Bioeconomic Analysis of Blue Swimming Crab (Portunus pelagicus) Fishery in the Gulf of Thailand

การวิเคราะห์ชีวเศรษฐศาสตร์ของการประมงปูม้าในอ่าวไทย

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บทคัดย่อ

งานวิจัยครั้งนี้มีวัตถุประสงค์เพื่อศึกษาสถานการณ์ของทรัพยากรปูม้าในอ่าวไทย เครื่องมือที่ใช้คือแบบจำลองชีวเศรษฐศาสตร์ โดยใช้ข้อมูลทุติยภูมิตั้งแต่ปี พ.ศ. 2533-2555 ผลการวิเคราะห์โดยใช้เส้นอุปทานที่วกกลับซึ่งราคาปูม้าผันแปรตามปริมาณผลจับ พบว่า ณ ระดับผลจับที่ให้ผลตอบแทนทางเศรษฐศาสตร์สูงสุด(MEY) การลงแรงงานประมงเท่ากับ 19,477 ลำ เมื่อเปรียบเทียบกับระดับผลจับยั่งยืนสูงสุด (MSY) การลงแรงงานประมง เท่ากับ 31,150 ลำ ณ การทำประมงโดยเสรี (OA) การลงแรงงานประมงเท่ากับ 38,391 ลำ แต่ในปี พ.ศ. 2555 มีการลงแรงงานประมงสูงถึง 49,751 ลำ ด้านผลการจับปูม้า พบว่า ณ ระดับผลจับที่ให้ผลตอบแทนทางเศรษฐศาสตร์สูงสุด (MEY) เท่ากับ 26,113 ตัน ผลจับยั่งยืนสูงสุด (MSY) 30,371 ตัน การทำประมงโดยเสรี (OA) จะมีผลจับ 28,743 ตัน และ ในปี พ.ศ. 2555 มีผลจับที่ 24,741 ตัน ดังนั้นการทำประมงปูม้าในอ่าวไทยเกินศักยภาพการผลิตการทดแทนโดยธรรมชาติ ซึ่งส่งผลให้ทรัพยากรปูม้าลดลงอย่างต่อเนื่อง ดังเห็นจากผลการจับปูม้าในปี พ.ศ. 2555 มีระดับการจับที่ต่ำกว่า ณ ระดับผลจับยั่งยืนสูงสุด (MSY) และระดับผลจับที่ให้ผลตอบแทนทางเศรษฐศาสตร์สูงสุด (MEY) โดยมีการลงแรงงานประมงที่ใช้จำนวนเรือที่สูงกว่า

คำสำคัญ: แบบจำลองชีวเศรษฐศาสตร์ ปูม้า อ่าวไทย

Abstract

This study aimed to analyze the status of blue swimming crab resource in the Gulf of Thailand. Blue swimming crab bioeconomic model was estimated using time-series data from 1990-2012. The results from the analysis using backward bending supply curve having price varied with catch of blue swimming crab fisheries showed that, the maximum economic yield (MEY) required an effort of 19,477 boats, compared with the maximum sustainable yield (MSY) at 31,150 boats, open access equilibrium (OA) at 38,391 boats while the actual effort in 2012 was 49,751 boats. The MEY catch was 26,113 tons compared to the MSY of 30,371 tons, open access of 28,743 tons while the actual catch in 2012 was only 24,741 tons. Blue swimming crab resource in the Gulf of Thailand had been overexploited, and the stock had been degraded. This was proved by, the actual catch in 2012, which was lower than both maximum sustainable yield and maximum economic yield in spite of the higher fishing effort.

Keywords: bioeconomic model, blue swimming crab, the Gulf of Thailand

Paper type: Research

1. Introduction

Blue swimming crab(*Portunus pelaqicus*), can be found throughout the sea water in the Indo-West Pacific Region, India, China, Vietnam, Thailand, and Indonesia (Taylor, 2013). In Thailand, blue swimming crab is an aquatic species and highly important to Thai economy. About 27,927 tons of total production were found in 2012, in which approximately 24,741 tons were from the Gulf of Thailand and 3,186 tons were from the Andaman Sea (Department of Fisheries, 2012).

The blue swimming crab is one of the living aquatic resources which has high value and increasing demand. It is used for direct consumption and as a raw material in the industry's processing. Thailand has been exporting blue swimming crab products to foreign countries. Annual report from Department of Fisheries, indicated that, in 2012, the export value of crab products was at 2,435 million baht, 61% was in airtight containers, 22% was fresh chilled or frozen, 12% was prepared or preserved, and the rest 5% was steamed boiled salted dried or smoked.

Boutson *et al*. (2009) reported that introduction of pot gear from Japan, in 1981, could increasing catches, especially small crab type. This resulted in the reducing of catch per unit effort and crab size caught. Further, there was no regulation to limit mesh size of gill net and crab trap which were the main fishing gears collected blue swimming crab. The main fishing gear of blue swimming crab in the Gulf of Thailand were crab gill net, crab trap, otter board trawl, and push net. There were few regulations on mesh size control for crab gillnets resulting in significant increased of numbers of bycatch species and small crabs (Songrak *et al*., 2013). The landings of blue swimming crab obtained had been decreased enormously during 1990-2010. According to Department of Fisheries (2012), in 1990, the catch was 30,402 tons, compared to 14,262 tons in 2010. This was probably due to the over-exploitation of blue swimming crabs.

The decline of blue swimming crab is believed to be consequences of problems such as overharvesting by efficient fishing gear, destruction of nursery habitat, harvesting ovigerous females and inefficient crab management. The high market demand has stimulated harvesting pressure on capture of blue swimming crab resources. This has resulted in overexploitation of blue swimming crabs and is illustrated by a steady decline in crab catches in Thailand with an average annual reduction in catches of -7.5 % (Fishstat, 2011).

This study is aimed to investigate the status of blue swimming crab fishery in the Gulf of Thailand. A bioeconomic model was used to investigate, and to estimate both economic and biological maximum level of yield and effort under open access (OA), maximum economic yield (MEY), and maximum sustainable yield (MSY), respectively. The model's results can be used for further recommendation for an operational management to maintain blue swimming crab stock abundance.

2. Objective

The objective of this study is to describe the status of blue swimming crab resource fishery in the Gulf of Thailand.

3. Expected

The expected outcome of the study is status of blue swimming crab fisheries in the Gulf of Thailand. This outcome would provide a useful guideline for policy formulation to further develop the blue swimming crab fishery. There is still a need for management measures of the blue swimming crab fishery to ensure the sustainability of blue swimming crab fishery.

4. Literature review

Bioeconomic model developed from the studies conducted by Gordon (1954) and Schaefer (1954a). Gordon-Schaefer model considered the production and the effort levels employed. The behaviour of the Gordon-Schaefer model is that it simulates how *total revenue* is balanced with *total cost* in an exploitation of a renewable natural resource. Cost and revenue functions are measured in term of fishing effort.

Bioeconomic model is composed of two parts, the biological and the economic part. In the case of inputs, fishing effort measures the human pressure applied to a determined resource. Each effort level corresponds to a cost level. This correspondence between biological (biomass) and economic (cost and revenue) sides is linked by prices. Indeed, their characteristics and design depend on the biological and economic structure of the fishery where they have to be developed, but it is possible to take into account some useful ideas of these models and adapt them to a specific region and fishery where a bioeconomic analysis is to be applied. Among the biological contributions to the bioeconomic models, recognized works shall be deserved to Fox (1970) and Pella and Tomlinson (1969). Contributions from the economic point of view may be deserved to Crutchfield and Zellner (1962), Smith (1969) and Clark (1976 and 1990).

The orthodoxy application of economic analysis on fisheries resources started with the static models developed by Gordon (1953 and 1954), Scott (1955a and 1955b) and Schaefer (1954a, 1954b, 1957, and 1959). After those original works economic discussion centered on the static and dynamic characteristics in theoretical bases. The former introduced the classic microeconomic analysis and incorporated essential questions as the property and decision regime for natural resource exploitation. The later incorporated, besides the aspects before mentioned. A temporal factor in the basic structure of the models, which allowed studies on the dynamic adjustment of fisheries biological and economic variables.

Cunningham *et al*. (1989) explained that there were two problems of challenging modeling such as; biological and economic challenges. The biological system was too complex to model because a stock of fish interacted richly with other fish stocks as predators or preys, and with the changing current, temperatures and other aspects of the marine environment. The model cannot completely govern the biological system because it was too complex and the furthered knowledge about it was needed to be clarified.

The basic theory behind marine overfishing was well discussed in the literature (Cunningham *et al*. 1985; Panayotou and Jetanavanich 1987; Schatz 1991). In brief, the theory started with the notion of the sea as a fishery resource owned by no one and whose exploitation was open to everyone. The biological theory would not be a sufficient basis for marine resource planning and management where economic concerns were important.

The economics and management of fisheries in the Gulf of Thailand have received only a limited amount of attention. Panayotou and Jetanavanich (1987) evaluated the levels of catch and fishing effort that gave rise to the static maximum economic yield (MEY) in fisheries for demersal species. They found that, in 1980s, the optimum annual MEY (given a mesh size of 2.5 cm) for demersal fisheries were 958,000 tons and 15.7 million standard fishing hours. The results implied that demersal catch in recent years had surpassed the level of static MEY. Panayotou and Jetanavanich recommended a license limitation program to bring the fishery into balance with MEY. Mahfuzuddin Ahmed *et at* (2007) drew similar conclusions on the status of demersal in the Gulf of Thailand, suggests that Schaefer and Fox's bioeconomice models indicating demersal fish stocks are both biologically and economically overfished. The fishery could earn additional economic rents by curtailing both excessive fishing effort and exploitation rates.

The purpose of this study is to provide a current bioeconomic analysis of blue swimming crab fisheries in the Gulf of Thailand, to estimate both economic and biological maximum levels of yield and effort, and to discuss corresponding measures to manage the fishery. This comparative static analysis would provide evidences of economic and biological and overfished stocks as a whole. The paper reviews the analysis of Panayotou and Jetanavanich in light of the current market, fishery and environmental conditions and provides policy recommendations. The following items will try to conjugate ideas towards an adequate management system and the sustainable development of the blue swimming crab fisheries.

5. Methodology

5.1 Study site and source of data

The study areas and landing places for the sampling of blue swimming crabs in the Gulf of Thailand covers 13 provinces and are separated by 3 coastal zones; Eastern, Upper and Western in the Gulf of Thailand. Secondary data are used in this study. Secondary data are taken from the related documents and statistics on the blue swimming crab fishing. The data for the blue swimming crab catches in the Gulf of Thailand by Thai vessels using otter-board trawl, pair trawl, beam trawl, push net, crab gill net and crab trap were available over the period 1990 – 2012. The data were collected from Fishery Information Technology Center, Department of Fisheries.

5.2 Statistical analysis

A bioeconomic model was employed to identify the optimal level of fishery. Maximum economic yield was identified and compared with the catch and effort of blue swimming crab fisheries at present. The standardization effort of blue swimming crab was standardized using ICES (1980) in Sparre and Venema (1998). The data of catch per unit of effort and invert demand function were analyzed.

5.3 Analytical model

5.3.1 Bioeconomic model

An estimation of the revenue function involves approximation of the underlying sustainable yield function which is a relationship between sustainable (Y) and effort (E). In case of single species fisheries, a sustainable function could be easily estimated by fitting a logistic growth curve to catch and effort data, a linear function between catch per unit of effort (Y/E) and effort. (Panayotou and Jetanavanich, 1987)

$$Y_s = aE - bE^2 \quad (1)$$

$$\frac{Y_s}{E} = a - bE \quad (2)$$

where, $a = qK$ $b = \frac{q^2 K}{r}$

The expression of equation (2) will usually show a diminishing relationship of effort to the catch per unit effort (CPUE).

From equation (1), to described in term of revenue and cost per unit of catch rather than per unit of effort, this is done by solving equation for E to obtain:

$$E = \left[a \pm \left(a^2 - 4bY\right)^{\frac{1}{2}} \right] / 2b \quad (3)$$

5.3.2 Economic model

To attain efficiency in the economic sense, the costs of fishing and revenues from selling the harvested fish must be taken into account. Using the variable price model, the cost and revenue are best described as functions of catch rather than fishing effort.

1) Cost function

Taking a fundamental static cost function, it is assumed that total cost (TC) of fishing directly depends on the amount of fishing effort (E). Give C as a cost per unit of fishing effort which is assumed constant, the long- run total cost function can be simply written as in equation (4) and (5)

$$TC = cE \quad (4)$$

$$MC = AC = c \quad (5)$$

Then substitute (3) into (4), the total cost as a function of catch can be written as (6). The calculation of average cost (AC) and marginal cost (MC) in term of catch can be found as in (7) and (8), respectively, (Panayotou and Jetanavanich, 1987)

$$TC = c\left[\left\{ a \pm (a^2 - 4bY)^{\frac{1}{2}} \right\} / 2b \right] \quad (6)$$

$$AC = \frac{TC}{Y} = \frac{cE}{Y} = \frac{c}{a - bE} = \frac{2c}{a \pm \left(a^2 - 4bY\right)^{1/2}} \quad (7)$$

$$MC = \frac{d(TC)}{dY} = \frac{c}{\pm\left(a^2 - 4bY\right)^{1/2}} \quad (8)$$

2) Revenue

To keep the assumption that the price of fish is constant, total revenue is simply the output produced and multiplied by this price, that is,

$$TR = pY \quad (9)$$

The average revenue and marginal revenue will then both be equal to price; that is,

$$AR = \frac{TR}{Y} = p \quad (10)$$

$$MR = \frac{d(TR)}{dY} \quad (11)$$

Then actually paid price will depend upon the quantity produced, thus the model is shown in the form of the log linear demand of blue swimming crab

$$p = \alpha Y^{\beta} \quad (12)$$

Where,
- *p*: the variable price of fish or AR
- *Y*: the catch or output
- α: maximum price that people would be prepared to pay for this particular fish species
- β: the slope of demand reflecting the effect of changes in catch on price

From (12), the total revenue (TR) and marginal revenue (MR) functions are then obtained as:

$$TR = \alpha Y^{1-\beta} \quad (13)$$

$$AR = \alpha Y^{\beta}$$

$$MR = (1-\beta)\alpha Y^{\beta} \quad (14)$$

3) Fisheries equilibrium

3.1) Open - access equilibrium

The open-access equilibrium obtained from the fishery leading to zero rent when no economic rent is obtained from the fishery or profit is zero. The open-access will reach at an output where total revenue is equal to total cost (TR =TC) or average revenue is equal to average cost (AR = AC or P = AC)

$$Y_{OA} \text{ at } \alpha Y^{\beta} = \frac{2c}{a \pm \left[\left(a^2 - 4bY\right)\right]^{\frac{1}{2}}} \quad (15)$$

$$E_{OA} = \frac{\left[\left(\alpha Y^{\beta}\right)a\right] - c}{b\left(\alpha Y^{\beta}\right)} \quad (16)$$

3.2)Maximum Economic Yield

The maximum economic yield (MEY) is a social optimum. Society is making the best economic use of its resources at this point (AR = MC), there is no overcapitalization and no social loss of overexploitation because the blue swimming crab price is equal to marginal costs. There are the maximum benefits at this point. The social benefits, in term of consumer surplus and resources rent, are maximized. The maximum economic yield (MEY) is at AR=MC so that,

$$Y_{MEY} \text{ at } \alpha Y^{\beta} = \frac{2c}{a \pm \left[\left(a^2 - 4bY\right)\right]^{\frac{1}{2}}} \quad (17)$$

$$E_{MEY} = \frac{\left[\left(\alpha Y^{\beta}\right)a\right] - c}{2b\left(\alpha Y^{\beta}\right)} \quad (18)$$

3.3) Maximum Sustainable Yield

Maximum sustainable yield (MSY) is another goal of fisheries management. Nevertheless, the concept of management is not required if the open-access exploitation level is below MSY. MSY is perhaps the dominance of fisheries research by biologists. Since, for a long time, biological overfishing is considered to comprise exploitation beyond the MSY level, MSY is the obvious goal if the underlying aim is to avoid overfishing and the MSY level. The effort level at MSY is received by taking the total differential equation (1) with respect to E, that is

$$E_{MSY} = \frac{a}{2b} \quad (19)$$

From equation (1) and (19), the catch and effort at maximum sustainable yield as follows;

$$Y_{MSY} = \frac{a^2}{4b} \quad (20)$$

6. Result and Discussion

6.1 Catch and effort data

The data of blue swimming crab in the Gulf of Thailand was collected from six major fishing gears, large scale fisheries consist of otter board trawl, pair trawler, beam trawler and push net. Small scale fisheries consist of crab gill net and crab trap. According to the data recorded in 2012, main fishing gear of blue swimming crab fishery was crab gill net. Mainly 61% of total catch in the Gulf of Thailand, followed by crab trap (21%), and otter board trawl (8%). The largest proportion of crab production was catching by gill net use due to the number of gill nets is more than other gears not because of its efficiency.

Catch and effort data from statistical record of five types of gear were used to standardize so that the total relative fishing effort representing all types of gear can be obtained. Accordingly, the number of fishing boats registered in The Gulf of Thailand from the Thai Fishing Vessels Statics has recorded of five types except crab trap boat, for that reason, the number of crab trap fishing vessels was calculated from the number of crab gill net fishing vessel multiplied by catch from crab trap, this result should be divided by the catch from crab gill net.

Documentary evidence of catches and fishing effort of crab gill net and crab trap was available from 1990 to 2012. Catches of blue swimming crab, in 1990, by crab gill net were 21,513 tons from 911 boats at 273,300 trips/year. The total catch in 2012 decreased to 15,124 tons but the number of boats increased to 1,915 and crab gill net effort was 574,500 trips/year. Catch per trip/boat was expected to be a better indicator for stock abundance than annual catch per vessel, because of the high variation in number of vessels and number of fishing trips per year. In 1990, catch per unit of effort or CPUE (tons/boat/trip) of blue swimming crab by crab gill net was 0.08 tons/boat/trip, reaching a peak at 0.12 tons/boat/trip in 2005, then, declined to 0.03 tons/boat/trip in 2012.

Crab trap catches were 2,035 tons of blue swimming crab harvested from 86 boats and crab trap effort was 19,389 trip/year. The total catch in 2012 decreased to 5,283 tons from 669 boats and crab trap effort increased to 150,525 trip/year. Catch per unit of effort or CPUE (tons/boat/trip) of blue swimming crab by crab trap in 1990 was 0.10 tons/boat/trip and declined to 0.04 tons/boat/trip in 2012.

The Catch per Unit of Effort (CPUE, tons/boat/trip) of blue swimming crab caught was measured by six types of fishing gear (crab gill net, crab trap, otter board trawl, pair trawler, beam trawler, push net), during 1990 - 2012. The outputs of the standardization are used to estimate the optimum fishing effort for blue swimming crab.

Table 1, the maximum sustainable yield (MSY) of the blue swimming crab fisheries in the Gulf of Thailand was 30,371tons/year and the MSY level of effort was at 31,150 boats. The regression analysis for model is shown at 1 % significance level. The actual catch and effort in 2012 were 24,741 tons with the relative effort of 49,751 boats.

The value of MSY will be achieved by reducing the fish effort to 31,150 boats based on the Schaefer Model. Therefore, the production of blue swimming crab in the Gulf of Thailand appears to be biologically overexploited in the sense of catch and effort exceeding significantly the MSY levels.

6.2 The cost function of blue swimming crab

The total cost of effort is proportional to the amount of fishing effort, implying that the opportunity cost of fishing effort is constant. This assumes that the fishermen and fishing fleet are homogenous and that the employment opportunity elsewhere in the economy is not affected by the size of the fishery.

Table 2 shows the cost per unit effort of crab gill net fishing units in blue swimming crab. In 2012, total cost of crab gill net by fishing boat of 7 meter length was 127,437 baht/boat/year or 424.79 baht/trip. Fixed cost consisting of depreciation (boat and engine and fishing gear) and maintenance (boat and engine and crab gill net gear) is 11% of the total cost. The depreciation of boat and engine (45%) and fishing gear (25%) comprise the highest imputed costs. Variable cost consists of fuel, labor cost, and ice is 89% of the total cost. Labor cost (53%) and fuel (39%) comprise the highest cash costs.

Table 1 Estimation by the Schaefer model using yield and relative effort of Blue swimming crab in the Gulf of Thailand during 1990-2012

Year	Total Yield (tons)	Relative Effort (boats)	CPUE (Schaefer) (ton/boat)
	YT(y)	YT(y)/R(y)	YT(y)/(YT(y)/R(y))
1990	30,402	28,258	1.08
1991	32,310	34,293	0.94
1992	31,784	21,836	1.46
1993	33,059	29,721	1.11
1994	35,157	33,041	1.06
1995	35,414	34,403	1.03
1996	36,219	31,335	1.16
1997	34,916	30,447	1.15
1998	37,281	31,487	1.18
1999	33,864	22,358	1.51
2000	37,219	26,255	1.42
2001	29,634	35,774	0.83

Year	Total Yield (tons)	Relative Effort (boats)	CPUE (Schaefer) (ton/boat)
	YT(y)	YT(y)/R(y)	YT(y)/(YT(y)/R(y))
2002	21,407	27,183	0.79
2003	22,825	17,860	1.28
2004	22,133	20,265	1.09
2005	18,567	11,189	1.66
2006	23,860	14,883	1.60
2007	16,638	36,015	0.46
2008	16,156	18,981	0.85
2009	15,132	31,931	0.47
2010	14,262	35,275	0.40
2011	18,411	56,210	0.33
2012	24,741	49,751	0.50
	Mean YT/R	**29,511**	**1.02**
Intercept, a			1.95
Slope, b			$-3.13*10^{-5}$
MSY Schaefer: $-0.25*a^2/b$			30,371 tons
F_{MSY} Schaefer: -0.5*a/b			31,150 boat

Note: YT= total yield; RT = relative CPUE

Source: Estimation.

Table 2 Cost per unit effort of crab gill net fishing units in blue swimming crab, 2012

Description	Baht/Boat/Year			Baht/Trip		
	Cash cost	Imputed cost	Total	Cash cost	Imputed cost	Total
Fixed cost(baht)	**0.00**	**13,737**	**13,737**	**0.00**	**45.79**	**45.79**
Depreciation of boat and engine	-	6,108	6,108	-	20.36	20.36
Depreciation of fishing gear	-	3,429	3,429	-	11.43	11.43
Boat and engine maintenance (baht/year)	-	3,201	3,201	-	10.67	10.67
Crab gill net maintenance (baht/year)	-	999	999	-	3.33	3.33
Variable cost (baht)	**113,700**	**0.00**	**113,700**	**379**	**0.00**	**379**
Fuel	44,700	-	44,700	149	-	149
Labor cost (1 person x 200 baht/trip)	60,000	-	60,000	200	-	200
Ice	9,000	-	9,000	30	-	30
Total cost (baht)	**113,700**	**13,737**	**127,437**	**379**	**45.79**	**424.79**

Note: Number of fishing trip per year of crab gill net (300 trips/year)

Source: Fisheries Economic Division, Department of Fisheries (2012)

Table 3 Estimated results of CPUE Schafer's model and inverted demand function of blue swimming crab

Equations	Coefficient	Standard Error	t-statistic	Adjusted R^2
Eq 1 : CPUE Schafer's model of blue swimming crab				0.74
Constant	1.9462	0.1984	9.8077***	
E	0.000313	4.88E-06	-6.4109***	

Eq 2 : Inverted demand function of blue swimming crab				0.96
Constant	1.0272	2.2249	0.4822[ns]	
lnY	-0.2681	0.1236	-2.1698***	
lnPEX	0.3194	0.0865	3.6948***	
lnI	0.8203	0.1131	7.2506***	

Note: ***, [ns] indicate the statistical significance at 0.01 and not statistically significant levels, respectively

6.3 The variable price model

The estimation results for CPUE Schafer's model of blue swimming crab in Table 3. In the equation (Eq1), the effort (E) showed negative impact on blue swimming crab per unit effort (Y/E). The explanatory value of CPUE of blue swimming crab was high and adjusted R^2 of 0.74. The estimated parameters were significant at 1 % significance level.

From equation of effort (Eq 1), they are shown as follows;

$$a = 1.95$$
$$b = 0.0000313$$

From Table 2, *c* is blue swimming crab cost per unit of effort as shown below;

c =127,437 baht/boat

Equation of effort the model was described in term of revenues and cost per unit of catch rather than per unit of effort as shown below;

$$E = \left[\frac{1.95 \pm \left[(1.95)^2 - 4(0.0000313)Y \right]^{\frac{1}{2}}}{2(0.0000313)} \right] \quad (21)$$

From equation of the total cost (6), average cost (7) and marginal cost (8) in terms of catch are obtained as:

$$TC = 127{,}437 \left[\frac{1.95 \pm \left[(1.95)^2 - 4(0.0000313)Y \right]^{\frac{1}{2}}}{2(0.0000313)} \right] \quad (22)$$

$$AC = \frac{2(127{,}437)}{1.95 \pm \left[(1.95)^2 - 4(0.0000313)Y \right]^{\frac{1}{2}}} \quad (23)$$

$$MC = \frac{127{,}437}{\pm \left[(1.95)^2 - 4(0.0000313)Y \right]^{\frac{1}{2}}} \quad (24)$$

The estimated inverted demand function for blue swimming crab is an estimation of both linear and log-linear functions. Log-linear function was chosen because it fit the data best with 1990-2012 blue swimming crab in Table 3. Price of blue swimming crab decreased. Export price of crab (PEX) had a positive impact with price of blue swimming crab. Per capita income (I) showed positive relation with price of blue swimming crab. About 96% of the variation of inverted demand function for blue swimming crab was explained in this equation with adjusted R^2 value of 0.96. The estimated parameters were significant at 1 % significance level.

In 2012, real export price of crab was 340,179 baht/tons and per capita income in 2012 was 129,564 baht. Equation (10) became:

$$P = 2{,}666{,}935Y^{-0.2681} \quad (25)$$

From equation (25), the total revenue (TR), average revenue (AR), and marginal revenue (MR) functions were as follows:

$$TR = PY = 2{,}666{,}935Y^{0.7319} \quad (26)$$

$$AR = P = 2{,}666{,}935Y^{-0.2681} \quad (27)$$

$$MR = \frac{dTR}{dY} = 1{,}951{,}930Y^{-0.2681} \quad (28)$$

From the above equations the catches of blue swimming crab fisheries at maximum sustainable yield (MSY), maximum economic yield (MEY), and open-access equilibrium (OA) could be calculated and compared to the catches in 2012.

Maximum Sustainable Yield

A sustainable yield function could be estimated by fitting a logistic growth curve to catch and effort data in Table 3 (Eq 1). The level of effort generating the maximum sustainable yield (MSY) can be obtained as follows:

$E_{MSY} = \frac{a}{2b}$ = 31,150 boats (29)

$MSY = \frac{a^2}{4b} = 30{,}371$ tons (30)

Maximum Economic Yield

The maximum economic yield (MEY) is at AR = MC thus;

$$2{,}666{,}935Y^{-0.2681} = \frac{127{,}437}{\pm\left[(1.95)^2 - 4(0.0000313)Y\right]^{\frac{1}{2}}} \quad (31)$$

Y = 26,113 tons

From above MEY, the effort level at MEY (E_{MEY}) is at $\frac{pa-c}{2bp}$ so that,

$$E_{MEY} = \frac{\left[(2{,}666{,}935Y^{-0.2681})(1.95)\right] - 127{,}437}{2(0.0000313)(2{,}666{,}935Y^{-0.2681})} \quad (32)$$

E_{MEY} = 19,477 boats

Open - access equilibrium

To obtain the open-access equilibrium where all profits are dissipated by setting AR=AC so that,

$$2{,}666{,}935Y^{-0.2681} = \frac{2(127{,}437)}{1.95 \pm \left[(1.95)^2 - 4(0.0000313)Y\right]^{\frac{1}{2}}} \quad (33)$$

Y = 28,743 tons

From above OA, The effort level at OA (E_{OA}) is at $\frac{pa-c}{bp}$ so that,

$$E_{OA} = \frac{\left[(2{,}666{,}935Y^{-0.2681})(1.95)\right] - 127437}{(0.0000313)(2{,}666{,}935Y^{-0.2681})} \quad (34)$$

E_{OA} = 38,391 boats

The results of variable price model of blue swimming crab fisheries consisted of the effort, catch, revenues, costs, profits, consumer surplus and total benefits corresponding to the various fishery conditions were presented in Table 4 and Figure 1.

From the variable price model of blue swimming crab fishery, the maximum economic yield (MEY) required an effort of 19,477 boats, compared with the maximum sustainable yield (MSY) at 31,150 boats, open access equilibrium (OA) at 38,391 boats and the actual (2012) of 49,751 boats. The MEY catch is 26,113 tons compared to the MSY of 30,371 tons, open access of 28,743 tons and the actual (2012) of 24,741 tons.

Table 4 Comparison of catch, revenue, coats and profits at different levels of effort based on a variable price model of blue swimming crab in the Gulf of Thailand

(Unit: million baht)

Condition	Effort (boats)	Catch (tons)	Revenues	Costs	Profits	Consumer surplus	Total benefits
Actual (2012)	49,751	24,741	4,380.81	6,340.12	-1,959.31	1,604.72	-354.59
MSY	31,150	30,371	5,090.08	3,969.66	1,120.42	1,864.53	2,984.95
MEY	19,477	26,113	4,557.32	2,482.09	2,075.23	1,336.86	3,412.09
Open access	38,391	28,743	4,892.43	4,892.43	0	1,790.84	1,790.84

Source: Estimation.

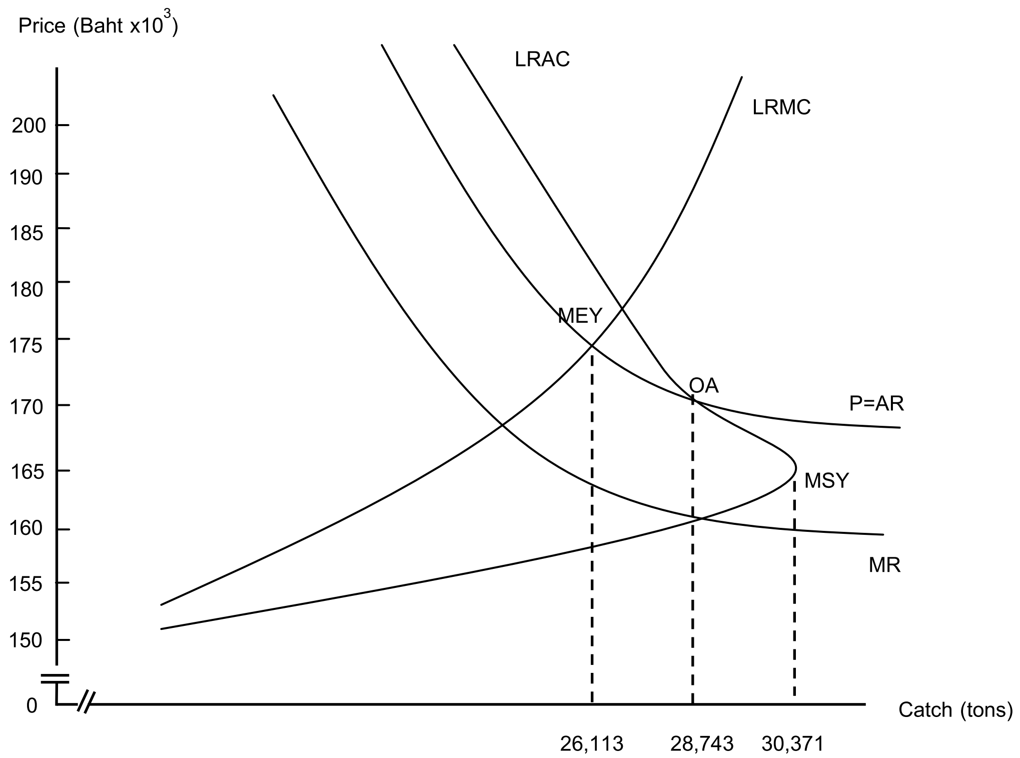

Figure 1 A variable price model applied to blue swimming crab fishery in the Gulf of Thailand.

At MSY the catch would as high as 30,371 tons at the effort of 31,150 boats with the benefits of 2,984.95 million baht. The catch at MEY would be 26,113 tons by 19,477 boats, less than half of the actual in 2012. The benefits would be highest at 3,412.09 million baht.

The comparison with at actual 2012 and at MEY in term of catch and profits were found in 2012. The blue swimming crab fisheries incurred a *"loss"* 4,034.54 million baht wherewith not operating at the MEY level of effort. In 2012 the effort is 49,751 boats higher than at MEY were 19,477 boats but in 2012, the catch is 24,741 tons lower than at MEY were 26,113 tons. The raising of revenue 176.51 million baht and the reduce effort saving 30,274 boats of excess effort costing.

In conclusion, production of blue swimming crab in the Gulf of Thailand appeared to be overexploited in the sense of catch and effort exceeding significantly the MSY and MEY levels.

7. Recommendations

The number of fishing boats have to be reduced. Current policies directed toward maintaining the stocks have to be strengthened. Regulation regard to prohibition trawlers boats from operating within 3 km from offshore should be strengthened. The effort to rationalize the fisheries is attempted via licenses required for commercial trawls and gillnets, but excess fishing capacity, small mesh sizes, and illegal fishing by the Thai fleet remain concerned. The level of fishing effort should at least be maintained at the present level to protect against overfishing.

Blue swimming crab management has implemented some restrictions including mesh size and closed period for fishing ovigerous females (October through December). Ovigerous females peaks in abundance during 2 periods: March-April and August-September. This information can be used to support decision making concerning the designation of fishing zones and the optimization of the blue swimming crab fishery (Nitiratsuwan *et al.,* 2010). However, management of the open access crab fishery is not well established. Poor enforcement has led to a reduction in landed crab size, thus reducing reproduction potential. The government should have additional management measures implemented for the blue swimming crab fishery, include a mesh size limit of crab gill net and crab trap.

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