subtropical fisheries. Fishermen targeting yellowfin often look for temperature front or breaks, upwelling, current convergences, eddies, seamount, and flocks of feeding seabirds and the best season to catch yellowfin tuna is in the spring and summer months (Beverly, 2003).

Historically, yellowfin tuna was principally caught by domestic and distant-water longline vessel (Langley et al. 2009). Although yellowfin can be caught in deeper water, longline caught yellowfin is usually taken in water from near the surface down to 25º – above the thermocline. This layer of water is called the mixed and intermediate layer. The preferred temperature range for yellowfin tuna is 18º to 28ºC, which roughly corresponds to temperatures found in the mixed and intermediate layer (Beverly, 2003).

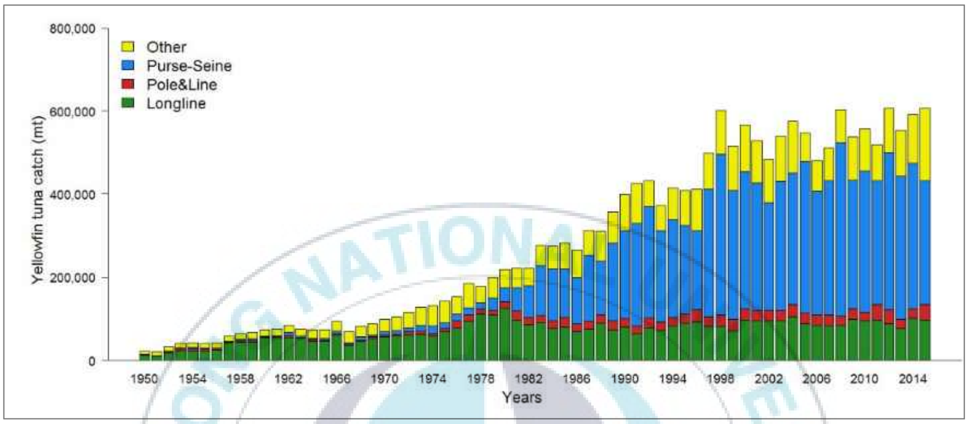

Fig. 4. Yellowfin tuna production by fishing gear in WCPO (Pilling et al, 2016)

Davies et al. (2014) stated that the annual yellowfin tuna catches in the WCPO increased from 100,000 mt in 1970 to about 600,000 mt in recent years, with the exception of a record catch of 650,000 mt in 2008. Since the early 1980s, the yellowfin tuna fishery has become increasingly dominated by purse seiners that catch the majority of the yellowfin tuna catches (61 percent in 2012), while the longline fleet accounted for 16 – 20 percent of the catch in recent years, primarily in the equatorial regions.

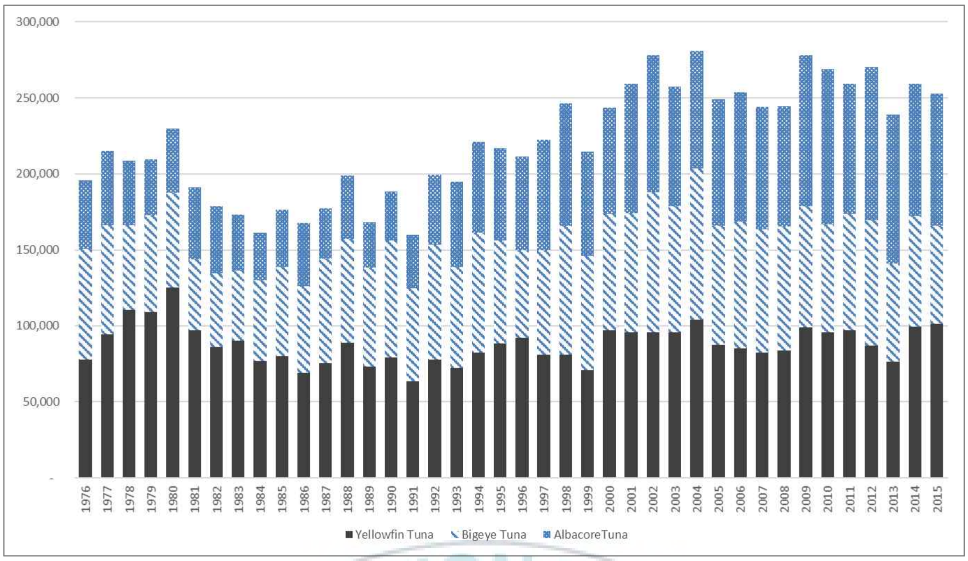

Fig. 5. Tuna production by longline in the WCPO.

The longline fishery provides the longest time series of catch estimates for the WCPO, with estimates available since the early 1950s. The longline fishery typically accounts for around 10 to 12 percent of the total WCPO tuna catch which competes against the much larger landed catch value of purse seine (Beverly, 2003).

The annual total longline tuna catch has been relatively stable during the past 25 years, with total catches generally between 130,000 and 200,000 mt and comprising almost entirely yellowfin, bigeye and albacore tuna. Catches in recent years have been at record levels, but the species composition (35 percent albacore, 35 percent yellowfin and 30 percent bigeye tuna in recent years) has changed significantly from the 1970s (18 percent albacore, 57 percent yellowfin tuna and 25 percent bigeye tuna in 1980), as a result of change of changes in fleets, operational areas and targeting practices (Beverly, 2003). Yellowfin tuna accounts for 40 percent of the overall tuna catch, followed by bigeye tuna with 32 percent and albacore with 28 percent respectively.

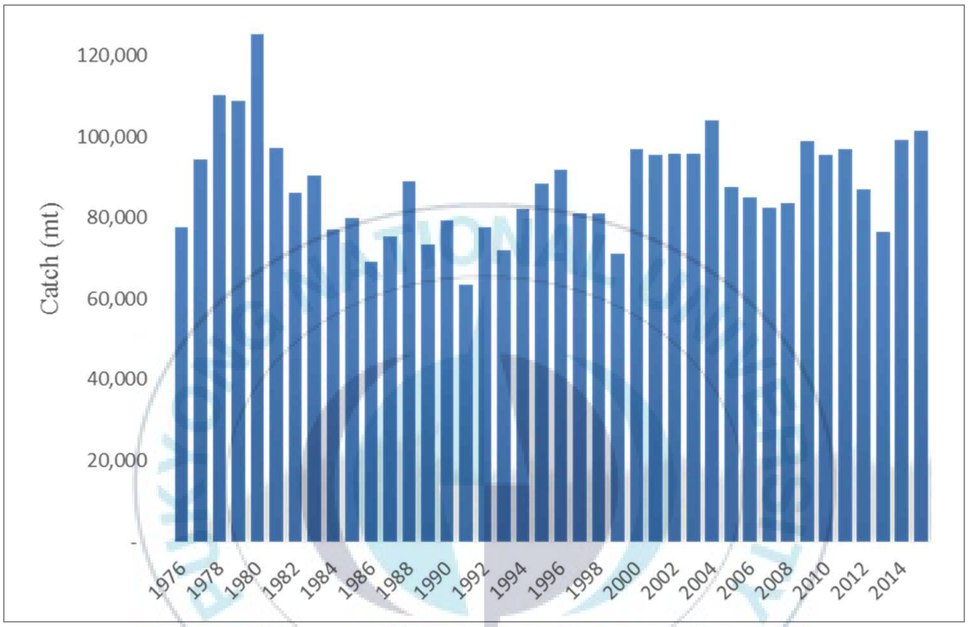

Fig. 6. Yellowfin tuna production by longline in the WCPO.

According to Davies et al., (2014), the level of yellowfin tuna catches by longline peaked in the late 1970s – early 1980s (120,000 mt), presumably partly related to changes in targeting practices by some of larger fleets. Joseph J. (2003) added that the large increases in the 1970-1980 period were the result of expansion of the fisheries in WCPO. Since then, there was a general decline in catch but the its steadily picked up, however this level of catches well below that of the late 1970s – early 1980s. As seen from the Figure 6, the total overall catch by the longline fisheries increased rapidly from an average 78,000 mt in 1990s to an average 92,000 mt by the 2015. Overall, the average yellowfin tuna catches remain relatively constant between 70,000 mt and 90,000 mt.

In 2014, the estimated value of the longline production was 18 percent higher than the previous year's due to the increases in both the average longline price (6 percent) and catch volume (11 percent). The 6 percent price increase in USD price for longline caught product was driven by strong increase in Japanese Yen (JPY) prices for sashimi caught product which more than offset the 8 percent depreciation of the JPY (FFA, 2015).

In line with estimated value and catch of total tuna longline fishery, the yellowfin production value and catch significantly increased from the previous year about 32 percent and 34 percent respectively. The total tuna and yellowfin catches and values during 2010 – 2015 in the WCPO are shown in Table 1.

Table 1. Production and production value of yellowfin tuna compared with total tuna in WCPO, 2010 – 2014.

Year	Yellowfin Tuna		Total Tuna	
	Catch (mt '000s)	Est. Catch Value (US$ millions)	Catch (mt '000s)	Est. Catch Value (US$ millions)
2010	94	774	270	1,816
2011	97	879	260	2,014
2012	87	769	272	2,068
2013	76	601	243	1,431
2014	102	792	269	1,685

Source: FFA, 2015

Chapter III. Methodology of Research

3.1. Approach Model

3.1.1. Surplus Production Model

Surplus production models are generally used in fisheries literature to find biological coefficients. Pascoe (1995) added these models are derived from catch and effort data. The catch and effort data can be gathered frequently using logbooks by fishermen.

The Schaefer (1957) model, Fox (1970) model, the Schnute (1977) developed by Schaefer model, and CY&P (1992) developed by Fox model, are commonly used. The Schaefer, Schunte and Walter and Hilborn models have logistic yield-effort relationship while the Fox and CY&P models follow exponential yield-effort relationship or a Gompertz curve (Richard, 1959). Both models are based on the steady-state relationship between stock size, fishing effort, and yield.

The Schaefer and Fox models are invalid for non-equilibrium conditions and may not represent the dynamic nature of catch and effort interaction (Schnute, 1977). Schnute (1977) modified the Schaefer model using an integration procedure. Clarke, Yoshimoto, and

Pooley (1992) using a taylor approximation was modified by the fox model. The Schaefer, Schnute, WH, Fox, and CY&P models are shown in Table 2.

Table 2. Estimating equation for surplus production models.

No	Model	Equation
		Logistic Growth Models
1	Schaefer	$(U_{n+1} - U_{n-1}/(2U_n) = r - (r/qK)\ (U_n) - q\ (E_n)$
2	Schnute	$\ln\ (U_{n+1}/U_n) = r - (r/qK)\ ((U_n + U_{n+1})/2) - q\ ((E_n+E_{n+1})/2)$
3	Walter & Hilborn (WH)	$(U_{n+1} - U_{n-1}) - 1 = r - (r/qK)\ U_n - qE_n$
		Exponential Growth Models
4	Fox	$(U_{n+1} - U_{n-1})/(2U_n) = r\ \ln\ (qK) - r\ \ln\ (U_n) - q\ (E_n)$
5	CY&P	$\ln(U_{n+1}) = (2r/(2+r))\ \ln(qK)] + ((2-r)/(2+r))\ \ln(U_n) - (q/(2+r))\ (E_n+E_{n+1})$

Source: Clarke, Yoshimoto and Pooley, 1992 (p119-120)

To determine the parameter r, q, and K, ordinary least square (OLS) with time series of catch and effort data are used. The overall goodness of fit of the estimated function can be assessed using the P-Value and the confirmation of the sign of each coefficient.

As the unfished population grow, the population will reach the natural 'carrying capacity', K, because, aside from natural variability around this level, population growth stops and growth rate of individual fish slows down. Intrinsic growth rate, r, is the increase in number of organism per unit of time, and will be greatest at intermediate levels. (Cochrane, K.L. (ed.). 2002).

The Logistic Growth Model - Maximum Sustainable Yield (MSY) [1]

MSY can be sustained for indefinite period of time due to its large yield and this happens at the level where the natural annual net growth of the fish stock is maximized.

The basis of the Schaefer model, like all subsequent surplus production models, is assumption that biomass next year, B_{y+1}, is determined by biomass this year, B_y, the growth in biomass over the year, G_y, and the level of catch, C_y. That is

$$B_{y+1} = B_y + G_y - C_y \quad (1)$$

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

$$G = r B (1 - B / K) \quad (2)$$

where K is the carrying capacity and r is the intrinsic growth rate (both constant) of the environment. Hence, when B = K, growth is zero.

Another key assumption of the Schaefer model is that catch per unit effort is proportional to the stock biomass, given by

$$U = q B \quad (3)$$

[1] Pascoe, S. 1995. Bioeconomic models and modelling: Theory and Practice. CEMARE, University of Portsmouth, 171pp.

where U is the catch per unit effort (CPUE) and q is the catchability coefficient. Catch is equal to the CPUE (U) times the level of effort.

$$C = q\,B\,E \qquad (4)$$

where E is the level of fishing effort.

In the equilibrium, the catch is equal to the growth rate so that $B_{y+1} = B_y$, equating equation 2 and 4

$$qEB = rB\left(1 - \frac{B}{K}\right)$$

$$B = K\left(1 - \frac{q}{r}E\right) \qquad (5)$$

Substituting equation 5 into equation 4, an expression can be derived relating the sustainable level of catch to the level of effort

$$C = \alpha E - \beta E^2 \qquad (6)$$

where $\alpha = q\,K$ and $\beta = q^2K / r$

The effort level is resulted in the maximum sustainable yield (MSY), E_{MSY}, could be obtained by setting the first order derivative, dC/dE, to 0:

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

$$E_{MSY} = \frac{r}{2q} \qquad (7)$$

The maximum sustainable yield (C_{MSY}) itself is determined by substituting equation 7 into catch equation 6, giving

$$C_{MSY} = q\left(\frac{r}{2q}\right)K\left(1 - \frac{q}{r}\cdot\frac{r}{2q}\right)$$

$$C_{MSY} = \frac{rK}{2}\left(\frac{1}{2}\right)$$

$$C_{MSY} = \frac{rK}{4} \quad (8)$$

The Exponential Growth Model - Maximum Sustainable Yield (MSY) [2]

An exponential growth models based on the Gompertz growth function are the logistic growth curve assumed in the Schaefer model as alternative, given by

$$G = r\,B \ln(K / B) \quad (9)$$

Unlike the logistic growth curve, which is parabolic with maximum growth occurring at K/2, the exponential growth curve is skewed.

A surplus production model based on such a growth assumption was developed by Fox (1970). As with the Schaefer model, the sustainable yield is equivalent to the growth of the population, given by

$$C = r\,B \ln(K/B) \quad (10)$$

Expecting that catch per unit of effort is proportion to the biomass, equation 10 can be re determined as

$$C = \frac{rU}{q}\left[\ln\frac{U_\infty}{q} - \ln\frac{U}{q}\right] \quad (11)$$

where U_∞ is the catch per unit effort (CPUE) that would occur if the stock was not exploited (U_∞ = q k) and U is, again the mean catches per unit of effort. Expanding out the right-

[2] Pascoe, S. 1995. Bioeconomic models and modelling: Theory and Practice. CEMARE, University of Portsmouth, 171pp.

hand side results in the cancellation of the ln(q) terms so that equation 11 can be simplified as

$$C = \frac{rU}{q}[\ln U_{\infty} - \ln U] \quad (12)$$

dividing equation 12 through by U result in

$$E = \frac{r}{q}(Ln\, U_{\infty} - LnU\,) \quad (13)$$

where E is, again the level of effort expended in the fishery. This could be remake to create

$$LnU \;= Ln\, U_{\infty} - (q/r)\, E \quad (14)$$

Exponential equation 14, the mean catch per unit effort in the Fox model can be conveyed as

$$U = U_{\infty}\; e^{-\left(\frac{q}{r}\right)E}$$

and hence catch can be conveyed as

$$C = U_{\infty}\, E\; e^{-\left(\frac{q}{r}\right)E} \quad \text{or}$$

$$C = \;qkE\;\; e^{-\left(\frac{q}{r}\right)E} \quad (15)$$

By the first order condition, the effort level of maximizes catch is obtained in the Fox model

$$\frac{dC}{dE} = qk\, e^{-\left(\frac{q}{r}\right)E}\left(1 - \frac{q}{r}E\right) = 0$$

Dividing both side by $qk\, e^{-\left(\frac{q}{r}\right)E}$ and solving the resulting equation for E gives

$$E_{MSY} = \frac{r}{q} \quad (16)$$

3.1.2. Bioeconomic Model

The basic bioeconomic model is a useful vehicle to introduce various biological and economic concepts. This model incorporates both the biological and economic parameters of a fishery through the models (Thunberg et al., 1998). At any point in time, harvest is a function of fishing effort and size of the fish stock. For any given population size, higher the effort, larger is the harvest (Anderson, 1986).

The Logistic Growth Model – Maximum Economic Yield (MEY) [3]

The logistic growth model used by Schaefer and the resultant catch and effort relationship was implicitly by Gordon (1954), who used it to develop in of the first bioeconomic models of fishery as following.

$$M\alpha x\, \pi = TR - TC$$

$$\pi = P.Q - c.E$$

$$\pi = P(\alpha E - \beta E^2) - c.E$$

$$\pi = P.\alpha E - P\beta E^2 - c.E \quad (17)$$

From this, the effort level in the maximum economic yield, E_{MEY}, can be discovered using the first order condition

$$\frac{d\pi}{dE} = P\alpha - 2P\beta E - c = 0$$

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[3] Pascoe, S. 1995. Bioeconomic models and modelling: Theory and Practice. CEMARE, University of Portsmouth, 171pp.

$$2P\beta E = P\alpha - c$$

$$E_{MEY} = \frac{P\alpha - c}{2P\beta}$$

$$E_{MEY} = \frac{P\alpha}{2P\beta} - \frac{c}{2P\beta}$$

$$E_{MEY} = \frac{\alpha - \frac{c}{P}}{2\beta} \quad (18)$$

Open Access Equilibrium (OAE) [4]

The open access equilibrium (OAE) occurs when all rents have been dissipated, such that P=0. The effort level of OAE can be estimated by setting equation 17 to zero, giving.

$$TR - TC = 0$$

$$P.\alpha E - P\beta E^2 - c.E = 0$$

$$P.\alpha - P\beta E - c = 0$$

$$P\beta E_{OAE} = P.\alpha - c$$

$$E_{OAE} = \frac{P.\alpha - c}{P\beta}$$

$$E_{OAE} = \frac{\alpha - \frac{c}{P}}{\beta} \quad (19)$$

[4] Pascoe, S. 1995. Bioeconomic models and modelling: Theory and Practice. CEMARE, University of Portsmouth, 171pp.

The Exponential Growth Model - Maximum Economic Yield (MEY) [5]

Similarly, as with the Gordon-Schaefer bioeconomic model, total revenue (R) in the Fox model can be determined as a fishing effort function by multiplying equation 15 by price, p.

$$R = pqkE \ \ e^{-\left(\frac{q}{r}\right)E} \tag{20}$$

Total cost (C) is again derived as a function of effort

$$C = cE \tag{21}$$

Total rent (P) in the fishery is given by subtracting equation 21 to equation 20

$$P = pqkE \ \ e^{-\left(\frac{q}{r}\right)E} - cE \tag{22}$$

From this, the level of effort that produces the maximum economic yield, E_{MEY}, can be found using the first order condition for profit maximization,

$$\frac{dP}{dE} = pqk \ e^{-\left(\frac{q}{r}\right)E} \left(1 - \frac{q}{r}E\right) - c \tag{23}$$

E_{MEY} cannot easily be expressed as a function of the model parameters due to the exponential function as compare to the related equation in the Gordon-Schafer model. The relation can be best expressed as

$$E_{M\,EY} = \frac{r}{q}\left[1 - \frac{c}{pqk} \ e^{\left(\frac{q}{r}\right)E_{m\,ey}}\right] \tag{24}$$

[5] Pascoe, S. 1995. Bioeconomic models and modelling: Theory and Practice. CEMARE, University of Portsmouth, 171pp.

Open Access Equilibrium (OAE) [6]

The open access equilibrium occurs when all rents have been dissipated, such that P=0. As with the Gordon-Schaefer model, the effort level in open access equilibrium could be estimated by setting equation 22 to zero, giving

$$pqk\ e^{-\left(\frac{q}{r}\right)E} = c \qquad (25)$$

Again, the left-hand side of equation is the average revenue per unit of effort (R/E), while the right-hand side is the average cost per unit of effort, (C/E). solving equation for E gives

$$E_{OAE} = \frac{r}{q}[\ln(pqk\ ) - \ln(c)] \qquad (26)$$

Equations for both logistic and exponential growth models are summarized in Table 3. These equations involve effort, catch, biomass and net rent of each MSY, MEY and OAE.

Table 3. Equation of static and dynamic bioeconomic models.

Level	Parameter	Logistic Growth Mode	Exponential Growth Model
Catch	Equation	qkE(1-qE/r)	qkE $e^{-(q/r)\ E}$
MSY	Effort(E_{MSY})	r/2q	r/q
	Catch (C_{MSY})	Kr/4	$qKE_{MSY}\ e^{-(q/r)\ Emsy}$
	Biomass (B_{MSY})	k(1-qE_{MSY}/r)	k e-(q/r) E_{MSY}
	Net.rent (π_{MSY})	pC_{MSY}-vE_{MSY}	pC_{MSY}-vE_{MSY}
MEY	E_{MEY}	r(1-v/(pqK))/(2q)	r/q[1-(v/pqK)$e^{(q/r)Emey}$]
	C_{MEY}	(Kr/4) [1-(v/(pqK))2]	qkE_{MEY}/ exp (E_{MEY} q/r)

[6] Pascoe, S. 1995. Bioeconomic models and modelling: Theory and Practice. CEMARE, University of Portsmouth, 171pp.

Level	Parameter	Logistic Growth Mode	Exponential Growth Model
	B_{MEY}	$C_{MEY}/(qE_{MEY})$	$C_{MEY}/(qE_{MEY})$
	π_{MEY}	$pC_{MEY}-vE_{MEY}$	$pC_{MEY} - vE_{MEY}$
OAE	E_{OAE}	r(1-v/(pqk))/q	r/q[LN(pqK)-LN(v)]
	C_{OAE}	qkE_{OAE} $(1-qE_{OAE}/r)$	qkE_{OAE} $e^{-(q/r)Eoae}$
	B_{OAE}	$Ke^{-(q/r)Eoae}$	$K(1-qE_{OAE}/r)$
	π_{OAE}	p C_{OAE} v E_{OAE}	p C_{OAE} v E_{OAE}

Source: Heedong, P. 2016

3.1.3. Price, Fishing Cost and Production value rate

Ex-vessel fish prices (price received by operator), fishing cost and catch rate are the three keys determinant of economic conditions prevailing in a fishery. Change in each can have significant impact on the financial viability of vessels operating in a fishery and the return generated from the exploitation of fish stocks (Skirtun, M. et al., 2015). Fish prices and fishing costs are specified in real term (USD).

Price

Real USD price for yellowfin imports to Japan followed a similarly steady trend over time. The nominal and real price trends for yellowfin tuna are presented in Figure 7.

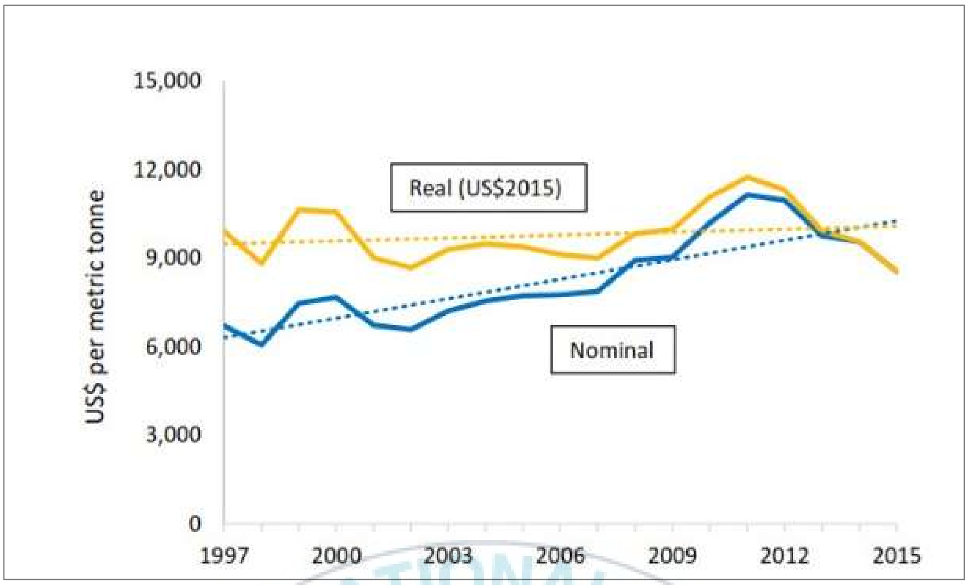

Fig. 7. Real and nominal prices for Japanese yellowfin imports from Oceania.

(**Source:** www.custom.go.th and www.customs.go.jp/toukei/info.tsdl_e.htm)

The average price of yellowfin tuna in 2014 was estimated to be about US$8,235 per mt which was accounted to the fresh and frozen markets. The other average tuna prices were US$2,876 per mt for albacore and US$ 9,395 per mt for bigeye tuna. Yellowfin tuna were estimated to contribute 46.46 percent of the average revenue from tuna longline, followed by bigeye tuna and albacore with 42.24 percent and 11.30 percent respectively over the period 1976 to 2015.

Table 4. Price of tuna caught by longline in US$ per metric ton, 2013 – 2014.

Longline	Albacore		Bigeye		Yellowfin	
	2013	2014	2013	2014	2013	2014
Fresh (US$ per mt)	2,512	2,876	10,934	9,855	9,773	9,563
Frozen (US$ per mt)	2,512	2,876	8,776	8,935	6,469	6,907
Average	2,512	2,876	9,855	9,395	8,121	8,235

Source: FFA, 2015

Fishing Cost

Hand and Forau (1997) stated the information about fishing cost per trip per vessel, and number of fishing trips per year is used to determine the unit cost of effort of every vessel per year. In according to FFA (2015), fuel is the most important operational cost across all fleets, subject to the largest fluctuations across all cost category and hence a major determines in the change in fishing cost over time.

The fishing cost data was acquired from an economic data collection program in Hawaii-based longline fisheries by Pacific Islands Fisheries Science Center (PIFSC) economists. The data is comprised of seven variable cost items commonly arising in Hawaii longline trips. Non-labor cost items include unit price, quantity used, and total costs of diesel fuel, engine oil, bait, ice, and total costs for gear, provisions, and communications (Kalberg, K. O., and M. Pan. 2015).

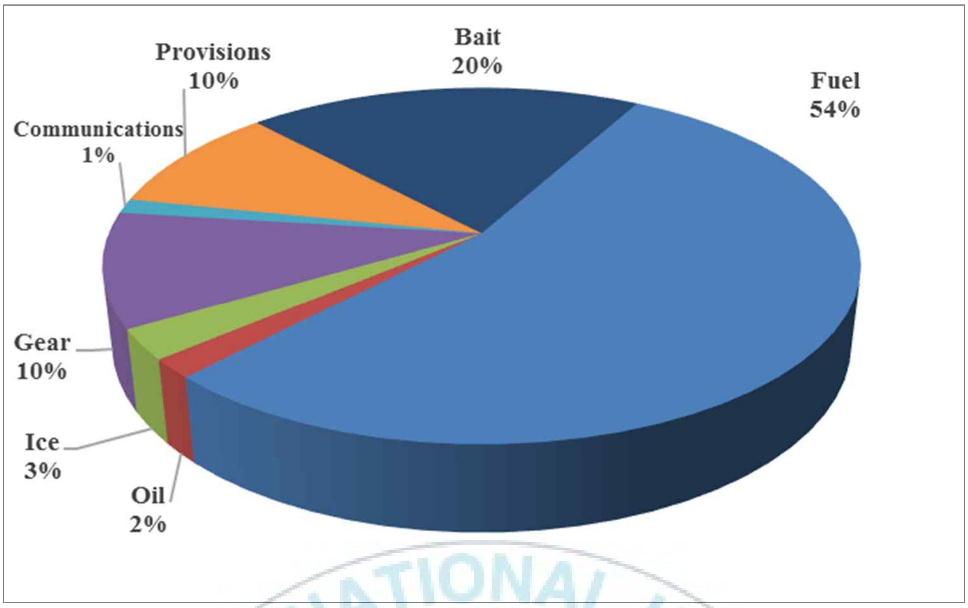

Fig. 8. The composition of average cost item (non-labor items) per trip period 2011-2012.

The average cost (non-labor items) of tuna longline vessel per trip was estimated at $30,700 in 2012. The data requested on the trio summary forms include cost data for fuel, bait, and other miscellaneous expenses. During the period 2004-2012, the average cost (non-labor items) per trip in the Hawaii tuna longline fishery were more than double, from $13,800 per trip to $30,700 per trip, due mainly to the increase in fuel price. In 2004, fuel cost made up about 45 percent of the total trip cost (non-labor items). However, in 2012, when the average yearly fuel price reached a high of $3.90 per gallon (the price paid by fishermen; the AAA price was $4.78/gallon), about 54 percent of the trip costs (non-labor items) were from fuel (Kalberg, K. O., and M. Pan. 2015).

Table 5. The average fishing cost of tuna longline vessel, 2012.

Cost Category	Average Cost Per Trip (US$)	Average Cost Per Year (US$)
Labor	24,735.43	173,148.00
Non-Labor	30,700.00	214,900.00
Fuel	*16,583.25*	*116,082.75*
Oil	*530.00*	*3,710.00*
Ice	*840.00*	*5,880.00*
Gear	*3,197.25*	*22,380.75*
Communications	*405.00*	*2,835.00*
Provisions	*2,983.25*	*20,882.75*
Bait	*6,161.25*	*43,128.75*
Total	US$55,435.43	US$ 388,048.00

Source: Kalberg, K. O., and M. Pan. 2015

The annual cost of fishing operation was estimated based on the average fishing cost of tuna longline vessel per trip in 2012. Depending on the size, longline vessels normally do the fishing operation around 45 days per trip. Given US$55,435 as the average fishing cost of tuna longline vessel per trip in 2012 times 7 trips per year, assuming this is the number of fishing trip taken, the average fishing operation cost was found to be US$388,048 per year. This cost is determined to calculate MEY and OAE level.

Production value rate

The distribution of longline catch between species compared to the corresponding distribution of the values differ significantly in the longline fishery. During the period 1976 – 2015 the contribution of production for the yellowfin tuna was 40 percent of the total catch, leaving albacore with 28 percent, and bigeye with 32 percent. In line, during the same period, the average of tuna production value showed yellowfin contributed 47 percent, albacore with 11 percent and bigeye tuna with 42 percent.

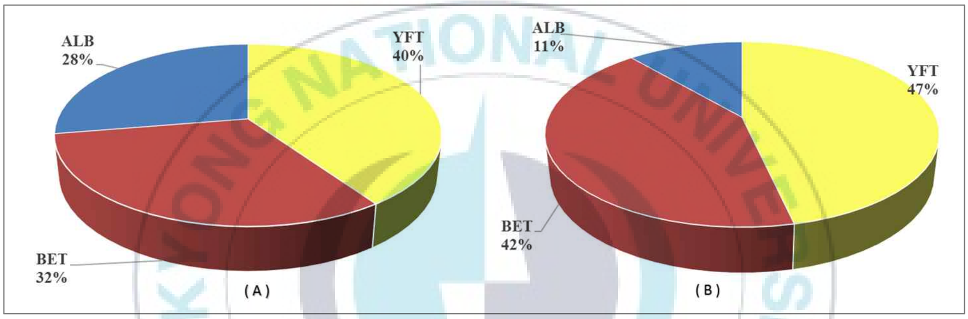

Fig. 9. (A) The distribution of longline production by species period 1976 – 2015; (B) The distribution of longline production value by species period 1976 – 2015.

3.2. Data Source

To analysis stock assessment in this research, time series data were obtained from WCPFC Tuna Fishery Book 2015 which include a time span of forty (40) years of catch-effort target species data set from 1976 to 2015. Catch of yellowfin tuna were expressed by total production in weigh, while the efforts were expressed by the number of vessel participating in the WCPO using tuna longline. Catch and effort data of yellowfin tuna caught by longline during 1976-2015 period are shown in Table 6.

Table 6. Catch and effort data of yellowfin tuna caught by longline, 1976-2015.

Year	Yellowfin Tuna Production (metric tons)	Number of Boat (Unit)
1976	77,570	3,196
1977	94,414	3,222
1978	110,202	3,562
1979	108,910	3,727
1980	125,113	3,837
1981	97,114	3,744
1982	86,149	3,453
1983	90,259	3,345
1984	76,988	3,428
1985	79,973	3,612
1986	68,999	3,603
1987	75,407	3,796
1988	88,855	3,559
1989	73,306	3,318

Year	Yellowfin Tuna Production (metric tons)	Number of Boat (Unit)
1990	79,300	2,847
1991	63,512	2,522
1992	77,739	3,684
1993	72,055	4,069
1994	82,184	4,301
1995	88,306	4,150
1996	91,887	3,692
1997	81,065	4,134
1998	81,077	3,994
1999	71,023	3,903
2000	96,851	3,875
2001	95,540	3,985
2002	95,644	4,015
2003	95,712	3,453
2004	104,059	3,121
2005	87,417	3,088
2006	84,994	2,961
2007	82,434	2,640
2008	83,637	2,514

Year	Yellowfin Tuna Production (metric tons)	Number of Boat (Unit)
2009	98,944	2,432
2010	95,521	2,582
2011	96,961	2,864
2012	86,976	2,726
2013	76,478	2,747
2014	99,181	2,796
2015	101,326	2,983

The overall catch of yellowfin tuna in the WCPO is reflected in the statistics of the FAO area 71, and to a lesser degree, area 61 (Suzuki, 1994). The annual catch of yellowfin tuna by longline was accounted about 70 - 100 thousand tons or 35 - 45 percent total catch of longline fishery.

Chapter IV. Result and Discussion

4.1. Catch per unit effort

The yellowfin tuna fisheries of the Western and Central Pacific Ocean are probably the most substantial and diverse in the world. The yellowfin catch by the longline fishery was the largest until end 1970s in the Western and Central Pacific Ocean (Suzuki, 1994). In addition, Suzuki (1988) described the development of the longline fishery in the Pacific as follows the operation of the (Japanese) longline was confined to the northwestern Pacific and did not last throughout the year in and before the 1940s.

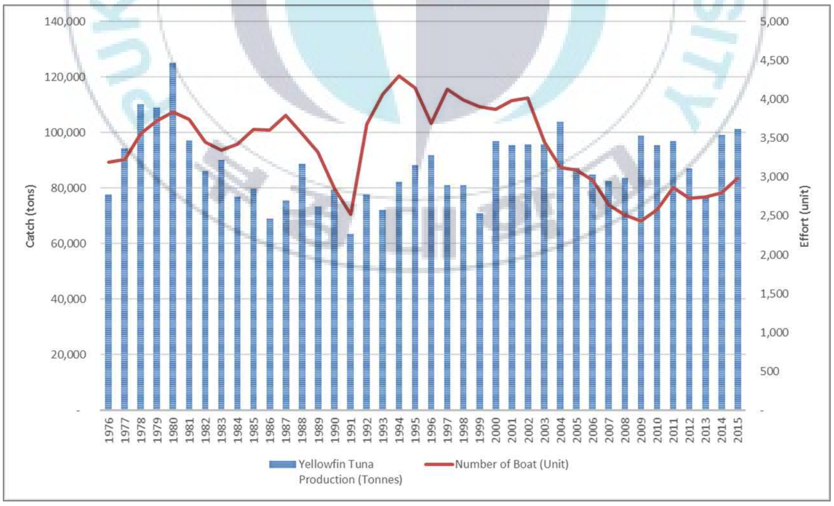

Fig. 10. Trend in catch and effort of YFT longline fisheries in WCPO, 1976 – 2015.

According to Chang et al., (2011), starting in the 1960s, several national promotion programs were implemented to strengthen the longline fleet. Total catch by the tuna longline fishery (including the offshore and distant water) increased rapidly from 8,000 mt in 1960 to an average 25,000 mt by the mid-1960s. After 1967, when construction of the largest harbor for distant water fishing vessels was completed, the catch further increased to 80,000 – 120,000 mt by 1980. During this period, the first vessel equipped with super cold freezers (lower than -60^{o}) were built (Hu, 2004), and began to target tropical tuna species (mainly BET and YFT) for Japanese sashimi market.

The time series of catch and CPUE in the yellowfin longline fishery exhibits a fluctuated pattern. Initially, from early 1980s to 1990s effort levels were high and catch rates low. Catch rates declined as effort levels increase year by year and the stock depleted in 1990s. However, starting from early 2000s CPUE went up and peaked up of 40.68 mt per unit vessel in 2009, then relatively stable in the five years after with the exception 2012 and 2013 which saw a downward. According to Chang et al., (2011), the factors cause change in CPUE such as change in the species target, fishing season and fishing ground. Catch per unit effort (number of fish per unit vessels) of yellowfin tuna taken by all longline vessel that participated in WCPO during period 1976 to 2015 are shown in Figure 11.

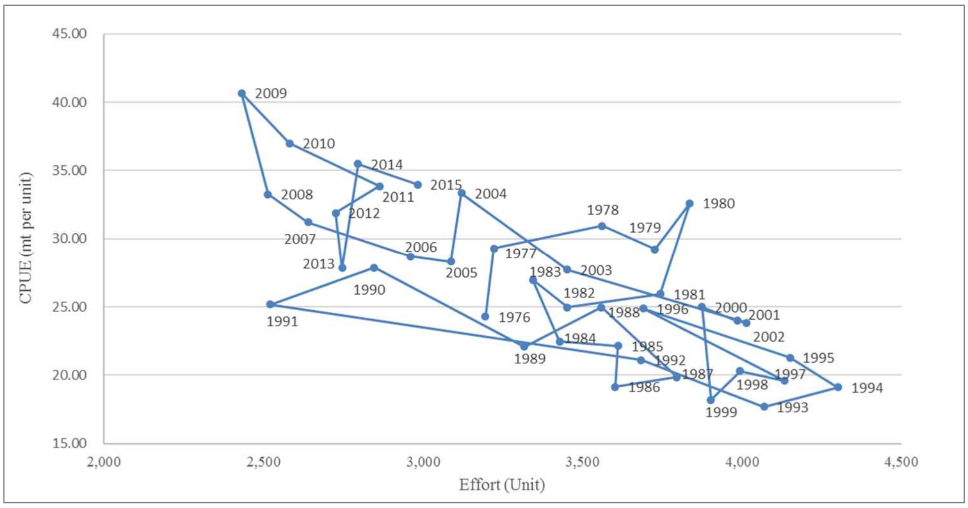

Fig. 11. Trend in catch and catch per unit effort of yellowfin tuna longline fisheries in WCPO, 1976 – 2015.

The correlation coefficient between the two variables (effort and catch) was estimated to be -0.7496 using Pearson's Correlation that calculated by excel (CORREL function). The correlation is negative when some values decreases as the other increases.

4.2. Estimates of Surplus Production Model

Several surplus production models were applied to the Western and Central Pacific Ocean (WCPO) yellowfin tuna longline fishery. The data catch and effort of yellowfin tuna was then used to determine biological coefficients in the assessment.

The models used ordinary least squares (OLS) regression in excel. In initial analyses, a number of outliers were identified by examining the standardized residual. The critical value for the standardized residual with 39 observations was 2.0244 at the 5 percent significance level. From Figure 12, it can be seen that a number of observation exceeded this value. In particular, 1999 was problematic for the Schunte. The existence of outlier may be indicative of either problem in the data or the use of an inappropriate functional forms of models. The regression results of five models are shown in Table 7.

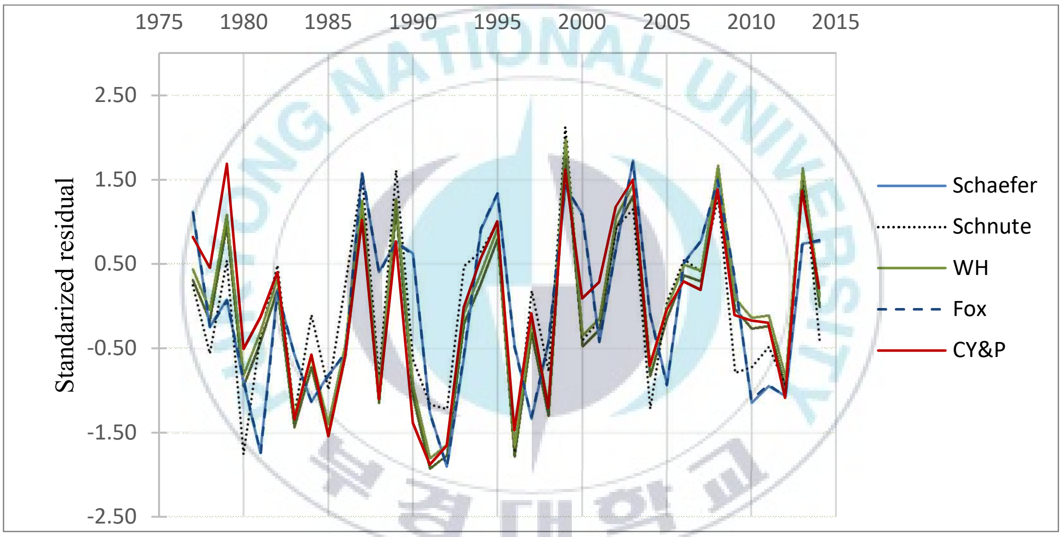

Fig. 12. Identification of outliers in yellowfin tuna longline fishery regressions.

Table 7. Statistical value of the Schaefer, Fox, Walter and Hilborn, the Schnute and CY&P for yellowfin tuna longline in WCPO.

	Parameter	Schaefer	Schnute	WH	Fox	CY&P
	R^2	0.01046053	0.00373890	0.12273100	0.01001739	0.64053157
	Adj. R^2	-0.04608458	-0.05160894	0.07399383	-0.04655305	0.62056110
	DW	1.320181	2.068414	2.024791	1.648865	1.857533
	Obs.	38	39	39	38	39
P-value	Intercept	0.574824061	0.736553133	0.121799735	0.565196893	0.003635941
	X1 (CPUE)	0.55570734	0.719153536	0.045622752	0.564634717	0.002161211
	X2 (Effort)	0.598601193	0.747987329	0.339463152	0.60572671	0.024703607

Schaefer, Schunte, Fox, WH, and CY&P appeared to estimate valid biological parameter and reasonable economic results for yellowfin tuna longline fisheries. Statistically, CY&P model was the best fit model to explain biological parameter with the data an $R^2 = 0.6405$ with 39 observations and 38 degrees of freedom ($p<0.05$) compared to them of the other models.

The coefficient variables (intercept, CPUE, and Effort) were checked for each surplus production model. The CY&P variable results were significant at the five percent level whereas intercept and CPUE variables were significant at the one percent level.

To support CY&P as the best fit model, Mean Square Error (MSE) were tested. MSE measures the ability of model to estimate catch. This is estimated as the average of the squared difference between the observed and estimated values (Gujarati, 1995). MSEs are estimated for each model from the estimated and actual catch series in Figure 13. The CY&P model had the lowest MSE, suggesting that the estimates of catch from this model were, on average, better than those estimated using other models.

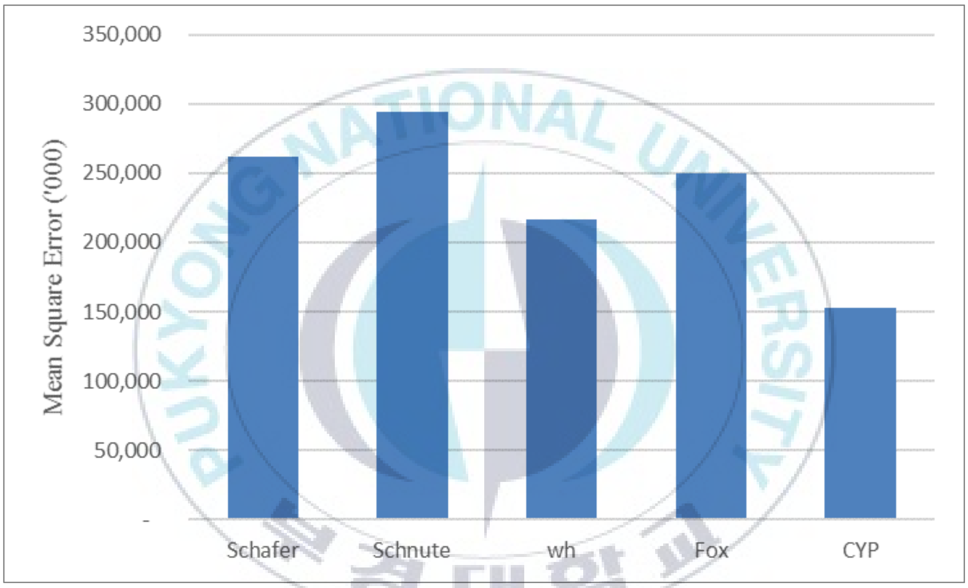

Fig. 13. Mean Square Error of the models in yellowfin tuna longline fishery.

On the basis of the statistic criteria, the CY&P model was found to have the highest R^2, significant at 5% level, the lowest relative standard error and the lowest MSE. Given this, CY&P model was the best fit model to explain yellowfin tuna longline fisheries.

The next step involves the calculation of "r" (intrinsic growth rate), "q" (catch ability), and "K" (carrying capacity). The result of the regression outputs of all models was used to estimate the parameters r, q, K respectively.

Because the complex structure of the five models, exact value of K could not be obtained directly. So, by using r and q values in an equation and CPUE coefficient in goal seeking in Excel, K values were obtained for the Schaefer, Fox, Walter and Hilborn, and Schnute models. For the CY&P model, to get r, q, K values, like for the previous four models, equations were arranged for r, q, K values. The complete parameters are showed in Table 8.

Table 8. Biological parameters estimated by the Schaefer, Fox, Walter and Hilborn, the Schnute and CY&P for yellowfin tuna longline in WCPO.

Parameter	Schaefer	Schnute	WH	Fox	CY&P
r	-0.13947113	-0.14750194	0.58176567	-0.06506961	0.65048747
q	-0.00002352	-0.00002497	0.00006414	-0.00002305	0.00019676
K	-2371144	-2201318	696658	-3379049	374033
E_{MSY}	2964.4	2953.8	4535.0	2822.9	3306.0
C_{MSY}	82676.5	81174.7	101322.9	80886.9	89506.4

The five models estimated coefficient r, q, and K, as the best model the CY&P model obtained the three coefficients r = 0.65048747, q = 0.00019676, and K = 374,033. The yield-effort relationship for the five surplus production models with actual catch and effort for yellowfin tuna in WCPO from 1976 to 2015 are showed in Figure 14. From the yield-effort curve comparison of five models, three models (WH, Fox and CY&P) were relatively closed to actual catch.

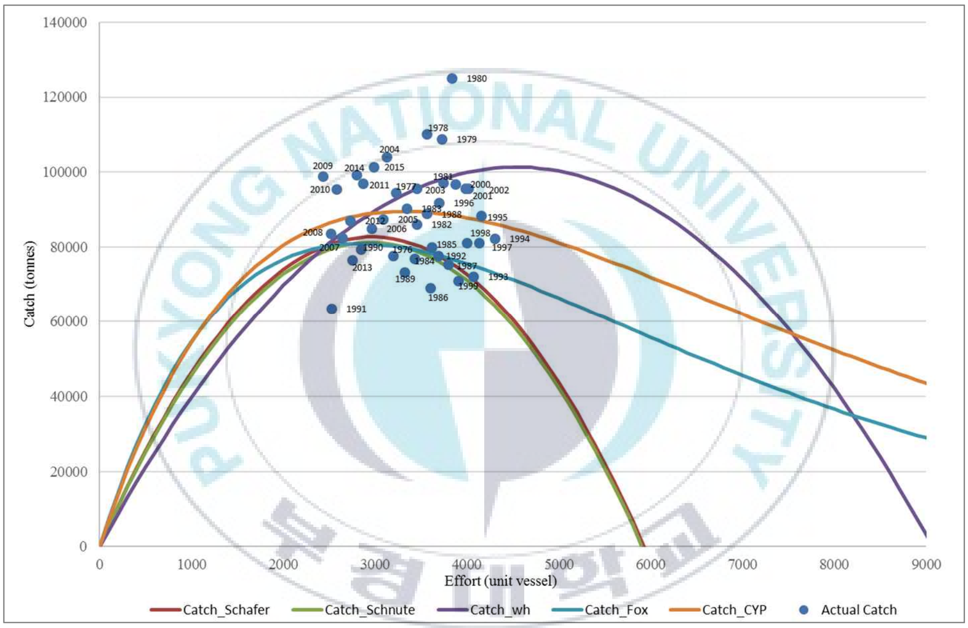

Fig. 14. Yield-effort relationship comparison for the five models.

CY&P model was used to describe the yellowfin tuna longline fisheries condition since it was found to be the most reliable out the five models examined. As seen on the yield-effort relationship of CY&P model in Figure 15, the actual catch lies around the MSY. E_{MSY}, fishing effort at maximum sustainable yield level, was estimated to be 3,306 unit vessels. And, C_{MSY}, catch at maximum sustainable yield, was estimated to be 89,506.4 metric tons (mt) catch then biomass in MSY level was estimated to be 137,598 metric tons. MSY is the greatest level of catch that can be removed on an indefinite basis without causing the stock to decline further.

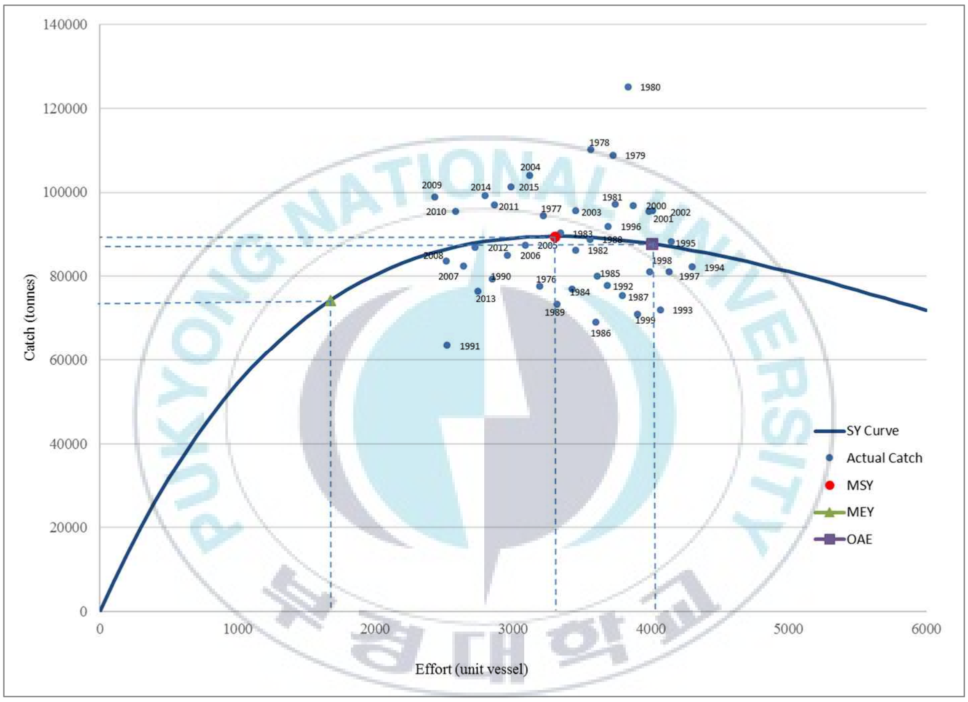

Fig. 15. Yield-effort relationship for CY&P with MSY, MEY, and OAE level.

The historical of exploitation yellowfin tuna longline fisheries in the mid-1970s until the latest 1990s exceeded the MSY level. Even though yellowfin tuna catches declined, fishing effort looks to have increased. These trends indicated that the fishery was biologically overfished. In the mid-2000s until 2015, the fishing effort was significantly reduced to below E_{MSY}, this resulted generally in observed positive trends of catch and stock biomass of yellowfin tuna. However, this condition still must manage strictly because the present level close to MSY level.

In the recent five years, the average CPUE obtained was 32.65 mt per vessel which was greater than the CPUE at MSY level with a value of 27.07 mt per vessel. This CPUE index showed the relative abundance in fish stock. Meanwhile, the average five-year value of fishing mortality was 92,184 mt with an effort of 2,832 unit was observed to have exceeded around 1.03 times above the MSY, indicating a recovered fish stock. In detail, from 2014 to 2015, the fishing mortality of yellowfin tuna longline fishery was 1.12 times greater than the catch rate at MSY level. In contrast, from 2012 to 2013, it was 0.91 times smaller than the fishing mortality rate at MSY level. The effort level responsible for this catch was close to E_{MSY}.

This condition was supported by the Scientific Committee from its latest assessment of yellowfin tuna which was conducted in 2014 using the fishing data from 1952 to 2012 for the WCPO region. However, Harley et al, (2015) obtained overall fishing mortality of yellowfin tuna caught by all three-fishing gears (longline, purse seine, and pole and line) was found to be around 0.72, which indicated that overfishing was not occurring but current effort is close to E_{MSY}, so the SC recommends no increase in effort for yellowfin tuna.

In order to manage yellowfin tuna fisheries in the WCPO region, WCPFC has considered management actions to reduce fishing mortality for example recommending to prevent the catch increasing of yellowfin from 2012 levels which would exceeded the MSY (Harley et al., 2015).

4.3. Estimates of Bioeconomic Model

Price and cost can be incorporated relatively easily into the surplus production model to derive a simple equilibrium bioeconomic model. From this model, estimates of the maximum economic yield (MEY) can be derived. Similarly, the level of effort that procedures the maximum economic yield and also the amount of effort that is likely to occur in the long run under open access (OAE) can also be estimated.

To achieve US$309,651,466 of maximum rent (π) or Maximum Net Profit (NP), the effort level (E_{MEY}) should be maintained around 1,674 unit vessels with an estimated C_{MEY} of yellowfin tuna of about 74,253 metric tons. This corresponded to the total revenue (TR) of 611,475,735, which when subtracted by total cost (TC) 301,824,270 will give the NP. Theoretically, the maximum rent at MEY level should be greater than at that of MSY level.

Table 9. The condition of fisheries economic at MSY, MEY, OAE level for yellowfin tuna longline fisheries in WCPO.

Fisheries Level	Vessel (Unit)	Catch (ton)	TR (US$)	TC (US$)	NP (US$)
MEY	1,674	74,253	611,475,735	301,824,270	309,651,466
MSY	3,306	89,506	737,085,162	596,019,195	141,065,967
OAE	4,008	87,751	722,631,889	722,631,889	0

However, in the 2014 catches of yellowfin tuna have reached higher level of net revenue of around US$ 312 million at effort levels higher than E_{MEY}. One possible contributing factor to increased catches beyond MSY level could be recovery productivity of fish stock from reduced the effort over the past years.

By increasing the effort level to around 4,008 vessels at OAE, the operation cost also increased to US$ 722,631,889. Using the equation TR – TC, the net profit was found to be zero. This is consistent with the open access condition TR – TC = 0, as illustrated in Figure 16.

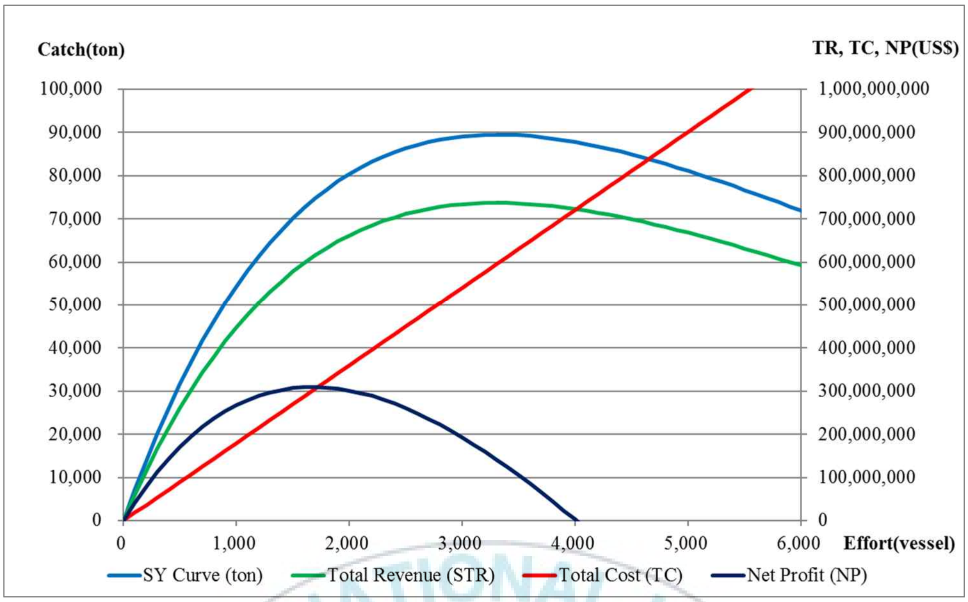

Fig. 16. Sustainable Yield (SY) Curve, Sustainable Total Revenue (STR), Total Cost (TC), Net Profit (NP) of the Yellowfin tuna longline fisheries are estimated by CY&P model.

Chapter V. Conclusion

Surplus production model described yellowfin tuna longline fisheries condition during time research 1976 – 2015 with relatively limited biological and economic data requirement; catch and effort data. The five models were explored to determine which model come to be the best for biological and economic analysis for yellowfin tuna longline fisheries in Western and Central Pacific Ocean. Based on the statistical results and other assessment, the CY&P model which was introduced by Clarke, Yoshimoto, and Pooley in 1992, was applied to explain the condition of this fishery. However, a more advance model must be applied for future studies to thoroughly analyze this fishery from the current surplus production model being used.

The present exploitation of yellowfin tuna caught in 2015 by longline contributes 40% (101,326 mt) of the total longline catch that was among the highest over the past ten years. The recent last years of yellowfin tuna catch had exceeded MSY level but the fishing effort were still below effort at MSY due to recovery of fish stock as well as proper management. According to CMM 2016-01, the Conservation and Management Measure for yellowfin and other tuna, in the Western and Central Pacific Ocean states that the fishing mortality rate of yellowfin should not be greater than C_{MSY}, i.e. $C_{MSY} < 1$. In order to reduce the risks of stocks becoming overfished and to promote fisheries sustainability as well as maintaining the current spawning biomass level, fishing mortality should be reduced to 12 percent or below catch at MSY level and maintain the effort level for yellowfin tuna longline fisheries. This condition only represented the yellowfin tuna catch by longline, however all yellowfin tuna fishing activities should be considered in the next study.

Biological overfishing led to economic overfishing to create economic losses, the bioeconomic model was used to calculate the fishery's rent with the economic objective to increase the level of the rent produced in the fishery. The fishing effort condition in 2014 was found to be higher than E_{MEY} but resulted in higher net revenue. Even though economically this condition supports higher profit, the fishing effort in 2015 however should be reduced by 44 percent around the E_{MEY} level through the full implementation of fisheries management measures in order to optimize sustainable economic condition.

Several management measures were identified from the output of this research on the bioeconomic assessment of yellowfin tuna longline fishery in WCPO that may improve the present biological and economic conditions of the fishery. In order to reduce fishing mortality of yellowfin tuna and other tuna species, closures for the yellowfin longline fishery should be implemented which will therefore result in the reduction of fishing effort. Identifying essential closures for spawning areas is necessary in order to enhance biological productivity of current stock biomass. Therefore, implementing capacity limit through effort reduction can result in reduced fishing mortality as well as increasing profitability. In order to reduce fishing effort capacity to a sustainable level, overfishing pressure should be alleviated and improvement on economic efficiency of the fishing fleet.

WCPFC with their conservation and management measures (CMM) should be implemented in the high seas and EEZs to ensure yellowfin tuna stocks are maintained at maximum sustainable yield with reasonable effort levels. Furthermore, CMM may positively impact the sustainability of the overall tuna fisheries by maintaining its value and benefits to its current member countries in the future.

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